Anna Bay and Tilligerry Creek Flood Study

Port Stephens Council

Final Report

4 December 2017

Anna Bay and Tilligerry Creek Flood Study

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Author:	Michael Reeves/Lih Chong
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Jacobs Group (Australia) Pty Limited
ABN 37 001 024 095
177 Pacific Highway
North Sydney NSW 2060 Australia
PO Box 632 North Sydney NSW 2059 Australia

T +61 2 9928 2100
F +61 2 9928 2500
www.jacobs.com

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Contents

Foreword

The primary objective of the New South Wales Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods, wherever possible. Under the Policy, the management of flood prone land remains the responsibility of local government.

The policy provides for a floodplain management system comprising the following five sequential stages:

1.	**Data Collection**	Involves compilation of existing data and collection of additional data
2.	**Flood Study**	Determines the nature and extent of the flood problem
3.	**Floodplain Risk Management Study**	Evaluates management options in consideration of social, ecological and economic factors relating to flood risk with respect to both existing and future development
4.	**Floodplain Risk Management Plan**	Involves formal adoption by Council of a plan of management for the floodplain
5.	**Implementation of the Plan**	Implementation of flood, response and property modification measures (including mitigation works, planning controls, flood warnings, flood preparedness, environmental rehabilitation, ongoing data collection and monitoring by Council)

Port Stephens Council is undertaking this flood study for the Anna Bay and Tilligerry Creek floodplain areas to investigate the existing and future flood risks in the study area in accordance with the NSW Government's *Floodplain Development Manual*. The study will also guide land use planning and future development on the floodplain in the study area.

This study represents the first and the second stages of the management process and has been prepared for Council by Jacobs.

Executive Summary

A flood study has been conducted on behalf of Port Stephens Council ("Council") for the 122km^2 Anna Bay and Tilligerry Creek study area including the localities of Anna Bay, Boat Harbour, One Mile, Fishermans Bay, Bobs Farm, Taylors Beach, Salt Ash, Tanilba Bay, Mallabula and Lemon Tree Passage. The purpose of this study is to investigate the existing and future flood risks in the study area and to provide information for the development of the subsequent floodplain risk management study and plan in accordance with the NSW Government's *Floodplain Development Manual*.

The catchment is comprised primarily of rural/agricultural areas and open space, with urban centres located at Anna Bay – Boat Harbour and Tanilba Bay – Lemon Tree Passage. The urban areas are served by stormwater drainage networks with pit and pipe drainage mainly in the streets. The terrain includes large areas of flat, low-lying floodplain at elevations less than 2m AHD, with steeper areas formed by sand hills and rocky outcrops. A number of trapped drainage points are present, formed by the sand hills as well as road embankments and levees. A number of drainage channels including Anna Bay Main Drain, Back Drain, Fern Tree Drain and Moors Drain as well as numerous minor drains form the main drainage paths for the floodplain areas.

Flood behaviour in the study area is complex, originating from tidal inundation, local catchment runoff and Hunter River overflows in rare flood events. The assessment considers combinations of concurrent flooding from these sources.

A range of data was obtained by Jacobs or provided by Council and other agencies in October/November 2015. The data includes reports of studies that have been undertaken in the area; spatial data including stormwater assets, surveyed cross sections and other GIS layers; recorded rainfall, water level and tide data; and modelling data including hydrologic and hydraulic models of Anna Bay and surrounding areas and groundwater modelling of aquifers in the study area. Additional topographic survey as collected of selected hydraulic structures, open drains and flood marks in August and September 2016. The features surveyed were selected based on the review of available data and gaps analysis.

Community consultation undertaken for the study included overviews and updates of the study posted on Council's website and social media, a newsletter and questionnaire mailed out to the community, and interviews with residents and stakeholders. This report has also been placed on public exhibition and reviewed by Council's Floodplain Advisory Panel.

Hydrologic modelling of has been undertaken based on a XP-RAFTS model to establish inflow hydrographs at numerous local sub-catchments in the study area. The modelling has been calibrated and verified against flooding observations provided by local residents of the April 2015 and January 2016 storm events.

The flood study assessment is based on TUFLOW 1D/2D dynamic hydraulic modelling developed specifically for this study. The flooding characteristics and catchment settings vary widely across the study area. As such, three separate TUFLOW models have been developed to estimate flooding in different areas and levels of detail:

- A "regional" TUFLOW model of the entire study area, to assess flooding in the predominantly rural land use setting. The regional model has been developed by extending the existing Williamtown – Salt Ash FRMS&P TUFLOW flood model (BMT WBM, 2015) to ensure consistency for the inflows into the study area from Hunter River overflows from Fullerton Cove. Flooding is assessed at a 20m model grid resolution; and
- Two finer-scale "urban" TUFLOW models of existing urbanised areas in the vicinity of Anna Bay. Flooding is assessed at a 2m grid resolution in order to account for smaller scale flow patterns in these urbanised areas, due to stormwater drainage and flow obstructions due to buildings.

The models have been run separately, with the results from the detailed urban models taking precedence over the regional model where these are available.

Design flood conditions are defined based on the full level of permissible development under Council's LEP 2013 and for existing climate conditions. Design flood events including the 20%, 10%, 5% and 1% AEP and

Probable Maximum Flood (PMF) events have been analysed. Flood mapping of depth, flood level, flow velocity and provisional flood hazard has been undertaken for selected event AEPs. Flood profile long sections for the major drains in Anna Bay, and inundation versus time plots for selected locations in the study area have been prepared. The flood hazard and hydraulic categories have been defined and mapped based on Council's Floodplain Risk Management Policy.

Flooding in the study area has been related to nearby river water level gauges in Port Stephens at Mallabula Point and the Hunter River at Raymond Terrace for potential flood warning applications. The detection of elevated water levels at the Mallabula Point gauge is unlikely to be useful for flood warning purposes as the gauge is in the immediate vicinity of the study area and there is unlikely to be a significant timing difference between the gauge and water levels in Tilligerry Creek. Flood gauging at Raymond Terrace may provide warning of overflows from Fullerton Cove and into the study area during events from the 0.5% AEP up to the PMF, which would cause significant flooding exceeding 2m in depth in areas of the study area. If there is a PMF event in the Hunter River, there is approximately 10 hours warning time from when the river level at Raymond Terrace exceeds 5.2m AHD (the 0.5% AEP peak flood level at Raymond Terrace) and when the Hunter River overflows reach the study area.

The flood planning area has been defined based on Council's Floodplain Risk Management Policy, by the area below the 1% AEP flood level under the climate change scenario (0.9m sea level rise and 20% increase in rainfall intensity) plus a 0.5m freeboard. The reduced extent of a 0.3m freeboard, which is suggested for application on overland flood flow areas, is also shown on the flood planning area mapping for consideration by Council.

The number of properties affected by varying maximum flood depths is summarised in **Table 1**. There are 5,241 properties in total in the study area. Properties in the study area have been classified based on the minimum flood AEP at which the property becomes flood-affected. For the purposes of this assessment, a property is considered "flood-affected" when it becomes more than 20% covered by floodwaters over 0.15m deep. This filter has been applied to exclude shallow depth of water which may not be considered as flooding. The maximum flood depth may not reflect the flood depth at the dwelling. The analysis is based on the land parcels spatial layer provided by Council and includes both private property as well as public property and other reserves and open space.

Table 1 Count of properties by maximum flood depth on each property*

Depth (m)	Design Flood Event				
	20% AEP	10% AEP	5% AEP	1% AEP	PMF
>0.15	688	774	955	1168	2508
>0.3	645	737	910	1138	2479
>0.5	471	535	645	863	2165
>1.0	285	320	373	440	1389
>2.0	78	89	104	142	561
Total	688	774	955	1168	2508

* For properties with >20% coverage by floodwaters over 0.15m deep. Number of properties with a maximum depth exceeding the depth category Example: in the 10% AEP there are 737 properties with a maximum flood depth of 0.3m or more.** Total of 5,241 properties in the study area.

Properties within the study area have been classified for flood emergency response based on NSW Government floodplain risk management guidelines. The classification has been undertaken for the 20% and 1% AEP and PMF events, and indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community. The classification is denoted preliminary and subject to update in the subsequent Floodplain Risk Management Study.

The impact of climate change on flooding in the study area has been assessed for the 5% and 1% AEP events for a range of scenarios, including:

- Year 2050 sea level (+0.4m), rainfall intensity derived from 1987 Australian Rainfall and Runoff
- Year 2050 sea level (+0.4m), 10% increase in rainfall intensity
- Year 2050 sea level (+0.4m), 20% increase in rainfall intensity
- Year 2100 sea level (+0.9m), rainfall intensity derived from 1987 Australian Rainfall and Runoff
- Year 2100 sea level (+0.9m), 20% increase in rainfall intensity
- Year 2100 sea level (+0.9m), 30% increase in rainfall intensity.

The PMF has also been assessed in combination with the Year 2100 sea level (+0.9m), with no increase in the PMF rainfall.

Large areas of the study area have existing development on low lying terrain, at elevations of 0.5 – 2m AHD, and are already susceptible to elevated tides and water levels during Port Stephens coastal and riverine flooding events, when tailwater levels may reach up to 1.8m AHD in the 1% AEP event. Depths of flooding on these low lying areas may therefore be expected to reach up to 2m or more in the year 2100 climate change flooding scenarios. Elevated 1% AEP event water levels in Tilligerry Creek would be approximately 2.2m AHD and 2.7m AHD at the year 2050 and 2100 horizons. Increased runoff in the 1% AEP event with 30% increase in rainfall intensity results in increases in flood depths in Anna Bay and other low points of approximately 0.2m, with up to 0.56m increase in Blanch Street low point.

In the PMF with year 2100 (+0.9m) sea level rise scenario, flood levels in the lower and middle section of Tilligerry Creek and to the west of Port Stephens Drive are 0.8 – 0.9m higher than for the current climate conditions. In the upper section of Tilligerry Creek to the western end of the study area flood levels are 0.1 – 0.75m higher than for the current climate conditions. In the Anna Bay Main Drain floodplain to the east of Port Stephens Drive flood levels are up to 0.4m higher than for the current climate conditions.

The depths of flooding over a number of key roads would be increased from the existing climate PMF, including Nelson Bay Road to the east of Marsh Road (eastern end), Marsh Road itself, Port Stephens Drive, Gan Gan Road through One Mile, and the western end of Lemon Tree Passage Road. This may affect emergency access on these roads in terms of depths experienced and the timing and duration of flooding. Overland flow areas above 3m AHD generally do not experience greater flood levels, as the PMF rainfall is not increased in the climate change scenario and the overland flow areas are above the influence of sea level rise.

A number of main flood problem areas have been identified in the study area. Two flood problem areas located in the Anna Bay township area are subject to significant development pressures as outlined in Council's Anna Bay Strategy and Town Plan. Potential mitigation options have been identified for each area, including structural and non-structural options for each area, as summarised in Table 2.

Table 2 Summary of Flood Problem Areas and Potential Mitigation

Flood Problem Area	Refer to	Potential Mitigation
Gan Gan Road between Morna Point Road and McKinley Swamp, Anna Bay	Section 10.1	· Divert and potentially upgrade the main stormwater line to discharge directly to Fern Tree Drain. · Upgrade the existing second drainage line, east of Morna Point Road. · Increase pit inlet capacity in combination with the above two options. · Form a floodway to drain McKinley Swamp floodwaters to Fern Tree Drain · A combination of the above.
Clark Street low point, Anna Bay	Section 10.2	· Thrust-boring of a large pipe/culvert through the sand hill to the north of the low point, discharging to the Main Drain floodplain.

Trapped low point at Gan Gan Road and Blanch Street, Boat Harbour	Section 10.3	· Upgrade/supplement existing, underperforming pipe outlet. New pipe/s need to be laid at deeper levels.
Marsh Road, Bobs Farm and Salt Ash	Section 10.4	· Raised building pads to achieve higher dwelling floor levels to reduce flood damages. However, adopting a policy such as this may encourage future development in this area which would expose a larger population and associated property to the existing flood risk, which will increase with climate change. · Voluntary house raising could be considered as a measure to reduce flood damages to existing development. · Increased cross drainage capacity to reduce times of inundation.
North side of Lemon Tree Passage Road, Salt Ash	Section 10.5	· Debris control structures at main cross culvert inlets. · Increased culvert capacity will permit better drainage of the area, provided that tailwater levels are low. · Improved capacity of existing drainage channels, including maintenance (management of vegetation and siltation) of the drains. · Maintenance of culverts and proposed debris control structures for debris and siltation. · Additional drains to improve connectivity of low points in the floodplain to drainage outlets. · Voluntary house raising to reduce flood damages to existing development. · Development controls including setting of appropriate habitable floor levels for future development.
Tanilba Bay urban area	Section 10.6	· Increase culvert capacity under Lemon Tree Passage 250m south of Avenue of the Allies · Floodway in the vacant block between 37 and 39 Tilligerry Track · Upgrade of existing 600mm pipe branch to at least a 1.05m diameter pipe in President Wilson Walk south of Lemon Tree Passage Road to prevent the flow surcharge · Increased pipe capacity crossing Lemon Tree Passage Road, along with increased pit capacity on the high side of Lemon Tree Passage Road and in Success Street · vegetation management and desilting of open channels through Tanilba Bay Golf Club course including.
Lemon Tree Passage urban area	Section 10.7	· New pit inlets at Paroa Avenue sag points and upgrade of the existing pipe capacity · New pit inlets and drainage of sag point on private properties on corner of Gould Drive and John Parade · New pit inlets and drainage of sag point on private properties on Meredith Avenue between Gould Drive and Johnson Parade.

An assessment of mitigation options has been undertaken for selected flood problem areas including parts of Anna Bay and surrounds including:

- Clark Street low point
- Low point in the vicinity of Gan Gan Road and Morna Point Road intersection
- McKinley Swamp and Gan Gan Road low points to the east (Anna Bay shops)
- Trapped low point at Gan Gan Road and Blanch Street
- Fern Tree Drain floodplain.

The assessment considers flooding under future development conditions associated with the Anna Bay Strategy and Town Plan. This will assist in identifying potential drainage upgrades to improve flooding conditions and realise the development potential of various areas. The assessment and outcomes are documented in Appendix J. Assessments of mitigation options are not normally included in flood studies. This is only a preliminary feasibility assessment of potential mitigation options. Council will not resolve to adopt any of these options until after the completion of the next stage under the floodplain development manual (Flood Risk Management Plan) where they will be subject to further design refinement, engineering feasibility assessments and community consultation.

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a flood study for the Anna Bay and Tilligerry Creek floodplain areas located in New South Wales in accordance with the scope of services set out in the contract between Jacobs and Port Stephens Council (the Client). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client, third parties, and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

Topographic data used in this study included data sourced from a LiDAR survey which was undertaken by third parties. The accuracy of this data has been verified against ground survey collected for this study.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs's Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

1.1 General

Jacobs has been engaged by Port Stephens Council (Council) to undertake a flood study in the Anna Bay and Tilligerry Creek area. The study area is located on the lower North Coast of NSW, and includes areas on the Tomaree Peninsula and Tilligerry Peninsula, located on either side of Tilligerry Creek (refer to Figure 1-1). Flooding in the study area is complex and during major events, floodwaters can interact with the Hunter River, Fullerton Cove and Tilligerry Creek, all of which have tidal influences and also contribute to flooding. This flood study involves the development and calibration/verification of hydrologic models and hydraulic models to determine the nature and extent of flooding in the area.

1.2 Purpose of this Flood Study

The purpose of this study is to investigate the existing and future flood risks in the study area and to provide information for the development of the subsequent floodplain risk management study and plan in accordance with the NSW Government's *Floodplain Development Manual*.

Key objectives of this study are to:

- Develop and calibrate/verify hydrologic and hydraulic models for the estimation of overland and mainstream flood behaviour in the study area, taking into account the influence and interaction of the various flooding mechanisms in the study area. The models are also to consider the performance of floodgates, hydraulic structures and the stormwater drainage network including overflows from the drainage network.
- Determine and describe design flooding behaviour and flood risk in the study area under the full permissible level of development and for current climate conditions, for a range of flood events between the 20% Annual Exceedance Probability (AEP) event and the Probable Maximum Flood (PMF) event.
- Assess the sensitivity of flood behaviour to changes in hydrologic and hydraulic characteristics in the catchments.
- Assess the impact of climate change on flood levels in the study area.
- Mapping of flooding characteristics (depth, level, velocity), flood hydraulic and hazard categories.
- Determine the Flood Planning Level (FPL) and Flood Planning Area (FPA), based on the 1% AEP event under future climate conditions – 2100 sea level rise (+0.9m above existing) and 20% increase in rainfall intensity.
- Identify the flood emergency response categories for different parts of the catchment and community.
- Identify and describe key flood problem areas, including potential mitigation.
- Analyse potential mitigation options for selected flood problem areas.

The outcomes from this flood study will form the basis for the identification, assessment and prioritisation of management measures during the subsequent floodplain risk management study and plan.

1.3 Structure of Report

This Draft Report documents methods, assumptions and findings of the study and is structured in the following sections:

- Foreword
- Section 1: Introduction (this section)
- Section 2: Background on the Study Area
- Section 3: Review of Available Data
- Section 4: Community Consultation

- Section 5: Hydrologic Modelling
- Section 6: Hydraulic Model Development
- Section 7: Model Calibration and Verification
- Section 8: Estimation of Design Floods
- Section 9: Design Flood Mapping and Analysis
- Section 10: Identification of Flood Problem Areas
- Section 11: Conclusions and Recommendations
- Section 12: Acknowledgements
- Section 13: References
- Section 14: Glossary
- Appendix A: Analysis of Historic Rainfall Event Data
- Appendix B: Community Consultation
- Appendix C: Model Calibration and Verification Data and Results
- Appendix D: Excerpts of Geotechnical Investigations Report for Anna Bay Catchment Drainage Flood Study (Coffey Partners, 1993)
- Appendix E: Design Flood Event Mapping
- Appendix F: Sensitivity Analysis Flood Impact Mapping
- Appendix G: Climate Change Analysis Flood Mapping
- Appendix H: Flood Planning Level and Hydraulic Category Mapping
- Appendix I: Emergency Response Classification of Communities
- Appendix J: Flood Mitigation for Anna Bay and Surrounds.

Legend

Study Area
Main Road
Waterway

0 1 2 3 4 5 Kilometres

N

1:75,000@ A3

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Figure 1-1 Study Area

2. Background on the Study Area

2.1 Description

The study area is 122km^2 in size and straddles the estuarine section of Tilligerry Creek and its floodplain, downstream from approximately the Nelson Bay Road crossing of Tilligerry Creek in Salt Ash. Localities in the study area include Anna Bay, Boat Harbour, One Mile, Fishermans Bay, Bobs Farm, Taylors Beach, Salt Ash, Tanilba Bay, Mallabula and Lemon Tree Passage.

Large sections of the study area lie on low, flat terrain at elevations lower than 2m AHD. These areas are existing or previous salt marsh and mangrove areas associated with the estuarine character of Tilligerry Creek and generally run along each side of the Creek, with an arm of low lying floodplain extending eastward in the north-east of the study area to form the Anna Bay Main Drain catchment and floodplain. Refer to Figure 2-1.

Moving away from Tilligerry Creek the terrain generally rises up as the landform becomes characterised with existing sand hills and sand dune areas at relatively steep grades on the right/ocean side of Tilligerry Creek on the Tomaree Peninsula, particularly at the rear of the Stockton Beach sand dunes, as well as remnant sand dunes on the left side of the Creek on the Tilligerry Peninsula. The sand hills and sand dunes form pockets and trapped low points in areas where runoff may pond before infiltrating to the groundwater. In areas where the groundwater is high, swamplands have formed. These include areas in the north-east and the west of the study area.

Raised bedrock formations and rocky outcrops are present around Anna Bay and Boat Harbour, along with some sand hill formations, help define the relatively steep terrain in parts of these localities.

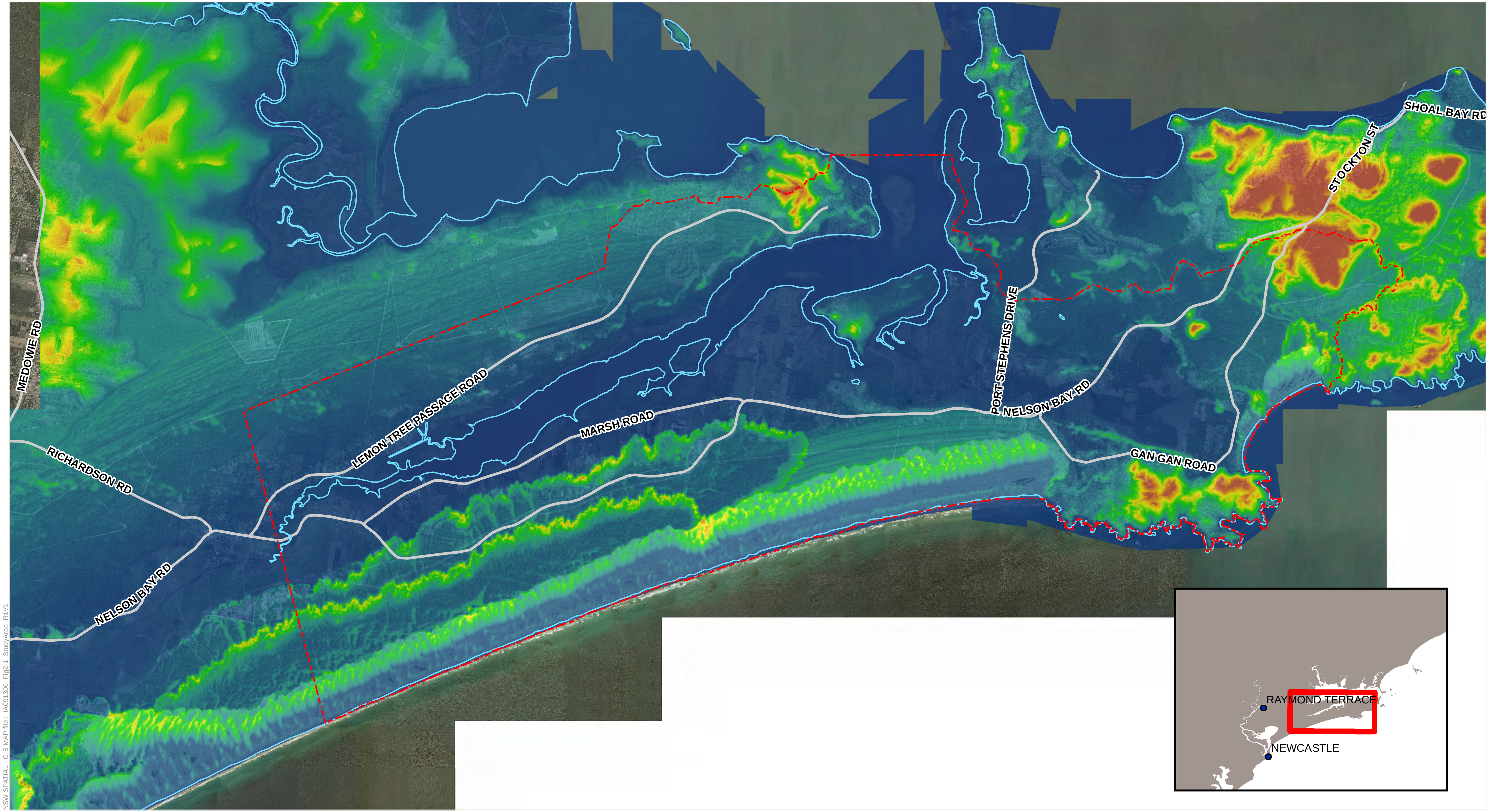
Numerous drainage channels, which were once watercourses or minor natural drains prior to settlement, drain the low-lying areas to Tilligerry Creek. These include Anna Bay Main Drain and tributary drains including Back Drain and Fern Tree Drain. Other major drains include Moors Drain which originates from Williamtown in the west and enters the upper section of Tilligerry Creek. There are a large number of minor, privately and public-owned drains located throughout the study area. These drains were constructed in the later 1800’s and early 1900’s to aid drainage of these low lying areas and improve the lands for agriculture (NSW DPI, 2008). Floodgates have been fitted on the majority of these drains to prevent backflow of saline estuary water into the new agricultural areas.

Overland flow paths occur generally in the steeper sections of the study area, draining runoff from the local catchments to Tilligerry Creek, floodplain areas, the various trapped low points around the study area or to the Tasman Sea.

A number of main roads cross the floodplains on filled embankments, including Nelson Bay Road, Marsh Road, Lemon Tree Passage Road and Port Stephens Drive. Although cross-drainage pipes and culverts are present through these road embankments, the drainage capacity of these structures is generally low and hampered by high tailwater levels in Tilligerry Creek, causing runoff to pond behind the road embankments until they are able to drain away.

2.2 Existing Development and Land Use

Land use in the majority of the study area consists of agricultural and rural properties and open space areas. Urban centres include the Anna Bay to Boat Harbour area and Tanilba Bay to Lemon Tree Passage areas, consisting mainly of residential development with predominantly free-standing houses and dwellings. Some commercial and light industrial properties are present. The urban areas are served by stormwater drainage networks with pit and pipe drainage mainly in the streets.



Legend

Elevation

160m AHD

0m AHD

Study Area

Main Road

Waterway

0 1 2 3 4 5 Kilometres

N

1:75,000@ A3

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Figure 2-1 Study Area Terrain

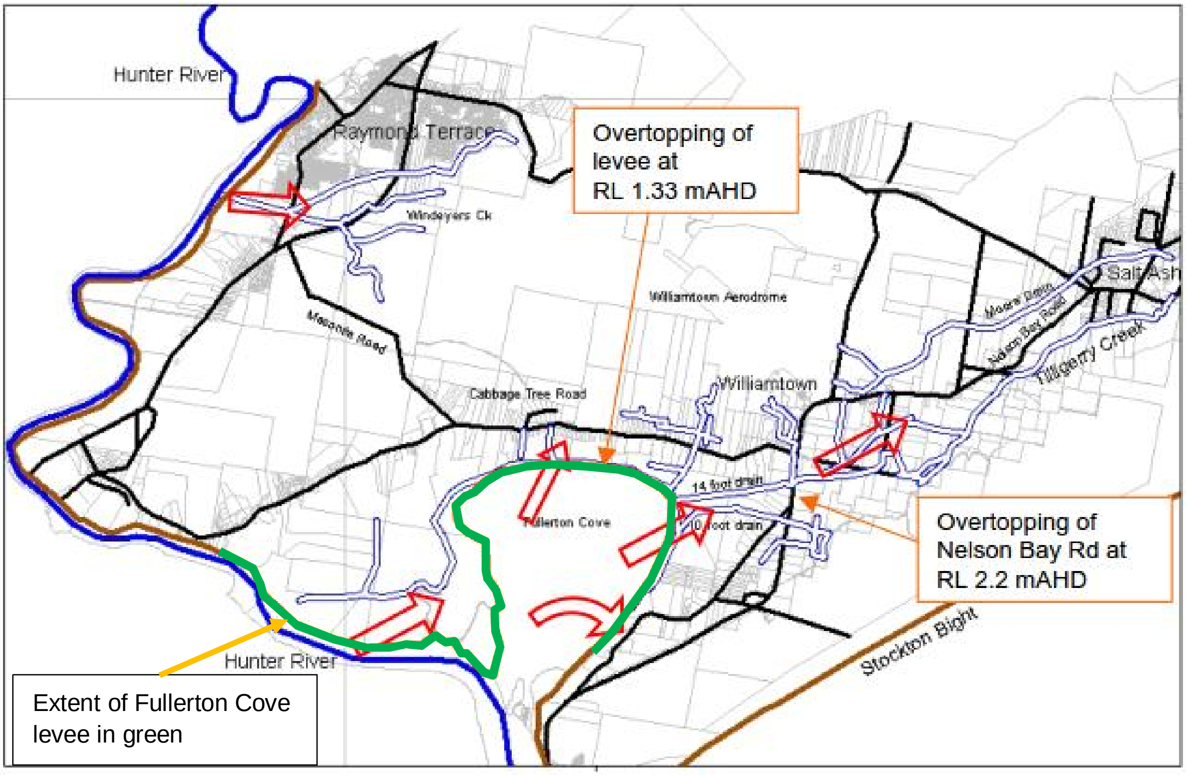
2.3 Flood Behaviour in the Study Area

The flood behaviour in the Anna Bay and Tilligerry Creek study area is complex, thus dictating the selection of the adopted modelling software, configuration of the flood model and the overall modelling approach. Factors which influence flooding behaviour include:

- Low-lying topography in large parts of the study area. Flooding in these areas are likely to be sensitive to downstream tailwater conditions, namely elevated estuary water levels in Port Stephens and Tilligerry Creek as a result of high tides, storm surge and riverine flooding originating from the Karuah River and Myall River, which drain to Port Stephens. The elevated estuary water levels may directly cause flooding if the existing flood gates are not operating properly. Otherwise, the elevated water levels would limit the drainage of local runoff from these low-lying areas.
- Connectivity with the Hunter River. Refer to Figure 2-2 for illustration. During large flood events in the Hunter River, floodwaters overflow Fullerton Cove levee and drain through the Tilligerry Creek floodplain in Williamtown and Salt Ash to Port Stephens. Minor overflows occur at localised low points in the levee in the present day 10% AEP event however these only result in localised increases in flooding (WBM, 2005). The levee is higher than the 10% AEP flood level in Fullerton Cove and hence there is no Hunter River inflow in this and more frequent flood events. Overflows over the Fullerton Cove levee into the Tilligerry Creek floodplain occur in the 5% AEP event and rarer, although drainage of these overflows into the current study area are restricted by the raised Nelson Bay Road embankment and cross drainage through the embankment. There is some minor flow through the Nelson Bay Road cross drainage culverts in the present day 2% AEP event and rarer, however this flow rate is relatively small and does not significantly contribute to flooding east of Nelson Bay Road including the parts of Tilligerry Creek floodplain within this study area.
- Local catchment rainfall-runoff also contributes to the flooding in the study area. This is the dominant flooding mechanism in parts of the study area, including the urban areas of Anna Bay, Boat Harbour, One Mile, Tanilba Bay and Lemon Tree Passage.

The hydraulic modelling needs to account for each of these flooding mechanisms in order to capture the peak flood levels.

Figure 2-2 Hunter River flooding mechanism (reproduced from Figure 3-1 of WBM, 2005)



2.4 History of Flooding

Major flooding has occurred in the study area in 1955 and 1990. The 1955 event originated from the largest Hunter Valley flooding event on record, with major flooding occurring throughout the Hunter Valley. Floodwaters overflowed from Fullerton Cove on the Hunter River and spilled into the Tilligerry Creek floodplain at Williamtown before flowing into the study area at Salt Ash and then draining to Port Stephens. Depths of flooding were reported to be knee-deep on pastures in the floodplain in Williamtown and Salt Ash (Lawson and Treloar, 1998).

Flooding during the 1990 event was caused by local catchment flooding, resulting from high depths of rainfall occurring over and around the study area. Rainfall totals of 450mm over 2 days and up to 480mm over 3 days fell at Williamtown, immediately west of the study area, while totals of 300mm occurred over 3 days in the north-eastern sections of the study area. These local rainfall totals are the highest on record in and around the study area. Unfortunately, there is an absence of reports of flooding depths from the available information.

Other significant rainfall events have been recorded in 1886, 1889, 1898, 1946, 1949, 1976, 1981, 1998, 2001, 2007, 2015 and 2016, according to available recorded rainfall data.

The April 2015 and January 2016 events occurred just prior to or during this study and rank relatively highly on the list of recorded storm events in the study area. Rainfall depths over 2 days were typically 280 – 300mm throughout the study area in the 2015 event with up to 380mm recorded in 3 days in the Tanilba Bay area. The 2016 event resulted in rainfall depths up to 300mm over 3 days in the southern end of the study area, the second highest on record after the 1990 event. Relatively low rainfall totals of 200mm over 3 days were experienced in the northern end of the study area. These events were selected for model calibration and are discussed in further detail in Section 3.5 and Section 7.2.

Photographs of flooding during the historic events were provided by residents and Council, and are shown on the following figures.

Figure 2-3 Yard flooding, Lemon Tree Passage Road, January 2016

Figure 2-4 Flooding in street, Tanilba Bay, April 2015 or January 2016

Figure 2-5 Overland flows in street, Tanilba Bay, April 2015

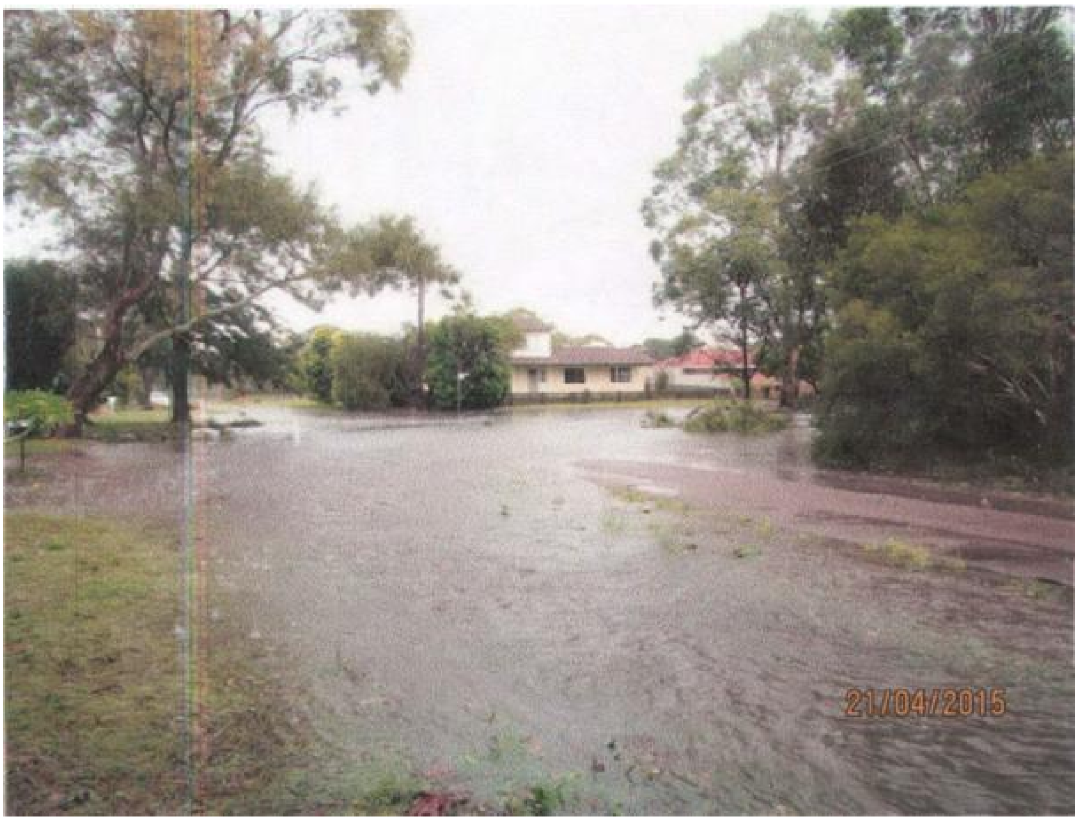


Figure 2-6 Overland flows in street, Tanilba Bay, April 2015

Figure 2-7 Flooding in yards and paddocks, Salt Ash, February 1990

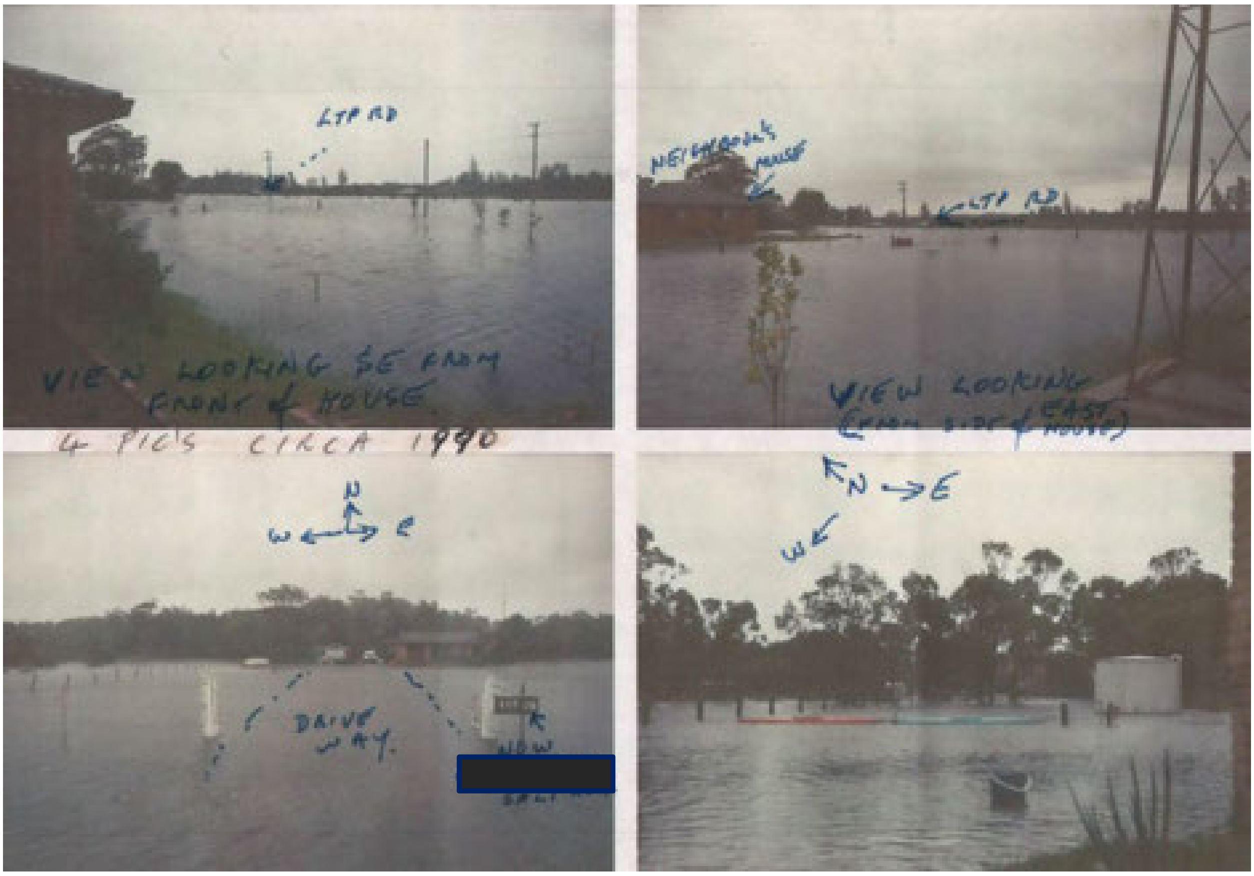


Figure 2-8 Flooding in yards and paddocks, Salt Ash, January 2016

Figure 2-9 Flooding in yards and paddocks, Salt Ash, January 2016

Figure 2-10 Flooding in paddocks, upper Main Drain floodplain, January 2016

Figure 2-11 Water over road, One Mile, January 2016

Figure 2-12 Yard flooding, Salt Ash, January 2016

3. Review of Available Data

3.1 Compendium of Data

A range of data was obtained by Jacobs or provided by Council and other agencies in October/November 2015 and is summarised in Table 3-1 below. The data includes reports of studies that have been undertaken in the area; spatial data including stormwater assets, surveyed cross sections and other GIS layers; recorded rainfall, water level and tide data; and modelling data including hydrologic and hydraulic models of Anna Bay and surrounding areas and groundwater modelling of aquifers in the study area.

Table 3-1 Data inventory

Data	Description	Source
Reports		
Draft Williamtown and Salt Ash Floodplain Risk Management Study – Final Draft	Draft Report outlining the modelling undertaken as part of the floodplain risk management study for the Williamtown and Salt Ash area	BMT WBM 2016
Anna Bay Catchment Drainage/ Flood Study Master plan	Flooding and drainage study for Anna Bay catchment including Main Drain for existing and two future development scenarios	Sinclair Knight Merz1995
Drainage Investigation Report Anna Bay North Structure Plan	Drainage investigation to identify trunk drainage required to mitigate potential impacts of future development	Parsons Brinckerhoff 2004
Remediation of Acid Sulphate Soils in the Tilligerry Creek Catchment	Acid sulphate soils study that included hydraulic modelling of channels around Anna Bay	NSW DPI 2011
Acid Sulphate Soil Assessments in the Anna Bay Catchment	Acid sulphate soils study that included data on water levels and floodgates around Anna Bay	NSW DPI 2008
Port Stephens Design Flood Levels – Climate Change Review	Assessment of the impact of climate change including the increase in river flows and sea level rise	WMAwater 2010
Port Stephens Flood Study	Defines design water levels in Port Stephens for a range of flood events	MHL 1998
Tilligerry Creek Flood Study	Outlines the calibration of hydrologic and hydraulic models used to define design flood events in Tilligerry Creek	Lawson and Treloar 1998
Spatial and Design Data		

LiDAR data	1m gridded DEM available for the whole study area	NSW LPI 2012/2013
Nelson Bay Road Upgrade Earthworks	Concept design earthworks model for Nelson Bay Road between Bobs Farm and Anna Bay	RMS 2015
Aerial photography	2012 aerial photography covering the study area	Vekta 2012
Stormwater infrastructure	Pits and pipe network across the study area	Port Stephens Council
Tilligerry Creek Floodgates	Details of the floodgates along Tilligerry Creek	NSW DPI
Nelson Bay Road Upgrade Drainage	Pavement and cross-drainage structures in the concept design for the Nelson Bay Road Upgrade	RMS 2015
Lemon Tree Passage Road Upgrade design	Pavement and cross-drainage structures	Port Stephens Council
Anna Bay Drainage Channels Cross sections	Surveyed cross sections along the drainage channels in Anna Bay	DPI 2008/2011
Tilligerry Creek Bathymetry	Surveyed cross sections along Tilligerry Creek	OEH 1995
Additional GIS layers	Roads, cadastre, LEP, land use, local boundaries.	Port Stephens Council
Drainage pumping station design data	Design drawings and pump technical data on Clark Street catchment and Salt Ash stormwater drainage pumping stations.	Port Stephens Council
Ground survey	Topographic survey of selected stormwater structures, culverts, open channels and other features commissioned for this study	Commissioned by Jacobs/PSC 2016
Recorded Data		
Daily Rainfall Data	Daily rainfall data for five stations in the Anna Bay region	BoM

Water Level Data	Water level data in the open drains in Anna Bay for 2009/2010	DPI 2011
Groundwater Level Data	A collection of 109 bores in the Salt Ash/Bobs Farm area	Hunter Water Corporation 2015
Tide Data	Water level data recorded at Malubulla Point in Port Stephens and Newcastle Harbour	MHL, Newcastle Ports
Modelling Data		
Anna Bay XP-RAFTS and MIKE-11 Models	Hydrologic and hydraulic models updated for a flood assessment for the proposed golf course estate development between Frost Road and Gan Gan Road	SKM 2004
Williamtown/Salt Ash XP-RAFTS and TUFLOW Models	Hydrologic and hydraulic models updated for the Williamtown/Salt Ash Flood Study Review	BMT WBM 2011
Williamtown/Salt Ash FRMS&P TUFLOW model	Updated hydraulic modelling which includes extension of model domain to Anna Bay, refinement of grid size and update of key drainage structures	BMT WBM 2015
MIKE-11/21 model for Anna Bay Acid Sulphate Soils	Hydrodynamic model of Anna Bay catchment and drains	WRL 2009, DPI 2011
Groundwater modelling of Tomago Aquifer	Groundwater modelling data and results of Tomago Aquifer including modelling of historic April 2015 storm event	Hunter Water 2015

3.2 Site Visit

Site inspections were undertaken on 22 October 2015 and 12 November 2015. The purpose of the site inspection was to gain a further understanding of the catchment characteristics, the nature of existing development and hydraulic constraints (including open channels and floodgates), and likely flood risk. Members of the Jacobs project team were accompanied by Council officers and representatives from OEH. Locations inspected on the site visit included potential trouble spots, drainage outlets, open channel and floodgate locations.

Observations made during the site visit included:

- Terrain is generally flat and low-lying with some higher ground. The low-lying areas are poorly drained via a series of open drains. The drains appear to become overgrown with vegetation periodically.
- Some areas including along Marsh Road are very low-lying and likely to be tidally-inundated during king tides.

- Soil profiles and landscapes appeared to be generally sandy. Low-lying parts of the study area have soils with a more muddy/clayey appearance.
- Land use is generally a mixture of semi-rural and forest, with urbanised areas in and around Anna Bay and Lemon Tree Passage.
- Floodgates are of a hinged-flap construction which automatically open and close in response to a water level differential between the upstream and downstream sides.
- Several inlets to culverts in Anna Bay township were observed to be blocked by debris.

Figure 3-1 Anna Bay Main Drain floodgates

Figure 3-2 Looking upstream from Anna Bay Main Drain floodgates

Figure 3-3 Main Drain crossing at Nelson Bay Road

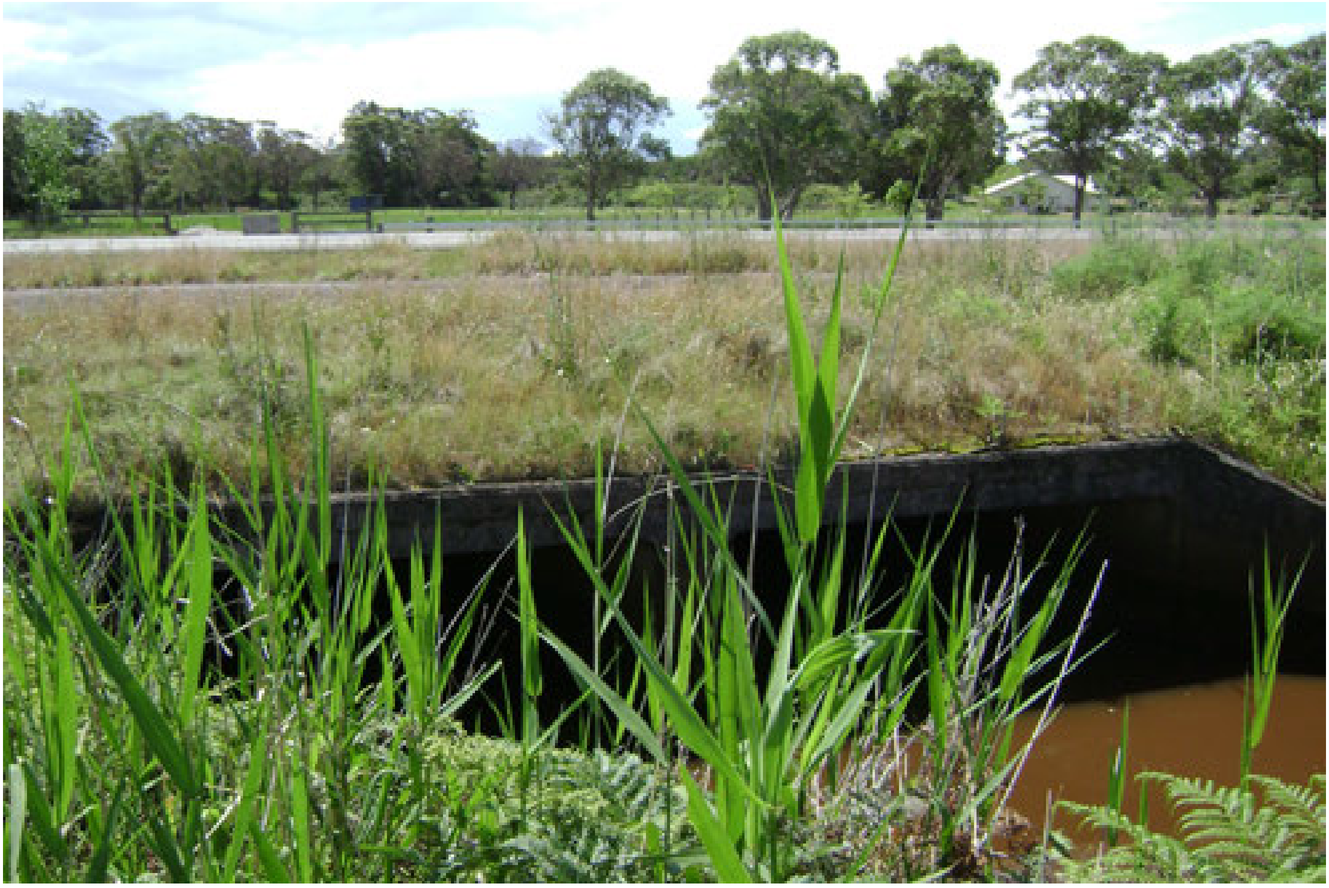


Figure 3-4 Culvert inlet portal on Fern Tree Drain in Anna Bay, partially obstructed by vegetation and debris

3.3 Previous Studies

The following reports were reviewed as they are relevant to flooding in the study area. Information considered useful to the current study has been highlighted.

- Draft Williamtown and Salt Ash Floodplain Risk Management Study – Final Draft (BMT WBM, 2016). This study builds on the previous Flood Study (WBM, 2005) and Flood Study Review (BMT WBM, 2012). It describes flooding behaviour from the Hunter River. Normally the Williamtown floodplain drains to Fullerton Cove but in large Hunter River Floods there are overflows into the floodplain draining into Tilligerry Creek. Nelson Bay Road is identified as a constraint on these flows. Tilligerry Creek can drain westwards towards the Hunter River (via Fullerton Cove) or eastwards to Port Stephens. Full drainage of the floodplain is expected to take 10-15 days. The 1990 flood was identified as the largest local runoff flood event. Elevated Hunter River water levels prevented drainage of the floodplain. The 1955 flood was identified as the largest flood on record for the Hunter River. The flood frequency analysis for the Hunter River gauge at Raymond Terrace was updated and the new AR&R 2013 IFD's were compared against the AR&R 1987 IFD's. Flood modelling was undertaken in XP-RAFTS and TUFLOW.

- Remediation of Acid Sulphate Soils in the Tilligerry Creek Catchment (NSW DPI, Report to the NSW Environmental Trust, 2011). The report investigated the water quality in the main drainage system of Anna Bay and the role that the floodgates play in contributing to the observed water quality. The report noted that the floodgates were found to be jammed open with debris when the logger was retrieved on two separate occasions and most likely had been for some time. The siltation of the channels downstream of the floodgates was also raised as an issue, with the tidal prism significantly attenuated at the flood gates. As part of this study a MIKE-21 hydrodynamic model was developed for the Anna Bay catchment by the Water Research Laboratory (WRL).

- Acid Sulphate Soil Assessments in the Anna Bay Catchment (NSW DPI, Report to the Hunter-Central Rivers CMA, 2008). Data collected as part of this study includes water levels (tidal and water level hydrographs) upstream and downstream of floodgates at Nelson Bay Road in August-September 2008, showing response to 200mm rainfall over a 4-day period. Other data collected as part of this study includes surveyed drain cross sections, flood gates, culverts and piezometer data and these have been reviewed in Section 3.4 and 3.5.

- Port Stephens Design Flood Levels – Climate Change Review (WMAwater 2010). This study assessed the impact of climate change on flood levels resulting from elevated ocean levels, wave run-up and major catchment flooding in Karuah and Myall Rivers for the 5% AEP, 1% AEP and an extreme event. Design peak water levels were determined by computer modelling undertaken by MHL in 1998 (see below). Increasing rainfall intensity was found to raise water levels by less than 0.1m.

- Port Stephens Flood Study (MHL 1998). Outlines design water levels in Port Stephens for the 5%, 2% and 1% AEP and extreme events based on storm surge, wave run-up and major catchment flooding in Karuah and Myall Rivers.

- Tilligerry Creek Flood Study (Lawson and Treloar 1998). This study utilised a WBNM hydrologic model and a MIKE11 hydraulic model to simulate flooding in Tilligerry Creek. The report states that groundwater bore records in the 1990 flood indicate that the water table is near the surface, hence a 0mm initial loss and 2.5mm continuing loss was adopted in the hydrologic model for the 1990 calibration event and also for the design events. It is likely that the magnitude of the 1990 flood is greater than the 1% AEP flood. The study also involved sensitivity to groundwater impacts, assessed by reducing the infiltration rate and by adding a nominal $10m^3/s$ baseflow to the creek.

- Anna Bay Catchment Drainage/Flood Study Masterplan (Sinclair Knight Merz, 1995). SKM prepared this study for Port Stephens Council in December 1995. Hydrologic and hydraulic investigations were carried out to estimate design flood levels on the floodplain for the 10 year and 100 year Average Recurrence Interval (ARI) events. Hydrologic investigations were carried out using XP-RAFTS. Hydraulic investigations were undertaken using the HEC-2 program. Topography of the floodplain represented in the HEC-2 model for Anna Bay Main Drain was obtained from 1:4000 orthophoto mapping and channel topography was obtained from plans provided by Port Stephens Council. Port Stephens Council also supplied information on waterway crossings. The HEC-2 model was run for existing conditions, and two future conditions involving development within the catchment and drainage improvements.

- Anna Bay Catchment Drainage Flood Study – Groundwater and Geotechnical Study (Coffey Partners, 1993). Details the groundwater and geotechnical/geophysical investigations undertaken in Anna Bay for the Sinclair Knight Merz (1995) flood study, described above.

- Proposed Golf Course Estate Development Between Frost Road and Gan Gan Road, Anna Bay – Flood Study Report (Sinclair Knight Merz, 2004). This study was undertaken for MIRVAC Homes to assess the impacts of a proposed resort and golf course estate development on flooding in Anna Bay. The assessment was based on updates to hydrologic and hydraulic modelling of the Anna Bay catchment, originally undertaken by SKM for Port Stephens Council in 1995, using more recent topographic survey data. The hydraulic modelling was updated to a MIKE-11 hydrodynamic model.

3.4 Spatial and Design Data

3.4.1 Topographic Data

Topographic data across the study area consists of LiDAR data captured by NSW Land and Property Information (LPI). The dataset has a vertical accuracy of 0.15m (one standard deviation) and was validated using ground survey collected for this study. The 1m digital elevation model (DEM) grid has been utilised for this study. The Port Stephens tiles were captured in 2012 and the Raymond Terrace tiles were captured in 2013. The data tiles were merged together by Jacobs to form a continuous DEM across the study area and surrounds. Comparison to surveyed channel cross sections indicates that the DEM is not accurate in areas of standing water or dense vegetation.

A DEM based on LiDAR and photogrammetry data has also been provided with the Williamtown/Salt Ash FRMS&P TUFLOW model at 5m resolution. It covers the Tilligerry Creek floodplain, including the tidal creek bathymetry, between Wiliamtown and Anna Bay. It does not include some of the higher ground adjacent to the floodplain and hence does not cover the entire current study area. There appear to be erroneous water depths in the mangrove channel section and the embayment section of Tilligerry Creek.

Comparison of the LPI LiDAR DEM to the Williamtown/Salt Ash FRMS&P TUFLOW DEM indicated inconsistencies of +/- 0.3m to over +/-1m in elevations, likely due to the different methods used in deriving the data. Since the FRMS&P TUFLOW DEM does not cover the entire study area, the LPI LiDAR has been adopted in this study to ensure consistency in the topographic data in the hydraulic modelling. The LPI LiDAR was validated against surveyed points on roads across the study area and observed to be typically +/-0.15m which is the reported accuracy of the LiDAR.

Topographic data was also provided for the Roads and Maritime Services (RMS) Nelson Bay Road Upgrade – Bobs Farm to Anna Bay (2015). This data comprises of the earthworks as part of the concept design. Additionally, concept design elevation data has been provided by Port Stephens Council for the Lemon Tree Passage Road upgrade.

3.4.2 Aerial Photography

Aerial imagery was provided by Council and covers the entire study area. The photography was captured in 2012 by Vekta.

3.4.3 Stormwater and Drainage Infrastructure

The stormwater infrastructure (pits and pipes) was provided as points and polylines in a GIS layer by Council. The asset ID was provided in this layer. A spreadsheet indicating the details of each asset was also provided by Council. The data is reasonably complete, although some assets have missing information or cannot be located in the GIS layer. Conduit dimensions are provided, however, Council has indicated that some dimensions indicated in the database appear to be erroneous and have recommended field verification of key conduits. Invert level and surface level data has not been provided.

Concept design of the Nelson Bay Road Upgrade drainage structures were provided by RMS. RMS have indicated that minor design changes have been made in the as-constructed works but are unlikely to have an effect on the current flood study. Details on Lemon Tree Passage Road Upgrade drainage works have also been provided by Council.

Details of cross-drainage structures in the Tilligerry Creek floodplain are provided in the Williamtown/Salt Ash FRMS&P TUFLOW model, including levels and dimensions. It is assumed that these structure details are accurate and do not require survey.

Floodgate locations along Tilligerry Creek were provided by NSW Department of Primary Industries (DPI) as georeferenced points. A selection of culverts along the open channel drains were also surveyed by NSW DPI. As part of the Nelson Bay Road Upgrade (RMS 2015), the concept design of the pavement and cross drainage works was obtained as drawings indicating structure sizes, locations and invert levels.

Limited details on drainage pumping stations at Clark Street catchment and Salt Ash have been provided by Council. Design drawings and pump rating curves have been requested.

3.4.4 Surveyed Cross Sections from Previous Studies

As part of the “Acid Sulphate Soil Assessments in the Anna Bay Catchment” (DPI 2008) study, cross sections of the Main Drain and Back Drain in the Anna Bay area (Figure 3-5) were surveyed. There were 16 cross sections surveyed in the Main Drain, down to the floodgates and 8 surveyed in the Back Drain (to the confluence with

Main Drain). Further cross sections were surveyed as part of the 2011 'Remediation of Acid Sulphate Soils in the Tilligerry Creek Catchment (DPI 2011) study. Cross sections were surveyed in Fern Tree Drain (12) and the unnamed/Bennetts Drain (7). The invert levels of minor side drains were surveyed at the point where the join the main drains. Some points on the levee in the downstream reaches of the Main Drain were also surveyed. Refer to Figure 3-5 for the drains surveyed by DPI. The surveyed cross sections were compared to LiDAR, and confirmed that the LiDAR elevations in the drains are generally inaccurate, due to the presence of in-channel vegetation and standing water preventing the detection of the true ground surface levels.

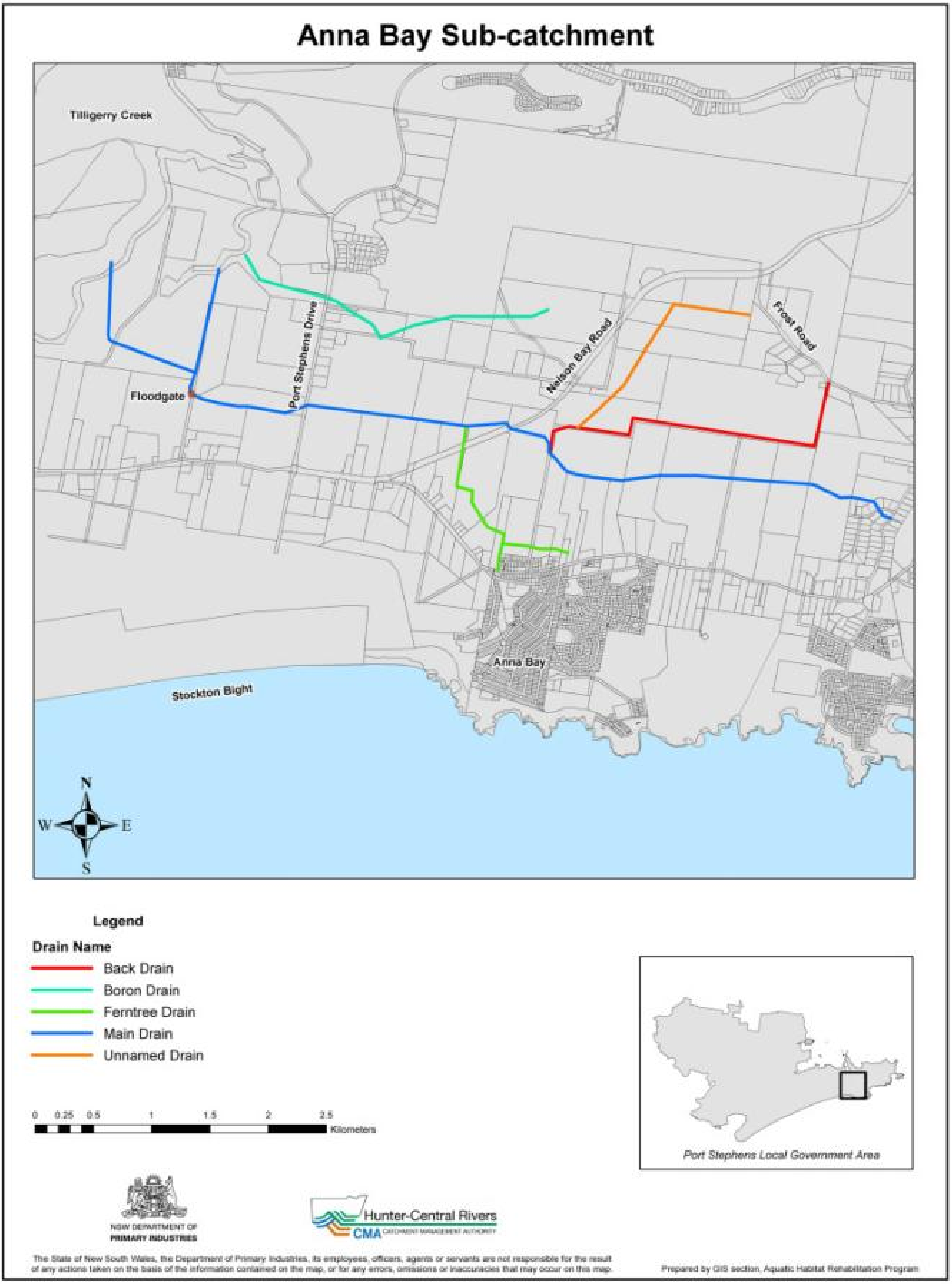
A bathymetric survey of the wider embayment section of Tilligerry Creek was undertaken by OEH in 1995. A number of cross sections were surveyed across the creek from Salt Ash to Lemon Tree Passage.

3.4.5 Additional GIS data

Additional GIS layers obtained include:

- Roads
- Cadastre
- LEP
- Land use
- Local suburb boundaries
- Drainage Union boundary

Figure 3-5 Anna Bay sub-catchment drainage system. *Source: DPI 2008*.



3.5 Recorded Data

3.5.1 Rainfall Data

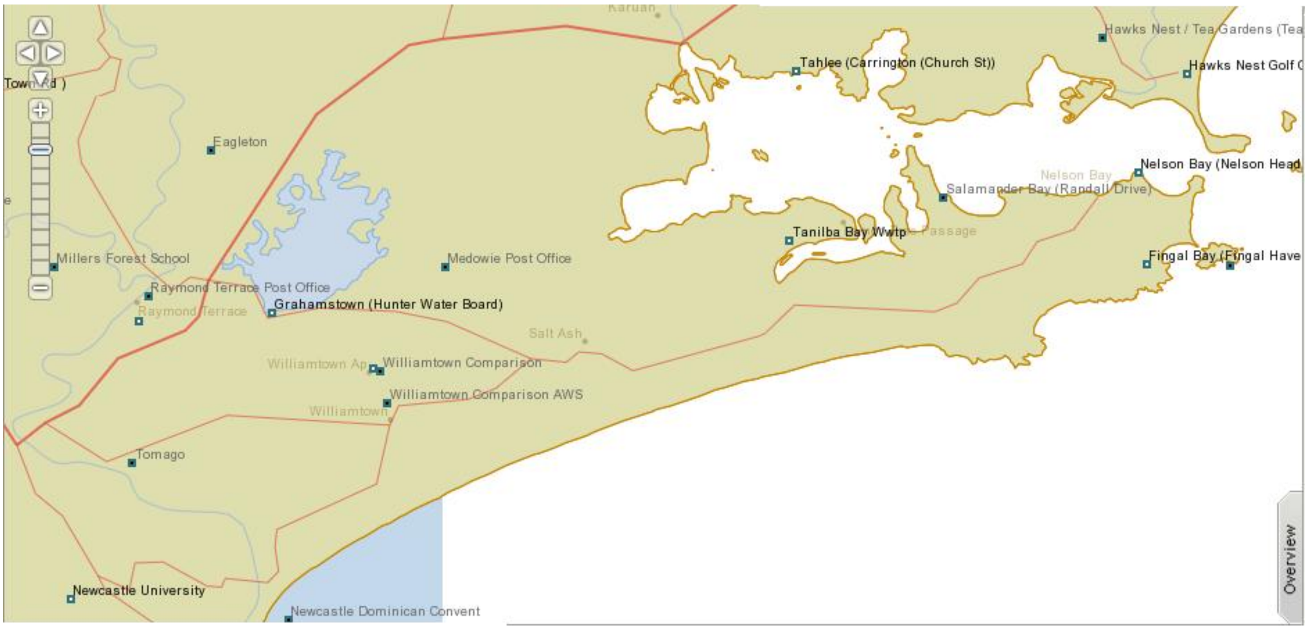
3.5.1.1 Daily Rainfall

Historic daily rainfall data was obtained from the Bureau of Meteorology's website. Data from five sites in the vicinity of Anna Bay was obtained and is summarised in below: Site locations for the selected gauges and other regional gauges are shown on Figure 3-6.

Table 3-2 Daily Rainfall Data

Gauge Number	Gauge Name	Start Date	End Date	Length of record (years)	Completeness (%)
061054	Nelson Bay (Nelson Head)	19/5/1881	26/11/2015	134.6	85.6
061411	Fingal Bay (Fingal Haven)	1/09/2007	31/10/2015	8.2	96.7
061303	Salamander Bay (Randall Drive)	21/05/1971	31/07/2007	36.2	98.8
061395	Tanilba Bay WWTP	1/01/2002	30/10/2015	13.8	85.0
061078	Williamtown RAAF	1/09/1942	26/11/2015	73.3	84.5

Figure 3-6 BoM Rainfall Gauges in Port Stephens region (source: BoM website. http://www.bom.gov.au/climate/data/index.shtml?bookmark=136)



The 1, 2, 3, 4 and 5 day rainfall totals were calculated for each of these gauges to determine the largest rainfall events for each gauge, refer to Table 3-3. Given that the duration of regional flood events in the study area can be in the order of weeks (Lawson & Treloar, 1998) due to runoff ponding in flat terrain and poor drainage conditions, these multiple-day rainfall totals are indicative of dates when significant flooding has occurred in the study area. Note that overland flooding in local catchments may be dictated by sub-daily rainfall events.

Note that the Fingal Bay and Tanilba Bay gauges have relatively short lengths of record (less than 15 years) and hence may not have recorded all significant rainfall events in recent history, while the Nelson Bay and Williamtown gauges have long lengths of record (more than 70 years). The Salamander Bay gauge has a moderately long record (36 years).

More detailed analysis of the historic rainfall data is provided in Appendix A, which indicates that the April 2015, and to a lesser extent, the January 2016 storms, generally rank in the top five storm events at the gauges which were open during these storms. The February 1990 storm appears to supersede the April 2015 and January 2016 storms at the southern end of the study area (i.e. around Williamtown), but not to the north of the study area (i.e. Nelson Bay). The remaining gauges at Tanilba Bay, Fingal Bay and Salamander Bay did not record the 1990 storm and the 2015 and 2016 storms and hence a comparison of the recent storms (2015 and 2016) to the 1990 event cannot be made.

The June 2007 storm event (the “Pasha Bulker storm”) is another recent significant storm event in the region. Rainfall from this system caused major flooding in the Hunter River and on the NSW Central Coast, to the south of the study area. However, the recorded rainfall depths from the June 2007 storm were exceeded in the study area by the rainfall depths from other historic storm events including the February 1990, April 2015 and January 2016 storms.

Table 3-3 Aggregated rainfall depths of historic storm events at selected gauges

Gauge Name and Number	Event Date and Aggregated Rainfall (mm)				
	1 day	2 day	3 day	4 day	5 day
Nelson Bay (Nelson Head) 061054	9/02/1889 258mm	21/04/2015 308mm	21/04/2015 331mm	16/04/1946 362mm	15/4/1946 393mm
Fingal Bay (Fingal Haven) 061411	22/04/2015 145mm	21/04/2015 284mm	20/04/2015 301mm	19/04/2015 307mm	19/04/2015 313mm
Salamander Bay (Randall Drive) 061303	6/02/1981 236mm	5/02/1981 265mm	2/02/1990 297mm	1/02/1990 302mm	6/05/2001 328mm
Tanilba Bay WWTP 061395	21/04/2015 209mm	5/01/2016 245mm	21/04/2015 345mm	20/04/2015 379mm	19/04/2015 379mm
Williamtown RAAF 061078	3/02/1990 276mm	3/02/1990 451mm	2/02/1990 474mm	2/02/1990 485mm	1/02/1990 488mm

3.5.1.2 Pluviograph Data

A data search revealed that closest pluvio gauge to the study area is located at Williamtown RAAF base (Station 061078) operated by BOM. There are no pluvio gauges located within the study area. Data from this station has been obtained for the selected storm events for the model calibration and verification, refer to Section 7.2. The data includes rainfall depths recorded at 1 minute intervals for the selected historic storm events.

3.5.2 Water Level Data

Water level data was collected at a number of locations in the Anna Bay open channel drains for 8 months in 2009 and 8 months in 2010 as part of the DPI acid sulphate soils study..

No streamflow data is available for any of the local creeks/drains in the Anna Bay area.

3.5.3 Groundwater Data

Groundwater piezometers exist in a number of locations across the study area. Hunter Water Corporation manages a network of 33 bores in north Stockton, with bi-monthly data available from November 1994 to June 2014. Data is available for the period June 1979 to November 1994 on a more sporadic basis.

There are an additional 76 bores throughout the Salt Ash / Bobs Farm area where monthly data is available from April 1976 to current. The data supplied includes the coordinates of the site and recorded water levels.

Groundwater level data was collected as part of the DPI acid sulphate soils study at 273 Gan Gan Rd, Anna Bay. The data was collected over four months from November 2008 to March 2009.

3.5.4 Tide Data

Tidal water level data is collected by Manly Hydraulics Laboratory (MHL) at Mallabula Point in Port Stephens, near the mouth of Tilligerry Creek. This data has been obtained for model calibration for the selected calibration/verification events.

3.5.5 Stormwater Drainage Pumping Data

Council has advised that recorded data of stormwater pumping volumes is not available for the Clark Street catchment pumping station or other pumping stations operated by Council. Design drawings of the Clark Street pump station, indicating pump model and various system dimensions and levels, were provided.

3.6 Modelling Data

3.6.1 Anna Bay XP-RAFTS and MIKE-11 Models

As part of the ‘Proposed Golf Course Estate Development Between Frost Road and Gan Gan Road, Anna Bay – Flood Study Report’ (SKM 2004), an XP-RAFTS hydrologic model and MIKE-11 hydraulic model was modified from the ‘Anna Bay Catchment Drainage/Flood Study Masterplan’, developed in 1995. These models are available to Jacobs. Details regarding these models can be found in the report. The hydrologic model can be updated for this study and used to determine catchment runoff flows for the Anna Bay area. Cross sections from the MIKE-11 model may be useful to compare with the available LiDAR data.

3.6.2 Williamtown/Salt Ash XP-RAFTS and TUFLOW Models

As part of the Willimatown/Salt Ash Flood Study Review (BMT WBM, 2011), an XP-RAFTS hydrologic model and TUFLOW hydraulic model of the Williamtown/Salt Ash area were updated and are available to Jacobs.

These models were subsequently reviewed and updated as part of the Williamtown – Salt Ash Floodplain Risk Management Study & Plan (FRMS&P) (BMT WBM, 2015). The models have been calibrated to the 1955 and 1990 flood events. The FRMS&P model is the most up to date model of the Lower Hunter River and Tilligerry Creek floodplains. The model includes the following extents:

- Lower Hunter River: The Hunter River downstream of Barties Creek at Osterley and the Williams River from upstream of Raymond Terrace to the outlet to the Tasman Sea, including floodplain areas in Hexham, Raymond Terrace, Tomago and Fullerton Cove. Model inflows are input in the Hunter River and Williams River at the upstream boundaries and local catchment inflows throughout the model domain. A tidal downstream boundary is represented at the Hunter River outlet.

- Tilligerry Creek floodplain: including floodplain areas in Fullerton Cove, Williamtown, Salt Ash and up to Anna Bay and Lemon Tree Passage. This area accepts overflows from the Hunter River at Fullerton Cove in large floods, which then flow through the floodplain and into Tilligerry Creek, discharging into Port Stephens. A tidal water level boundary is represented at the Tilligerry Creek outlet. Additional inflows are represented in the Tilligerry Creek floodplain upstream of the Nelson Bay Road/Lemon Tree Passage Road intersection. The area downstream of this location is outside the FRMS&P study area and is not modelled in detail

3.6.3 Groundwater Modelling of Tomago Sandbeds

Groundwater aquifer modelling has been undertaken by Hunter Water for the Tomago Aquifer, on the northern side of the Tilligerry Creek floodplain (Reference: Hancock, C. 2011. Groundwater Model of Tomago Aquifer. Prepared by Hunter Water with the assistance of SKM/Jacobs. Final Report, October 2011).

Results from the modelling were reviewed to determine if infiltrated rainfall following large storm events are likely to return to the surface in sufficient volumes to contribute to the flooding problem at some time after the storm event. This is a potential issue in the study area due to the sandy soils and high infiltration rates in certain locations including the extensive sand hill areas. The raised water table in the sand hill areas following high rainfall events would at some stage discharge to the surface and potentially contribute to flooding. Additionally, the extended duration for the floodplain to drain during a flood event may provide a sufficiently long time for groundwater-to-surface water flows to contribute to flooding.

The response of the aquifer to the historic April 2015 storm event, which caused significant flooding in the Williamtown area, has been analysed. The groundwater-to-surface water flux was estimated as being up to 180ML/day (monthly averaged) following initial infiltration of the rainfall and then discharge to the drains and Tilligerry Creek. This discharge includes that only from the Tomago Aquifer on the northern side of the Tilligerry Creek floodplain. Advice from the groundwater modelling project team was that this value could be doubled to account for groundwater discharge from the North Stockton Aquifer on the southern side of the floodplain.

There is some uncertainty in translating the timing of this groundwater discharge to floodwater for the purposes of this flood study, relating to the time-step intervals in the groundwater model of one month and converting the monthly-averaged fluxes to daily inflows, in addition to uncertainty of the timing of peak groundwater discharge, which may vary by up to one month. Converting the groundwater model from a monthly to a daily timestep requires significant effort and is not considered feasible or within the scope of this project.

As discussed in Section 3.3, sensitivity testing of the effect of groundwater inflows was assessed in the Tilligerry Creek Flood Study (Lawson and Treloar 1998). A nominal groundwater inflow rate of $10m^3/s$ was input into the MIKE11 model to coincide with the February 1990 calibration flood, in addition to increased runoff due to nil infiltration rates. Note that this assumed baseflow is 5x that of the modelled groundwater inflow from the Tomago Aquifer following the April 2015 event (180ML/day is equivalent to $2m^3/s$), and 2.5x the total groundwater inflow if the North Stockton Aquifer baseflow is also considered. The input of the baseflow resulted in a 0.04m increase in peak flood levels for the February 1990 flood event, suggesting that flood levels are relatively insensitive to the groundwater inflows.

Given the difficulties discussed above, rather than allow for high rainfall losses and infiltration and a subsequent groundwater inflow in the hydrologic and hydraulic modelling, it is recommended to adopt more conventional rainfall loss parameter values in the modelling to ensure that excessive rainfall is not lost from the system. This is a robust approach which has been adopted in flood studies in adjacent catchments in Medowie and Williamtown – Salt Ash for Council.

3.7 Hydraulic Structures and Topographic Survey

Survey of selected hydraulic structures and open drains was conducted in August and September 2016. The features surveyed were selected based on the review of available data and gaps analysis. Given the large study area only key features were selected for survey. The details of the remaining non-critical structures were estimated based on Council's asset data base and available topographic data.

Figure 3-7 Tomago Aquifer Groundwater Model Extent

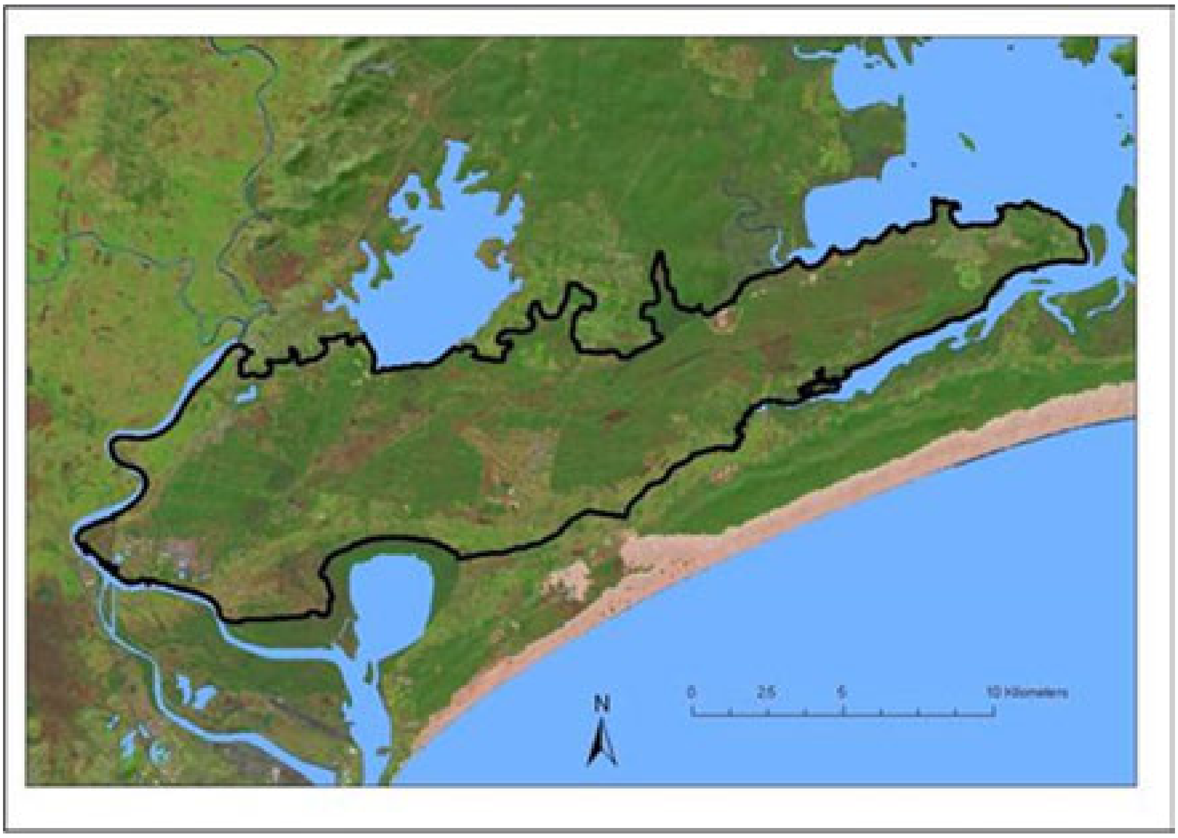
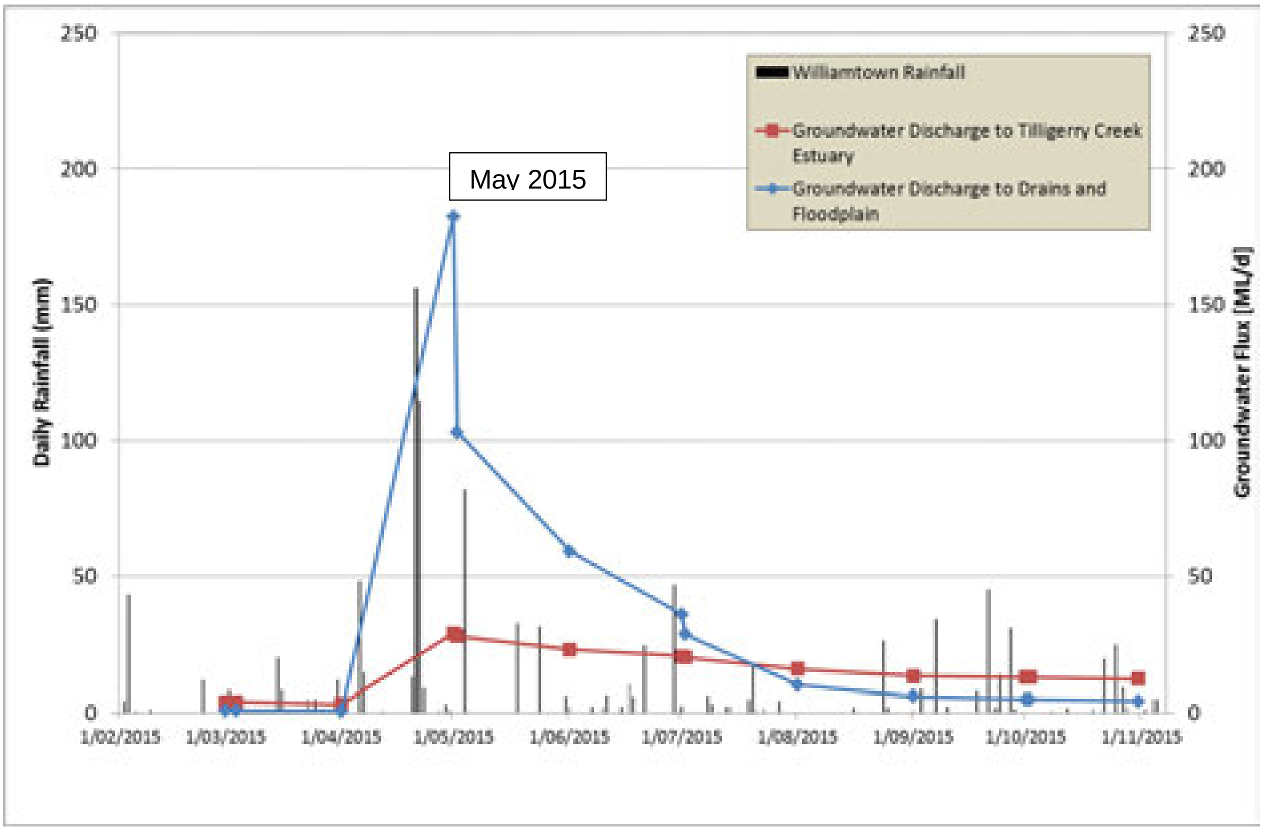


Figure 3-8 Modelled groundwater-surface water flux from Tomago Aquifer for April 2015 storm event



4. Community Consultation

4.1 Website and social media

Messages and web content were prepared and posted on Council's floodplain risk management website on their home page, as well as posted on social media to introduce the flood study at its inception, and provide updates at key milestones during the study.

4.2 Community questionnaire

A community questionnaire was prepared by Jacobs for distribution to the community. This is an important aspect of the flood study process and aims to gather information from locals regarding historic flooding including flood behaviour and flood levels which may help in the calibration of the flood models. The questionnaire was mailed to residents in the study area and be made available online. A copy of the questionnaire can be found in Appendix B.

The responses to the questionnaire have been analysed to identify flood marks for historic flood events and other flood intelligence for model calibration. Numerous responses did identify flooding as having occurred during the recent April 2015 (72 responses) and the January 2016 (54 responses) flood events. Fourteen (14) respondents with observations from these flood events were short-listed for contact by telephone for further information and potentially organise for on-site interviews and survey of flood marks on their property. Eventually, five respondents could be contacted by phone, of which two provided sufficient further information by phone and the remaining three respondents were interviewed on site. Two flood marks were surveyed, both in the Salt Ash area. The information from all the questionnaire responses and the follow-up flood data were used in the model calibration and verification, refer to Section 7.

Only few respondents reported observing the significant flooding in 1990 (two) and 1955 (one) events, which may be expected due to the time elapsed since these events.

Other issues of concern identified in the responses included the maintenance of open drains and flood gates, flood gates becoming blocked by debris and causing them not to operate properly, development pressures and impacts on flooding, inundation of foreshore areas during king tides and generally poor drainage conditions.

A summary of the questionnaire responses is contained in Appendix B.

4.3 Anna Bay Drainage Union

A meeting with the Anna Bay Drainage Union was held on 12 November 2015. The Drainage Union was formed in 1910 to manage and maintain the Anna Bay drainage network, which was originally constructed in 1897 to improve drainage in the area and hence improve soils (i.e. reduce waterlogging) for agriculture. The Drainage Union is responsible for managing and maintaining the drainage network, and in the past has commissioned the installation and upgrades of the floodgates.

The Drainage Union is staffed by long-standing members of the local community, and hence were consulted during the meeting for information on previous flooding events, operation of the drainage infrastructure, maintenance regimes of the drainage network and views on the current and future management of the drainage network.

4.4 Floodplain Advisory Panel

The Draft Report for this study was presented to the Port Stephens Floodplain Advisory Panel on 13 June 2017, including key stakeholders and community representatives. Feedback from this meeting was incorporated into the Final Draft Report, and approval was given to subsequently place the updated report on public exhibition for review and feedback from the general public and stakeholders.

4.5 Public Exhibition and Presentation

The Final Draft Report was placed on public exhibition in October and November 2017, with a public information session held during the exhibition period on 26 October 2017 at Birubi Point Community Hall. Members of the community were invited to make written submissions on the study. The submissions and the responses formulated by Jacobs and Council are presented in Appendix B.

5. Hydrologic Modelling

5.1 Model Set Up

5.1.1 Catchment Areas

The hydrologic modelling from previous studies does not fully cover the current study area, or are considered too coarse to suit the purposes of the study. Hence, model sub-catchments have been defined at sufficient detail to cover the study area.

Sub-catchments for the XP-RAFTS model were delineated based on the LiDAR topographic data and with consideration of features including raised road embankments and drainage structures. Sub-catchments in urbanised areas were delineated to fit with the stormwater drainage network. The sub-catchment delineation is shown in Figure 5-1.

5.1.2 Pervious and Impervious Fractions

Pervious and impervious fractions in each sub-catchment in design conditions were estimated based on the maximum permissible level of development under Council's existing LEP 2013. In some areas, the level of approved development under the LEP is greater than the existing level of development. For each sub-catchment, the major land use zonings were identified and the area of each land use estimated, and subsequently the total impervious area and sub-catchment impervious % calculated. The impervious fractions used for different land use types are summarised in Table 5-1. Areas of standing water and swampland were identified from the aerial imagery. The land use adopted for the design floods is shown on Figure 5-2.

Note that for the model calibration, the hydrologic modelling represented the contemporary land use at the time of the model calibration events in 2015 and 2016.

5.1.3 Surface Roughness (PERN)

Roughness values (referred to as "PERN" in XP-RAFTS) were assigned based on the dominant land use within the sub-catchment. These have been identified and adjusted based on the model calibration and verification.

For pervious areas, the following roughness values have been adopted based on the dominant land use in each sub-catchment:

- Urban and residential areas: PERN = 0.025
- Rural and cleared areas: PERN = 0.06
- Natural and forested areas: PERN = 0.1.

Impervious areas were assigned a roughness value of n = 0.015. Lower values reflect a smoother catchment surface which results in a quicker runoff response rate, while higher values reflect a rougher catchment and slower runoff response rate.

Table 5-1 Typical impervious fraction by land use (based on LEP)

Land use	% Impervious	Corresponding LEP zones
Urban residential	60%	R2, R3
Urban high impervious	75%	Selected areas for caravan parks and holiday parks. Mainly RE1, RE2 an RU2. These selected areas were observed on aerial photos to be highly paved (e.g. dense spacing of cabins and high portion of paved access roads and car park areas).
Residential large lot	40%	R5
Residential environmental living	30%	E4
Rural	5%	RU1
Open Space	0% (rural and natural areas) 5% (urban and peri-urban areas)	E1, E2, E3, E4
Commercial	100%	B1, B2
Industrial	90%	B5, IN2, IN5
Road Corridor 1	50%	N/A
Road Corridor 2	30%	N/A
Water and swamp	100%	N/A

Legend

- Study Area
- Anna Bay - Tilligerry Creek XP-RAFTS Sub-Catchments
- Previous Williamtown - Salt Ash FRMS Sub-Catchments (WBM, 2015)

0 1 2 3 4 5 Kilometres

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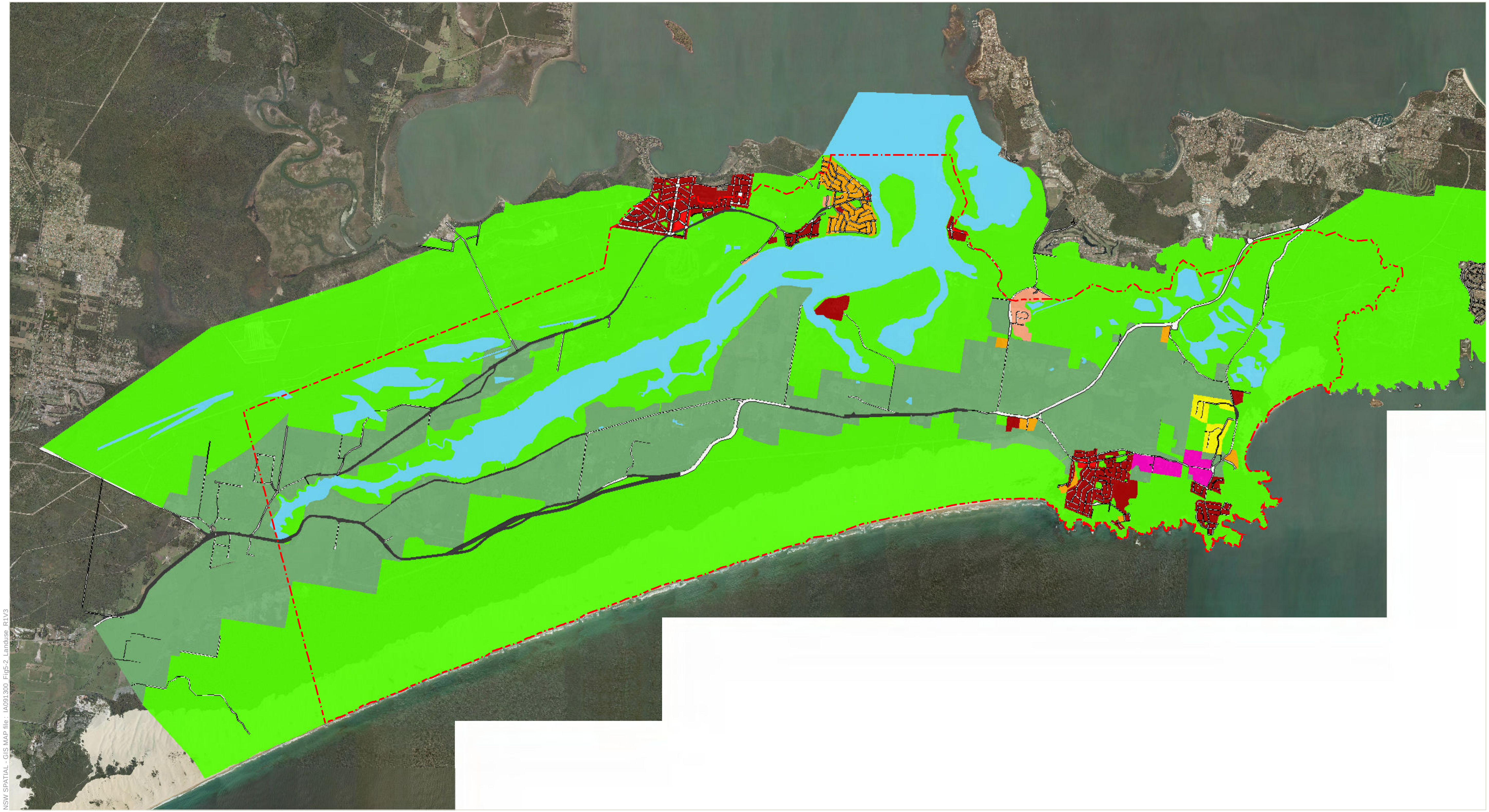
Figure 5-1 XP-RAFTS Sub-Catchments



Legend

Land Use

- Urban residential
- Urban High Impervious
- Residential large lot
- Residential environmental living
- Rural
- Open Space
- Commercial
- Industrial
- Road 1
- Road 2
- Water and swamp
- Study Area

0 1 2 3 4 5 Kilometres

N

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Figure 5-2 Land Use for Hydrologic Modelling

5.1.4 Catchment Slopes

Catchment slopes were estimated for each sub-catchment based on the estimated flow path length and the difference in elevation between the highest and lowest points in the catchment. The height difference between these two points was divided by the flow path length.

5.1.5 Channel Routing

The local sub-catchment runoff hydrographs will be input and routed in the subsequent TUFLOW hydraulic model. Hence, channel routing and lagging was not represented in the XP-RAFTS model.

5.2 Soil Type and Rainfall Losses

An initial and continuing loss model is utilised in the XP-RAFTS model. The rainfall losses are varied depending on the soil type in each sub-catchment. A groundwater and geotechnical study (Coffey Partners, 1993) was undertaken for the Anna Bay Catchment Drainage/Flood Study Masterplan (Sinclair Knight Merz, 1995) which identified two main soil types, including

1) Predominantly clayey soils composed of organic clays. These extend across the flat, low-lying parts of the catchment, typically below 2m AHD elevation; and
2) Predominantly sandy soils, in the remaining parts of the catchment. These included the soils in the sand dune land formations in addition to the residual soils overlying rocky outcrop landscapes.

The survey was limited to the Anna Bay catchment area. Areas of the clayey soil types were estimated for the remainder of the study area based on the presence of flat, low relief areas below 2m AHD, particularly those areas adjoining Tilligerry Creek. Remaining areas are assumed to be predominantly sandy soils. The spatial distribution of the clayey soils derived using this approach is consistent with the broad-scale Australian soil landscape mapping. Visual field observations broadly validate the assumed soil distributions.

Further hydrologic assessment during the model calibration and verification phase indicated that a third soil type needs to be defined in the hydrologic modelling to separately represent the sand dunes present at the rear of the ocean beaches including Stockton Beach, Birubi Beach and One Mile Beach. These formations consist of Aeolian sand with elevations from 3m AHD to 20m AHD. It is necessary to represent very high continuing rainfall losses in these areas to match resident observations that no flooding occurs in these areas. Initial modelling indicated runoff from these areas pools in trapped low points between the dunes to significant depths, which is contrast with the local observations.

In summary, the following soil types have been identified for the hydrologic modelling based on guidance from the calibration process, with different rainfall infiltration and runoff generation capacity:

- Predominantly clayey soils, located in low-lying (< 2m AHD) areas. Low infiltration capacity, high runoff generation.
- Sand dune areas consisting of front- and back-dune areas behind the ocean beaches. Very high infiltration capacity, low runoff generation.
- Predominantly sandy soils consisting of remaining areas of the study area. Moderate infiltration capacity, moderate runoff generation.

The adopted distribution of the above soil types for the hydrologic modelling is indicated on Figure 5-3. The adopted rainfall losses for the calibration and verification events are summarised in Section 7.3.3. The design rainfall losses, specifically the continuing losses, are based on the calibration rainfall losses and are summarised in Section 8.2.5.

Soil mapping has been prepared and compiled by the NSW Government for the entire state, and was released during the course of this study subsequent to the hydrologic modelling. The adopted soil types and distributions were compared to the NSW Government data set and was found to be generally similar in extents and the mapped soil types and properties.

Legend

Soil Type by Sub-Catchment

Predominantly Clayey

Predominantly Sandy

Sand Dunes

Study Area

0 1 2 3 4 5 Kilometres

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Figure 5-3 Hydrologic Modelling Assumed Soil Types

5.3 Validation of Design Discharges

The XP-RAFTS hydrologic modelling has been validated by comparing the local sub-catchment peak runoff rates against estimates for sub-catchments of similar size in the Williamtown – Salt Ash Floodplain Risk Management Study XP-RAFTS modelling (BMT WBM, 2015). The catchments are described as undeveloped, with either vegetated or rural/vegetated land cover. Refer to Table 5-2. The Williamtown – Salt Ash model has previously been calibrated/verified as a part of the flood study for that catchment.

Table 5-2 Hydrologic modelling validation – 1% AEP flow estimates

Catchment name	Area	Slope	XP-RAFTS
Anna Bay – Tilligerry Creek Flood Study			
SA_57	1.34km^2	1.6%	13.2m^3/s
Ext_8	1.41km^2	0.8%	10.4m^3/s
Williamtown – Salt Ash Flood Study			
169	1.37km^2	1%	8.9m^3/s
2008	1.47km^2	1%	9.4m^3/s

The 1% AEP flow estimates in the current modelling are considered to be consistent with that from the Williamtown – Salt Ash model. The differences between the models is attributed to:

- Assumed impervious % for undeveloped areas: the current flood study model conservatively assumes that such areas are 5% impervious, while the Williamtown – Salt Ash model assumes 0% impervious.
- Adopted rainfall IFD: The current model adopts the IFD pattern for Anna Bay, from Council's drainage design guidelines. The previous Williamtown – Salt Ash model adopts the Williamtown IFD, which has rainfall intensities approximately 7% lower than the Anna Bay data.
- Area and vectored slope of the catchments: Sensitivity testing in the XP-RAFTS model confirmed the influence of these parameters.

Based on the model validation the current XP-RAFTS modelling is considered to be reliable.

6. Hydraulic Model Development

6.1 Model Selection

The TUFLOW 1D-2D modelling software package was selected for this flood study. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment as it has:

- Capability in representing complex two-dimensional flow patterns on the floodplain, including flows over the irregular catchment surface, through street networks and around buildings, and flow ponding and storage in low-lying areas.
- Capability in representing culverts, flood gates and stormwater drainage networks, including interflows between the network and floodplain including system surcharges.
- Capability in representing time-varying inflows and water level boundaries, as the timing of Hunter River overflows and downstream tidal water levels may influence peak flooding conditions.
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs.

The existing Williamtown-Salt Ash Floodplain Risk Management Study & Plan (FRMS&P) TUFLOW flood model (BMT WBM, 2015) was utilised as the basis for the flood modelling assessment for the Tilligerry Creek floodplain, and extended to cover the entire study area of this flood study. Refer to Section 6.2 for further details of the model update. The model was developed and run in TUFLOW.2016-03-AB-w64 in double precision.

6.2 Configuration of Hydraulic Model

6.2.1 Extent and Structure

The flooding characteristics and catchment settings vary widely across the study area. As such, three separate TUFLOW models have been developed to estimate flooding in different areas and levels of detail:

- A “regional” TUFLOW model of the entire study area, to assess flooding in the predominantly rural land use setting. The regional model has been developed by extending the existing Williamtown – Salt Ash FRMS&P TUFLOW flood model (BMT WBM, 2015) to ensure consistency for the inflows into the study area from Hunter River overflows from Fullerton Cove. Flooding is assessed at a 20m model grid resolution; and
- Two finer-scale “urban” TUFLOW models of existing urbanised areas in the vicinity of Anna Bay (including Boat Harbour and One Mile) and Lemon Tree Passage (including Tanilba Bay and Mallabula). Flooding is assessed at a 2m grid resolution in order to account for smaller scale flow patterns in these urbanised areas, due to stormwater drainage and flow obstructions due to buildings.

The TUFLOW models are comprised of:

- A 2D domain of the catchment surface reflecting the catchment topography, with varying roughness as dictated by land use.
- Drainage culverts and pipes as 1D features. Flood gates are represented in these features.
- Major open drains are modelled as 1D features.
- A 1D network of pits and pipes representing the stormwater network in the urban models only. The pits have a defined inflow capacity as dictated by their type and size.
- Obstructions to flow are represented as 2D objects, including existing buildings, in the urban models only.

Refer to the following report sections for details on these features. The extents of the TUFLOW models are shown on **Figure 6-1**. Note that aside from extension of the Williamtown-Salt Ash FRMS&P model to cover the current study area, no further modifications to the model have been made. Refer to BMT WBM (2015) for details of the TUFLOW model set up for the Hunter River floodplain, outside this study area.

Legend

- Regional TUFLOW Model (20m grid)
- Urban Area TUFLOW Model (2m grid)
- Study Area
- 1D Channel
- 1D Pipes and Culverts
- 1D Pipes and Culverts with Floodgate

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Figure 6-1 TUFLOW Model Configuration

6.2.2 Model Topography

LiDAR data captured by NSW Land and Property Information (LPI) in 2012 for the Port Stephens area was adopted for the TUFLOW model catchment topography within the study area. This topographic data was preferred over the existing topographic data in the Williamtown-Salt Ash FRMS&P model, as the FRMS&P model terrain does not cover the entire current study area, and LPI dataset provides a continuous terrain data set across the study area. The LiDAR was validated against ground survey collected across the study area for this study and was found to be within +/- 0.15m of the surveyed points, which is considered satisfactory.

The FRMS&P model terrain was retained for areas outside the current study area. Bathymetry of the Tilligerry Creek bed was extracted from the Williamtown-Salt Ash FRMS&P TUFLOW model.

Surface levels for the Nelson Bay Road upgrade and Lemon Tree Passage Road upgrade were defined based on design data from NSW Roads and Maritime Services (RMS) and Council, respectively.

6.2.3 Drainage Culverts and Floodgates

The locations and dimensions of drainage culverts in the models are based on spatial data from Council and from the Nelson Bay Road upgrade and Lemon Tree Passage Road upgrade designs. Invert levels have been surveyed for selected key culverts, and levels derived from the road upgrade designs where available. The remaining culvert levels have been estimated based on information in the Council's assets data base. Floodgates have been represented at the relevant culverts by denoting these culverts as unidirectional flow structures.

6.2.4 Open Drains

Open drains identified in the study area in Council's drainage assets data base have been represented as 1D channel features in TUFLOW. In the Anna Bay area, these include the Main Drain, Back Drain, Fern Tree Drain, Boron Drain and Unnamed Drain (refer to Figure 3-5). Selected key drains are modelled using surveyed cross sections. Remaining drains are modelled with cross sections extracted from the LiDAR. A number of additional drains have been identified from aerial imagery and LiDAR, and have been included in the hydraulic modelling.

6.2.5 Urban Stormwater Network

The stormwater drainage network in the urbanised areas of Anna Bay, Boat Harbour, One Mile, Tanilba Bay, Mallabula and Lemon Tree Passage are represented in the urban area TUFLOW models. These consist of stormwater pits and pipes.

6.2.5.1 Stormwater Pits

The stormwater pits provide a dynamic linkage between the underground drainage network and the 2D TUFLOW model domain, representing the floodplain. Water is able to flow between the drainage network and floodplain, depending on the hydraulic conditions.

The location of the stormwater pits and associated attributes were available from Council in GIS format. Locations of structures were updated based on survey where available. Pit inflow relationships were defined in terms of flow depths versus pit inflow.

TUFLOW automatically calculates hydraulic energy losses in the pits based on the alignment of pipes connected to each pit and the flows in each pipe. The calculations are based on the Engelhund manhole loss approach (*TUFLOW User Manual*, BMT WBM, 2016).

6.2.5.2 Stormwater Conduits

Each of the stormwater pits and pipes in the Council drainage asset data base are modelled in the TUFLOW models. Pipes down to a diameter of 225mm are represented. The conduits are represented as circular pipes or rectangular culverts with dimensions matching those stated in the asset data base. Invert levels and dimensions were verified with survey for selected pipes.

6.2.6 Clark Street Catchment Drainage Pump

The trapped low point at Clark Street, Anna Bay, is pumped out by a submersible pump located in a sump pit at the catchment low point. Water is pumped through a 150mm diameter pipe up the hill along Gan Gan Road to the west and discharges into the stormwater drainage system to the Anna Bay village detention basins.

The manufacturer's technical data for the pump model (Grundfos AP100.100.45) indicates that for the head difference of 5.7m between the pump inlet and the discharge point at the top of the hill the pumping rate is 44L/s. The drainage network in the TUFLOW modelling was schematised to allow this maximum flow to drain from the Clark Street low point. It is noted that this pump rate is insignificant compared to the local catchment inflow rates of $2m^3/s$ in, for example, the 20% AEP event. Hence, peak flood depths would not be sensitive to the assumed pump flow rate.

6.2.7 Building Polygons

Buildings in the urban area models are represented as solid objects in the floodplain as the model grid resolution is sufficiently fine to do so. This means that buildings form impermeable boundaries within the model, and while water can flow around buildings, it cannot flow across their footprint. This is a conservative approach in the modelling to cover the worst-case across all building types. From visual inspection it appears the large majority of houses are slab on ground. Underfloor areas of raised floor houses may also be used as storage space which reduces flood storage and conveyance. A conservative approach as adopted in the modelling is considered prudent.

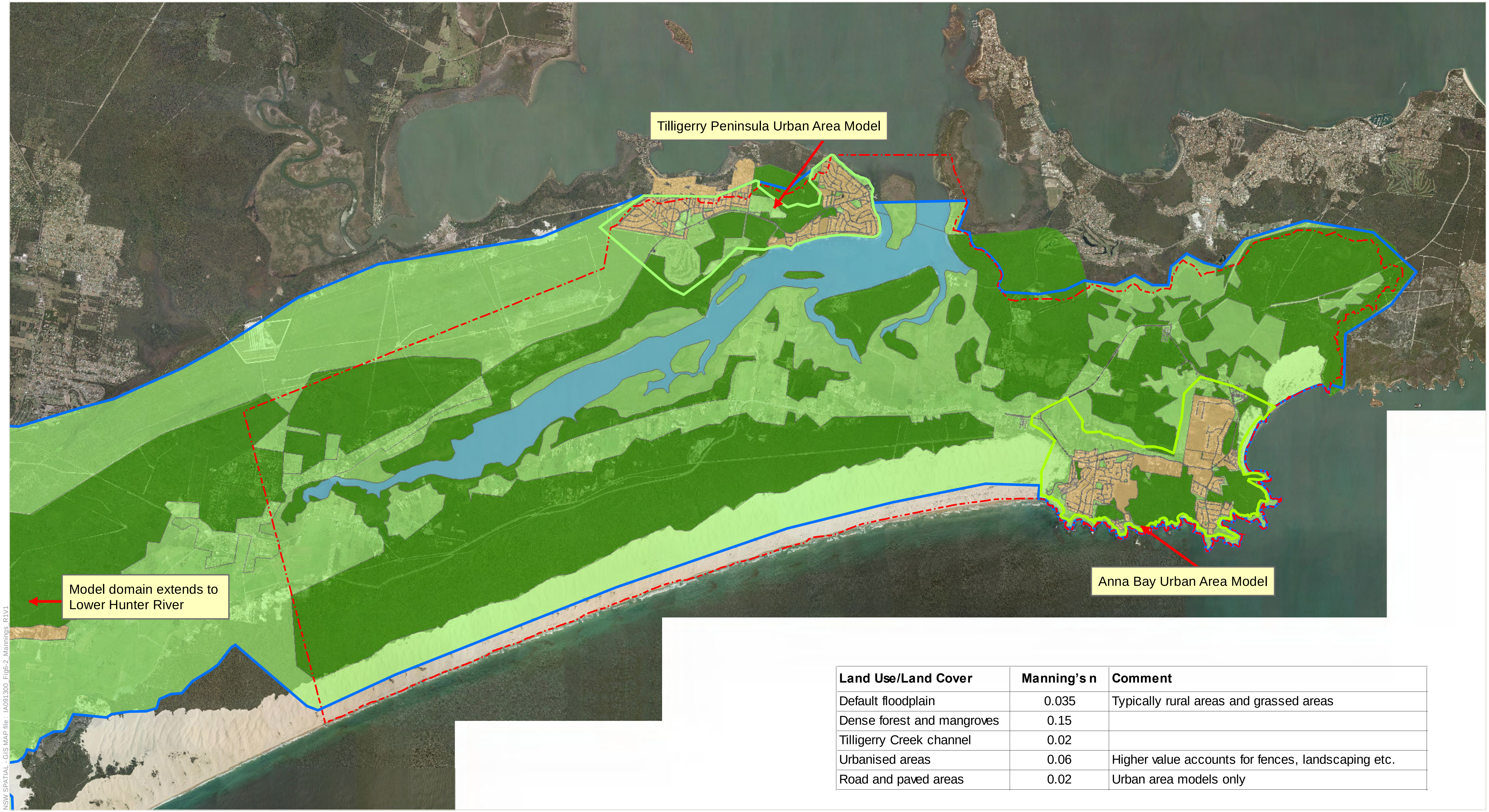
The building polygons were superimposed on the model grid to make model computational cells under the footprints inactive. Buildings are not represented in the regional flood model.

6.2.8 Surface Roughness

The adopted Manning's n hydraulic roughness parameter values are summarised in Table 6-1 and are consistent with those adopted in the Williamtown – Salt Ash FRMS&P TUFLOW modelling. The extent of the adopted Manning's n values are shown on Figure 7-2.

Table 6-1 TUFLOW Model Grid Hydraulic Roughness Values

Land Use/Land Cover	Manning's n	Comment
Default floodplain	0.035	Typically rural areas and grassed areas
Dense forest and mangroves	0.150	
Tilligerry Creek channel	0.020	
Urbanised areas	0.060	Higher value accounts for fences, landscaping etc.
Road and paved areas	0.020	Urban area models only



Land Use/Land Cover	Manning's n	Comment
Default floodplain	0.035	Typically rural areas and grassed areas
Dense forest and mangroves	0.15	
Tilligerry Creek channel	0.02	
Urbanised areas	0.06	Higher value accounts for fences, landscaping etc.
Road and paved areas	0.02	Urban area models only

Legend

Material

- Default Floodplain
- Dense Forest and Mangroves
- Tilligerry Creek Channel
- Urban Areas
- Road and Paved Areas
- Regional TUFLOW Model (20m grid)
- Urban Area TUFLOW Model (2m grid)
- Study Area

0 1 2 3 4 5 Kilometres

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Figure 6-2 TUFLOW Adopted Manning's n Values

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6.3 Boundary Conditions

6.3.1 Model Inflows

Inflows into the regional and urban area TUFLOW models include:

- Hunter River and Williams River inflows, as adopted in the Williamtown – Salt Ash FRMS&P TUFLOW model. These inflows have been derived from previous flood studies on the Hunter River and Williams River for Port Stephens Council and Newcastle City Council. Refer to BMT WBM (2015) for more details.
- Local catchment inflows on the Hunter River floodplain and Tilligerry Creek floodplain upstream of this study area. Refer to Refer to BMT WBM (2015) for more details.
- Local catchment inflows on the Tilligerry Creek floodplain in this study area, estimated in XP-RAFTS hydrologic modelling. Refer to Section 5.

6.3.2 Tailwater Boundaries

Tidal tailwater boundaries are adopted at the Hunter River outlet, the Tilligerry Creek outlet to Port Stephens and along the coastal boundary with the Tasman Sea along Anna Bay, Boat Harbour and One Mile.

In the urban area models, tailwater level hydrographs have been extracted from the regional model and applied as the downstream water level boundaries.

6.3.3 Infiltration of Floodwaters

6.3.3.1 Description

Infiltration of ponded floodwaters has been represented in the TUFLOW models for the sand dunes present at the rear of the ocean beaches including Stockton Beach, Birubi Beach and One Mile Beach. These formations consist of Aeolian sand with elevations from 3m AHD to 20m AHD, with trapped low points situated between individual dunes. The infiltration has been included in the hydraulic modelling calibration, since there were residents responding to the questionnaire reporting that flooding does not occur at their property in these dune areas. Preliminary modelling without the infiltration resulted in floodwaters ponding to depths exceeding 2m in these areas (including the respondent's property) which is inconsistent with the reported drainage behaviour during historic storm events.

This infiltration is a separate process to what is represented by the continuing losses in the hydrologic modelling. The continuing losses represent the initial infiltration of rainfall falling on the catchment surface. When the rainfall rate exceeds the continuing loss rate (in mm/hr) is when runoff is generated, which then flows to the trapped low points and ponds. The separate infiltration process then allows this ponded runoff to percolate into the ground to groundwater. The groundwater can cause inundation of these low lying areas if the water table rises to the surface, however this is a process which is outside the scope of this flood study, which deals primarily with flooding due to surface runoff.

6.3.3.2 Adopted Rates

The areas where infiltration is applied in the hydraulic modelling are indicated on Figure 6-3. An infiltration rate of 300mm/hr has been assumed for most of the indicated sand dune areas. This is within the range of 180 to 360mm/hr quoted for sand in Australian Runoff Quality (Engineers Australia, 2006). It is higher than the maximum infiltration rate of 5.6m/day (i.e. 233mm/hr) estimated from on-site testing at three borehole sites in Anna Bay by Coffey Partners (1993) however these were in low-lying areas (1 – 2m AHD) in the vicinity of Main Drain where the bore logs indicated the presence of sandy clay and clay soils from 0.5m depth below the ground surface. The assumed infiltration rate of 300mm/hr is considered a reasonable estimate for the identified sand dune areas where the trapped low points are at higher elevations and the presence of shallow clayey sands is unlikely.

An infiltration rate of 50mm/hr is assumed for an area in the vicinity of the Clark Street trapped low point in Anna Bay. The lower infiltration rate compared to the sand dune areas has been assumed due to the presence of indurated (semi-bonded) sand and clayey sand in the bore log at this location (Coffey Partners, 1993). The selection of this value is also guided by the permeability testing undertaken by Coffey Partners (1993) at several sites in the vicinity of Anna Bay township. Excerpts from the Coffey Partners (1993) report are included in Appendix D. Permeability was tested at sites locations AB5, AB6 and AB7. These yielded permeability rates of 3 – 5.6m/day (125 – 233mm/hr). The following observations were made:

- The lowest rate was at AB6, although having the cleanest/deepest sandy soil profile (bore and water table plot attached), has the highest water table.
- The sites AB5 and AB7 have 4.3-5.6m/day permeability but the bore logs show significantly more clay mixed into the soil profile, compared to AB4 (Clark Street).
- By comparison, Clark Street (AB4) has deep sand soil profile with some mixed clay, and water table was consistently at deep levels (<3m depth).

Based on the above the 50mm/hr assumed infiltration rate at Clark Street is considered reasonably low/conservative compared to the other test sites, despite having significantly deeper water table and more sandy/less clayey soil profile. This infiltration rate is therefore considered appropriate in the hydraulic model at Clark Street.

A similar infiltration rate could not be justified in Anna Bay township, where shallow depth to bedrock and a high proportion of impervious surfaces would significantly limit the infiltration rate.

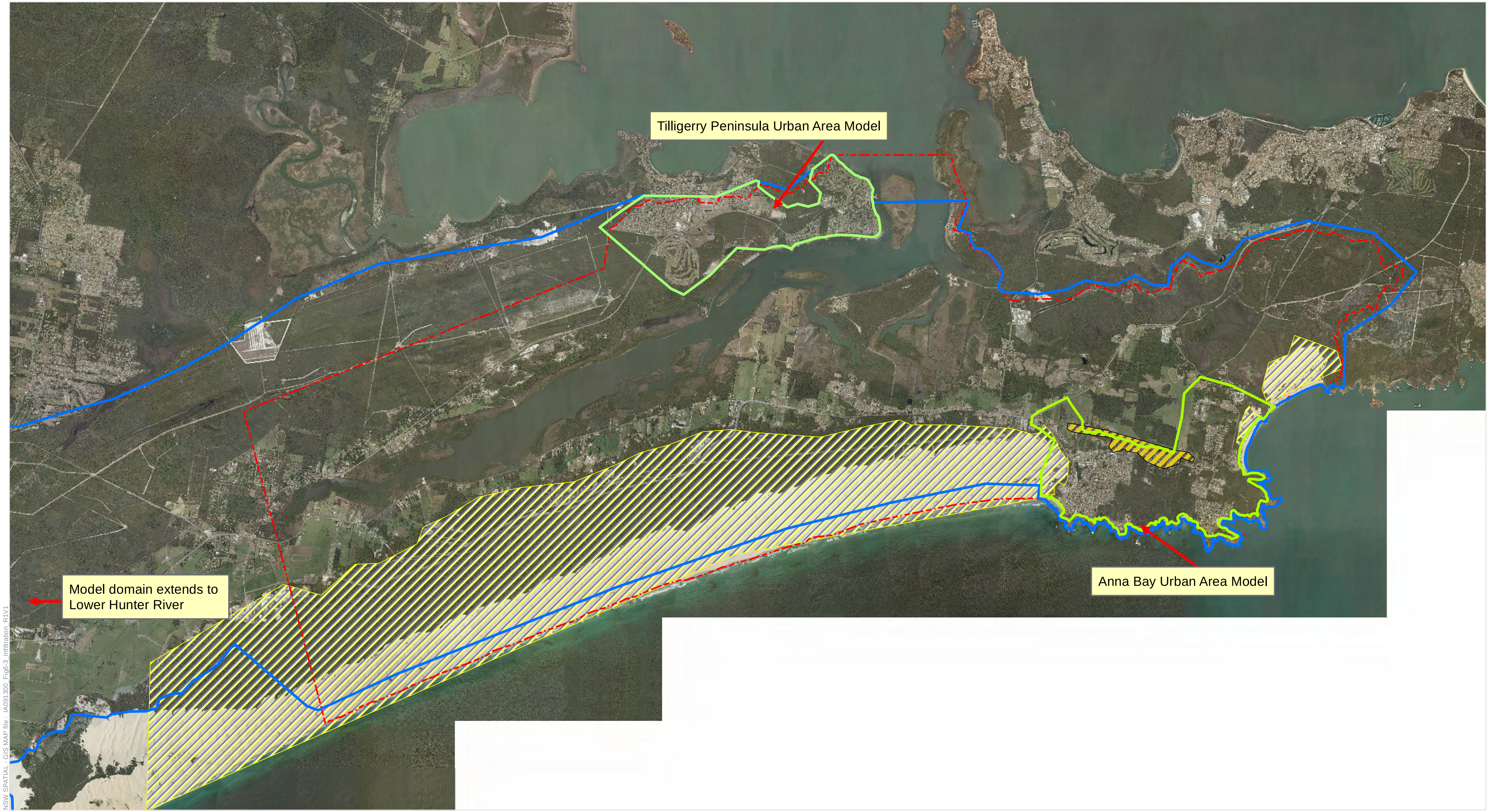
6.3.3.3 Sensitivity Testing

Without the infiltration, depths of flooding of up to 1.5m were estimated in the hydraulic model for the April 2015 storm event, and Gan Gan Road becomes cut-off by flooding up to 0.8m deep. Such magnitude of flooding was not reported and Gan Gan Road was not described as being cut off during this event. With the inclusion of the infiltration rate, the maximum depths of flooding are reduced to 0.8m and Gan Gan Road affect by depths less than 0.15m.

6.3.3.4 Assessed Impact of Groundwater on Infiltration

The likelihood of infiltration rates being suppressed by high groundwater levels was assessed by review of the Hunter Water bi-monthly groundwater logs provided for the North Stockton Aquifer area for the period November 1994 to June 2014. Twenty boreholes are located within the sand dune areas with the average depth to groundwater over the period of record typically being greater than 1.5m. Only at two boreholes does the water table reach the surface or near the surface (<0.1m deep) over the period of record, at the end of June 1998, and these are located in forested sand dune areas at the south-western extremity of the study area. This was in response to a wet mid-April to June, with 600mm of rain falling in this period. The remaining boreholes exhibit minimum depths to groundwater of greater than 0.3m, and typically greater than 0.7m across the boreholes. It is therefore considered unlikely that the sand dune infiltration rates would become impeded and affect flooding, given that a significant amount of rainfall is required in the preceding months, and that the resulting high water table impacts only localised areas in the identified sand dune areas.

The infiltration rates indicated in Figure 6-3 have been adopted in the design case flood modelling.



Legend

Infiltration Area

- Sand Dune (Infiltration Rate 300mm/hr)
- Clark Street Low Point (Infiltration Rate 50mm/hr)
- Regional TUFLOW Model (20m grid)
- Urban Area TUFLOW Model (2m grid)
- Study Area

0 1 2 3 4 5 Kilometres

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Figure 6-3 TUFLOW Model Infiltration Areas

7. Model Calibration and Verification

7.1 Overview

This study has relied mainly on observed depths of flooding during past flood events given by local residents. This anecdotal information is considered indicative as only the general location of the observation is usually given, with the observer unlikely to have measured actual depths and may have estimated the depth of flooding from a distance, and the depths are often rounded up to the nearest 0.1m. However, the reported flood depths are still useful information for validating the general behaviour of flooding predicted by the flood models. These depths were connected to Australian Height Datum (AHD) using the LiDAR data.

Where possible, more accurate flood levels have been obtained by topographic survey of flood marks which have been identified by local residents.

The general approach involved running the hydrologic and hydraulic models in tandem and comparing the flood depths and flow patterns to reported observations. The model configuration and parameter values were adjusted as necessary with the aim of achieving a satisfactory fit to the observations.

Calibration of the Hunter River and parts of the Tilligerry Creek floodplain upstream of this study area was undertaken as a part of the Williamtown – Salt Ash FRMS&P and preceding flood studies, and has not been revisited in this study.

7.2 Selection of Calibration and Verification Events

The model calibration and verification events were selected from a review of the historic rainfall data and residents' questionnaire responses. The April 2015 storm event was selected as the calibration event and the January 2016 storm as the verification event based on availability of rainfall data in the study area, the magnitude of these storm events when compared to others in the rainfall records and the high number of flood observations in the questionnaire responses. These storms are in the top five largest events at the rainfall gauges in the vicinity of the study area, refer to Section 3.5.1.

The April 2015 storm event is the largest on record at the Tanilba Bay (station 061395) and Fingal Bay (station 061411) rainfall gauges. These have been open since January 2002 and September 2007, respectively, and hence did not record the February 1990 storm event, which the Williamtown RAAF gauge (station 061078) indicates was a larger event. Nevertheless, the recent occurrence of the April 2015 and January 2016 storms is beneficial for model calibration and verification as residents' memories of the flooding are likely to be fresher and catchment conditions are unlikely to have changed significantly since the events.

7.3 Adopted Parameter Values for Model Verification

7.3.1 Land Use

The land use for the model calibration and verification was assumed to be the existing land use, which has not significantly changed since the calibration/verification events in April 2015 and January 2016. The existing land use is of a lower level of development in some areas compared to the permissible development in the LEP, which has been adopted in the design case modelling. The impervious areas in the calibration hydrologic modelling were adjusted to reflect these catchment conditions.

7.3.2 Rainfall Data

Pluvio data from the Williamtown RAAF gauge was used to temporally distribute the recorded daily rainfall depths at the Tanilba Bay gauge and Fingal Bay gauge. The daily rainfall data and cumulative sub-daily rainfall depths are shown in Appendix C.

7.3.3 Rainfall Losses

Rainfall losses in the XP-RAFTS model adopted for the model calibration and verification are summarised in Table 7-1. The values have been selected following sensitivity testing of the rainfall losses, in particular the initial losses for sandy soils. Note that the initial losses may appear to be high when compared to the values typically adopted for design event modelling, since the calibration modelling analyses an entire storm event, whereas the design event modelling usually considers the main storm burst within an overall storm. The loss values for impervious and paved areas are also indicated.

Table 7-1 Adopted rainfall losses for model calibration and verification

Soil Type	Initial Loss (mm)	Continuing Loss (mm/hr)
Predominantly clayey	10	2.5
Predominantly sandy	100	6
Sand dunes	100	25
Impervious/paved areas	1	0

The rainfall losses are markedly higher than initially anticipated during the hydrologic modelling phase of the study. The early estimates of up to 10mm initial loss and 4mm/hr continuing loss for sandy soils resulted in excessive runoff volumes being generated and modelled flooding depths exceeding observed depths and flood marks by over 300mm.

The initial losses for the predominantly sandy and sand dune soils are considered rather high when compared to the recommended values of up to 35mm in Australian Rainfall and Runoff for design storm events, but the high loss values were necessary in order to replicate the observed flooding around Salt Ash where surveyed flood marks and more detailed observations of flooding were available. These may have skewed the calibration results towards underestimates in other parts of the study area where lower losses may have been applicable, such as in the urbanised centres of Tanilba Bay and Anna Bay, as opposed to the forested catchments draining to Salt Ash. However, it was difficult to justify varying the parameter values across the large study area in the absence of more detailed and spatially-extensive data.

The continuing losses for clayey soils and sand dunes are upper-bound estimates recommended in the XP-RAFTS 2000 reference manual (XP Software, 2000). The continuing loss adopted for the predominantly sandy soils are lower than the recommended range of 10 – 25mm/hr, but was considered necessary to allow for the potential presence of clayey soils and high water table. Visual inspection of the aerial photography indicated areas of ponding and swamps in some of the sandy catchment areas.

7.3.4 Culvert and Stormwater Pit Blockage

Culverts were generally assumed to be 50% blocked, but were reduced to 0% and 20% as necessary in order to obtain a better calibration. Stormwater pits were assumed to be 20% blocked for on-grade pits and 50% for sag pits.

7.3.5 Tailwater Conditions

Recorded tidal water levels at the MHL Mallabula gauge (station 209461) were adopted for the tailwater conditions at the mouth of Tilligerry Creek in the calibration and verification event modelling. This gauge was selected as it is adjacent to the creek and hence would experience and record local tailwater conditions including tidal lag from the Port Stephens heads as well as elevated water levels due to Karuah River inflows.

The next closest tide gauge is located at Shoal Bay, 15km downstream of Tilligerry Creek, and would not experience these local tailwater conditions.

For ocean water levels along the ocean shoreline of Anna Bay to One Mile, the tidal water levels for Newcastle Pilot Station (West tide gauge).

7.4 Modelled Flood Behaviour

7.4.1 April 2015 Storm Event

The April 2015 storm event resulted in flooding across the study area, resulting from the following flooding mechanisms:

- Higher than normal water levels in Port Stephens and Tilligerry Creek over 1.3m AHD as a result of a large spring tide and storm surge.
- Cumulative rainfall depths over a three day period of approximately 270 – 350mm, generating local catchment runoff.
- Given the catchment terrain and setting, the runoff generally collected and pooled in broad low points, obstructed from draining away by natural ridges and raised road embankments and levees, and relatively small drainage structures. The elevated tailwater levels in Tilligerry Creek also impeded the free drainage of the floodwaters.
- Overland flows occurred in natural flow paths and roadways in the steeper parts of the study area, including parts of Anna Bay, Boat Harbour, Tanilba Bay, Mallabula and Lemon Tree Passage.
- Floodwaters from the Hunter River and Fullerton Cove did not contribute to flooding in the study area. The Hunter River floodwaters would need to overtop Nelson Bay Road at Williamtown to flow in Tilligerry Creek into the study area, and this did not occur in the April 2015 event. Flow did pass through the road cross drainage culverts but these flows were only minor.

The elevated tailwater level is higher than Marsh Road levels in several sections and would have caused the road to be inundated and cut off. Inundation depths are up to 0.5 – 1m on the high side of Marsh Road as a result of tidal inundation and, to a lesser extent, local runoff. The duration of inundation is approximately 4-5 days due to elevated tailwater levels and low capacity of the drainage culverts.

Depths of flooding in Anna Bay catchment in the floodplain along Main Drain and Back Drain upstream of the floodgates are estimated to be 0.5 – 1m as a result of local catchment runoff. Similar to Marsh Road, the duration of flooding in this area is 5 – 6 days due to the low relief of the floodplain, as low as 0.3m AHD, which is lower than a normal high tide level in Tilligerry Creek.

The modelling indicates parts of Anna Bay village are inundated to depths of 0.7m and up to 1m in localised areas. Gan Gan Road would be cut off with this magnitude of flooding. Clark Street low point had flooding to 0.8m deep, with depths of water over Gan Gan Road of 0.2m at this location. The magnitude of this flooding could not be confirmed due to an absence of observations in this area. Refer to the discussion in Section 7.5.1. The modelling indicates that the duration of flooding is 1.5 days, coinciding with the timing of the several rainfall bursts during this storm event. This indicates that the area drains relatively quickly following each storm burst.

Other areas in Anna Bay, One Mile and Boat Harbour experience local overland flooding in flow paths which pass through properties and in roads with flow depths generally less than 0.3m. There are a number of trapped low points as well as a number of flood detention basins where depths of flooding reach up to 2m.

Flooding in Salt Ash, including the floodplain areas of Tilligerry Creek and Moors Drain, was caused by local catchment runoff rather than due to overflows from the Hunter River at Fullerton Cove. Flood depths in this area are generally up to 0.5m for the properties along Nelson Bay Road from Tilligerry Creek bridge up to and including the western end of Marsh Road, and along Lemon Tree Passage Road from (and including) Michael Drive to the eastern end of Brownes Road. The duration of flooding is up to 6 days due to the obstruction to drainage caused by the raised road embankments in this area and the relatively low capacity cross drainage structures across the roads. Some areas do not completely drain, becoming trapped low points and ponding areas.

Flooding in the urbanised areas of Tanilba Bay, Mallabula and Lemon Tree Passage is as a result of local overland flooding within natural flow paths and in roads, typically to depths of 0.3m. A number of trapped low points occur in roads and in the natural terrain which result in flood depths generally up to 0.5m. Ponding in roadways occurs in President Wilson Walk, Tanilba Bay, and Meredith Avenue and Cook Parade in Lemon Tree Passage, with depths up to 0.5m. Ponding also occurs in a number of other streets to a lesser extent, though these areas of ponding still impact adjacent residential properties. The floodwaters in these areas is observed to generally drain away relatively quickly after each rainfall burst (approximately 6 hours).

Flow velocities in the main floodplain areas and trapped low point areas in the study area are generally low, less than 0.3m/s, due to the flat terrain of these areas. The flow velocities in overland flow paths which occur in the Anna Bay and Boat Harbour urban areas, in addition to those in Tanilba Bay, Mallabula and Lemon Tree Passage may exceed 1.5m/s due to the steeper terrain. Many of these flow paths occur in roadways and the relatively smooth pavement areas contribute to the higher flow velocities.

7.4.2 January 2016 Storm Event

The January 2016 storm event resulted in the following conditions which influenced flooding:

- Smaller lunar tides than the April 2015 storm, resulting in lower peak tailwater levels in Tilligerry Creek and Port Stephens of less than 0.8m AHD (0.5m lower than the April 2015 tailwater levels).
- Cumulative rainfall depths over a four day period of approximately 240 – 330mm, generating local catchment runoff. Peak rainfall intensities were lower.
- By locality, compared to April 2015,rainfall depths were lower in the Anna Bay area, and slightly higher in the Bobs Farm, Salt Ash, Tanilba Bay and Lemon Tree Passage areas.
- Overflows did not occur from the Hunter River and Fullerton Cove and so not did contribute to flooding in the study area.

As a result of the above conditions, flooding was less severe in the Anna Bay area, with depths of flooding in the floodplain adjacent to Main Drain and Back Drain typically from 0.3 – 0.7m. There was also generally only localised flooding in the urbanised areas of Anna Bay, Boat Harbour and One Mile. Clark Street low point had flooding to 0.5m deep, which did not cause Gan Gan Road to be cut off.

Depths of inundation in the Bobs Farm along Marsh Road were estimated to be 0.3 – 0.7m, with the lower tides and tailwater levels contributing to the reduced flooding as the tide did not overtop Marsh Road.

Flooding through the Salt Ash area was slightly greater in depth due to the higher rainfall depths recorded in this area. Depths were 0.3 – 0.6m, approximately 50 – 100mm greater than in the April 2015 event.

Durations of inundation during the January 2016 event were approximately 4 – 5 days around Anna Bay and Marsh Road, and 5 – 7 days around Salt Ash. Some areas do not completely drain, becoming trapped low points and ponding areas.

In the Tanilba Bay and Lemon Tree Passage area flood depths were typically 0.2 – 0.4m, which is less due to the lower rainfall depths and rainfall intensities compared to the April 2015 event.

Flow velocities and durations of inundation were observed to be similar to those in the April 2015 event.

7.5 Comparison to Observed Flooding

7.5.1 Discussion

The questionnaire responses were analysed to determine the dates of historic flooding and the number of respondents experiencing flooding in each event. Observations such as flood depth, level and extents, indicative locations for previous flooding, flow directions etc. were consolidated in a data base and mapped on Figure C-1 in Appendix C. Comparison of the flood modelling results to the observations is made in Tables C-1 to C-3 in Appendix C.

The flood model generally provides a reasonable match to the observed flooding depths and behaviour, with the modelled flood levels and depths generally within +/- 0.15m of the reported flooding, which is considered satisfactory. Several observations of “flooding” were attributed to local drainage issues as the areas were located close to a sub-catchment divide rather than along overland flow paths or at main drainage low points and flood storage areas.

Parts of the town centre in Anna Bay were modelled as having significant flooding in the April 2015 simulation, with depths of flooding to 0.7m, and up to 1m in localised areas. Flooding of Gan Gan Road is estimated to have reached 0.7m which would have caused the road to be cut off. Property flooding and damage would have been significant if such flooding happened in the actual event. Unfortunately, there were no flooding observations reported by questionnaire respondents to confirm or refute this magnitude of flooding, and Council to date have not been able to provide information on whether significant flooding occurred or the road was cut off in the Anna Bay area during the April 2015 event. Review of available geophysical and groundwater data indicated that implementing an infiltration loss in the hydraulic model was not justified to reduce these flood depths due to low ground elevations (less than 3m AHD) and potentially shallow water table of 1m depth (Coffey Partners, 1993). The relatively high imperviousness of this urbanised location would also reduce overall infiltration of floodwaters.

The model calibration and verification was considered challenging due to the large study area (122km^2) with the catchment areas being simplified into a representation of three predominant soil types and resultant runoff potential. In reality it is very likely that there is vastly greater diversity in the soil types, underlying geologies (i.e. presence or absence of shallow bedrock) and resulting influence on infiltration and groundwater processes. It is, however, difficult to justify increasing the variability in the soil types and corresponding hydrologic response without more detailed catchment data, the collection of which is outside the scope of this flood study. The calibrated and verified hydrologic and hydraulic models presented here are considered the best-estimates for flood estimation given the available catchment and historic flood data.

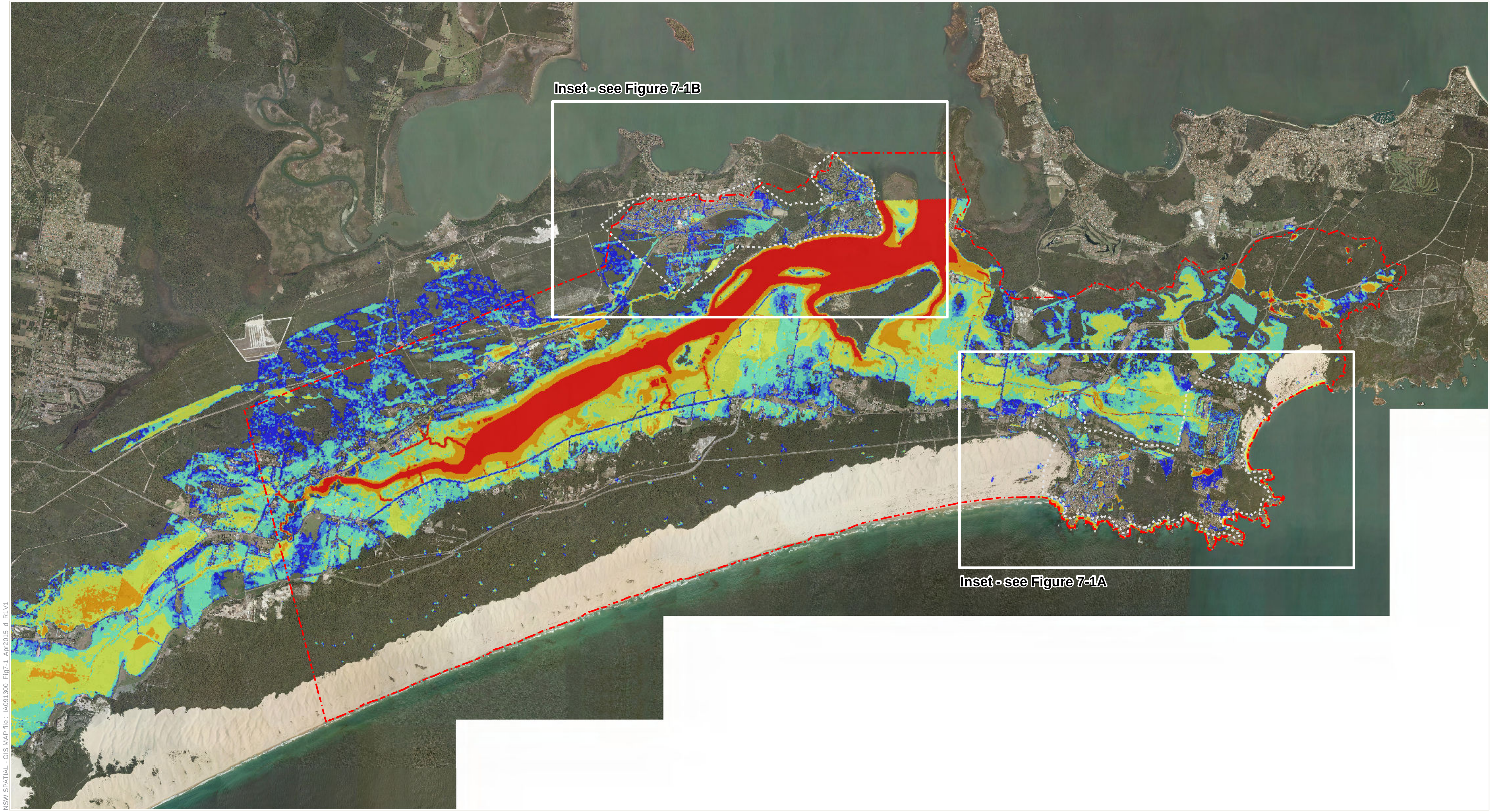
The modelled flood depth variance from the observed flood behaviour may also be attributed to uncertainty of other factors such as blockage of culverts and hydraulic structures by debris and sediment. These conditions may vary from event to event and even during events, and are generally not known during particular flood events. The flooding behaviour at some locations is sensitive and depends on the precise degree of blockage.

7.5.2 Calibration Event Flood Mapping

Flood mapping is presented for the April 2015 and January 2016 events on Figure 7-1 and Figure 7-2, respectively. In the areas covered by the more detailed 2m grid urban area flood models, the modelling results from these models apply and supersede the coarser results from the 20m grid regional flood model.

It should be noted that the flood mapping does not reflect any ponding or inundation caused by subsequent seepage of groundwater to the surface following rainfall events.

Each storm event produced greater flooding than the other in different parts of the study area, influenced by the critical flooding mechanism in each area (e.g. flash flooding versus storage-volume driven), the total rainfall depth and intensity of rainfall in each storm event at each location. In general the April 2015 event produced greater flooding in the Anna Bay and Bobs Farm areas, and similar or slightly greater in the Tanilba Bay and Lemon Tree Passage areas, while the January 2016 event produced slightly greater flooding in the Salt Ash area. This is generally consistent with the residents’ reports of flooding in these storm events.



Legend

Peak flood depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Study Area
- Urban Area TUFLOW Model (2m grid)

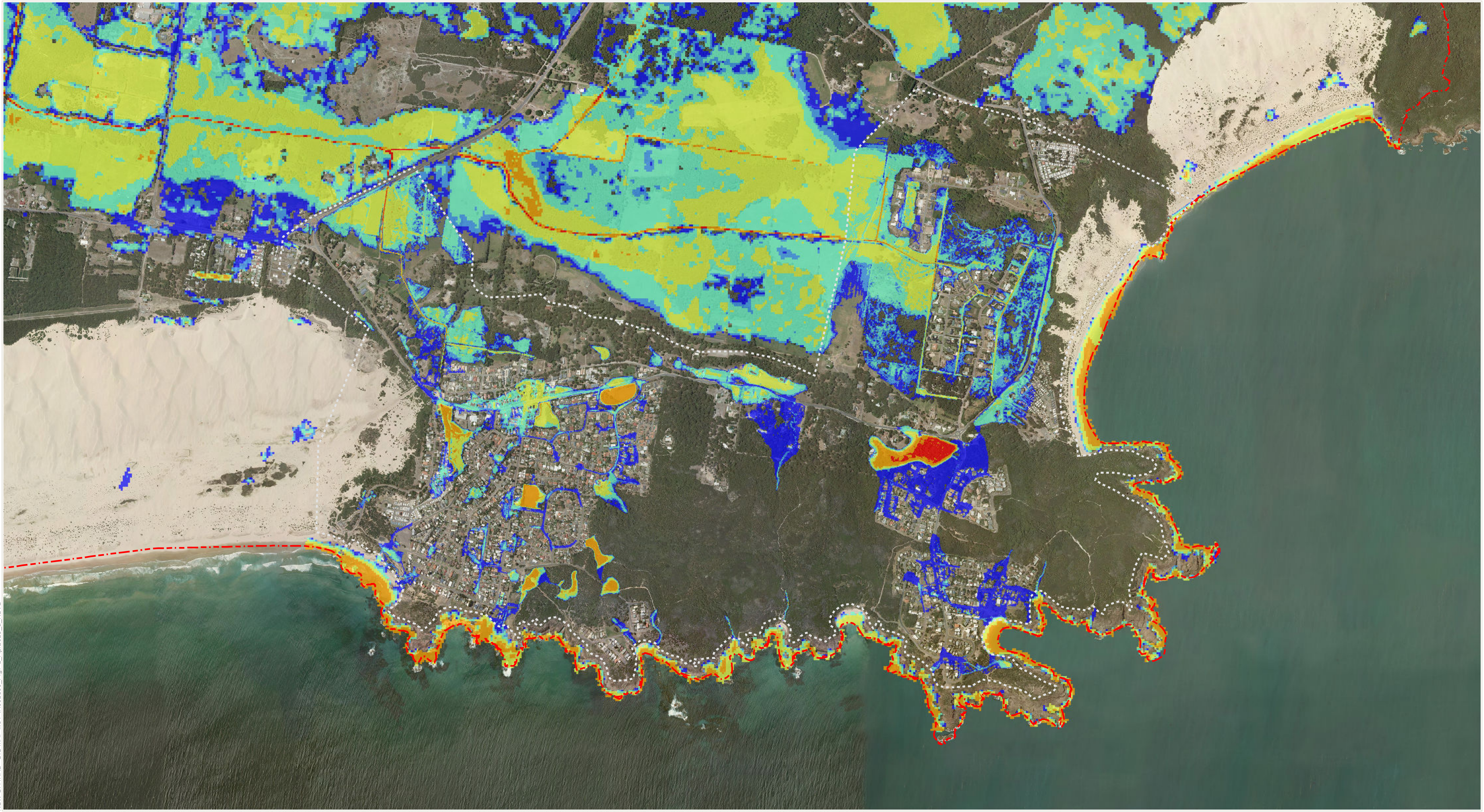
0 1 2 3 4 5 Kilometres

N

1:75,000@ A3

Figure 7-1 Calibration Flood Event Mapping - April 2015 Event - Overall Study Area View

JACOBS



Legend

Peak flood depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Study Area

Urban Area TUFLOW Model (2m grid)

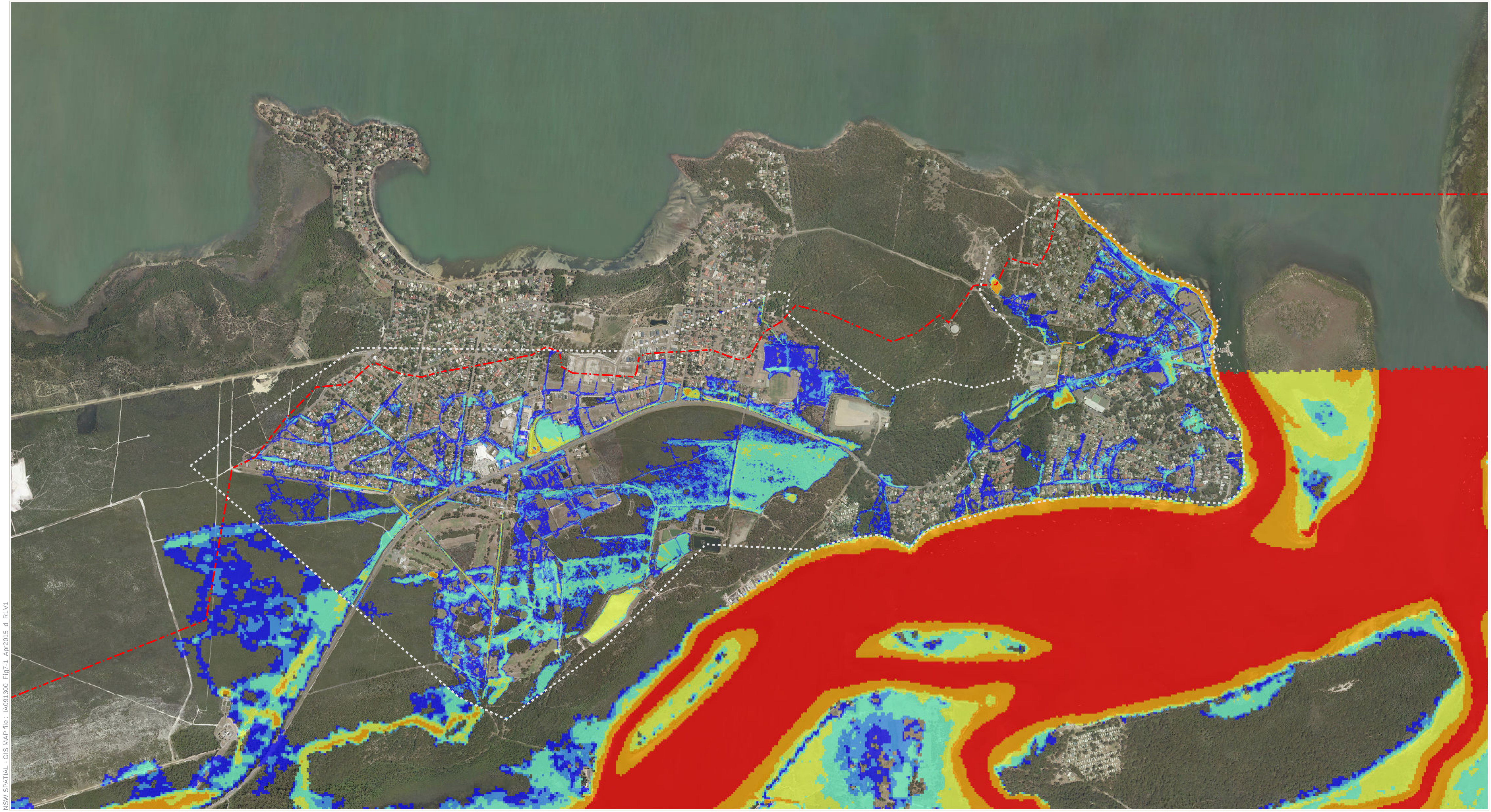
0 1 Kilometres

N

1:20,000@ A3

JACOBS

Figure 7-1A Calibration Flood Event Mapping - April 2015 Event - Anna Bay Urban Area



Legend

Peak flood depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Study Area

Urban Area TUFLOW Model (2m grid)

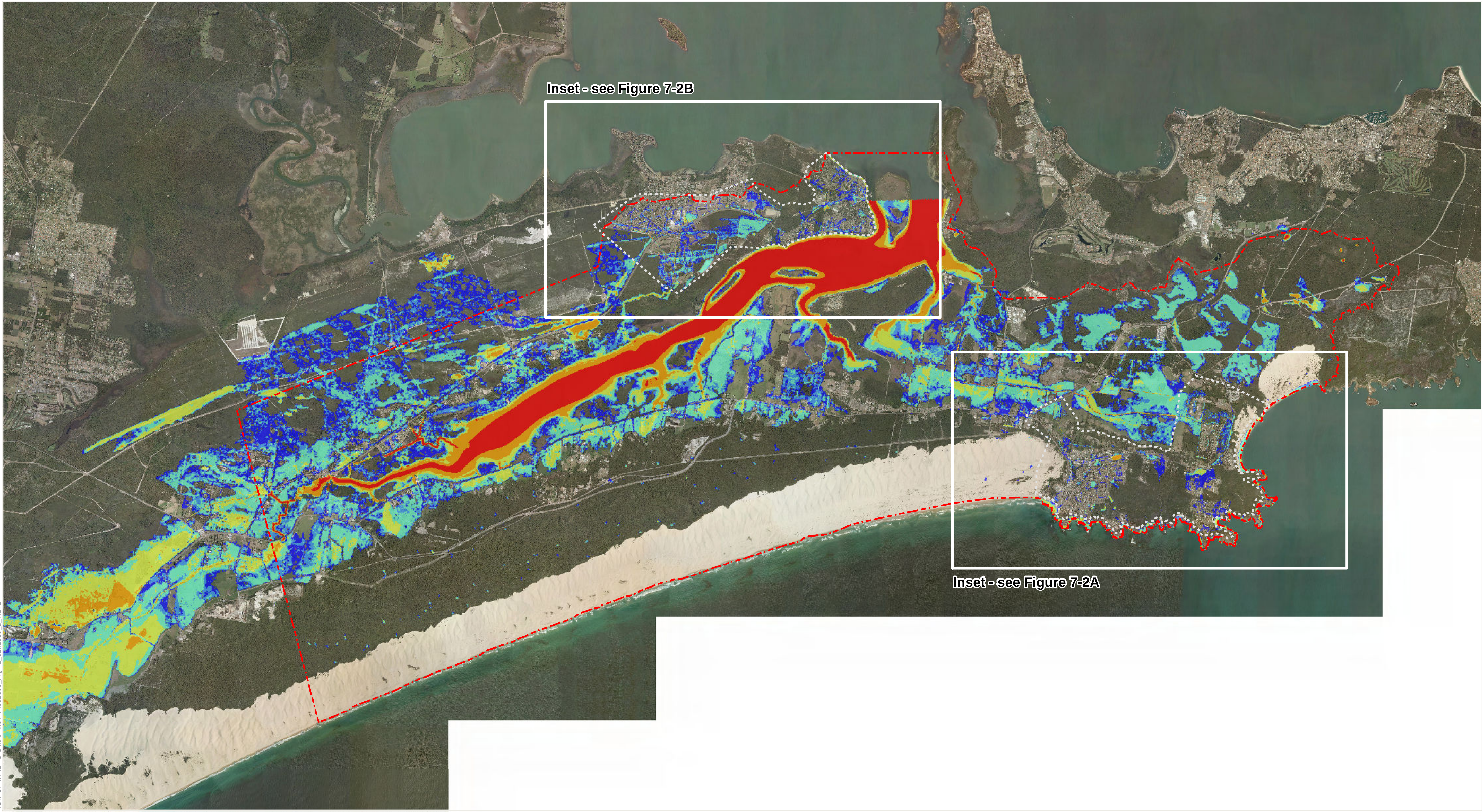
0 1 Kilometres

N

1:20,000@ A3

JACOBS

Figure 7-1B Calibration Flood Event Mapping - April 2015 Event - Tilligerry Peninsula Urban Area



Legend

Peak flood depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Study Area
- Urban Area TUFLOW Model (2m grid)

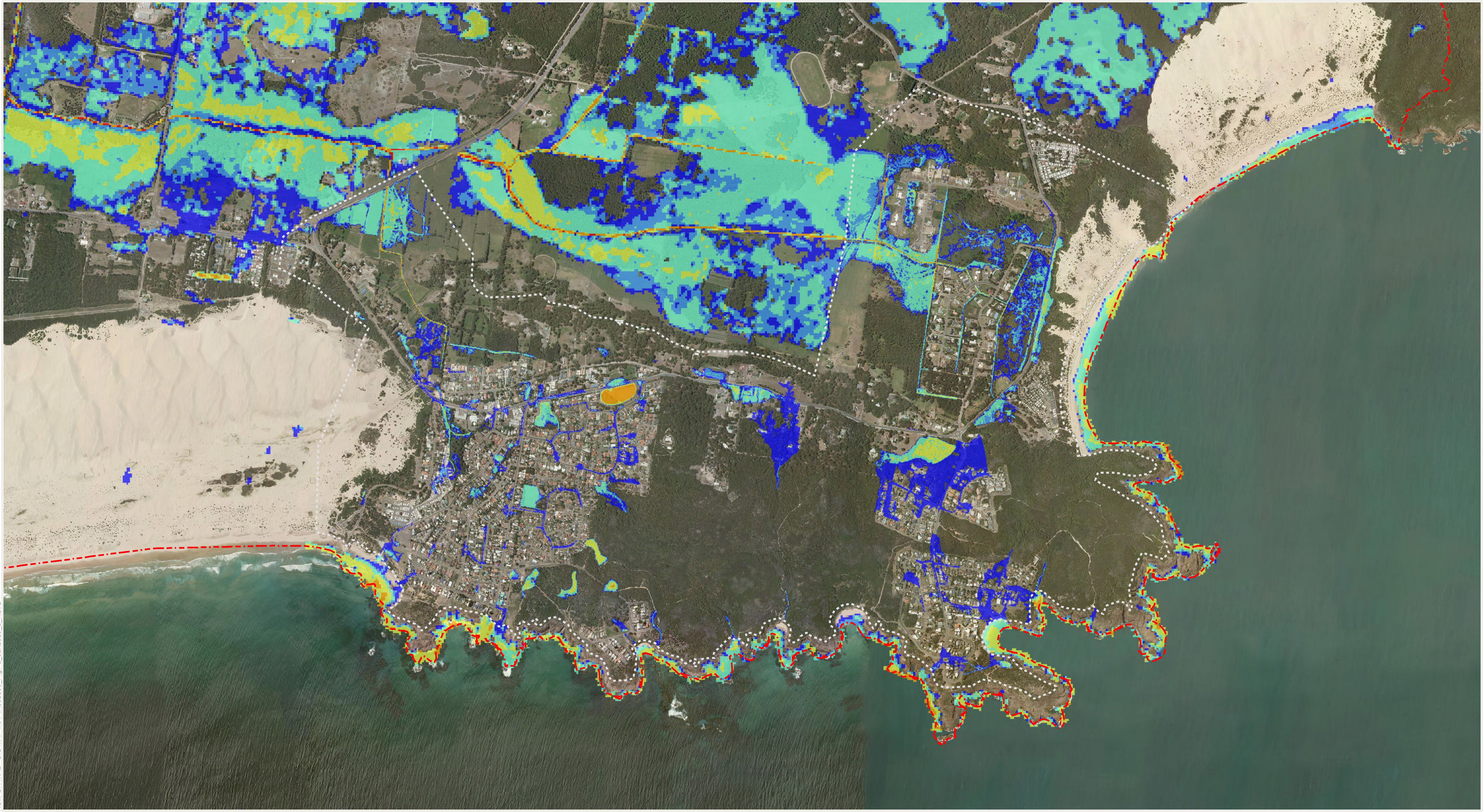
0 1 2 3 4 5 Kilometres

N

1:75,000@ A3

JACOBS

Figure 7-2 Verification Flood Event Mapping - January 2016 Event - Overall Study Area View



NSW SPATIAL - GIS MAP file : IA091300_Fig7-2_Jan2016_d_R1V1

Legend

Peak flood depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0
- Study Area
- Urban Area TUFLOW Model (2m grid)

0 1 Kilometres

N

1:20,000@ A3

Figure 7-2A Verification Flood Event Mapping - January 2016 Event - Anna Bay Urban Area

JACOBS

Legend

Peak flood depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

- Study Area
- Urban Area TUFLOW Model (2m grid)

0 1 Kilometres

N

1:20,000@ A3

JACOBS

Figure 7-2B Verification Flood Event Mapping - January 2016 Event - Tilligerry Peninsula Urban Area

8. Estimation of Design Floods

8.1 Catchment and Climate Conditions for Design Flood

The design floods have been estimated for "current conditions" including current climate (sea levels and rainfall intensities) and development (full development under Council's LEP 2013).

8.2 Adopted Model Parameters for Design Events

8.2.1 Land Use in Hydrologic Model

Land use, for the purposes of the calibration event hydrologic modelling, was based on existing land use. For the design event modelling the fully developed catchment conditions associated with the Local Environment Plan (LEP) 2013 land zoning was adopted. This has typically no change for most of the study area, with exception of within the Anna Bay urban area where some currently rural, open space and low density residential areas are earmarked for a higher level of urbanisation, resulting in a higher level of catchment imperviousness and higher runoff potential. The hydrologic model sub-catchments were updated from the calibration runs to reflect this level of development. Refer to Section 5.1.2 for further details.

8.2.2 Design Rainfall

The rainfall design data for this study for events up to and including the 1% AEP event was generated within the XP-RAFTS model applying the rainfall intensity, frequency and duration (IFD) relationship based on data presented in Table 9-1. The adopted IFD data is that specified for the Anna Bay area, which covers the majority of the study area, in Council's handbook for drainage criteria (Port Stephens Council, 2008).

Table 8-1 Adopted IFD parameters

IFD Parameter	Value
1 hour 2 year ARI mm/hr	35.4
12 hour 2 year ARI mm/hr	7
72 hour 2 year ARI mm/hr	2.2
1 hour 50 year ARI mm/hr	70
12 hour 50 year ARI mm/hr	14
72 hour 50 year ARI mm/hr	4.5
Skewness G	0
Geographical factor 2 year ARI F2	4.315
Geographical factor 50 year ARI F50	16.05

Estimates of the Probable Maximum Precipitation (PMP) for the study catchment up to 6 hours duration were prepared using the procedures given in *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method* ("GSDM"; BOM, 2003).

Estimates of the Probable Maximum Precipitation (PMP) for the study catchment for durations longer than 24 hours were prepared using the procedures given in the Generalised Southeast Australia Method ("GSAM"; Minty et. al., 1996) and the Revised Generalised Tropical Storm Method ("GTSMR"; Walland et. al., 2003).

8.2.3 Temporal Patterns

Temporal patterns for all events storm durations up to, and including, the 1% AEP event were sourced from the XP-RAFTS model for Zone 1. These are based on the ARR 1987 temporal patterns. The temporal pattern for the PMP event was sourced from BOM (2003).

The recent ARR 2016 IFD's and temporal patterns were released during the course of this study following the hydrologic model development and estimation of design flood hydrographs, and hence could not be accommodated in this study. This was discussed and agreed upon with Council.

Temporal patterns for the PMP events were adopted from the GSDM, GTSMR and GSAM methods as appropriate.

8.2.4 Areal Reduction Factors

Areal reduction factors are often applied in hydrologic assessments of catchment areas larger than $1km^2$ to reduce the relatively high point-location design rainfall depths and intensities in order to reflect the lower, catchment-averaged depth or intensity. Based on the guidance in ARR 2016, reduction factors of 0.86 – 0.98 are estimated for catchment areas up to $10km^2$ in south-east Australia.

Although the current study area is approximately $160km^2$ in size, the drainage outlets within the study area are spatially dispersed with maximum local catchment areas of $10km^2$, and typically much less than this. Therefore, with minimum reduction factor values being relatively close to 1.0 for the local catchments in the study area, no areal reduction factor has been applied to the hydrologic assessment of the local catchments for this flood study.

8.2.5 Hydrologic Rainfall Losses

The proposed rainfall losses for the design event runs, and comparison to the adopted calibration run loss values, are summarised in Table 8-2. The continuing loss values for each soil type were estimated through the model calibration process and retained for the design event modelling . The initial losses were reduced from the relatively high values adopted in the calibration event modelling for the purpose of defining the design flood. This was due to the design storm event accounting for only the main storm rainfall burst, and excluded the pre-burst rainfall. The initial losses were therefore reduced to account for the pre-burst rainfall being captured by the initial losses. In contrast, modelling of the calibration event included the pre-burst rainfall and the higher adopted initial losses representing a relatively dry catchment prior to the main storm burst. Adoption of the calibration run initial loss values in the design flood estimation would result in significantly reduced runoff being generated, and hence a likelihood that the peak design flood levels would also be underestimated.

Table 8-2 Proposed rainfall losses for design event modelling

Soil Type	Calibration	Design Runs
Predominantly clayey	IL 10mm CL 2.5mm/hr	IL 10mm (lower limit recommended in ARR 1987) CL 2.5mm/hr (recommended value in ARR 1987)
Predominantly sandy	IL 100mm CL 6mm/hr	IL 10mm (lower limit in ARR 1987) CL 6mm/hr (derived from calibration)
Sand dunes	IL 100mm CL 25mm/hr	IL 35mm(upper limit in ARR 1987) CL 25mm/hr (upper limit suggested by XP-RAFTS user manual and confirmed in calibration)
Impervious/paved areas	IL 1mm CL 0mm/hr	

8.2.6 Infiltration of Runoff and Floodwaters

Infiltration rates of 300mm/hr in sand dune areas, and 50mm/hr around Clark Street low point were adopted in the design event modelling. Refer to Section 6.3.3 for discussion on the selection of the infiltration rates.

8.2.7 Blockages

The blockage factors adopted in the calibration runs were also adopted for the design runs. These are summarised below:

- Culvert inlets: typically 50% blocked for culverts, including Main Drain flood gates. The exception to this is the Main Drain culverts at Nelson Bay Road, where a 20% blockage is assumed due to the large culvert dimensions (3.2m x 1.5m). The large majority of culverts in the study area are observed to be in vegetated areas with a high likelihood of floating debris during a flood event. Further, the flat terrain and culvert grades mean that there is risk of the culverts and approach channels becoming silted with accumulated sediment.
- Bridges: Nelson Bay Road bridge over Tilligerry Creek is assumed to be unblocked due to its 20m wide span.
- Stormwater pits: 20% for on-grade pits, 50% for sag pits.

8.2.8 Floodgates

For the purposes of estimating the design floods, culverts with floodgates in the study area are assumed to be unidirectional, meaning that when tailwater levels are higher than upstream water levels the floodgate flaps are assumed to close and prevent backflow. However, it should be noted that the flaps may not close properly due to debris propping the flaps slightly open. This would potentially result in tidal inundation of upstream areas, which may exacerbate flooding if a storm event were to occur concurrently due to higher initial water levels in the upstream areas.

8.2.9 Adopted initial water levels in TUFLOW models

Floodplain areas in the regional and detailed urban models are assumed to have no initial standing water at the start of the model simulations. In the Anna Bay urban model, an initial water level of 0m AHD is assumed for water levels in Main Drain and the other drains. This is consistent with the average water levels recorded in Main Drain by DPI (2011), which showed that during dry periods water levels in Main Drain can drop below 0m AHD.

The initial water level influences the peak flood level estimated by the flood model, particularly in areas where the flood behaviour is driven by flood storage and volume. Any water present in these areas at the start of a storm reduces the available flood storage and hence would increase the peak flood levels. Minimum ground levels in the Main Drain floodplain are around 0.5m and hence initial water levels would need to be greater than this to start significantly reducing available flood storage.

8.3 Consideration of Concurrent Flooding Events

8.3.1 Description of Different Flooding Mechanisms

As previously highlighted, the Anna Bay – Tilligerry Creek study area is a large and diverse floodplain area in terms of terrain and hydrologic setting. As such, it is subject to flooding resulting from a range of phenomena, including:

- Local catchment runoff, caused by rainfall being converted to surface runoff and inundation in the catchment areas within the study area itself and external areas which drain to Tilligerry Creek. This includes areas between Fullerton Cove and the Tilligerry Creek estuary;
- Overflows from the Hunter River at Fullerton Cove. During moderate flood events in the Hunter River such as the 5% AEP, floodwaters begin to overtop the levee encircling Fullerton Cove but are constrained from contributing to flooding in the study area by the raised Nelson Bay Road at Williamtown. Nelson Bay Road

is not overtopped in the 1% AEP event and flows through the road cross culverts are only small. In large and extreme riverine flood events such as the 0.5% AEP and PMF the Hunter River has a more substantial contribution to flooding in the study area;

- Elevated tide and ocean levels in Port Stephens and on the ocean frontage along Stockton/Birubi Beach and the shorelines along Anna Bay, Boat Harbour and One Mile. Note that the elevated water levels in Port Stephens are also influenced by riverine flooding from the Karuah and Myall Rivers.

The design flood levels estimated by this flood study need to account for the contributions to peak flooding conditions from each of these sources. However, it is generally considered unlikely that the peak flooding conditions from each mechanism and for each event AEP would occur concurrently. Assuming that a 1% AEP local storm event in the study area coincides with a 1% AEP tailwater level in Port Stephens may result in an overestimate of design flood levels, compared to a more realistic combination of flooding mechanism events.

The approach used in this study is an envelope approach, where for example, the 1% AEP local catchment flood is analysed coinciding with the 5% AEP tide level, and then the 1% AEP tide level analysed coinciding with the 5% AEP catchment flood. The maximum envelope is taken from the peaks of the two scenarios to define the peak flood level in the study area. This approach is recommended in “Floodplain Risk Management Guide – Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways” (OEH, 2015) and has been adopted in the Williamtown – Salt Ash Flood Study Review (WBM 2005) and Williamtown – Salt Ash Floodplain Risk Management Study and Plan (BMT WBM, 2015) for Port Stephens Council. The adopted coincident flooding conditions for this study are detailed in Section 8.3.3.

8.3.2 Estimates of the Flooding from the Different Mechanisms

8.3.2.1 Local Catchment Flooding

The flooding caused by local catchment runoff has been estimated by hydrologic modelling described in Section 5 with the parameter values in Section 8.1.

8.3.2.2 Hunter River Flows

The regional flood model extends to upstream of Raymond Terrace, with inflows from the Hunter River catchment, Williams River catchment and local catchments between Raymond Terrace and the river outlet input into the model as adopted in BMT WBM (2015). Overflows from the Hunter River are the dominant flooding mechanism in the Tilligerry Creek floodplain in Williamtown and parts of Salt Ash upstream of the study area, but only influences flooding in small portions of the study area and only flood events larger than the 10% AEP events. Refer to Section 9.7.1.

8.3.2.3 Port Stephens and Ocean Tidal Boundaries

Previous studies estimated the elevated tidal and flood levels applicable to the Port Stephens area. These are summarised in Table 8-3.

Table 8-3 Estimated Elevated Tidal Water Levels in Port Stephens Area

Tide Event AEP	Tailwater Level (m AHD)		
	Ref 1	Ref 2	Ref 3
50% (see note below)	1.44	-	Adopt High High Water Spring (Solstice Spring) 1.25
20% (see note below)	1.48	-	
10%	1.51	-	
5%	1.55	1.70	1.40
2%	1.58	-	
1%	1.62	1.80	1.45
0.5%	1.65	-	
PMF or “Extreme”	-	1.80	

- Ref 1: Williamtown – Salt Ash Flood Study (WBM, 2005) Table 5-6 Tailwater levels in Tilligerry Creek at Mud Point
- Ref 2: Port Stephens Design Flood Levels – Climate Change Review (WMAwater, 2010), Derived from Port Stephens Flood Study, (MHL, 1997).
- Ref 3: Floodplain Risk Management Guide – Modelling the Interaction of Catchment Flooding and Oceanic Inundation in Coastal Waterways (OEH, 2015).
- Note: For the purposes of this study, the 2 year and 5 year ARI events are referred to as the “50% AEP” and “20% AEP” events.

It is observed that there is some variance between the estimates from the different studies. For the purposes of this study the higher of the available estimated values has been adopted for the relevant water bodies:

- Port Stephens: adopt values from Ref 2 for 5% AEP and greater; adopt values from Ref 1 for values up to 10% AEP.
- Ocean frontage (Anna Bay detailed model only): adopt values from Ref 3.

8.3.3 Adopted Design Flood Conditions

The combinations of local catchment flooding, Hunter River flooding and Port Stephens water level conditions assumed for the regional model in this study are summarised in Table 8-4, and are generally consistent with OEH (2015) recommendations of adopting 1% AEP catchment flood with a 5% AEP ocean tailwater boundary. Refer to Section 8.5.2 for details on how concurrent events and downstream tailwater levels are treated in the detailed urban area models.

Table 8-4 Adopted Design Joint Flood Scenarios – Regional Model

Flood Envelope AEP	Dominant Flood Mechanism	Flood Event AEP		
		Hunter River	Local Catchment	Port Stephens
20%**	Local Catchment	*20%**	20%	20%
	Hunter River	N/A. Hunter River does not overflow from Fullerton Cove in the 20% event		
	Port Stephens/Tide	N/A. incorporated into local event run		
10%	Local Catchment	*10%**	10%	10%
	Hunter River	N/A. Hunter River does not overflow from Fullerton Cove in the 10% event		
	Port Stephens/Tide	N/A. incorporated into local event run		
5%	Local Catchment	*20%**	5%	10%
	Hunter River	*5%**	20%	5%
	Port Stephens/Tide	N/A. incorporated into Hunter River event run		
1%	Local Catchment	*10%**	1%	5%
	Hunter River***	1%	10%	50%**
	Port Stephens/Tide	*10%**	10%	1%
PMF	Local Catchment	1%	PMF	1%
	Hunter River	PMF	1%	1%
	Port Stephens/Tide	N/A. Extreme tide level is the same as the 1% AEP		

* Denotes that Hunter River does not overflow at Fullerton Cove in this flood event.

** For the purposes of this study, the 2 year and 5 year ARI events are referred to as the “50% AEP” and “20% AEP” events.

*** A 50% AEP tailwater condition was adopted for the 1% AEP Hunter River flood run, for consistency with BMT WBM (2015). Ultimately, there is little inflow into the study area from the Hunter River and the 1% AEP design flood is dominated by the other flood mechanisms.

8.4 Design Storm Durations

A range of storm durations was assessed to determine the critical storm durations in each of the regional and detailed urban flood models. These were determined to be:

- Regional model: the 48 hour duration event was determined to be the critical event due to the typically flat terrain and flood storage-driven floodplain areas, in addition to the Hunter River critical event being the 48 hour event. Durations including the 6, 9, 12, 24, 48 and 72 hour duration events were assessed for the 1% AEP.
- Anna Bay detailed urban model: the 2, 9, 12 and 48 hour duration events were determined to be critical, depending on the location in the catchment. This range of critical event durations reflects the mixture of steeper, overland flow-type areas (shorter critical duration) and flat low-lying floodplain areas, trapped low points and flood detention basins (longer critical durations). Durations including the 25 minute and 2, 6, 9, 12, 24 and 48 hour duration events were assessed for the 1% AEP. Note that there were generally minor differences in flood depths (< 0.1m) between the critical duration events.
- Tilligerry Peninsula detailed urban model: the 2, 9 and 12 hour duration events were determined to be critical in the majority of the model domain, again reflecting the presence of steeper areas (shorter critical duration) and trapped low points and flood detention basins (longer critical durations). Flooding of the low-lying foreshore area of Lemon Tree Passage are dominated by elevated Port Stephens/Tilligerry Creek water levels which are partly influenced by the 48 hour regional model critical event, and the tailwater levels in the detailed model have been defined to reflect this. Durations including the 25 minute and 2, 6, 9 and 12 hour duration events were assessed for the 1% AEP. Note that there were generally minor differences in flood depths (< 0.1m) between the critical duration events.

8.5 Tailwater Levels

8.5.1 Timing of Peak Tailwater Levels in Regional Model

The Port Stephens tide peak was adjusted in its timing to coincide with the flood peak in the regional flood model. For the local catchment flooding event this flood peak is around 23 hours after the start of the 48 hour critical event, while for the Hunter River flood event the peak is around 51 hours.

8.5.2 Integration of Regional and Detailed Urban Models

The regional and detailed urban models for Anna Bay and Tilligerry Peninsula were developed and run separately to assess the different critical flooding mechanisms in each model domain area, largely determined by the terrain and catchment setting, and the critical storm durations producing peak flooding in each area. Tailwater levels from the regional flood model were extracted at appropriate locations and input as dynamic water level boundaries for the detailed urban models, so that the peak flood levels at the downstream interface between the detailed models and the regional model were consistent.

The shorter duration storm events in the urban models were run such that the storms were assumed to start at the same time as the start of storm and start of rise in the dynamic tailwater levels, derived from the regional model 48 hour storm. The longer events in the urban models (i.e. the 48 hour in the Anna Bay model and 12 hour in the Tilligerry Peninsula model) were run such that the peak tailwater levels were timed to coincide at the same time as the peak flooding in the urban models. Examples of how the tailwater levels were applied in coincidence with the different storm durations are shown in Figure 8-1 and Figure 8-2 for the Anna Bay and Tilligerry Peninsula models, respectively. The models were run for a sufficiently long time to capture the peak flooding from catchment runoff and from tailwater influences.

Figure 8-1 Schematised example of applying the dynamic tailwater level in the Anna Bay detailed urban model

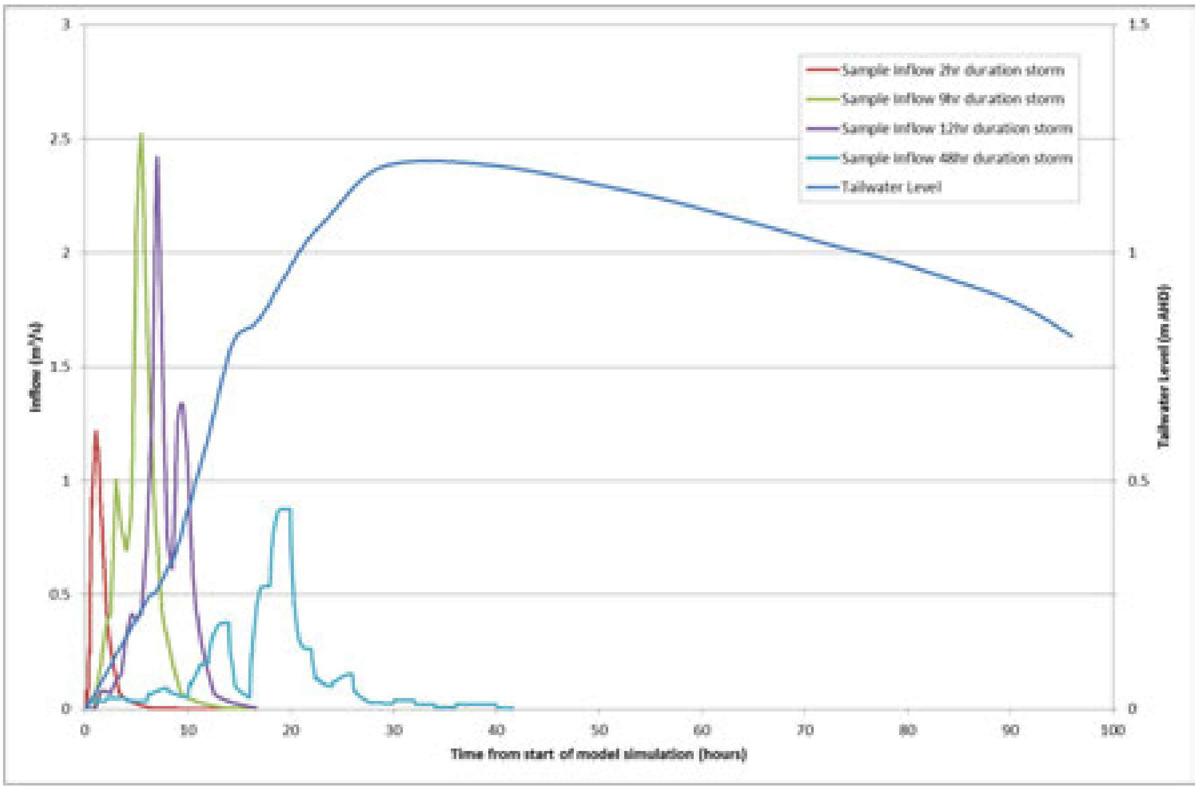
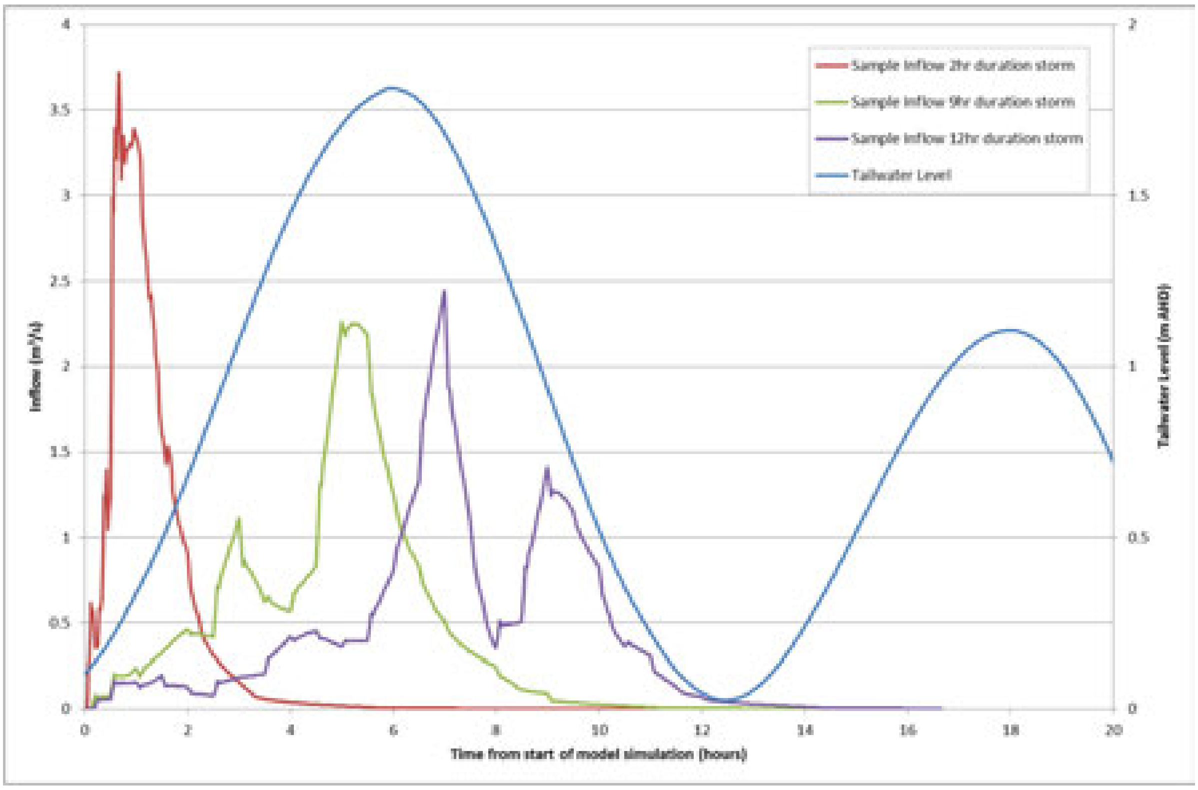


Figure 8-2 Schematised example of applying the dynamic tailwater level in the Tilligerry Peninsula detailed urban model



8.5.3 Ocean Water Level in Detailed Anna Bay Model

For simplicity, a static ocean water level of up to the 1% AEP level (1.45m AHD) was used along the ocean foreshore in the Anna Bay detailed model for the design flood modelling. This was considered appropriate as the development areas and stormwater and overland flow outfalls into the ocean are located at higher elevations (minimum 3m AHD) and hence insensitive to unsteady tailwater condition. Further, the critical storm event along the foreshore is the 2 hour event, and it was considered appropriate to assume a static water level to replicate the coincident tailwater peak.

8.6 Consideration of the Contribution of Groundwater Flows to Flooding

There are anecdotal reports of groundwater interactions with surface water in the study area, with concerns that these groundwater to surface water flows may contribute to flooding during a storm event. It is thought that, during a major storm event, rainfall could infiltrate into some of the more permeable sandy soils in the sand dune and aquifer areas, and then discharge back to the surface during the storm and flood event. Significant consideration was made during this study of this potential contribution of groundwater to flooding. This hydrologic process has not been studied in sufficient detail in this study area and adds another level of complexity to this study. There is no local recorded data available to support or quantify an additional groundwater inflow into the hydraulic model.

The flood modelling has attempted to account for some of the effects of groundwater on flood event runoff generation by defining a number of parts of the catchments as a “water and swamp” land use type, where the ground is assumed to be saturated and rainfall cannot infiltrate into the soil and runs off in its entirety.

In an attempt to account for the rainfall volume which infiltrates into the ground and resurfaces during a storm event, this study has adopted what is considered to be more conventional rainfall loss parameters in the hydrologic modelling, thus keeping this water on the surface rather than assuming it infiltrates to groundwater and then resurfaces. This approach and the adopted parameters are consistent with the flood studies undertaken in the adjacent Medowie (WMAwater, 2012) and Williamtown – Salt Ash (WBM, 2005) study areas for Council.

In terms of the surfacing of previously stored groundwater during a flood event, the available groundwater modelling (refer to Section 3.6.3) indicates that following the significant April 2015 storm event, groundwater discharged back to the surface in the Tilligerry Creek floodplain at maximum rate of 4m^3/s (an inflow of 2m^3/s is stated in Section 3.6.3 for the Tomago Sandbeds. This value is doubled to 4m^3/s to account for additional inflows from the adjacent North Stockton Sandbeds). This is a minor contribution to total inflows compared to the peak design 1% AEP catchment inflows of 70m^3/s, and would result in an approximately 6% increase in flood depths if the peak groundwater outflow coincided with the flood event. However, the groundwater modelling indicates that the groundwater discharge peaked approximately 2 weeks after the storm event. This continued for months after the storm event, eventually tailing off. Peak flood levels in the study area are determined by the surface runoff resulting from the rainfall event rather than by the groundwater discharge, and occur up to 1 day after the rainfall event. By the time the groundwater inflows peak, the flooding from the surface water has drained away from the floodplain. Hence the groundwater discharge was omitted from the design flood modelling as peak flood depths were deemed not to be sensitive to these minor groundwater inflows.

9. Design Flood Mapping and Analysis

9.1 Foreword on the Flood Mapping

The flood model results and flood mapping represents the flooding conditions for the "present day" and does not represent any changes due to climate change including sea level rise and increases in rainfall intensity. The flood mapping does represent the flooding conditions associated with fully permissible development under Council's LEP 2013. Changes with respect to these and other factors are discussed in Section 7.3.1 and Section 8.2.1 (land use) and Section 9.13 (climate change).

The maximum envelope of flood behaviour parameters (depth, level, velocity, velocity x depth, flood hazard) was derived for each event AEP, considering the maximum values over each combination of flood mechanisms and storm event duration.

Flood inundation along the ocean foreshore in the Anna Bay – One Mile area is due to ocean water levels rather than from catchment runoff.

9.2 Flood Depth and Flood Level Mapping

Flood depths are mapped in metres on Figures E-1 to E-5 in Appendix E. Flood levels are mapped in m AHD on Figures E-6 to E-10 in Appendix E.

Note that since the present day 1% AEP and PMF design floods both adopt the same tailwater condition (i.e. the present day 1% AEP water level in Port Stephens of 1.8m AHD) the peak flood levels in Tilligerry Creek are similar (+/-50mm) downstream from Tanilba Bay Golf Club and downstream of Port Stephens Drive. This section of the creek is dominated by backwater flooding from Port Stephens. The peak flood levels in these design events diverge with distance upstream from Tanilba Bay Golf Club as the Hunter River flood inflows increasingly dominate in the PMF event. The PMF is 2m higher than the present day 1% AEP at Nelson Bay Road crossing of Tilligerry Creek. Along Main Drain, the PMF is 0.1m higher than the present day 1% AEP between Port Stephens Drive and Nelson Bay Road, and 0.2m higher upstream of Nelson Bay Road.

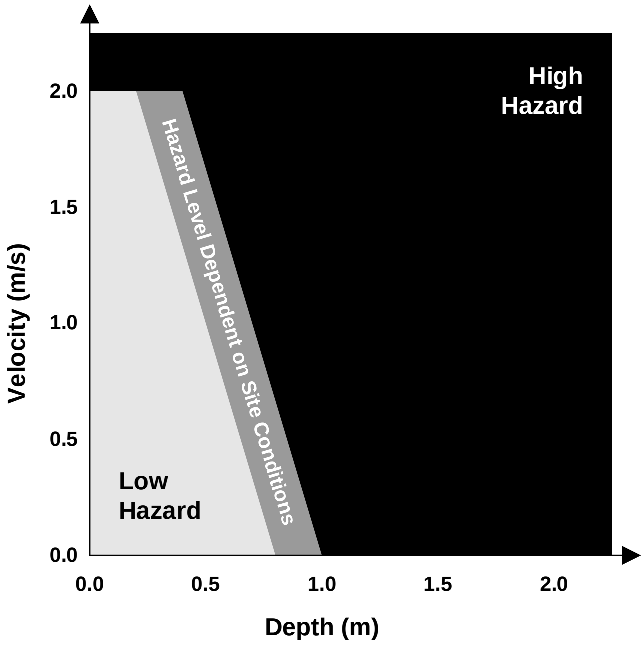
9.3 Flow Velocities

Flow velocities are mapped in m/s on Figures E-11 to E-15 in Appendix E. It is observed that apart from in the steeper, hilly parts of the study area where overland flow velocities are higher, flow velocities are typically slow as a result of flat terrain and high tailwater levels. Flow velocities in Main Drain and other drains are generally sluggish at velocities typically less than 0.5m/s. Higher flow velocities could be expected if a local catchment flood event coincided with lower tailwater levels, however, the higher tailwater levels were adopted to maximise the design flood level estimates. Lower tailwater is expected to result in higher velocities in the drains which would produce higher flood hazard rating (refer to Section 9.4). However, the hazard rating in the drains is high in any case due to the depths of water. The high tailwater runs therefore already capture the high flood hazard rating for the drain areas.

9.4 Provisional Flood Hazard

The TUFLOW modelling results were used to delineate the provisional flood hazard areas for the study area from interpretation of the present day 20%, 10%, 5%, 1% AEP and PMF event results, based on the hydraulic hazard category diagram presented in the *Floodplain Development Manual* (NSW Government, 2005), shown in Figure 9-1. The TUFLOW model calculates the hazard rating at each cell and computational time step, rather than calculating the rating based on the peak depth and peak velocity. The "transitional" hazard areas (hazard level dependent on site conditions) have been nominally classified as areas affected by high hazard flooding.

Figure 9-1 Hydraulic Hazard Category Diagram (reproduced from Figure L2 in NSW Floodplain Development Manual)



Hazard categories delineated in this study are based on depths and velocities of floodwaters and do not consider evacuation, isolation, flood damages and social impacts of flooding, hence, these categories are considered provisional. The provisional flood hazard mapping is presented in Appendix E.

Note that due to the relatively coarse grid size in the regional model, the provisional flood hazard mapping in the Anna Bay drains does not indicate the flood hazard in sufficient detail. It is observed that stretches of high flood hazard are broken up with stretches of low flood hazard in the drainage channels, which is not reflective of the actual conditions. It may be assumed that the drainage channels are subject to high flood hazard in all flood events due to the high depths of water in the channels. Note that the flood hazard rating of the channel and drain areas are not expected to be sensitive to the assumed high tailwater conditions. Even though if low tailwater conditions would result in higher velocities and potentially higher flood hazard rating in the drains, the flood hazard rating within the drains is expected to be high in any case due to the excessive flood depths within the drains.

9.5 Water Level Profiles

Long sections of design flood profiles for Main Drain, Back Drain and Fern Tree Drain are provided in Appendix E. The profiles show that the design flood levels in Main Drain are lower than the Tilligerry Creek peak water levels indicating that floodwaters backflow from the creek after overtopping the various road embankments and levees.

9.6 Flood Inundation Plots

Plots of flood level versus time are presented in Appendix E and indicate the durations of inundation of selected areas in the study area during the design flood events. The selected locations include roads and identified flood problem areas, and are shown on Figure E-25 in Appendix E.

9.7 Discussion on Flood and Drainage Behaviour

Refer to Figure 9-2 for the flooding areas discussed below. Note that all flooding issues may not have been identified, such as localised flooding and isolated issues with drainage and flow obstructions which may historically have occurred but are not captured by the modelling. The described flooding behaviour has been characterised based on the modelling of current day full permissible development (LEP 2013) and climate conditions. Flooding behaviour may change as a result of changes to catchment and development conditions and in response to climate change.

9.7.1 Flooding from Hunter River

Overflows from Fullerton Cove during major Hunter River flood events is identified as the cause of peak flooding in the Tilligerry Creek floodplain in the Williamtown – Salt Ash area upstream of this study area particularly in large events (WBM, 2005; BMT WBM, 2012). However, it has been observed in this study that this flooding mechanism causes peak flooding conditions in only a small portion of the study area, and only in large and extreme flood events.

As described in Section 2.3, the Fullerton Cove levee is overtopped by Hunter River floodwaters in the present day 5% AEP event and rarer. However the raised Nelson Bay Road embankment in Williamtown is a major obstruction to these floodwaters being conveyed to the east into the current study area and is only overtopped and significantly contributes to flooding in the current study area in events including and rarer than the present day 0.5% AEP event, as stated in BMT WBM (2005). Although there are minor flows through the road cross drainage culverts, these are relatively small flow rates and do not significantly contribute to flooding in the study area. Therefore, out of the flood events assessed in this study, only in the PMF does the Hunter River significantly contribute to flooding in the study area.

9.7.2 Main Drain, Back Drain and Fern Tree Drain

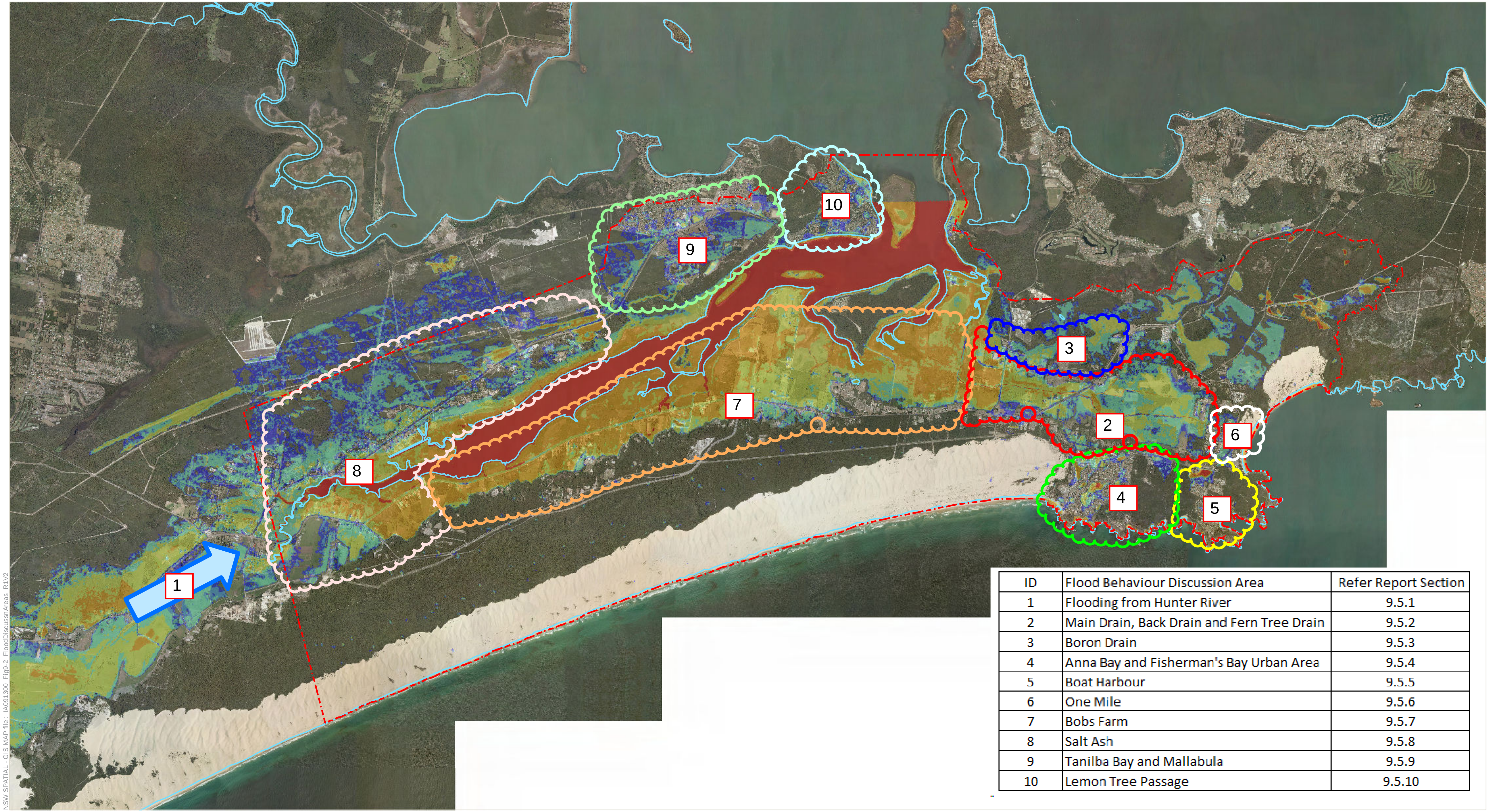
These major drainage channels drain the flat, low-lying rural areas of Anna Bay, discharging to Tilligerry Creek at Taylors Beach. The Main Drain flood gates are located 800m downstream of Port Stephens Drive which prevent normal high tide levels in Tilligerry Creek backing up Main Drain and inundating the low-lying rural areas. However, elevated ocean and tide levels overtop the levees at the flood gates and over Port Stephens Drive to then back up via the drains to upstream of Nelson Bay Road.

Port Stephens Drive is overtopped by tidal inundation in events above the 10% AEP event. Nelson Bay Road itself is not inundated in events up to and including the present day 1% AEP.

Peak flooding of the low-lying areas adjacent to Main Drain, Back Drain and Fern Tree Drain upstream of Nelson Bay Road is caused mainly by local catchment flooding, although this is impeded from draining by high tailwater levels. The elevated Port Stephens water levels can also cause flooding in moderately rare (5% AEP) events due to water backing up Main Drain.

Downstream of Nelson Bay Road the critical flooding mechanism is elevated tidal levels from Port Stephens.

Sea Winds Village at the corner of Gan Gan Road and Frosts Road is adjacent to the unnamed drain, which connects to Main Drain. The majority of this property is flood-free though the southern fringe may be affected by flooding in unnamed drain.



ID	Flood Behaviour Discussion Area	Refer Report Section
1	Flooding from Hunter River	9.5.1
2	Main Drain, Back Drain and Fern Tree Drain	9.5.2
3	Boron Drain	9.5.3
4	Anna Bay and Fisherman's Bay Urban Area	9.5.4
5	Boat Harbour	9.5.5
6	One Mile	9.5.6
7	Bobs Farm	9.5.7
8	Salt Ash	9.5.8
9	Tanilba Bay and Mallabula	9.5.9
10	Lemon Tree Passage	9.5.10

Refer to Section 9.5 of the report for discussion on the flood behaviour in each of the highlighted areas.

Figure 9-2 Areas for Flood Behaviour Discussion

Depths of flooding in the floodplain areas adjacent to the drains are up to 0.5m upstream of Port Stephens Drive, and exceeding 1m in areas downstream of Port Stephens Drive in the present day 20% AEP event. In the present day 1% AEP event these areas experience depths of up to 1m and 1.5m for the areas upstream and downstream of Port Stephens Drive, respectively.

Flooding upstream of Port Stephens Drive is mainly low flood hazard in up to the 5% AEP event on the floodplain areas outside of the drains. In the present day 1% AEP there are large areas of high hazard flooding in the area. Downstream of Port Stephens Drive the floodplain areas are predominantly high hazard areas in events rarer than the present day 10% AEP.

9.7.3 Boron Drain

Boron Drain is the drainage channel located north of Main Drain, joining Main Drain downstream of Port Stephens Drive. Residential and light industrial properties adjacent to Boron Drain on Port Stephens Drive are mainly affected by elevated Port Stephens water levels with some contribution from local catchment flooding.

Depths of flooding in the floodplain areas adjacent to Boron Drain are up to 0.5m upstream of Port Stephens Drive, and up to 0.9m in areas downstream of Port Stephens Drive in the present day 20% AEP event. In the present day 1% AEP event these areas experience depths of up to 0.7m and 1.2m for the areas upstream and downstream of Port Stephens Drive, respectively.

Flooding in this area outside of the drain is mainly low hazard in up to the present day 1% AEP.

9.7.4 Anna Bay and Fishermans Bay Urban Areas

There are a number of trapped low points in Anna Bay urban area in which local runoff collects and may cause flooding of properties and businesses. Major low points are located along Gan Gan Road including McKinley Swamp (between James Paterson Street and the town centre), Morna Point Road intersection, Anna Bay Public School and Clark Street low point. Flood detention basins are located adjacent to the Morna Point Road and Anna Bay Public School low points. These low points are drained by the stormwater network to McKinley Swamp, which is then drained by a pipe and culvert line to Fern Tree Drain, which joins Main Drain downstream of Nelson Bay Road. Flooding in the Anna Bay township is not significantly influenced by backwater from the lower areas of Fern Tree Drain near Nelson Bay Road.

The Clark Street low point is drained by a submersible pump, which pumps the water up the hill along Gan Gan Road to the stormwater system. However, this has a very low capacity (maximum 44L/s) and is insignificant compared to the local catchment inflow rates in even frequent events.

Other low points include:

- near Pacific Avenue/Davidson Street and at Clonmeen Avenue. These are drained by the Gan Gan Road stormwater network;
- The detention basin at Blake Parade and in the vegetated area to the south-east of Hanson Avenue (this latter area is undeveloped, but zoned for residential land use in the LEP). These are drained by the stormwater network along Argyle Street to the ocean. There are also sag points in the road at Morna Point Road/Blake Parade, and Argyle Road north of Scott Street; and
- There are several low points in the natural vegetated areas along Fishermans Bay Road, and to the north of Old Main Road near Anna Bay Public School, which are not drained by stormwater infrastructure.

Overland flows occur in roads including Essington Way and Dunmore Avenue. There are natural overland flow paths adjacent to Park Street and High Street in Fishermans Bay, and to the south of Clark Street low point.

During the present day 20% AEP event both detention basins on Gan Gan Road are expected to overtop or become drowned out by flooding from the road low points. This is attributed to the poor drainage capacity of the stormwater system.

Some properties in this area experience flood depths at the dwelling of 0.3 – 0.5m in the present day 20% AEP event, mainly in the Gan Gan Road and Morna Point Road intersection and at Clark Street low point, in addition to several properties in the residential area south of Gan Gan Road, including adjacent to Blake Street detention basin. Flooding depths on these properties exceed 0.7m in the 1% AEP.

In the PMF, there is widespread flooding affecting properties to depths exceeding 1m, with approximately 20 properties experiencing depths greater than 2m.

High flood hazard areas occur in the present day 20% and 10% AEP events in most of the low points identified above. They do not impact on properties.

High hazard flooding begins to impact properties adjacent to the Gan Gan Road and Morna Point Road low point and Clark Street low point in the 5% AEP event. There is also some high hazard flooding in Essington Way in the present day 5% AEP event which is confined to the road. In the 1% AEP event there is high hazard flooding affecting two properties to the south-east of the Blake Street detention basin.

9.7.5 Boat Harbour

Flooding in Boat Harbour urban area, south of Gan Gan Road, is generally caused by overland flows in the flow paths adjacent to Blanch Street and Boat Harbour Road, draining to Boat Harbour Beach. Overland flows may also occur in roads including Blanch Street and Hawkes Way.

The trapped low point in the vegetated area near Gan Gan Road and Blanch Street collects local runoff, ponding to depths exceeding 2m. There is a 375mm outlet pipe crossing under Gan Gan Road which discharges to the upper end of Main Drain, however it is located at a high elevation (5.5m AHD) which is above the present day 1% AEP flood level and therefore is ineffective at draining floodwaters from this low point. Flooding in the low point may rise to levels which inundate the low point of Gan Gan Road at this location to depths exceeding 0.5m. Flooding in this low point may also affect adjacent rural residential properties. This low point may eventually drain out via infiltration through sandy soils, however this infiltration has not been quantified and has therefore not been represented in the flood model.

Flooding depths on properties in Boat Harbour are generally shallow, although a number of properties experience flooding depths of 0.5m or more in the present day 20% AEP. Depths reach 1m in the 1% AEP on these properties.

Flooding in the Gan Gan Road/Blanch Street trapped low point does not affect properties in the present day 20% AEP, but approximately three dwellings are flooded by depths up to 0.5m in the 1% AEP. In the PMF event, approximately 10 dwellings would be affected by flood depths exceeding 2m.

High hazard flooding in the Gan Gan Road/Blanch Street does not directly impact on adjacent dwellings in up to the present day 1% AEP event, although there is close encroachment to several dwellings. There is also some high hazard flooding in Blanch Street and Hawkes Way in all events assessed which is confined to the road.

9.7.6 One Mile

The One Mile residential area in the vicinity of Eucalyptus Drive and Reflections Drive and other local roads are affected by local catchment flooding in addition to flood and tidal waters backing up from Main Drain. The area is served by a number of local drains connected to Main Drain. Most of the residences appear to be built on filled formations above the PMF level. Properties are generally flood-free in the 1% AEP, with yard flooding of up to 1m in the PMF.

Parts of the One Mile Beach holiday park near Hannah Parade are affected by local catchment flooding to depths of up to 0.5m, which drains out by a 450mm diameter pipe under Gan Gan Road to local drains and eventually Main Drain.

There are swampy areas in the undeveloped natural areas of One Mile which are flood affected. Rural residential properties in this area are generally above the present day 1% AEP level.

In the residential area, high hazard flooding is confined to the drainage channels and does not directly affect properties.

9.7.7 Bobs Farm

Flood-affected areas of Bobs Farm are mainly located north of Nelson Bay Road, caused predominantly by tidal inundation from Tilligerry Creek. The elevated tide levels overtop Marsh Road at a number of locations. Local catchment runoff also contributes to flooding, although this contribution is likely to be minor. The flood gate flaps on the culverts prevent backflow of the tide waters. Drainage of floodwaters from this area would be restricted by the elevated tide levels. Flooding on properties along Marsh Road are typically 0.5 – 1m in the present day 20% AEP with some deeper areas, and 1 – 2m deep in the present day 1% AEP. Peak present day 1% AEP flood levels in this area range from 1.86m AHD at the eastern end of Marsh Road, up to 1.92m AHD at the western end, occurring on both sides of Marsh Road. The Hunter River flooding significantly dominates the PMF, particularly at the western end of Marsh Road, with flood levels up to 1.4m higher than the local catchment PMF. At the eastern end of Marsh Road, this increment is reduced to 0.1m.

There are other flood-affected areas in Bobs Farm located to the south of Nelson Bay Road and east of the eastern end of Marsh Road which drain via culverts under Nelson Bay Road to Tilligerry Creek. These areas are dominated by local catchment flooding, although drainage is likely to be restricted by elevated tide levels. Flooding in this area is relatively minor with areas of inundation of 0.4m deep in the present day 20% AEP, and up to 0.8m in the present day 1% AEP.

Some isolated pockets of flooding may occur in large events in trapped low points between sand dune formations, resulting from local runoff. This water would eventually drain away by infiltration into the sandy soil.

High hazard flooding affects large areas of Bobs Farm in the 20% AEP event and rarer, particularly along Marsh Road and areas adjacent to Tilligerry Creek. These areas become very widespread in the present day 5% and 1% AEP events.

9.7.8 Salt Ash

Flooding in Salt Ash is dominated by local catchment runoff, elevated tides or overflows from the Hunter River, depending on the location and the AEP of the flood event. Areas of Salt Ash along Marsh Road are mainly affected by elevated tides. Overtopping and flooding of properties on the southern side of Marsh Road by elevated tides occurs in the same manner as described for Bobs Farm.

The areas to the south of Nelson Bay Road adjacent to Janet Parade are dominated by local catchment runoff in events up to the present day 5% AEP, but then are heavily influenced by tidal flooding in the present day 1% AEP when sections of Nelson Bay Road become overtopped by elevated tides and the local runoff is restricted from draining to the estuary. In the PMF, flooding in this area is dominated by the overflows from the Hunter River.

Flooding in areas adjacent to Tilligerry Creek to the south of Nelson Bay Road is not dominated by any particular flooding mechanism in the present day 1% AEP event, with only a small increment in peak flood levels between the Hunter River flood event (1.31m AHD) and the local catchment and tide flooding events (1.30 and 1.28m AHD, respectively). Local catchment flooding involves the catchment runoff on the Tilligerry Creek floodplain between Fullerton Cove and Nelson Bay Road. Again, in the PMF event flooding in this area is dominated by the overflows from the Hunter River. There is no development in this area and within the study area which is affected by the present day 1% AEP flood

On the southern side of Lemon Tree Passage Road and to the west of Brownes Road, tidal flooding is the dominant flooding mechanism with 1% AEP flood levels of 1.93m AHD. Some dwellings appear to be below this flood level.

In the vicinity of Brownes Road most properties are on land elevated above the 1% AEP tide level and hence these properties are mainly affected by local catchment flooding, although there is some development (mainly sheds) adjacent to the estuary and mangroves which are at low elevations and which would be affected by elevated tides. Most dwellings appear to be above the present day 1% AEP flood level.

The area on the northern side of Lemon Tree Passage Road are mainly affected by local catchment flooding, with runoff generated on the rural properties and on the natural vegetated and swampy areas to the north and uphill of these properties. The runoff flows in a generally south-east direction toward Lemon Tree Passage Road and is intercepted by a series of open drains which conveys flows to cross drainage culverts under Lemon Tree Passage Road. The road itself, in addition to other local roads including Michael Drive, Tonia Avenue, Francene Avenue and Rookes Road, are built on a raised embankment and obstructs flows from draining across the floodplain. Both the drains and the culverts have low capacities, and drainage through the culverts is restricted by elevated tailwater levels. Ground levels on the high side of Lemon Tree Passage Road are low (1 – 1.5m AHD) and hence properties may be affected by tidal inundation in the event that the Council-maintained floodgates on the culverts are not operating properly. During site inspection, it was observed that at a number of floodgates the gate flaps were obstructed from closing fully due to vegetation debris jamming the gates partially open. In this scenario backflow of tidal waters would inundate the upstream properties. However, peak flood levels in this area are caused by local runoff events, with modelling indicating that the flood levels are insensitive to the partial opening of the floodgates (refer to Section 9.12 and Table 9-4 for discussion on sensitivity analysis). Therefore, for the purposes of the design flood estimation it is assumed that the floodgates are operating properly and prevent backflow.

Flooding depths on the properties on the northern side of Lemon Tree Passage Road in Salt Ash is up to 0.3 – 0.5m in the present day 20% AEP event, and up to 0.8m in the present day 1% AEP event. Approximately half of dwellings in this area appear to be below the 1% AEP flood level. Some properties also appear to be below the present day 20% AEP flood level. The Hunter River flooding significantly dominates the PMF, with flood levels up to 2m higher than the local catchment generated PMF.

High flood hazard areas in the Marsh Road area of Salt Ash are widespread, particularly in the 10% AEP event and rarer. In other areas of Salt Ash, high hazard flooding is mainly confined to the drainage channels in events up to the present day 1% AEP event.

9.7.9 Tanilba Bay and Mallabula

Flooding in the Tanilba Bay and Mallabula urban area is caused by local catchment runoff which then collects in low points, mainly road sags as well as swales along some roads and in several detention basins in the urban area. Significant areas of flooding include Lloyd George Grove at President Wilson Walk, Tilligerry Track, swales adjacent to Avenue of the Allies, Poilus Parade, Pershing Place, Clemenceau Crescent and a low point on the corner of Lemon Tree Passage Road and Avenue of the Allies. Flooding depths in these sag points is typically 0.3m but reaches up to 0.7m at Lloyd George Grove at President Wilson Walk and in Tilligerry Track in the present day 1% AEP. A number of properties are affected by flooding in these areas, particularly those adjacent to Lloyd George Grove at President Wilson Walk. These areas drain via the stormwater network, open channels and culverts under Lemon Tree Passage Road, discharging to open channels in Tanilba Bay Golf Club which then discharge to Tilligerry Creek. Areas to the east of President Wilson Walk drain via a series of detention basins then to the east via open channels, before discharging via culvert into the open area south of Lemon Tree Passage Road, opposite Mallabula Sports Complex. Limited drainage capacity is the main contributor to these flooding issues.

Flooding also occurs in Success Street as a result of stormwater surcharging from the pipe system and then collecting in the sag point of this street. This was observed by local residents during recent flooding events and caused inundation of properties. The local catchment draining to this location is relatively small and it is not likely to be a main contributor to flooding in this area.

High flood hazard areas are limited to drainage channels, swales and detention basins in events up to the present day 1% AEP event.

9.7.10 Lemon Tree Passage

Flooding in Lemon Tree Passage is mainly caused by local catchment runoff and overland flooding, however, roads and properties along the foreshore of Tilligerry Creek are low lying and are affected by elevated tide levels.

Overland flows occur in the vicinity of Daniel Crescent, Blanch Street, Meredith Avenue, Cambridge Avenue and Dean Parade. Overland flows are generally 0.2 – 0.4m deep in the 1% AEP event. There are also several low points in the terrain at Meredith Avenue at Mackie Street and near Gould Drive, and near Paroa Avenue, where local runoff and elevated tides can pond to depths exceeding 0.5m in the present day 1% AEP event.

Flooding in Cook Parade exceeds 0.5m as a result of tidal inundation. Flooding in John Parade is 0.3 – 0.5m due to tidal inundation.

A number of properties in Lemon Tree Passage are affected by overland flooding, although the worst-affected properties are those in the vicinity of the Paroa Avenue low point which is a collection point for local runoff, and those at Meredith Avenue at Mackie Street and along Cook Parade which are susceptible to tidal inundation. Flood depths on properties are typically up to 0.3m in the present day 20% AEP event and up to 0.5m in the present day 1% AEP event in these locations.

High flood hazard areas are generally limited to the immediate foreshore area, drainage channels and swales in events up to the present day 1% AEP event. There is also high flood hazard area in the vegetated low point on Kenneth Parade opposite Club Lemon Tree, in addition to localised areas in Mackie Street. No properties appear to be affected by high hazard flooding in up to the present day 1% AEP event.

9.8 Inundation of Roads

An analysis of the AEP at which roads become inundated and cut off by floodwaters was undertaken at 29 locations in the study area. This is based on the flood event AEP at which the roads become affected by peak depths exceeding 0.3m at the crown of the road, above which it is assumed that access by larger emergency services vehicles (four-wheel drives, trucks, etc.) may start to become restricted. Note that shallower depths than 0.3m, potentially down to 0.2m, are likely to be hazardous to normal passenger vehicles.

The locations for the analysis were generally on main roads and some local access roads which are likely to be required for emergency access. The selected locations are at the main identified low points on these roads, and are shown on Figure 9-3. The event AEPs at which each location becomes cut off are summarised on Table 9-1.

ID	Location	ID	Location
1	Gan Gan Rd at Morna Point Rd	16	Lemon Tree Passage Rd 120m south of Michael Dr
2	Gan Gan Rd Clark St low point	17	Lemon Tree Passage Rd 100m north of Michael Dr
3	Gan Gan Rd 250m west of Blanch St	18	Rookes Rd 500m north of Lemon Tree Passage Rd south end
4	Northern end Eucalyptus Dr	19	Rookes Rd 240m west of Lemon Tree Passage Rd north end
5	Nelson Bay Road 270m north of Gan Gan Road south end	20	Lemon Tree Passage Rd 500m north of Rookes Rd south end
6	Nelson Bay Road 850m north of Gan Gan Road south end	21	Lemon Tree Passage Rd 450m south of Rookes Rd north end
7	Nelson Bay Road 160m north of Frost Road	22	Lemon Tree Passage Rd 1.2km east of Oyster Cove Rd
8	Port Stephens Dr 820m north of Nelson Bay Rd	23	Tilligerry Track at President Poincare Pde
9	Research Dr Wallis Ck crossing	24	South end Ave of the Allies
10	Nelson Bay Rd 500m east of Marsh Rd east end	25	Llyoyd George Grove at President Wilson Walk
11	Nelson Bay Rd at Marsh Rd west end	26	Lemon Tree Passage Rd 180m east of Oyster Farm Rd
12	Nelson Bay Rd 720m west of Marsh Rd west end	27	Lemon Tree Passage Rd 170m west of Industrial Cres
13	Marsh Rd 650m from Nelson Bay Rd west end	28	Meredith Ave at Mackie St
14	Nelson Bay Rd 600m east of Lemon Tree Passage Rd	29	Cook Pde 80m north of Meredith Ave
15	Marsh Rd 1.5km from Nelson Bay Rd east end		

Legend

Road Inundation Assessment Location

Study Area

0 1 2 3 4 5 Kilometres

N

1:75,000@ A3

NSW SPATIAL - GIS MAP file : IA091300_Fig9-3_RoadInundation_Locs_R1V2

JACOBS

Figure 9-3 Road Inundation Assessment Locations

Table 9-1 Frequency and depth of flooding of selected roads

ID	Location	Road Level (m AHD)	Flood Depth (m)					AEP when road cut off*
			20% AEP	10% AEP	5% AEP	1% AEP	PMF	
1	Gan Gan Rd at Morna Point Rd	3.1	0.30	0.45	0.57	0.71	2.16	20%
2	Gan Gan Rd Clark St low point	5.13	0.45	0.47	0.49	0.65	1.98	<20%
3	Gan Gan Rd 250m west of Blanch St	3.55	0.08	0.08	0.08	0.41	3.97	1-5%
4	Northern end Eucalyptus Dr	1.78	0.12	0.12	0.12	0.13	0.48	>1%
5	Nelson Bay Road 270m north of Gan Gan Road south end	1.65	-	-	-	-	0.52	>1%
6	Nelson Bay Road 850m north of Gan Gan Road south end	1.92	-	-	-	-	0.28	>1%
7	Nelson Bay Road 160m north of Frost Road	3.98	-	-	-	-	0.91	>1%
8	Port Stephens Dr 820m north of Nelson Bay Rd	1.23	-	-	0.32	0.51	0.63	5%
9	Research Dr Wallis Ck crossing	1.5	0.05	0.05	0.24	0.35	0.37	1-5%
10	Nelson Bay Rd 500m east of Marsh Rd east end	1.94	-	-	-	-	0.07	-
11	Nelson Bay Rd at Marsh Rd west end	1.66	-	-	-	0.06	2.34	>1%
12	Nelson Bay Rd 720m west of Marsh Rd west end	1.84	-	-	-	-	2.18	>1%
13	Marsh Rd 650m from Nelson Bay Rd west end	1.11	0.23	0.33	0.69	0.81	2.23	10-20%
14	Nelson Bay Rd 600m east of Lemon Tree Passage Rd	1.87	-	-	-	-	2.38	>1%
15	Marsh Rd 1.5km from Nelson Bay Rd east end	1.03	0.41	0.47	0.72	0.84	1.01	<20%
16	Lemon Tree Passage Rd 120m south of Michael Dr	1.78	-	0.06	0.11	0.23	2.44	>1%
17	Lemon Tree Passage Rd 100m north of Michael Dr	1.73	-	-	0.02	0.14	2.34	>1%
18	Rookes Rd 500m north of Lemon Tree Passage Rd south end	1.88	-	-	-	-	1.73	>1%
19	Rookes Rd 240m west of Lemon Tree Passage Rd north end	2.33	-	-	-	0.16	0.58	>1%
20	Lemon Tree Passage Rd 500m north of Rookes Rd south end	2.21	-	-	-	-	1.34	>1%
21	Lemon Tree Passage Rd 450m south of Rookes Rd north end	2.2	-	-	-	-	0.77	>1%
22	Lemon Tree Passage Rd 1.2km east of Oyster Cove Rd	3.73	-	0.02	0.10	0.19	0.49	>1%
23	Tilligerry Track at President Poincare Pde	7.19	0.50	0.52	0.55	0.64	1.04	<20%
24	South end Ave of the Allies	7.49	-	0.04	0.07	0.11	0.72	>1%
25	Lloyd George Grove at President Wilson Walk	7.41	0.42	0.46	0.52	0.65	1.09	<20%
26	Lemon Tree Passage Rd 180m east of Oyster Farm Rd	7.73	0.29	0.30	0.31	0.34	0.63	10%
27	Lemon Tree Passage Rd 170m west of Industrial Cres	8.33	0.06	0.06	0.07	0.12	0.83	>1%
28	Meredith Ave at Mackie St	1.74	0.13	0.17	0.26	0.35	0.93	1-5%
29	Cook Pde 80m north of Meredith Ave	1.26	0.30	0.45	0.57	0.71	2.16	20%

* Road is deemed to be cut-off when depth over road exceeds 0.3m.

The following observations are made about the road inundation:

- The main roads of Nelson Bay Road and Lemon Tree Passage Road in the study area are generally accessible in events up to and including the present day 1% AEP, but would become cut off at a number of locations during the PMF.
- Roads which are susceptible to becoming cut off include Gan Gan Road, Marsh Road, Tilligerry Track, President Wilson Walk and Cook Parade, with inundation to depths greater than 0.3m in the present day 20% AEP event and smaller.
- The analysis does not consider whether roads outside of the study area become cut off by flooding, therefore restricting access during flood events. These roads include Nelson Bay Road and Richardson Road in Williamtown, which would limit access from the west.
- Adoption of a lower cut-off depth of inundation would increase the frequency at which the roads are deemed to be cut-off.
- Flood depth indicator signs are recommended for roads which become cut-off in the present day 10% AEP event or more frequent. These are roads which are frequently flooded and are likely to experience significant depths of flow.

9.9 Flood Affectation of Properties

Properties in the study area have been classified based on the minimum flood AEP at which the property becomes flood-affected. For the purposes of this assessment, a property is considered “flood-affected” when it becomes more than 20% covered by floodwaters over 0.15m deep. This filter has been applied to exclude shallow flows of water which may not be considered as flooding.

The number of properties affected by varying maximum flood depths in each flood AEP are summarised in Table 9-2 and includes private properties as well as public property and other reserves and open space. There are 5,241 properties in total in the study area. The maximum flood depth may not reflect the flood depth at the dwelling.

Table 9-2 Count of properties by maximum flood depth on each property*

Depth (m)	Design Flood Event				
	20% AEP	10% AEP	5% AEP	1% AEP	PMF
>0.15	688	774	955	1168	2508
>0.3	645	737	910	1138	2479
>0.5	471	535	645	863	2165
>1.0	285	320	373	440	1389
>2.0	78	89	104	142	561
Total	688	774	955	1168	2508

* For properties with >20% coverage by floodwaters over 0.15m deep. Number of properties with a maximum depth exceeding the depth category Example: in the 10% AEP there are 737 properties with a maximum flood depth of 0.3m or more.

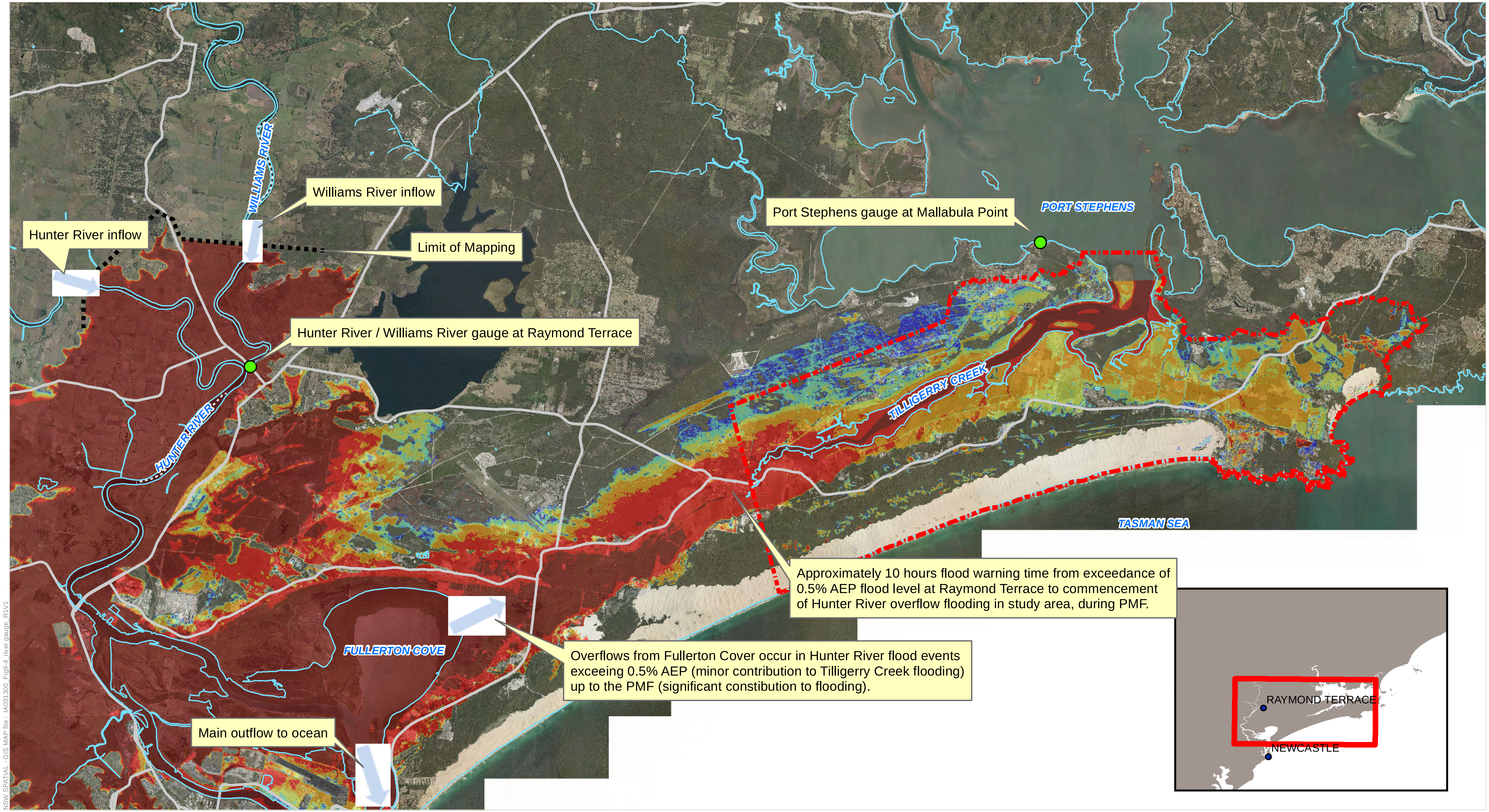
** Total of 5,241 properties in the study area.

9.10 River Level Gauges and Flood Warning

There is a water level gauge at Mallabula Point operated by Manly Hydraulics Laboratory (NSW Department of Finance, Services and Innovation, Station number 209461) which measures water levels in Port Stephens. The detection of elevated water levels at this gauge are unlikely to be useful for flood warning purposes as the gauge is in the immediate vicinity of the study area and there is unlikely to be a significant timing difference between the gauge and water levels in Tilligerry Creek. The gauge level is based on Port Stephens Hydro Datum, and should be adjusted by -0.959m to convert to Australian Height Datum (m AHD).

While flooding in the study area is dominated by tidal and local catchment flooding for events up to the 1% AEP, flood overflows from the Hunter River via Fullerton Cove may contribute to flooding in events rarer than the 0.5% AEP event up to the PMF (WBM, 2005). Note that the 0.5% AEP Hunter River flood just overtops Nelson Bay Road and only has a minor contribution to flooding in the study area.

The PMF would result in significant flooding depths exceeding 2m and velocities exceeding 1m/s. Flood flows would come from the west, which would not be the direction of flow that residents may be accustomed to. There would be warning of such flooding occurring by observation of flood levels at river gauges on the Hunter River at Raymond Terrace (MHL Station 210452/BOM Station 561037) and other upstream locations. If there is a PMF event in the Hunter River, there is approximately 10 hours warning time from when the river level at Raymond Terrace exceeds 5.2m AHD (the 0.5% AEP peak flood level at Raymond Terrace) and when the Hunter River overflows reach the study area. The gauge at Raymond Terrace is based on Australian Height Datum. Refer to Figure 9-4 for the locations of the water level gauges and PMF behaviour.



Legend

Peak flood depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- > 4.0
- Study Area
- Main Road
- Waterway

0 1 2 3 4 5 Kilometres

N

1:125,000 @ A3

Figure 9-4 River Gauge Locations and PMF Behaviour

9.11 Validation of Results

The modelling results from this study are compared to previous flood studies in the study area. Some of the modelling and outcomes from previous studies were used directly as inputs into the current modelling, including those from the Williamtown – Salt Ash flood study/Floodplain Risk Management Study, and Port Stephens flood and climate change studies. The results are therefore expected to be directly comparable and hence not used in the validation. The model validation is discussed on a location basis below.

9.11.1 Main Drain between Nelson Bay Road and outlet to Tilligerry Creek

Sinclair Knight Merz (1995) quoted preliminary estimates of design flood levels at the mouth of Tilligerry Creek from PWD (1993) of up to 2.2m AHD for the 1% AEP event in Port Stephens, though noting that the PWD study was still underway at that time and more reliable estimates would be forthcoming. The final 1% AEP design water level determined by PWD (1993) was 1.8m AHD, which was adopted in this current study.

Nevertheless, Sinclair Knight Merz (1995) suggested that 2.2m AHD could be applied as a design flood level for low lying areas of Anna Bay. This did not consider that the elevated tailwater levels are not static, and that the levees in line with Main Drain floodgates and embankments at Port Stephens Drive and Nelson Bay Road would obstruct and limit the volume of tidal water which can backflow up Main Drain. As a result of these considerations, the current TUFLOW modelling estimates a peak 1% AEP flood level downstream of Nelson Bay Road of 1.48m AHD due to the lower adopted tailwater levels and consideration of the levee and embankment flow obstructions.

Sinclair Knight Merz (1995) did assume a reduced tailwater level of 1.7m AHD for their hydraulic modelling, which is similar to what is adopted in this study. This previous flood study, utilising a steady state HEC-2 flood model, estimated peak flood levels at in Main Drain at Nelson Bay Road of 1.99m AHD which is significantly higher than the current estimate of 1.46m AHD. This is attributed to the HEC-2 model being a backwater calculation model, which takes the static tailwater level and projects it upstream with the flood gradient determined by the catchment inflows. Further, the previous modelling cross sections do not extend across the entire floodplain determined by this flood study, and as it is a steady flow model the floodplain storage and detention of flood flows is not accounted for. Both these factors would contribute to higher flood estimates by underestimating the flow cross sectional area and overestimating the flow rates. However, as highlighted before, the main driver behind the variance in flood levels is because the current modelling considers the obstructions in the floodplain in limiting the volume of backflow of high tailwater levels, which is the primary driver of peak flooding in the 1% AEP event in the Main Drain floodplain, while the Sinclair Knight Merz (1995) does not. The current modelling is therefore considered a more reliable estimator of flooding in the Main Drain area.

Flow through the Main Drain Nelson Bay Road culverts in the 1% AEP event were compared between the two studies, and were observed to be 8m^3/s in the Sinclair Knight Merz (1995) study, and 4.7m^3/s in the current study. This is attributed to the significant floodplain storage effects in the current TUFLOW model and the poor drainage due to high tailwater levels downstream of the culvert.

Flows in the 1% AEP event were also compared for the culvert flows on Fern Tree Drain at Nelson Bay Road, and were found to be comparable, with 3.3m^3/s from the Sinclair Knight Merz (1995) study, and 2.6m^3/s in the current study. The variance is likely to be due to floodplain storage being accounted for in the current study, along with the stormwater detention basins being implemented in Anna Bay since the 1995 study.

9.11.2 Main Drain Floodplain upstream of Nelson Bay Road

Given the large discrepancy between the current design flood level estimates and that from previous studies, further validation of the flood model results was undertaken. A comparison was undertaken of volumes derived separately from the rainfall excesses in the hydrologic model, inflow volumes into the hydraulic model and the volume of flood waters in the hydraulic model in the Main Drain floodplain upstream of Nelson Bay Road. The volumes were all observed to be similar (approximately 1,300,000m^3) and hence there is confidence that the flooding in this area as well as other areas is not being underestimated due to lost or missing inflow volumes in the modelled system.

9.11.3 Anna Bay Town Catchment Area

Flood levels in Parsons Brinkerhoff (2004) at a number of locations in the Anna Bay town catchment area are tabulated in that report and have been summarised in comparison with flood levels from this current study in Table 9-3. Locations are based on the Parsons Brinkerhoff modelling and are shown on Figure 9-5. The modelling from the Parsons Brinkerhoff study is largely based on the previous modelling by Sinclair Knight Merz (1995) updates to account for changes in the drainage system and addition of flood detention basins in Anna Bay. The Parsons Brinkerhoff study is therefore the most suitable for the current model validation as the catchment conditions are similar.

Flood levels in the two studies are similar at the lower end of Fern Tree Drain (node 10g, 10f) however it is observed that further upstream (10d, 10e) there is some variance in the flood levels of up to 0.25m.

At node 2b (McKinley Swamp) flood levels are significantly higher in the current study due to the model terrain representing a flow control point of 3.45m AHD. This is a high point in the land surface near Old Main Road. In contrast the Parsons Brinkerhoff (2004) modelling only picks up the crown level on Gan Gan Road of 2.62m AHD. This explains the higher flood levels in this location in the current study, and would result in higher outflows from the Swamp in the 2004 modelling, which may explain the higher flood levels in Fern Tree Drain at nodes 10d and 10e. Changes in the drain invert levels may also be a factor in the differences, however cross sectional data is not available from the previous study to confirm this.

On the reach of Fern Tree Drain behind Old Main Road (nodes 10b and 10c) the higher flood levels in the Parsons Brinkerhoff (2004) study may be explained by approximately twice the peak flow in the drain. This is due to the flows from node 10a being conveyed through to 10b, whereas in the current modelling the catchments draining to 10a flow to a trapped low point and do not flow on to 10b.

Flood levels in the detention basins (node 3b and 3d) are higher in the current study, most likely due to the higher tailwater levels in McKinley Swamp preventing better drainage of the basins through the stormwater system.

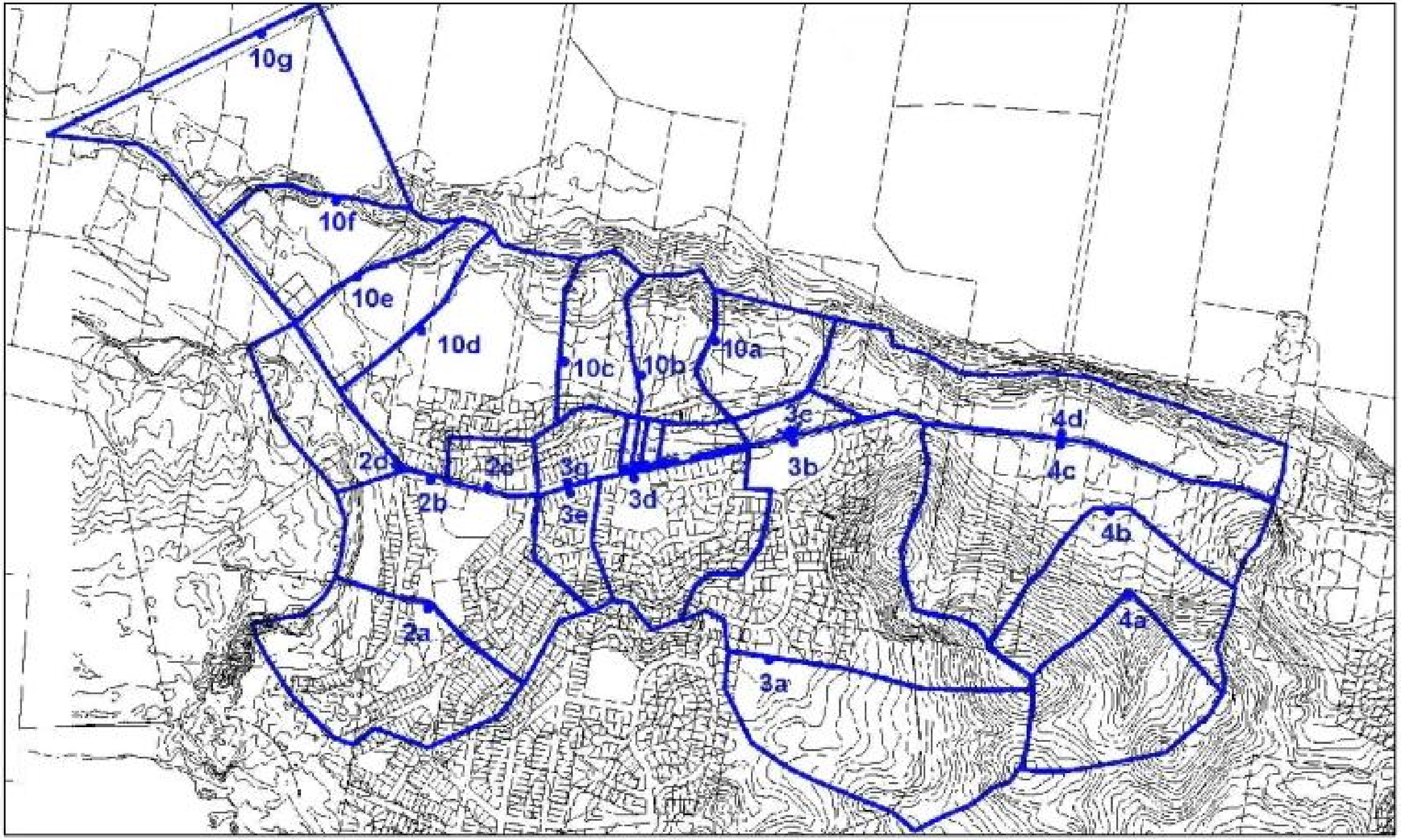
The flood levels at the Clark Street low point are similar for the 1% AEP, but differ by 0.5m in the 10% AEP with the current study estimating a higher level. It is unclear what pumping rate has been assumed in the Parsons Brinkerhoff study to validate this result.

Table 9-3 Comparison of Estimated Design Flood Levels with Parsons Brinkerhoff (2004) in Anna Bay Town Catchment Area

Node*	10% AEP		1% AEP		Comment
	PB (2004)	Jacobs (2017)	PB (2004)	Jacobs (2017)	
10a	4.12	Not flooded	4.18	Not flooded	Flows are 2.5m^3/s in PB, 1.5^3/s in Jacobs. Catchment 10a in PB (2004) is assumed to flow into Fern Tree Drain but the LiDAR suggests flows are trapped in a low point
10b	1.90	1.66	2.11	1.75	
10c	1.79	1.59	1.93	1.71	
10d	1.74	1.46	1.88	1.63	
10e	1.5	1.36	1.78	1.60	
10f	1.33	1.31	1.65	1.54	
10g NBR	1.21	1.19	1.52	1.39	
2b McKinley Swamp	2.42	2.93	3.05	3.58	The current TUFLOW model and LiDAR picks up a high point/crest to the north of the swamp and Gan Gan Road at 3.45m AHD north of Old Main Road which controls the flood level in the swamp. PB modelling has a weir level of 2.62m AHD hence lower flood level in PB study.
3d Basin 1	3.4	3.61	3.64	3.81	
3b Basin 2	4.21	4.6	4.52	4.68	
4c Groundwater pump	5.14	5.65	5.78	5.77	

* Refer to Figure 9-5 for node locations.

Figure 9-5 Parsons Brinkerhoff (2004) flood model node locations



9.12 Sensitivity Analysis

A number of scenarios have been assessed for the 5% and 1% AEP flood event to test the sensitivity of the model results to changes in the adopted parameter values, including:

- Rainfall losses – decreased
- Hydraulic roughness – decreased
- Hydraulic roughness – increased
- Blockage of hydraulic structures – increased
- Floodgates partially open to backflow

The scenarios are described and the impacts summarised in Table 9-4. The changes in flood levels are mapped in Appendix F.

9.13 Climate Change Analysis

The NSW Floodplain Development Manual (DIPNR, 2005) requires consideration of climate change in the preparation of Floodplain Risk Management Studies and Plans, with further guidance provided in:

- Floodplain Risk Management Guideline – Practical Consideration of Climate Change (DECC, 2007); and
- Flood Risk Management Guide – Incorporating Sea Level Rise Benchmarks in Flood Risk Assessments (DECCW, 2010).

Council's Sea Level Rise Policy, formally adopted in May 2009, incorporates the State-wide sea level rise planning benchmarks applicable at the time and which are covered in the two documents listed above. The Sea Level Rise Policy sets another policy requirement for consideration of climate change in flood studies in Port Stephens LGA.

Key elements of future climate change (e.g. sea level rise, rainfall intensity) are therefore important considerations in the ongoing floodplain risk management in the study area. The impact of climate change on flooding in the study area has been assessed for a range of scenarios, including:

- Year 2050 sea level (+0.4m), current rainfall intensity
- Year 2050 sea level (+0.4m), 10% increase in rainfall intensity
- Year 2050 sea level (+0.4m), 20% increase in rainfall intensity
- Year 2100 sea level (+0.9m), current rainfall intensity
- Year 2100 sea level (+0.9m), 20% increase in rainfall intensity
- Year 2100 sea level (+0.9m), 30% increase in rainfall intensity.

The 5% and 1% AEP events were analysed and impacts determined, in terms of changes from the design flood levels (current sea level and rainfall). The PMF was also assessed in combination with the year 2100 sea level rise scenario to assist with future emergency planning. The peak flood depths and the change in flood levels for the climate change scenarios are mapped in Appendix G.

Table 9-4 Sensitivity Analysis Description and Results Summary

Scenario	Sensitivity Parameter Value	Change in Flood Level compared to design flood levels
Rainfall losses – decrease	Initial Losses 0mm Continuing Losses 50% of design values	No change along Tilligerry Creek including Marsh Road as flooding is mainly dominated by tailwater. Main Drain floodplain: 0.06 – 0.1m increase in 1% and 5% AEP Blanch Street low point: +0.3m in 5% AEP, +0.36m in 1% AEP Clark Street low point: +0.12m in 5% AEP, +0.10m in 1% AEP McKinley Swamp: +0.3m in 5% AEP, +0.1m in 1% AEP Other main storages and ponding areas: typically +0.1m to +0.2m increase in 1% and 5% AEP Overland flow areas: typically < 0.05m.
Friction – increase	+20% of design values	Generally insensitive (+/- 0.05m)
Friction – decrease	-20% of design values	Generally insensitive (+/- 0.05m). Localised areas up to +/- 0.1m Up to +0.08 in Main Drain floodplain between Port Stephens Drive and Nelson Bay Road.
Blockage - increase	Set at a blockage factor of 90% for culvert inlets and stormwater pit inlets (design values range from 20 – 50% blockage factor)	No change along Tilligerry Creek including Marsh Road as flooding is mainly dominated by tailwater. Main Drain floodplain downstream of Nelson Bay Road: No change or up to +0.03m in 1% and 5% AEP Main Drain floodplain upstream of Nelson Bay Road: -0.01m in 1% and 5% AEP. Flows are held back in upstream areas due to the blockage. One Mile residential area: +0.35m in 5% AEP, +0.3m in 1% AEP Blanch Street low point: +0.09m in 1% and 5% AEP. Blockage of local street drainage results in increased runoff to the low point. Clark Street low point: No change McKinley Swamp: +0.54m in 5% AEP, +0.17m in 1% AEP Anna Bay shops low point: +0.2m in 5% AEP, +0.17m in 1% AEP Morna Point Road low point: +0.09m in 5% AEP, +0.06m in 1% AEP Other ponding areas in Anna Bay: +0.1m to +0.3m Northern side of Lemon Tree Passage Road in Salt Ash: +0.1m to +0.5 in 5% AEP, +0.1m to +0.2m in 1% AEP Low points in Tanilba Bay and Lemon Tree Passage: less than 0.05m Overland flows in urban areas: typically insensitive (< +0.05m), some flow paths in Boat Harbour to +0.15m

Scenario	Sensitivity Parameter Value	Change in Flood Level1
Floodgates partially open	Floodgates 10% open with a 50% debris blockage (i.e. 95% blocked) in the backflow direction. Assumed 50% blocked in the forward flow direction	Insensitive (< +0.02m).

Large areas of the study area have existing development on low lying terrain, at elevations of 0.5 – 2m AHD. These areas, including Marsh Road in Bobs Farm and Salt Ash and the northern side of Lemon Tree Passage Road in Salt Ash, are already susceptible to elevated tides and water levels during Port Stephens coastal and riverine flooding events, when tailwater levels may reach up to 1.8m AHD in the 1% AEP event. Depths of flooding on these low lying areas may therefore be expected to reach up to 2m or more in the year 2100 sea level rise flooding scenarios. Elevated 1% AEP event water levels in Tilligerry Creek would be approximately 2.2m AHD and 2.7m AHD at the year 2050 and 2100 horizons. Increased runoff in the 1% AEP event with 30% increase in rainfall intensity results in increases in flood depths in Anna Bay and other low points of approximately 0.2m, with up to 0.56m increase in Blanch Street low point.

Flood levels in the area between Port Stephens Drive and Nelson Bay Road increase more than the sea level rise, as the increased sea levels and tailwater levels in the climate change cases are able to overtop the various road embankments and levees to greater depths, allowing greater backwater inflow and flood levels in this area to equilibrate with the Tilligerry Creek flood level. In the current climate conditions, the flood levels in this area are lower than Tilligerry Creek due to the lesser backwater inflows over the embankments and through culverts.

Increases in flood levels in overland flow areas are generally not sensitive to the increased rainfall intensity in the climate change scenarios, typically less than 0.15m increase in the 30% rainfall increase scenario for the 1% AEP event. Trapped low points, ponding and storage areas respond more to the increased rainfall intensities and inflow volumes, with flood level increases of 0.3 – 0.5m typical for areas such as Blanch Street low point, Clark Street low point and McKinley Swamp.

In the PMF with year 2100 (+0.9m) sea level rise scenario, flood levels in the lower and middle section of Tilligerry Creek and to the west of Port Stephens Drive are 0.8 – 0.9m higher than for the current climate conditions. In the upper section of Tilligerry Creek to the western end of the study area flood levels are 0.1 – 0.75m higher than for the current climate conditions. In the Anna Bay Main Drain floodplain to the east of Port Stephens Drive flood levels are up to 0.4m higher than for the current climate conditions.

The depths of flooding over a number of key roads would be increased from the existing climate PMF, including Nelson Bay Road to the east of Marsh Road (eastern end), Marsh Road itself, Port Stephens Drive, Gan Gan Road through One Mile, and the western end of Lemon Tree Passage Road. This may affect emergency access on these roads in terms of depths experienced and the timing and duration of flooding.

Overland flow areas above 3m AHD generally do not experience greater flood levels, as the PMF rainfall is not increased in the climate change scenario and the overland flow areas are above the influence of sea level rise.

9.14 Provisional Flood Planning Level and Flood Planning Area

9.14.1 General

The flood planning area is defined by the extent of the area below the flood planning level (FPL) and delineates the area and properties where flood planning controls are proposed, for example, minimum floor levels to ensure that there is sufficient freeboard of building habitable floor levels above the design flood. Other controls may be considered, such as policies on fence construction to ensure flow paths are unobstructed, or rezoning.

Port Stephens Council has adopted the 1% AEP flood in climate change scenario of the year 2100 (+0.9m sea level) and 20% increase in rainfall intensity for the flood planning level design flood. A comparison between the ARR 1987 design rainfall IFD's with the recently released ARR 2016 IFD's indicated a general 20% increase in rainfall estimates. ARR 1987 IFD's were adopted as the best available data at the time of modelling however this comparison supports the use of increased rainfall intensities from a planning context.

A freeboard of 0.5m has been adopted by Council across Port Stephens LGA according to Council’s Floodplain Risk Management Policy. This freeboard level which is applicable to all types of flooding including mainstream flooding and overland flow flooding.

A reduced freeboard of 0.3m has been considered for adoption by Council for areas affected by overland flows. This would reflect the generally lower magnitude and shallower flows and lower allowance required in the flooding conditions for factors such as wind waves over floodwaters, which can raise the high water marks above still water flood levels. A reduced freeboard for overland flood areas has been adopted by other Councils in NSW. Adoption of a 0.3m freeboard for overland flow areas would require an amendment of the Floodplain Risk Management Policy.

The provisional flood planning area mapping is shown in Appendix H and shows the flood planning area with the adopted 0.5m freeboard as per Council policy. The outline with a 0.3m freeboard in overland flow areas is also shown for comparison. The mapping is denoted provisional subject to feedback from Council and the Floodplain Advisory Panel, and adoption by Council.

In this study area, the area deemed to be affected by mainstream flooding largely includes the Tilligerry Creek floodplain, up to an FPL elevation of 3.2m AHD. This level relates to a Port Stephens current climate 1% AEP water level of 1.8m AHD + 0.9m sea level rise + 0.5m freeboard. Above this elevation, flooding is deemed to be overland flow flooding, and the FPL is the maximum of 3.2m AHD or the FPL design flood level + 0.3m freeboard.

On the Anna Bay Main Drain and Fern Tree Drain floodplains, the mainstream FPL is lower than 3.2m AHD. The main source of flooding in these areas is from the Tilligerry Creek elevated water levels, which are restricted from backflowing up to the floodplain upstream of Nelson Bay Road by culverts and levees. The mainstream flooding FPL in the floodplain upstream of Nelson Bay Road varies from 2.89m to 3.0m AHD.

It was considered appropriate to delineate the flood planning area on the more significant flow paths and not on those with shallow flows which may be considered sheet flow and “drainage”, and are unlikely to pose a risk to private property. These shallow flow paths are presented on other flood mapping to show continuity of flow paths through the catchment area.

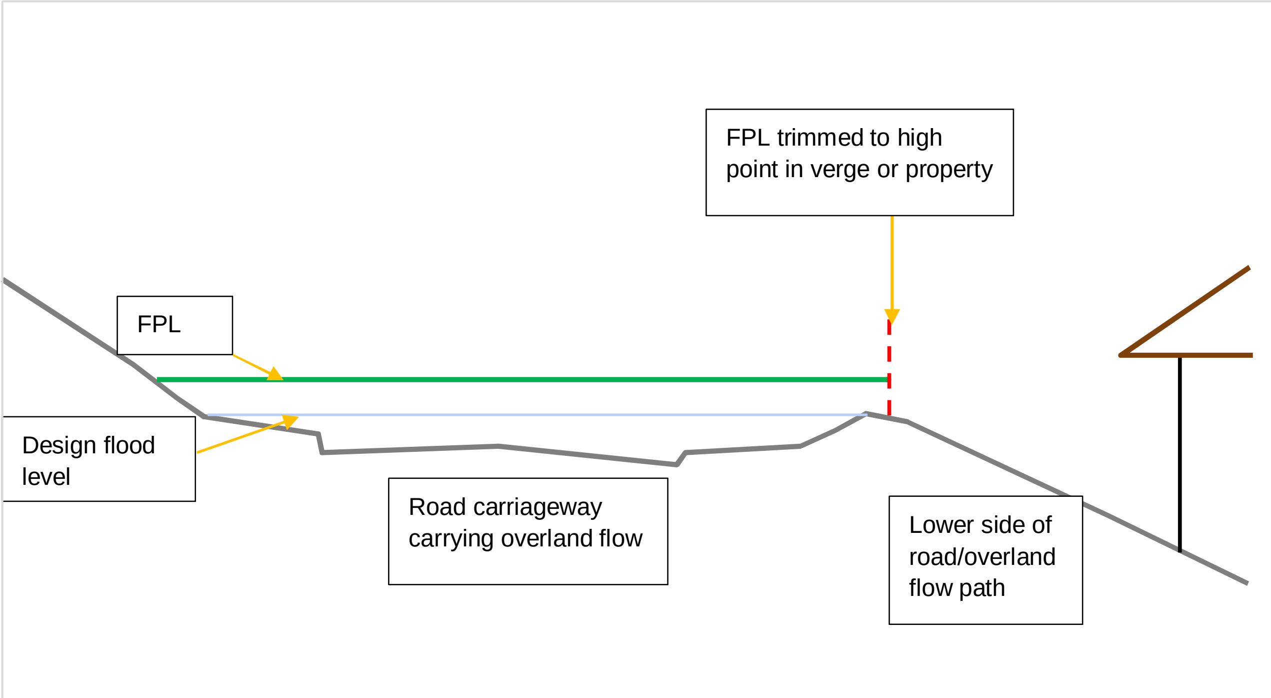
The areas for delineation of the flood planning area were selected via the following steps:

1) Filter out areas with depth <150mm. Such shallow flow depths are unlikely to pose a risk.
2) Identify areas of isolated ponding for potentially filtering out.
3) If there are a number of small “ponds” almost connecting up then this indicates an active flow path and hence should be included (the ponds are to be joined up for the flood planning area).

If the flood planning level surface, when extended out from the filtered and trimmed design flood surface, does not intersect with the ground surface then further trimming is applied. This situation often occurs in urban areas, where overland flows occur within roads which traverse the catchment slope and the calculated FPL surface extends out over the low side of the road, where the land surface continuously falls away and hence the FPL surface does not intersect. In this case the FPL surface is trimmed to the high point, usually in the road verge. This approach was agreed with Council. Refer to Figure 9-6.

In lieu of the FPL being applied to the low-side properties, additional measures such as a minimum floor level above finished ground level (say, 0.3m) should be considered by Council for protection of those properties in the case of minor overflows from the road flow path. Any further refinement to the FPL mapping could be considered during the subsequent Floodplain Risk Management Study phase.

Figure 9-6 Illustration of treatment of Flood Planning Level area on traversing overland flow paths



9.14.2 Approval to Adopt 0.3m Freeboard for Overland Flow Areas

Council's current floodplain risk management policy requires the flooding planning level in all flooding areas to include a 0.5m freeboard. Council are considering altering the policy to adopt a freeboard of 0.3m for overland flow areas. Council has the support of OEH and the Floodplain Advisory Panel to revise the floodplain risk management policy, after public exhibition. If the revised policy is adopted by Council it is recommended that the flood planning level and flood planning area mapping be refined and updated for use during the Floodplain Risk Management Study.

9.15 Provisional Hydraulic and Hazard Categories

The provisional hydraulic categories have been defined as per Council's Floodplain Risk Management Policy and described below:

1. Floodways are areas where floodwaters are actively conveyed, and include waterways (i.e. Tilligerry Creek) drainage channels such as Main Drain, and natural flow paths. Blockage of floodways by development or land filling may result in flood level impacts as the passage of flood flows becomes obstructed. Not all minor drains have been mapped as floodways, particularly those on private property. The floodways have been defined based on the 1% AEP flood.

2. Flood storage areas are areas outside of the floodways where floodwaters may sit within the floodplain and are characterised by relatively high depths (assumed to be 0.5m in this study) and low velocities. These areas are not active flow areas. Floodplain filling of these areas can cause adverse impacts to flood levels in adjacent areas by the loss of floodplain storage volume. The flood storage areas have been defined based on the 1% AEP flood.

3. Flood fringe areas are areas characterised by shallow flows at low velocity. Significant changes to flood behaviour are unlikely for isolated or localised development or land filling. However, cumulative effects of multiple developments in flood fringe areas on flooding should still be considered. In this study, the flood fringe area is defined by areas outside the floodways and flood storages areas, up to the flood planning level.

The above hydraulic categories have been divided with the flood hazard categories that are mapped on Figure E-19 in Appendix E. The hydraulic categories are mapped in Appendix H and are denoted “provisional”, subject to feedback from the Port Stephens Floodplain Advisory Panel and consideration of evacuation, isolation, flood damages and social impacts of flooding which will occur in the floodplain risk management study phase. Refer to Figure 9-6 for the defined hydraulic categories.

Note that the “Minimal Risk” area, for land between the FPL and the PMF level, has not been defined at this stage. In some areas the PMF is lower than the FPL. Refinement of the Flood Planning Area mapping should be considered at the FRMS stage to consider limiting the mapping to the PMF extent.

9.16 Emergency Classification of Communities

Properties within the catchment have been classified based on the floodplain risk management guideline *Flood Emergency Response Planning – Classification of Communities* (DECC, 2007). The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community. It is considered preliminary and subject to update in the subsequent Floodplain Risk Management Study. The classification has been undertaken for the 20%, 1% AEP and PMF events, with mapping provided in Appendix I.

The categories identified included:

- Indirectly Affected: Areas which are not flood affected and whose access is not cut-off, but may be affected by flood impacts to services and infrastructure in the area.
- Overland Escape Route: Areas where vehicular access is cut-off but can be evacuated on foot to higher ground. The evacuation route may not be via roads. Pedestrian access is considered to be cut off when depths over roads exceed 0.3m.
- High Trapped: Areas which are above the peak flood level but whose evacuation routes are cut-off. Islands are surrounded by flood waters and whose evacuation routes are cut-off. The location of the dwelling on the lot is considered in the analysis, and an area is considered flooded and foot access cut off when depths exceed 0.3m.
- Low Trapped Island: Areas which are surrounded by flood waters during early stages of the flood, and which become submerged as the flood peaks. The location of the dwelling on the lot is considered in the analysis, and an area is considered flooded and foot access cut off when depths exceed 0.3m.

The rising road access category has been excluded from the analysis as there are a limited number of roads with rising road access due to flat or undulating terrain.

This emergency classification assessment generally assumes that evacuation will be to the closest higher ground which may be overland/uphill, and not necessarily over road. Rate of rise of floodwaters is not considered. The classification for the more frequent events also does not consider that the suitable evacuation routes for these more frequent events may become cut-off in rarer events. For example, a resident may be preparing to evacuate via a certain road assuming that a 20% AEP flood is occurring, but the flooding becomes more severe than what was expected which causes that evacuation route to become flooded and unsafe.

10. Identification of Flood Problem Areas

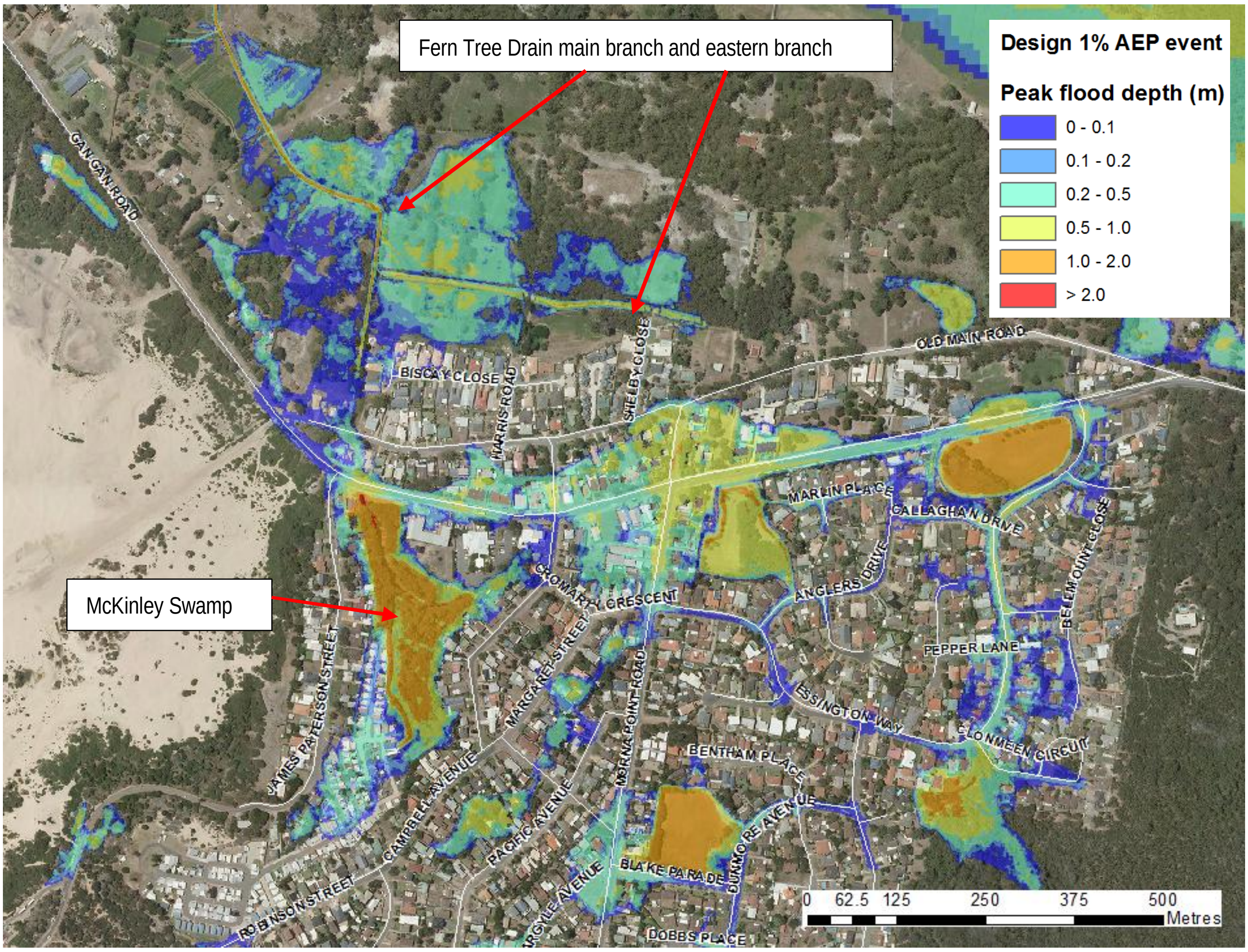
A number of flood problem areas have been identified based on the flood modelling assessment and are discussed in the following sub-sections. These locations were nominated as they experience significant flooding, have a relatively large number of existing flooded properties or are proposed development areas, or relate to flood access. Potential mitigation measures are outlined.

Mitigation options have been trialled in the flood modelling for selected locations around Anna Bay and Boat Harbour, as agreed with Council, and are discussed in Appendix J. The focus for assessment of mitigation options in this study has been limited to the Anna Bay area given the immediate development pressures. Assessment of mitigation for other parts of the study area should be considered in the subsequent floodplain risk management study.

10.1 Gan Gan Road between Morna Point Road and McKinley Swamp, Anna Bay

Drainage of this trapped low point is heavily restricted by flat terrain and pipe grades and high tailwater levels in the stormwater network discharge point in McKinley Swamp. Flow rates of only 0.2 – 0.5m^3/s are achieved in the 1% AEP event in the main drainage line along Gan Gan Road (0.6 to 0.9m diameter pipe). Drainage of McKinley Swamp itself is also restricted by relatively low flows through the drainage culvert to Fern Tree Drain. There is also a high point in the land surface near Old Main Road which restricts the swamp floodwaters freely draining via the surface to Fern Tree Drain. Refer to Figure 10-1 for a locality map.

Figure 10-1 Locality map, Gan Gan Road between Morna Point Road and McKinley Swamp



Potential mitigation options include:

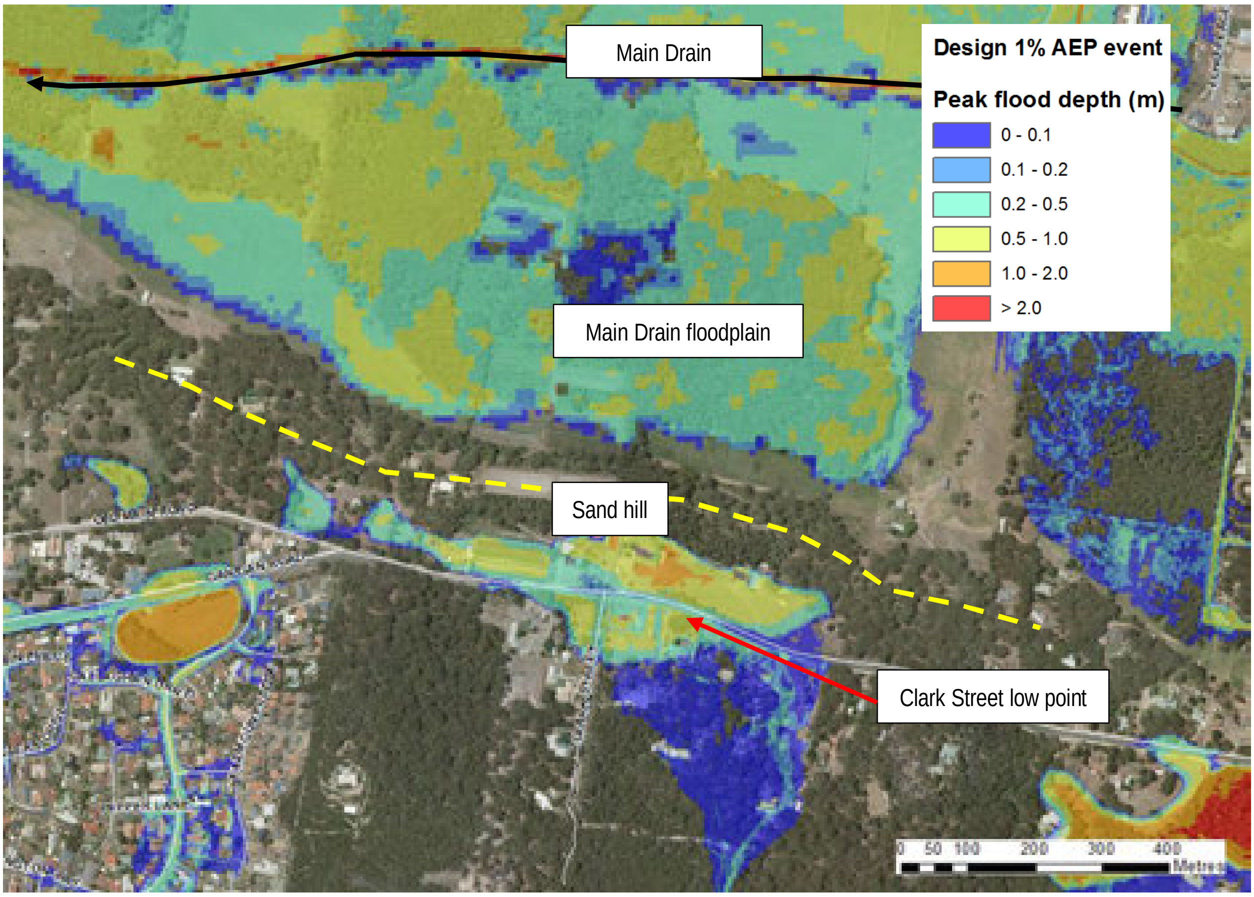
- Divert and potentially upgrade the main stormwater line such that it bypasses McKinley Swamp and discharges directly to Fern Tree Drain. Tailwater levels in the drain are approximately 1.5m lower than in McKinley Swamp.
- Upgrade the existing second drainage line, just to the east of Morna Point Road, which discharges to the eastern end of Fern Tree Drain.
- Increase pit inlet capacity in combination with the above two options.
- Form a floodway to drain McKinley Swamp floodwaters via surface flow by lowering surface levels in the vicinity of Old Main Road by up to 1m.
- A combination of the above.

The options above may require the creation of drainage easements to accommodate pipe diversions and upgrades and the proposed floodway.

10.2 Clark Street Low Point, Anna Bay

Drainage of this location is limited to a low-capacity submersible pump, which discharges to the main Anna Bay drainage network, in addition to infiltration to the soil. This location is earmarked for increased development density as a part of the Anna Bay Strategy and Town Plan and requires a drainage solution to fulfil the development potential. Refer to Figure 10-2 for a locality map.

Figure 10-2 Locality map, Clark Street low point



Increased pump capacity is not considered feasible as the flood inflow rates are high (2m^3/s in the 20% AEP event) and the existing stormwater network does not have capacity to accept significantly greater flows. Building a stormwater line either to the east or west along Gan Gan Road is not considered practical due the rise in ground levels of up to 8m and a lack of suitable discharge points.

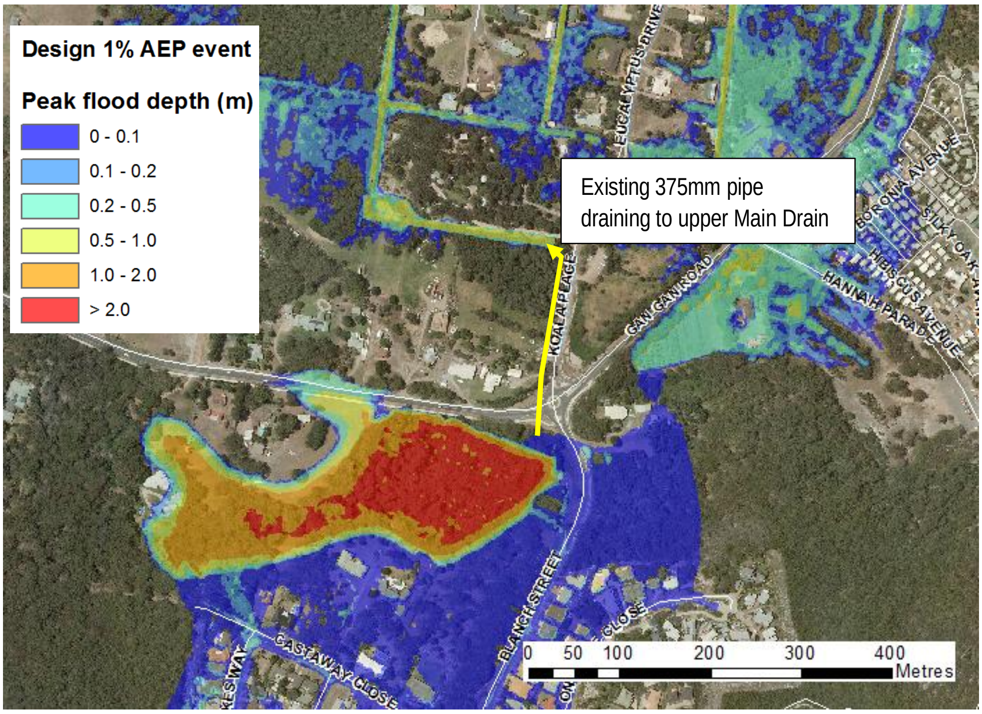
Thrust-boring of a large pipe or culvert through the sand hill to the north of the low point, discharging to the Main Drain floodplain is likely to be the most hydraulically effective potential drainage solution for this location. There is sufficient grade between the trapped low point (ground level 4.7m AHD) and the Main Drain floodplain (1m AHD) to efficiently drain this location. A section of approximately 200m would be required to be thrust-bored. Further, a new drain would need to be excavated to link the pipe discharge point to Main Drain. This option is likely to be of high expense due to the extent of works and technologies involved.

Filled embankments for new developments in this area would need to be 1.5 – 2m approximately to achieve 500mm freeboard above the 1% AEP flood level if no drainage upgrades are implemented. This option would increase flood levels and impact on other properties which are not being developed in coincidence, unless compensatory flood storage is provided. Overall, this option is not considered feasible as filling this area for the development would raise the flood level if other options are not implemented. Providing compensatory storage would require additional land and this is likely to be uneconomical and cause more environmental damage.

10.3 Trapped Low Point at Gan Gan Road and Blanch Street Intersection, Boat Harbour

As previously mentioned, this trapped low point has a small 375mm pipe outlet at a surveyed invert level of 5.5m AHD which is above the 1% AEP flood level. No soil infiltration is represented in the hydraulic model as the soils are mainly low permeability, clayey soils in the low parts of this low point (as confirmed on Figure 3 in Coffey (1994) geotechnical report in Appendix D). Based on this assumption, the modelled flood levels do not draw down during the storm events. That is, they collect in the low point and build up to the peak and then stay constant. In reality the floodwaters would slowly infiltrate laterally through the higher sandy soils under Gan Gan Road although this is likely to be at a relatively slow rate. The PMF level is above the pipe however the small pipe capacity and high likelihood of blockage by flood debris means that rates of drawdown are slow. Refer to Figure 10-3 for locality.

Figure 10-3 Locality map, trapped low point at Gan Gan Road and Blanch Street



The flood problem in this location is due to flood depths of up to 0.5m at several properties in the 1% AEP and high hazard flooding to approximately 20 properties in the PMF, in addition to the low point on Gan Gan Road being cut off for potentially long durations by floodwaters.

Potential mitigation works include:

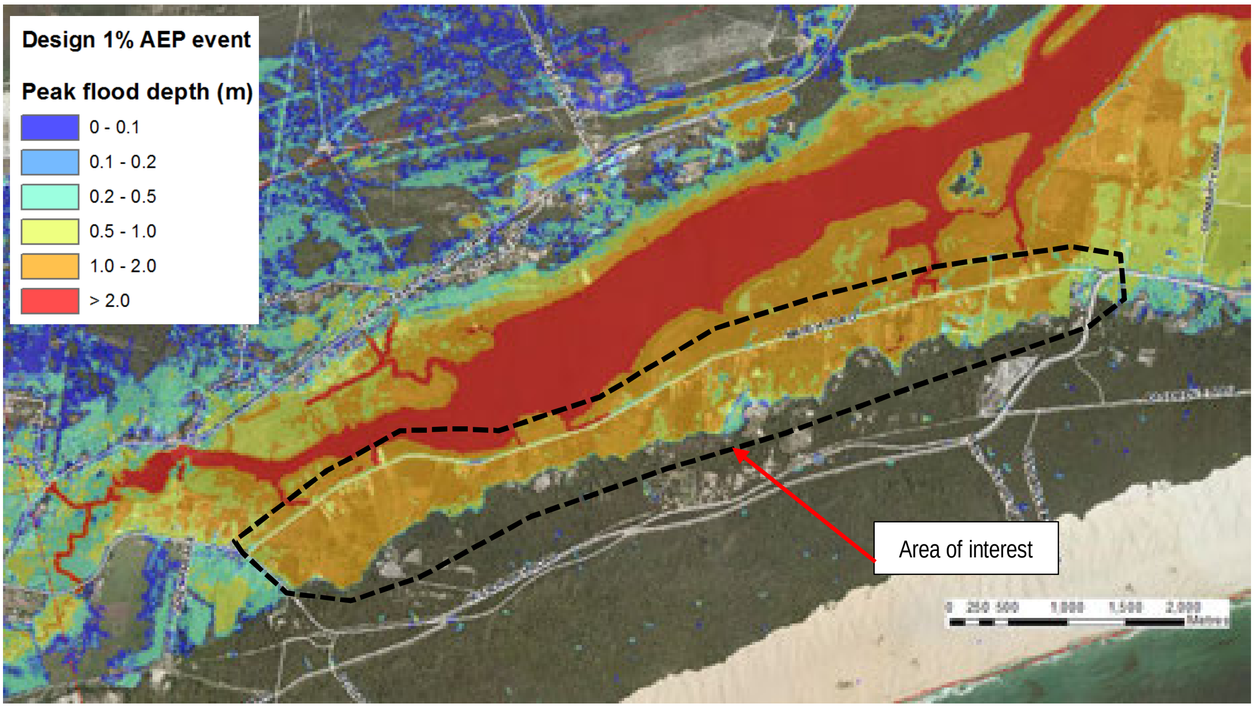
- Upgrading the existing outlet pipe, however the new pipe would need to be laid at significantly lower elevations, with the 1% AEP flood level is 3.96m AHD. Laying the pipe using conventional trenching techniques is likely to be difficult due to relatively high ground elevations (up to 7m AHD along the current pipe alignment) and hence very deep trench depths.

10.4 Marsh Road, Bobs Farm and Salt Ash

Flooding in this area is due to elevated tide levels overtopping Marsh Road in the rarer flood events. Existing rural residential development is present on very low-lying land of elevations between 0.3 – 1m AHD. Large sections of Marsh Road are lower than 1m AHD. During flood events, overland evacuation on foot becomes too hazardous and residents may become trapped when Marsh Road is cut off and flood depths exceed 1m.

Drainage solutions would not be effective due to the nature of flooding. Setting appropriately high flood planning levels and raising habitable floor levels would be the most feasible option. This is particularly critical when considering the impacts of climate change on increased sea levels and risk of tidal inundation in this and other low lying areas in the study area. Refer to Figure 10-4 for a locality map.

Figure 10-4 Locality map, Marsh Road



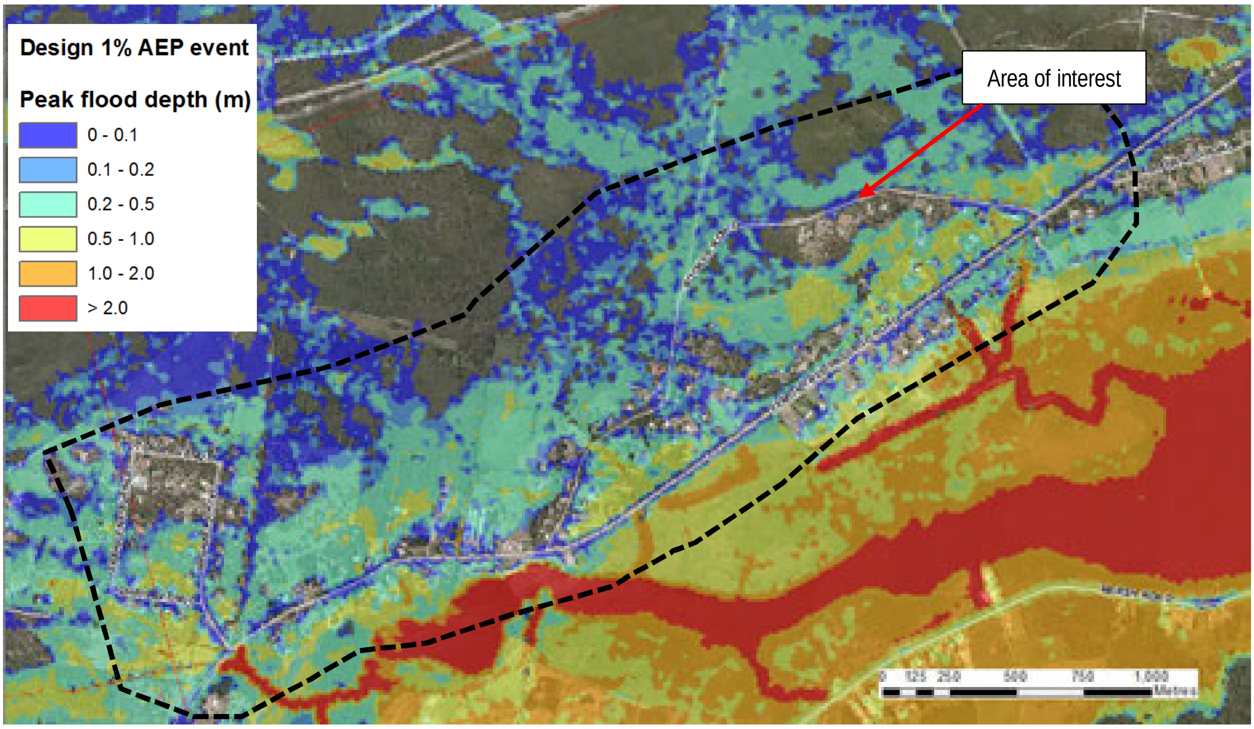
Potential mitigation works include:

- Raised building pads to achieve higher dwelling floor levels are a potential option in this area to reduce flood damages due to the main flooding mechanism being tidal inundation. Because of this there would not be a flooding impact to flooding events such as the 5% AEP and rarer resulting from a loss of floodplain storage. However, adopting a policy such as this may encourage future development in this area which would expose a larger population and associated property to the existing flood risk. This risk will increase markedly with climate change and sea level rise, since the main flooding mechanism in this area is tidal inundation. Additionally, flooding depths resulting from local catchment runoff are likely to increase.
- Voluntary house raising could be considered as a measure to reduce flood damages to existing development.
- Increased cross drainage capacity would be beneficial by reducing the times of inundation following a flood event.

10.5 North Side of Lemon Tree Passage Road, Salt Ash

Most of the properties in this area, particularly those immediately uphill of Lemon Tree Passage Road, are situated on very low-lying land of elevations between 1.2 – 2m AHD. This means that even relatively frequent flood events in Tilligerry Creek such as a 20% AEP event would present high tailwater levels of 1.5m AHD as a result of combined storm surge and catchment runoff, preventing free drainage of local catchment runoff which is the main cause of flooding. Additionally, much of this area is flat in terrain and low points in the floodplain are not well connected to the network of drainage channels serving this area. The drainage channels themselves are often shallow, heavily vegetated and not well maintained. Refer to Figure 10-5 for a locality map.

Figure 10-5 Locality map, north side of Lemon Tree Passage Road, Salt Ash



Some of the drainage culverts in this area were observed to be affected by vegetation debris, which blocked the inlets and reducing inlet capacity, as well as blocking the downstream end floodgate flaps. Figure 10-6 and Figure 10-7 show examples of this in Salt Ash. The latter has the effect of preventing the floodgates from closing properly, thus allowing king tides from backflowing through the culverts and inundating properties, which has been reported by residents in the past[1].

Note, however, that peak flood levels in this area are caused by local runoff events, with modelling indicating that the flood levels are insensitive to the partial opening of the floodgates. Therefore, for the purposes of the design flood estimation it is assumed that the floodgates are operating properly and prevent backflow.

Potential mitigation options include:

- Debris control structures on the upstream side of the main cross drainage culverts under Lemon Tree Passage Road may reduce the likelihood of blockage of inlets and downstream floodgates by debris.
- Increased culvert capacity will permit better drainage of the area, provided that tailwater levels are low.
- Improved capacity of existing drainage channels, including maintenance (management of vegetation and siltation) of the drains.
- Maintenance of culverts and proposed debris control structures for debris and siltation.
- Additional drains to improve connectivity of low points in the floodplain to drainage outlets.
- Voluntary house raising could be considered as a measure to reduce flood damages to existing development.
- Development controls including setting of appropriate habitable floor levels could be considered for future development.

The drainage improvements outlined above may provide some minor reductions in peak flood levels and depths, however, these improvements would be limited by the poor drainage conditions and flat terrain. These improvements are also likely to be nullified by climate change and rising sea levels.

[1] It was reported by the residents that tidal inundation through leaking through the flood gates did happen in the past, affecting parts of yards, but the peak water levels were low compared to the flooding from the historic flood events e.g. April 2015.

Water level monitoring undertaken for the acid sulphate soil remediation study (DPI 2011) suggested that water levels upstream of Anna Bay Main Drain floodgates are not sensitive to the leakage through the flood gates, with a water level range of approximately 100mm recorded. This suggested that initial conditions and peak flood levels are not sensitive to the leakage through the floodgates.

The culverts at the flood gates are not fully but predominantly unidirectional. Backflow capacity is estimated to be 5% of the outflow capacity (photos suggest approximately 10% opening, with 50% of that opening blocked by debris). Sensitivity testing indicated that peak design flood levels are not sensitive to the partial opening (10% open, 50% blocked) of the flood gates.

Figure 10-6 Debris accumulation on upstream side of road cross drainage culvert, Salt Ash

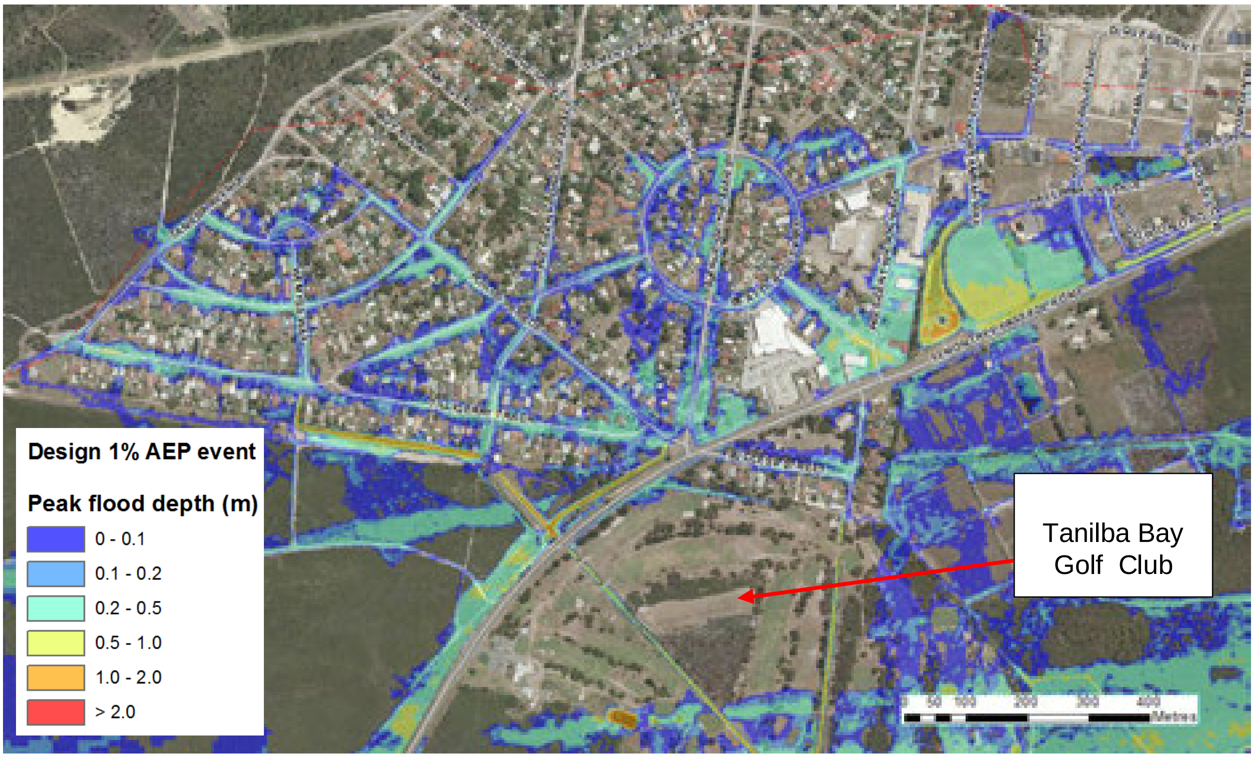
Figure 10-7 Debris accumulation propping open the same floodgate, Salt Ash

10.6 Tanilba Bay Urban Area

The main flood problem areas in Tanilba Bay are in road sag points, requiring improved drainage capacity. Refer to Figure 10-8 for a locality map. The following options could be considered:

- Increase culvert capacity under Lemon Tree Passage 250m south of Avenue of the Allies. Currently 2 x 900mm diameter pipes. The drainage channels upstream of this culvert are drowned out by the backwater from the culvert. There is approximately 1m head difference across the culvert. Reducing the water levels upstream of the culvert would improve the drainage of road sags in Tilligerry Track and Avenue of the Allies.
- The vacant block between 37 and 39 Tilligerry Track is an extension of President Poincare Parade, and a high point in the ground surface prevents the sag point in Tilligerry Track at this location to drain freely. A floodway could be constructed to connect the sag point to the downstream drainage open channels. It is noted however that this land is used for vehicle access to the rear of the adjoining properties.
- There is an existing 1.05m diameter pipe crossing Lemon Tree Passage Road at President Wilson Walk, however, this reduces to a 600mm diameter pipe at a sump pit part way down President Wilson Walk. This constraint prevents better drainage of the low point at Lloyd George Walk and President Wilson Walk, on the high side of Lemon Tree Passage Road. Additionally, flows surcharge at this pit causing flooding of properties in Success Street. The existing 600mm pipe branch should be upgraded to at least a 1.05m diameter pipe to prevent the flow surcharge. Pipe capacity crossing Lemon Tree Passage Road should also be considered, along with increased pit capacity on the high side of Lemon Tree Passage Road and in Success Street.
- The above drainage systems discharge into open channels through the Tanilba Bay Golf Club course. From the aerial photography sections of the channels appear to be silted up and become heavily vegetated. Maintenance of these channels may improve the drainage conditions for the upstream urban area.

Figure 10-8 Locality map, Tanilba Bay urban area



10.7 Lemon Tree Passage Urban Area

The worst flood-affected properties in this area are located along the foreshore on streets including Cook Parade, John Parade, Mackie Street, Shearman Avenue and lower sections of Meredith Parade, among others, and are primarily susceptible to tidal inundation and storm surge. Refer to Figure 10-9 for a locality map.

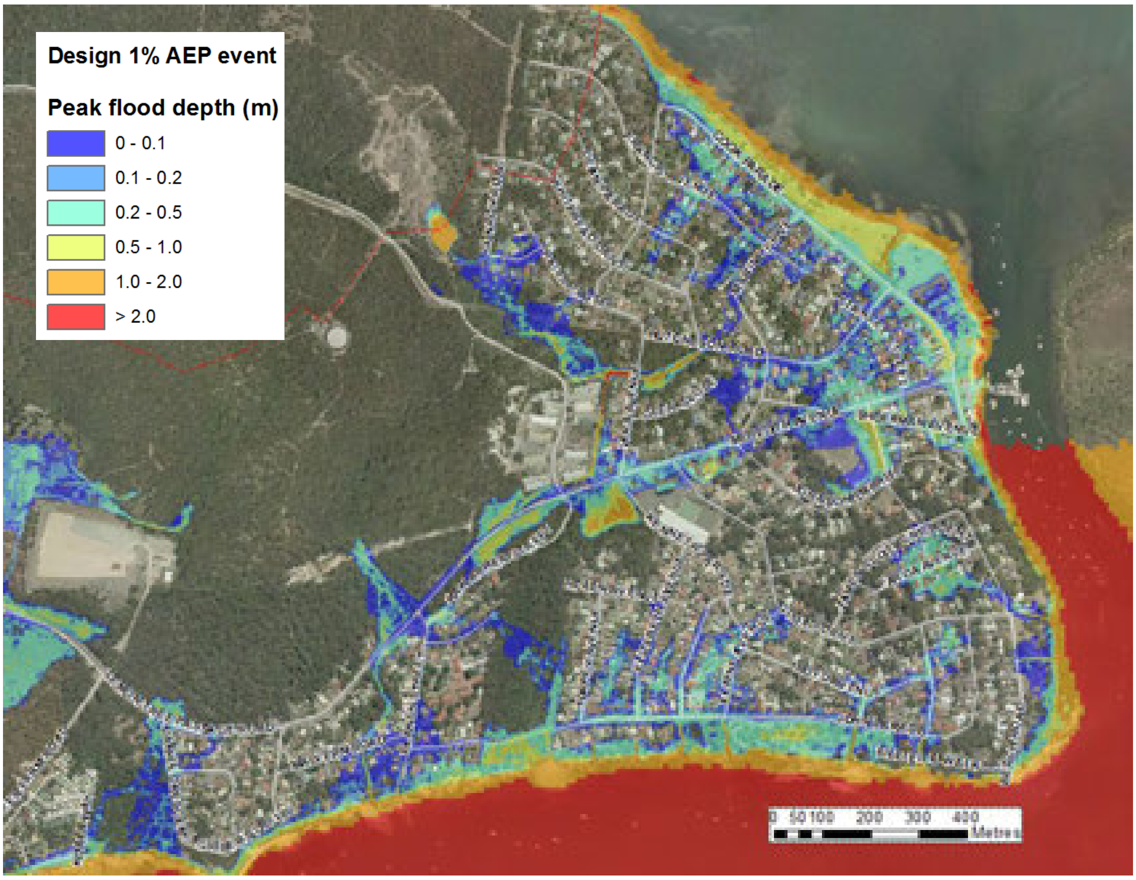
The most appropriate and sustainable mitigation measures are planning and development controls. Permanent levees and removable flood barriers could be effective but are unlikely to be sustainable in the long term.

Flooding problem areas where drainage upgrades may be beneficial include:

- Low points at Paroa Avenue and adjacent properties, currently drained by a 525mm diameter pipe network. There is currently only a junction pit at the main low point on private property. A sump pit at this location and upgrade of the existing pipe capacity is likely to improve flooding conditions.
- Low point on private properties on corner of Gould Drive and John Parade. There is currently drainage on the adjacent streets but no drainage of the low point.

  Low point on private properties on Meredith Avenue between Gould Drive and Johnson Parade. There is currently drainage on the adjacent streets but no drainage of the low point.

Figure 10-9 Locality map, Lemon Tree Passage urban area



10.8 Mitigation Assessment for Selected Areas

An assessment of mitigation options has been undertaken for selected flood problem areas including parts of Anna Bay and surrounds. The assessment considers flooding under future development conditions associated with the Anna Bay Strategy and Town Plan with the objective of identifying potential drainage upgrades to improve flooding conditions and realise the development potential of various areas. The assessment and outcomes are documented in Appendix J.

Note that the identified mitigation options are indicative and may not necessarily be implemented. A wide range of options for improving flooding conditions in the study area will be investigated in the subsequent Floodplain Risk Management Study and Plan, and may include the potential options discussed in this study. Issues which will be considered in evaluating options include hydraulic performance and constraints, costs, sources of funding, engineering constraints, community consultation and environmental impacts, and these will affect the options' feasibility and priority.

11. Conclusions and Recommendations

11.1 Conclusions

Project data including existing studies and hydrologic/hydraulic models, topographic and spatial data and design data for civil works and hydraulic structures has been provided by Port Stephens Council and reviewed by Jacobs for quality and data gaps. The findings of the review will guide how the available data will be used in the model development stage, and has informed the development of the survey brief.

Community consultation has been undertaken including newsletters and progress updates on Council's website and social media. Questionnaires were distributed to the community to gather information on historic flood events and views on flooding issues. Observations on, in particular the recent April 2015 and January 2016 flood events, were collected which were used in the hydrologic and hydraulic model calibration and verification. Only few respondents reported observing the significant flooding in 1990 and 1955 events, which may be expected due to the time elapsed since these events.

Hydrologic modelling has been developed in XP-RAFTS to cover the entire study area and to define local catchment inflows. The estimated local catchment inflows have been validated against the previous hydrologic modelling for the Williamtown – Salt Ash Floodplain Risk Management Study.

Hydraulic models have been developed in the TUFLOW modelling software. Given the large study area of mainly rural and natural landscapes interspersed with several urban centres, a broader-scale model using a 20m model grid has been developed to define the regional flooding characteristics, with two separate 2m grid models developed for the Anna Bay and the Tilligerry Peninsula urban areas to estimate the overland flooding behaviour within these developed areas.

Model calibration and verification has been undertaken with adjustment of hydrologic and hydraulic parameters to achieve a satisfactory fit to observations of historic flooding behaviour. The model calibration process is complicated by the large study area and highly variable topography and soil types and the resulting runoff potential. Infiltration of floodwaters in highly permeable sand dune areas has been represented in the hydraulic modelling as a separate process to the rainfall losses in the hydrologic modelling. Infiltration rates of up to 300mm/hr have been adopted in order to replicate the minimal or no ponding of runoff in sand dune trapped low points as reported by some residents. The adopted infiltration rates are supported by site-specific soil permeability testing.

Design flooding conditions have been estimated based on design rainfall being run through the hydrologic models to derive catchment inflows, in addition to consideration of elevated tailwater levels in Port Stephens contributing to flooding by restricting the drainage of local catchment inflows or by direct tidal inundation. Inflows of floodwaters from the Hunter River into the study area have also been accounted for, with significant contribution only occurring in events larger than the 1% AEP, when Nelson Bay Road is overtopped by the overflows from Fullerton Cove. The design flood conditions relate to full permissible development under Council's LEP 2013, and for current climate (sea levels and rainfall) conditions

Flood mapping of depths, levels, flow velocities and provisional flood hazard has been prepared for this report. Flooding conditions have been characterised for different areas in the study area. The main low points on key roads have been identified and the frequency at which these road low points become cut-off have been identified.

The number of properties affected by varying maximum flood depths in each flood AEP are summarised in Table 12-1 and includes private properties as well as public property and other reserves and open space. There are 5,241 properties in total in the study area. The maximum flood depth may not reflect the flood depth at the dwelling.

Table 11-1 Count of properties by maximum flood depth on each property*

Depth (m)	Design Flood Event				
	20% AEP	10% AEP	5% AEP	1% AEP	PMF
>0.15	688	774	955	1168	2508
>0.3	645	737	910	1138	2479
>0.5	471	535	645	863	2165
>1.0	285	320	373	440	1389
>2.0	78	89	104	142	561
Total	688	774	955	1168	2508

* For properties with >20% coverage by floodwaters over 0.15m deep. Example: in the 10% AEP there are 737 properties with a maximum flood depth of 0.3m or more.

** Total of 5,241 properties in the study area.

Flooding in the study area has been related to nearby river water level gauges in Port Stephens at Mallabula Point and the Hunter River at Raymond Terrace for potential flood warning applications. The detection of elevated water levels at the Mallabula Point gauge is unlikely to be useful for flood warning purposes as the gauge is in the immediate vicinity of the study area and there is unlikely to be a significant timing difference between the gauge and water levels in Tilligerry Creek. Flood gauging at Raymond Terrace may provide warning of overflows from Fullerton Cove and into the study area during events from the 0.5% AEP up to the PMF, which would cause significant flooding exceeding 2m in depth in areas of the study area. If there is a PMF event in the Hunter River, there is approximately 10 hours warning time from when the river level at Raymond Terrace exceeds 5.2m AHD (the 0.5% AEP peak flood level at Raymond Terrace) and when the Hunter River overflows reach the study area.

Climate change analysis has been undertaken to determine peak flooding conditions under sea level rise and increased rainfall scenarios. Sensitivity assessment has also been conducted to determine the change in flood levels due to variation in model parameters.

The provisional flood planning level (FPL) and flood planning area has been derived based on the 1% AEP flood in climate change scenario of the year 2100 (+0.9m sea level) and 20% increase in rainfall, as per Council's Floodplain Risk Management Policy. A 0.5m freeboard has been adopted in setting the FPL according to Council's Floodplain Risk Management Policy. This freeboard level is applicable to all types of flooding including mainstream flooding and overland flow flooding. However, it may be considered appropriate to adopt a reduced freeboard of 0.3m in areas affected by overland flows to reflect the generally shallower nature of these flows and reduced risk of variance in the peak flood levels (e.g. due to wind waves on floodwaters). Overland flows in this study area are defined as catchment runoff areas (generally above 3.2m AHD) outside the mainstream flooding areas of Tilligerry Creek and Main Drain floodplain.

Properties within the study area were classified for flood emergency response based on NSW Government floodplain risk management guidelines. The classification indicates the relative vulnerability of different areas of the catchment and considers the ability to evacuate certain parts of the community.

A number of main flood problem areas have been identified in the study area, two of which are in the Anna Bay township area, which is subject to significant development pressures as outlined in Council's Anna Bay Strategy and Town Plan. Potential mitigation options have been identified for each area, including structural and non-structural options for each area, as summarised in Table 11-2.

Table 11-2 Summary of Flood Problem Areas and Potential Mitigation

Flood Problem Area	Refer to	Potential Mitigation
Gan Gan Road between Morna Point Road and McKinley Swamp, Anna Bay	Section 10.1	· Divert and potentially upgrade the main stormwater line such that it bypasses McKinley Swamp and discharges directly to Fern Tree Drain. · Upgrade the existing second drainage line, just to the east of Morna Point Road · Increase pit inlet capacity in combination with the above two options. · Form a floodway to drain McKinley Swamp floodwaters via surface flow to Fern Tree Drain · A combination of the above.
Clark Street low point, Anna Bay	Section 10.2	· Thrust-boring of a large pipe/culvert through the sand hill to the north of the low point, discharging to the Main Drain floodplain.
Trapped low point at Gan Gan Road and Blanch Street, Boat Harbour	Section 10.3	· Upgrade/supplement existing, underperforming pipe outlet. New pipe/s need to be laid at deeper levels.
Marsh Road, Bobs Farm and Salt Ash	Section 10.4	· Raised building pads to achieve higher dwelling floor levels to reduce flood damages. However, adopting a policy such as this may encourage future development in this area which would expose a larger population and associated property to the existing flood risk, which will increase with climate change · Voluntary house raising could be considered as a measure to reduce flood damages/risk to existing development. · Increased cross drainage capacity to reduce times of inundation following a flood event.
North side of Lemon Tree Passage Road, Salt Ash	Section 10.5	· Debris control structures on the upstream side of the main cross drainage culverts to reduce the likelihood of blockage of inlets and downstream floodgates by debris. · Increased culvert capacity will permit better drainage of the area, provided that tailwater levels are low. · Improved capacity of existing drainage channels, including maintenance (management of vegetation and siltation) of the drains. · Maintenance of culverts and proposed debris control structures for debris and siltation. · Additional drains to improve connectivity of low points in the floodplain to drainage outlets. · Voluntary house raising could be considered as a measure to reduce flood damages to existing development. · Development controls including setting of appropriate habitable floor levels could be considered for future development.
Tanilba Bay urban area	Section 10.6	· Increase culvert capacity under Lemon Tree Passage 250m south of Avenue of the Allies · Construction of a floodway in the vacant block between 37 and 39 Tilligerry Track to drain the sag point in Tilligerry Track

		· Upgrade of existing 600mm pipe branch to at least a 1.05m diameter pipe in President Wilson Walk south of Lemon Tree Passage Road to prevent the flow surcharge · Increased pipe capacity crossing Lemon Tree Passage Road should also be considered, along with increased pit capacity on the high side of Lemon Tree Passage Road and in Success Street · Maintenance of open channels through Tanilba Bay Golf Club course including vegetation management and desilting.
Lemon Tree Passage urban area	Section 10.7	· New pit inlets at Paroa Avenue sag points and upgrade of the existing pipe capacity · New pit inlets and drainage of sag point on private properties on corner of Gould Drive and John Parade · New pit inlets and drainage of sag point on private properties on Meredith Avenue between Gould Drive and Johnson Parade.

An assessment of mitigation options has been undertaken for selected flood problem areas including parts of Anna Bay and surrounds including:

- Clark Street low point
- Low point in the vicinity of Gan Gan Road and Morna Point Road intersection
- McKinley Swamp and Gan Gan Road low points to the east (Anna Bay shops)
- Trapped low point at Gan Gan Road and Blanch Street
- Fern Tree Drain floodplain.

The assessment considers flooding under future development conditions associated with the Anna Bay Strategy and Town Plan with the objective of identifying potential drainage upgrades to improve flooding conditions and realise the development potential of various areas. The assessment and outcomes are documented in Appendix J. Note that the identified mitigation options are indicative and may not necessarily be implemented. A wide range of options for improving flooding conditions in the study area will be investigated in the subsequent Floodplain Risk Management Study and Plan, and may include the potential options discussed in this study. Issues which will be considered in evaluating options include hydraulic performance and constraints, costs, sources of funding, engineering constraints, community consultation and environmental impacts, and these will affect the options’ feasibility and priority.

11.2 Recommendations

- Further refinement of the provisional Flood Planning Level and Flood Planning Area should be considered in the subsequent FRMS stage, that is, whether the PMF (under climate change sea levels) is to be used to limit the extent of the Flood Planning Area.
- Council's current floodplain risk management policy requires the flooding planning level in all flooding areas to include a 0.5m freeboard. Council are considering altering the policy to adopt a freeboard of 0.3m for overland flow areas. Council has the support of OEH and the Floodplain Advisory Panel to revise the floodplain risk management policy, after public exhibition. If the revised policy is adopted by Council it is recommended that the flood planning level and flood planning area mapping be refined and updated for use during the Floodplain Risk Management Study.
- The potential mitigation options assessed and discussed in Appendix J for selected areas should be further refined and investigated as a part of a wide range of options for improving flooding conditions in the study area. Issues which will be considered in evaluating options include hydraulic performance and constraints, costs, sources of funding, engineering constraints, community consultation and environmental impacts, and these will affect the options’ feasibility and priority.

12. Acknowledgements

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- Members of the Anna Bay Drainage Union;
- NSW Department of Primary Industries;
- Water Research Laboratory, University of New South Wales;
- Council officers; and
- NSW Office of Environment and Heritage.

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14. Glossary

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. In this study AEP has been used consistently to define the probability of occurrence of flooding. It is to be noted that design rainfalls used in the estimation of design floods up to and including 100 year ARI (i.e. 1% AEP) events was derived from 1987 Australian Rainfall and Runoff. Hence the following relationship between AEP and ARI applies to this study. 20% AEP ≈ 5 year ARI; 10% AEP = 10 year ARI; 5% AEP = 20 year ARI; 2% AEP = 50 year ARI; 1% AEP = 100 year 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 occurrences 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.
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.
Development	Is defined in Part 4 of the EP&A Act <u>In fill development</u>: 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. E.g. The urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of exiting urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. e.g. As urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.
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.

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 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 susceptibility to flooding by the PMF event. Note that the term flooding liable land covers the whole floodplain, not just that part below the FPL (see flood planning area)
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 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 include both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defines 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 SES.
Flood planning levels (FPLs)	Are the combination 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 "designated flood" or the “flood standard” used in earlier studies.
Flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings and structures subject to flooding, to reduce or eliminate flood damages.
Flood readiness	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. <u>Existing flood risk</u>: the risk a community is exposed to as a result of its location on the floodplain. <u>Future flood risk</u>: 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 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 flow, or a significant increase in flood levels.
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.
Hazard	A source of potential harm or 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.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
m AHD	Metres Australian Height Datum (AHD)
m/s	Metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or "cumecs". A unit of measurement of creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Modification measures	Measures that modify either the flood, the property or the response to flooding.
Overland flow path	The path that floodwaters can follow as they are conveyed towards the main flow channel or if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation 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.
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.
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 a streamflow, also known as rainfall excess.
Stage	Equivalent to water level (both measured with reference to a specified datum)
TUFLOW	TUFLOW is a computer program which is used to simulate free-surface flow for flood and tidal wave propagation. It provides coupled 1D and 2D hydraulic solutions using a powerful and robust computation. The engine has seamless interfacing with GIS and is widely used across Australia.
XP-RAFTS	XP-RAFTS is a computer program which is used to simulate catchment rainfall-runoff and is widely used across Australia.