PORT STEPHENS & GREAT LAKES COUNCILS

PORT STEPHENS
DESIGN FLOOD LEVELS
CLIMATE CHANGE REVIEW

NOVEMBER 2010

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FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. Flood Study
- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management
- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan
- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Port Stephens Flood Study constitutes the first stage of the management process and was completed in 1997 with publication of a three stage Flood Study Report. Subsequently the Port Stephens Foreshore (Floodplain) Management Study and Plan were completed in 2002. This Design Flood Level – Climate Change Review has been undertaken to provide advice regarding the implications of climate change on the design flood levels in the Port Stephens estuary.

EXECUTIVE SUMMARY

Port Stephens is a large tidal estuary with a waterway area of approximately 140 square kilometres and a total catchment area of 2900 square kilometres. It is located 150 kilometres north of Sydney and 50 kilometres north of Newcastle. It is administered by both Port Stephens and Great Lakes Councils.

The majority of the foreshore area is undeveloped rural lands. The developed areas largely consist of residential buildings and tourist related facilities. It is an area of high aesthetic quality and the foremost feature of the region.

Elevated water levels occur in Port Stephens mainly as a result of:

- ocean influences - tides and storm surges,
- wind and wave activity within the estuary,
- rainfall from the local catchment – Karuah River and Myall Lakes (this factor provides the least influence on levels).

There are no accurate historical records on the inundation of land or buildings though it is known that several building floors have been inundated in the recent past. Wind wave activity has been recorded as a hazard on many occasions (particularly May 1974), the main impacts being erosion of the foreshore, waves breaking above the high water mark and inundation of low lying land. There are no records of damages to buildings or structures (apart from seawalls or other structures on the immediate foreshore).

Based on the findings of the Port Stephens Flood Study and Foreshore (Floodplain) Management Study, up to 180 buildings would be inundated in a 1% AEP flood event (over 300 in an Extreme event) producing over $2.4 million of tangible flood damages. Approximately 40% of these damages are from the villages of Lemon Tree Passage, Lower Pindimar and Tea Gardens.

The NSW Government's Flood Policy provides for:

- a framework to ensure the sustainable use of floodplain environments,
- solutions to flooding problems,
- a means of ensuring new development is compatible with the flood hazard.

Implementation of this Policy requires a four stage approach, the first of which is preparation of a Flood Study to determine the nature and extent of the flood problem and this is followed by preparation of a Floodplain Management Study and Plan. These stages were completed in 2002.

Subsequent to completion of these studies it is generally accepted by the scientific community (Intergovernmental Panel on Climate Change) that climate change is likely to raise ocean levels and may have other adverse impacts such as an increase in rainfall intensities.

This climate change review study was initiated by Port Stephens and Great Lakes Councils to help determine the possible implications of climate change on the adopted design flood levels in the Port Stephens estuary. The study builds on the Port Stephens Flood Study (Stages 1 to 3) completed in 1997 which defines design flood levels for the foreshore area and the Port Stephens Foreshore (Floodplain) Management Study and Plan completed in 2002.

The key outcomes of this review are:

- a climate change induced ocean level increase will raise the design flood levels and wave runup levels by the same amount as the assumed ocean level rise,
- a climate change induced rainfall increase of up to 30% will raise flood levels in the Port Stephens estuary by less than 0.1m,
- the assumed climate change induced ocean level increase and consequent flood level rise should be applied with the current freeboard allowance of 0.5m (i.e no reduction in the assumed ocean level rise should occur just because there is some allowance for climate change in the freeboard allowance),
- the current minimum Flood Planning Level of 2.5 mAHD (with climate change induced ocean level rise of 0.9m it will be 3.4 mAHD) has been adopted throughout the estuary foreshore (these level DO NOT include wave runup which should be determined on a site by site basis). However this means that at some locations there is a much greater freeboard than 0.5m. There is therefore an opportunity to lower the proposed climate change Flood Planning Level of 3.4 mAHD by assuming a non uniform level in the estuary.

1. INTRODUCTION

1.1. General

Port Stephens (Figure 1) is a large tidal estuary on the central coast of New South Wales, approximately 150 kilometres north of Sydney and 50 kilometres north of Newcastle. The northern area is administered by Great Lakes Council and the southern area by Port Stephens Council. It has a waterway area of about 140 square kilometres with a total catchment area of 2900 square kilometres, the Karuah River (1500 km^2) and Myall River (780 km^2) catchments comprise nearly 80% of the total. The main features of the estuary are identified in Table 1.

Table 1: Port Stephens Estuary Main Features

Total Catchment Area	2900 km^2
Area of Estuary	140 km^2 (5% of the total catchment area)
Length of Estuary	24 km in an east-west direction
Width of Estuary	varying from 1.5 to 6 km in a north-south direction
Perimeter Length	over 80 kilometres
Water Depth	varies from 2 m to over 30 m at Soldiers Point
Contributing Catchments	Karuah River 1500 km^2 Myall River 780 km^2 Port Stephens Waterway 140 km^2 Twelve Mile Creek 80 km^2 Reedy Creek 15 km^2 The remainder (385 km^2) comprises small local catchments.

Port Stephens is a relatively large waterway with moderate depths (less than 10 m). Consequently significant local wind waves can be generated which cause inundation of the foreshore area. It is divided into two embayments east and west of Soldiers Point (Figure 2). Ocean waves penetrate through the 1300 m wide ocean entrance between Yacaaba and Tomaree Heads but their impacts are limited to the eastern embayment.

The majority of the foreshore is undeveloped and consists of rural lands (refer Figure 2). The main centres of development on the southern shore are the residential and tourist centres of Shoal Bay, Nelson Bay, Salamander Bay, Soldiers Point, Lemon Tree Passage, Mallabula and Tanilba Bay. The other centres are at Karuah at the mouth of the Karuah River, North Arm Cove, Bundabah, Pindimar and Tea Gardens, and Hawks Nest at the mouth of the Myall River.

The study area comprises the foreshores of Port Stephens estuary and adjoining areas which are affected by flooding/inundation from the estuary. It does not include inundation as a result of local catchment runoff, inadequate local drainage or flooding up the tributary creeks including the Karuah and Myall Rivers. These issues have (or will be) investigated in separate studies.

1.2. Study Objectives

The study objectives are summarised as follows:

- Review the approach taken in the Port Stephens Flood Study to determine design flood levels.
- Provide comment on the validity of the design flood approach in light of current guidelines.
- Outline the NSW Government's approach for the assessment of climate change on flood levels.
- Provide comment on whether an approach for the assessment of climate change on flood levels can be adopted for the Port Stephens estuary without the need for further hydraulic modelling.
- Provide comment on the adopted 0.5m Freeboard.
- Provide comment on the most appropriate approach for updating design flood levels along the Myall River (Great Lakes Council).

1.3. The Floodplain Management Process Completed to Date

This study is concerned with the immediate foreshore area of the Port Stephens estuary. It is referred to as a "foreshore" rather than a "floodplain" to reflect the fact that the study area surrounds an estuary rather than a river and incorporates some aspects of the coastal/estuarine interface not usually considered in a typical flood or floodplain management study. However, the study has been administered under the framework of the floodplain management process.

The floodplain management process was developed in the 1986 Floodplain Development Manual. The process has been updated and revised in the 2001 Floodplain Management Manual and subsequently in the 2005 Floodplain Development Manual (Reference 1).

The Port Stephens Flood Study (References 2, 3 and 4) established design flood levels for the Extreme and the 1%, 2% and 5% AEP (Annual Exceedance Probability) events. These design flood levels are a combination of elevated ocean "stillwater" levels plus a wave runup component. The elevated ocean levels occur as a result of estuarine tides plus local and ocean wind effects. The results of the study showed that wave runup on the foreshore may increase the stillwater design levels by up to 1.5 m. The Flood Study completed the first stage of the management process.

The subsequent Foreshore (Floodplain) Management Study (Reference 5) was undertaken to fully identify the flood problem and canvass various measures to mitigate the effects of flooding and wave action, and to prevent future flood damages. The penultimate product of the process was completion of the Foreshore (Floodplain) Management Plan (Reference 6) in 2002 which describes how the affected lands are to be managed in the future. Both the Study and the Plan involved community interaction to ensure that the measures were fully supported.

A glossary of flood related terms is provided in Appendix A.

2. THE FLOOD PROBLEM

2.1. Observed Flood Problem

Port Stephens is different to many other areas affected by flooding in that there is very little qualitative or quantitative flood history. The following summarises the problems identified by the community or observed during previous studies.

- **Inundation of Building Floors:** Up to 10 houses have experienced above floor inundation. Of these only 3 (most likely) have resulted from inundation from the estuary with the remainder inundated from local catchment runoff. It is likely that other buildings have been inundated in the past but the residents are either unaware of the problem or did not respond to past surveys.
- **Inundation of Yards:** Over 60 residents indicated in previous studies that parts of their land have been inundated in the past. Some will have been from tidal inundation and wave action, but many will be from local catchment runoff which has ponded in low points within the properties, or from overland flow from upstream. It is also likely that a number of residents did not disclose that their properties have been inundated, either because they thought it unimportant, or they considered it would adversely affect the value or development potential of their properties.
- **SES Intervention**: According to SES records, the SES has not carried out damage reduction measures (sand bagging), evacuations or similar as a result of foreshore flooding, or has been called out to assist following any form of inundation or erosion event.
- **Erosion:** Several areas have a history of foreshore erosion, in particular Shoal Bay, Jimmy's Beach, Salamander Bay/Corlette Point and Tanilba Bay. The problem is continuing today and was the most significant issue raised by residents in past studies. A large number of residents have had part of their land eroded and fear that further erosion may threaten their houses. In the May 1974 storm several houses were at risk at Corlette Point and Port Stephens Council placed rock to protect them.

In summary it would appear that inundation of buildings has not been a major immediate re-occurring problem for residents. Erosion concerns far outweigh inundation concerns.

Section 2.5 provides details of building floors inundated in the design flood events.

2.2. Flooding Mechanisms

Flooding of the foreshore area surrounding Port Stephens can result from a combination of the following four factors:

1. *elevated ocean levels* resulting from astronomical tides, barometric pressure effects, and wind and wave setup which force water into the estuary,
2. *wave runup* around the foreshores of the estuary causing local inundation of property as well as foreshore erosion,
3. *significant rainfall over the Karuah and Myall River catchmen*ts. The level in the estuary

rises as inflows from the upstream catchments and direct rainfall over the estuary exceeds the outflow to the ocean. The impact of catchment rainfall is only significant when it occurs in conjunction with elevated ocean levels. In the absence of an elevated ocean level catchment runoff will not produce a significant flooding problem in the estuary,

4. *rainfall over the local catchment* which is unable to drain away quickly and so ponds in low areas. This is usually termed local flooding and causes inconvenience but generally not above floor flooding. It is exacerbated by elevated estuary levels.

This study is primarily concerned with the potential effects of climate change on the first three causes of inundation and not local catchment runoff.

2.3. Nature of the Hazards

Foreshore flooding results from a combination of stillwater and wave runup inundation.

Stillwater refers to the general estuary water level without the effects of waves. The term is somewhat misleading because during storms there is always some wave action as a result of ocean and local wind activity, and water levels even with wave effects excluded are not "still", but tend to rise and fall in response to wind gusts, wave sets, currents, etc. Stillwater does include inflows from the tributaries (Karuah & Myall Rivers and others).

Wave runup refers to the increase in water level that occurs along a foreshore when waves break and expend their remaining energy by running up the foreshore. The height the waves reach depends upon a number of factors such as the beach profile, foreshore exposure to the prevailing winds, and/or the presence of structures on the foreshore (vegetation, rock walls, buildings).

There is also **Local runoff** which refers to runoff from the local upstream catchment, sometimes called overland flow, crossing roads and inundating private property and possibly buildings. This form of inundation has not been addressed in this study.

The hazards associated with stillwater inundation and wave runup impacts differ as a result of their different characteristics. Peak stillwater levels will last for up to one to two hours and so will persist long enough to inundate building floors below the peak level regardless of how far they are from the foreshore, even if doors and windows are closed. However the water will rise relatively slowly and without a significant velocity component. The relatively shallow depth of inundation, low velocities and ease of access to high ground means that the risk to life is low.

Wave runup will also occur over an extended period of time but within this time the peak level will be reached only a few times as large waves and surges impact on the foreshore. This will probably be near the peak of the storm and around the maximum still water level period. Wave runup (in isolation) will probably not cause inundation of floor levels if doors and windows are closed but, dissipation of the wave energy will erode banks and damage foreshore structures. The impacts of wave runup will mainly be restricted to the immediate foreshore area, with properties further back less affected as the wave energy dissipates. Wave runup does increase the risk to life, but residents can generally still easily and safely move to high ground.

2.4. Review of Flood Study

2.4.1. Stage 1 - Analysis and Review of Existing Information (MHL623, July 1992) - Reference 2

Historical data and previous studies were examined with the aim of determining the various components that might influence flood levels in the estuary. Bathymetric, tidal, wave, wind, rainfall and runoff data were collected and analysed. Local residents were canvassed but did not reveal any specific details on historical flood levels. The study determined that flood levels were influenced by:

- **astronomical tide levels.** Along the NSW coast tides vary from 0.4 m up to 1.1 m depending on the lunar cycle.
- **ocean storm surge effects.** These are mainly the result of low barometric pressures during storms which cause ocean water levels to rise, plus the effect of strong onshore winds which push ocean waters onto the coast.
- **local wind set up.** This is a localised rise in the water level caused by strong onshore winds in an estuary.
- **wave set up.** This occurs as a result of waves (ocean or local) shoaling, breaking and pushing water towards the foreshore.
- **runoff from the Karuah River and Myall River catchments.** In a confined river channel runoff effects will tend to dominate. However, where the estuary is wide and deep runoff impacts dissipate.
- **wave runup.** This is the vertical height (above the “stillwater” level) to which water from a wave will run up the face of the shoreline. Wave runup occurs when waves reach the shoreline, break and expend their remaining energy as wave runup. The level of runup depends upon the local foreshore profile and the presence of foreshore structures.

The study acknowledged that each of the above factors does not necessarily occur together, and that an allowance has to be made for their joint probability. The possible impact of future climatic change ocean level rise due to Greenhouse gas emissions (climate change) was also considered to be relevant. This study was followed by References 3 (Stage 2) and 4 (Stage 3) which quantified the design flood levels for what is known as “stillwater” flooding and “wave runup” flooding respectively.

2.4.2. Stage 2 - Design Water Levels and Wave Climate (MHL759, February 1997) - Reference 3

For the Stage 2 investigations, computer models were established to examine flood conditions (5%, 2%, 1% AEP and extreme events) around the foreshore of Port Stephens and Tilligerry Creek. The design ocean levels for Port Stephens entrance were based on the Sydney tidal database (Fort Denison) and determined as:

5% AEP	1.43 mAHD,
2% AEP	1.47 mAHD,
1% AEP	1.50 mAHD.

The study found that within the estuary the design water level varied depending upon a number of factors including:

- the design ocean levels,
- runoff from the major catchments of the Karuah and Myall Rivers and Tilligerry Creek (which produces a gradient from the western to the eastern embayment),
- local wind effects.

A two dimensional (2D) hydraulic model was used to analyse the effects of the above three factors and this level was designated as the design "stillwater" level for Port Stephens without wave runup. The results combine the effects of each of the above three components and are provided for 42 sites around the foreshore (Figure 2) on Figures 3 and 4 and Table 2. In summary the ocean levels affect the entire estuary by a similar amount, the runoff from the major catchments largely only affects the riverine areas of the Karuah and Myall River and it is the local wind effects that produce the greatest difference in peak levels over the estuary (as the wind causes a local elevation in the water level). The results in Table 2 indicate that the maximum variation in level (generally from west to east) was approximately 0.4 m.

Table 2: Design Peak Water Levels (m AHD)

		Wave Runup (refer Section 2.4.3 for details)(2)			Stillwater - No Wave Runup but includes elevated ocean levels + catchment runoff + local wind effects		
Site	**Location**	**5% AEP**	**1% AEP**	**Extreme**	**5% AEP**	**1% AEP**	**Extreme**
1	Tomaree	overtops seawall			1.5	1.5	1.6
2	Shoal Bay East	2.3	2.5	2.6	1.5	1.5	1.6
3	Shoal Bay West	2.7	2.8	3.0	1.5	1.6	1.6
4	Nelson Head East	2.9	3.1	3.4	1.5	1.6	1.6
5	Little Nelson Bay	1.9	2.4	2.5	1.5	1.6	1.6
6	Fly Point	2.1	2.3	2.4	1.5	1.6	1.6
7	Nelson Bay	3.1	3.3	overtops seawall	1.5	1.6	1.6
8	Dutchmans Bay	2.2	2.6	2.7	1.6	1.6	1.7
9	Redpatch Point	2.5	2.8	2.9	1.6	1.7	1.7
9a	Sandy Point	2.4	2.3	2.9	1.6	1.7	1.7
10	Corlette Point	2.2	2.3	2.7	1.6	1.7	1.7
11	Salamander Bay	1.9	2.0	2.3	1.6	1.7	1.7
12	Wanda Wanda Head	2.0	2.0	2.1	1.6	1.7	1.8
13	Kangaroo Point	2.3	2.4	2.7	1.6	1.7	1.8
14	Soldiers Point East	2.5	2.6	3.1	1.6	1.7	1.8
15	Soldiers Point West	1.8	1.9	2.1	1.7	1.7	1.8
16	Greenplay Point	1.7	1.8	2.3	1.7	1.8	1.8
17	Mud Point	1.7	1.8	2.3	1.7	1.8	1.8
18	Diemar Point	overtops seawall			1.7	1.8	1.8
19	Taylor Beach	1.7	1.8	2.3	1.7	1.8	1.8
20	Lemon Tree	1.7	1.8	2	1.7	1.8	1.8
21	Mallabula Point	2.1	2.2	2.3	1.7	1.8	1.8
22	Tanilba Bay	1.8	1.8	2.0	1.7	1.8	1.9

23	Bato Bato Point	2.4	2.5	3.1	1.8	1.9	1.9
24	Oyster Cove	2.2	2.2	2.2	1.8	1.9	2
25	Swan Bay	2.1	2.2	2.3	1.8	1.9	1.9
26	Davis Point	1.8	1.9	2.0	1.8	1.9	2.0
27	Lillies Point	2.1	2.2	2.4	1.8	1.9	2.0
28	Karuah Bridge	1.8	1.9	2.0	1.8	1.9	2.0
29	Correebah	2.3	2.4	2.7	1.7	1.8	1.9
30	Carrington	2.0	2.2	2.3	1.7	1.8	1.9
31	Baromee Point	2.2	2.3	2.4	1.7	1.8	1.8
32	Baromee Hill	2.2	2.3	2.4	1.7	1.8	1.8
33	Bundabah	1.7	1.8	2.0	1.7	1.8	1.8
34	Fame Point	3.2	3.4	3.9	1.7	1.8	1.8
35	Lower Pindimar	2.3	2.4	2.7	1.6	1.7	1.8
36	Orungall Point	2.0	2.2	2.4	1.6	1.7	1.7
37	Pindimar	2.0	2.0	2.2	1.6	1.7	1.7
38	Limestone	1.6	1.7	1.7	1.6	1.7	1.7
39	Tea Gardens	1.6	1.8	2.3	1.6	1.8	2.3(1)
40	Hawks Nest	1.5	1.7	2.0	1.5	1.7	2.0(1)
41	Jimmy's Beach West	2.9	3.1	3.4	1.5	1.6	1.6
42	Jimmy's Beach East	2.5	2.6	2.9	1.5	1.6	1.6
Notes:							
(1)	Affected by Myall River flow, particularly in the Extreme event.						
(2)	Highlighted	numbers indicate where the wave runup level exceeds 2.5 mAHD.					

A review of the sensitivity results (refer Appendix B for copies of the tables from Reference 3) for the 1% AEP indicates the following.

- **Table J6** indicates that with no runoff inflows or wind effects the peak levels in the estuary range from 1.5 mAHD at the entrance (Site 1) to a maximum of 1.67 mAHD at the western foreshore (Sites 23 to 29).
- **Table J6** also indicates that with the inclusion of inflows but no wind effects the peak levels in the estuary increase by a maximum of 0.05m except in the confined floodplain areas of the Karuah River (Site 28) and the Myall River (Sites 39 and 40). This indicates that the inclusion of runoff makes little difference to the peak water levels and this is further confirmed by **Table J3**. **Table J3** indicates that increasing the peak inflows by 10% makes less than 0.05m change in the peak water level even at the confined floodplain areas of the Karuah River (Site 28) and the Myall River (Sites 39 and 40). Comparison of the peak levels in the estuary for the 1% AEP and Extreme flood (Table 2 in this report) indicates a difference in level of a maximum of 0.1m except in the confined floodplain areas of the Myall River (Sites 39 and 40). The Extreme flow was estimated as twice the 1% AEP flow in the Karuah River. These results indicate that a climate change induced increase in rainfall intensities of up to 30% can effectively be ignored except in the confined floodplain areas of the Myall and Karuah Rivers.
- The most significant factor affecting the peak water levels within the estuary is the direction of the local wind setup. This factor can increase water levels by up to 0.3m. **Table J6** provided results for the east, south east, south and south west wind directions. Winds from the south west lowered water levels compared to the No wind scenario by up to 0.3m at sites in the west (Sites 22 and 23) (this wind direction was not adopted as the design scenario). However winds from the east increased water levels

compared to the No wind scenario by up to 0.2m at sites in the west (Sites 24 to 27).

- **Table J5** indicates the results of lowering the assumed 1% AEP peak ocean level from 1.5 mAHD to 1.1 mAHD and assuming No wind effects. The results indicate that the peak water levels are reduced by approximately 0.4m. This suggests that a climate change induced increase in the peak ocean level will raise flood levels within the estuary by a comparable amount to the ocean level increase.

2.4.3. Stage 3 - Foreshore Flooding (MHL880, June 1998) - Reference 4

At any location around the foreshore of Port Stephens, the flood level depends upon a combination of the design water levels adjacent to the site (determined in Section 2.4.2 - Stage 2 of the study) and the effect of wave runup.

The wave climate in Port Stephens is a combination of local wind waves and ocean waves, the latter generally only occurring in the eastern embayment. Significant ocean wave heights of over 3.0 m were determined for the immediate entrance area but were generally less than 0.5 m. Wind waves occur throughout the estuary with the size of the wave generated dependant upon, the fetch length, the depth of water, and the wind speed duration and direction. Significant wind wave heights of over 2.0 m were determined for some exposed locations but values around 1.0 m were more common.

For the purposes of the Flood Study a typical beach profile was used at each of 42 sites around the foreshore and the 1% and 5% AEP levels determined as the maximum level for two coincidences of wind and water levels (design ocean level plus 1 year ARI wind waves or 1 year ARI water level (1.26 mAHD) plus design local wind waves). An extreme level was also estimated. The wave runup design flood level results are shown on Figure 3 and Table 2.

The report identifies a number of guidelines regarding the analysis and use of the wave runup results:

- The cross sections (describing the foreshore) may change in time.
- One cross section was taken as being representative of the site. This is an approximation and in reality there may be significant changes in the cross_section away from the site.
- The design levels are only accurate at each of the 42 sites. Outside these sites the actual levels may vary.
- If significant development is to be undertaken, site specific analysis should be undertaken.
- Where buildings are located close to the foreshore the impact of wave runup needs to be addressed more closely (openings to the building, structural integrity).
- The actual design flood levels behind foreshore seawalls depend upon the distance from the seawall and the presence of any buildings.

2.5. Review of Foreshore (Floodplain) Management Study- Reference 5

The Port Stephens Foreshore (Floodplain) Management Study (Reference 5) constituted the second stage of the floodplain management process and had the following objectives:

- to identify the nature and extent of the problem giving consideration to the depth of inundation, wave impact forces and flood access requirements. The number of building floors inundated at each site (Figure 2) is provided on Figure 5 with the average annual damages for private developments (year 2002) estimated as $840,000 (assuming wave runup damages),
- to facilitate discussion with local authorities and the public,
- to determine the social and economic effects of inundation, including the level of preparedness,
- to determine management measures to mitigate the effects of inundation on existing and future developments,
- to review Councils' current flood policy provisions and examine the implications to planning of adhering to or amending the policy,
- to examine the environmental and social impact of any proposed works,
- to review submissions following public exhibition of the reports.

This study did not undertake any hydrologic or hydraulic modelling of the potential impacts of climate change (Greenhouse Effect) but concluded:
"There is a high likelihood that the Greenhouse Effect will have a significant adverse impact upon design flood levels in Port Stephens and consequently increase the annual average damages. There are no means of lessening the Greenhouse Effect other than a world wide reduction in the production of greenhouse gases. Both Councils should continue to monitor the available literature and reassess their Flood Policy as appropriate. At a minimum both Councils should obtain the most current information available from the Department of Land and Water Conservation every two years."

2.6. Review of Foreshore (Floodplain) Management Plan- Reference 6

The Port Stephens Foreshore (Floodplain) Management Plan (Reference 6) constituted the third stage of the floodplain management process and documented the Standard Conditions regarding flooding for Development Applications along the Port Stephens foreshore (in Appendix A). The four key requirements were:

1. **Determination of the Flood Planning Level (FPL)**. A minimum FPL level of 2.5 mAHD was adopted but this may be higher if the Design Wave Runup Level (DWRL) at the location exceeds this level and the land is within 50m of Mean High Water (MHW – assumed to be 0.5 mAHD) which is the assumed limit of any wave runup. These criteria means that land beyond 50m from MHW **and** above 2.5 mAHD are not subject to the conditions.
2. **Assessment of potential Erosion and Coastal/Estuarine Issues**.
3. **Implementation of suitable Building Controls and Evacuation**.
4. **Assessment of Local Overland Flooding**.

2.7. Applicability of this Assessment

Wave runup produces two broad effects, inundation which is the subject of this study and foreshore erosion which is not the subject of this study. Erosion has only been mentioned in this study as it is a foreshore hazard and needs to be addressed as part of Council's climate change development control procedures, along with inundation. However this study is not concerned with quantifying the potential effects of a change in erosion and/or sedimentation due to climate change.

Inundation of foreshore properties can occur either from the estuary or as a result of local catchment runoff trying to enter the estuary. This study is solely concerned with the effect of climate change on inundation and wave runup from the estuary, not from catchment runoff. It may well be that higher flood levels at some foreshore properties will result from local catchment runoff. The effect on road drainage has also not been considered within this study.

3. CLIMATE CHANGE AND OTHER ISSUES

3.1. Background

The 2005 Floodplain Development Manual (Reference 1) requires that Flood Studies and Floodplain Risk Management Studies consider the impacts of climate change on flood behaviour. Since completion of the Port Stephens Foreshore (floodplain) Management Study and Plan in 2002 (References 5 & 6), current best practice for considering the impacts of climate change (ocean level rise and rainfall increase) have been evolving rapidly.

3.1.1. Key References

Key references on climate change in NSW have included:

- release of the Fourth Assessment Report by the Inter-governmental Panel on Climate Change (IPCC) in February 2007 (Reference 7), which updated the Third IPCC Assessment Report of 2001 (Reference 8);
- preparation of the Climate Change Adaptation Actions for Local Government by SMEC Australia for the Australian Greenhouse Office in mid 2007 (Reference 9);
- preparation of the Climate Change in Australia by CSIRO in late 2007 (Reference 10), which provides an Australian focus on Reference 7;
- release of the Floodplain Risk Management Guideline Practical Consideration of Climate Change by the NSW Department of Environment and Climate Change in October 2007 (Reference 11 - referred to as the DECC Guideline 2007);
- preparation of the Hunter, Central and Lower North Coast Regional Climate Change Project Report 3: Climate Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW (Hunter and Central Coast Regional Environmental Strategy, 2009 -Reference 12);
- release of the NSW Policy Statement on Sea Level Rise (October 2009) (Reference 13) which states: *"Over the 20th century, global sea levels have risen by 17 cm and are continuing to rise. The current global average rate is approximately three times higher than the historical average. Sea level rise is a gradual process and will have medium- to long-term impacts. The best national and international projections of sea level rise along the NSW coast are for a rise relative to 1990 mean sea levels of up to 40 cm by 2050 and 90 cm by 2100. There is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that the current trends will be reversed"*;
- In August 2010 the NSW State Government Department of Environment, Climate Change and Water produced the following:
    - o Flood Risk Management Guide (Reference 14) incorporating sea level rise benchmarks in flood risk assessments,
    - o Coastal Risk Management Guide (Reference 15) incorporating sea level rise benchmarks in coastal risk assessments,

  In August 2010 The Department of Planning also exhibited:
    - o NSW Coastal Planning Guideline -Adapting to Sea Level Rise (Reference 16).

As a result of the information provided in the above and other documents, and to keep up-to-date with current best practice, this review of the effect of climate change on design flood levels has been undertaken. It should be noted that the estimated rise in ocean/sea level along the NSW coast varies between the above reports and at this time there is no absolute value that has been adopted by all experts.

The DECC Guideline 2007 (Reference 11) advice on climate change indicates that the following scenarios should be considered.

ocean level rise (subsequently superseded by Reference 13):

- low level ocean rise = 0.18 m,
- medium level ocean rise = 0.55 m,
- high level ocean rise = 0.91 m.

and sensitivity analysis into the increase in peak rainfall and storm volume:

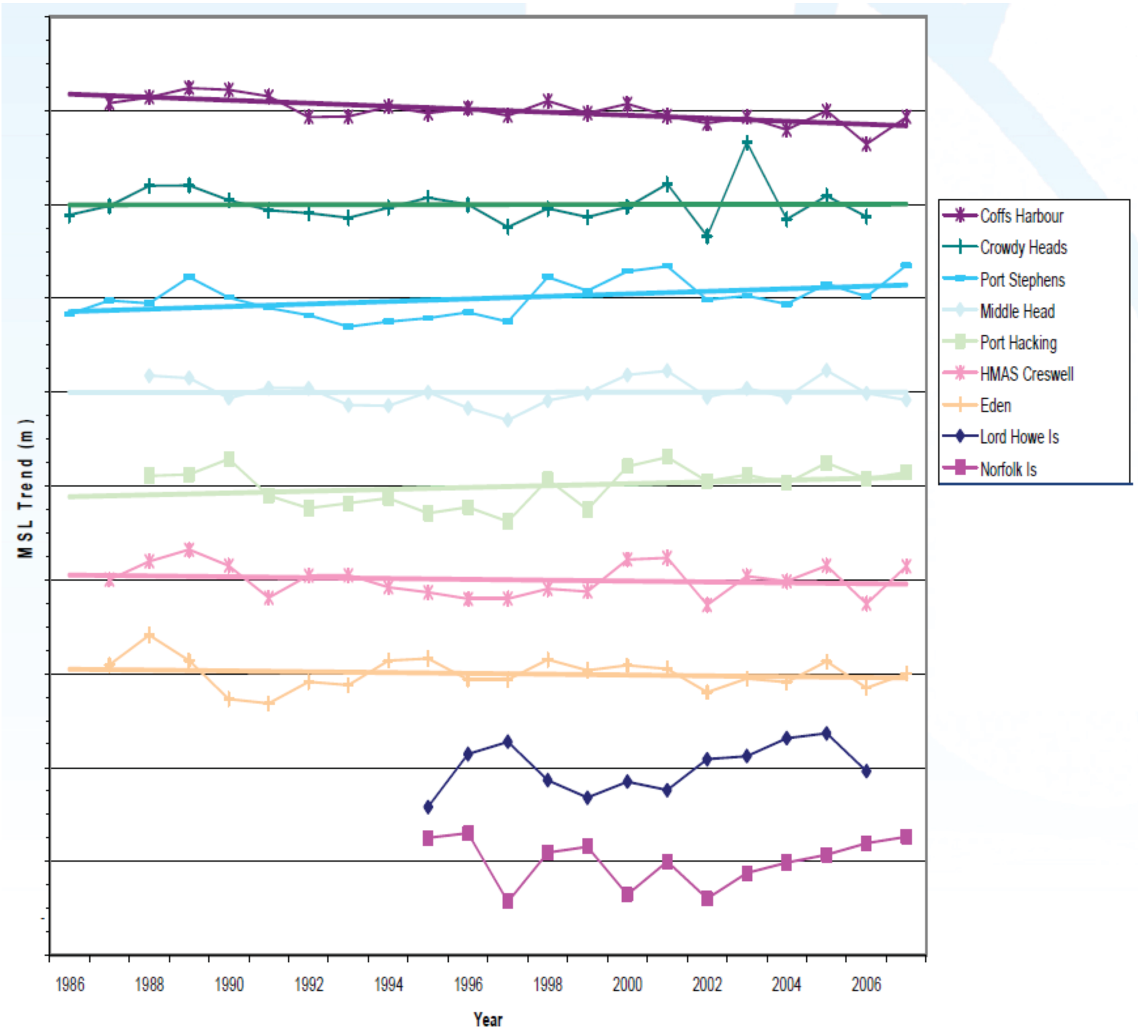
- low level rainfall increase = 10%,
- medium level rainfall increase = 20%,
- high level rainfall increase = 30%.

A high level rainfall increase of up to 30% is recommended for consideration due to the uncertainties associated with this aspect of climate change and to apply the "precautionary principle". It is generally acknowledged that a 30% rainfall increase is probably overly conservative and that a timeframe for the provision of definitive predictions of the actual increase is unknown.

The NSW Policy Statement on Sea Level Rise (October 2009 – Reference 13) indicates that the *"best national and international projections of sea level rise along the NSW coast are for a rise relative to 1990 mean sea levels of 40 cm by 2050 and 90 cm by 2100. However, the IPCC in 2007 also acknowledged that higher rates of sea level rise are possible"*. Thus this document supersedes the DECC Guideline 2007 (Reference 11) advice on climate change. It is also acknowledged that the existing freeboard allowance **cannot** be used to allow for climate change and sensitivity analysis on the impacts.

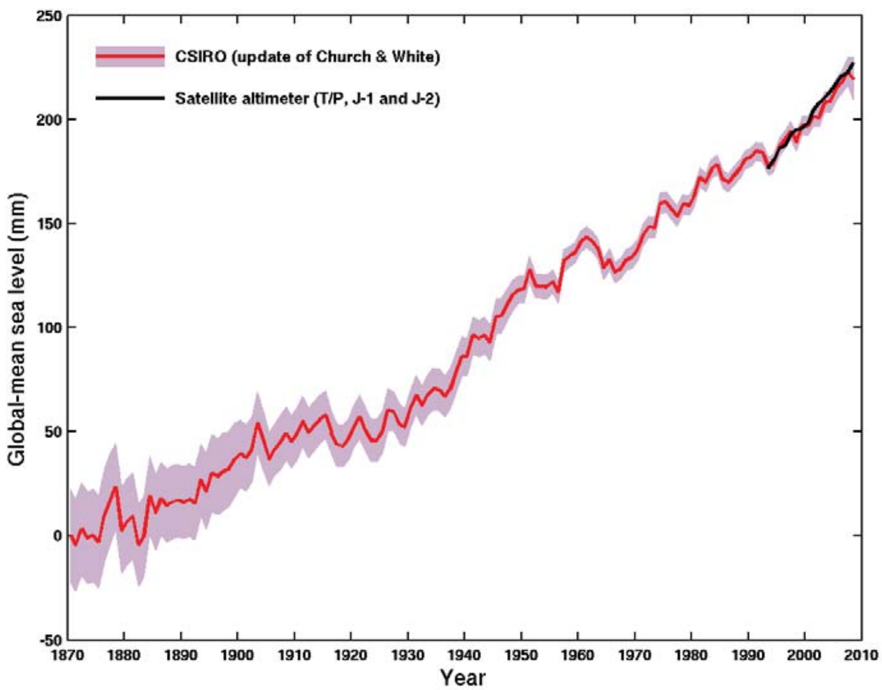
3.1.2. Change in Mean Sea Level

Manly Hydraulics Laboratory recently undertook an assessment of the change in mean sea level at the ocean level recorders along the NSW coast since data has been available (1987 to date). The results (see below) indicate that there is an average annual increase of 2.7 mm in that period. However it should be noted that at other locations there has been a corresponding decrease (Coffs Harbour).



A recent technical paper by Church et al (Reference 17) states:

"The few long-term coastal sea-level records (the earliest dating from about 1700; Woodworth 1999) and sea-level records estimated from coastal sediment cores (e.g. Gehrels et al. 2005, 2006) indicate an increase in the rate of rise from the 19th to the 20th century. Estimates of global-averaged sea level indicate an acceleration in the rate of rise during the 20th century (Church and White 2006; Jevrejeva et al. 2006; Woodworth et al. 2009; refer Figure 1 below). Since 1993, the rate of rise has been over 3 mm yr-1 (Church and White 2006; Leuliette et al. 2004; Beckley et al. 2007) compared with the 20th century average of about 1.7 mm yr-1; whether this represents a further sustained increase in the rate of rise is not yet clear (Church et al. 2008a)."



*"**Figure 1.** Global mean sea level from 1870 to 2008 with one standard deviation error estimates, updated from Church and White (2006, red), and the Topex/Poseidon/Jason-1 and -2 satellite altimeter global mean sea level (based on standard processing as in Church and White 2006) from 1993 to 2008 is in black. Both series have been set to a common value at the start of the altimeter record in 1993."*

3.2. Effect of Ocean Level Rise on Design Flood Levels

A climate change induced increase in the ocean level can affect the design flood levels in the Port Stephens estuary in two ways, by affecting the **Stillwater** (includes design ocean levels + catchment inflows + wind setup within the estuary) flood levels and the **Wave Runup** flood levels.

3.2.1. Effect on Stillwater Flood Levels

It is assumed with a climate change induced ocean level rise that the entire tidal cycle will gradually be raised over time and according to advice in Reference 13 in 2050 it will be raised by 40cm in 2050 and by 90cm by 2100 (from 1990 levels). Thus the design ocean levels will be raised by a similar amount assuming that there is no change in the storm surge or ocean wave setup components. Thus by 2050 the 1% AEP design ocean level will rise from 1.5 mAHD to 1.9 mAHD and to 2.4 mAHD by the year 2100. Based on the results from Reference 3 (Section 2.4.2) the Stillwater flood levels in the Port Stephens estuary will therefore rise by a similar amount (refer Tables 3 and 4).

The possible increase in wind setup (significant component affecting the stillwater flood levels) due to climate change is unknown at this time and has therefore not been considered.

The increase in the lateral extent of inundation will depend on the slope of the land. In places the land rises steeply and thus the increase in extent will be less than a few metres. In other places the increase may be say 20m if the slope is a 1m rise over 50 metres. As an example the change in Flood Planning Level extents (due to both an increase in the Stillwater and Wave Runup extents) at Sandy Point/Corlette Point (Sites 9a & 10), Salamander Bay (Site 11), and Lemon Tree/Mallabula Point (Sites 20 & 21) are shown in Appendix C with the climate change adjusted levels shown on Figure 6.

3.2.2. Effect on Wave Runup Levels

Reference 4 (results shown in Table 2 herein) indicate that for the majority of sites (exceptions are Sites 5, 8 and 9) the 1% AEP runup level is greater than the 5% AEP runup level by a similar difference to the water level in the estuary. Based on this it is reasonable to assume that the wind runup peak levels will rise by a similar amount to the climate change induced ocean level rise (refer Tables 3 and 4). The implications of an ocean level rise on wave runup levels are:

- the peak water level will generally rise by the same amount as the increase in the climate change ocean level. However, at some sites the local topography will limit the increase in level (overtopping the sea wall). Only a detailed site inspection can ascertain the exact magnitude of the increase at each location,
- the lateral extent of inundation (as the peak level is greater) would be greater depending upon the slope of the land,
- the starting point (MHW or 0.5 mAHD) for the assumed 50m lateral extent of the wave runup extent would move further landward as the starting point would rise,
- at this time there is no indication that the assumed 50m wave runup extent would increase.

As an example the change in Flood Planning Level extents (due to both an increase in the Stillwater and Wave Runup extents) at Sandy Point/Corlette Point (Sites 9a & 10), Salamander Bay (Site 11), and Lemon Tree/Mallabula Point (Sites 20 & 21) are shown in Appendix C with the climate change adjusted levels shown on Figure 6.

3.3. Effect of Rainfall Increase on Design Flood Levels

A climate change induced increase in rainfall intensities over the Port Stephens catchment will have NO significant effect on the **Wave Runup** flood levels. Based on the results from Reference 3 (Section 2.4.2) a 30% increase in rainfall intensity will raise the **Stillwater** flood levels by less than 0.1m.

3.4. Proposed Climate Change Design Flood Levels

Study Outcome No 1: a climate change induced ocean level increase will raise the design flood levels and wave runup levels by the same amount as the assumed ocean level rise

The assessment indicates that the wave runup and Stillwater design flood levels shown in Table

2 can be adjusted upwards by 0.4m and 0.9m to take into account a climate change induced ocean level rise.

Study Outcome No 2: a climate change induced rainfall increase of up to 30% will raise flood levels in the Port Stephens estuary by less than 0.1m. Tables 3 and 4 show the wave runup and stillwater flood levels indicated in Table 2 increased by 0.4m (year 2050) and 0.9m (year 2100) due to ocean level rise with no increase due to increased rainfall intensities or changes to the wind setup component. It should be noted that the wave runup levels are conservative and are likely to be lower than this maximum value as the topography (e.g above sea wall or change in foreshore structure) changes with increased height. Only a detailed site inspection can ascertain the exact magnitude of the wave runup increase at each location.

Table 3: Design Flood Levels (m AHD) with 0.4m Ocean Level Rise

		Wave Runup (as per Table 2)			Stillwater - No Wave Runup (as per Table 2)		
Site	**Location**	**5% AEP**	**1% AEP**	**Extreme**	**5% AEP**	**1% AEP**	**Extreme**
1	Tomaree	overtops seawall			1.9	1.9	2.0
2	Shoal Bay East	2.7	2.9	3.0	1.9	1.9	2.0
3	Shoal Bay West	3.1	3.2	3.4	1.9	2.0	2.0
4	Nelson Head East	3.3	3.5	3.8	1.9	2.0	2.0
5	Little Nelson Bay	2.3	2.8	2.9	1.9	2.0	2.0
6	Fly Point	2.5	2.7	2.8	1.9	2.0	2.0
7	Nelson Bay	3.5	3.7	overtops seawall	1.9	2.0	2.0
8	Dutchmans Bay	2.6	3.0	3.1	2.0	2.0	2.1
9	Redpatch Point	2.9	3.2	3.3	2.0	2.1	2.1
9a	Sandy Point	2.8	2.7	3.3	2.0	2.1	2.1
10	Corlette Point	2.6	2.7	3.1	2.0	2.1	2.1
11	Salamander Bay	2.3	2.4	2.7	2.0	2.1	2.1
12	Wanda Wanda Head	2.4	2.4	2.5	2.0	2.1	2.2
13	Kangaroo Point	2.7	2.8	3.1	2.0	2.1	2.2
14	Soldiers Point East	2.9	3.0	3.5	2.0	2.1	2.2
15	Soldiers Point West	2.2	2.3	2.5	2.1	2.1	2.2
16	Greenplay Point	2.1	2.2	2.7	2.1	2.2	2.2
17	Mud Point	2.1	2.2	2.7	2.1	2.2	2.2
18	Diemar Point	overtops seawall			2.1	2.2	2.2
19	Taylor Beach	2.1	2.2	2.7	2.1	2.2	2.2
20	Lemon Tree	2.1	2.2	2.4	2.1	2.2	2.2
21	Mallabula Point	2.5	2.6	2.7	2.1	2.2	2.2
22	Tanilba Bay	2.2	2.2	2.4	2.1	2.2	2.3
23	Bato Bato Point	2.8	2.9	3.5	2.2	2.3	2.3
24	Oyster Cove	2.6	2.6	2.6	2.2	2.3	2.4
25	Swan Bay	2.5	2.6	2.7	2.2	2.3	2.3
26	Davis Point	2.2	2.3	2.4	2.2	2.3	2.4
27	Lillies Point	2.5	2.6	2.8	2.2	2.3	2.4
28	Karuah Bridge	2.2	2.3	2.4	2.2	2.3	2.4
29	Correebah	2.7	2.8	3.1	2.1	2.2	2.3
30	Carrington	2.4	2.6	2.7	2.1	2.2	2.3
31	Baromee Point	2.6	2.7	2.8	2.1	2.2	2.2
32	Baromee Hill	2.6	2.7	2.8	2.1	2.2	2.2
33	Bundabah	2.1	2.2	2.4	2.1	2.2	2.2
34	Fame Point	3.6	3.8	4.3	2.1	2.2	2.2
35	Lower Pindimar	2.7	2.8	3.1	2.0	2.1	2.2
36	Orungall Point	2.4	2.6	2.8	2.0	2.1	2.1

37	Pindimar	2.4	2.4	2.6	2.0	2.1	2.1
38	Limestone	2.0	2.1	2.1	2.0	2.1	2.1
39	Tea Gardens	2.0	2.2	2.7	2.0	2.2	2.7
40	Hawks Nest	1.9	2.1	2.4	1.9	2.1	2.4
41	Jimmy's Beach West	3.3	3.5	3.8	1.9	2.0	2.0
42	Jimmy's Beach East	2.9	3.0	3.3	1.9	2.0	2.0

Table 4: Design Flood Levels (m AHD) with 0.9m Ocean Level Rise

		With Wave Runup (as per Table 2)			Stillwater - No Wave Runup (as per Table 2)		
Site	**Location**	**5% AEP**	**1% AEP**	**Extreme**	**5% AEP**	**1% AEP**	**Extreme**
1	Tomaree	overtops seawall			2.4	2.4	2.5
2	Shoal Bay East	3.2	3.4	3.5	2.4	2.4	2.5
3	Shoal Bay West	3.6	3.7	3.9	2.4	2.5	2.5
4	Nelson Head East	3.8	4.0	4.3	2.4	2.5	2.5
5	Little Nelson Bay	2.8	3.3	3.4	2.4	2.5	2.5
6	Fly Point	3.0	3.2	3.3	2.4	2.5	2.5
7	Nelson Bay	4.0	4.2	overtops seawall	2.4	2.5	2.5
8	Dutchmans Bay	3.1	3.5	3.6	2.5	2.5	2.6
9	Redpatch Point	3.4	3.7	3.8	2.5	2.6	2.6
9a	Sandy Point	3.3	3.2	3.8	2.5	2.6	2.6
10	Corlette Point	3.1	3.2	3.6	2.5	2.6	2.6
11	Salamander Bay	2.8	2.9	3.2	2.5	2.6	2.6
12	Wanda Wanda Head	2.9	2.9	3.0	2.5	2.6	2.7
13	Kangaroo Point	3.2	3.3	3.6	2.5	2.6	2.7
14	Soldiers Point East	3.4	3.5	4.0	2.5	2.6	2.7
15	Soldiers Point West	2.7	2.8	3.0	2.6	2.6	2.7
16	Greenplay Point	2.6	2.7	3.2	2.6	2.7	2.7
17	Mud Point	2.6	2.7	3.2	2.6	2.7	2.7
18	Diemar Point	overtops seawall			2.6	2.7	2.7
19	Taylor Beach	2.6	2.7	3.2	2.6	2.7	2.7
20	Lemon Tree	2.6	2.7	2.9	2.6	2.7	2.7
21	Mallabula Point	3.0	3.1	3.2	2.6	2.7	2.7
22	Tanilba Bay	2.7	2.7	2.9	2.6	2.7	2.8
23	Bato Bato Point	3.3	3.4	4.0	2.7	2.8	2.8
24	Oyster Cove	3.1	3.1	3.1	2.7	2.8	2.9
25	Swan Bay	3.0	3.1	3.2	2.7	2.8	2.8
26	Davis Point	2.7	2.8	2.9	2.7	2.8	2.9
27	Lillies Point	3.0	3.1	3.3	2.7	2.8	2.9
28	Karuah Bridge	2.7	2.8	2.9	2.7	2.8	2.9
29	Correebah	3.2	3.3	3.6	2.6	2.7	2.8
30	Carrington	2.9	3.1	3.2	2.6	2.7	2.8
31	Baromee Point	3.1	3.2	3.3	2.6	2.7	2.7
32	Baromee Hill	3.1	3.2	3.3	2.6	2.7	2.7
33	Bundabah	2.6	2.7	2.9	2.6	2.7	2.7
34	Fame Point	4.1	4.3	4.8	2.6	2.7	2.7
35	Lower Pindimar	3.2	3.3	3.6	2.5	2.6	2.7
36	Orungall Point	2.9	3.1	3.3	2.5	2.6	2.6
37	Pindimar	2.9	2.9	3.1	2.5	2.6	2.6
38	Limestone	2.5	2.6	2.6	2.5	2.6	2.6
39	Tea Gardens	2.5	2.7	3.2	2.5	2.7	3.2
40	Hawks Nest	2.4	2.6	2.9	2.4	2.6	2.9
41	Jimmy's Beach West	3.8	4.0	4.3	2.4	2.5	2.5
42	Jimmy's Beach East	3.4	3.5	3.8	2.4	2.5	2.5

3.5. Other Relevant Issues

The following are issues that are relevant to the outcomes of this study.

3.5.1. Freeboard

Freeboard is defined in the Floodplain Development Manual (Reference 1) as:
"Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level."

The manual indicates that the following factors are included within the freeboard:

- Uncertainties in estimates of flood levels,
- "Local factors" not defined in the broad scale approach,
- Increases in water level due to wave action (not applied <u>in addition</u> to the wave runup levels),
- Increases in water level due to uncertainty in climate change predictions,
- The cumulative effect of subsequent infill development (not relevant for stillwater flood levels due to the size of the estuary).

It could be argued that as the freeboard already includes some allowance for climate change then say the assumed 0.9m ocean level rise by the year 2010 can be reduced to say 0.7m. This approach is not valid as the freeboard is a factor of safety around the "best estimate" (this is discussed in Reference 14 which states *"Freeboard should not therefore be used to allow for sea level rise impacts, which should be quantified and applied separately …"*). Thus if the best estimate of ocean level rise is 0.9m, the freeboard allowance in the Flood Planning Level will still have an allowance (not defined) for a climate change factor of safety.

Study Outcome No 3: the assumed climate change induced ocean level increase and consequent flood level rise should be applied with the current freeboard allowance of 0.5m (i.e no reduction in the assumed ocean level rise should occur just because there is some allowance for climate change in the freeboard allowance).

3.5.2. Change in Karuah River Design Inflows

The Karuah River Flood Study (Reference 18) indicates that the current estimates of peak flows on the Karuah River at Karuah have increased significantly from those quoted in Reference 3 (this change has occurred due to a re-estimate of the hydrology).

Table 5: Comparison of Peak Flows at Karuah

Event	Reference 3	Reference 18
5% AEP	1687 m^3/s	2508 m^3/s
2% AEP	2295 m^3/s	3354 m^3/s
1% AEP	2857 m^3/s	4060 m^3/s
Extreme (Reference 3) or PMF (Reference 18)	6136 m^3/s	12713 m^3/s

There is a 42% increase in the 1% AEP flows from Reference 3 to Reference 18. Thus the inclusion of the flows estimated in Reference 18 would raise the flood levels in the Port Stephens estuary compared to those adopted Reference 3. However, as indicated by the results from Reference 3 this increase will have less than a 0.1m increase in water level in the estuary.

3.5.3. Is the Existing Minimum Flood Planning Level of 2.5 mAHD too Conservative?

The existing uniform minimum Flood Planning Level (FPL) of 2.5 mAHD was adopted as part of the Port Stephens Foreshore (Floodplain) Management Plan (Reference 6) as it was simple to apply and required no decisions about boundaries between different levels. Figure 3 indicates the levels of the Stillwater and wave runup design levels. Figure 3 also indicates that the minimum FPL of 2.5 m AHD is up to 0.4m above the existing 1% AEP flood level +0.5m freeboard, thus in places the current minimum FPL is unduly conservative.

Study Outcome No 4: the current minimum Flood Planning Level of 2.5 mAHD (with climate change induced ocean level rise of 0.9m it will be 3.4 mAHD by the year 2100) has been adopted throughout the estuary foreshore. However this means that at some locations there is a much greater freeboard than 0.5m. There is therefore an opportunity to lower the proposed climate change Flood Planning Level of 3.4 mAHD by assuming a non uniform level in the estuary.

3.5.4. Is the Adopted Design Ocean Levels Approach Appropriate?

The main determinant of the stillwater design flood levels in the Port Stephens estuary is the design ocean levels. These were taken from analysis of the Fort Denison record in Sydney Harbour (Reference 3) and described in Section 2.4.2.

As part of studies at Lake Macquarie an analysis of the Port Stephens water level record was undertaken and the results are shown on Figures 7 and 8. These indicate that ocean anomalies of up to 0.5m have been recorded and in the major rainfall events of February 1990 and June 2007 (both produced significant flooding on Lake Macquarie and Tuggerah Lakes) the rainfall was associated with ocean anomalies.

Whilst the above record cannot be described as a rigorous analysis it does indicate that elevated ocean levels, above the highest astronomical tide have occurred, and the adopted approach is therefore not unreasonable.

4. APPROACH FOR UPDATING MYALL RIVER DESIGN FLOOD LEVELS

4.1. Myall River Catchment

The Myall River catchment (780 km^2) comprises:

- Myall River to Boombah Broadwater (360 km^2),
- Boombah Broadwater, Boolambyte Lake and Myall Lake (100 km^2),
- Boolambyte Creek (50 km^2),
- Surrounding hills, marshes and plains (270km^2).

From Boombah Broadwater (Tamboy) to Tea Gardens the Myall River follows a 15 km meandering path surrounded by heavily vegetated floodplain. The Myall River enters the Port Stephens estuary by two channels to the north and east of Corrie Island Nature Reserve. The majority of the floodplain is within the Myall Lakes National Park and is largely uninhabited.

4.2. Lower Myall River Flood Analysis

The Lower Myall River Flood Analysis (Reference 19) is the only State Government funded study of flooding on the Myall River. There has been other privately funded studies (Reference 20) but no subsequent Flood Study funded as part of the State Government program as outlined in Reference 1.

Reference 19 was undertaken using the best available approach at the time (based on the 1977 edition of Australian Rainfall & Runoff rather than the current 1987 edition) but there have been significant advancements in the hydrologic and hydraulic models available for use and in particular the availability of ALS survey which provides more accurate definition of the floodplain. The hydraulic model used was a steady state backwater program with outflow from the lakes represented as an outflow function. A Public Works hydrosurvey provided definition of the Myall River downstream of Tamboy but the sections are only crudely defined by today's standards (they are shown in the report but at a scale which is unsuitable to accurately digitise).

Design flood gradients are provided from Tea Gardens to Tamboy based on different tailwater levels in the Port Stephens estuary.

Reference 20 was undertaken for a private developer to assess the effects of climate change for a proposed residential development located east of the intersection of Toonang Drive and Myall Street. This study established a XPSWMM model of the Myall River using the same cross sections as Reference 19 with the inclusion of some additional river cross sections. The focus of the study was on local drainage within the proposed development rather than the potential effects of climate change on Myall River flood levels.

4.3. Proposed Approach to Update the Myall River Flood Study

Both References 19 and 20 are limited by the relatively unsophisticated hydrologic modelling and storage routing approach through Myall Lakes. However as the flood levels at Tea Gardens (only major settlement) are largely determined by the water level in the Port Stephens estuary (as they are at Karuah on the Karuah River) the design flood levels at Tea Gardens could be estimated with a fairly high degree of accuracy using a relatively simple modelling approach.

Initially a thorough investigation should be undertaken to obtain all historic records of flooding on the Myall River. The use of a suitable hydrologic model and 2D hydraulic model, incorporating current ALS survey, would ensure a Flood Study compatible with present standards is obtained for the entire lakes and Lower Myall River. However as the majority of the floodplain is National Park with no existing or proposed future development the value of obtaining more up to date flood levels throughout the entire floodplain, including the lakes, is questionable.

Flood levels in Tea Gardens and Hawks Nest are required for development control purposes and it is suggested that an up to date hydrologic model is obtained and calibrated but only a relatively crude 2D model is adopted for routing the flows through the lakes system to Tea Gardens, with a more detailed 2D model at Tea Gardens. ALS should be used to determine the stage storage characteristics of the lakes (i.e above 0 m AHD) and no bathymetry of the lakes is required. Along the Myall River downstream of Tamboy it may be possible to locate the original hydrographic survey (Reference 20 obviously did) as this would save time and costs. However it is likely that further detailed hydrographic survey may be required near Tea Gardens if the original survey or any subsequent survey that is located is inadequate. The use of ALS can significantly reduce the extent hydrographic survey that may be required.

5. ACKNOWLEDGEMENTS

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- Department of Environment, Climate Change and Water,
- Port Stephens Council,
- Great Lakes Council,
- NSW State Government.

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Figures

FIGURE 1

CATCHMENT MAP

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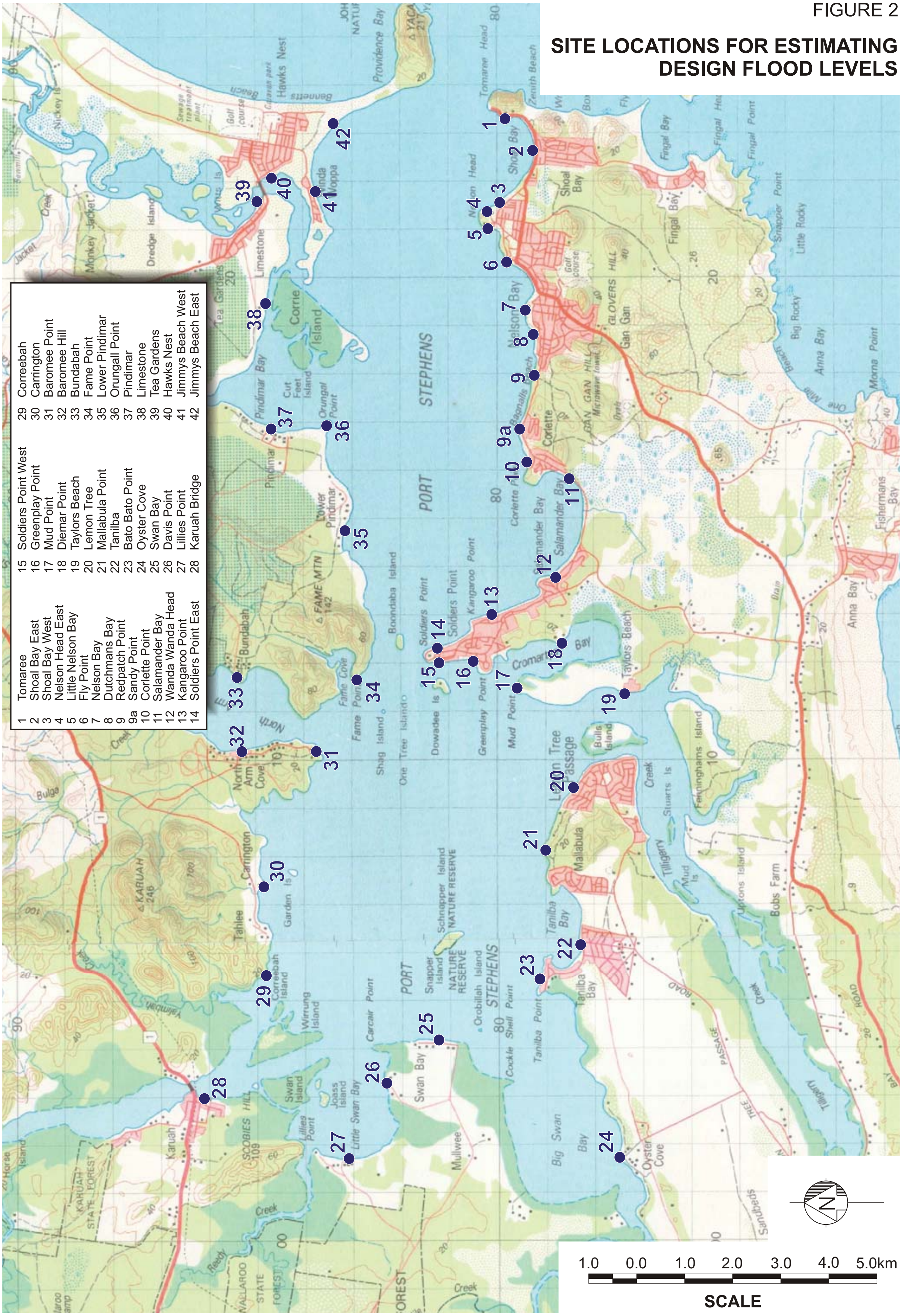
FIGURE 2

SITE LOCATIONS FOR ESTIMATING DESIGN FLOOD LEVELS



1	Tomaree	15	Soldiers Point West	29	Correebah
2	Shoal Bay East	16	Greenplay Point	30	Carrington
3	Shoal Bay West	17	Mud Point	31	Baromee Point
4	Nelson Head East	18	Diemar Point	32	Baromee Hill
5	Little Nelson Bay	19	Taylors Beach	33	Bundabah
6	Fly Point	20	Lemon Tree	34	Fame Point
7	Nelson Bay	21	Mallabula Point	35	Lower Pindimar
8	Dutchmans Bay	22	Tanilba	36	Orungall Point
9	Redpatch Point	23	Bato Bato Point	37	Pindimar
9a	Sandy Point	24	Oyster Cove	38	Limestone
10	Corlette Point	25	Swan Bay	39	Tea Gardens
11	Salamander Bay	26	Davis Point	40	Hawks Nest
12	Wanda Wanda Head	27	Lillies Point	41	Jimmys Beach West
13	Kangaroo Point	28	Karuah Bridge	42	Jimmys Beach East
14	Soldiers Point East				

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FIGURE 3
PORT STEPHENS DESIGN FLOOD LEVELS

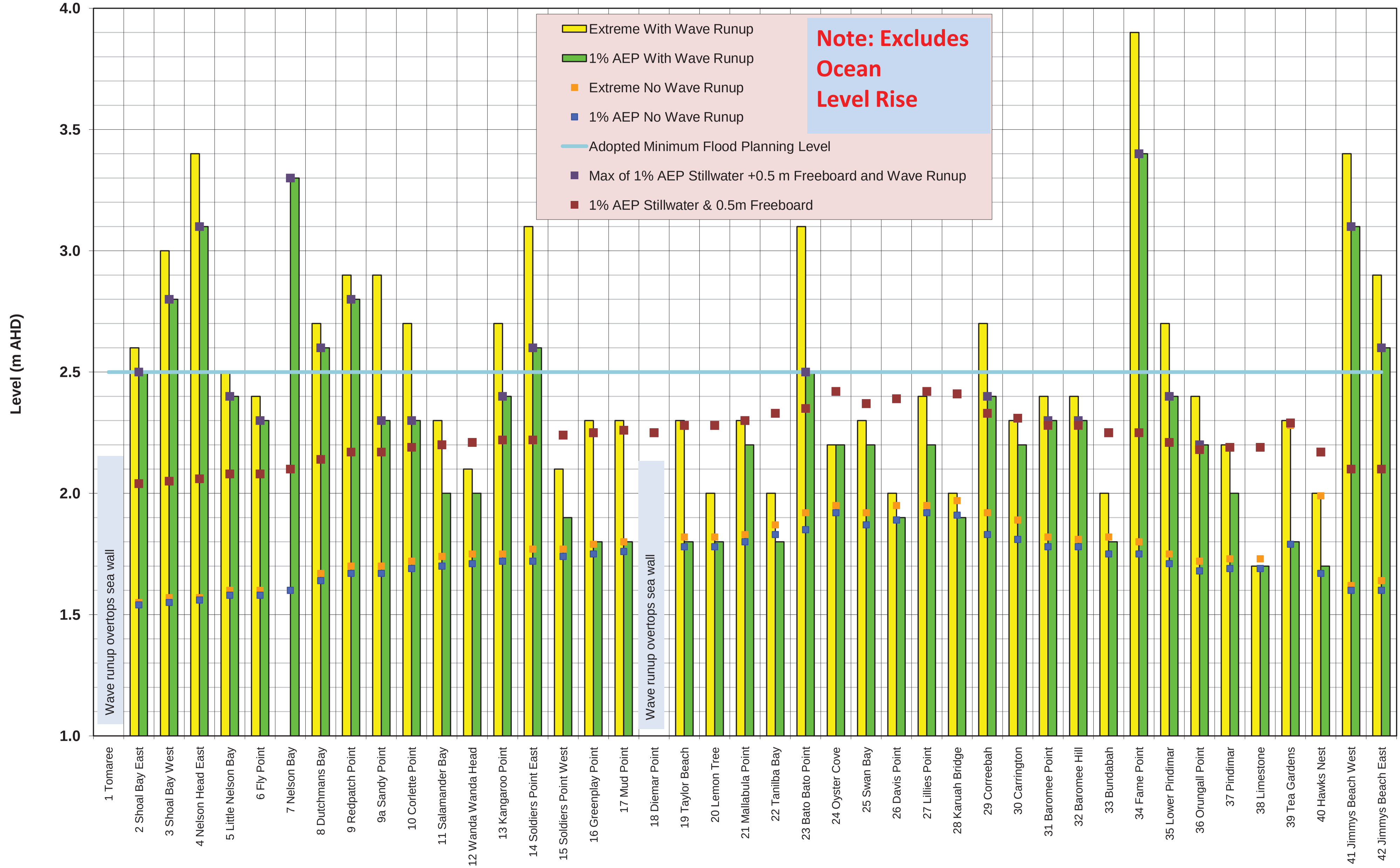


FIGURE 4

FLOOD GRADIENTS STILLWATER INUNDATION

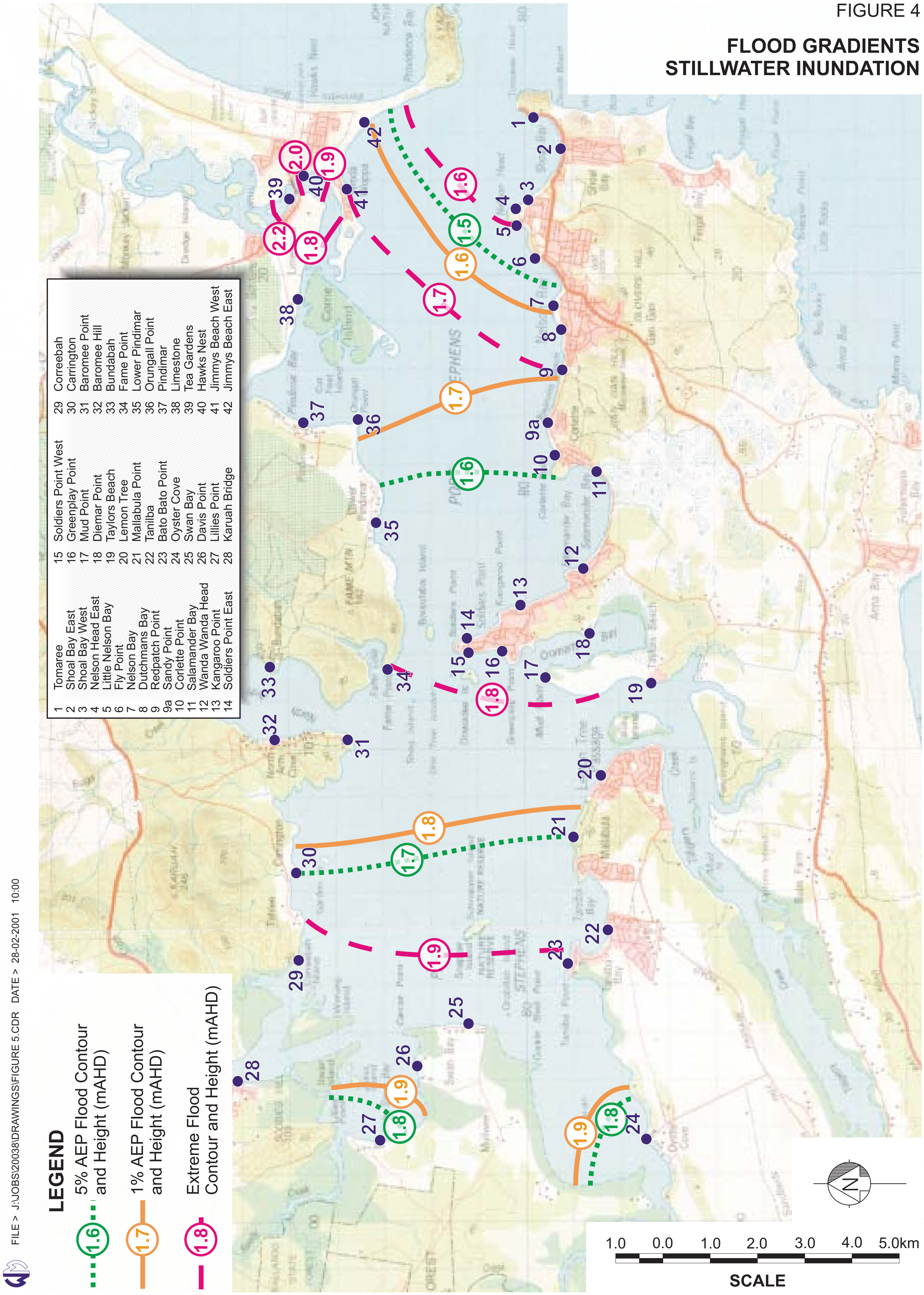
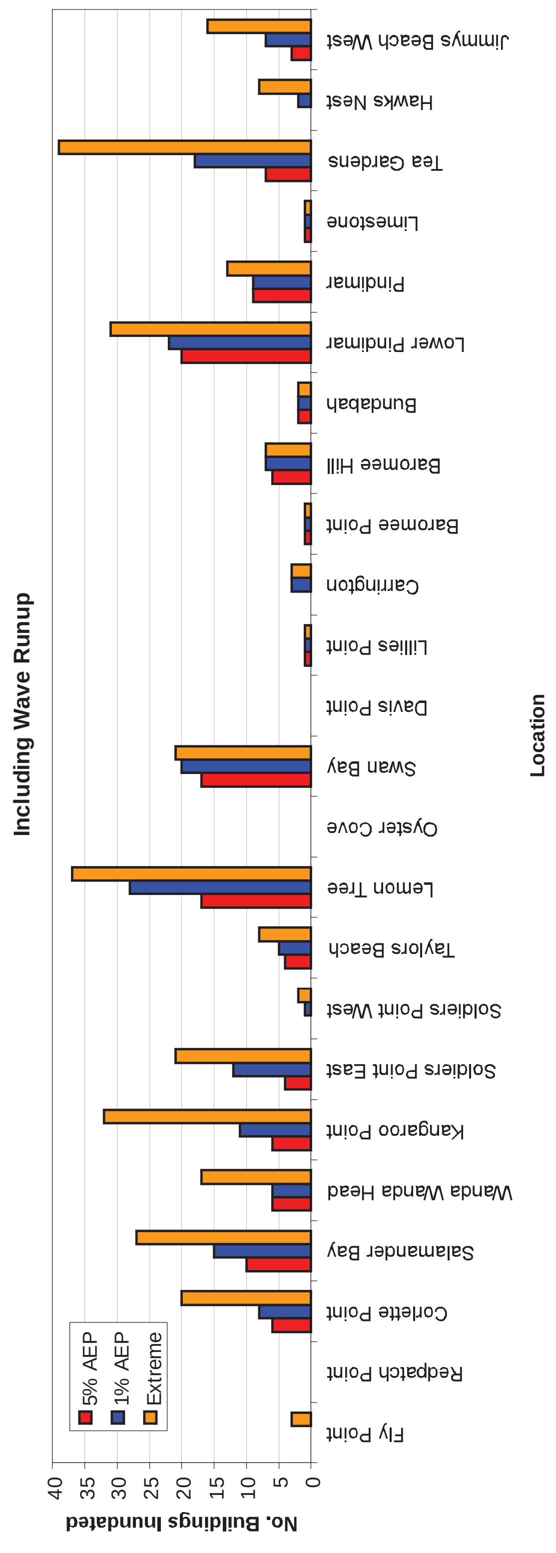


FIGURE 5

BUILDINGS INUNDATED
EXISTING CONDITIONS



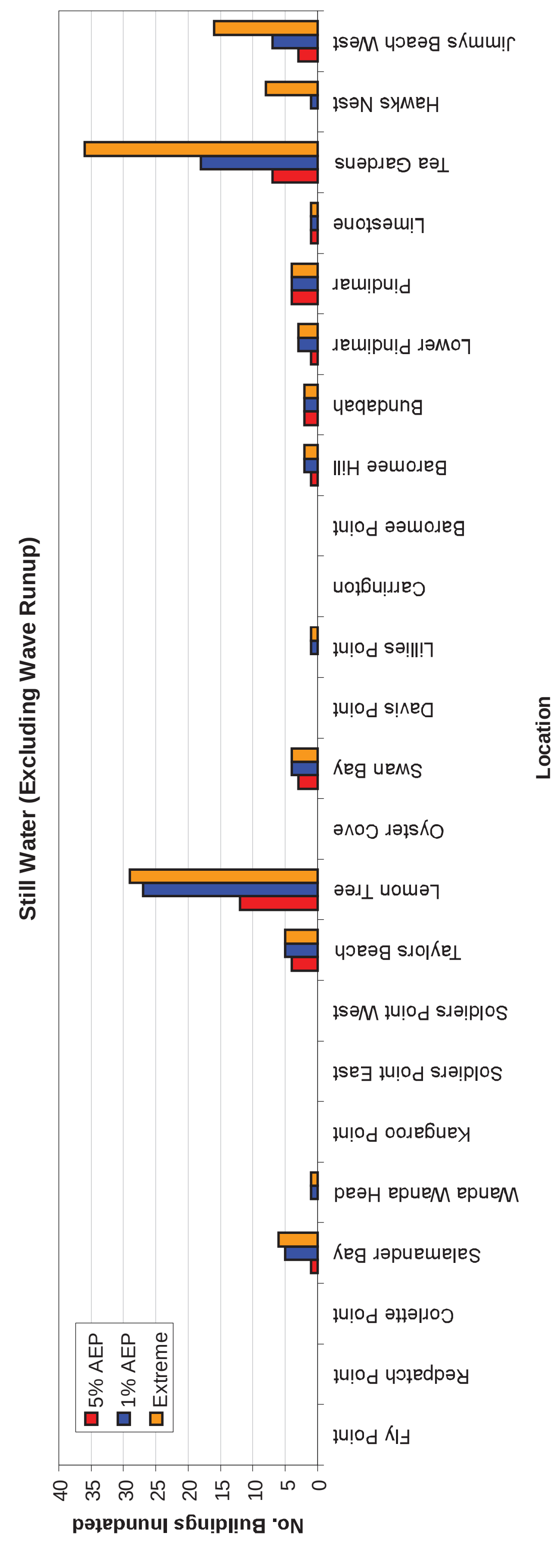


FIGURE 6

PORT STEPHENS DESIGN FLOOD LEVELS INCLUDING CLIMATE CHANGE

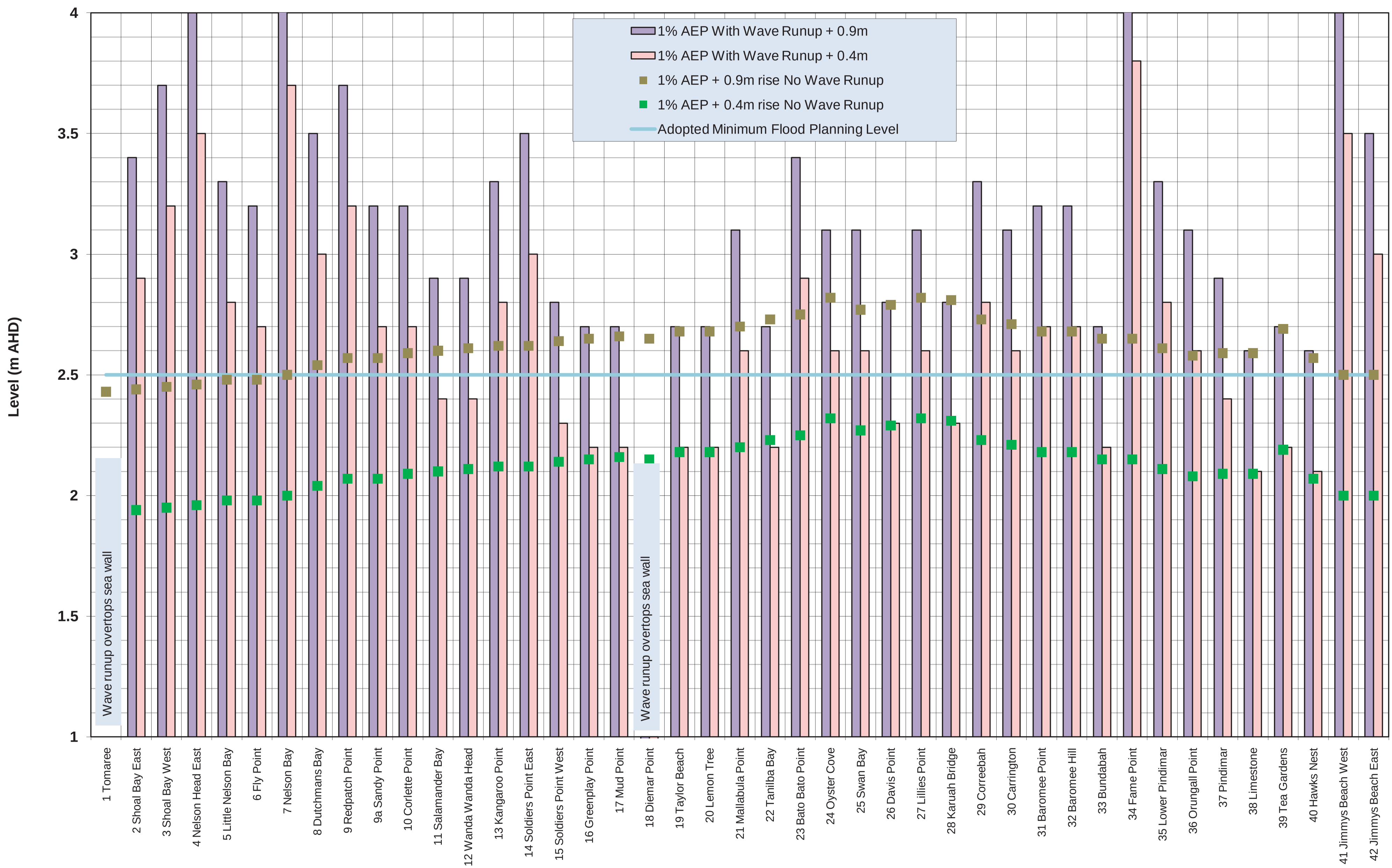


FIGURE 7

PORT STEPHENS TIDAL ANALYSIS

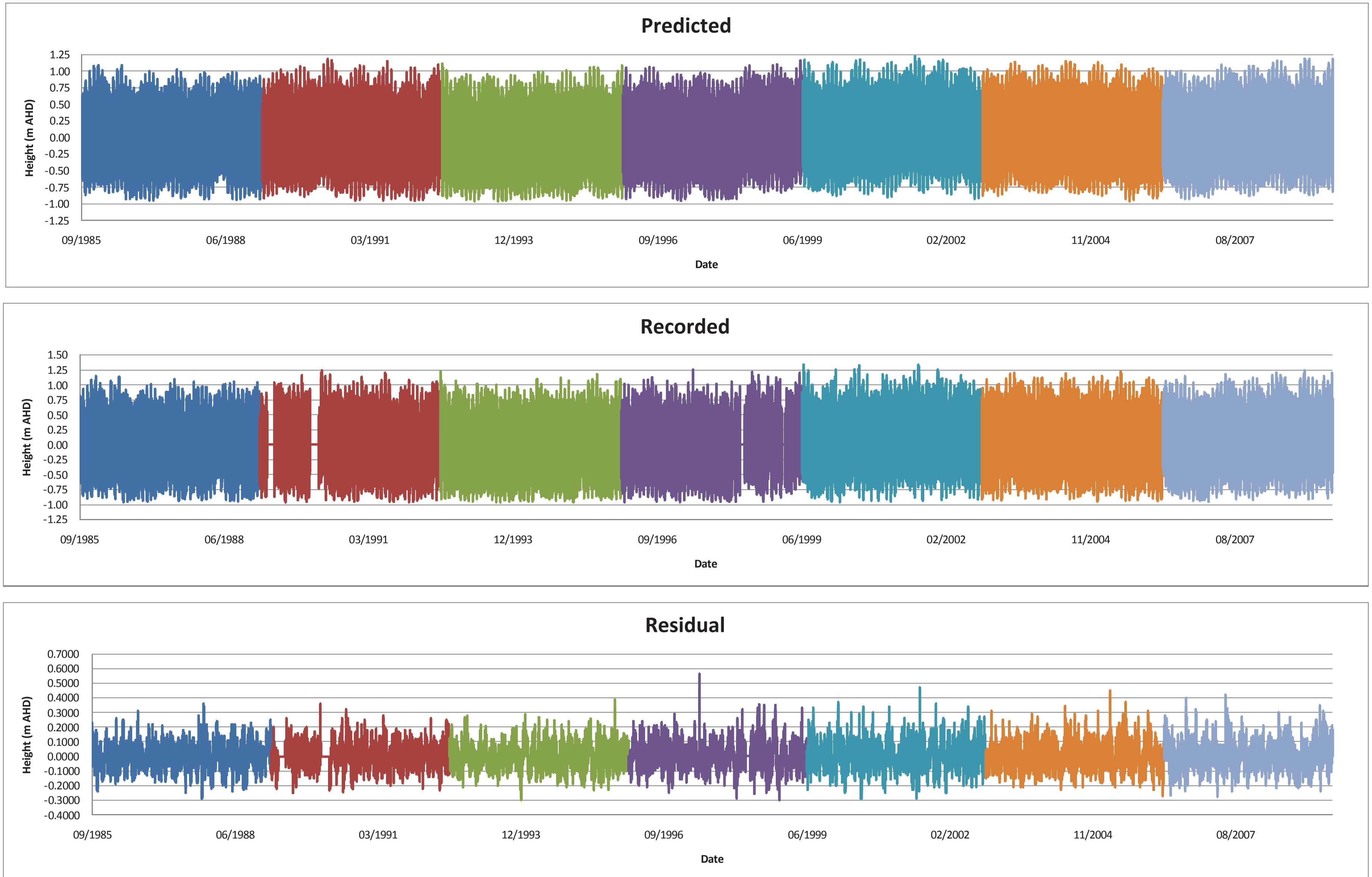


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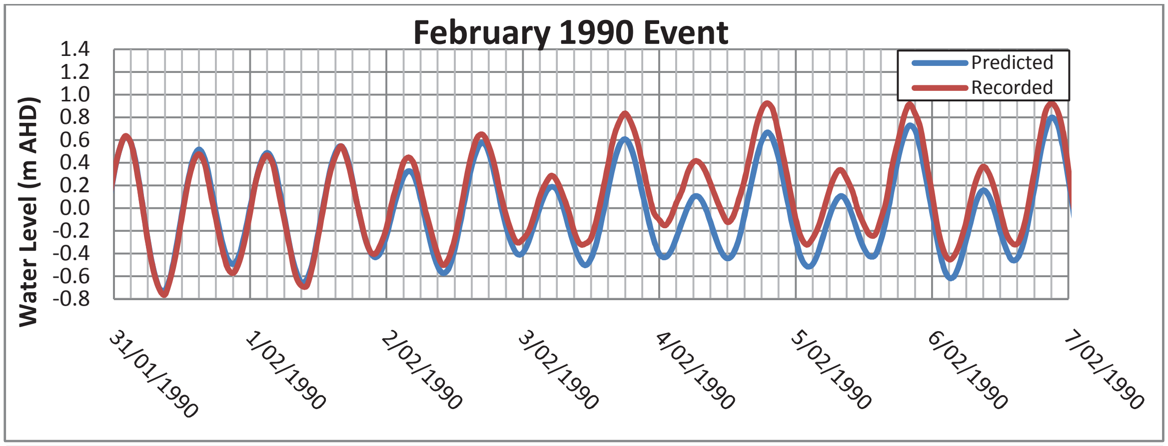
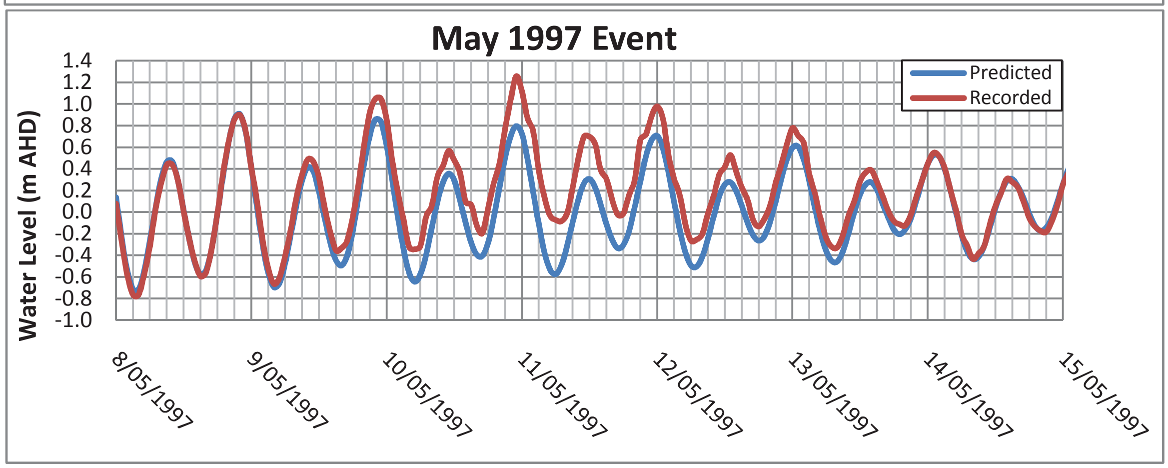
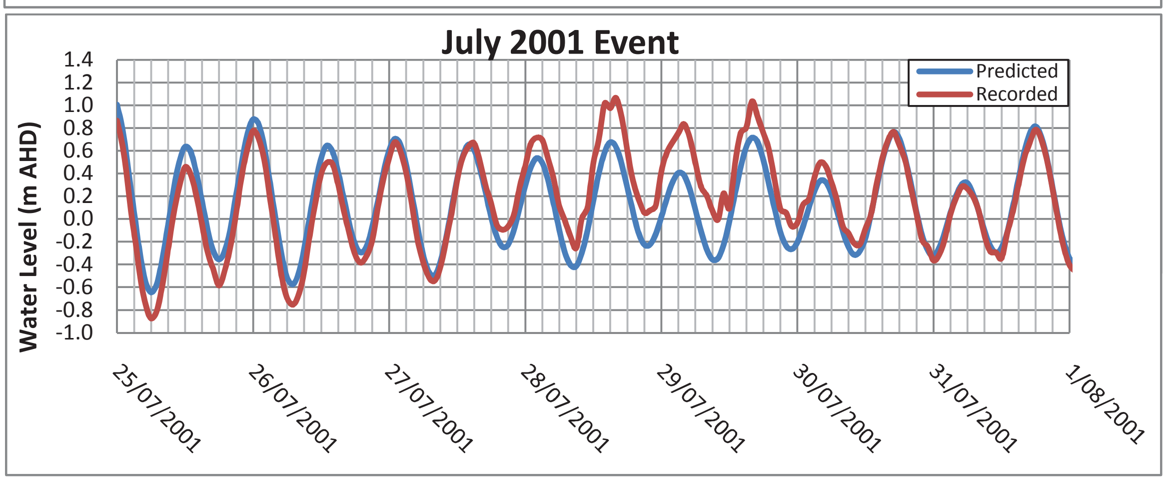
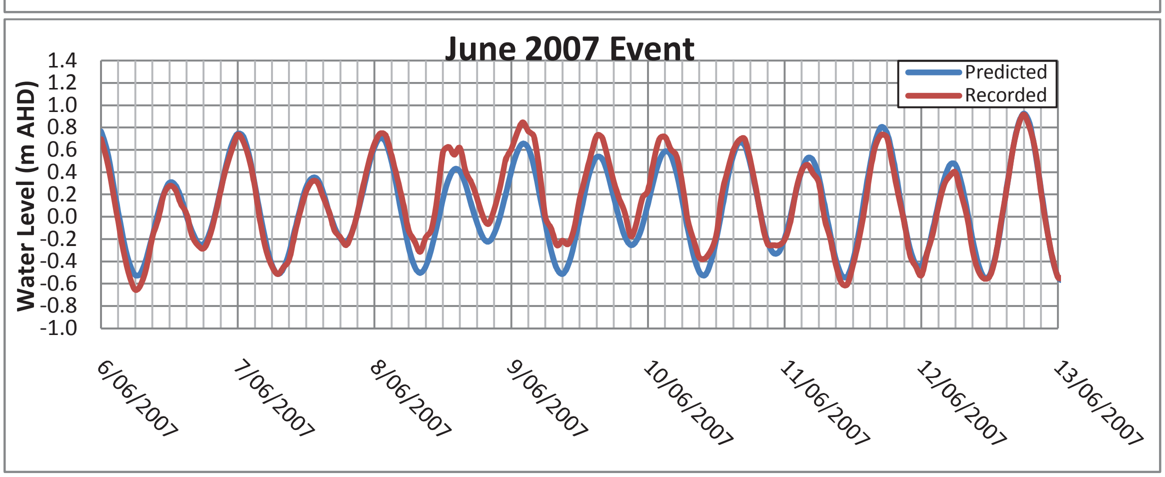
FIGURE 8

PORT STEPHENS TIDAL ANOMALIES









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Appendix A

APPENDIX A: GLOSSARY OF TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN) A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ecologically sustainable development (ESD) Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas The remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).

flood mitigation standard The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the

	impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.

merit approach — The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains.

The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.

minor, moderate and major flooding — Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.

moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.

major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures — Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.

peak discharge — The maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF) — The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP) — The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability — A statistical measure of the expected chance of flooding (see AEP).

risk — Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

runoff — The amount of rainfall which actually ends up as streamflow, also known as

	rainfall excess.
stage	Equivalent to “water level”. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

Table J3 Sensitivity Tests - 1% AEP Flood and Storm Tide
Effect of Flow Variation

Point	Site	1% Test Conditions	1% Test Conditions Q*1.05	1% Test Conditions Q*1.10
1	Tomaree	1.53	1.53	1.53
2	Shoal Bay E	1.53	1.53	1.53
3	Shoal Bay W	1.54	1.54	1.54
4	Nelson Head E	1.54	1.54	1.54
5	Nelson Head W	1.56	1.56	1.56
6	Little Bay	1.56	1.56	1.56
7	Nelson Bay	1.57	1.57	1.57
8	Bagnalls Beach E	1.58	1.58	1.58
9	Bagnalls Beach W	1.60	1.60	1.60
10	Corlette Point	1.62	1.62	1.62
11	Salamander Bay	1.62	1.62	1.62
12	Round Head	1.62	1.62	1.62
13	Kangaroo Point	1.62	1.62	1.62
14	Soldiers Point E	1.62	1.62	1.64
15	Soldiers Point W	1.65	1.64	1.65
16	Greenpatch Point	1.67	1.66	1.66
17	Mud Point	1.67	1.67	1.67
18	Diemans Point	1.67	1.67	1.67
19	Taylors Beach	1.69	1.69	1.69
20	Lemon Tree	1.68	1.68	1.68
21	Mallabula Point	1.67	1.68	1.68
22	Tanilba Bay	1.68	1.68	1.68
23	Tanilba Point	1.69	1.69	1.69
24	Oyster Cove	1.71	1.71	1.71
25	Swan Bay	1.69	1.68	1.69
26	Carcair	1.69	1.69	1.69
27	Little Swan	1.69	1.69	1.70
28	Karuah Bridge	1.76	1.76	1.77
29	Correebah	1.68	1.68	1.68
30	Carrington	1.68	1.68	1.68
31	Baromee	1.67	1.67	1.67
32	North Arm Cove	1.67	1.67	1.67
33	Dead Mans Point	1.67	1.67	1.67
34	Fame Point	1.65	1.65	1.65
35	Lower Pindimar	1.62	1.62	1.62
36	Orungall Point	1.60	1.60	1.60
37	Pindimar	1.60	1.60	1.60
38	Limestone	1.60	1.60	1.60
39	Tea Gardens	1.65	1.67	1.68
40	Hawks Nest	1.57	1.58	1.60
41	Winda Woppa	1.55	1.55	1.55
42	Wanderrebah	1.55	1.55	1.55

Table J5 Sensitivity Tests - 1% AEP Flood and Tide
Effect of Ocean Water Level

Point	Site	1% 1% Storm Tide (1.5 m AHD)	1% 2 m ISLW (1.1 m AHD)
1	Tomaree	1.53	1.10
2	Shoal Bay E	1.53	1.10
3	Shoal Bay W	1.54	1.10
4	Nelson Head E	1.54	1.10
5	Nelson Head W	1.56	1.12
6	Little Bay	1.56	1.12
7	Nelson Bay	1.57	1.14
8	Bagnalls Beach E	1.58	1.16
9	Bagnalls Beach W	1.60	1.18
10	Corlette Point	1.62	1.19
11	Salamander Bay	1.62	1.20
12	Round Head	1.62	1.20
13	Kangaroo Point	1.62	1.20
14	Soldiers Point E	1.62	1.22
15	Soldiers Point W	1.65	1.23
16	Greenpatch Point	1.67	1.24
17	Mud Point	1.67	1.25
18	Diemans Point	1.67	1.25
19	Taylors Beach	1.69	1.27
20	Lemon Tree	1.68	1.26
21	Mallabula Point	1.67	1.25
22	Tanilba Bay	1.68	1.26
23	Tanilba Point	1.69	1.27
24	Oyster Cove	1.71	1.30
25	Swan Bay	1.69	1.26
26	Carcair	1.69	1.27
27	Little Swan	1.69	1.28
28	Karuah Bridge	1.76	1.37
29	Correebah	1.68	1.26
30	Carrington	1.68	1.26
31	Baromee	1.67	1.25
32	North Arm Cove	1.67	1.24
33	Dead Mans Point	1.67	1.25
34	Fame Point	1.65	1.23
35	Lower Pindimar	1.62	1.21
36	Orungall Point	1.60	1.19
37	Pindimar	1.60	1.18
38	Limestone	1.60	1.18
39	Tea Gardens	1.65	1.23
40	Hawks Nest	1.57	1.15
41	Winda Woppa	1.55	1.12
42	Wanderrebah	1.55	1.10

Table J6 Sensitivity of Peak Water Levels for 1% AEP to Wind (Storm Tide + Flood + Wind)

N	Site	Storm tide	Storm tide Flood	Storm tide Flood E Wind 1%	Storm tide Flood SE Wind 1%	Storm tide Flood S Wind 1%	Storm tide Flood SW Wind 1%
1	Tomaree	1.51	1.53	1.53	1.52	1.51	1.49
2	Shoal Bay E	1.51	1.53	1.54	1.52	1.50	1.48
3	Shoal Bay W	1.51	1.54	1.55	1.54	1.51	1.48
4	Nelson Head E	1.51	1.54	1.56	1.55	1.52	1.48
5	Nelson Head W	1.53	1.56	1.58	1.57	1.54	1.50
6	Little Bay	1.53	1.56	1.58	1.58	1.55	1.50
7	Nelson Bay	1.55	1.57	1.60	1.58	1.55	1.48
8	Bagnalls Beach E	1.56	1.58	1.64	1.62	1.57	1.47
9	Bagnalls Beach W	1.57	1.60	1.67	1.65	1.58	1.48
10	Corlette Point	1.58	1.62	1.69	1.66	1.60	1.48
11	Salamander Bay	1.58	1.62	1.70	1.67	1.60	1.47
12	Round Head	1.58	1.62	1.71	1.68	1.62	1.47
13	Kangaroo Point	1.58	1.62	1.72	1.69	1.62	1.48
14	Soldiers Point E	1.58	1.62	1.72	1.70	1.65	1.50
15	Soldiers Point W	1.60	1.65	1.74	1.72	1.65	1.48
16	Greenpatch Point	1.62	1.67	1.75	1.72	1.65	1.50
17	Mud Point	1.62	1.67	1.76	1.72	1.64	1.51
18	Diemans Point	1.62	1.67	1.75	1.71	1.62	1.52
19	Taylors Beach	1.65	1.69	1.78	1.72	1.62	1.50
20	Lemon Tree	1.64	1.68	1.78	1.72	1.62	1.48
21	Mallabula Point	1.62	1.67	1.80	1.75	1.62	1.44
22	Tanilba Bay	1.64	1.68	1.83	1.76	1.62	1.37
23	Tanilba Point	1.65	1.69	1.85	1.79	1.64	1.37
24	Oyster Cove	1.67	1.71	1.92	1.77	1.50	1.15
25	Swan Bay	1.64	1.69	1.87	1.81	1.68	1.40
26	Carcair	1.65	1.69	1.89	1.85	1.74	1.44
27	Little Swan	1.66	1.69	1.92	1.87	1.76	1.39
28	Karuah Bridge	1.66	1.76	1.91	1.89	1.83	1.60
29	Correebah	1.64	1.68	1.83	1.83	1.77	1.54
30	Carrington	1.62	1.68	1.81	1.80	1.76	1.57
31	Baromee	1.62	1.67	1.78	1.76	1.70	1.52
32	North Arm Cove	1.62	1.67	1.78	1.76	1.71	1.54
33	Dead Mans Point	1.62	1.67	1.75	1.76	1.73	1.60
34	Fame Point	1.60	1.65	1.75	1.74	1.68	1.52
35	Lower Pindimar	1.58	1.62	1.71	1.70	1.65	1.50
36	Orungall Point	1.57	1.60	1.68	1.68	1.65	1.53
37	Pindimar	1.56	1.60	1.68	1.69	1.69	1.57
38	Limestone	1.56	1.60	1.65	1.68	1.69	1.60
39	Tea Gardens	1.27	1.65	1.67	1.73	1.79	1.77
40	Hawks Nest	1.28	1.57	1.57	1.60	1.67	1.66
41	Winda Woppa	1.52	1.55	1.57	1.58	1.60	1.56
42	Wanderrebah	1.51	1.55	1.55	1.58	1.60	1.58

Appendix C

FIGURE B1
SITES 9a & 10
SANDY POINT&
CORLETTE POINT


FIGURE B2
SITE 11
SALAMANDER BAY
Current Flood Planning Area
Year 2100 Flood Planning Area

FIGURE B3
SITES 20 & 21
LEMON TREE &
MALLABULA POINT