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Williamtown / Salt Ash Flood Study Review

Final Report

R.N2037.001.02

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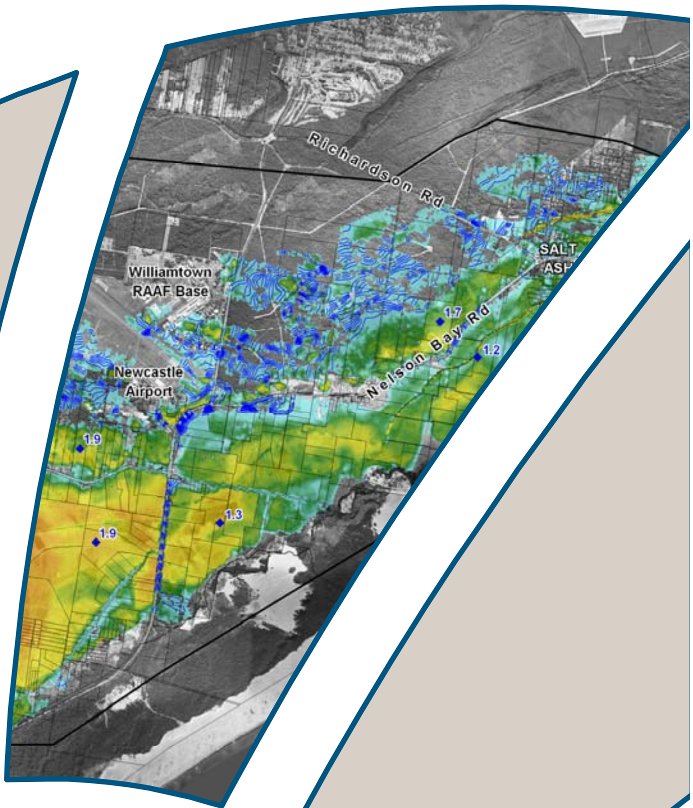

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Williamtown / Salt Ash Flood Study Review Final Report

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Title :	Williamtown / Salt Ash Flood Study Review –Final Report
Author :	Daniel Williams
Synopsis :	Final Report for the Williamtown / Salt Ash Flood Study Review covering the updating of computer models, and establishment of preliminary design flood behaviour.

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EXECUTIVE SUMMARY

Introduction

The Williamtown / Salt Ash Flood Study (WBM, 2005) was prepared for Port Stephens Council (Council) to define the existing flood behaviour between Raymond Terrace and Salt Ash and establish the basis for subsequent floodplain management activities. The Williamtown / Salt Ash Flood Study Review has been prepared to inform Council of the likely changes in flood behaviour within the study area that may arise through future climate change conditions.

The primary objective of the Flood Study Review is to establish design flood conditions for the 2050 and 2100 planning horizons, considering the potential impacts of climate change. The study has produced information on flood flows, velocities, levels and extents for the 1% AEP flood event, considering likely climate change impacts of increased sea level and rainfall intensities. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study;
- Refinement of existing hydrologic and hydraulic models;
- Determination of design flood conditions for the 1% AEP flood event under various climate change conditions; and
- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

Catchment Description

The Williamtown / Salt Ash district is located adjacent to the lower reaches of the Hunter River, on the mid-north coast of NSW. The Hunter River drains a catchment area of approximately 21,000 km^2, nearly all of which lies upstream of Raymond Terrace. Much of the study area floodplain is located between Fullerton Cove to the west and Port Stephens to the east. Nelson Bay Road limits the transfer of flood waters from Fullerton Cove into the Williamtown floodplain. Tilligerry Creek, which flows to Port Stephens, has a set of flood gates and levee located at Salt Ash. These structures typically prevent elevated water levels in Port Stephens from flooding the Salt Ash floodplain.

The study area is located between Raymond Terrace to the west and Salt Ash to the east and is around 90km^2 in size. Land use within the local catchment area primarily consists of bushland (60%), rural pasture (25%) and urban development (15%). The floodplain area principally remains undeveloped and largely occupied by rural farming.

The main urban communities within the study area include Tomago and Raymond Terrace, however as these are situated on higher ground they are unlikely to be affected by flooding. Properties situated within the lower-lying parts of the stud area are situated along Cabbage Tree Road, Nelson Bay Road and Lemon Tree Passage Road, with higher concentrations of urbanisation at both Williamtown and Salt Ash.

Model Development

The best approach to assess the impact of climate change on the Lower Hunter and its exchange of flows to the Tilligerry Creek floodplain is to model the Lower Hunter from upstream of Windeyers Creek to Newcastle Harbour. This enables the impact of greater river flows (from increased design rainfall) and increased sea levels to be assessed properly in both isolation and combination. The Williams River Flood Study was recently completed by BMT WBM in 2009 and incorporates a model of the Williams River and the Lower Hunter River from Green Rocks to Newcastle Harbour. The availability of this model and the original Williamtown / Salt Ash Flood Study model enables the best approach for this study to be undertaken, by linking the hydraulic models from each study.

As requested by Council, the floodplain topography was updated to incorporate the LiDAR aerial survey data, acquired through the Department of Planning Central and Hunter Coasts LiDAR Project January 2007. The data was delivered as a gridded bare earth DEM with a 2m resolution. The quality assurance report states that the raw data has a vertical accuracy of +/- 150mm RMSE and a horizontal accuracy of +/- 600mm RMSE.

Model Calibration and Validation

The hydrologic and hydraulic models used in this study (i.e. those from both the Williamtown / Salt Ash Flood Study and the Williams River Flood Study) were previously calibrated and verified to available historical flood event data to establish the values of key model parameters and confirm that the models were capable of accurately predicting real flood events. Details of this process can be found in the relevant report for each flood study.

Model topography, cell size and other parameters, such as roughness values, were retained from the original models (albeit with some minor local modifications). Accordingly a model re-calibration was not required. However, the baseline 1% AEP modelled flood level was matched to that of the Flood Frequency Analysis at Raymond Terrace.

Design Event Modelling and Output

The developed 1D/2D linked hydrodynamic model was used to derive baseline flood conditions in the study area for the 1% AEP design event. This was compared to the original Williamtown / Salt Ash Flood study output. Although some localised differences were observed, the results from the two models were broadly similar. Climate change scenarios were then applied to the baseline condition to assess their relative impacts. The scenarios considered were combinations of 2050 and 2100 sea level rise conditions with baseline, +10% and +30% increase in flood flows.

The model results for the baseline 1% AEP and climate change have been presented in a detailed flood mapping series for the study area. The flood data presented includes design flood inundation, peak flood water levels, depths and velocities.

Provisional flood hazard categorisation in accordance with Figure L2 of the NSW Floodplain Development Manual (2005) has been mapped, in addition to the hydraulic categories (floodway, flood fringe and flood storage) for flood affected area for the baseline and climate change scenario model results.

Conclusions

A sea level rise of 0.4m by 2050, results in around a 0.2m increase to the 1% AEP flood level in Fullerton Cove. A sea level rise of 0.9m by 2100, results in around a 0.6m increase to the 1% AEP flood level in Fullerton Cove. For the 1% AEP event peak flood levels in Fullerton Cove increase by around 0.1m and 0.3m for the 10% and 30% flow increases respectively.

The dominant flooding mechanism (in terms of peak design water levels) for the Williamtown / Salt Ash locality is mainstream Hunter River flooding. Under these conditions, Hunter River flooding results in Fullerton Cove filling and discharging into the Tilligerry Creek floodplain, under cross-drainage structures and through overtopping of Nelson Bay Road. The baseline flood level within the Tilligerry Creek floodplain is increased from 1.2m AHD to 2.6m AHD, under the worst case climate change scenario.

The flood levels along Windeyers Creek are driven by flow conditions in the Hunter River downstream of Raymond Terrace. At this location, the sea level rise scenarios have little impact on peak flood levels. There is only a small difference between flood levels for the baseline condition and the 2100 scenario. However, the increased flood flow scenarios do have a significant impact, with peak flood levels increasing by around 0.2m and 0.6m for the 10% and 30% flow increases respectively. The baseline flood level at this location is increased from 4.4m AHD to 5.2m AHD, under the worst case climate change scenario.

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GLOSSARY

annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) 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 (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (see also average recurrence interval)
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
attenuation	Weakening in force or intensity
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 20yr ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in tems 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).
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.
flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as “stage”.
flood liable land	see flood prone land

floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Management Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood planning levels (FPL)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of landuse and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood source	The source of the floodwaters. In this study, the Hunter River is the primary source of floodwaters.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determining the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
geomorphology	The study of the origin, characteristics and development of land forms.
gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
historical flood	A flood that has actually occurred.

hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrodynamic	Pertaining to the movement of water
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrographic survey	Survey of the bed levels of a waterway.
hydrologic	Pertaining to rainfall-runoff processes in catchments
hydrology	The term given to the study of the rainfall-runoff process in catchments.
isohyet	Equal rainfall contour
morphological	Pertaining to geomorphology
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
pluviometer	A rainfall gauge capable of continously measuring rainfall intensity
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
riparian	The interface between land and waterway. Literally means "along the river margins"
runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
sub-critical	Refers to flow in a channel that is relatively slow and deep
topography	The shape of the surface features of land
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
water level	See flood level.

1 INTRODUCTION

The Williamtown / Salt Ash Flood Study (WBM, 2005) was prepared for Port Stephens Council (Council) to define the existing flood behaviour between Raymond Terrace and Salt Ash and establish the basis for subsequent floodplain management activities. The Williamtown / Salt Ash Flood Study Review has been prepared to inform Council of the likely changes in flood behaviour within the study area that may arise through future climate change conditions, particularly in relation to flood planning levels.

1.1 Study Location

The Williamtown / Salt Ash district is located adjacent to the lower reaches of the Hunter River. The Hunter River drains a catchment area of approximately 21,000 km^2, nearly all of which lies upstream of Raymond Terrace and Williamtown. Tilligerry Creek, which flows east to Port Stephens, drains much of the low-lying floodplain area located within the study area.

The study area lies partly within the Hunter River floodplain, but also includes the floodplains at a number of local catchments including:

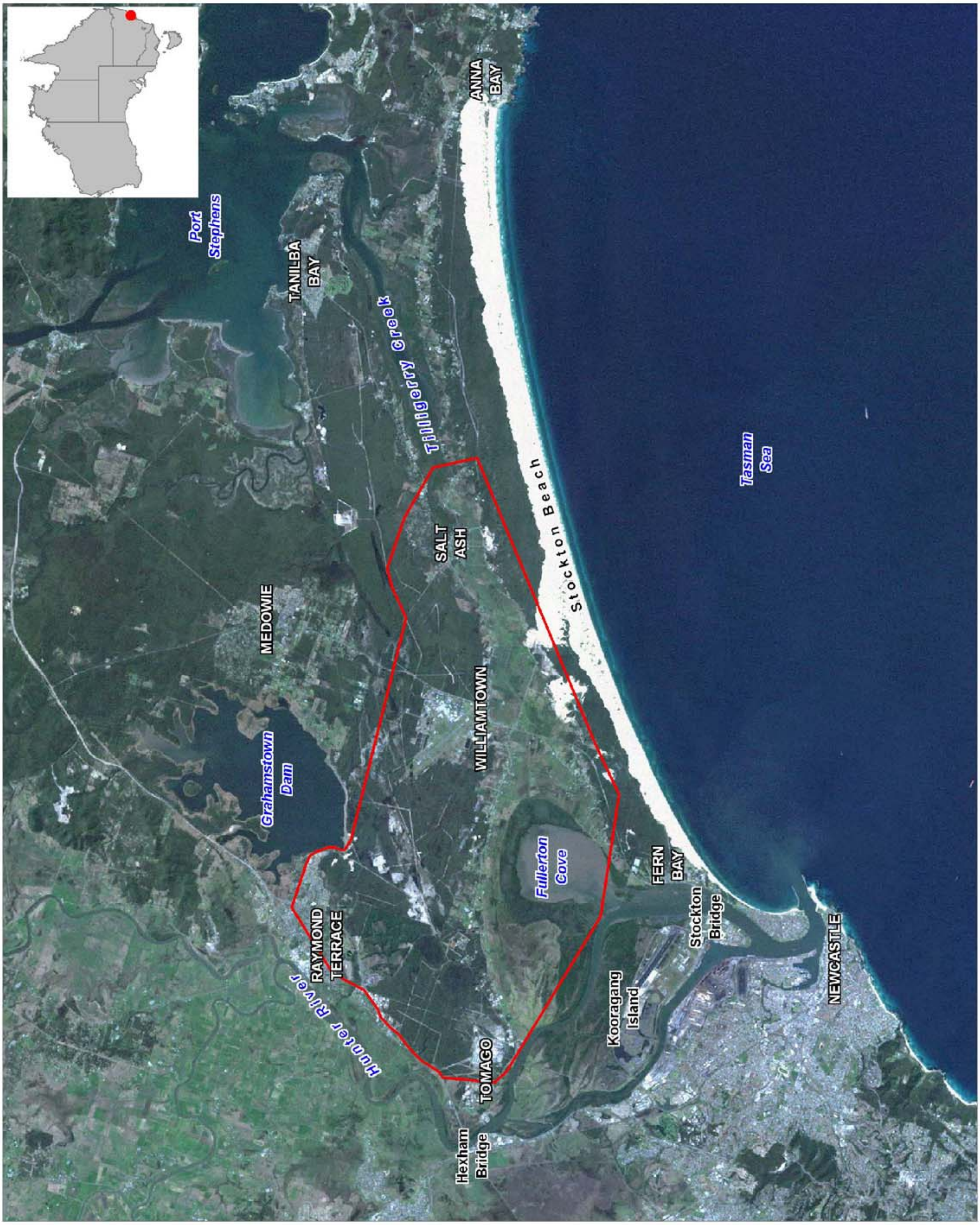
- Windeyers Creek located south and east of Raymond Terrace;
- The Moors Drain flowing between the Williamtown RAAF base and Salt Ash into Tilligerry Creek;
- Tilligerry Creek between Fullerton Cove Nelson Bay Road, Salt Ash; and
- Minor drainage channels draining to Tilligerry Creek or directly to Fullerton Cove.

The total study area covers over 130 km^2, comprising a combination of forested areas, pastures and urban lands. The extents of the study are shown on Figure 1-1.

1.2 Study Background

The Williamtown / Salt Ash Flood Study (WBM, 2005) investigated in detail the flood behaviour in the study area. As part of the study a 2D hydrodynamic model was developed and calibrated. A range of design flood simulations were undertaken to assess the impacts of a combination of flood mechanisms, including Hunter River flooding, elevated ocean levels and local catchment runoff. Design flood magnitudes considered included the 50%, 20% 10%, 5%, 2%, 1% and 0.5% AEP events and the PMF.

The release of the Department of Planning Guidelines for adapting to sea level rise (August 2010) requires Councils to consider sea level rise within any strategic planning being undertaken by Council. While it is envisaged that a full investigation of sea level rise would occur within a Floodplain Risk Management Study, Council has commissioned this Flood Study Review to assist in the assessment of current development applications in the study area.



Title:

Study Locality

Figure: **1-1**

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1.3 The Need for Floodplain Management

The townships located within the study area (parts of Raymond Terrace, Williamtown, Salt Ash) have experienced a range of floods over the years. Flooding results due to a combination of three mechanisms: rainfall on the local catchments, inundation from the Hunter River floods and tides in Fullerton Cove and Port Stephens.

Flooding in the study area occurred in 1990 following heavy rainfall over the local catchments. Runoff from the upper catchment areas accumulated in the lower floodplains where drainage was then inhibited by relatively high tidal levels on the downstream side of the floodgates on Tilligerry Creek.

Notable flooding also occurred in 1955, when the Major Hunter River flood overtopped Fullerton Cove and inundated the Tilligerry Creek floodplain.

The potential for climate change impacts is now a key consideration for floodplain management. The NSW Government has released a guideline for practical consideration of climate change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. Accordingly, this increase in design rainfall will translate into increased design flood inundation in the study area, such that future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

Low-lying coastal areas, such as those surrounding Fullerton Cove and Tilligerry Creek are at high risk to climate change. The potential for future sea level rise is now expected to be the biggest driver for floodplain management around coastal and estuarine systems such as the Hunter Estuary and Port Stephens. The issue of future sea level rise presents particular challenges to future development, as the risks associated with flooding will progressively increase during the lifetime of the development. It may be such that risks do not manifest until the development is nearing the end of its design life.

There also remains inherent uncertainty regarding the projected extents of sea level rise in the future. The NSW Government has adopted a policy that advocates consideration of increased sea levels by 0.4m by 2050, and 0.9m by 2100. However, there is potential for sea level rise to occur slower, or indeed faster, than these rates.

Floodplain risk management considers the consequences of flooding on the community and aims to develop appropriate floodplain management measures to minimise and mitigate the impact of flooding. This incorporates the existing flood risk associated with current development, and future flood risk associated with future development and changes in land use.

Accordingly, Council desires to approach local floodplain management in a considered and systematic manner. This study comprises the initial stages of that systematic approach, as outlined in the Floodplain Development Manual (NSW Government, 2005). The approach will allow for more informed planning decisions within the floodplain of the Williamtown / Salt Ash area.

1.4 The Floodplain Management Process

The State Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the Government's Floodplain Development Manual (2005).

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 State Government through the following four sequential stages:

Stages of Floodplain Management

	Stage	Description
1	Flood Study	Determines the nature and extent of the flood problem.
2	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
3	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of environmental plans to ensure new development is compatible with the flood hazard.

Stage 1 of the above process was completed by WBM in 2005. This study is provided as a supplement to the original flood study, incorporating the potential impacts of climate change on design flood conditions. This will enable Council to effectively manage development applications within the study area for the immediate future, prior to undertaking the Floodplain Risk Management Strategy.

1.5 Study Objectives

The primary objective of the Flood Study Review is to establish design flood conditions for the 2050 and 2100 planning horizons, considering the potential impacts of climate change. The study has produced information on flood flows, velocities, levels and extents for the 1% AEP flood event, considering likely climate change impacts of increased sea level and rainfall intensities. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study;
- Further development and of existing hydrologic and hydraulic models;
- Determination of design flood conditions for a the 1% AEP flood event under various climate change conditions; and

- Presentation of study methodology, results and findings in a comprehensive report incorporating appropriate flood mapping.

The principal outcome of the flood study is the understanding of flood behaviour in the catchment in response to climate change and in particular design flood level information that will be used to set appropriate flood planning levels for the study area.

1.6 About This Report

This report documents the Study's objectives, results and recommendations.

Section 1 introduces the study.

Section 2 provides an overview of the approach adopted to complete the study.

Section 3 details the development of the computer models.

Section 4 comments on model calibration.

Section 5 presents the adopted design flood inputs and boundary conditions .

Section 6 presents design flood simulation results and associated flood mapping.

2 STUDY APPROACH

2.1 The Study Area

2.1.1 Catchment Description

The Williamtown / Salt Ash district is located adjacent to the lower reaches of the Hunter River, on the mid-north coast of NSW. The Hunter River drains a catchment area of approximately 21,000 km^2, nearly all of which lies upstream of Raymond Terrace and Williamtown.

The topography of the catchment is shown in Figure 2-1. The study area is low-lying, with most locations at an elevation of below RL 10m AHD and a significant proportion below RL 2m AHD. Much of the higher land is located within the north and west of the area, between Raymond Terrace, Williamtown and Tomago. The eastern boundary of the area is characterised by a large, elevated dune system, which separates the Tilligerry Creek floodplain from the Tasman Sea. Local catchment runoff predominantly drains to the floodplain areas located around Fullerton Cove and Tilligerry Creek. Tilligerry Creek can drain westwards to the Hunter River, via Fullerton Cove, or eastwards to Port Stephens.

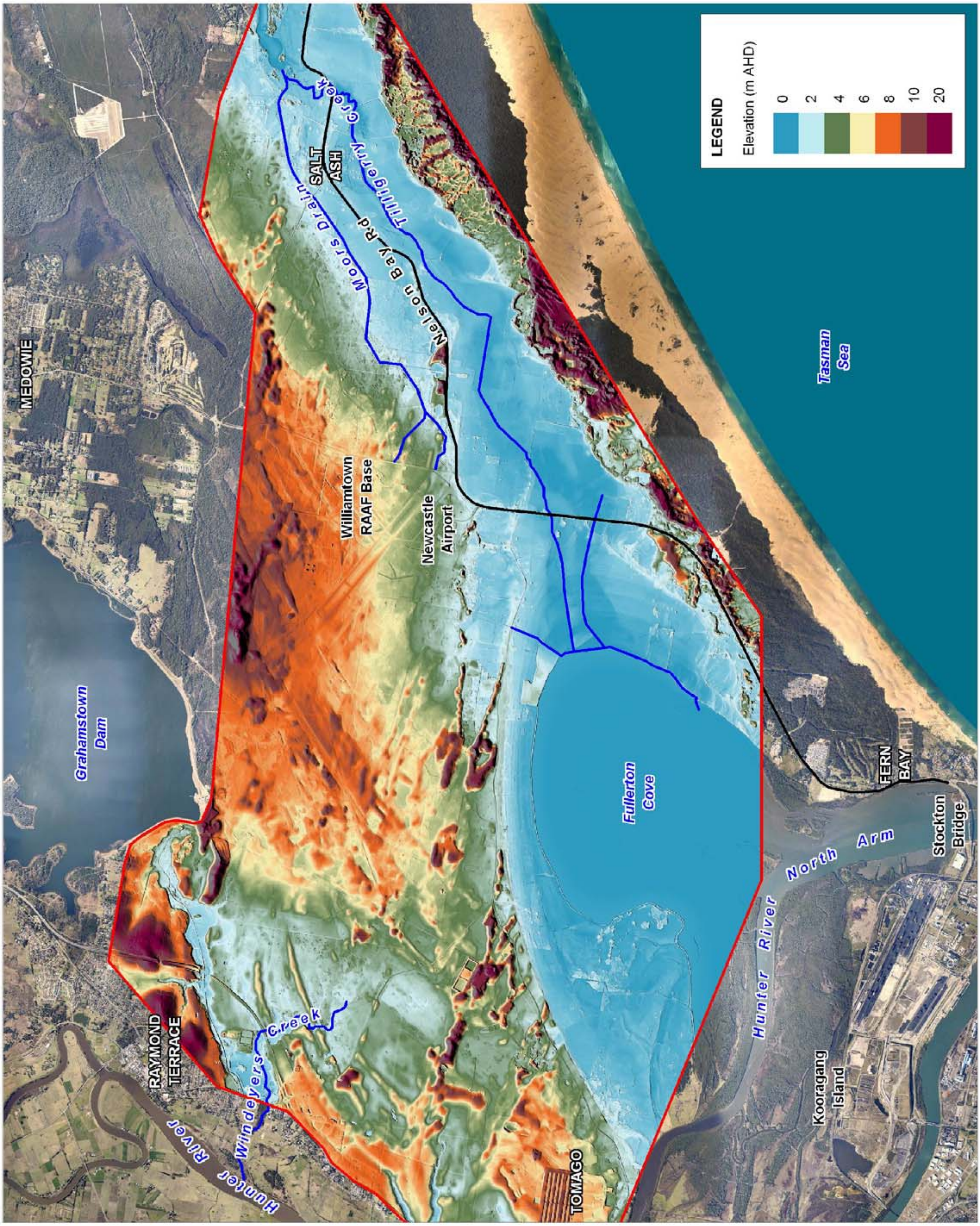
Much of the study area floodplain is located between Fullerton Cove to the west and Port Stephens to the east. Nelson Bay Road limits the transfer of flood waters from Fullerton Cove into the Williamtown floodplain. Tilligerry Creek, which flows to Port Stephens, has a set of flood gates and levee located at Salt Ash. These structures typically prevent elevated water levels in Port Stephens from flooding the Salt Ash floodplain.

During large flood events on the Hunter River a portion of the flood waters will flow eastwards from Fullerton Cove and into Port Stephens, through the Tilligerry Creek floodplain area. The transfer of water through this floodplain area is controlled by a number of topographic features – most notably the physical obstruction of Nelson Bay Road, which is elevated above the floodplain. Flow of water through Nelson Bay Road is restricted to only a small number of culverts, until the flood waters are sufficient to overtop the road crest.

Land use within the catchment primarily consists of bushland (60%), rural pasture (25%) and urban development (15%). The floodplain area principally remains undeveloped and largely occupied by rural farming.

The main urban communities within the study area include Tomago and Raymond Terrace, however as these are situated on higher ground they are unlikely to be affected by flooding. Properties situated within the lower-lying parts of the study area are situated along Cabbage Tree Road, Nelson Bay Road and Lemon Tree Passage Road, with higher concentrations of urbanisation at both Williamtown and Salt Ash.

The study area is traversed by a number of important road connections, most notably Nelson Bay Road, which is the only transport route in and out of Port Stephens and Cabbage Tree Road. In order to provide flood-free transport routes, most of the transport routes are elevated above the natural floodplain levels, constructed on embankments with waterway openings (bridges/culverts) at appropriate cross drainage locations.



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Topography of the Study Area

Figure: **2-1**

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2.1.2 Previous Investigations

The Williamtown / Salt Ash Flood Study was completed by WBM in 2005 and is being supplemented by this study to assess the impacts of climate change on the previously determined flood levels within the study area. The Williamtown / Salt Ash Flood Study report contains comprehensive information on previous investigations and available flood data within the study area. The background information covered by the report included:

- Previous investigations within the study area;
- Historical flood information;
- Rainfall data; and
- Topographic survey data.

2.2 Compilation and Review of Available Data

2.2.1 Existing Studies

In addition to the Williamtown / Salt Ash Flood Study a number of other relevant studies were reviewed to assist in the Flood Study Review.

2.2.1.1 Williams River Flood Study (BMT WBM, 2009)

Dungog Shire Council and Port Stephens Council commissioned the Williams River Flood Study in order to define the riverine flood behaviour in the Williams River from Raymond Terrace to 5km upstream of Dungog. The study encompasses the Lower Hunter River (from Green Rocks to Newcastle Harbour) and investigates the effect of combined flooding from both the Hunter and Williams Rivers.

The Williams River study and model development was subsequent to the completion of the Williamtown / Salt Ash Flood Study. Therefore, the Williamtown / Salt Ash model boundaries for the Hunter River were extracted from the Lower Hunter Flood Study (PWD, 1994). These boundary conditions were only applicable for the baseline flooding conditions and were static, i.e. non-responsive to flood volumes lost to the Tilligerry Creek floodplain. It was not applicable to utilise these boundaries when assessing the impacts of climate change in this study. The availability of the Williams River model enables a robust representation of flow exchange from the Hunter River to the Tilligerry Creek system, providing a more dynamic inflow to the study area to be established.

Inflow boundaries from the Hunter River and Williams River and downstream tidal boundaries at Newcastle Harbour were available from the Williams River model and were utilised in this study to assess the impact of climate change on flood behaviour within the study area.

2.2.1.2 Port Stephens Design Flood Levels – Climate Change Review (WMA Water, 2010)

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 (MHL, 1998) and the Port Stephens Foreshore (Floodplain) Management Study and Plan (WMA, 2002).

None of the previous studies assessing flood levels in Port Stephens had considered potential climate change. The study found that the design still water levels within Port Stephens would also rise by the 0.4m and 0.9m levels recommended for sea level rise predictions for 2050 and 2100.

The design flood levels provided by the Port Stephens Climate Change Review at Taylors Beach (which is located where Tilligerry Creek enters Port Stephens) have been used to define downstream boundary conditions on Tilligerry Creek for this study.

2.2.2 Council Data

Digitally available information such as aerial photography, cadastral boundaries, topography, watercourses, drainage networks, land zoning, vegetation communities and soil landscapes were provided by Council in the form of GIS datasets.

The most significant dataset that has become available since the Williamtown / Salt Ash Flood Study is the LiDAR survey data, which was captured by Fugro during 2007 and 2008. Council have requested that this data be incorporated into the flood mapping process of this study. Recent high resolution aerial imagery has also become available for the study area since the Williamtown / Salt Ash Flood Study.

2.3 Site Inspection

A site inspection was undertaken during the course of the study to confirm the size and arrangement of culvert structures that provide cross-drainage through the elevated road embankments, principally along Nelson Bay Road. The high resolution aerial imagery had indicated the presence of a few structures that were not included in the original Williamtown / Salt Ash model. These locations were visited to measure culvert dimensions and depth of obverts beneath the road crest. Locations of key structures that already existed within the Williamtown Flood Study model were also visited for verification purposes.

The verification of existing modelled structures observed little difference to the existing details. The most significant observed difference was a discrepancy in the height of the culverts situated on Tilligerry Creek that provide cross-drainage through Nelson Bay Road at the Fullerton Cove end. The measured height on site was 1.5m, compared to the modelled height of 3m.

The measurement of additional structures not included within the Williamtown / Salt Ash Flood Study model included:

- Twin 2.5m x 2.0m box culvert arrangements at an additional two locations along the Fullerton Cove end of Nelson Bay Road;
- Nine 600mm diameter pipe culverts distributed across four locations along Nelson Bay Road, between Williamtown and Salt Ash; and
- Two 600mm diameter and one 825mm diameter pipe culverts at three locations along Nelson Bay Road, east of Salt Ash and the Tilligerry Creek crossing.

2.4 Development of Computer Models

2.4.1 Hydrological Models

Hydrological models were developed for both the Williamtown / Salt Ash Flood Study and the Williams River Flood Study. These models provide local catchment inflows to the study area and cover some 90km^2. The development of the hydrological models is discussed further in Section 3.1.

2.4.2 Hydraulic Models

Hydraulic models were developed for both the Williamtown / Salt Ash Flood Study and the Williams River Flood Study. These models were combined and further developed as part of this study. This was necessary due to:

- The complex interaction of flood flows on the Hunter River, Windeyers Creek and Tilligerry Creek, particularly with the greater hydraulic connectivity from increased water levels associated with climate change scenarios; and
- The sensitivity of flood levels in Fullerton Cove to increased tide levels at Newcastle Harbour.

The hydraulic model (discussed in Section 3.2) developed for this study comprises a two-dimensional (2D) representation of the study area, the Lower Hunter River and the Williams River.

2.5 Calibration and Sensitivity Testing of Models

The hydrologic and hydraulic models that were used in this study (i.e. those from both the Williamtown / Salt Ash Flood Study and the Williams River Flood Study) were calibrated and verified to available historical flood event data to establish the values of key model parameters and confirm that the models were capable of accurately predicting real flood events. Details of this process can be found in the relevant report for each flood study.

2.6 Establishing Design Flood Conditions

Design floods are statistical-based events which have a particular probability of occurrence. For example, the 1% Annual Exceedance Probability (AEP) event, which is sometimes referred to as the 1 in 100 year Average Recurrence Interval (ARI) flood, is the best estimate of a flood with a peak discharge that has a 1% (i.e. 1 in 100) chance of occurring in any one year. For this study, design floods were based on the recommendations of existing studies:

- Hunter River flow conditions from the Lower Hunter River Flood Study (PWD, 1994) and match the flood frequency analysis at Raymond Terrace;
- Newcastle Harbour tide and surge conditions from the Williams River Flood Study (BMT WBM, 2009), which are consistent with those adopted in the Lower Hunter flood model (DHI, in progress); and
- Tilligerry Creek boundary conditions from the Port Stephens Design Flood Levels – Climate Change Review (WMA Water, 2010).

Design flood conditions have then been updated to account for future climate change impacts. This includes:

- A 0.4m rise in sea levels by 2050 and a 0.9m rise by 2100; and
- Both a 10% and 30% increase in design rainfall intensities.

The design flood conditions form the basis for floodplain management in the catchment and in particular design planning levels for future development controls. The predicted design flood conditions are presented in Section 5.

2.7 Mapping of Flood Behaviour

Design flood mapping is undertaken using output from the hydraulic model. Maps are produced showing water level, water depth and velocity for each of the design events. The maps present the peak value of each parameter. Provisional flood hazard categories and hydraulic categories are derived from the hydraulic model results and are also mapped. The mapping outputs are described in Section 6 and presented in Appendix A.

3 MODEL DEVELOPMENT

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. For this study, two types of models were used:

- Hydrologic models of the Williams River and local catchment runoff for the study area; and
- A hydraulic model of the Williams River, Lower Hunter River and the study area.

The **hydrologic models** simulate the catchment rainfall-runoff processes, producing the river/creek flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the channel and floodplains, producing flood levels, flow discharges and flow velocities.

Information on the topography and characteristics of the catchments, watercourses and floodplains are built into the models. Recorded historical flood data, including rainfall, flood levels and river flows, are used to simulate and validate (calibrate and verify) the models. The models produce as output, flood levels, flows (discharges) and flow velocities.

Development of a hydraulic model follows a relatively standard procedure:

1. Discretisation of the catchment, watercourses, floodplain, etc.
2. Incorporation of physical characteristics (river cross-sections, floodplain levels, structures etc).
3. Establishment of hydrographic databases (rainfall, river flows, flood levels) for historic events.
4. Calibration to one or more historic floods (calibration is the adjustment of parameters within acceptable limits to reach agreement between modelled and measured values).
5. Verification to one or more other historic floods (verification is a check on the model's performance without further adjustment of parameters).
6. Sensitivity analysis of parameters to measure dependence of the results upon model assumptions.

Once model development is complete it may then be used for:

- Establishing design flood conditions;
- Determining levels for planning control; and
- Modelling development or management options to assess the hydraulic impacts.

3.1 Hydrologic Model

The existing hydrologic models from both the Williamtown / Salt Ash Flood Study and the Williams River Flood Study were adopted. Both models were developed in the XP-RAFTS software and no further model development was required for the purposes of this study.

3.2 Hydraulic Model

3.2.1 Williamtown / Salt Ash Flood Study Model

The Williamtown / Salt Ash Flood Study included the development of a hydraulic model for the study area. This model is a fully hydrodynamic 1D/2D linked model, utilising the TUFLOW software modelling package. The model is based on a 2D domain grid resolution of 40m, with elevations sampled at cell centres, cell sides and cell corners – i.e. at 20m spacing. The model includes 1D representation of drainage channels, creeks and hydraulic structures. Other significant hydraulic controls, such as elevated road embankments are incorporated as 3D polylines to ensure that the crest levels that control flood propagation are properly defined.

The Hunter River flood inputs to the Williamtown / Salt Ash Flood Study model were extracted from the Lower Hunter River Flood Study and applied as water level boundaries at Windeyers Creek and Fullerton Cove. A downstream tidal water level boundary was applied to Tilligerry Creek and local catchment inflows were input as flow hydrographs, output from the XP-RAFTS hydrological model.

The existing model boundary configuration of water level boundaries to represent inflows to the study area from the Hunter River is not suitable for considering the impacts of climate change. The modelled water levels from the Lower Hunter River Flood Study are only representative of the baseline flow, tidal and topographic conditions at the time of the study. These boundaries cannot simply be modified to properly assess the impacts of climate change on flood behaviour within the study area. The interaction of flood flows on the Hunter River, Windeyers Creek and Tilligerry Creek and the sensitivity of flood levels in Fullerton Cove to increased tide levels at Newcastle Harbour is complex. This requires a more robust model boundary configuration to predict flood levels in the study area to a reasonable accuracy.

The best approach to assess the impact of climate change on the Lower Hunter and its exchange of flows to the Tilligerry Creek floodplain is to model the Lower Hunter from upstream of Windeyers Creek to Newcastle Harbour. This enables the impact of greater river flows (from increased design rainfall) and increased sea levels to be assessed properly in both isolation and combination. The Williams River Flood Study (BMT WBM, 2009) incorporates a model of the Williams River and the Lower Hunter River from Green Rocks to Newcastle Harbour. The availability of this model enables the best approach for this study to be undertaken, by linking the hydraulic models from each study.

3.2.2 Williams River Flood Study Model

The Williams River Flood Study (BMT WBM, 2009) included the development of a hydraulic model for the Williams River catchment from Dungog to Raymond Terrace. It also incorporates the Lower Hunter River from Green Rocks to Newcastle Harbour. As for the Williamtown / Salt Ash Flood Study, this model is a fully hydrodynamic 1D/2D linked model, utilising the TUFLOW software modelling package. Similarly, the model is also based on a 2D domain grid resolution of 40m.

Model inflows for the Williams River catchment were derived from hydrologic modelling of sub-catchment runoff using the XP-RAFTS software and the AR&R guidelines for estimating design rainfall. The Hunter River inflow boundary is consistent with that utilised by the Lower Hunter River Flood Study. The downstream tidal level boundary at Newcastle Harbour is consistent with the adopted boundary in the Lower Hunter flood model being developed for Newcastle City Council by DHI.

3.2.3 Linking of the Two Models

The Williams River Flood Study model was taken as the base model and was extended to incorporate the additional area modelled by the Williamtown / Salt Ash model. Hydraulic controls, hydraulic structures, model boundaries and roughness details etc. from the Williamtown model were replicated in the new model, whilst ensuring that any instances of duplication were avoided. Some additional minor modifications were also undertaken to improve model stability, in line with recent TUFLOW improvements. The result of this composite model construction was a 1D/2D linked hydrodynamic model, covering the Williams River from Dungog to Raymond Terrace, the Hunter River from Green Rocks to Newcastle Harbour and the Tilligerry Creek floodplain area from Fullerton Cove to Salt Ash. This includes the significant hydraulic controls of Nelson Bay Road and the Tilligerry Creek floodgates.

3.2.4 Updating of Model Topography

As requested by Council, the floodplain topography was updated to incorporate the LiDAR aerial survey data, acquired through the Department of Planning Central and Hunter Coasts LiDAR Project January 2007. The data was delivered as a gridded bare earth DEM with a 2m resolution. The quality assurance report states that the raw data has a vertical accuracy of +/- 150mm RMSE and a horizontal accuracy of +/- 600mm RMSE. Ground filtering algorithms, specifically designed to suit this data set, had then been applied to the raw point cloud to produce the bare earth DEM. The dataset is generally of a good quality, however, the filtering algorithms struggle to remove areas of dense low-lying vegetation of wetland areas, such as reed beds and mangroves. Therefore, the topography around Fullerton Cove, which has large areas of these vegetation types, was left unchanged from the original model. The areas that were updated were restricted to that between Raymond Terrace, Tomago and Williamtown and between Fullerton Cove and Salt Ash.

Additional changes to the model topography were also made to Fullerton Cove and the Hunter River channel between Fullerton Cove and Newcastle Harbour. This was done to improve the transition between areas covered by bathymetric survey (in-channel regions) and areas covered by photogrammetric survey (floodplain regions). The original model DEM did not have a smooth transition between the two datasets and as a result was impacting slightly on the channel conveyance capacity.

3.2.5 Verification of Hydraulic Structure Representation

A site inspection was undertaken during the course of the study to confirm the size and arrangement of culvert structures that provide cross-drainage through the elevated road embankments. The high resolution aerial imagery had indicated the presence of a few structures that were not included in the original Williamtown / Salt Ash model. These locations were visited to measure culvert dimensions and depth of obverts beneath the road crest. Locations of key structures that already existed within the Williamtown Flood Study model were also visited for verification purposes.

The verification of existing modelled structures observed little difference to the existing details. The most significant difference was a discrepancy in the height of the culverts situated on Tilligerry Creek that provide cross-drainage through Nelson Bay Road at the Fullerton Cove end. The measured height on site was 1.5m, compared to the modelled height of 3m.

The measurement of additional structures not included within the Williamtown / Salt Ash Flood Study model included:

- Twin 2.5m x 2.0m box culvert arrangements at an additional two locations along the Fullerton Cove end of Nelson Bay Road;
- Nine 600mm diameter pipe culverts distributed across four locations along Nelson Bay Road, between Williamtown and Salt Ash; and

Two 600mm diameter and one 825mm diameter pipe culverts at three locations along Nelson Bay Road, east of Salt Ash and the Tilligerry Creek crossing. The location of these structures is shown in Figure 3-1.

3.2.6 Baseline Boundary Conditions

The new model boundary inputs were configured to provide conditions consistent with those adopted in the Williamtown / Salt Ash Flood Study. The conditions applied at each of the model boundaries are summarised below and then discussed in further detail:

- 1% AEP flow conditions on the Hunter River at Raymond Terrace;
- 50% AEP flood conditions in Port Stephens and Newcastle Harbour; and
- 10% AEP local catchment inflows.

Of these conditions, it is the 1% AEP flow within the Hunter River that drives the critical flood conditions of the study area. Although the other boundary conditions have some impact on the flood behaviour, it is dominated by high flows in the Hunter River.

3.2.6.1 Hunter River Inflow at Green Rocks

The adopted inflow hydrograph at Green Rocks is representative of a 1% AEP flow condition. It is based on a scaled hydrograph of the 1955 flood event, with a peak flow of around 6100m^3/s. This is the same inflow boundary used for both the Lower Hunter River Flood Study and the Williams River Flood Study. The combination of Hunter River and Williams River inflows adopted provides for a 1% AEP flood level at Raymond Terrace, consistent with the flood frequency analysis as discussed below.

3.2.6.2 Williams River Inflows

The inflow boundaries for the Williams River catchment have been adopted from the hydrological model developed for the Williams River Flood Study. The 1% AEP 48hr duration event hydrographs were used and scaled by a factor of 1.4. This was done to match the 1% AEP flood level of 4.84m AHD at William Street, Raymond Terrace. The 4.84m AHD flood level was determined through a Flood Frequency Analysis, undertaken as part of the Lower Hunter River Flood Study. The flood level at this location is generated from the combined flows of the Hunter River and Williams River. A flood level of 4.84m AHD at William Street, Raymond Terrace is equivalent to a combined peak flow of around 9,000m^3/s.

3.2.6.3 Newcastle Harbour Sea Levels

The time series used for the downstream boundary at Newcastle Harbour is tidally varying with a peak level of 0.85m AHD. This is the same boundary used for the Williams River Flood Study and by DHI for the Lower Hunter model. A design storm surge condition has been applied on top of the tidal boundary to provide a 50% AEP peak level. The surge has a duration of 40 hours, as adopted in the Williams River Flood Study and is similar to that recommended by Appendix A of the Draft Flood Risk Management Guide (DECCW, 2009). This appendix was formerly Guideline 5 of Ocean Boundary Conditions for Hydraulic Flood Modelling. The combined tide and surge boundary has a peak level of 1.17m AHD.

3.2.6.4 Tilligerry Creek Downstream Boundary

The downstream boundary conditions in Tilligerry Creek are reflective of flood conditions in Port Stephens. Inspection of the Port Stephens Flood Study and the Port Stephens Design Flood Levels – Climate Change Review suggests that a 50% AEP flood level of around 1.5m AHD is appropriate at Taylors Beach. Taylors Beach is located at the mouth of Tilligerry Creek and so this flood level has been adopted as the downstream boundary condition for Tilligerry Creek in the model. This is consistent with the level adopted for the Williamtown / Salt Ash Flood Study. The tidal boundary used for Newcastle has also been adopted for Tilligerry Creek. The storm surge component has been scaled to provide a peak level of 1.5m AHD.

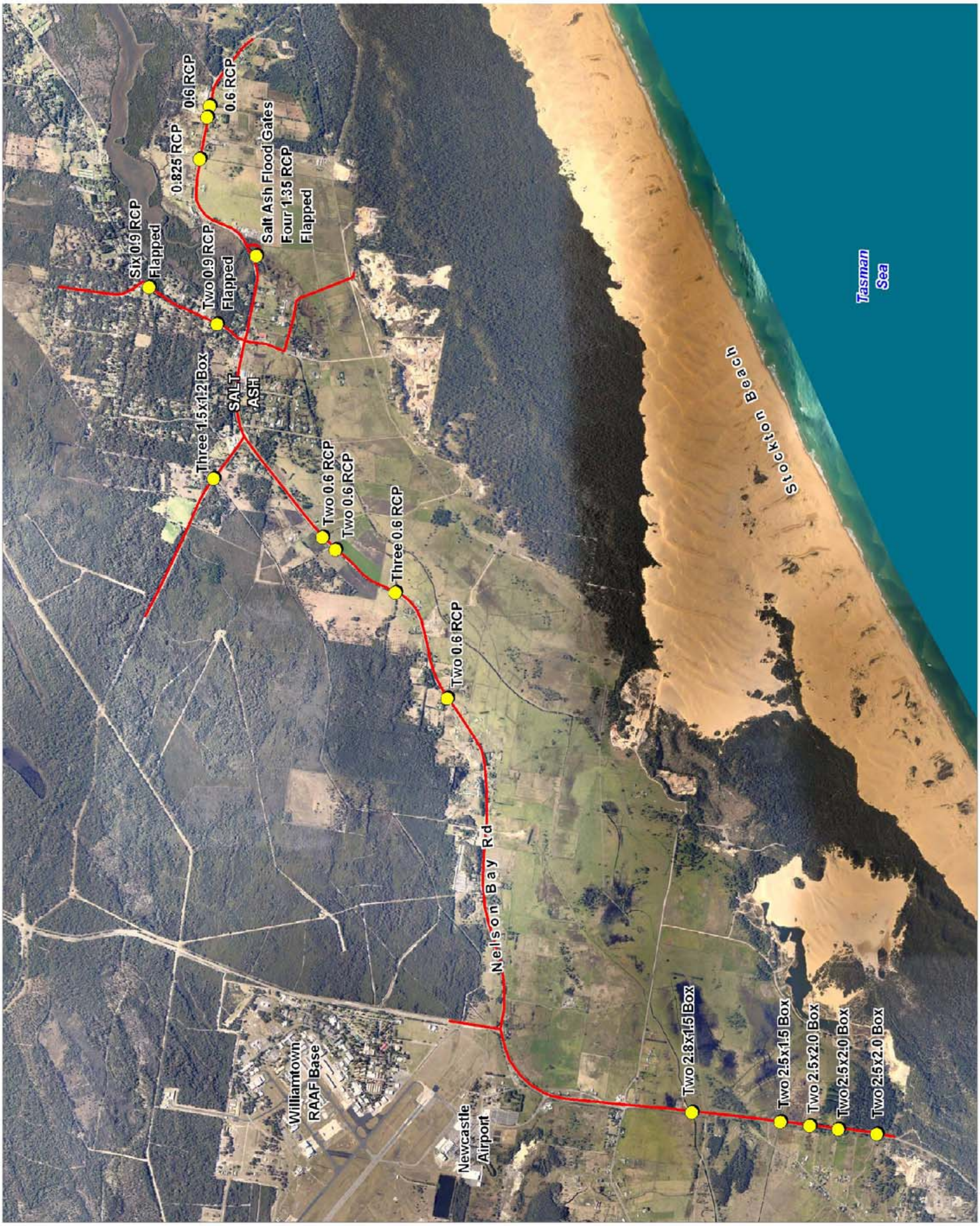
3.2.6.5 Local Catchment Inflows

Local catchment inflows for the Hunter River downstream of Raymond Terrace and within the Williamtown / Salt Ash study area have been derived from the appropriate hydrological models. The 10% AEP 48 hour duration inflows have been adopted, as consistent with the Williamtown / Salt Ash Flood Study.

3.2.7 Climate Change Boundary Conditions

The objective of the study was to assess the impact of climate change on flood behaviour within the study area. The boundaries established for the baseline flooding condition were modified to represent the potential impacts of climate change on both sea levels and rainfall intensities.

Current guidelines predict that a likely outcome of future climatic change will be an increase in mean sea level. NSW Sea Level Rise Policy Statement (DECCW, 2009) provides projected increases in mean sea level for NSW of 0.4m and 0.9m, for the years 2050 and 2100 respectively. Based on these guidelines the design ocean boundaries have been raised by 0.4m and 0.9m to assess the potential impact of climate change on flood behaviour in the study area. This is appropriate for both the boundaries at Newcastle Harbour and Tilligerry Creek. The Port Stephens Design Flood Levels – Climate Change Review states that this projected increase in sea levels is also applicable to Port Stephens.



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Key Hydraulic Structures

Figure:

3-1

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The NSW Government has released a guideline for practical consideration of climate change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. Accordingly, this increase in design rainfall will translate into increased design flood inundation in the Williamtown / Salt Ash study area, such that future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk. Council has requested that the impact of a 10% and 30% increase be assessed for both the 2050 and 2100 sea level rise scenarios. The sensitivity of changes in design rainfall intensities and associated increases in flood flows have been modelled through an increase of inflow hydrographs by 10% and 30%.

4 MODEL CALIBRATION AND VALIDATION

The hydrologic and hydraulic models used in this study (i.e. those from both the Williamtown / Salt Ash Flood Study and the Williams River Flood Study) were previously calibrated and verified to available historical flood event data to establish the values of key model parameters and confirm that the models were capable of accurately predicting real flood events. Details of this process can be found in the relevant report for each flood study.

Model topography, cell size and other parameters, such as roughness values, were retained from the original models (albeit with some minor local modifications). Accordingly a model re-calibration was not required. However, the baseline 1% AEP modelled flood level was matched to that of the Flood Frequency Analysis at Raymond Terrace, as discussed in Section 3.2.6.2.

5 DESIGN FLOOD CONDITIONS

The Williamtown / Salt Ash Flood study tested a range of coincident design flood conditions, including Hunter River flows, elevated sea levels and local catchment runoff. The study found that the critical condition when determining the 1% AEP flood levels within the study area was a 1% AEP design flow in the Hunter River – for which 50% AEP sea level and 10% AEP local catchment inflow conditions were adopted. Council requested that this set of flood conditions be used as the baseline 1% AEP design flood for this study.

5.1 Hunter River Flow

The flow conditions in the Hunter River are the dominant mechanism influencing flood behaviour in the study area for the 1% AEP event. As discussed in Section 3.2.6, the model inflows from the Hunter River and Williams River combine at Raymond Terrace to produce the design flow hydrograph for the Lower Hunter River. This combined flow has been calibrated at Raymond Terrace by scaling the Williams River inflow components to produce a 1% AEP level of 4.84m AHD, consistent with the Flood Frequency Analysis at Raymond Terrace was matched. This flood level is produced by a peak flow of around 9,000m^3/s, the hydrograph for which has been extracted from the model and presented in Figure 5-1. The Hunter River flow has also been increased by 10% and 30% to assess climate change impacts of increased rainfall intensity.

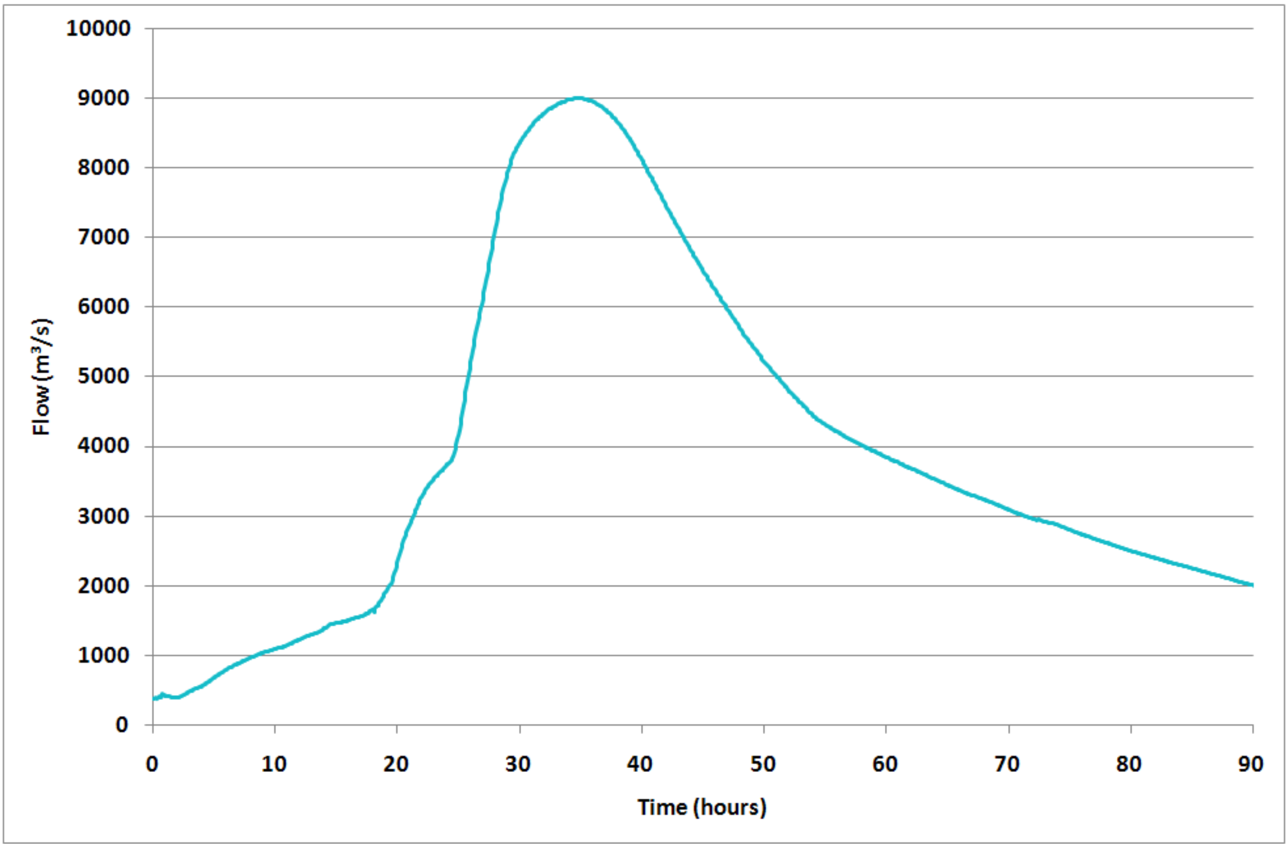


Figure 5-1 Hunter River 1% AEP Flow at Raymond Terrace

5.2 Coincident Downstream Conditions

The downstream boundaries at Newcastle Harbour and Tilligerry Creek are representative of a 50% AEP design condition, which is consistent with that adopted for the Williamtown / Salt Ash Flood Study. The elevated water levels at Newcastle Harbour had been determined through an analysis of 24 years of tide gauge data and were adopted by the Lower Hunter River Flood Study and the Williams River Flood Study. The water level recurrence distribution is presented in Figure 5-2, with the adopted water level for the 50% AEP event at 1.17m AHD.

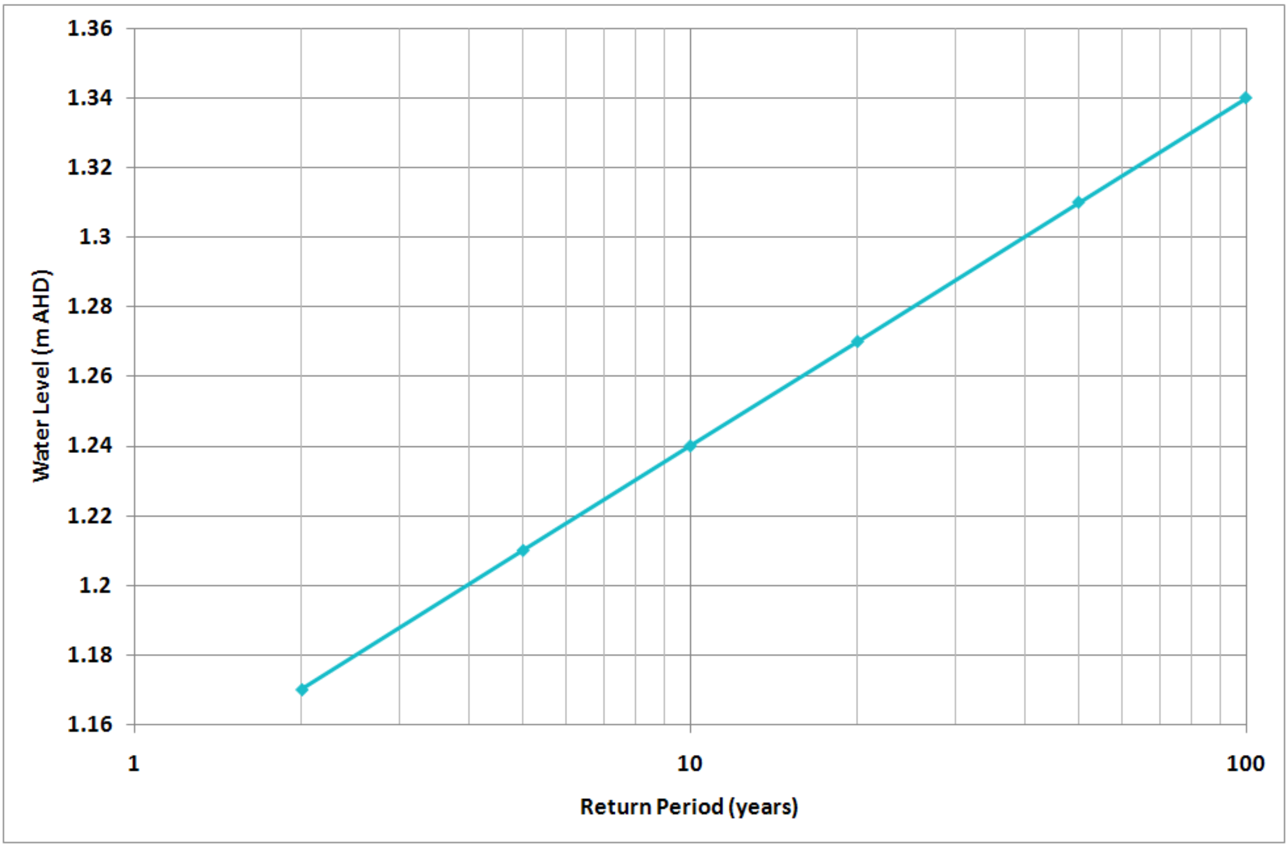


Figure 5-2 Port of Newcastle Extreme Water Levels

The time series used for the downstream boundary at Newcastle Harbour is tidally varying with a peak level of 0.85m AHD. This is the same boundary used for the Williams River Flood Study and by DHI for the Lower Hunter model. A design storm surge condition has been applied on top of the tidal boundary to provide a 50% AEP peak level (i.e. 1.17m AHD). The surge has a duration of 40 hours, as adopted in the Williams River Flood Study and is similar to that recommended by Appendix A of the Draft Flood Risk Management Guide (DECCW, 2009). The peak elevated water level was timed to coincide with the peak flow on the Hunter River, in order to provide “worst case” conditions in Fullerton Cove.

The downstream boundary conditions in Tilligerry Creek are reflective of flood conditions in Port Stephens. Review of the Port Stephens Flood Study and the Port Stephens Design Flood Levels – Climate Change Review suggests that a 50% AEP flood level of around 1.5m AHD is appropriate at Taylors Beach. Taylors Beach is located at the mouth of Tilligerry Creek and so this flood level has been adopted as the downstream boundary condition for Tilligerry Creek in the model, as previously adopted for the Williamtown / Salt Ash Flood Study. The tidal boundary used for Newcastle has also been adopted for Tilligerry Creek. The storm surge component has been scaled to provide a peak level of 1.5m AHD. The 50% AEP design water level boundaries used at Newcastle Harbour and on Tilligerry Creek are presented in Figure 5-3. These downstream boundaries have also been increased by 0.4m and 0.9m to represent sea level rise climate change scenarios for 2050 and 2100 respectively.

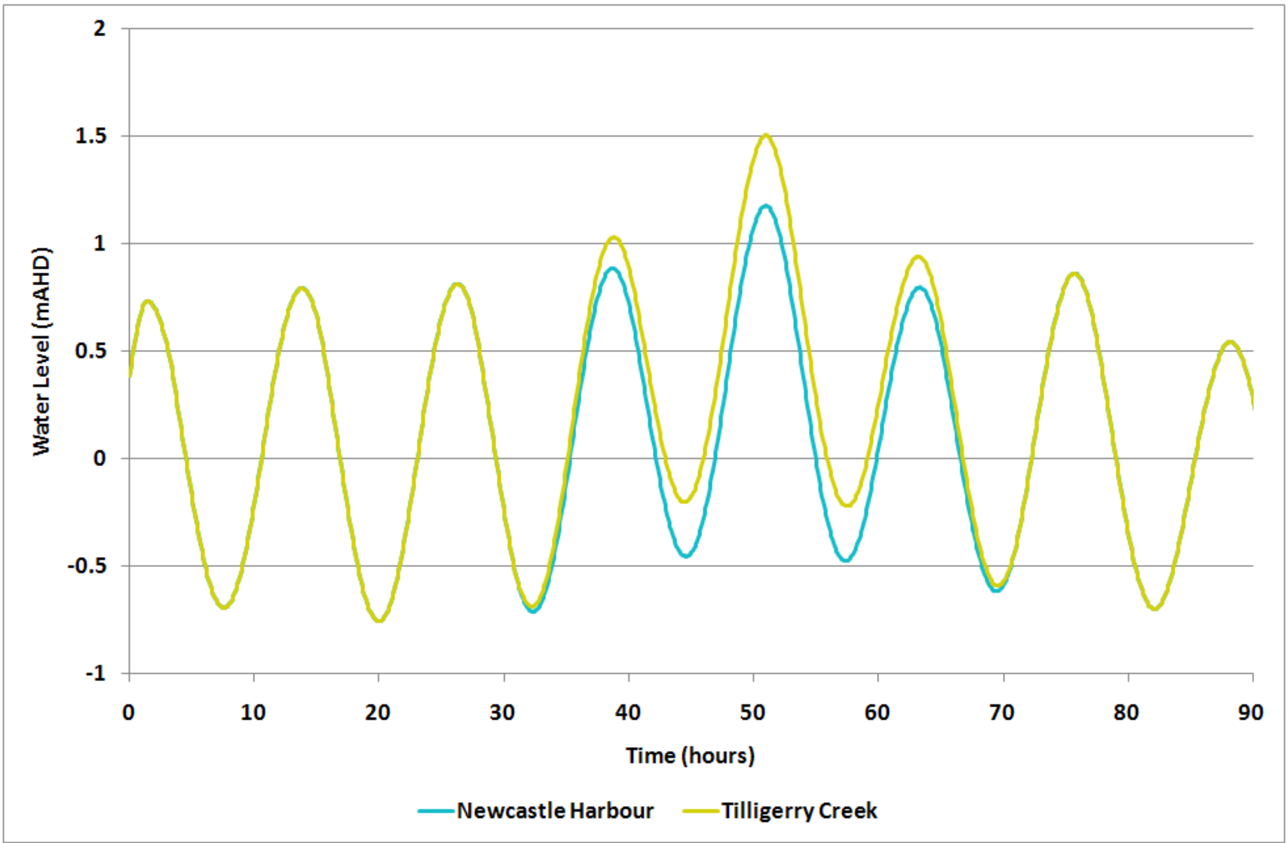


Figure 5-3 Newcastle Harbour and Tilligerry Creek 50% AEP Water Levels

5.3 Local Catchment Inflows

Local catchment inflows for the Hunter River downstream of Raymond Terrace and within the Williamtown / Salt Ash study area have been derived from the appropriate hydrological models. The 10% AEP 48 hour duration inflows have been adopted, consistent with the Williamtown / Salt Ash Flood Study. These local catchment inflows have been increased by 10% and 30% to assess climate change impacts of increased rainfall intensity. The impact of these local catchment inflows on the overall flood behaviour in the study area is minimal in comparison to the Hunter River flow and influence of downstream boundary conditions.

5.4 Simulated Design Events

Council identified a list of climate change scenarios to be applied to the 1% AEP baseline flood condition (Run 11 from the Williamtown / Salt Ash Flood Study). The modelled scenarios are summarised in Table 5-1. The results from this series of model runs are presented in Section 6.

Table 5-1 Model Design Runs

Design Flood Condition	Hunter River Flow	Newcastle Harbour Water Level	Tilligerry Creek Water Level	Local Catchment Inflows
Baseline	1% AEP (9,000m^3/s)	50% AEP (1.17m AHD)	50% AEP (1.5m AHD)	10% AEP 48h duration
2050	1% AEP (9,000m^3/s)	50% AEP +0.4m (1.57m AHD)	50% AEP +0.4m (1.9m AHD)	10% AEP 48h duration
2050 +10%	1% AEP +10% (9,900m^3/s)	50% AEP +0.4m (1.57m AHD)	50% AEP +0.4m (1.9m AHD)	10% AEP 48h duration +10%
2050 +30%	1% AEP +30% (11,700m^3/s)	50% AEP +0.4m (1.57m AHD)	50% AEP +0.4m (1.9m AHD)	10% AEP 48h duration +30%
2100	1% AEP (9,000m^3/s)	50% AEP +0.9m (2.07m AHD)	50% AEP +0.9m (2.4m AHD)	10% AEP 48h duration
2100 +10%	1% AEP +10% (9,900m^3/s)	50% AEP +0.9m (2.07m AHD)	50% AEP +0.9m (2.4m AHD)	10% AEP 48h duration +10%
2100 +30%	1% AEP +30% (11,700m^3/s)	50% AEP +0.9m (2.07m AHD)	50% AEP +0.9m (2.4m AHD)	10% AEP 48h duration +30%

6 DESIGN FLOOD RESULTS

A range of design event scenarios were simulated to determine the impact of climate change on the 1% AEP flood behaviour in the study area. The results of these model runs are presented in this section.

6.1 Comparison with Original Flood Study Results

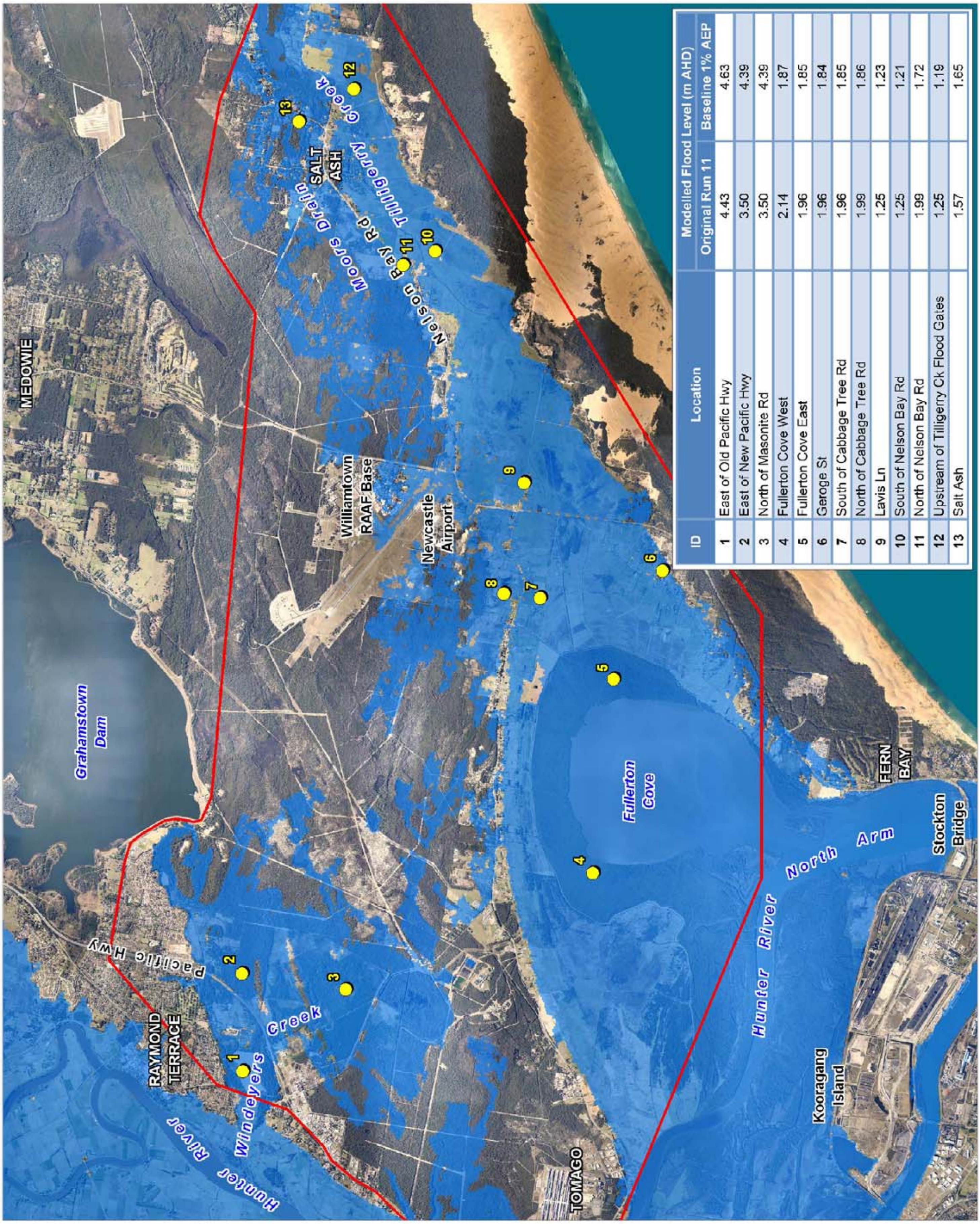
The development of a new TUFLOW model to properly assess the impact of climate change for this study resulted in a new baseline 1% AEP flood condition being established. The outputs of the current baseline 1% AEP design event conditions were compared to those from the equivalent Run 11 of the Williamtown / Salt Ash Flood Study. Figure 6-1 shows the flood extents for the baseline 1% AEP event with flood level comparisons to the original Run 11 results at 13 locations. It can be seen that for most locations there is a good match between the previous and new baseline results, with differences of round 0.1m or less. However, there are a few locations where the difference between the two is significantly greater than 0.1m:

- All three comparison points along Windeyers Creek (location nos. 1, 2 and 3 on Figure 6-1);
- Between Moors Drain and Nelson Bay Road (location no. 11); and
- Fullerton Cove West (location no. 4).

The points along Windeyers Creek are significantly different due to the modelled water levels at the confluence with the Hunter River. The Williamtown / Salt Ash Flood Study adopted the water level results from the Lower Hunter River Flood Study model at this location, which had a peak level of 4.45m AHD. The new modelled level at the confluence is around 4.8m AHD (see Figure 6-2). The Hunter River flood level drives flow along Windeyers Creek, which in turn fills the storage area to the east of the Pacific Highway. The total volume of water flowing from the Hunter River along Windeyers Creek determines the flood level reached in the storage area. A higher flood level in the Hunter River will result in a higher flood level in the storage area. When comparing the two models, an increase of 0.25m in the Hunter River (at the Windeyers Creek confluence) has resulted in a 0.9m increase to the east of the Pacific Highway.

The water level comparison between Moors Drain and Nelson Bay Road shows a difference of around 0.3m. The lower water levels modelled for the new baseline 1% AEP event are a result of the cross drainage structures which have been added to the model. The original Run 11 had no cross drainage along Nelson Bay Road between Williamtown and Salt Ash. A site inspection for this study confirmed the presence of nine 600mm diameter RCPs. The inclusion of these structures in the model has enabled transfer of water through the Nelson Bay Road hydraulic control, lowering upstream flood levels.

The Williamtown / Salt Ash Flood Study adopted a water level gradient across Fullerton Cove based on the results of the Lower Hunter River Flood study, as presented in Figure 6-2. The new baseline 1% AEP model generates a minimal gradient across Fullerton Cove, as it is predominantly a storage area. This can be seen in Figure 6-1, which shows only a 20mm difference in levels across Fullerton Cove. The different model configurations between the Run 11 and new baseline 1% AEP account for the 0.3m difference in flood levels at Fullerton Cove West.



ID	Location	Modelled Flood Level (m AHD)	
		Original Run 11	Baseline 1% AEP
1	East of Old Pacific Hwy	4.43	4.63
2	East of New Pacific Hwy	3.50	4.39
3	North of Masonite Rd	3.50	4.39
4	Fullerton Cove West	2.14	1.87
5	Fullerton Cove East	1.96	1.85
6	Geroge St	1.96	1.84
7	South of Cabbage Tree Rd	1.96	1.85
8	North of Cabbage Tree Rd	1.99	1.86
9	Lavis Ln	1.25	1.23
10	South of Nelson Bay Rd	1.25	1.21
11	North of Nelson Bay Rd	1.99	1.72
12	Upstream of Tilligerry Ck Flood Gates	1.25	1.19
13	Salt Ash	1.57	1.65

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Comparison of Baseline 1% AEP Design Event with Original Flood Study Run 11

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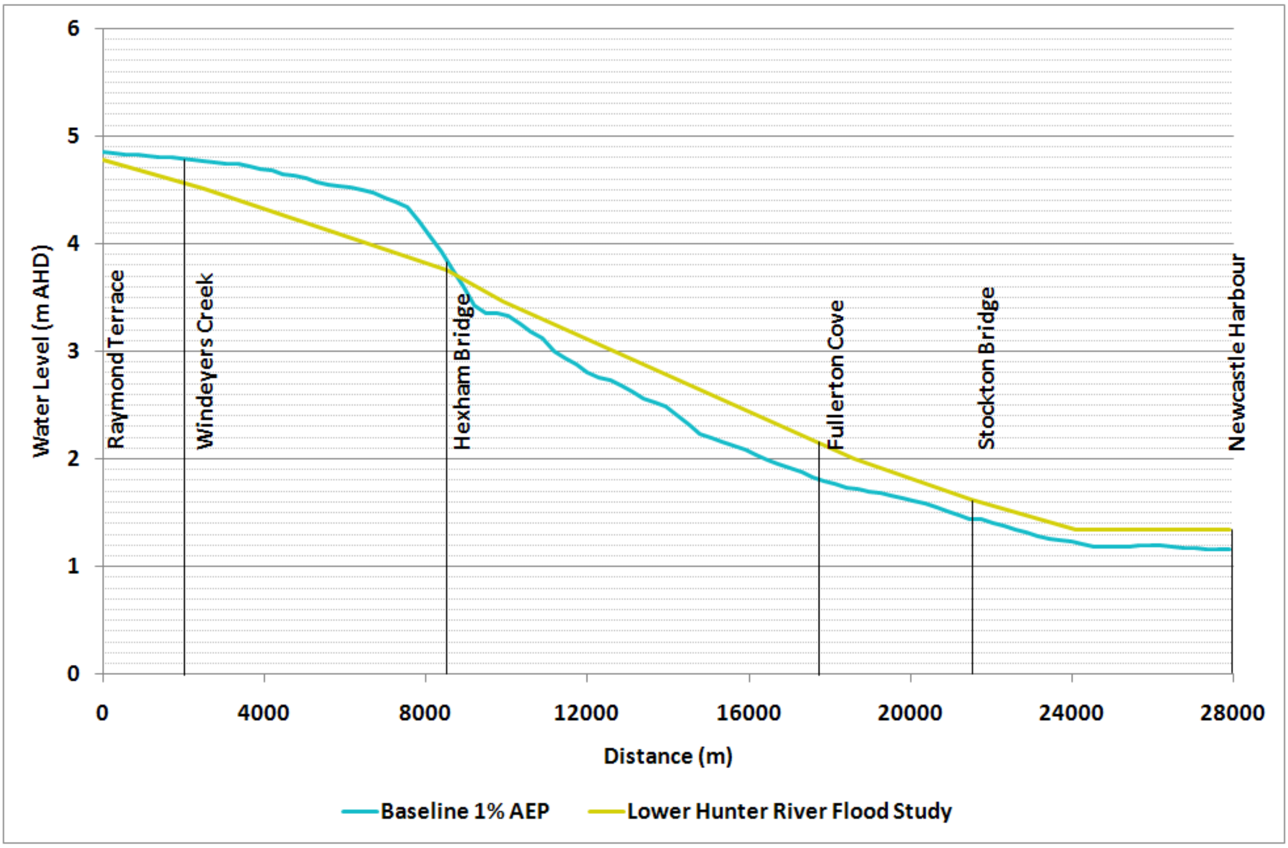


Figure 6-2 Comparison of Baseline Event with Lower Hunter River Flood Study

Elsewhere, the two models provide similar flood levels for the 1% design event. The key location within the study area is that to the south of Nelson Bay Road – between points 9 and 12 on Figure 6-1. In this area the model results of the Williamtown / Salt Ash Flood Study and the new baseline 1% AEP event are similar, with less than a 0.1m difference at Lavis Lane, to the south of Nelson Bay Road and upstream of the Tilligerry Creek flood gates.

6.2 Peak Flood Levels, Depths and Velocities

The design flood results are presented in a flood mapping series in Appendix A. For the simulated baseline 1% AEP event and climate change maps of peak flood level and depth and velocities are presented covering the modelled area.

Flood levels at key locations within the study area (as shown in Figure 6-1) are reported in Table 6-1. Longitudinal profiles showing predicted flood levels along the Hunter River and the Tilligerry Creek floodplain are shown in Figure 6-3. Flood extents for the baseline 1% AEP event are shown on Figure 6-1. The overall flood inundation extents for the baseline 1% AEP condition and climate change scenarios are very similar. The increase in flood inundation area from the 1% AEP event with climate change is limited given the study area topography. Floodwaters are generally confined within the broad floodplain regions, with flood depths increasing with flood event magnitude, but not generally resulting in substantial increase in floodplain area inundation.

Table 6-1 Modelled Flood Levels at Key Locations

ID	Location	Modelled Flood Level (m AHD)						
		Baseline	2050	2050 +10%	2050 +30%	2100	2100 +10%	2100 +30%
1	East of Old Pacific Highway	4.63	4.64	4.86	5.27	4.69	4.91	5.31
2	East of New Pacific Highway	4.39	4.42	4.68	5.19	4.48	4.74	5.24
3	North of Masonite Road	4.39	4.42	4.68	5.19	4.49	4.74	5.24
4	Fullerton Cove West	1.87	2.12	2.26	2.54	2.46	2.56	2.81
5	Fullerton Cove East	1.85	2.10	2.24	2.51	2.45	2.55	2.78
6	George Sreet	1.84	2.10	2.24	2.50	2.45	2.55	2.76
7	South of Cabbage Tree Road	1.85	2.10	2.24	2.51	2.45	2.55	2.76
8	North of Cabbage Tree Road	1.86	2.11	2.24	2.50	2.45	2.54	2.76
9	Lavis Lane	1.23	1.44	1.58	2.26	2.28	2.42	2.67
10	South of Nelson Bay Road	1.21	1.44	1.58	2.20	2.23	2.37	2.58
11	North of Nelson Bay Road	1.72	1.74	1.82	2.18	2.22	2.36	2.57
12	Upstream of Tilligerry Creek Flood Gates	1.19	1.43	1.57	2.08	2.27	2.33	2.45
13	Salt Ash	1.65	1.80	1.82	1.88	2.36	2.38	2.42

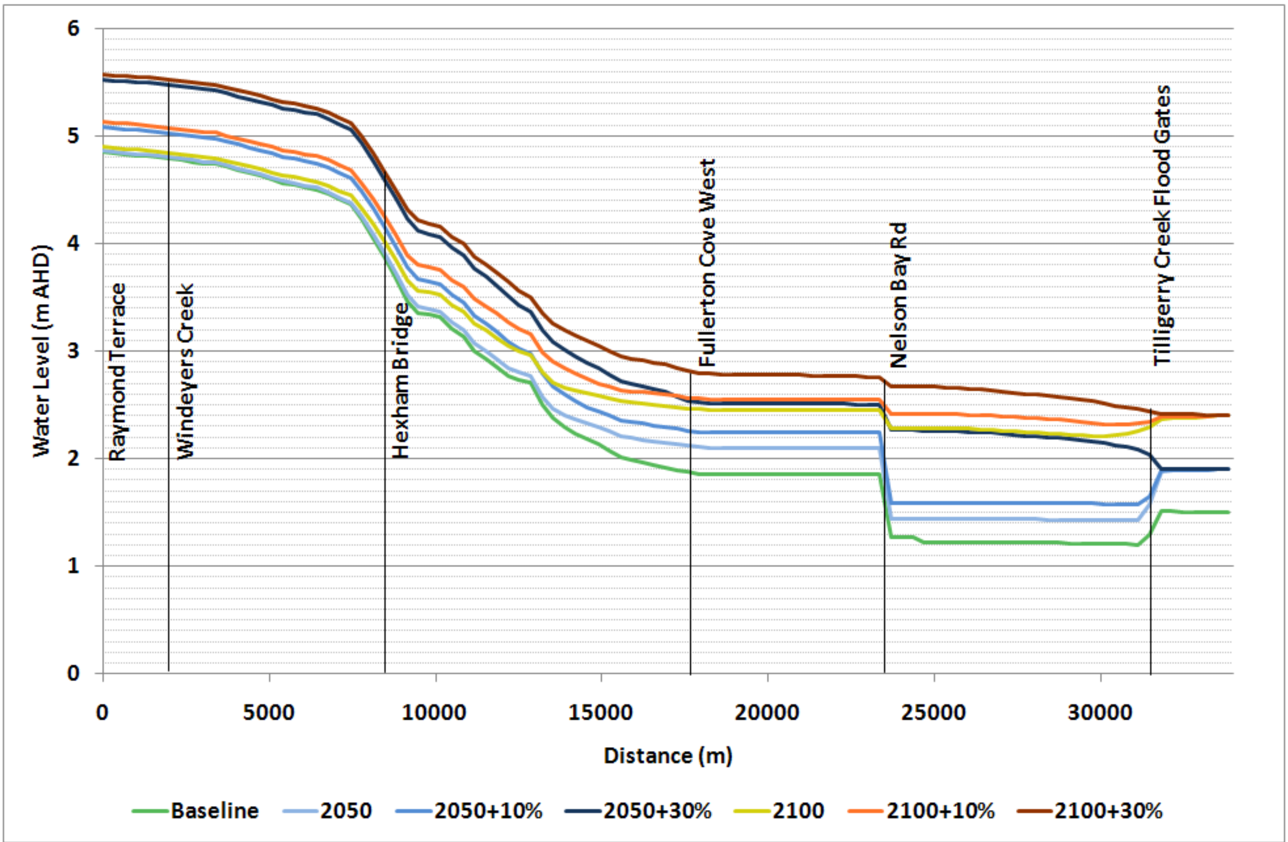


Figure 6-3 Design Flood Level Profiles

From Figure 6-3 it can be seen that upstream of Hexham Bridge the sea level rise scenarios have little impact on peak flood levels. There is only a small difference between flood levels for the baseline condition and the 2100 scenario. However, the increased flood flow scenarios do have a significant impact, with peak flood levels increasing by around 0.2m and 0.6m for the 10% and 30% flow increases respectively.

Between Hexham Bridge and Fullerton Cove the influence of sea level rise becomes more apparent, with the impact of increased flood flows reducing. A sea level rise of 0.4m by 2050, results in around a 0.2m increase to the 1% AEP flood level in Fullerton Cove. A sea level rise of 0.9m by 2100, results in around a 0.6m increase to the 1% AEP flood level in Fullerton Cove. The impact of increased flood flows on peak flood levels in Fullerton Cove is less pronounced than upstream of Hexham Bridge, due to the more expansive floodplain. For the 1% AEP event peak flood levels increase by around 0.1m and 0.3m for the 10% and 30% flow increases respectively.

The response of peak flood levels to potential climate change impacts in the study area between Nelson Bay Road and the Tilligerry Creek flood gates is more complex than further upstream. In this area the flood levels are driven by the volume of water spilling into the Tilligerry Creek floodplain over Nelson Bay Road at both Williamtown and Salt Ash, from the Hunter River and Tilligerry Creek respectively. For the baseline condition, 2050 and 2050+10% scenarios, the flow of water into the floodplain area is largely restricted to the capacity of the cross drainage structures through Nelson Bay Road. Once the flood levels increase further and significant amounts of water begin to spill over Nelson Bay Road, the floodplain area quickly fills, producing much higher flood levels. This is the case for the 2050+30% and all three 2100 climate change scenarios. For these events a flood gradient across the floodplain area becomes evident and is particularly pronounced for both the 2050+30% and 2100+30% flood flow scenarios.

Table 6-2 shows the total volumes spilling over Nelson Bay Road from both the Williamtown (Fullerton Cove) end and the Salt Ash (Port Stephens) end and into the floodplain area for each scenario. Spill volumes from Fullerton Cove (Williamtown) increase with the higher flood conditions in the Hunter River. Increased water levels in Port Stephens result in a greater volume of water overtopping the floodgates at Salt Ash. As the storage volume behind the flood gates becomes filled, the amount of water spilling over the flood gates reduces, as the structure becomes drowned. This is evident by the reduced volume from the 2100 to the 2100+10% scenario.

For the 2050+30% and 2100+30% scenarios, substantial overtopping of Nelson Bay Road from Fullerton Cove occurs, filling the Tilligerry Creek floodplain storage area. This enables Fullerton Cove and Port Stephens to become fully connected with convective flood flow through the Tilligerry Creek floodplain (as indicated by the hydraulic gradient shown in Figure 6-3). Under such conditions the contribution of flood volume from the Salt Ash end is insignificant.

Flood depths in the study area are typically in the order of 0.5m to 1m in the Tilligerry Creek floodplain and 1m to 2m in the Windeyers Creek storage area. These increase for the climate change scenarios, up to 1m to 2m in the Tilligerry Creek floodplain and over 2m in the Windeyers Creek storage area, for the 2100+30% scenario.

Table 6-2 Flood Volumes Spilling over Nelson Bay Road

Scenario	Flood Spill Volumes over Nelson Bay Road (m^3)		
	Williamtown	Salt Ash	Total
Baseline	63	5	68
2050	1,300	2,700	4,000
2050+10%	5,800	2,700	8,500
2050+30%	46,000	18	46,000
2100	17,000	17,000	34,000
2100+10%	33,000	13,000	46,000
2100+30%	90,000	4,100	94,000

The flooding of the Hunter River is characterised by relatively high flood velocities. In-channel velocities are typically in the order of 2m/s, with floodplain velocities between 0.5m/s and 1m/s. Within the study area the velocities are generally lower, being generally less than 0.25m/s. However, localised velocities can be higher, in the order of over 1m/s. This is likely to be influenced by local topography, particularly in the local catchment flooded areas, where velocities along major flow paths will be higher. However, velocity results in these areas should be treated with caution as the relatively coarse model grid resolution of 40m is unlikely to represent localised velocity variances in sufficient detail.

6.3 Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain Development Manual (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant affect on the flood pattern or flood levels.

The definition of flood impact categories that was considered appropriate for application within the study area was based on a combination of velocity*depth and depth parameters. The adopted hydraulic categorisation is defined in Table 6-3.

Hydraulic category mapping for the baseline 1% AEP event and climate change scenarios are included in Appendix A. It is also noted that mapping associated with the flood hydraulic categories may be amended in the future, at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts (e.g. if it is to change from floodway to flood storage).

Table 6-3 Hydraulic Categories

Floodway	Velocity * Depth > 0.5	Areas and flowpaths where a significant proportion of floodwaters are conveyed (including all bank-to-bank creek sections).
Flood Storage	Velocity * Depth < 0.5 and Depth > 0.5 metres	Areas where floodwaters accumulate before being conveyed downstream. These areas are important for detention and attenuation of flood peaks.
Flood Fringe	Velocity * Depth < 0.5 and Depth < 0.5 metres	Areas that are low-velocity backwaters within the floodplain. Filling of these areas generally has little consequence to overall flood behaviour.

6.4 Provisional Hazard

The NSW Government's Floodplain Development Manual (2005) defines flood hazard categories as follows:

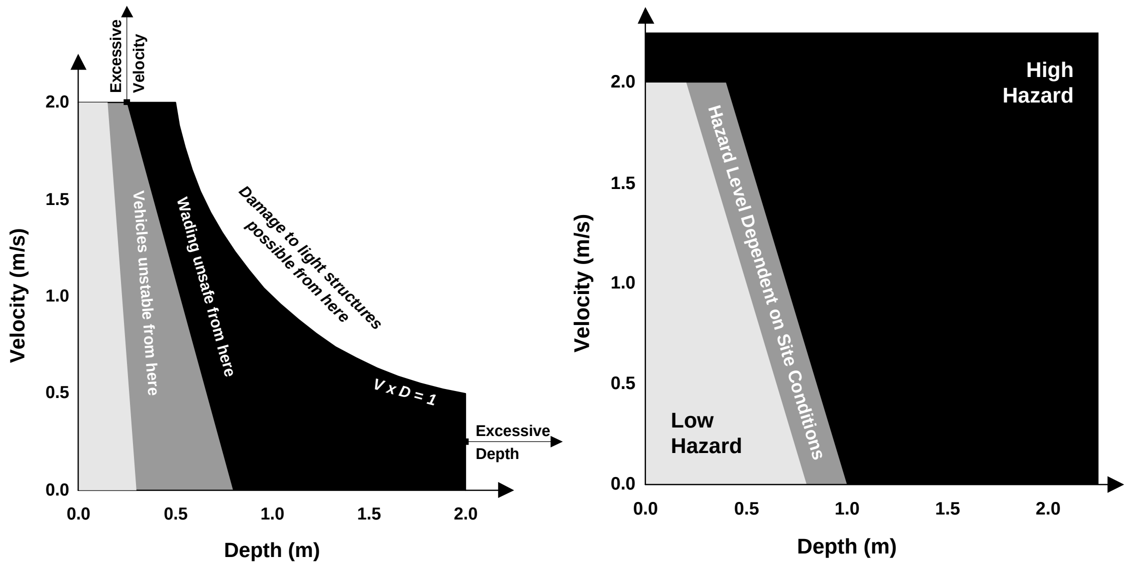
- **High hazard** – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and
- **Low hazard** – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

- Size of the Flood
- Rate of Rise - Effective Warning Time
- Community Awareness
- Flood Depth and Velocity
- Duration of Inundation
- Obstructions to Flow
- Access and Evacuation

The provisional flood hazard level is often determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities have no major threat.

Figures L1 and L2 in the Floodplain Development Manual (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 6-4.



Velocity Depth Relationships **Provisional Hazard Categories**

Figure 6-4 Provisional Flood Hazard Categorisation

The provisional hydraulic hazard is included in the mapping series provided in Appendix A for the baseline 1% AEP event and climate change scenarios.

7 CONCLUSIONS

The objective of the study was to assess the impacts of climate change on the baseline 1% AEP flood condition within the Williamtown / Salt Ash Flood Study area. Central to this was the development of a new two-dimensional hydraulic model of the study area, in order that the impacts could be properly assessed.

In completing the flood study review, the following activities were undertaken:

- Review of relevant studies regarding flood conditions and climate change impacts within Port Stephens;
- Site inspection to confirm the presence and configuration of key hydraulic structures;
- Merging of the existing Williamtown / Salt Ash Flood Study and Williams River Flood Study modelled to produce a composite model capable of properly assessing the impact of climate change in the study area;
- Updating of model topography with available LiDAR survey data;
- Calibration of 1% AEP design event flood levels with the 4.84m AHD level from the Flood Frequency Analysis at Raymond Terrace;
- Prediction of design flood conditions in the catchment using the developed model; and
- Production of design flood mapping series.

The climate change scenarios that were considered were combinations of 2050 and 2100 sea level rise conditions with baseline, +10% and +30% flood flows. A sea level rise of 0.4m by 2050, results in around a 0.2m increase to the 1% AEP flood level in Fullerton Cove. A sea level rise of 0.9m by 2100, results in around a 0.6m increase to the 1% AEP flood level in Fullerton Cove. For the 1% AEP event peak flood levels in Fullerton Cove increase by around 0.1m and 0.3m for the 10% and 30% flow increases respectively.

The dominant flooding mechanism (in terms of peak design water levels) for the Williamtown / Salt Ash locality is mainstream Hunter River flooding. Under these conditions, Hunter River flooding results in Fullerton Cove filling and discharging into the Tilligerry Creek floodplain, under cross-drainage structures and through overtopping of Nelson Bay Road. The baseline flood level within the Tilligerry Creek floodplain is increased from 1.2m AHD to 2.6m AHD, under the worst case climate change scenario.

The flood levels along Windeyers Creek are driven by flow conditions in the Hunter River. Hunter River flood water provides a backwater influence in Windeyers Creek, which fills the storage area to the east of the Pacific Highway. The total volume of water flowing from the Hunter River along Windeyers Creek determines the flood level reached in the storage area. A higher flood level in the Hunter River will result in a higher flood level in the storage area. At this location, the sea level rise scenarios have little impact on peak flood levels. There is only a small difference between flood levels for the baseline condition and the 2100 scenario. However, the increased flood flow scenarios do have a significant impact, with peak flood levels increasing by around 0.2m and 0.6m for the 10% and 30% flow increases respectively. The baseline flood level at this location is increased from 4.4m AHD to 5.2m AHD, under the worst case climate change scenario.

The flood study review will form the basis for the subsequent floodplain risk management activities, being the next stage of the floodplain management process.

8 REFERENCES

BMT WBM (2005) *Williamtown / Salt Ash Flood Study*

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PWD (1994) *Lower Hunter River Flood Study*

WMA (2010) *Port Stephens Design Flood Levels – Climate Change Review*