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Lower Myall River and Myall Lakes Flood Study

Final Report:
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Great Lakes COUNCIL

Lower Myall River and Myall Lakes Flood Study - Incorporating Projected Climate Change Effects

Final Report

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Title :	Lower Myall River and Myall Lakes Flood Study Final Report
Author :	Rohan Hudson
Synopsis :	Report for the Lower Myall River and Myall Lakes Flood Study covering the available data, the development and calibration of the hydrologic and hydraulic models and the presentation of design flood conditions, including sensitivity testing and an assessment of climate change.

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GLOSSARY

afflux	The change in water level from existing conditions resulting from a change in the watercourse or floodplain – e.g. construction of a new bridge.
annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (see also average recurrence interval)
Australian Height Datum (AHD)	National survey datum corresponding approximately to mean sea level.
Astronomical Tide	Astronomical Tide is the cyclic rising and falling of the Earth's oceans water levels resulting from gravitational forces of the Moon and the Sun acting on the Earth.
attenuation	Weakening in force or intensity
average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20yr ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
Australian Rainfall and Runoff (AR&R)	Engineers Australia publication pertaining to rainfall and flooding investigations in Australia
calibration	The adjustment of model confuguration and key parameters to best fit an observed data set
catchment	The catchment at a particular point is the area of land that drains to that point.
design flood event	A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).
development	Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodways and buildings.
discharge	The rate of flow of water measured in tems of vollume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.

flood fringe	Land that may be affected by flooding but is not designated as floodway or flood storage.
flood hazard	The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
flood liable land	see flood prone land
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The co-ordinated management of activities that occur on the floodplain.
floodplain risk management plan	A document outlining a range of actions aimed at improving floodplain management. The plan is the principal means of managing the risks associated with the use of the floodplain. A floodplain risk management plan needs to be developed in accordance with the principles and guidelines contained in the NSW Floodplain Management Manual. The plan usually contains both written and diagrammatic information describing how particular areas of the floodplain are to be used and managed to achieve defined objectives.
Flood planning levels (FPL)	Flood planning levels selected for planning purposes are derived from a combination of the adopted flood level plus freeboard, as determined in floodplain management studies and incorporated in floodplain risk management plans. Selection should be based on an understanding of the full range of flood behaviour and the associated flood risk. It should also take into account the social, economic and ecological consequences associated with floods of different severities. Different FPLs may be appropriate for different categories of landuse and for different flood plans. The concept of FPLs supersedes the "standard flood event". As FPLs do not necessarily extend to the limits of flood prone land, floodplain risk management plans may apply to flood prone land beyond that defined by the FPLs.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).
flood source	The source of the floodwaters.
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.
floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.

freeboard	A factor of safety usually expressed as a height above the adopted flood level thus determing the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.
geomorphology	The study of the origin, characteristics and development of land forms.
gauging (tidal and flood)	Measurement of flows and water levels during tides or flood events.
historical flood	A flood that has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrodynamic	Pertaining to the movement of water
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrographic survey	Survey of the bed levels of a waterway.
hydrologic	Pertaining to rainfall-runoff processes in catchments
hydrology	The term given to the study of the rainfall-runoff process in catchments.
hyetograph	A graph showing the depth of rainfall over time.
Intensity Frequency Duration (IFD) Curve	A statistical representation of rainfall showing the relationship between rainfall intensity, storm duration and frequency (probability) of occurrence.
intermittently closed and open Lake/Lagoon (ICOLL)	A Lake/Lagoon that is seperated from the ocean by a sand beach barrier or berm and is subject to forces that act to close the entrance (waves, tides and wind) and those that act to maintain an open entrance (flood flows and dredging), which results in the Lake/Lagoon being intermittently closed and open to the ocean.
isohyet	Equal rainfall contour
morphological	Pertaining to geomorphology
peak flood level, flow or velocity	The maximum flood level, flow or velocity that occurs during a flood event.
pluviometer	A rainfall gauge capable of continously measuring rainfall intensity
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
riparian	The interface between land and waterway. Literally means "along the river margins"

runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
stage	See flood level.
stage hydrograph	A graph of water level over time.
sub-critical	Refers to flow in a channel that is relatively slow and deep
topography	The shape of the surface features of land
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
validation	A test of the appropriateness of the adopted model configuration and parameters (through the calibration process) for other observed events.
water level	See flood level.

1 INTRODUCTION

The Lower Myall River and Myall Lakes Flood Study is being prepared for Great Lakes Council (GLC or The Council) to define the existing flood behaviour in the Lake and River and establish the basis for subsequent floodplain management activities.

This study will update the previous flood analysis (PWD, 1980) utilising state-of-the-art modelling technologies and up-to-date topographical and hydrological information. The current Flood Study considers existing flood behaviour and the influence of potential climate change.

The study is being prepared to meet the objectives of the NSW State Government's Flood Prone Land Policy. This project has been conducted under the State Assisted Floodplain Management Program and received State financial support provided by the Office of Environment and Heritage (OEH).

The study is being undertaken in a staged approach as outlined below:

- Stage 1 - Collection, Compilation and Review of Available Information;
- Stage 2 – Acquisition of Additional Data
- Stage 3 – Develop Hydrologic and Hydraulic Models;
- Stage 4 – Calibration and Verification of Models
- Stage 5 – Design Flood Assessment including Climate Change Analysis; and
- Stage 6 - Final Reporting including Flood Hazard Assessment and Mapping.

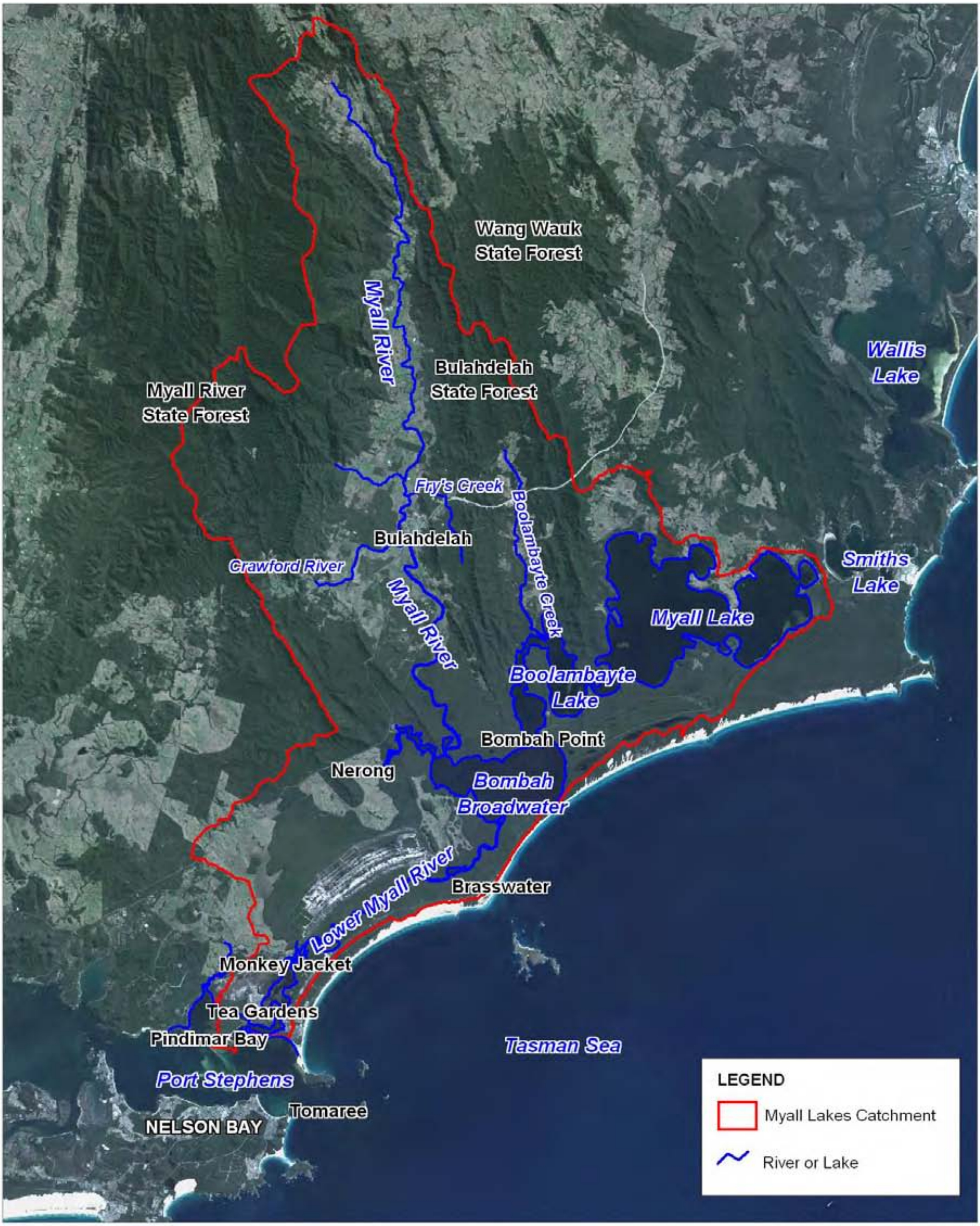
This draft report provides a detail of the six stages and represents the key output of the study.

1.1 Study Location

The Lower Myall River catchment encompasses an area of approximately 900 km^2 and is located north of Port Stephens in the Great Lakes Council Local Government Area (LGA) as shown in Figure 1-1. The Myall Lakes comprise a series of three interconnected water bodies lying between the coastal sand barriers and the hills of Bulahdelah, north of Port Stephens.

The major freshwater inflow to the Lakes is via the Myall River, which drains an area of approximately 445 km^2 and enters the Lake system at the north western extremity of the Broadwater. From its headwaters the River flows through the township of Bulahdelah and enters the Bulahdelah Plain which acts as extended lake storage in times of major flooding. The Lake system is in turn drained by the 28 km long Lower Myall River which exits the Broadwater at Tamboy and drains into Port Stephens at Corrie Island via Corrie Creek (i.e. the Northern Channel) and Paddy Marrs Inlet (i.e. the Eastern Channel).

A more detailed description of the Study Area is presented in Section 2.1.



Title:
Study Locality

Figure: 1-1

Rev: A

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1.2 Study Background

Flooding of the Myall Lake system and Lower Myall River can be caused by a combination of fluvial and ocean storm events. Increasing development pressure in the Tea Gardens and Hawks Nest area means that an increased understanding of current and future flood behaviour is required.

The only previous study on the Myall Lakes is The Lower Myall River Flood Analysis undertaken in 1980 by the then NSW Department of Public Works. The study determined design flood levels for the 1% and 5% Annual Exceedance Probability (AEP) design flood events and an estimation of an extreme flood event. However, the study is considered rudimentary by today's modelling standards, using a one dimensional (1D) estuarine model.

This Flood Study will utilise significant advances in the methodologies used to predict flood behaviour, including updates in modelling techniques and the capture of high quality ground level data (LiDAR).

1.3 The Need for Floodplain Management at Myall Lakes and Lower Myall River

Significant floods on the Myall Lakes have occurred in the 1890's (~3.7 m AHD), 1927 (~2.7 m AHD) and 1963 (~2.2 m AHD). Other floods that resulted in Lake levels above 1.2 m AHD have occurred in March 1977, May 1977, March 1978, May 2003, April 2008 and July 2011.

While the majority of the Myall Lakes floodplain lies within National Park, fluvial discharge may contribute to flooding at Tea Gardens (where development pressure is an issue) such that a study of the Lakes is required to assist floodplain management in the lower reaches of the Lower Myall River.

There appears to be no information on recent significant ocean flood events occurring on the Lower Myall.

In order to reduce the risk to existing flood prone properties and manage the future land use of flood prone land, effective floodplain management strategies are required.

While a previous flood analysis (PWD, 1980) is available for the Lower Myall it is based on limited data and a 1D model. This Flood Study will provide utilise state-of-the-art models and additional data sets to update the previous flood assessment and will also consider the potential impacts of climate change on flood risk within the catchment.

1.4 The Floodplain Management Process

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

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

The Policy provides for technical and financial support by the NSW Government through the four sequential stages shown in Table 1-1.

Table 1-1 Stages of Floodplain Management

	Stage	Description
1	Formation of a Committee	Established by Council and includes community group representatives and State agency specialists.
2	Data Collection	Past data such as flood levels, rainfall records, land use, soil types etc.
3	Flood Study	Determines the nature and extent of the flood problem.
4	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed developments.
5	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
6	Implementation of the Floodplain Risk Management Plan	Construction of flood mitigation works to protect existing development. Use of local environmental plans to ensure new development is compatible with the flood hazard.

This study represents Stage 3 of the above process and aims to provide an understanding of existing and future flood behaviour within the Myall Lakes catchment.

1.4.1 Climate Change Policy

The primary impacts of climate change in coastal areas are likely to result from sea level rise and an increase in rainfall intensity, which may lead to increased coastal erosion, tidal inundation and flooding.

The NSW Government adopted sea level rise (SLR) planning benchmarks in 2009 to ensure consistent consideration of sea level rise in coastal areas of NSW. These planning benchmarks are an increase above 1990 mean sea levels (MSL) of 40cm by 2050 and 90cm by 2100. In 2012 the NSW Government changed its SLR policy allowing individual Councils to determine their own SLR planning benchmarks. It is understood that the Great Lakes Council is intending to adopt an increase above 1990 MSL of 50cm by 2060 and 90cm by 2100.

For the Lower Myall, climate change impacts are expected to increase the frequency, severity and duration of flooding. This is partly due to higher lake levels as a result of sea level rise, but also higher intensity rainfall events and increases in storm surge.

In 2007 the NSW Government released a guideline for practical consideration of climate change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. Accordingly, this increase in design rainfall will translate into increased flood inundation in the Myall Lakes. Future planning and floodplain management in the catchment will need to take due consideration of this increased flood risk.

In consultation with The Council and the Office of Environment and Heritage (OEH), a range of climate change sensitivity tests incorporating combinations of sea level rise and increased design rainfall intensity will be formulated. The results of these sensitivity tests will be compared to base case (i.e. models with existing sea level and climate) in order to assess the potential increase in flood risk due to climate change.

1.5 Study Objectives

The primary objective of this Flood Study is to define the flood behaviour under historical, existing and future conditions (incorporating potential impacts of climate change) in the Myall Lakes and Lower Myall River for a full range of design flood events. The study provides information on flood levels and depths, velocities, flows, hydraulic categories and provisional hazard categories. The Flood Study is to be used to identify the impact on flood behaviour as a result of future climate change. Specifically, the study incorporates:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertake a community consultation and participation program to identify local flooding concerns, collect information on historical flood behaviour and engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Probable Maximum Flood (PMF), 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events for catchment and ocean derived flooding; and
- Examine potential impact of climate change using the latest guidelines.

The models and results produced in this study are intended to:

- Outline the flood behaviour within the catchment to aid in strategic land use management planning; and
- Form the basis for a subsequent floodplain risk management study where detailed assessment of flood mitigation options and floodplain risk management measures will be undertaken.

1.6 About This Report

This report documents includes the following sections:

Section 1 introduces the study.

Section 2 provides an overview of the study and summary of background information.

Section 3 outlines the community consultation program undertaken.

Section 4 details the development of the computer models.

Section 5 details the hydraulic model calibration and validation process.

Section 6 details the design flood conditions.

Section 7 details the design flood results and associated flood mapping.

Section 8 details the climate change analysis

2 STUDY APPROACH

2.1 The Study Area

The study area of the Lower Myall Flood Study includes the Myall Lake system, comprising the Broadwater, Boolambayte and Myall Lakes and the Lower Myall Channel and Floodplain extending from Tamboy to Port Stephens (Figure 1-1). While the catchment extends along the Myall River upstream to Bulahdelah and beyond, this area has only been incorporated into the model to accurately define the flood risk to the Lower Myall and is not part of the actual study.

2.1.1 Catchment Description

The Lower Myall River catchment covers an area of 909 km^2 extending north-east from Port Stephens to cover the Myall Lakes and northwards along the Myall River to Bulahdelah and 30 km beyond (see Figure 1-1). A significant proportion of the catchment lies within 15 km of the coastline and is typically below 10 m AHD in elevation. At the top of the catchment of the Myall River, the valley floor is approximately 100 m AHD while elevations at the top of the western catchment boundary exceed 500 m AHD. The catchment topography is shown in Figure 2-1.

A summary of the major sub-catchments areas is presented in Table 2-1 while the location of the sub-catchment boundaries is presented in Figure 2-1. The Myall River catchments (including Crawford River) contribute 48% (435.1 km^2) of the total catchment area. The water way (lake) area of the catchment is also significant comprising 102 km^2, 11.2% of the total catchment area.

Table 2-1 Summary of Major Catchment Areas

Name	Area (km^2)	Included Lake Area (km^2)
Myall Lake	132.7	65.0
Boolambayte Creek and Lake	113.7	14.0
Crawford River	124.0	0
Myall River (above Bulahdelah)	237.6	0
Myall River (below Bulahdelah)	73.5	0
Nerong Creek	88.8	0
Bombah Broadwater	52.0	23.0
Lower Myall	86.8	0
Total	**909.1**	**102.0**

The Myall River drains the majority of the catchment into Bombah Broadwater and is fed by the Crawford River and Frys Creek above Bulahdelah. Above Bulahdelah, the valley is typically steeper and the channel is 20-30 m wide. Below Bulahdelah, the floodplain flattens out and the channel widens to 50-60 m and a low lying geomorphologically active floodplain provides significant storage during flood events. The channel and floodplain is also influenced by a tailwater from the Lakes which can take weeks to months to fully drain after significant flood events. Boolambayte Creek drains the next largest catchment and comprises a well-defined drainage channel that is reasonably steep and hence more efficient at conveying runoff. The Nerong catchment is predominantly a very flat sandy catchment with few defined channels and hence is less efficient at conveying runoff into Bombah Broadwater.

The Lakes system consists of Myall Lake to the North which connects through the smaller Boolambayte Lake into Bombah Broadwater. The lakes and floodplain provide considerable flood storage. A stage-area-volume relationship of the available storage (above Brasswater) is provided in Eqn 2.1 & 2.2 and summarised in Table 2-2.

Waterway Area (km^2) = 18.08 x WL + 102.45 Eqn 2.1

Storage Volume (GL) = 9.0281 x WL^2 + 103.66 x WL + 277.38 Eqn 2.2

The Lakes are drained by the Lower Myall which runs for 28 km from the Bombah Broadwater into Port Stephens. The Lower Myall consists of a typically 2 m deep, 50-80 m wide channel and a 1000 – 1500 m wide floodplain at 0.5 – 1.5 m AHD. Above Monkey Jacket fluvial processes have dominated floodplain and channel morphology while tidal processes have been the key force in shaping channel features between Monkey Jacket and Port Stephens. The Lower Myall drains through the townships of Tea Gardens, Hawks Nest and Winda Woppa before discharging at Corrie Island via Corrie Creek (i.e. the Northern Channel) and Paddy Marrs Inlet (i.e. the Eastern Channel) into Port Stephens.

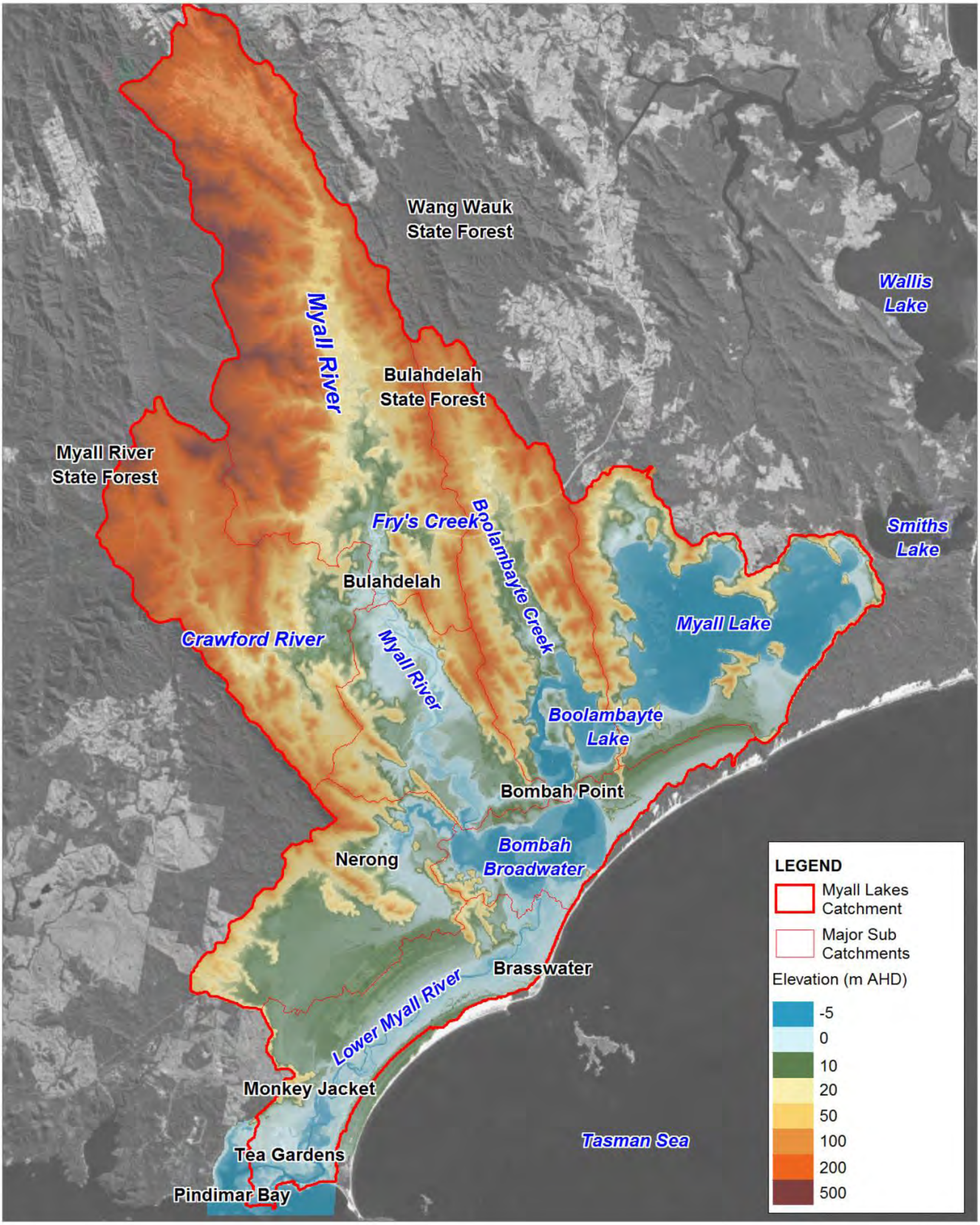
The suburbs of Tea Gardens, Hawks Nest and to a lesser degree Winda Woppa comprise the main population centres (~3,500 people) within the Lower Myall floodplain. There are several properties at Nerong which may also be flood affected. Smaller localities which may be flood effected include Tamboy, Bombah Point and a number of camping sites along Mungo Brush Road.

Outside the populated townships, the catchment is predominantly National Park, farmland and woodland. The Pacific Highway which now bypasses Bulahdelah is the only significant transport route, and while being located in the contributing catchment is outside of the study area.

Table 2-2 Myall Lakes Stage – Area – Volume Relationship

WL (mAHD)	Area (km2)	Volume (GL) above 0mAHD
0.00	102.5	0.0*
0.10	104.3	10.5
0.20	106.1	21.1
0.25	107.0	26.5
0.50	111.5	54.1
0.75	116.0	82.8
1.00	120.5	112.7
1.25	125.1	143.7
1.50	129.6	175.8
1.75	134.1	209.1
2.00	138.6	243.4
2.50	147.7	315.6
3.00	156.7	392.2
3.50	165.7	473.4
4.00	174.8	559.1

* Lake Volume at 0 m AHD is 277.4 (GL).



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Topography of the Myall Lakes Catchment

Figure: **2-1**

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2.2 Compilation and Review of Available Data

2.2.1 Previous Flood Studies

Details of previous flood studies relevant to the current study are presented below. The PWD (1980) study will be of most relevance to the current study. An extension of the flood study that included a consideration of sediment transport dynamics is presented in MHL (1993). A number of studies (i.e. DWLC (2002), PWD (1991) and PWD (1994)) were undertaken to determine flood risk at Bulahdelah. The Port Stephens Flood Study (MHL, 1996) will be used to determine a suitable downstream boundary condition for ocean storm surge design events.

BMT WBM (2011) provides a sediment and hydrodynamic assessment of the Lower Myall River and will be used to determine a suitable design bathymetry for the Eastern Channel.

2.2.1.1 Lower Myall River Flood Analysis (PWD NSW, 1980)

In 1980 the Public Works Department NSW undertook a study to define and understand local flood behaviour for both land development and river hydraulics purposes. A mathematical (steady state) model was used to synthesise a range of expected flood events (5% & 1% AEP) in the Lake System and Lower Myall River.

The flood model used was an in-house 1D steady state flood model that used 25 cross-sections to represent the channel and floodplain of the Lower Myall River between Winda Woppa and Tamboy. The cross-section data was collected by the Public Works Department in 1977 using a local low water datum which was later corrected to AHD using an approximate correction with associated errors of 0.3 m.

The model was calibrated to the April 1927, March 1977, May 1977 and March 1978 historic events.

Peak Myall Lake heights were derived by running the model for a number of predetermined hydrologic conditions and applying them for various durations. The resulting design flood values are listed in Table 2-3.

Table 2-3 Design Flood Values (PWD, 1980)

	1% AEP	5% AEP
Optimal Duration (days)	7 to 10	7 to 10
Average Rainfall Intensity (mm/hour)	3.6	2.9
Peak Lake Level (m AHD)	3.00	2.56
Peak Lake Outflow (m^3/s)	290	210

A range of sensitivity testing of the design events was undertaken to assess the impact of changes key model parameters on peak lake levels. Tests included sensitivity to: rainfall; rainfall loses; lake storage; initial lake level and river discharge rating. The ten sensitivity tests concluded that the 1% AEP lake level could range between 2.54 and 3.22 m AHD, while the 5% AEP lake level could range between 2.18 and 2.75 m AHD. A crude estimate of a probable maximum flood event predicted lake levels as high as 5 m AHD, with an associated peak river outflow of 1000 m^3/s.

Some other key points from the study include:

- Near the mouth (i.e. downstream of Tea Gardens) flood behaviour is almost independent of river flooding.
- The effect of river flood flows at Tea Gardens is less than 10 centimetres for a high tide and will decrease as tidal flood level rise.
- Adopted rainfall losses for the study are initial loss of 30 mm and continuing loss of 0 mm/hr
- Lake area was assumed to be 113 km^2 at 0 m AHD and 170 km^2 at 3 m AHD.
- Storage within the model was represented by: Area (km^2) = 113 + 19 x lake level (m AHD)
- An initial lake level of 0.5 m AHD was (arbitrarily) adopted.

2.2.1.2 *Lower Myall River Compilation of Data (MHL, 1993)*

Lower Myall River Compilation of Data (MHL, 1993) was undertaken to summarise existing data on estuarine processes in the Lower Myall River. It was undertaken as an initial stage in the preparation of an estuary process study of the area and includes previously unpublished data and text material.

The report details use of a numerical model used to determine hydraulic and morphologic processes occurring in the Lower Myall River. The model is described as an unsteady, one-dimensional numerical estuarine model developed by Fischer in 1970. The model used 30 segments to define the area between the Broadwater and Port Stephens. Of relevance to the current study is the estimation of maximum probable water levels as presented in Table 2-4. The event considers the maximum flood levels that would occur when an extremely rare flood peak coincided with a combination of storm surge, king tide and wave set-up. The flood event was based on the April 1927 storm with an estimated flood height of 3.2 m AHD and a peak storm surge tide of 2.26 m AHD at Paddy Marrs Inlet.

Table 2-4 Maximum Probable Water Levels (MHL, 1993)

Site	Extreme
The Confluence	2.23
Hawks Nest Bridge	2.29
North Tea Gardens	2.43
Durness	2.7
The Pines	3.00
Rooke Island	3.14
The Brasswater	3.18
The Broadwater	3.21

2.2.1.3 *Myall River Floodplain Risk Management Study for Bulahdelah (DLWC, 2002)*

The DLWC (2002) study focused on flooding from the Myall River and its tributaries. Key relevant points of interest from the report include:

- The Myall River has a catchment area of 365km^2 at the Pacific Highway, with the major tributary (Crawford River) having a catchment area of 125km^2.

- The largest floods occurred in 1897 and 1927.
- Smaller floods occurred in 1947 and 1953 with less severe floods occurring in 1985 and 1987.
- MIKE11 (1D) and RMA2 (2D) modelling was undertaken to determine flood levels, velocities and hazard.
- The study was based on previous investigations including PWD (1991) and PWD (1994) which used the WBNM catchment model to determine the relevant hydrological inputs.

2.2.1.4 Bulahdelah Flood Appraisal (PWD, 1991)

The Bulahdelah Flood Appraisal (PWD, 1991) was carried out to define the nature and extent of the flood hazard at Bulahdelah under existing catchment conditions. The study area extends along the Myall River between a location 430 m downstream of the Pacific Highway bridge, and some 2 km upstream of the bridge at Lee Street. A WBNM hydrologic model and a MIKE11 hydraulic model were used to calculate peak flood levels for the 1%, 2% and 5% AEP floods.

Key relevant points of interest from the report include:

- The MIKE11 model used seven surveyed cross-sections from Lee St Bridge to downstream of the Pacific Highway.
- Model hydrology was calculated using the WBNM runoff-routing method with six catchment inputs.
- The model was calibrated to flood events in October 1985 and November 1987.
- An initial rainfall loss of 21 mm and continuing losses of 2.5 mm/hr were adopted for the 1987 flood and the design floods. For the 1985 flood an initial loss of 0 mm was adopted due to considerable rainfall prior to the event.
- A critical storm duration of 36 hours was found to produce a peak discharge of 2100 m^3/s at the Bulahdelah bridge.

2.2.1.5 Frys Creek Flood Study (PWD, 1994)

The Frys Creek Flood Study (PWD, 1994) was carried out to define the nature and extent of the flood hazard at Bulahdelah under existing catchment conditions. The Frys Creek confluence with the Myall River is approximately 3 km upstream of the Pacific Highway Bridge. At this location the Myall River and Frys Creek have catchment areas of 240 km^2 and 18 km^2 respectively

This study was only a minor extension to the Bulahdelah Flood Appraisal (see above) and does not contain any additional information relevant to this study.

2.2.1.6 Port Stephens Flood Study (MHL, 1996)

The Port Stephens Flood Study (MHL, 1996) was undertaken to determine the nature and extent of flooding around the foreshore of Port Stephens and Tilligerry Creek. The design water levels and wave conditions were estimated for the 1%, 2%, 5% AEP and extreme flood events.

Key relevant points of interest from the report include:

- A two-dimensional (MIKE21) model was used to estimate water level conditions around the Port Stephens foreshore. The model included ocean tides (including storm surges), flood runoff and local wind setup.
- Elevated ocean levels are they key control to peak water levels in Port Stephens.
- Wind setup may vary water levels within Port Stephens by up to 0.3 m depending on wind direction.
- Design water levels and wave conditions were calculated at 42 locations around Port Stephens. Design water levels for four locations relevant to the current study are presented in Table 2-5.
- A WBNM model of the Karuah River catchment was developed to calculate inflows from the 1473 km^2 catchment. Because of the catchment size AR&R (1987) could not be used in the study. IFD data for the catchment was determined by BOM from daily records of mean catchment rainfall for ten stations in and around the catchment. Design temporal patterns for the 24, 48, 72, 96 and 120 hour storm durations were derived by BOM from the storms used in the Generalised Southeast Australia Method (GSAM) for the coastal zone prior to smoothing.
- Design ocean still water levels were based on an analysis of the Sydney tidal database and are presented in Table 2-6. A storm surge duration of 72 hours was applied to predicted Sydney tides from 27 April 1990.

Table 2-5 Design Water Levels (no wave action) (MHL, 1996)

Site	Extreme	1% AEP	5% AEP
Pindimar	1.73	1.69	1.6
Tea Gardens	2.28[1]	1.79[1]	1.62
Hawks Nest	1.99[1]	1.67[1]	1.52
Winda Woppa	1.62	1.6	1.51

Note 1: Affected by Myall River flow, particularly in the Extreme event.

Table 2-6 Design Ocean Levels adopted for Port Stephens Entrance (MHL, 1996)

Probability of Occurrence	Still Water Level (m AHD)
5% AEP	1.43
2% AEP	1.47
1% AEP	1.50

2.2.2 Water Level Data

MHL operates four continuous water level gauges that are of relevance to the study. Three gauges are located within the catchment while the Tomaree Gauge is located at the entrance to Port Stephens (refer to Table 2-7 for details). The locations of the four operational MHL water level gauges are shown in Figure 2-2. A number of other temporary or short term gauges are also relevant to the study and are described in Section 5.2.

Table 2-7 Lower Myall Water Level Data Gauges (MHL)

Name	Start Date	Comment
Bulahdelah	15/11/1984	Influenced by lake tailwater
Bombah Point	17/07/2001	Used as primary calibration data set
Tea Gardens	16/12/2008	Salinity data also available
Tomaree	23/09/1985	Used for tidal boundary conditions

2.2.3 Historical Flood Levels

Historic flood data has been used in model calibration to determine appropriate model parameters (such as initial and continuing losses and also roughness values) and in model validation to improve confidence in model predictions. A review of previous flood studies indicates that there is sufficient data available for the proposed calibration and verification process.

The following historical floods and their associated peak water levels were identified by MHL (1993) and are based on PWD (1980):

- 1890s - 3.7 m AHD (Myall Lakes) ;
- 1927 - 2.7 to 3.2 m AHD (Myall Lakes);
- 1963 - 2.2 m AHD (Tamboy, Myall Lakes);
- March 1977 - 1.2 m AHD (Bombah Point, Myall Lakes);
- March 1978 - 1.31 m AHD (Bombah Point, Myall Lakes); and
- May 1978 - 1.3 m AHD (Bombah Point, Myall Lakes).

Inspection of the Bombah Point water level gauge from July 2001 to May 2012 indicates several other significant flood events as presented in Table 2-8.

Table 2-8 Recent Peak Bombah Point Flood Levels (m AHD)

Date	Flood Level (mAHD)	Rainfall
27th April 2008	1.45*	~ 400mm in 20 days
29th May 2003	1.39	300 – 600 mm in 30 days
25th July 2011	1.27	~245 mm in 15 days
16th June 2011	1.20	310 – 370 mm in 28 days
19th February 2009	1.13	
22nd October 2004	1.05	

* This is an estimated value as discussed in Section 5.5.1.2.

2.2.4 Rainfall Data

MHL operates two pluviometers within or in close vicinity to the Lower Myall catchment. The location and period of record for each pluviometer is presented in Table 2-9.

Table 2-9 Summary of Pluviometers near the Myall Lakes Catchment

Location	Start / End Date
MHL - Bulahdelah	06/08/1996 – Current
MHL – Tarbuck Bay	16/05/1996 – Current

In addition to the pluviometers, there are thirteen daily read rainfall gauges (including closed gauges) operated by the Bureau of Meteorology (BoM) located within or in close vicinity to the Myall Lakes catchment. The daily read rainfall gauges are shown in Table 2-10 with their respective period of record. The distribution of these rainfall gauges (including the pluviometers) is shown in Figure 2-3.

Table 2-10 Summary of BoM Daily Read Gauges for the Myall Lakes Catchment

Gauge No.	Location	Start Year
60002	Bulahdelah Post Office	30/10/1905
60095	Bungwahl	04/03/2002
60096	Cabbage Tree Mountain	20/03/2002
61072	Carrington House (Tahlee)	30/03/1887
60099	Crawford	03/09/2002
60123	Hawks Nest (Golf Club)	01/01/2008
61054	Nelson Bay	19/05/1881
60028	Seal Rocks	07/09/1897
0144	Smiths Lake (Patsys Flat Rd)	30/03/1980
61071	Stroud Post Office	29/04/1889
60159	Warranulla Lodge	01/01/2005
60148	Willina	17/06/2003
60065	Wootton	12/02/2002

Further discussion on recorded rainfall data for historical events is presented with the model calibration and validation data in Section 5.

Title:
Water Level Gauges Relevant to Study

Figure: 2-2

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Approx. Scale

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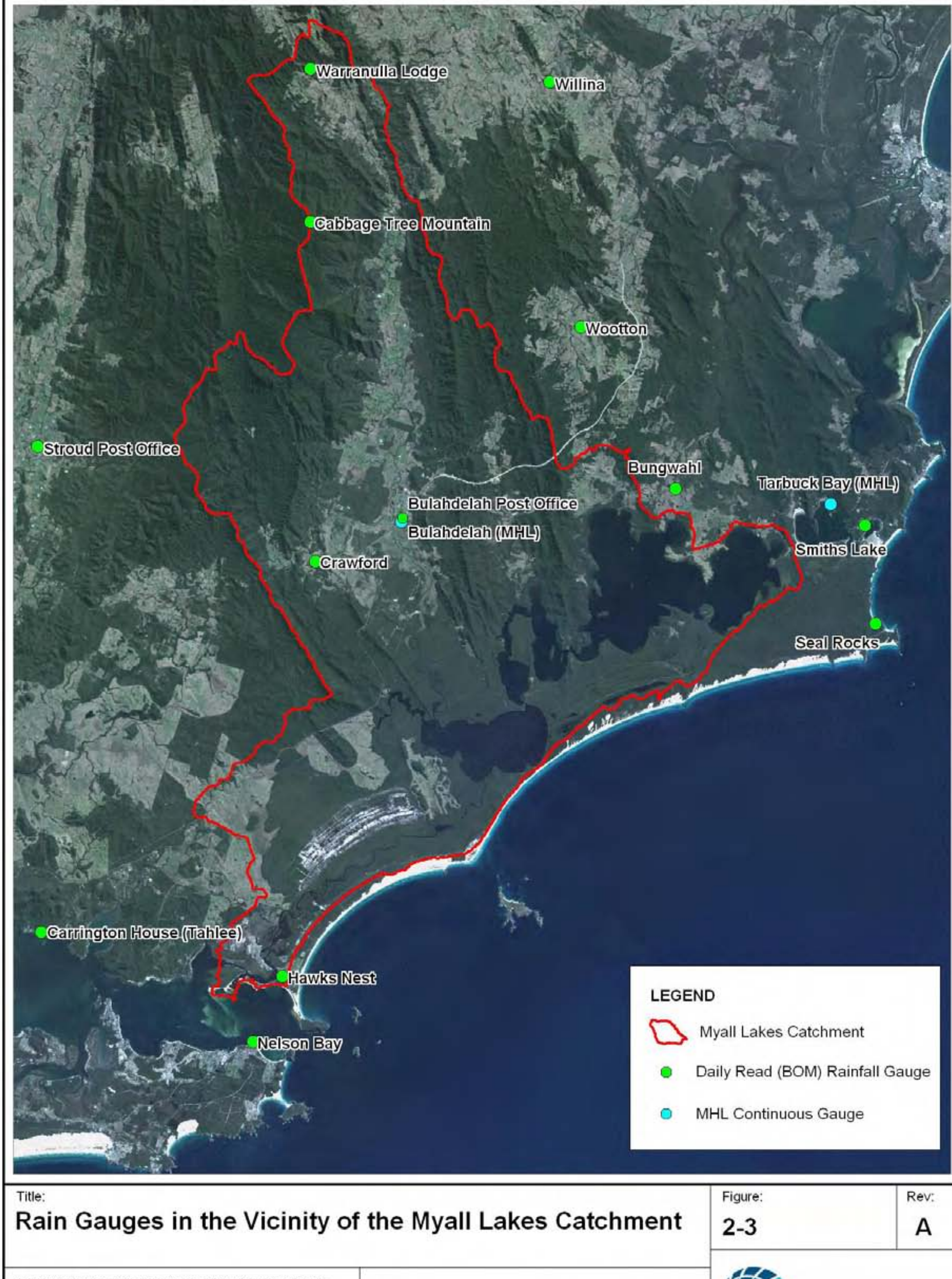

Title:
Rain Gauges in the Vicinity of the Myall Lakes Catchment

Figure: 2-3

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2.2.5 Topographic Data

Raw LiDAR data (in the form of ground surface points) was provided for part of the Lower Myall catchment by GLC. The LiDAR data were collected between the 1st and 21st August 2008 by AAM Hatch. The LiDAR data was supplied with a stated vertical accuracy +/- 0.15m and horizontal accuracy +/- 0.25m. It should be noted that the stated vertical and horizontal accuracy of the LiDAR data is only applicable to land surface areas. The LiDAR data points were used to derive a high resolution (5 m grid) digital elevation model (DEM) of the Lower Myall floodplain. The extent of available LiDAR is presented in Figure 2-4.

Smoothed Shuttle Radar Topography Mission (SRTM) data collected by NASA in February 2000 and purchased from Geo Science Australia (2011) was used in areas where no LiDAR was available. This data was combined to create a 10m DEM of the land surface for the entire catchment. Checks of the DEM revealed a number of patches of inconsistent data in both the LiDAR and SRTM data sets which were fixed through the use of triangulation patches applied in the TUFLOW model geometry.

2.2.6 Bathymetry Data

Bathymetry data used in the Flood Study includes:

- Myall Lake and Myall River hydrographic survey data collected in 2001 by DECCW. This survey data covers the Myall Lakes, Lower Myall River and the north eastern section of Port Stephens.
- Myall River Entrance hydrographic survey collected in September 2009 by DECCW, covering the Lower Myall River (below Tea Gardens), Corrie Creek (Northern Channel) and Paddy Marrs Inlet (Eastern Channel).

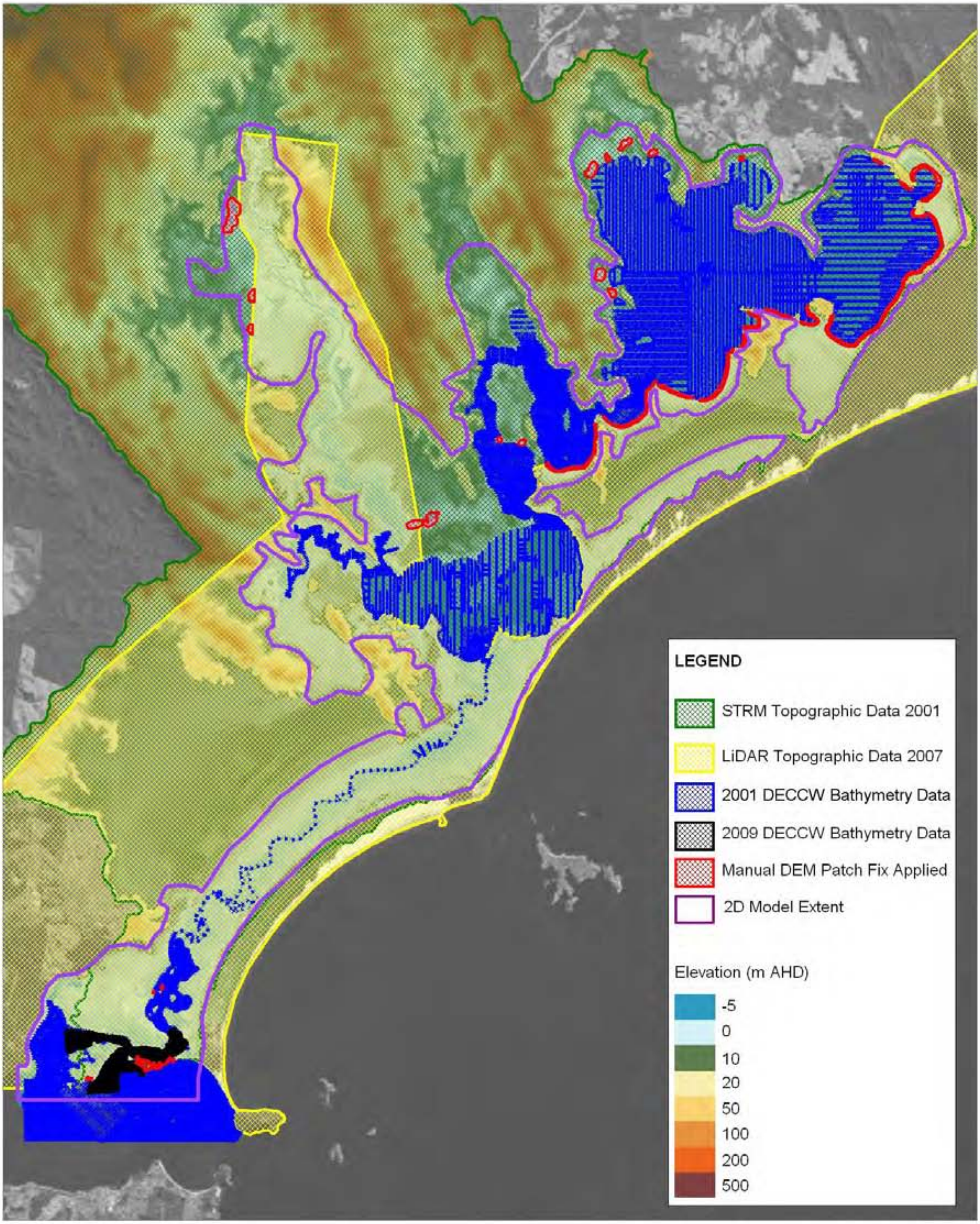
The extents of these data sets are presented in Figure 2-4. GIS software was used to generate a DEM of the combined bathymetric data sets.

2.2.7 Model DEM Generation

The topographic and bathymetric data sets were combined to produce a single DEM of the model area. Where inconstancies between the two data sets were present, triangulation patches were used to provide an appropriate smoothed representation of model topography (refer to Section 4.2.2).

2.2.8 Survey Check Data

Ground survey at a number of transects along the Lower Myall Floodplain was undertaken to ensure that the LiDAR data was able to accurately represent the ground surface in areas where dense vegetation was present. Ground survey elevation data was collected in June 2012 and was found to generally be consistent with the elevation data derived from the LiDAR data set. This indicates that the LiDAR data is of suitable accuracy along the floodplain and is appropriate for use in the flood study. A comparison of the ground survey and LiDAR data is presented in Appendix A.



Title:
Sources of Topographic and Bathymetric Data

Figure: 2-4

Rev: A

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0 3.75 7.5km

Approx. Scale

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2.3 Community Consultation

The success of a floodplain management plan hinges on its acceptance by the community, residents within the study area, and other stake-holders. This can be achieved by involving the local community at all stages of the decision-making process. This includes the collection of their ideas and knowledge of flood behaviour in the study area, together with discussing the issues and outcomes of the study with them.

The key elements of the consultation program undertaken for the study are discussed in Section 3.

2.4 Development of Computer Models

2.4.1 Hydrological Model

For the purpose of the Flood Study, a hydrological model (discussed in Section 4.1) was developed to simulate the rate of storm runoff from the catchment. The model predicts the amount of runoff from rainfall and the attenuation of the flood wave as it travels down the catchment. This process is dependent on:

- Catchment area, slope and surface coverage;
- Variation in distribution, intensity and amount of rainfall; and
- Antecedent conditions of the catchment.

The output from the hydrological model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are used by a hydraulic model to simulate the passage of a flood through the catchment to the downstream study limits at Port Stephens.

2.4.2 Hydraulic Model

The hydraulic model (discussed in Section 4.2) developed for this study provides for a two-dimensional (2D) representation of the Myall Lakes and Lower Myall River.

The hydraulic model is applied to determine flood levels, velocities and depths across the study area for historical and design events.

2.5 Calibration and Sensitivity Testing of Models

The hydrological and hydraulic models were calibrated and verified to available historical flood event data to establish the values of key model parameters and confirm that the models were capable of adequately simulating real flood events.

The following criteria are generally used to determine the suitability of historical events to use for calibration or validation:

- The availability, completeness and quality of rainfall and flood level event data;
- The amount of reliable data collected during the historical flood information survey; and

- The variability of events – preferably events would cover a range of flood sizes.

The available historical information highlighted three flood events with sufficient data to support a calibration process – the July 2011, May 2003 and April 2008 events. The July 2011 event has been selected as the primary calibration event as it is the only where water level data for Tea Gardens is available. Due to data availability, the May 2003 and April 2008 events have been used for model validation.

The calibration and validation of the model are presented in Section 5.

3 COMMUNITY CONSULTATION

3.1 The Community Consultation Process

Community Consultation has been limited in this stage (undertaking the flood study) of the floodplain management process. The existence of previous studies combined with the characteristics of the study area and presence of automated water level recorders meant that no additional flood level information was required.

The consultation process has aimed at informing the community of the flood study and its likely outcome as a precursor to subsequent floodplain management activities.

Elements of the consultation process include:

- Development of an information website; and
- Public Exhibition of the draft Flood Study.

3.1.1 Information Website

An information website containing relevant details of the flood study has been developed and can be accessed from a link from the Great Lakes Council, Flooding and Flood Management webpage.

3.1.2 Public Exhibition

Great Lakes Council has undertaken an Integrated Planning approach for floodplain management guided by a Gateway Determination from NSW Department of Planning and Environment on 28 August 2014. Community engagement effort was shared between Council's Design and Investigation Division and Strategic Planning Division. This approach provided a more effective forum for the public to discuss a wider range of matters covering flood modelling, hazards and responses along with proposed strategic planning measures.

The Planning Proposal, Draft Great Lakes Development Control Plan (DCP) Amendments and Draft Lower Myall River and Myall Lakes Flood Study were placed on public exhibition in accordance with the Gateway Determination, between 22 December 2014 and 30 January 2015 inclusive. During the public exhibition period Council officers organised official notifications in all local newspapers in December and January; public information sessions in Stroud, Nabiac, Tea Gardens, Pacific Palms and Forster, media releases and a notification in the January 2015 Council Communicator which was sent to 18,376 rate payers. The information session at Tea Gardens was held on Thursday, 15 January 2015.

The hard copy documents were available at all Council District Offices and the Customer Service Centre in Forster during the public exhibition period and all information was available on the Council website.

Unfortunately, in response to the public exhibition of the Flood Study, no submissions were received. This is seen to be a result of widespread awareness and acceptance of the modelling and results contained in the Flood Study. Improved modelling gave a high degree of Council and public confidence in the outcomes which basically conveyed good news in the reduction of design flood levels. Council had also notified the public of the intention to utilise draft results for planning and engineering purposes prior to completion of the final report. It was felt that all these factors contributed to the lack of questions remaining the time of the information session.

4 MODEL DEVELOPMENT

Computer models are the most accurate, cost-effective and efficient tools to assess a catchment's flood behaviour. Traditionally, for the purpose of the Flood Study, a hydrological model and a hydraulic model are developed.

The **hydrological model** simulates the catchment rainfall-runoff processes, producing the stormwater flows which are used in the hydraulic model.

The **hydraulic model** simulates the flow behaviour of the overland flow paths, creeks and lagoon producing flood levels, flow discharges and flow velocities.

Both of these models were calibrated interactively.

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

Development of a hydraulic model follows a relatively standard procedure:

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

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

- establishing design flood conditions (as part of the current Flood Study);
- determining levels for planning control (as part of the floodplain risk management study); and
- modelling development or management options to assess the hydraulic impacts (as part of the floodplain risk management study).

4.1 Hydrological Model

The hydrological model simulates the rate at which rainfall runs off the catchment. The amount of rainfall runoff from the catchment is dependent on:

- the catchment slope, area, vegetation, urbanisation and other characteristics;
- variations in the distribution, intensity and amount of rainfall; and

- the antecedent moisture conditions (dryness/wetness) of the catchment.

These factors are represented in the model by:

- Sub-dividing (discretising) the catchment into a network of sub-catchments inter-connected by channel reaches representing the creeks and rivers. The sub-catchments are delineated, where practical, so that they each have a general uniformity in their slope, landuse, vegetation density, etc;
- The amount and intensity of rainfall is varied across the catchment based on available information. For historical events, this can be very subjective if little or no rainfall recordings exist.
- The antedecent moisture conditions are modelled by varying the amount of rainfall which is "lost" into the ground and "absorbed" by storages. For very dry antedecent moisture conditions, there is typically a higher initial rainfall loss.

The output from the hydrological model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are used by the hydraulic model to simulate the passage of the flood through the Myall Lakes catchment.

The RAFTS-XP software was used to develop the hydrological model using the physical characteristics of the catchment including catchment areas, ground slopes and vegetation cover as detailed in the following sections.

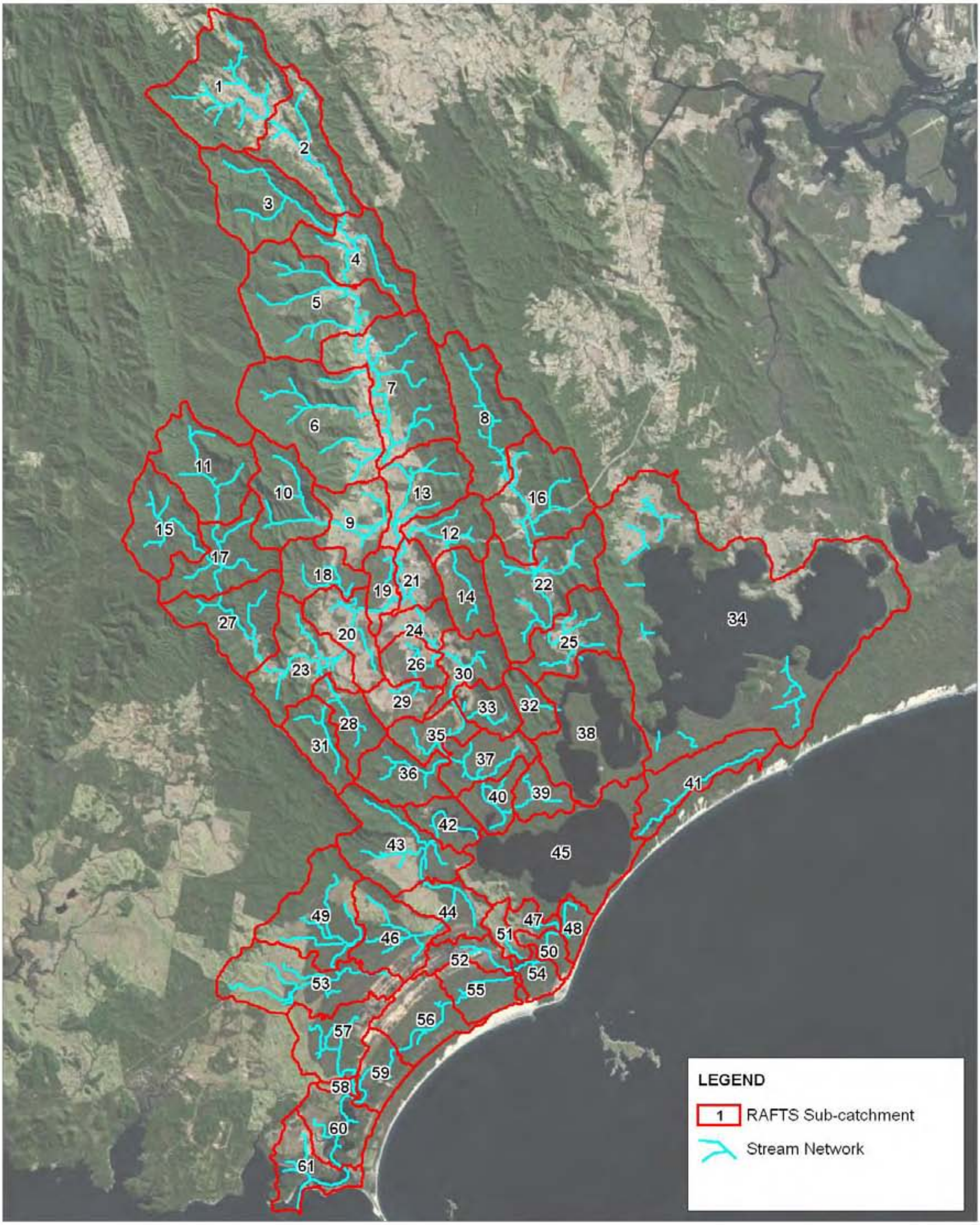
4.1.1 Catchment Delineation

The Myall Lakes catchment drains an area of approximately 909 km^2 into Port Stephens. For the hydrological model this area has been delineated into 61 sub-catchments as shown in Figure 4-1. The sub-catchment delineation provides for generation of flow hydrographs at key confluences or inflow points to the hydraulic model.

Table 4-1 summarises the key catchment parameters adopted in the RAFTS-XP model, including catchment area, vectored slope and stream length. A PERN (roughness) value of 0.12 was selected for all catchments. As nearly all catchments are predominantly rural / forested they were considered 100% pervious. For the catchments containing the main Lake waterbodies, the lake area was considered to be 100% impervious effectively providing for direct rainfall contribution to the lake storage.

Table 4-1 RAFTS-XP Sub-catchment Properties

Catchment Label	Area (ha)	Slope (%)	Stream Length (km)	Catchment Label	Area (ha)	Slope (%)	Stream Length (km)
1	2934	1.95	8.8	33	630	0.71	5.4
2	1769	1.12	8.3	34 (land)	6700	0.5	n/a
3	1972	2.94	10.7	34 (lake)	6500	n/a	n/a
4	1484	0.99	5.8	35	734	0.5	5.2
5	2829	2.62	3.5	37	950	0.76	3.0
6	3305	3.45	8.7	38 (land)	1520	2	n/a
7	2838	0.5	10.5	38 (lake)	1400	n/a	n/a
8	2065	1.51	10.5	39	591	0.06	5.0
9	1137	1.08	4.1	40	643	0.4	4.5
10	1510	4.26	7.8	41	1421	0.06	12.5
11	1879	2.43	9.1	42	646	0.4	5.3
12	905	0.83	3.8	43	1941	0.81	2.9
13	1467	0.57	6.3	44	895	0.21	4.3
14	899	1.25	6.8	45 (land)	1480	1	n/a
15	1476	2.41	8.2	45 (lake)	2300	n/a	n/a
16	2134	0.59	6.2	46	1428	0.2	5.2
17	1526	1.72	5.1	47	286	0.19	4.2
18	922	1.65	5.9	48	348	0.78	4.0
19	529	0.3	2.6	49	1863	0.18	3.4
20	1060	0.24	3.3	50	335	-0.27	2.6
21	643	0.36	5.1	51	322	0.46	4.7
22	2334	0.66	4.8	52	545	0.28	7.5
23	1676	0.62	7.3	53	2093	0.08	9.8
24	593	0.41	4.6	54	390	-0.53	1.7
25	1349	0.94	3.1	55	836	0.6	6.2
26	643	0.01	4.3	56	1273	0.43	5.2
27	1624	1.76	5.8	57	1317	0.18	8.6
28	821	0.66	2.7	58	115	0.38	1.3
29	610	0.55	3.7	59	718	0.42	6.3
30	909	1.2	4.2	60	1090	0.53	6.1
31	855	1.45	6.0	61	1046	0.42	5.5
32	542	2.81	4.4				



Title:
RAFTS Model Sub-catchment Layout

Figure: 4-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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4.1.2 Rainfall Data

Rainfall information is the primary input and driver of the hydrological model which simulates the catchment's response in generating surface run-off. Rainfall characteristics for both historical and design events are described by:

- Rainfall depth – the depth of rainfall occurring across a catchment surface over a defined period (e.g. 250 mm in 120 hours or average intensity 2.083 mm/hr); and
- Temporal pattern – describes the distribution of rainfall depth at a certain time interval over the duration of the rainfall event.

Both of these properties may vary spatially across the catchment during any given event and between different events.

The procedure for defining these properties is different for historical and design events. For historical events, the recorded hyetographs at continuous rainfall gauges provide the observed rainfall depth and temporal pattern (refer Section 2.2.4 for rainfall gauge locations). Where only daily read gauges are available within a catchment, assumptions regarding the temporal pattern may need to be made.

For design events, rainfall depths are most commonly determined by the estimation of intensity-frequency-duration (IFD) design rainfall curves for the catchment. Standard procedures for derivation of these curves are defined in AR&R (2001). Similarly AR&R (2001) defines standard temporal patterns for use in design flood estimation. AR&R (2001) only provides IFD curves for durations up to 72 hours. As the primary flood mechanism for the Myall Lakes is flood volume it is likely that events of greater than 72 hours will produce the highest flood volume and hence peak water level. It is possible that an alternate method of defining the design events will be required as discussed in Section 6.

The rainfall inputs for the historical calibration/validation events are discussed in further detail in Section 5.

4.1.3 Rainfall Losses

The antecedent catchment condition reflecting the degree of wetness of the catchment prior to a major rainfall event directly influences the magnitude and rate of runoff. The initial loss-continuing loss model has been adopted during the hydrological modelling process. The initial loss component represents a depth of rainfall effectively lost from the system and not contributing to runoff and simulates the wetting up of the catchment to a saturated condition. The continuing loss represents the rainfall lost through soil infiltration once the catchment is saturated and is applied as a constant rate (mm/hr) for the duration of the runoff event.

The rainfall loss parameters for the historical calibration/validation events and design events are discussed in further detail in Section 5 and Section 6 respectively.

4.2 Hydraulic Model

BMT WBM has used the fully 2D software modelling package TUFLOW for the study. TUFLOW has the capability to simulate the dynamic interaction of in-bank flows in open channels, major underground drainage systems, and overland flows through complex overland flowpaths using a linked 2D / 1D flood modelling approach. TUFLOW is specifically orientated towards establishing flow and inundation patterns in coastal waters, estuaries, rivers, floodplains and urban areas where the flow behaviour is essentially 2D in nature and cannot or would be awkward to represent using a 1D model, and accordingly is well suited to model the conditions in the Myall Lakes catchment.

4.2.1 Extents and Layout

Consideration needs to be given to the following elements in constructing the model:

- topographical data coverage and resolution (e.g. LiDAR data);
- location of recorded data (eg. levels/flows for calibration);
- location of controlling features (eg. dams, levees, bridges);
- catchment specific factors (e.g. lagoon entrance); and
- computational limitations.

With consideration to the available survey information and local topographical and hydraulic controls, a multi-domain 2D model was developed using a 20 m grid to represent the Lower Myall channel and floodplain and a 50 m grid to represent the Lakes and Myall channel and floodplain.

The floodplain area modelled within the 2D domain comprises a total area of approximately 313 km^2 comprising of 236 km^2 at 50m resolution and 77 km^2 at 20 m resolution. Model extents are presented in Figure 4-2.

It should be noted that TUFLOW samples elevation points at the cell centres, mid-sides and corners, so a 20 m cell size results in DEM elevations being sampled every 10 m. This resolution was selected to give necessary detail required for accurate representation of floodplain, channel and channel entrance topography.

4.2.2 Topography

The ability of the model to provide an accurate representation of the flood behaviour of the catchment ultimately depends upon the quality of the underlying topographic data. For the Myall Lakes model, a high resolution DEM was derived from a combination of the following data sets (refer to Sections: 2.2.5, 2.2.6 and 2.2.7 for further details):

- LiDAR survey data;
- SRTM survey data; and
- Myall Lakes and Lower Myall bathymetry survey data.

The ground surface elevation for the TUFLOW model grid points are sampled directly from the DEM. A number of triangulation patches were used to provide an appropriate smoothed representation of model topography where inconstancies or errors in topography data sets were present.

4.2.3 Lower Myall Entrance Channel Bathymetry

Bathymetry for the entrance to the Lower Myall is based on survey data collected in September 2009. Significant morphological change to the Eastern Channel (between Corrie Island and Winda Woppa Spit) has reduced the navigability and hydraulic capacity of this flow path. The Northern Channel which discharges into Pindimar Bay is less morphologically active. As they key hydraulic constraint is along the upper reaches of the Lower Myall, morphological change to entrance channel bathymetry is unlikely to significantly influence fluvial flood behaviour.

4.2.4 Structures

There no hydraulically significant bridges or culverts within the model domain. The bridge at Tea Gardens will have an insignificant influence on channel hydraulics due to the wide channel and low hydraulic gradients present at this location.

4.2.5 Hydraulic Roughness

The development of the TUFLOW model requires the assignment of different hydraulic roughness (Manning's 'n') zones. These zones are delineated from aerial photography identifying different land-types (e.g. forest, cleared lands, lakes and channels, etc) for modelling the variation in flow resistance. Aerial photography was used to delineate the Manning's 'n'; surface roughness zones as presented in Figure 4-3.

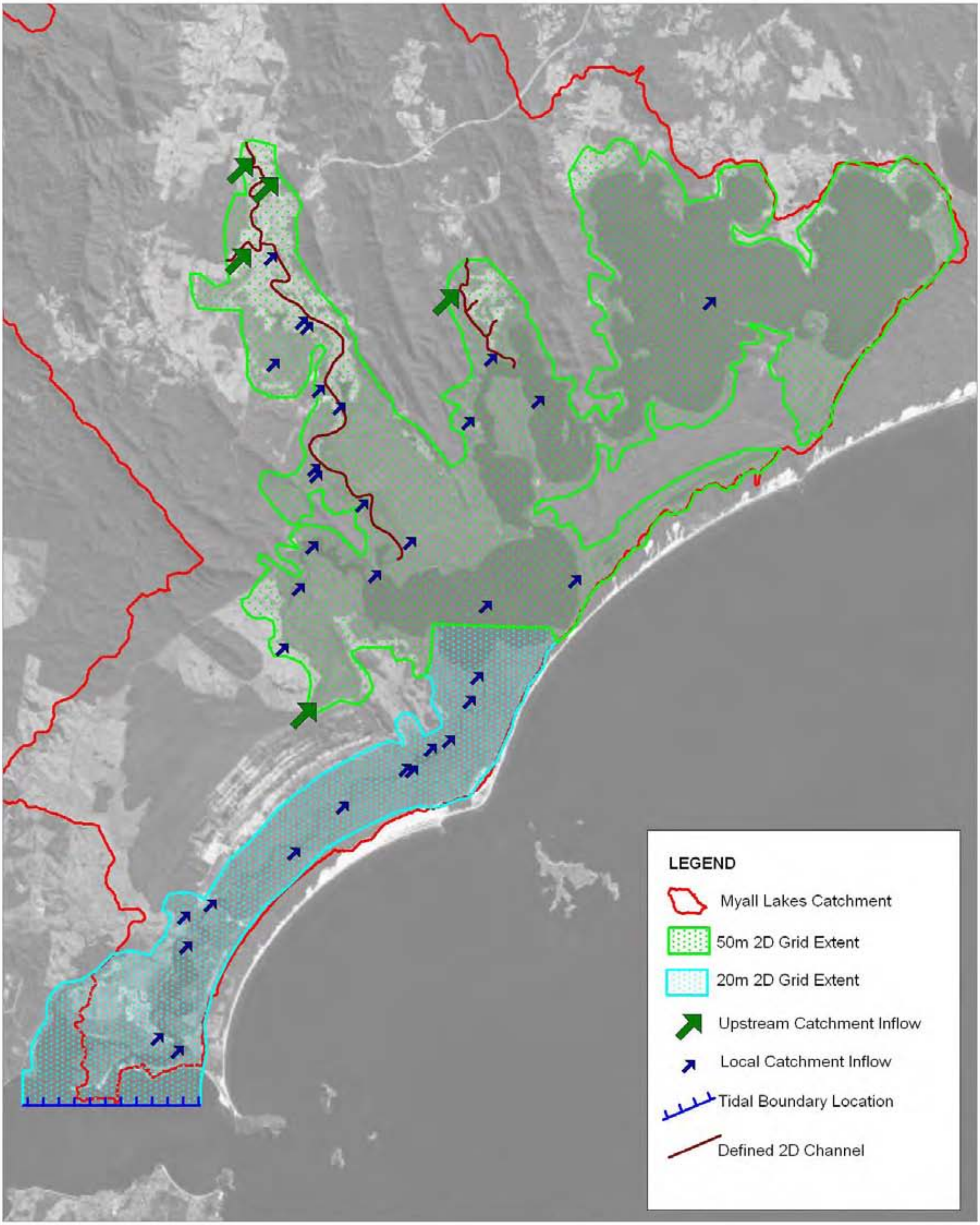
The hydraulic roughness is one of the principal calibration parameters within the hydraulic model and has a influence on flow routing and flood levels. During the model calibration process the Manning's 'n' surface roughness values are adjusted (within reasonable bounds) to provide best fit for peak water level profiles. .

4.2.6 Boundary Conditions

The model boundary conditions are derived as follows:

- Inflow – the catchment runoff is determined through the hydrological model and is applied to the TUFLOW model as flow vs. time inputs. These are applied at major sub-catchment inflow points and along the modelled watercourses; and
- Downstream Water Level – the downstream model limit corresponds to the tidal water level of Port Stephens. A water level time series has been applied at this location for the duration of the modelled events.

The adopted water levels for the downstream boundary condition for the calibration and design events are discussed in Section 5 and Section 6 respectively. The layout of the 2D hydraulic model is shown in Figure 4-2.



Title:
TUFLOW Model Layout

Figure: 4-2

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Approx. Scale

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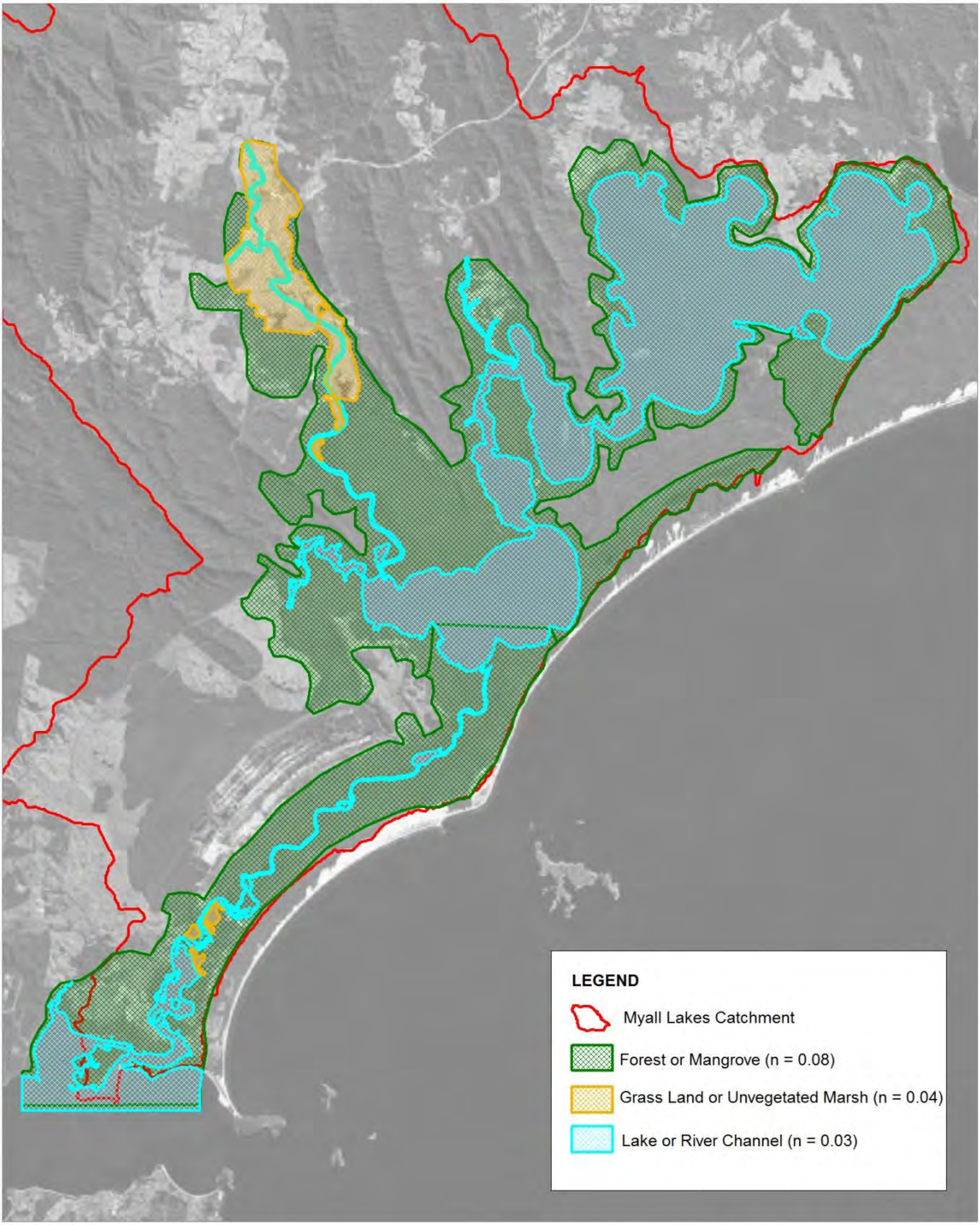

Title:

TUFLOW Model Roughness Values

Figure: **4-3**

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5 MODEL CALIBRATION AND VALIDATION

5.1 Selection of Calibration Events

The selection of suitable historical events for calibration and validation of flood models is largely dependent on the availability of relevant historical flood information. Ideally the calibration and validation process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design events to be considered.

Review of the available rainfall and water level data for the Myall Lakes catchment originally highlighted three flood events with sufficient data to support a calibration process – the July 2011, April 2008 and May 2003 event. The July 2011 event has been selected as the primary calibration event due to the fact that it is the only event captured by the MHL water level gauge at Tea Gardens. The May 2003 and April 2008 events have been used for model validation. During the course of the flood study a significant flood event (in early-March 2013) occurred and was also used as a validation event.

In addition to the four flood events a tidal calibration exercise has also been used to increase confidence in the models ability to replicate tidal fluctuations along the Lower Myall. The calibration period in late-September 2009 covers a period of intensive data collection undertaken by MHL in September 2009.

Table 5-1provides a summary of the adopted model calibration and validation events. Whilst the March 2013 event represents the most recent and highest in term of peak level for the adopted model calibration/validation events, the event occurred during the course of the study subsequent to the main model build and calibration process. Accordingly the event was adopted for model validation only.

Table 5-1 Summary of Adopted Model Calibration/Validation Events

Date	Bombah Broadwater Peak Flood Level (mAHD)	Comment
July 2011	1.27	Principal fluvial calibration event
May 2003	1.39	Fluvial validation event
April 2008	1.45	Fluvial validation event
March 2013	1.75	Fluvial validation event
September 2009	0.1	Principal tidal calibration event

5.2 September 2009 – Tidal Calibration

A tidal calibration exercise was undertaken to ensure the model could reproduce observed tidal fluctuations along the Lower Myall. The model was run for a ten day simulation period from the 17th September 2009 and compared to observed data collected by MHL during a period of intensive data collection in late-September 2009 as reported in (MHL, 2010).

The tidal calibration exercise ensures that the selected model configuration (including model extents, bathymetry grid size and model roughness) is capable of reproducing observed tidal fluctuations along the Lower Myall.

5.2.1 Downstream Boundary Conditions

Tidal water level data (see Figure 5-1) collected by MHL at Tomaree (see Figure 5-2 for location) was used to "drive" the model at the downstream boundary.

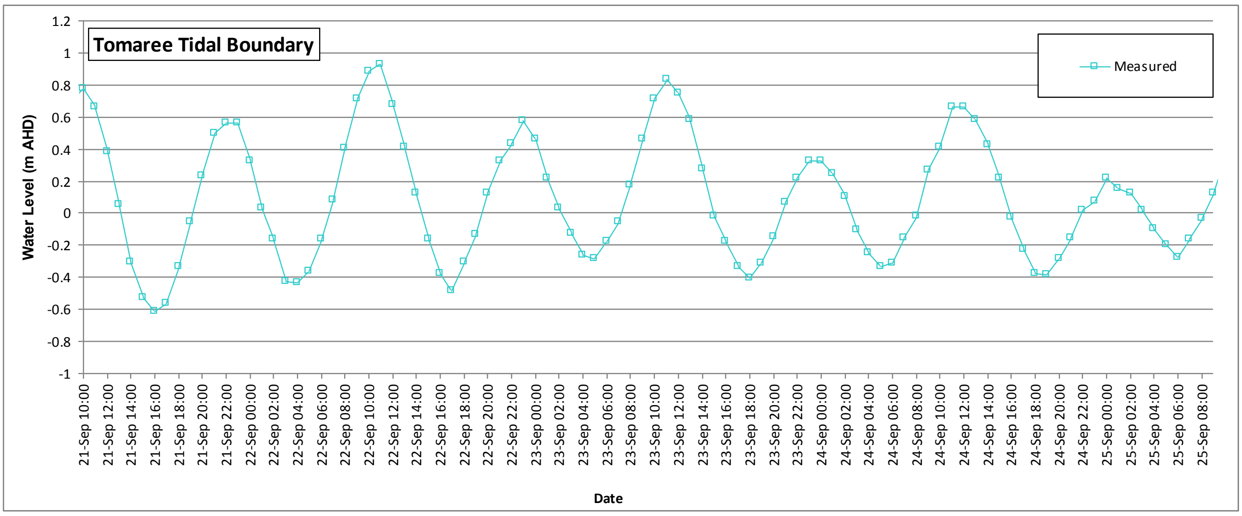

Figure 5-1 Tidal Calibration – Tomaree Applied Water Level Boundary Data

5.2.2 Adopted Model Parameters

Hydraulic model parameters as described in Section 4 were used in the tidal calibration exercise. A sensitivity test of channel model roughness indicated that adopting n = 0.03 provided a better match to observed data than if n = 0.025 was used.

5.2.3 Observed and Simulated Tidal Conditions, September 2009

Observed and simulated tidal conditions for the period 21 to 25 September 2009 are presented in Figure 5-3 to Figure 5-8 for six locations along the Lower Myall (see Figure 5-2). The comparison of observed to modelled data indicates that the model is able to closely replicate both the timing and magnitude of tidal fluctuations along the Lower Myall.

Title:

Water Level Measurement Sites

Figure: 5-2

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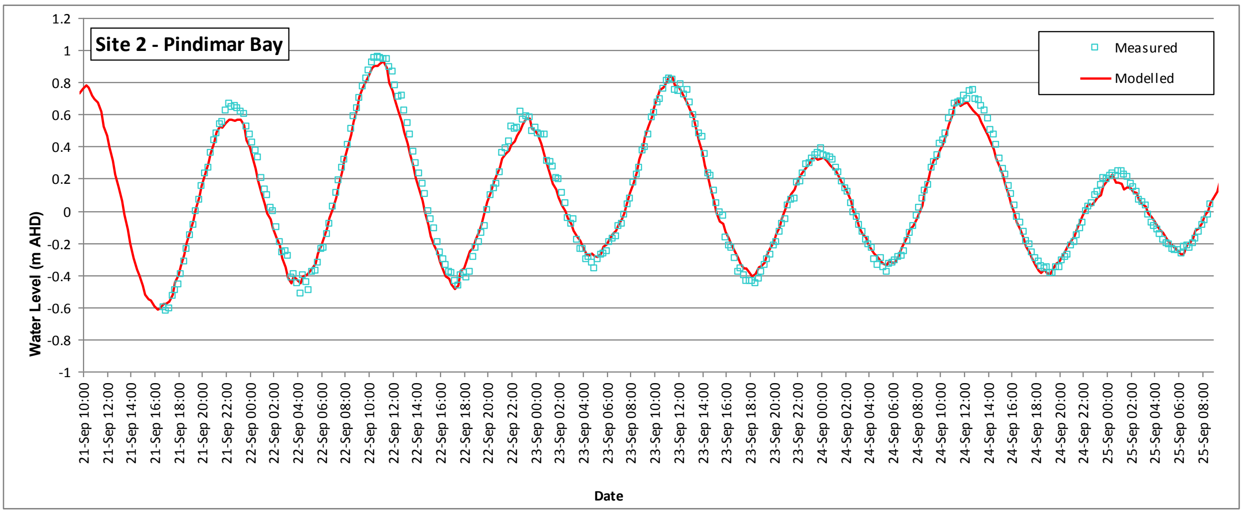


Figure 5-3 Tidal Calibration – Pindimar Bay

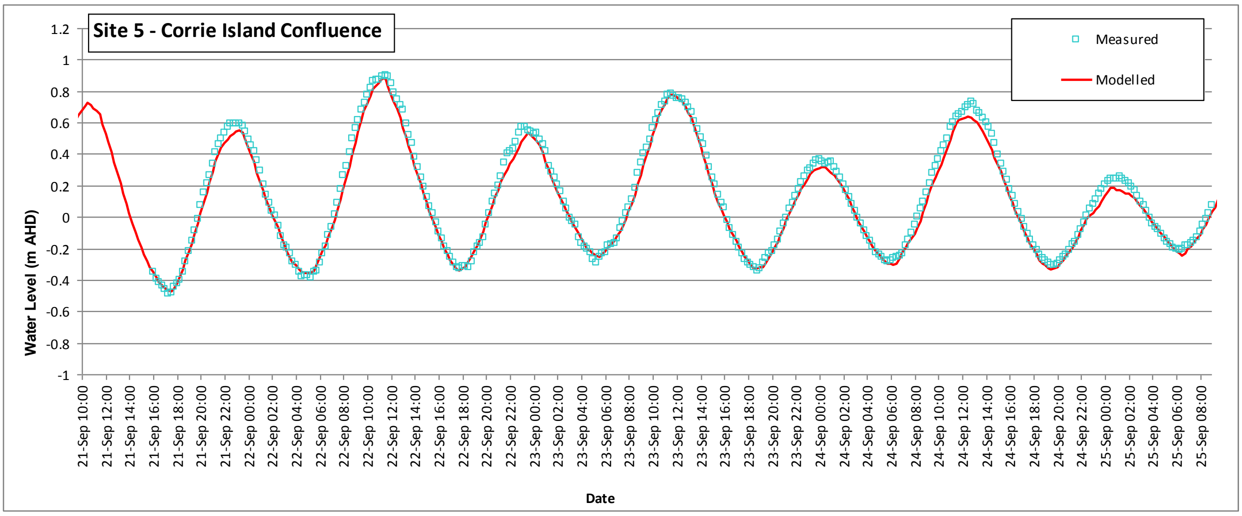


Figure 5-4 Tidal Calibration – Corrie Island

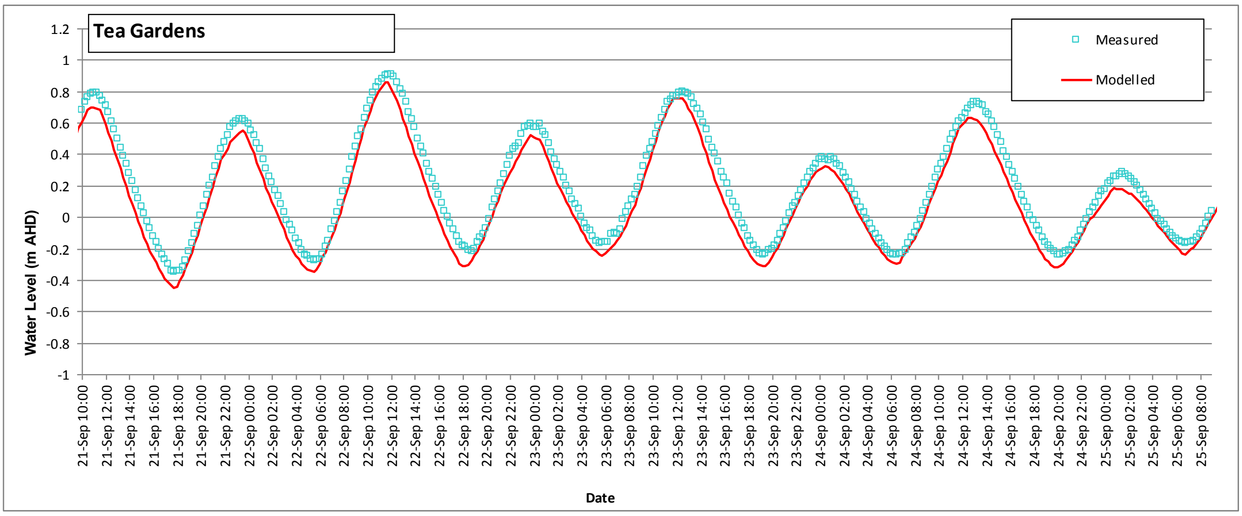


Figure 5-5 Tidal Calibration – Tea Gardens

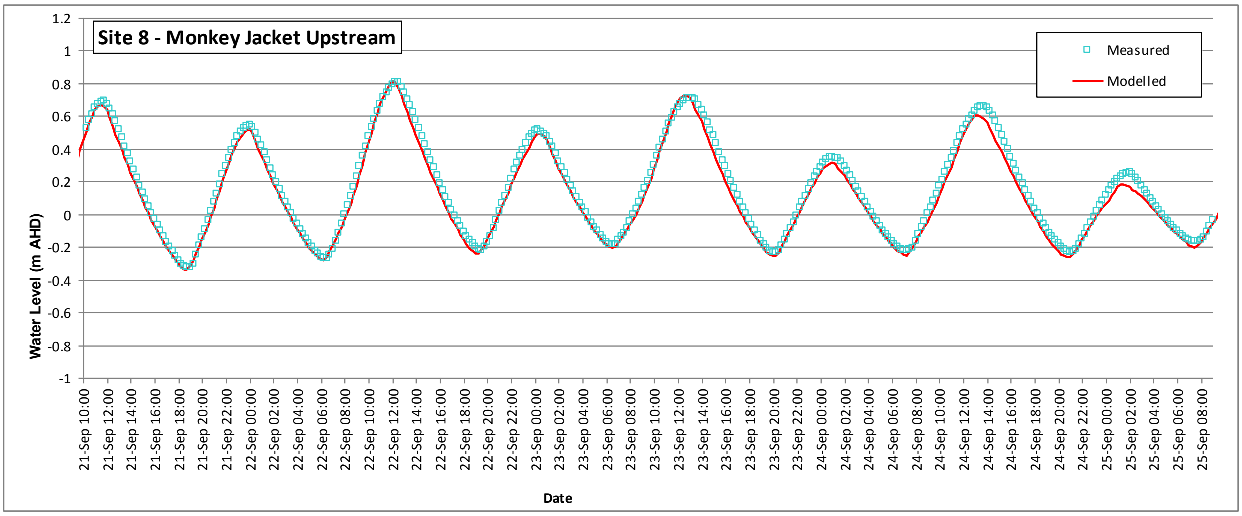


Figure 5-6 Tidal Calibration – Monkey Jacket

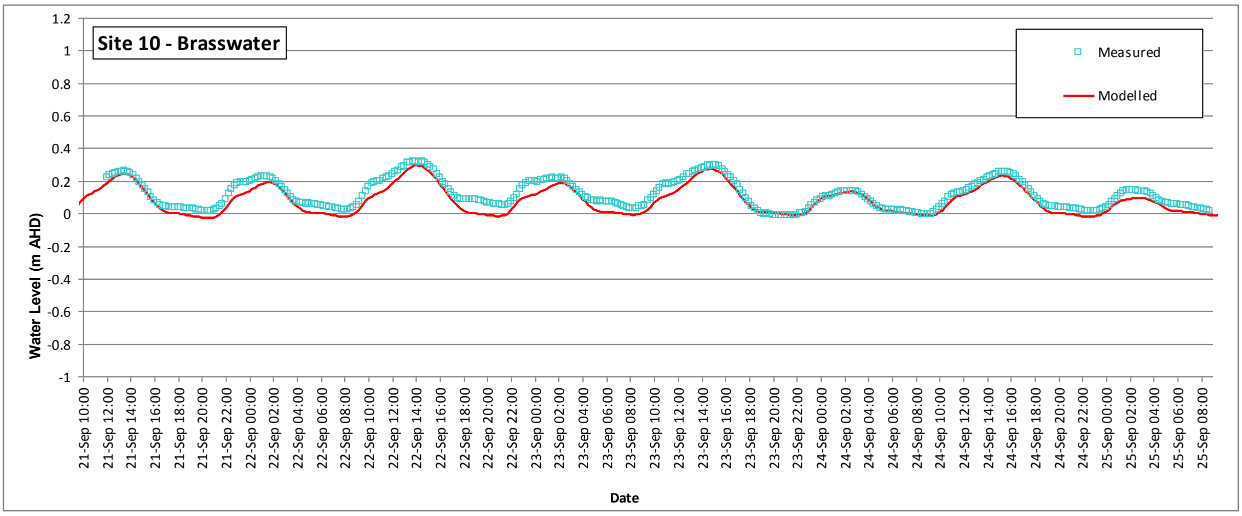


Figure 5-7 Tidal Calibration – Brasswater

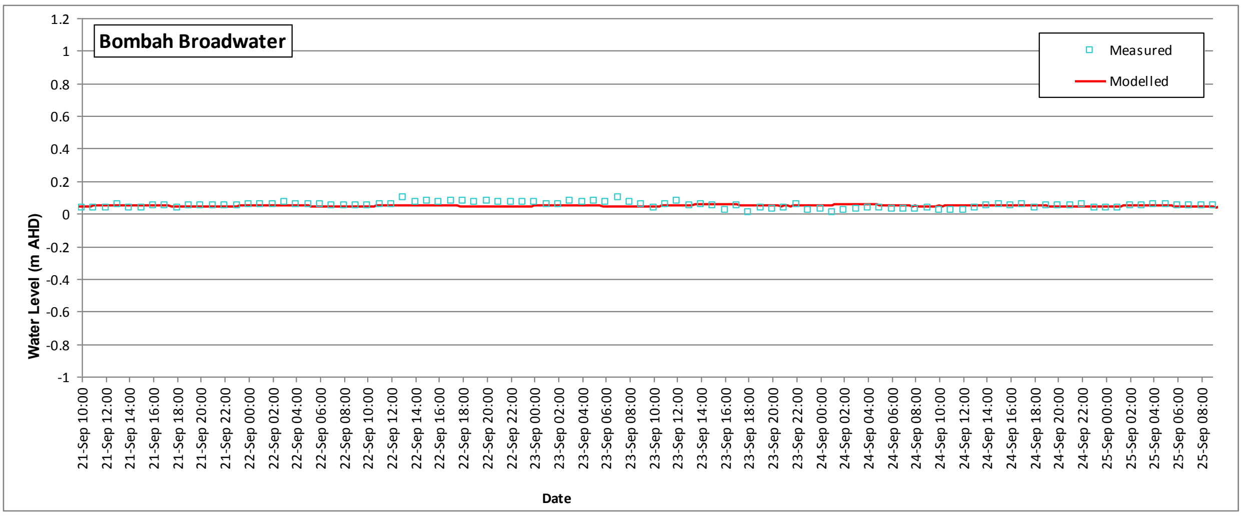


Figure 5-8 Tidal Calibration – Bombah Broadwater

5.3 July 2011 Model Calibration

The July 2011 flood has been used as the model calibration event, given the availability of rainfall and good quality water level data. Excluding the recent March 2013 event it was the only significant flood event where water level data at Tea Gardens was available.

5.3.1 Calibration Data

5.3.1.1 Rainfall Data

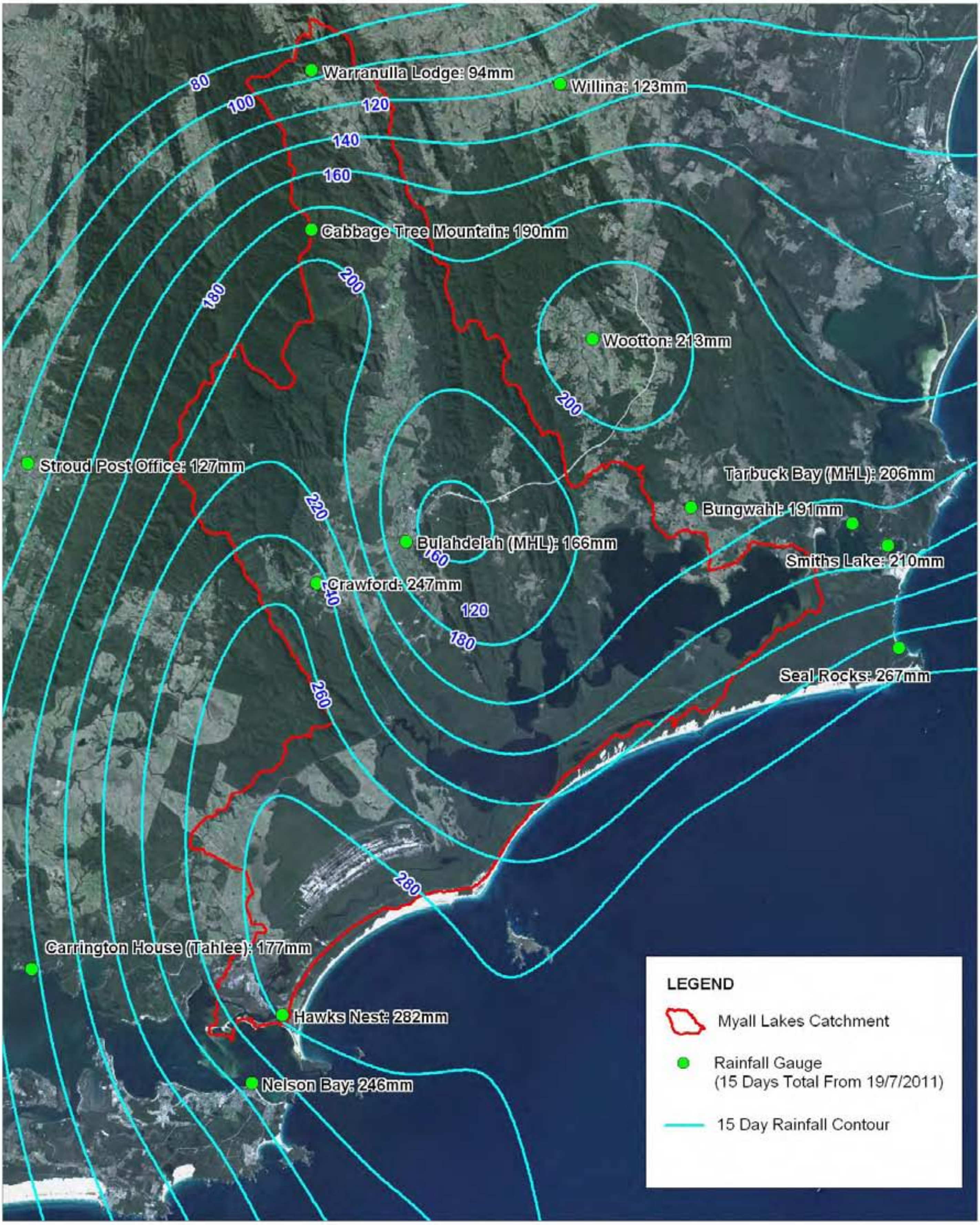
There were fourteen active rainfall gauges within or in close proximity to the Myall Lakes catchment for the July 2011 event. Two of these gauges were continuous read gauges operated by MHL with the remaining twelve gauges being daily read gauges operated by BoM.

The recorded daily totals (for the 24 hours to 9am) for the period 9am July 19th – 29th 2011 are summarised in Table 5-2. No rain was recorded at any of the gauges for the five days: 30th July to 3rd August. The rainfall distribution (15 day totals) for the July 2011 event is shown in Figure 5-9.

Data from two MHL pluviometers was available for the event. Daily totals for the gauge at Bulahdelah and Tarbuck Bay have been summarised in Table 5-1 while a time-series of cumlative rainfall for the two pluvio-gauges for the period July 19th – 29th 2011 is presented in Figure 5-10.

Table 5-2 Recorded Rainfall (Daily to 9am) July 2011 Event

Gauge	19/7	20/7	21/7	22/7	23/7	24/7	25/7	26/7	27/7	28/7	29/7	Total
Bulahdelah (MHL)	0	14	30	68	36	19	0	0	0	0	0	**166**
Bungwahl	0	15	52	67	49	7	0	0	0	0	0	**190**
Cabbage Tree Mountain	0	32	44	71	31	12	0	0	0	0	0	**190**
Crawfords River	0	21	60	93	46	25	1	0	0	0	1	**247**
Hawks Nest Golf Club	0	25	38	105	59	45	0	0	0	10	0	**282**
Nelson Bay	0	24	40	81	46	49	0	0	0	7	0	**246**
Seal Rocks	0	12	75	111	42	22	0	0	0	5	0	**267**
Smiths Lake	1	16	52	71	39	26	0	0	0	6	0	**210**
Stroud	0	19	36	46	23	4	0	0	0	0	0	**127**
Tahlee	0	18	52	55	34	17	0	0	0	0	0	**177**
Tarbuck Bay (MHL)	0	15	47	78	45	20	0	0	0	3	0	**206**
Warranulla	1	14	26	34	14	3	0	0	0	0	0	**93**
Willina	2	11	30	56	16	6	0	0	0	1	0	**122**
Wootton	0	16	58	88	38	11	1	0	0	0	0	**212**
Average	**0**	**18**	**46**	**73**	**37**	**19**	**0**	**0**	**0**	**2**	**0**	**195**



Title:

July 2011 Rainfall Distribution

Figure: 5-7

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5.3.1.2 Water Level Data

Water level data for the July 2011 event was available at Bombah Point, Bulahdelah and Tea Gardens.

The recorded water level time series at Bombah Point and Bulahdelah for the July 2011 event is presented in Figure 5-10. Water level data at Bombah Point is likely to be representative of water levels in the Bombah Broadwater, Boolambayte and Myall Lakes. Lake levels at the start of the event are ~0.5 m AHD with a peak lake level of 1.27 m AHD occurring on the 25th July.

The Bulahdelah water level gauge is able to provide information on catchment response on the Myall River just downstream of the Pacific Highway Bridge. At this location river levels are fairly responsive to rainfall intensity, though are also affected by a tailwater from the Lakes. A slight datum error in the gauges is evident with Bulahdelah water level being shown to be slightly below Bombah Point water levels from the 26th of July. The sustained reverse water level gradient suggested by the data would appear to be in error.

Observed water levels at Tea Gardens are presented in Figure 5-11. The relationship between recorded ocean water levels (Tomaree), observed water levels at Tea Gardens and Bombah Point water levels is also presented in Figure 5-11. Strong southerly winds from the 18 – 22 July, 2011 are the most likely reason why Tea Garden high tides are greater than those measured at Tomaree. High fluvial discharge and entrance bathymetry are likely to cause higher low water levels at Tea Gardens compared to Tomaree.

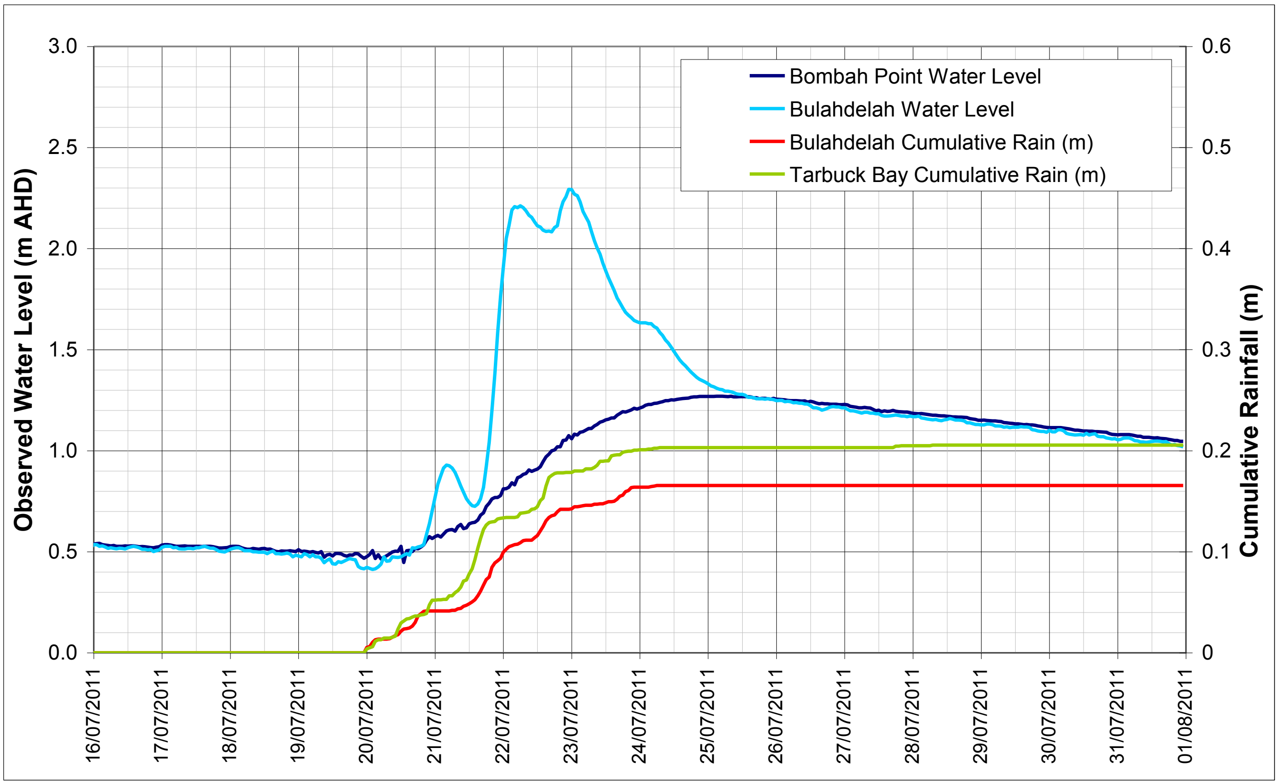


Figure 5-10 Observed Water Levels and Cumulative Rainfall – July 2011

5.3.2 Downstream Boundary Conditions

Ocean tide (water level) data was available for the July 2011 event from a continuous tide gauge maintained by MHL at Tomaree at the entrance to Port Stephens. This water level data (as presented in Figure 5-11) was used as the downstream boundary for the July 2011 event.

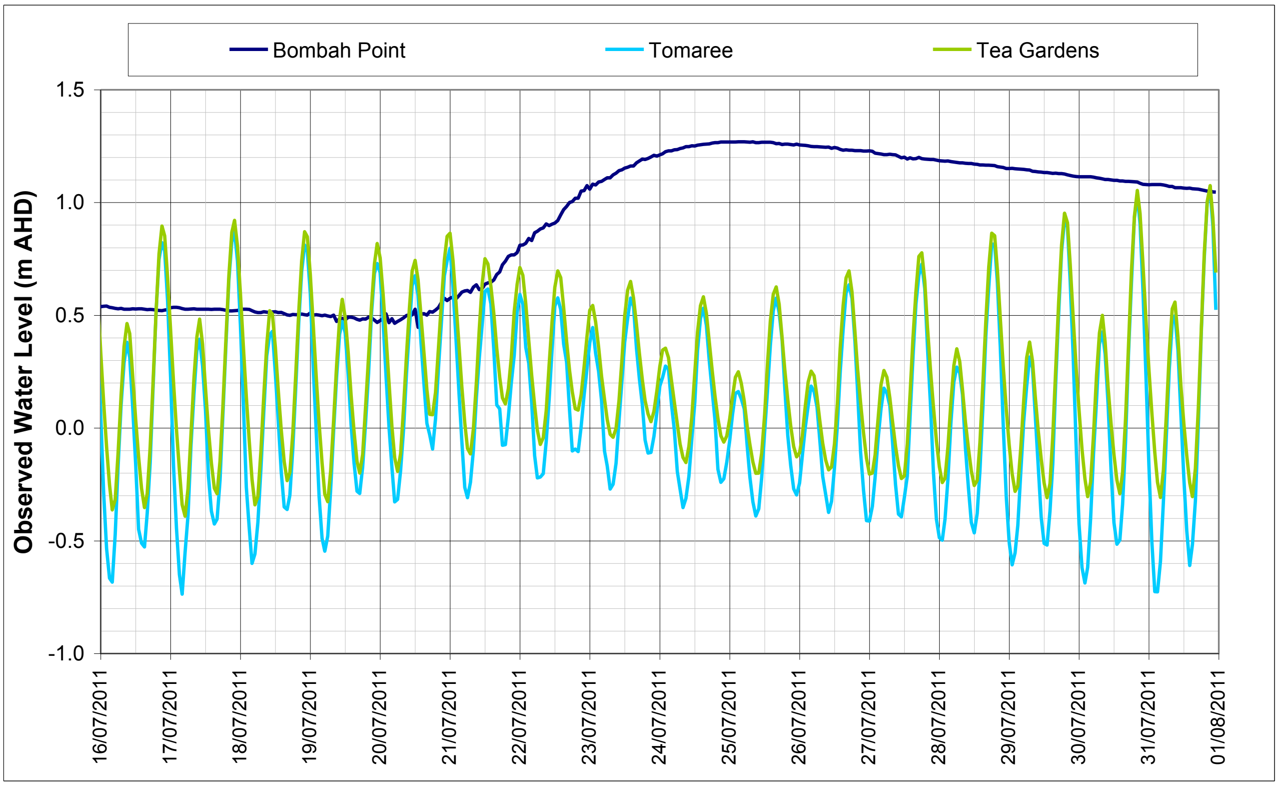


Figure 5-11 July 2011 Recorded Tidal Water Level

5.3.3 Rainfall Losses

Typical design loss rates applicable for NSW catchments east of the western slopes are initial loss of 10 to 35 mm and continuing loss of 2.5mm/hr (AR&R, 2001). For historical events however, the initial loss is indicative of the catchment wetness and any rainfall that fell prior to the modelled storm burst.

Initial rainfall losses of 0mm, 15mm and 30mm have been simulated for the July 2011 event. An initial loss of 15mm was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the July 2011 event.

For longer duration events where total rainfall depth is the key determinate of runoff volume, the selection of a continuing loss value can have a significant influence on total rainfall depth. Continuing losses of 0 mm/hr, 0.5 mm/hr and 1.0 mm/hr have been simulated for the July 2011 event. A continuing loss of 0.5 mm/hr was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the July 2011 event.

5.3.4 Adopted Model Parameters

The model calibration centred around the selection of appropriate total rainfall depth and temporal pattern, the adjustment of the: sub-catchment PERN values, Bx storage routing factor and rainfall loss values (hydrological model parameters) and the initial water level (IWL), Manning's 'n' values for the floodplain and channel (hydraulic model parameters).

The final parameter values adopted, as shown in Table 5-3 were found to give a good result in representing the hydrological and hydraulic behaviour in the Myall Lakes catchment for the July 2011 event.

Table 5-3 July 2011 Model Parameters

Parameter	Value	Comment
Total Rainfall Depth (mm)	190	This value is close the numeric average of the 14 gauges in or adjacent to the catchment and provides a good match to the observed peak lake water level.
Temporal Pattern	Bulahdelah	This gauge was selected as it is the only pluviometer located in the Myall Lakes catchment and it provides an acceptable match to observed water level data.
Initial Loss (mm): pervious area impervious area	 15 0	The 15mm initial loss provided the best fit for initial catchment response and total storm volumes with respect to available data for the July 2011 event.
Continuing Loss (mm/hr): pervious area impervious area	 0.5 0	The 0.5mm continuing loss provided the best fit for total storm volume (i.e. peak water level) with respect to available data for the July 2011 event.
Storage modification Factor Bx	1.0	Default value found appropriate
PERN	0.06 -0.12	Variable adjusted dependent on surface coverage – e.g. 0.12 for forested catchment and 0.06 for pasture/grass land.
Manning's 'n' (channels and lake areas)	0.03	Determined during calibration to provide best fit for peak water level profiles.
Manning's 'n' (grassed or un-vegetated floodplain)	0.04	Determined during calibration to provide best fit for peak water level profiles.
Manning's 'n' (heavily forested floodplain)	0.08	Determined during calibration to provide best fit for peak water level profiles.
Initial Water Level (m AHD)	0.48	Based on observed water level data.

5.3.5 Observed and Simulated Flood Conditions July 2011

Calibration data for the July 2011 event includes available water level time series at the Bombah Point and Tea Garden gauges. While calibration data is available for Bulahdelah, as this area is outside the key study area, a coarse model resolution was adopted to maintain reasonable model simulation times. This coarse (50m) model representation was unable to adequately resolve channel conveyance and hence modelled water levels in this area are not accurate.

A comparison of recorded and simulated water levels at Bombah Point for the July 2011 is presented in Figure 5-12. The simulated results show that a good model calibration has been achieved for a number of aspects of the simulated catchment flood behaviour:

- Catchment runoff response – the relative timing of the observed and simulated water level hydrographs shows a good agreement through the simulated event. This shows the catchment runoff processes are being well simulated. Spatial variation in rainfall (as presented in Figure 5-9) and temporal variation in rainfall (as presented in Figure 5-10) result in minor differences between observed and modelled water levels for the rising limb of the hydrograph. The modelled falling limb is also slightly more rapid than that observed and is likely to be due to a lack of groundwater processes in the hydrological model.
- Peak flood levels – the peak flood levels show an excellent agreement. This indicates that appropriate hydrological and hydraulic parameters have been achieved through the model calibration process.
- Total flood volumes – the area under the water level time series graph is indicative of the total flood volume for the event. As evident in the observed vs. simulated comparisons, the water level profiles generally track the same for the duration of the event, and accordingly the total volumes would appear to be in good agreement. The adopted rainfall depth and the modelled initial and continuing loss parameters provide for a good representation of total runoff volume generated from the catchment.

The comparison of recorded and simulated water levels at Tea Gardens is presented in Figure 5-13. The close simulation of the tidal fluctuations at this location indicates an adequate model representation in terms of downstream boundary conditions, roughness parameters and bathymetry for the Lower Myall. The difference in high tide levels from the 20th – 24th July is likely to be due to influence of wind or barometric pressure which is not simulated in the model (as discussed in Section 5.3.1.2).

In terms of the catchment wide response, the simulated inundation extent and water level gradients for the July 2011 event are shown in Figure 5-14. The simulated conditions indicate the typical hydraulic gradients along the Myall and Lower Myall Rivers.

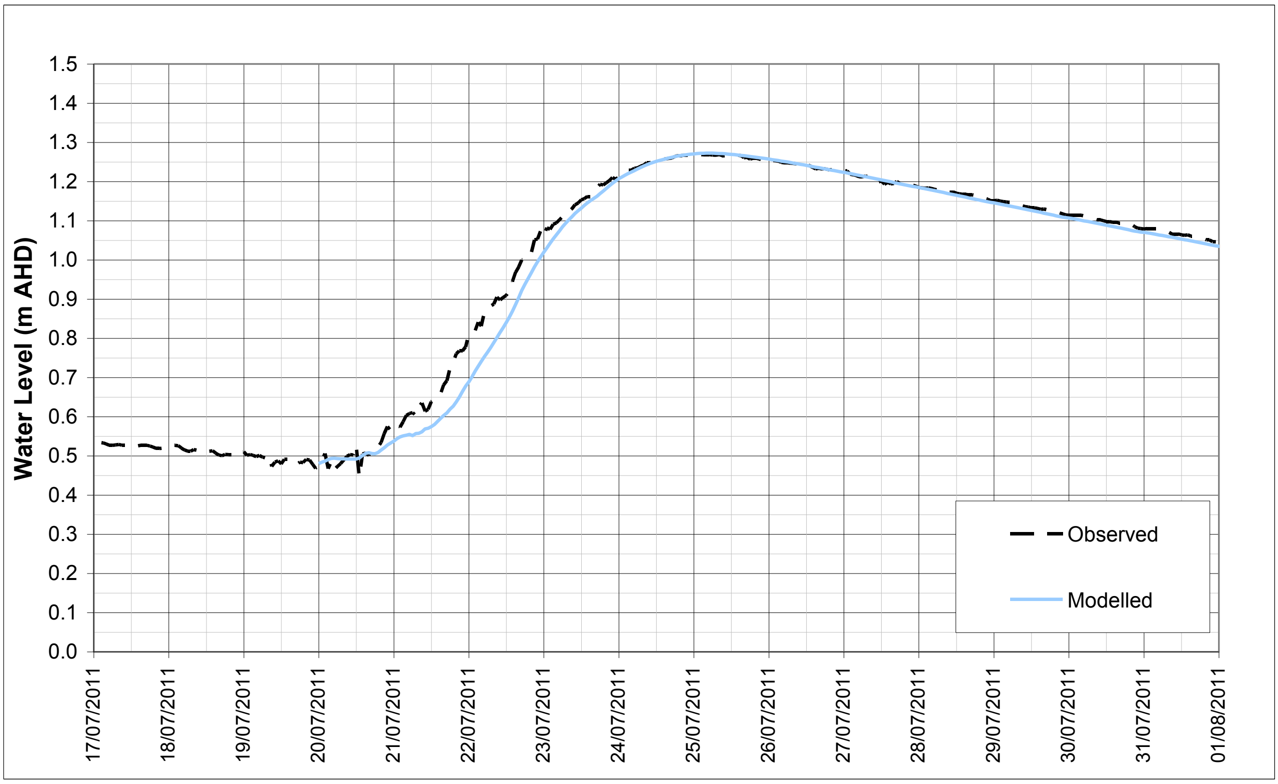


Figure 5-12 Bombah Point Water Level Calibration – July 2011

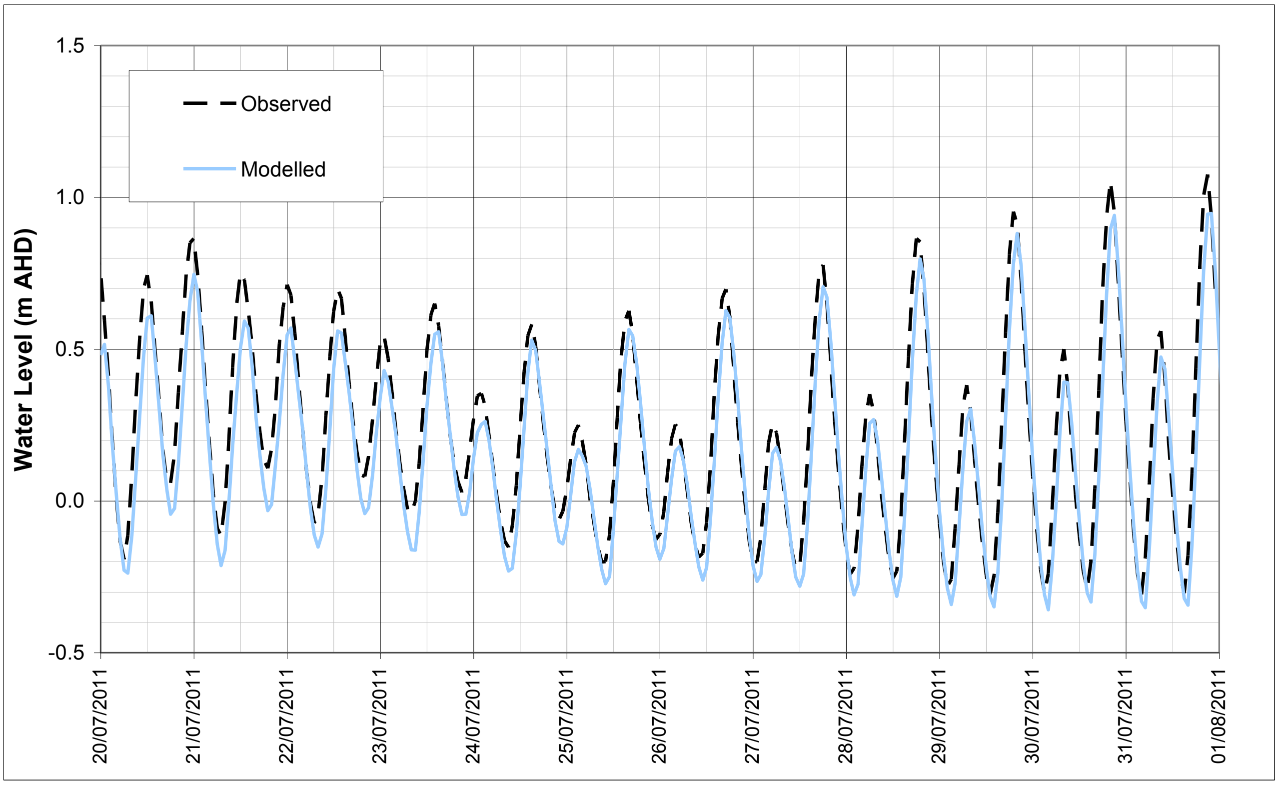
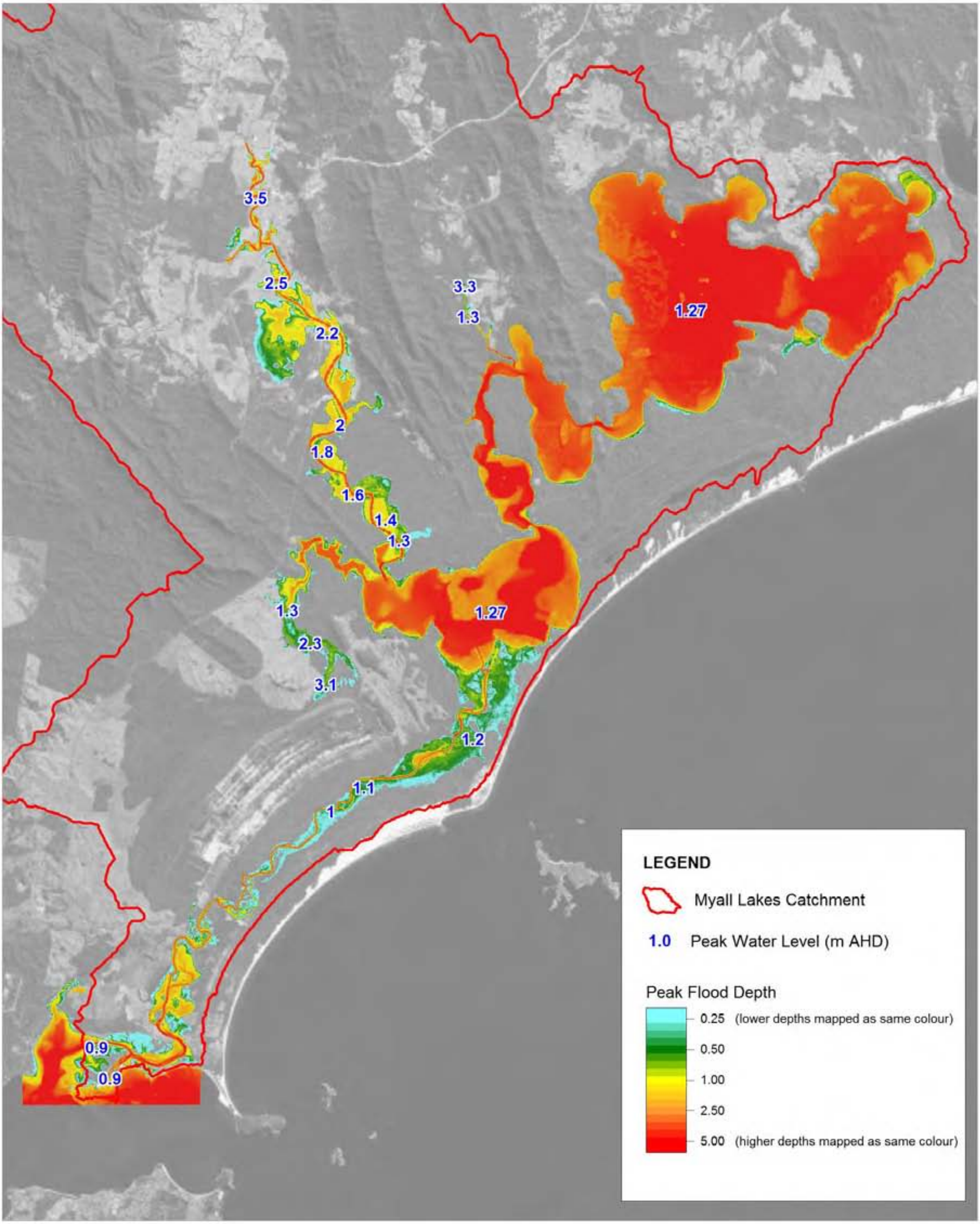


Figure 5-13 Tea Gardens Water Level Calibration – July 2011



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July 2011 Simulated Peak Flood Levels & Inundation

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5.4 May 2003 Model Validation

The May 2003 flood has been used as the model validation event, given the availability of rainfall and good quality water level data.

5.4.1 Validation Data

5.4.1.1 Rainfall Data

There were eleven active rainfall gauges within or in close proximity to the Myall Lakes catchment for the May 2003 event. Two of these gauges were continuous read gauges operated by MHL with the remaining nine gauges being daily read gauges operated by BoM.

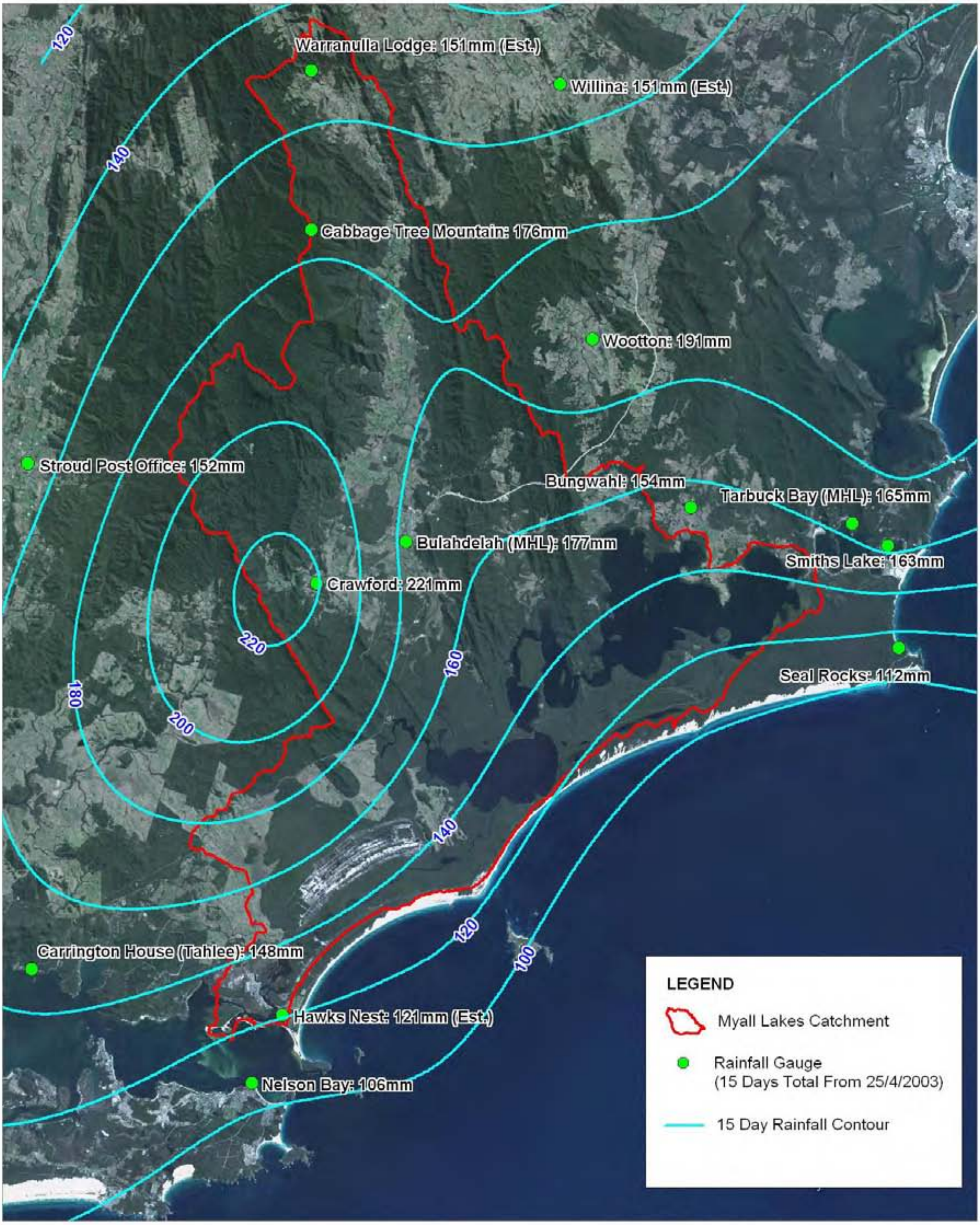
The recorded daily totals (for the 24 hours to 9am) for the period 9am May 25th – June 4th 2003 are summarised in Table 5-4. No rain was recorded at any of the gauges for the five days: June 5th to 9th. The rainfall distribution (15 day totals) for the May 2003 event is shown in Figure 5-15. Estimates of total rainfall for the three inactive gauges (Warranulla, Willina and Hawks Nests) are based on interpolation from nearby gauges.

Data from two MHL pluviometers was available for the event. Daily totals for the gauge at Bulahdelah and Tarbuck Bay have been summarised in Table 5-4 while a time-series of cumlative rainfall for the two pluvio-gauges for the period May 25th – June 4th 2003 is presented in Figure 5-16.

Table 5-4Recorded Rainfall (Daily to 9am) May 2003 Event

Gauge	25/5	26/5	27/5	28/5	29/5	30/5	31/5	01/6	02/6	03/6	04/6	Total
Bulahdelah (MHL)	0	22	106	36	11	0	0	0	1	1	0	**177**
Bungwahl	0	7	95	42	6	0	0	0	0	4	0	**154**
Cabbage Tree Mountain	0	21	118	25	8	2	0	0	0	2	0	**176**
Crawfords River	0	20	117	68	7	1	0	0	8	0	0	**221**
Hawks Nest Golf Club	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	**n/o**
Nelson Bay	1	37	31	14	19	1	0	0	0	3	0	**106**
Seal Rocks	0	25	33	35	12	0	0	0	0	7	0	**112**
Smiths Lake	0	28	77	40	15	0	0	0	0	2	0	**163**
Stroud	0	39	76	29	6	0	0	0	1	0	0	**152**
Tahlee	0	28	59	54	6	0	0	1	0	0	0	**148**
Tarbuck Bay (MHL)	0	30	76	41	15	0	1	0	1	2	1	**165**
Warranulla	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	**n/o**
Willina	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	**n/o**
Wootton	0	7	131	43	6	0	0	0	0	4	0	**191**
Average	**0**	**24**	**84**	**39**	**10**	**0**	**0**	**0**	**1**	**2**	**0**	**160**

Note: n/o (gauge not operational during this event)



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May 2003 Rainfall Distribution

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5.4.1.2 *Water Level Data*

Water level data for the May 2003 event is available at Bombah Point and Bulahdelah.

The recorded water level time series at Bombah Point and Bulahdelah for the May 2003 event is presented in Figure 5-16. Water level data at Bombah Point is likely to be representative of water levels in the Bombah Broadwater, Boolambayte and Myall Lakes. Lake levels at the start of the event on the 25th May are 0.78 m AHD with a peak lake level of 1.4 m AHD occurring on the 29th May.

The Bulahdelah water level gauge is able to provide information on catchment response on the Myall River just downstream of the Pacific Highway Bridge. At this location river levels are fairly responsive to rainfall intensity, though are also affected by a tailwater from the Lakes.

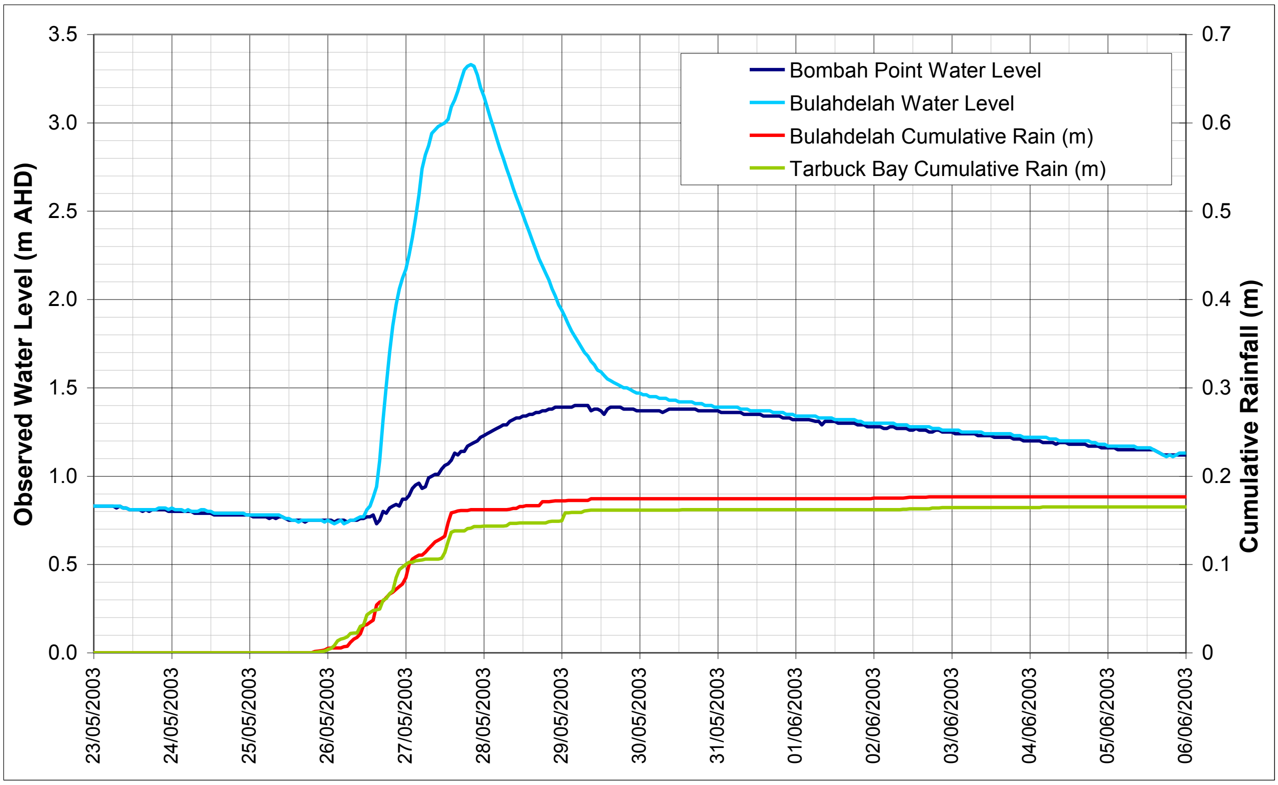


Figure 5-16 Observed Water Levels and Cumulative Rainfall – May 2003

5.4.2 Downstream Boundary Conditions

Ocean tide (water level) data was available for the May 2003 event from a continuous tide gauge maintained by MHL at Tomaree at the entrance to Port Stephens. This water level data (as presented in Figure 5-17) was used as the downstream boundary for the May 2003 event.

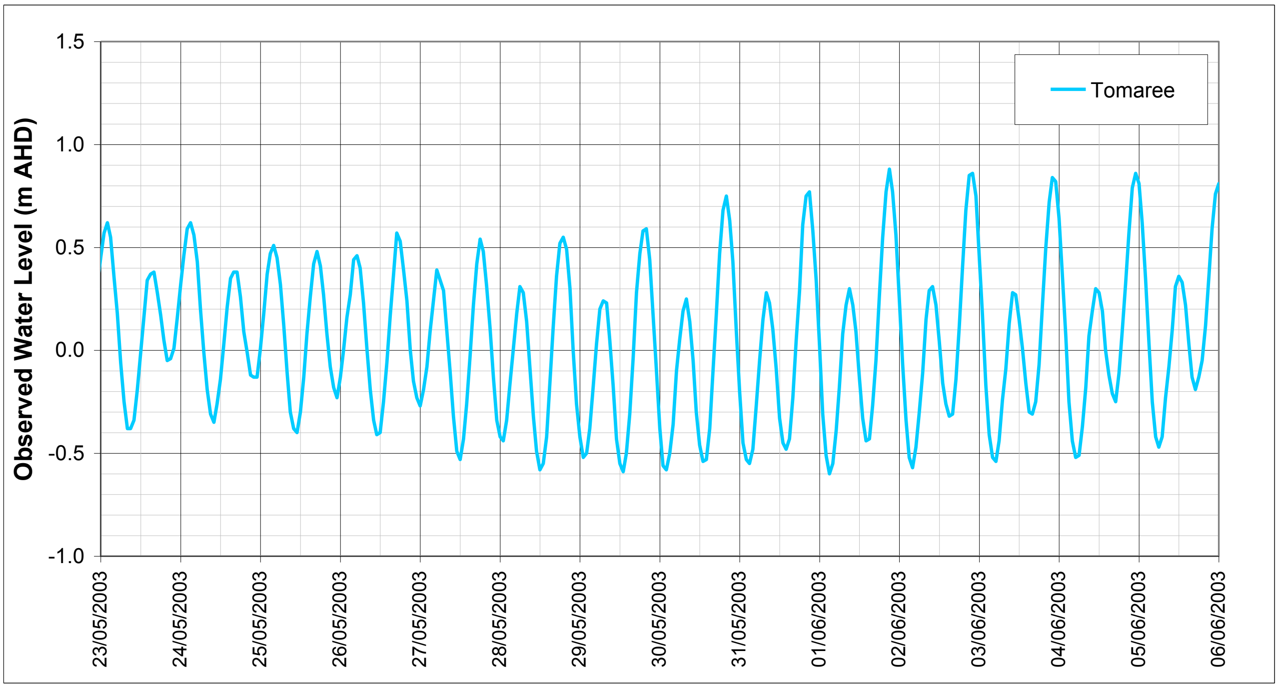


Figure 5-17 May 2003 Recorded Tidal Water Levels

5.4.3 Rainfall Losses

Initial rainfall losses of 0mm, 15mm and 30mm have been simulated for the May 2003 event. As with the calibration event, an initial loss of 15mm was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the May 2003 event.

For longer duration events where total rainfall depth is the key determinate of runoff volume, the selection of a continuing loss value can have a significant influence on total rainfall depth. Continuing losses of 0 mm/hr, 0.5 mm/hr and 1.0 mm/hr have been simulated for the May 2003 event. As with the calibration event, a continuing loss of 0.5 mm/hr was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the May 2003 event.

5.4.4 Adopted Model Parameters

The model validation centred on the selection of appropriate total rainfall depth, with all other parameters using those determined by the model calibration event as presented in Table 5-3. For the May 2003 event a total rainfall depth of 165 mm (which is close to the arithmetic average of the 11 available rainfall gauges) provided a good match to the observed peak water level.

5.4.5 Observed and Simulated Flood Conditions May 2003

The water level time series at Bombah Point is the key validation data for the May 2003 event. A comparison of recorded and simulated water levels at Bombah Point for the May 2003 is presented in Figure 5-18. The simulated results show that a good model validation has been achieved for a number of aspects of the simulated catchment flood behaviour:

- Catchment runoff response – the relative timing of the observed and simulated water level hydrographs shows a good agreement through the simulated event. This shows the catchment runoff processes are being well simulated. Spatial variation in rainfall (as presented in Figure 5-15) and temporal variation in rainfall (as presented in Figure 5-16) result in minor differences between observed and modelled water levels for the rising limb of the hydrograph. The modelled falling limb is also slightly more rapid than that observed and is likely to be due to a lack of groundwater processes in the hydrological model.

- Peak flood levels – the peak flood levels show an excellent agreement. This indicates that appropriate hydrological and hydraulic parameters have been achieved through the model calibration process.
- Total flood volumes – the area under the water level time series graph is indicative of the total flood volume for the event. As evident in the observed vs. simulated comparisons, the water level profiles generally track the same for the duration of the event, and accordingly the total volumes would appear to be in good agreement. The adopted rainfall depth distribution and the modelled initial and continuing loss parameters provide for a good representation of total runoff volume generated from the catchment.

A comparison of recorded and simulated water levels at Tea Gardens is not available for this validation event as the recorder has only been operational since December 2008.

In terms of the catchment wide response, the simulated inundation extent and water level gradients for the May 2003 event are shown in Figure 5-19. The simulated conditions indicate the typical hydraulic gradients along the Myall and Lower Myall Rivers.

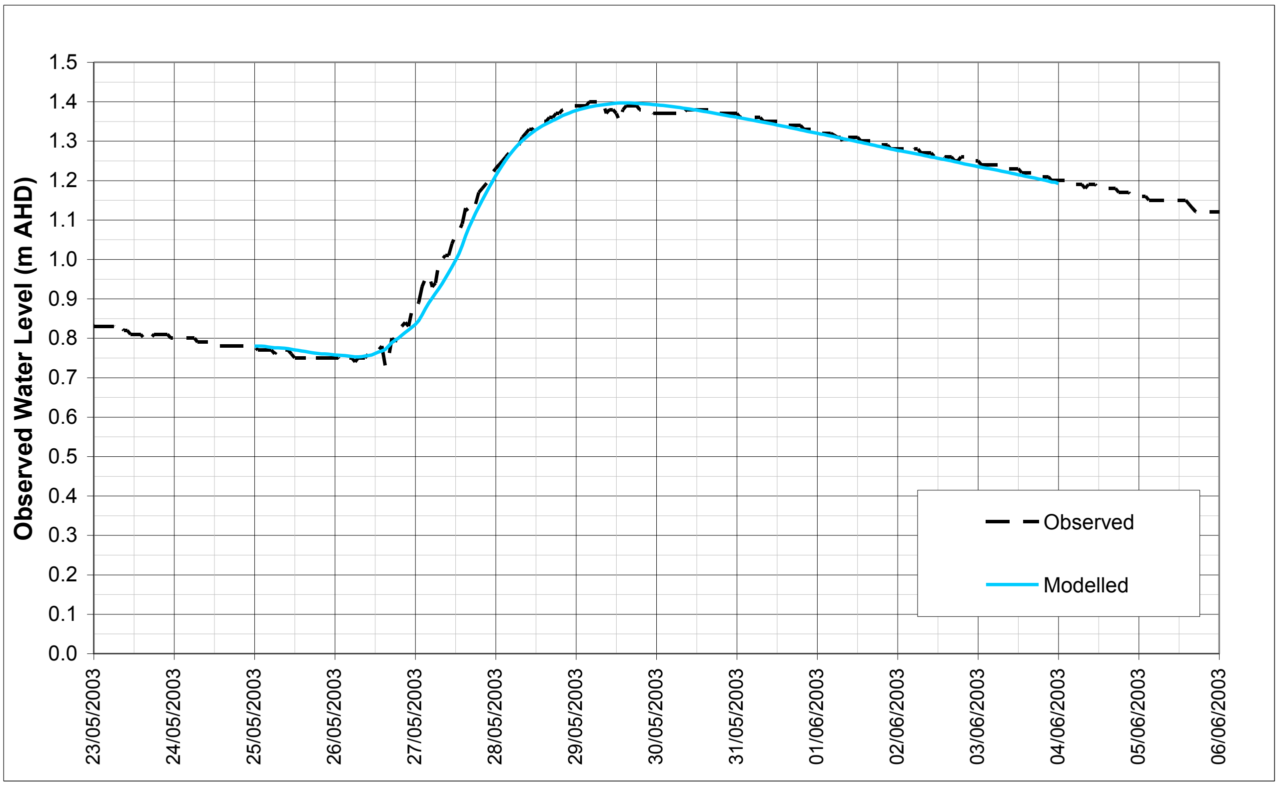
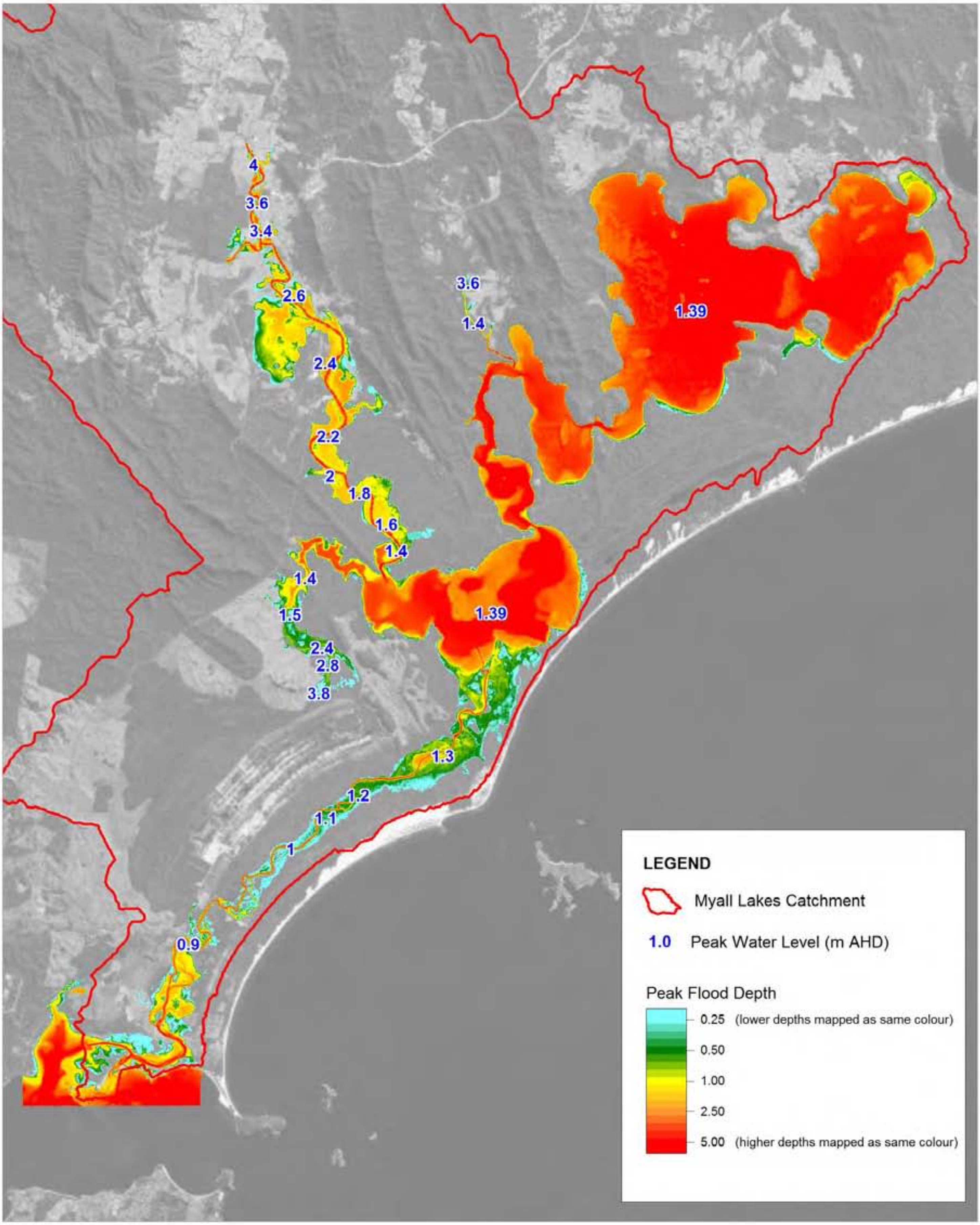


Figure 5-18 Bombah Point Water Level Calibration – May 2003



Title:

May 2003 Simulated Peak Flood Levels & Inundation

Figure: **5-19**

Rev: **A**

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Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_013_May2003_Innundation.WOR

5.5 April 2008 Model Validation

The April 2008 flood has been used as the model validation event, given the availability of rainfall and good quality water level data. There is considerable uncertainty regarding recorded water level at Bombah Point for this event which needs to be considered when comparing simulated to recorded water levels.

5.5.1 Validation Data

5.5.1.1 Rainfall Data

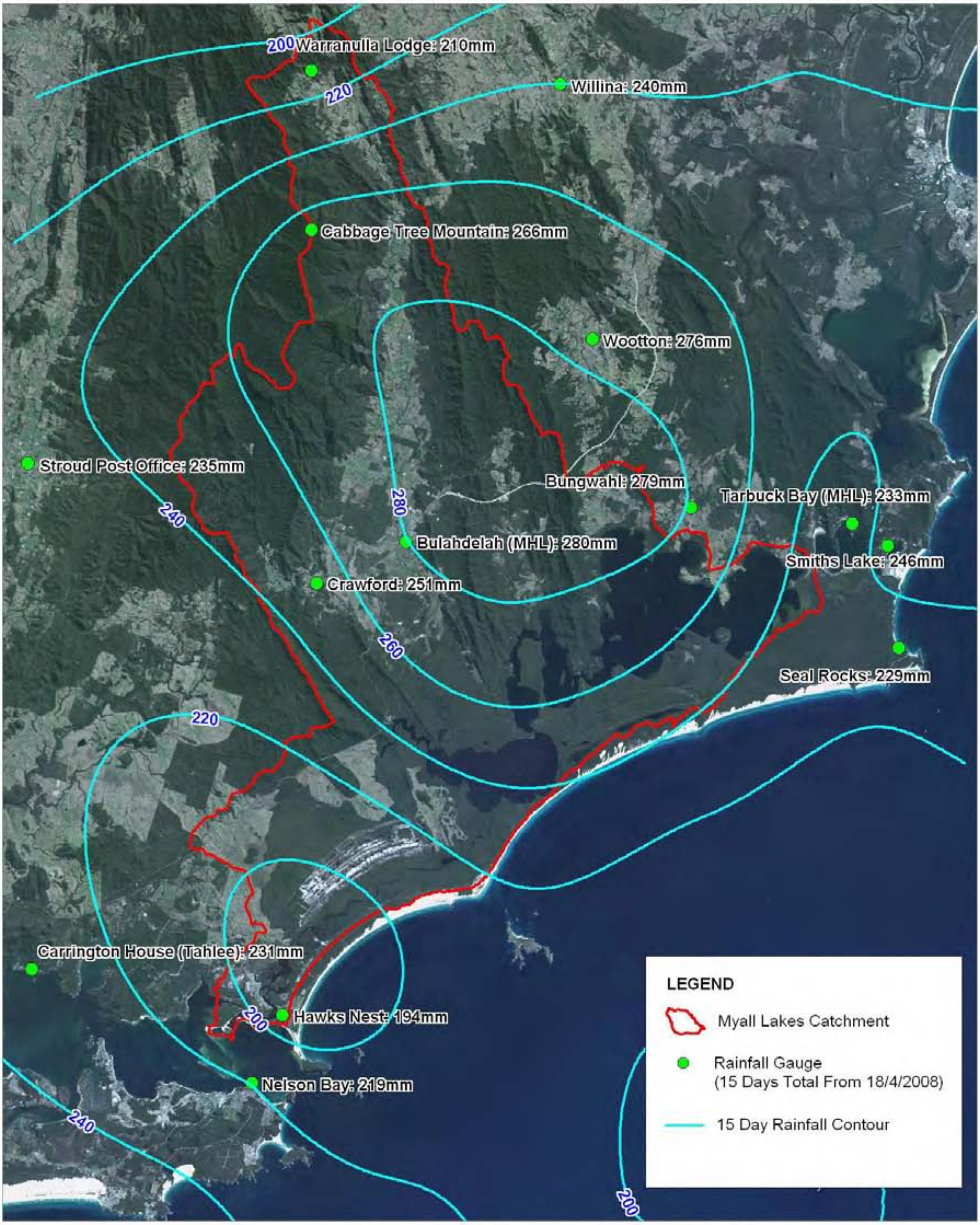
There were fourteen active rainfall gauges within or in close proximity to the Myall Lakes catchment for the April 2008 event. Two of these gauges were continuous read gauges operated by MHL with the remaining twelve gauges being daily read gauges operated by BoM.

The recorded daily totals (for the 24 hours to 9am) for the period 9am April 18th – 28th 2008 are summarised in Table 5-2. No rain was recorded at any of the gauges for the five days: April 29 to May 4th. The rainfall distribution (15 day totals) for the April 2008 event is shown in Figure 5-20.

Data from two MHL pluviometers was available for the event. Daily totals for the gauge at Bulahdelah and Tarbuck Bay have been summarised in Table 5-5 while a time-series of cumlative rainfall for the two pluvio-gauges for the period April 18th – 28th 2008 is presented in Figure 5-21.

Table 5-5 Recorded Rainfall (Daily to 9am) April 2008 Event

Gauge	18/4	19/4	20/4	21/4	22/4	23/4	24/4	25/4	26/4	27/4	28/4	Total
Bulahdelah (MHL)	2	11	25	10	34	54	19	113	13	0	0	**280**
Bungwahl	8	6	20	6	33	53	29	103	21	0	0	**279**
Cabbage Tree Mountain	8	21	29	10	20	22	11	110	35	0	0	**266**
Crawfords River	9	12	12	12	37	39	30	93	7	0	0	**251**
Hawks Nest Golf Club	3		14	13	35	46		68	16	0	0	**194**
Nelson Bay	1	2	12	32	24	69	14	64	2	0	0	**219**
Seal Rocks		6	10	14	37	56	15	69	23	0	0	**229**
Smiths Lake	1		6	6	38	63	28	67	37	0	0	**246**
Stroud		8	6	6	33	30	43	99	11	0	0	**235**
Tahlee	8	5	15	15	17	59	27	77	8	0	0	**231**
Tarbuck Bay (MHL)	1	4	10	6	37	53	28	66	30	0	0	**233**
Warranulla	3	5	21	7	23	41	44	44	22	0	0	**210**
Willina	2	13	26	15	26	49	30	66	13	0	0	**240**
Wootton	2	4	16	8	17	56	18	150	5	0	0	**276**
Average	**4**	**8**	**16**	**11**	**29**	**49**	**26**	**85**	**17**	**0**	**0**	**242**



Title:

April 2008 Rainfall Distribution

Figure: 5-20

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Approx. Scale

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5.5.1.2 Water Level Data

Water level data for the April 2008 event was available at Bombah Point and Bulahdelah.

The recorded water level time series at Bombah Point and Bulahdelah for the April 2008 event is presented in Figure 5-21. Water level data at Bombah Point is likely to be representative of water levels in the Bombah Broadwater, Boolambayte and Myall Lakes. Examination of the MHL Bombah Point water level data indicates an error with the gauge occurred during the event. Recorded water levels at Bombah Point are constantly higher than that observed at Bulahdelah for the period 25th April to 1st May which MHL has confirmed was due to a gauge error at Bombah Point.

An estimate of corrected water levels at Bombah Point is presented in Figure 5-22. From midday 28th April to midday 1st May water levels observed at Bulahdelah have been adopted. However, from the start of the day on the 25th May to midday 28th April, an estimated time series of water levels based on typical lake level profiles was generated.

Lake levels at the start of the event on the 18th April are 0.25 m AHD with a peak lake level of approximately 1.45 m AHD occurring on the 26th April.

The Bulahdelah water level gauge is able to provide information on catchment response on the Myall River just downstream of the Pacific Highway Bridge. At this location river levels are fairly responsive to rainfall intensity, though are also affected by a tailwater from the Lakes.

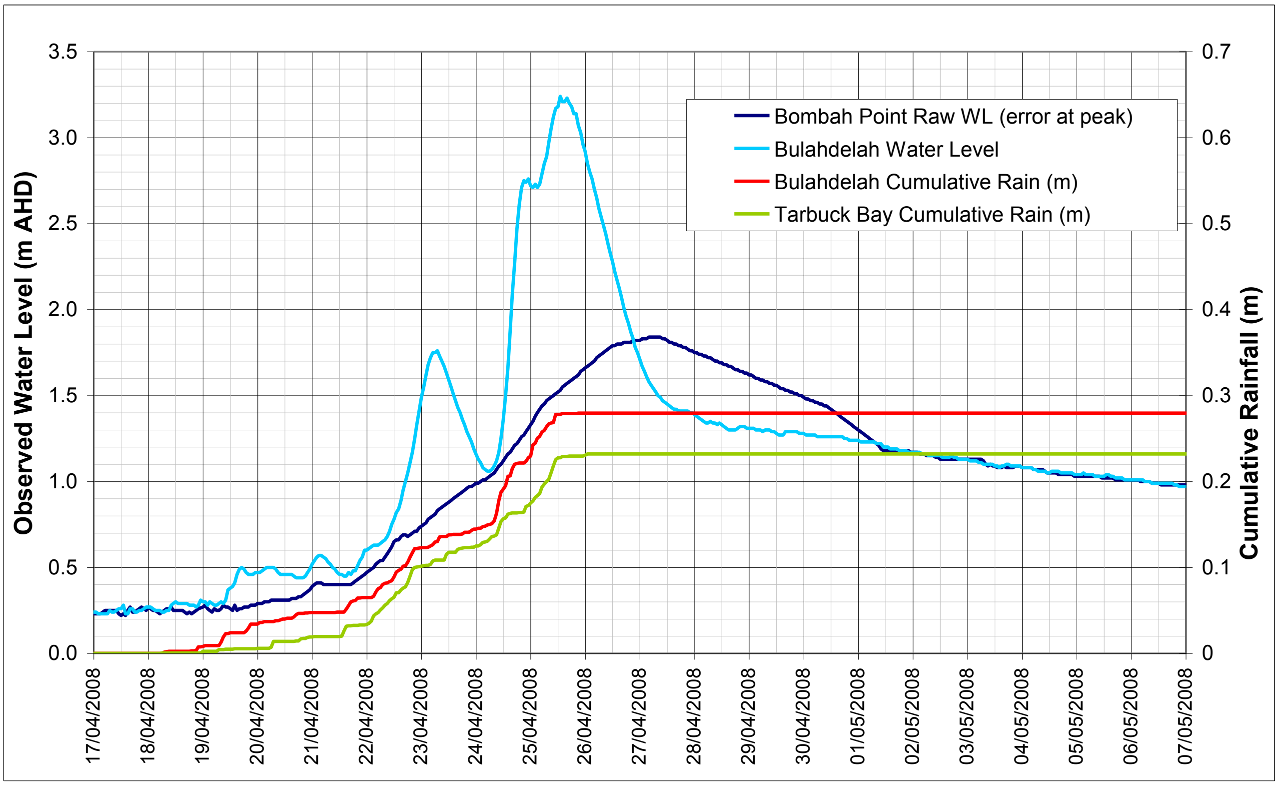


Figure 5-21 Observed Water Levels and Cumulative Rainfall – April 2008

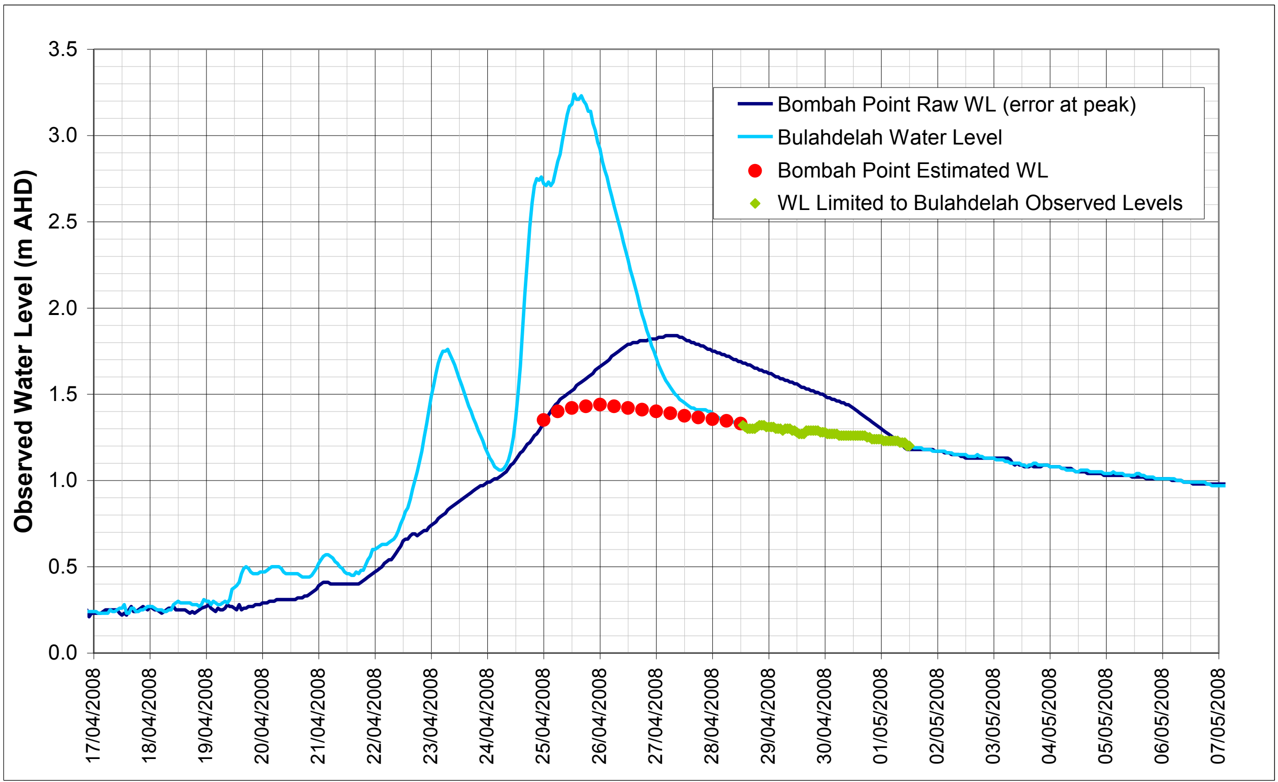


Figure 5-22 Suggested Corrections to Recorded Bombah Point Water Levels – April 2008

5.5.2 Downstream Boundary Conditions

Ocean tide (water level) data was available for the April 2008 event from a continuous tide gauge maintained by MHL at Tomaree at the entrance to Port Stephens. This water level data (as presented in Figure 5-23) was used as the downstream boundary for the April 2008 event.

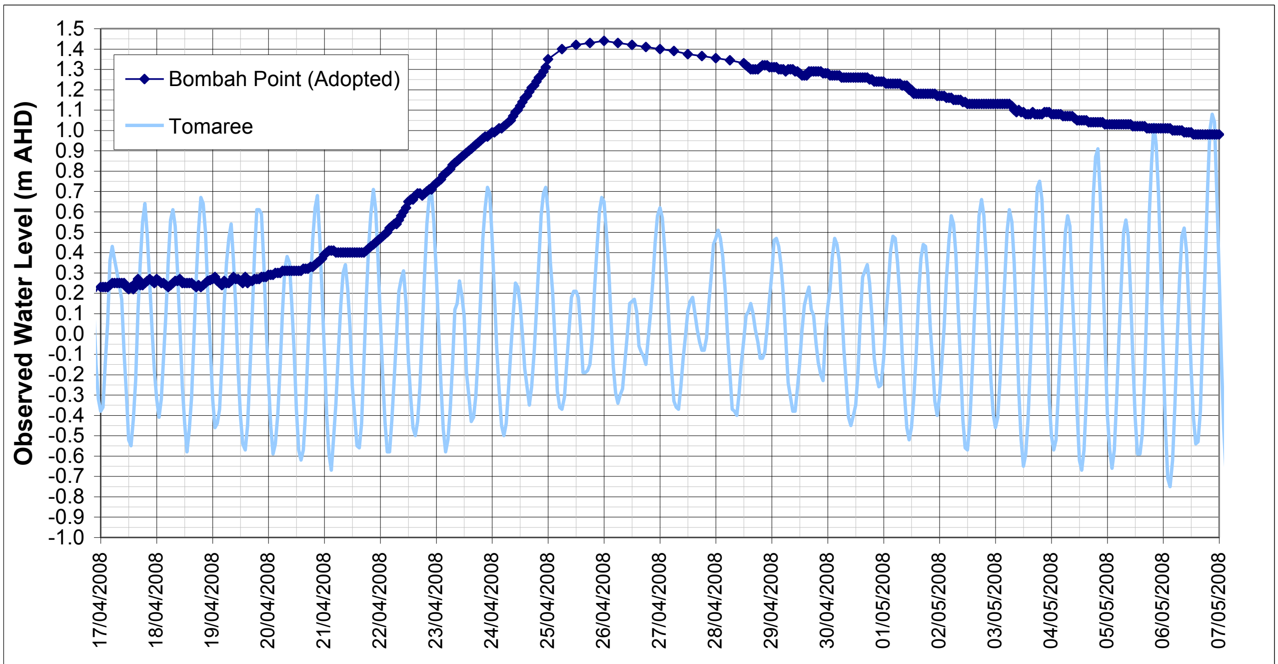


Figure 5-23 April 2008 Recorded Tidal Water Level

5.5.3 Rainfall Losses

Initial rainfall losses of 0mm, 15mm and 30mm have been simulated for the April 2008 event. As with the two previous events, an initial loss of 15mm was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the April 2008 event.

For longer duration events where total rainfall depth is the key determinate of runoff volume, the selection of a continuing loss value can have a significant influence on total rainfall depth. Continuing losses of 0 mm/hr, 0.5 mm/hr and 1.0 mm/hr have been simulated for the April 2008 event. Again as per the two previous events, a continuing loss of 0.5 mm/hr was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the April 2008 event.

5.5.4 Adopted Model Parameters

The model validation centred on the selection of appropriate total rainfall depth, with all other parameters using those determined by the model calibration event as presented in Table 5-3. For the April 2008 event a total rainfall depth of 250 mm (which is close to the arithmetic average of the 14 available rainfall gauges) provided a reasonable match to the observed peak water level (after appropriate corrections were applied to the recorded data set).

5.5.5 Observed and Simulated Flood Conditions April 2008

The water level time series at Bombah Point is the key validation data for the April 2008 event. A comparison of recorded and simulated water levels at Bombah Point is presented in Figure 5-24. The simulated results show that a reasonable model validation (considering uncertainty in the observed data set) has been achieved for a number of aspects of the simulated catchment flood behaviour:

- Catchment runoff response – the relative timing of the observed and simulated water level hydrographs shows a good agreement through the simulated event. This shows the catchment runoff processes are being well simulated. Spatial variation in rainfall (as presented in Figure 5-20) and temporal variation in rainfall (as presented in Figure 5-21) result in some differences between observed and modelled water levels for the rising limb of the hydrograph. However, it is important to note that there is considerable uncertainty regarding observed data for this event from the 21st April to 2nd May. The modelled falling limb is in good agreement with that observed.

- Peak flood levels – the peak flood levels show a reasonable agreement (within 0.1 m) to that observed. Though again due to gauge error there us a degree of uncertainly with the estimated observed peak level. After consideration of gauge errors and spatial and temporal rainfall variation the validation still indicates that appropriate hydrological and hydraulic parameters have been achieved through the model calibration process.

- Total flood volumes – the area under the water level time series graph is indicative of the total flood volume for the event. As evident in the observed vs. simulated comparisons, the water level profiles generally track the same for the duration of the event, and accordingly the total volumes would appear to be in good agreement. The adopted rainfall depth distribution and the modelled initial and continuing loss parameters provide for a good representation of total runoff volume generated from the catchment.

A comparison of recorded and simulated water levels at Tea Gardens is not available for this validation event as the recorder has only been operational since December 2008.

In terms of the catchment wide response, the simulated inundation extent and water level gradients for the April 2008 event are shown in Figure 5-25. The simulated conditions indicate the typical hydraulic gradients along the Myall and Lower Myall Rivers.

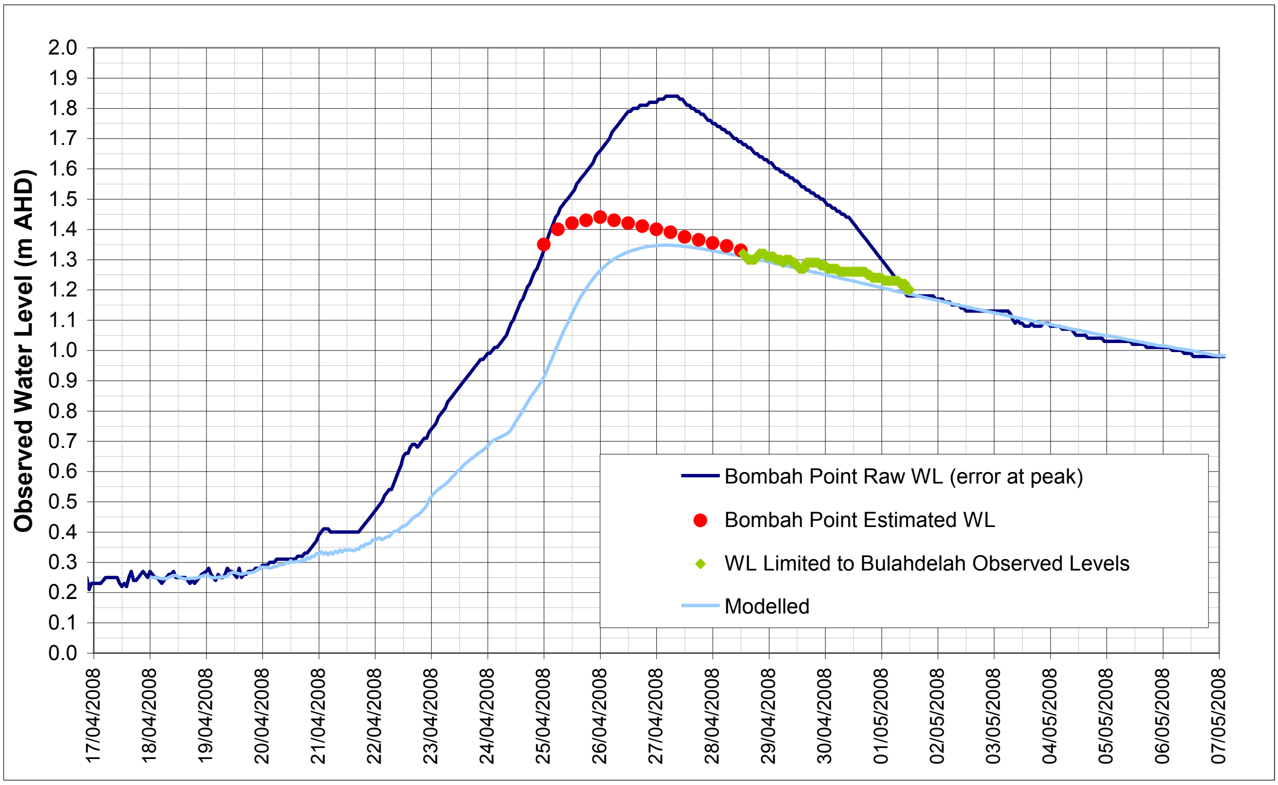
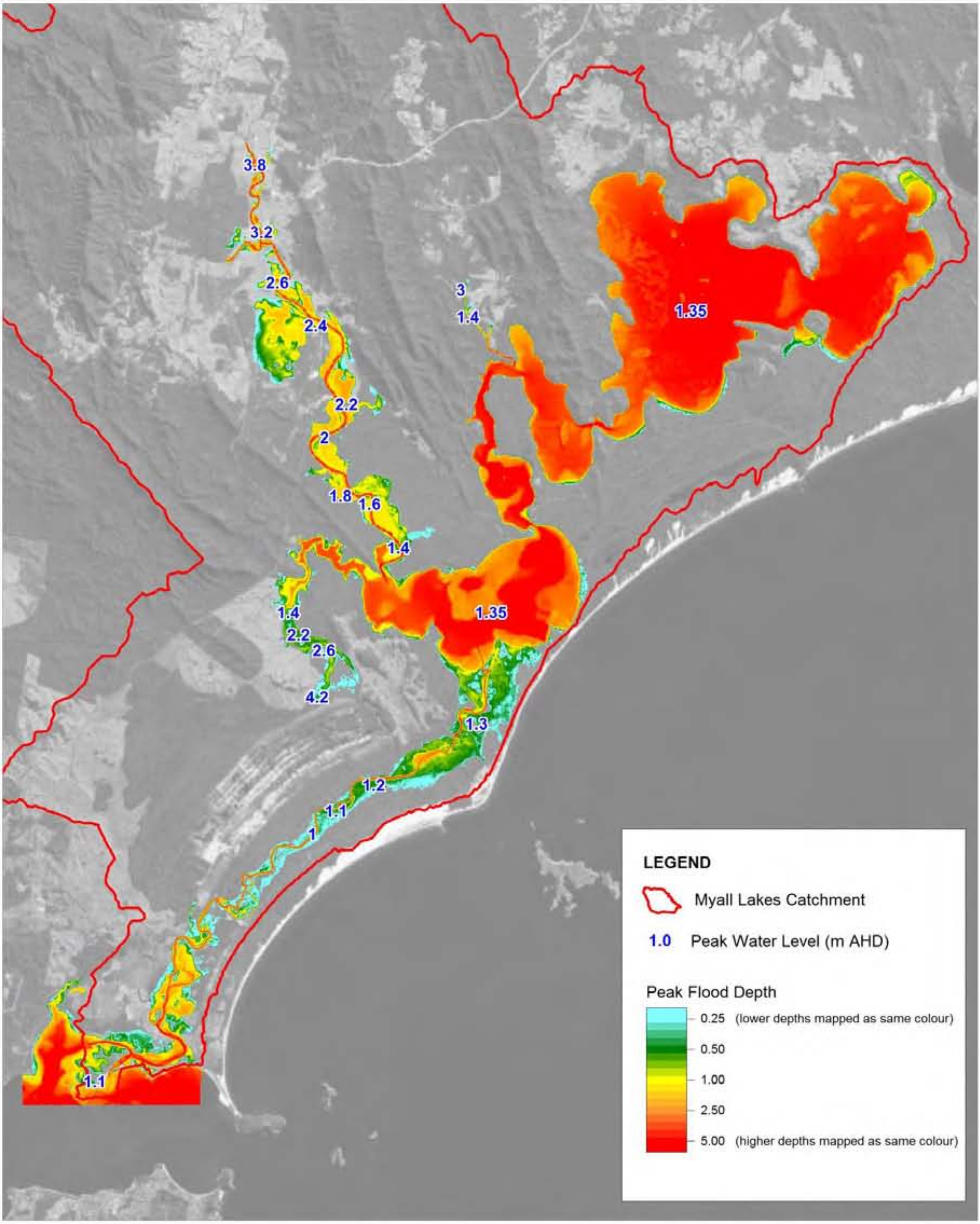


Figure 5-24 Bombah Point Water Level Calibration – April 2008



Title:

April 2008 Simulated Peak Flood Levels & Inundation

Figure: 5-25

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Approx. Scale

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5.6 March 2013 Model Validation

The March 2013 flood has been used as an additional model validation event, and represents the largest flood event observed on the Lower Myall in over 40 years. The availability of rainfall, good quality water level data and a number of survey flood marks along the lower reaches of the system provide good observed data to compare to model predictions.

5.6.1 Validation Data

5.6.1.1 Rainfall Data

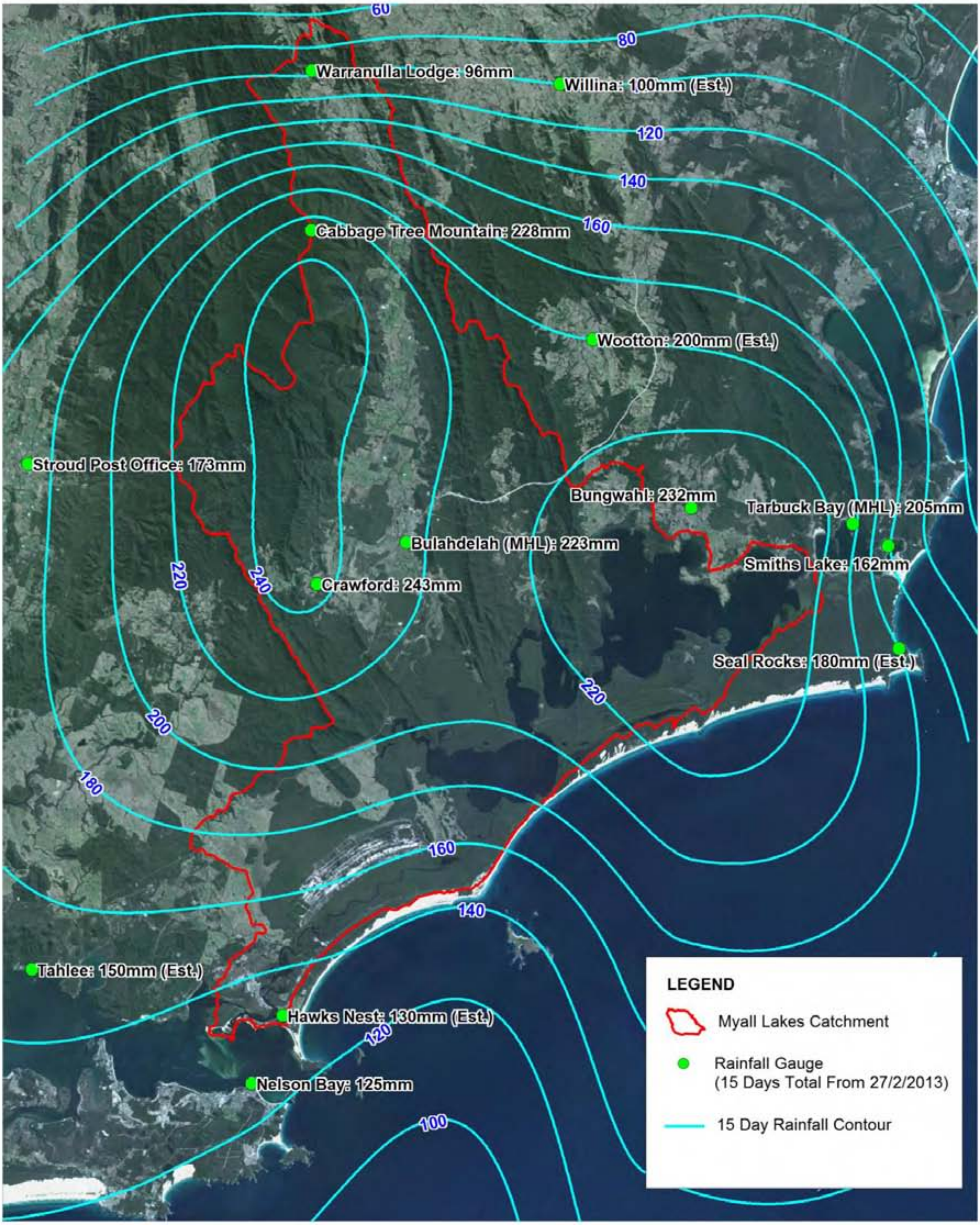
There were nine active rainfall gauges within or in close proximity to the Myall Lakes catchment for the March 2013 event. Two of these gauges were continuous read gauges operated by MHL with the remaining seven gauges being daily read gauges operated by BoM. No rainfall data was available for Tahlee or Willina at the time the validation exercise was undertaken and the Seal Rocks gauge was closed in October 2012. The Wootton gauge data appeared spurious and was excluded from analysis.

The recorded daily totals (for the 24 hours to 9am) for the period 9am February 27th – March 9th 2013 are summarised in Table 5-6 Table 5-2. The rainfall distribution (15 day totals) for the March 2013 event is shown in Figure 5-9. Excluding Warranulla data (due to low value) the numeric average of the eight gauges is 199 mm for the event, with 189 mm falling in three days.

Data from two MHL pluviometers was available for the event. Daily totals for the gauge at Bulahdelah and Tarbuck Bay have been summarised in Table 5-6while a time-series of cumlative rainfall for the two pluvio-gauges for the period February 27th – March 9th 2013 is presented in Figure 5-27.

Table 5-6 Recorded Rainfall (Daily to 9am) March 2013 Event

Gauge	27/2	28/2	1/3	2/3	3/3	4/3	5/3	6/3	7/3	8/3	9/3	Total
Bulahdelah (MHL)	0.0	0.0	16.0	165.5	40.5	1.0	0.0	0.0	0.0	0.0	0.0	**223**
Bungwahl	0	0	10	194	28	0	0	0	0	0	0	**232**
Cabbage Tree Mountain	7	0	39	108	51	22	1	0	0	0	0	**228**
Crawfords River	0	0	23	181	33	6	0	0	0	0	0	**243**
Nelson Bay	0	0	38	71.4	14.2	1.5	0	0	0	0	0	**125.1**
Smiths Lake	0	0	0	138	23	0.2	0	1.4	0	0	0	**162.6**
Stroud	0	0	27.6	107.8	31.6	6.4	0	0	0	0	0	**173.4**
Tarbuck Bay (MHL)	0.0	14.5	47.0	77.5	44.5	19.5	0.0	0.0	0.0	2.5	0.0	**205.5**
Warranulla	1.4	0.2	11.8	47	24.6	9.4	0.4	1.2	0	0.2	0	**96.2**
Average	**0.9**	**1.6**	**23.6**	**121.1**	**32.3**	**7.3**	**0.2**	**0.3**	**0.0**	**0.3**	**0.0**	**187.6**
Average (excluding Warranulla)	**0.9**	**1.8**	**25.1**	**130.4**	**33.2**	**7.1**	**0.1**	**0.2**	**0.0**	**0.3**	**0.0**	**199.1**



Title:
March 2013 Rainfall Distribution

Figure: **5-26**

Rev: **A**

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Approx. Scale

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5.6.1.2 Water Level Data

Water level data for the March 2013 event was available at Bombah Point, Bulahdelah and Tea Gardens.

The recorded water level time series at Bombah Point and Bulahdelah for the March 2013 event is presented in Figure 5-27. Water level data at Bombah Point is likely to be representative of water levels in the Bombah Broadwater, Boolambayte and Myall Lakes. Lake levels at the start of the event are ~0.8 m AHD with a peak lake level of 1.75 m AHD occurring on the 4th March.

The Bulahdelah water level gauge is able to provide information on catchment response on the Myall River just downstream of the Pacific Highway Bridge. At this location river levels are fairly responsive to rainfall intensity, though are also affected by a tailwater from the Lakes.

Observed water levels at Tea Gardens are presented in Figure 5-28. The relationship between recorded ocean water levels (Tomaree), observed water levels at Tea Gardens and Bombah Point water levels is also presented in Figure 5-28. High fluvial discharge and entrance bathymetry are likely to cause higher low water levels at Tea Gardens compared to Tomaree. A gauge error at Tea Gardens is evident on the 2nd March.

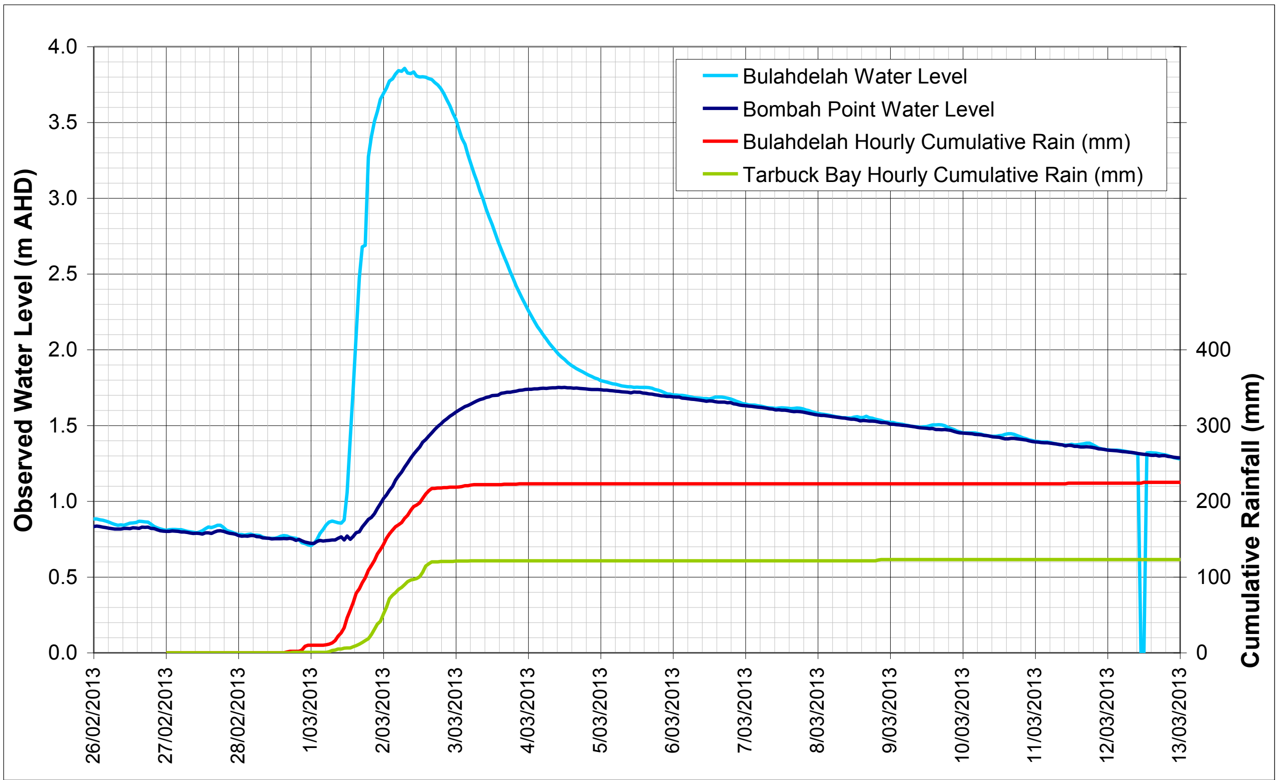


Figure 5-27 Observed Water Levels and Cumulative Rainfall – March 2013

5.6.2 Downstream Boundary Conditions

Ocean tide (water level) data was available for the March 2013 event from a continuous tide gauge maintained by MHL at Tomaree at the entrance to Port Stephens. This water level data (as presented in Figure 5-28) was used as the downstream boundary for the March 2013 event.

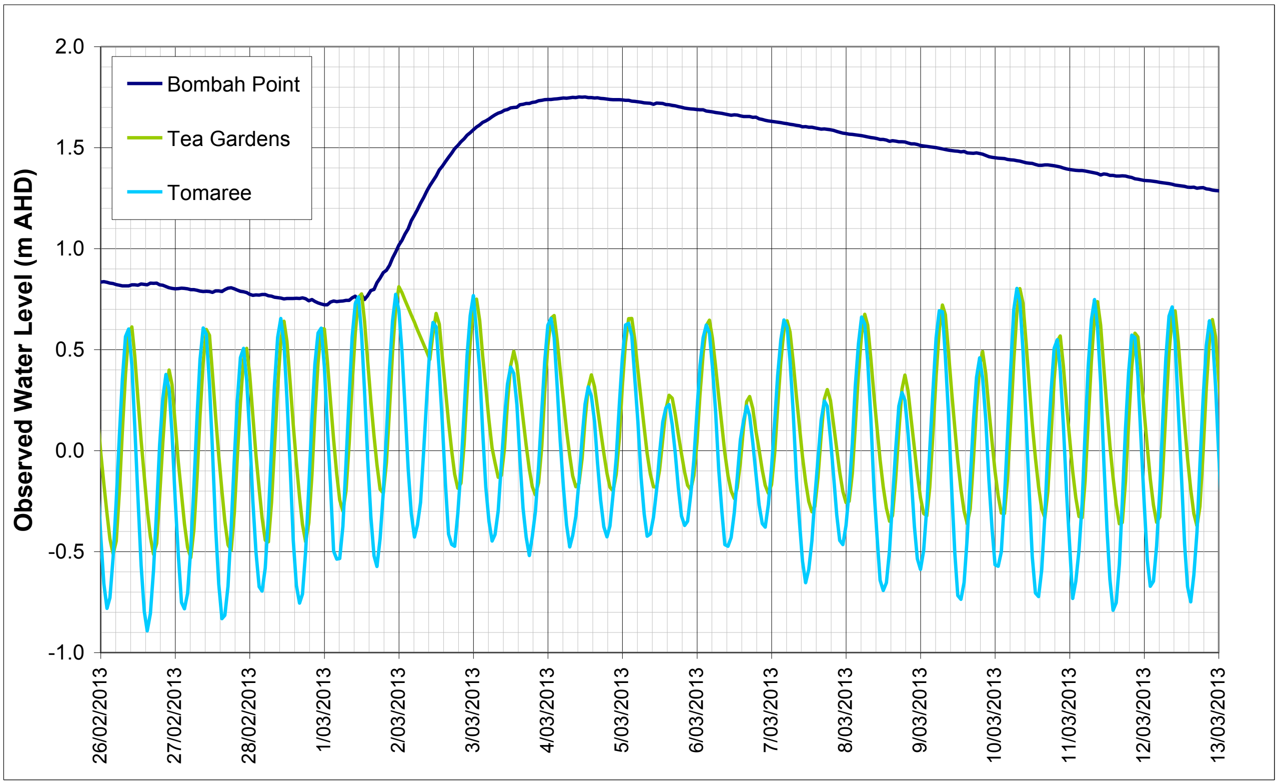


Figure 5-28 March 2013 Recorded Tidal Water Level

5.6.3 Rainfall Losses

Initial rainfall losses of 0mm, 15mm and 30mm have been simulated for the March 2013 event. An initial loss of 0mm was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the March 2013 event. This is likely to be due to a large event that occurred in the catchment on the 23rd February 2013 less than a week before the validation event.

For longer duration events where total rainfall depth is the key determinate of runoff volume, the selection of a continuing loss value can have a significant influence on total rainfall depth. Continuing losses of 0 mm/hr, 0.1 mm/hr and 0.5 mm/hr have been simulated for the March 2013 event. A continuing loss of 0.1 mm/hr with a rainfall depth of 200 mm was found to provide the best fit to the observed hydrological behaviour in the Myall Lakes for the March 2013 event. However, a continuing loss of 0.5 mm/hr with a rainfall depth of 220 mm was found to provide a good fit to observed water level data.

5.6.4 Observed and Simulated Flood Conditions March 2013

Validation data for the March 2013 event includes available water level time series at the Bombah Point and Tea Garden gauges. While calibration data is available for Bulahdelah, as this area is outside the key study area, a coarse model resolution was adopted to maintain reasonable model simulation times. This coarse (50m) model representation was unable to adequately resolve channel conveyance and hence modelled water levels in this area are not accurate.

A comparison of recorded and simulated water levels at Bombah Point for the March 2013 is presented in Figure 5-29. The simulated results show that a good model calibration has been achieved for a number of aspects of the simulated catchment flood behaviour:

- Catchment runoff response – the relative timing of the observed and simulated water level hydrographs shows a good agreement through the simulated event. This shows the catchment runoff processes are being well simulated. Spatial variation in rainfall (as presented in Figure 5-26) and temporal variation in rainfall (as presented in Figure 5-27) result in minor differences between observed and modelled water levels for the rising limb of the hydrograph.

- Peak flood levels – the peak flood levels show an excellent agreement. This indicates that appropriate hydrological and hydraulic parameters have been achieved through the model calibration process.

- Total flood volumes – the area under the water level time series graph is indicative of the total flood volume for the event. As evident in the observed vs. simulated comparisons, the water level profiles generally track the same for the duration of the event, and accordingly the total volumes would appear to be in good agreement. The adopted rainfall depth and the modelled initial and continuing loss parameters provide for a good representation of total runoff volume generated from the catchment.

The comparison of recorded and simulated water levels at Tea Gardens is presented in Figure 5-30. The close simulation of the tidal fluctuations at this location indicates an adequate model representation in terms of downstream boundary conditions, roughness parameters and bathymetry for the Lower Myall. A gauge error at Tea Gardens is evident on the 2nd March.

In terms of the catchment wide response, the simulated inundation extent and water level gradients for the March 2013 event are shown in Figure 5-31. The simulated conditions indicate the typical hydraulic gradients along the Myall and Lower Myall Rivers.

5.6.5 Observed and Simulated Flood Markers

This significant flood event in March 2013 was the largest flood observed on the Lower Myall in 40 years and provided a good opportunity to collect additional flood level data that could be used to check the accuracy of the flood model. GLC collected 10 survey marks along a 11.5 km distance upstream of Tea Gardens. The flood observation marks were established on the 7th March (three days after the peak of the flood) and surveyed in some 2-3 weeks later.

The observed and modelled flood peaks are presented in Table 5-7 with the location of the survey marks shown in Figure 5-32. Excluding the survey marks which were wind affected (2A, 3A, 4A &

5A) or potentially erroneous (10A) all points were within 12cm of the modelled data. Points 1A, 6A and 7A were within 2 cm indicating an excellent calibration. Observations at points 8A and 9A are 10 cm and 12 cm below the modelled peak levels. It is possible that these flood markers do not represent the true flood peak but may have been the 2nd or 3rd tidally influenced flood peak that arrived after the true flood peak. However, it is also possible that a lower roughness value may be applicable along this reach of the river

Table 5-7 March 2013 Event Flood Marks (Observed vs Modelled)

ID	Observed (m AHD)	Modelled (m AHD)	Difference (m)	GTC comments
1A	0.83	0.81	-0.02	protected, high confidence
2A	0.99	0.82	-0.17	wind, low confidence
3A	0.94	0.83	-0.11	wind, low confidence
4A	1.05	0.84	-0.21	wind, low confidence
5A	1.06	0.85	-0.21	wind, low confidence
6A	0.86	0.87	0.01	protected, moderate confidence
7A	0.88	0.90	0.02	good mark, high confidence
8A	0.91	1.01	0.10	good mark, high confidence
9A	0.98	1.10	0.12	reasonable mark, moderate confidence
10A	0.95	1.24	0.29	mark moved, ~0.1m error possible
Average			-0.02	

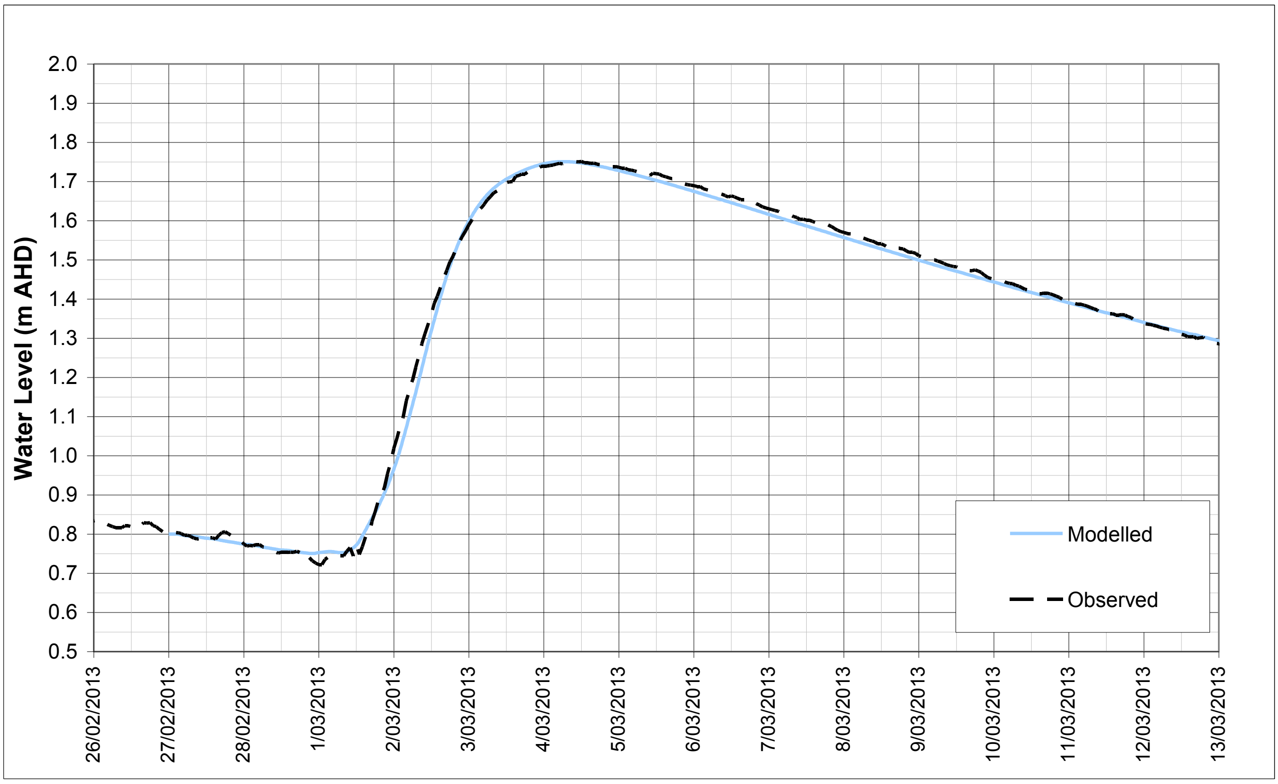


Figure 5-29 Bombah Point Water Level Calibration – March 2013

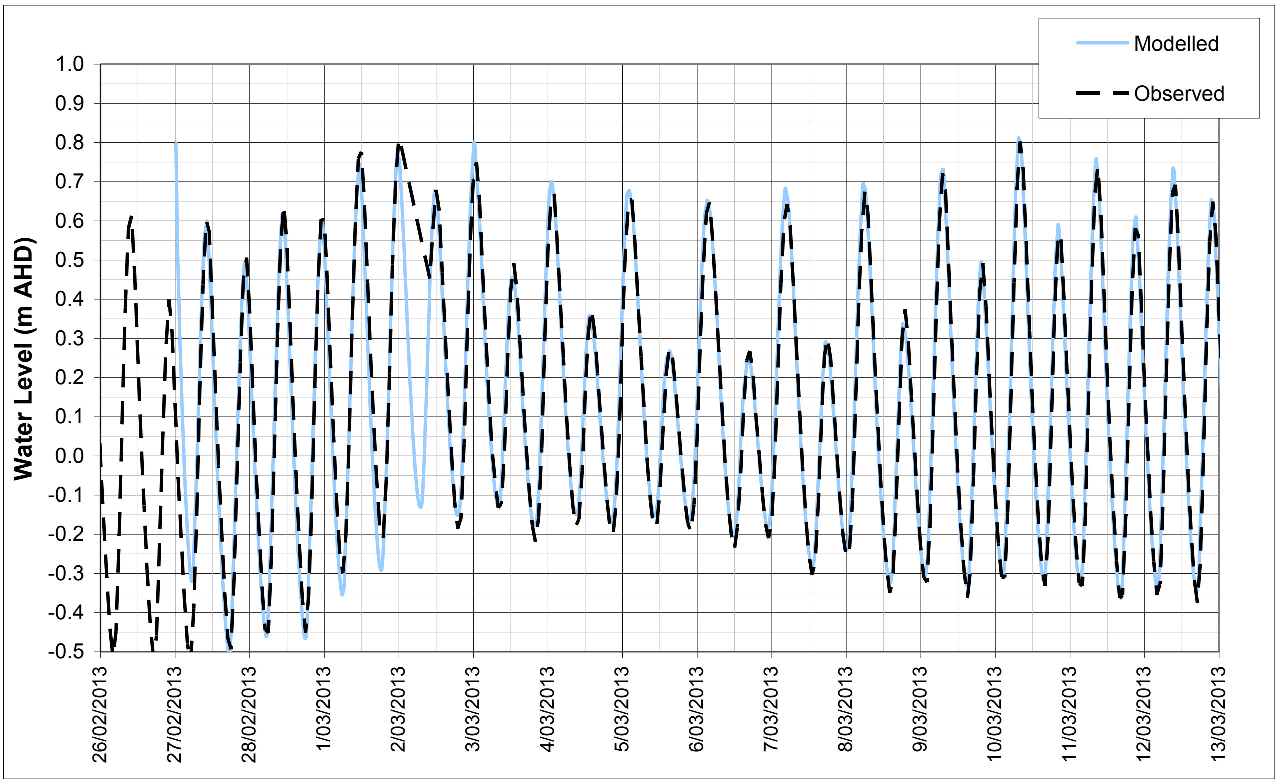
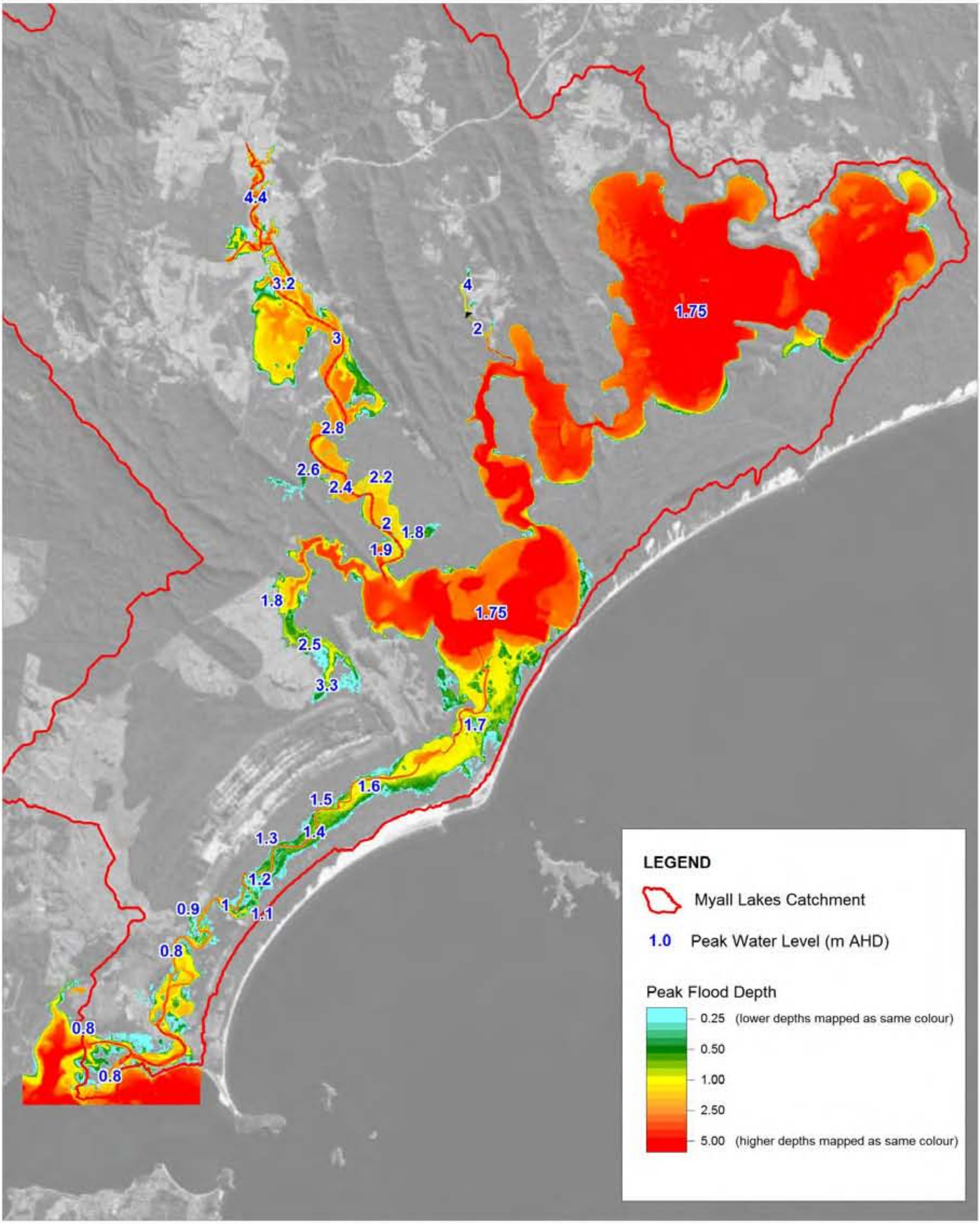


Figure 5-30 Tea Gardens Water Level Calibration – March 2013



Title:
March 2013 Simulated Peak Flood Levels & Inundation

Figure: 5-31

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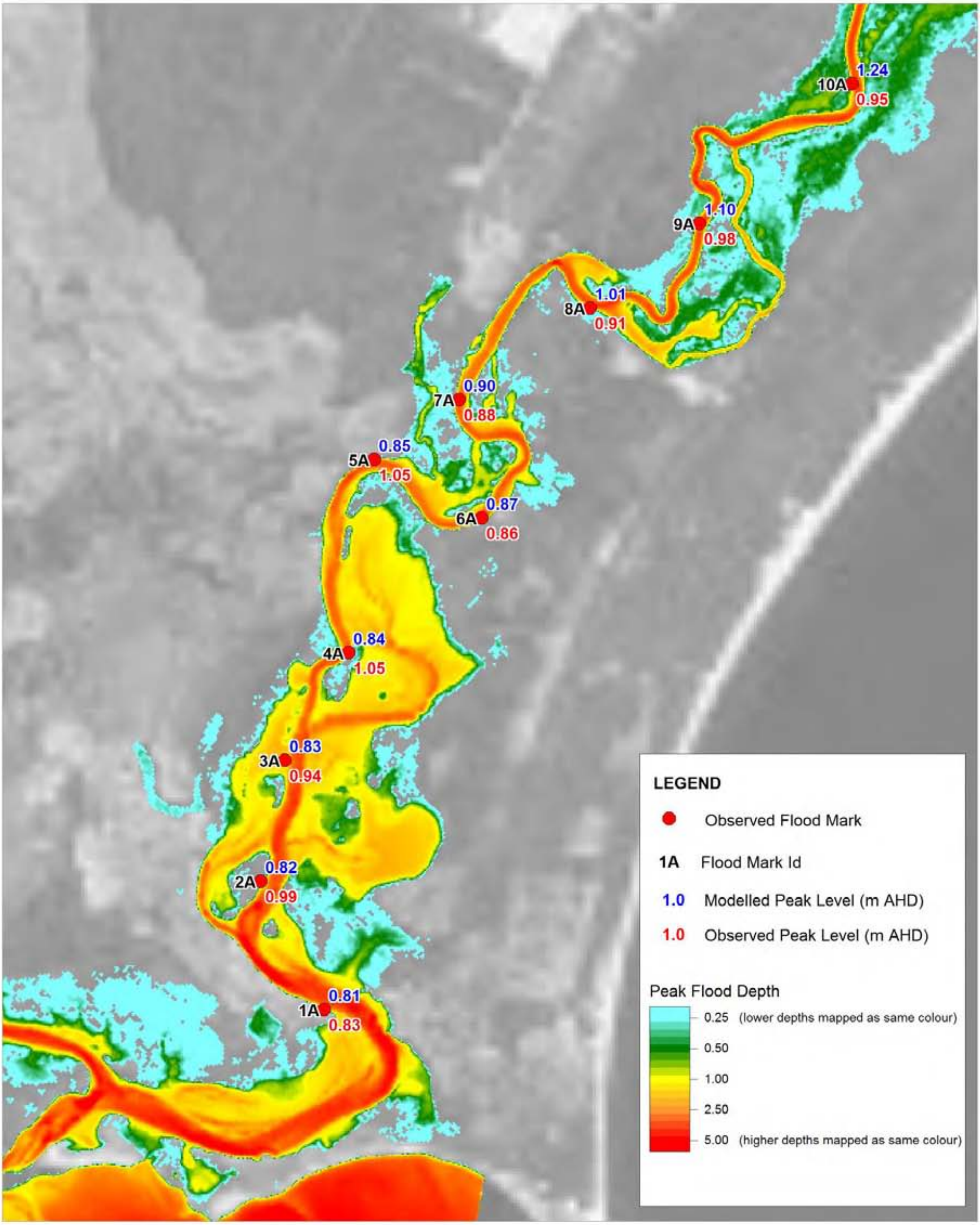

Title:
March 2013 Observed vs Modelled Flood Markers

Figure: **5-32**

Rev: **A**

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5.7 Determination of Design Model Parameters

In calibrating the models emphasis is generally placed on reaching agreement between recorded and simulated flood conditions with respect to peak water levels and relative timing of occurrence.

The model calibration achieved reasonable agreement in regards to observed conditions within the Myall Lakes catchment for the principal calibration event of July 2011 and validation events of May 2003, April 2008 and March 2013. The final model parameter values adopted, as shown in Table 5-8, have been maintained (as per the calibration events) for design event simulation.

Given the limited amount of calibration data available, it is important to acknowledge the limitation of the calibration process undertaken. All of the parameters have been kept within normal bounds generally considered for a catchment study of this nature. Further consideration has been given to sensitivity testing of key model parameters on design flood conditions as presented in Section 7.11.

Table 5-8 Calibrated Design Model Parameters

Parameter	Value	Comment
Initial Loss (mm): pervious area impervious area	 15 0	The 15mm initial loss provided the best fit for initial catchment response and total storm volumes with respect to available data for the calibration and validation events.
Continuing Loss (mm/hr): pervious area impervious area	 0.5 0	The 0.5mm continuing loss provided the best fit for total storm volume (i.e. peak water level) with respect to available data for the calibration and validation events.
Storage modification Factor Bx	1.0	Default value found appropriate
PERN	0.06 -0.12	Variable adjusted dependent on surface coverage – e.g. 0.12 for forested catchment and 0.06 for pasture/grass land.
Manning's 'n' (channels and lake areas)	0.03	Determined during calibration to provide best fit for peak water level profiles.
Manning's 'n' (grassed or un-vegetated floodplain)	0.04	Determined during calibration to provide best fit for peak water level profiles.
Manning's 'n' (heavily forested floodplain)	0.08	Determined during calibration to provide best fit for peak water level profiles.

6 DESIGN FLOOD CONDITIONS

Design floods are hypothetical floods used for land use planning and floodplain risk management investigations. They are based on having a probability of occurrence specified either as:

- Annual Exceedance Probability (AEP) expressed as a percentage; or
- Average Recurrence Interval (ARI) expressed in years.

This report uses the AEP terminology. Refer to Table 6-1 for a definition of AEP and the ARI equivalent.

Table 6-1 Design Flood Terminology

AEP[1]	ARI[2]	Comments
0.5%	200 years	A hypothetical flood or combination of floods likely to occur on average once every 200 years or with a 0.5% probability of occurring in any given year
1%	100 years	As for the 0.5% AEP flood but with a 1% probability or 100 year return period.
2%	50 years	As for the 0.5% AEP flood but with a 2% probability or 50 year return period.
5%	20 years	As for the 0.5% AEP flood but with a 5% probability or 20 year return period.
10%	10 years	As for the 0.5% AEP flood but with a 10% probability or 10 year return period.
20%	Approx. 5 years	As for the 0.5% AEP flood but with a 20% probability or 5 year return period.
50%	Approx. 2years	As for the 0.5% AEP flood but with a 50% probability or 2 year return period.
Extreme Flood / PMF[3]		A hypothetical flood or combination of floods which represent an extreme scenario.

1 Annual Exceedance Probability (%)
2 Average Recurrence Interval (years)
3 A PMF (Probable Maximum Flood) is not necessarily the same as an Extreme Flood.

The design events simulated include the PMF event, 0.5%, 1%, 5%, 10%, 20% and 50% AEP events for both ocean and catchment derived flooding. The 1% AEP flood is generally used as a reference flood for land use planning and development control.

In determining the design floods it is necessary to take into account:

- Design rainfall parameters (rainfall depth, temporal pattern and spatial distribution). These inputs drive the hydrological model from which design flow hydrographs are extracted as inputs to the hydraulic model;
- Design initial Lake water level; and
- Design downstream ocean boundary levels.

In determining the design floods it is necessary to take into account the critical storm duration of the catchment (small catchments are more prone to flooding during short duration storms while for large catchments longer durations will be more critical). Because the focus of this flood study is the Lower Myall short duration events were not considered.

6.1 Design Rainfall

An examination of the critical storm duration showed that peak lake levels occur due to storms of with duration greater than 3 days. As standard AR&R IFD design rainfall statistics are only currently available for durations up to 3 days, site specific flood frequency analysis of rainfall data was required to determine design conditions for the Lower Myall flood study.

The derivation of location specific design rainfall parameters (e.g. rainfall depth and temporal pattern) for the Lower Myall system is presented below.

6.1.1 Site Specific Rainfall Depth Frequency Analysis

Site specific flood frequency analysis of local rainfall data was required to determine design rainfall conditions and the critical duration flood event on the Lower Myall. Over 100 years of daily rainfall data was available from the Bulahdelah Post Office gauge (see Section 2.2.4) making it suitable for flood frequency analysis. A number of other nearby gauges also have greater than 100 years of daily data available. The location of the Bulahdelah gauge, approximately the centroid of the catchment, means that it is the most appropriate gauge for use in determining design rainfall statistics for the study.

The rainfall data was used to determine annual maximums for 3, 5, 7 and 10 days cumulative totals. These series of annual maximums were then analysed using the flood frequency analysis package Flike (Kuczera, 1999) to determine rainfall depth probability statistics for the 3, 5, 7 and 10 day duration events. A log-normal probability distribution was found to provide a good fit to the data series. Design rainfall depths for the 1% AEP (~ 1 in 100 year) event for the 3, 5, 7 & 10 day storms are presented in Table 6-2.

Table 6-2 Bulahdelah PO 1% AEP Rainfall Depths for 3, 5, 7 & 10 Day Duration Events

Event Duration (Days)	1% AEP Rain Depth (mm)
3	393
5	438
7	479
10	525

Comparison to AR&R Method

The 3 day site specific 1% AEP rain depth (393 mm) for Bulahdelah Post Office was shown to be in close agreement to the 72 hour (3 day) rainfall depth predicted for the same location using the AR&R (1987) method which gives the 1% AEP average intensity of 5.29 mm/hr (381 mm).

Critical Duration

The rainfall depths determined by the site specific flood frequency analysis were used to generate hydrologic inputs using the RAFTS model described in Section 4. An areal reduction factor of 0.95 was adopted as recommended in AR&R (2001). The adopted temporal pattern was based on the AR&R 72 hour storm but linearly stretched to the required duration. Initial losses of 15 mm and continuing losses of 0.5 mm/hr were also adopted based on the model calibration described in Section 5. The model hydrology was then applied to the hydraulic (TUFLOW) model run to determine the peak water levels (as presented in Table 6-3 and Figure 6-1) for the three events. The results show that the 7 day storm event produces the highest peak lake level and hence is deemed the critical duration for the lakes system.

Table 6-3 Maximum Lake Levels for 5, 7 & 10 Day 1% AEP Events

Event Duration	Rainfall (mm) after Areal Reduction	Peak Tuflow Lake Level (mAHD)
5 Day	416	2.35
7 Day	455	2.38
10 Day	499	2.37

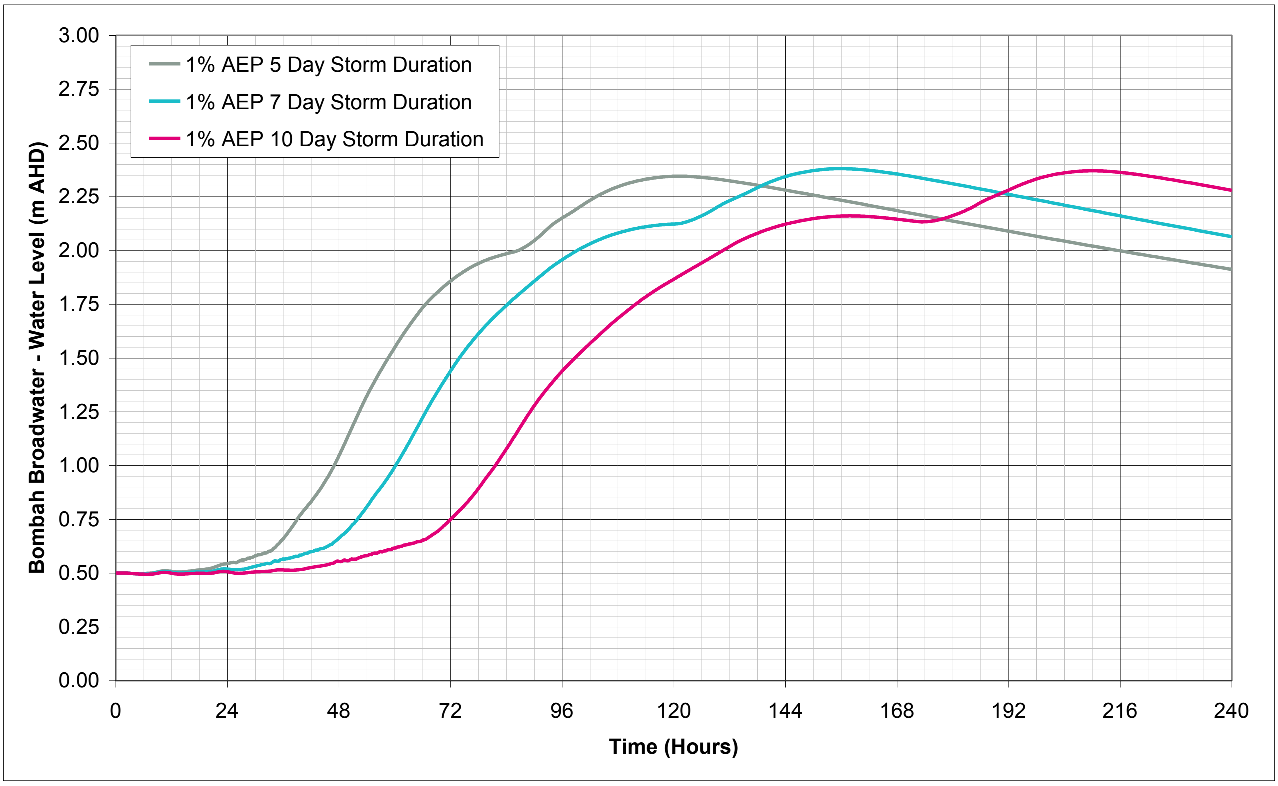

Figure 6-1 Predicted Water Levels for 3 Different Duration 1% AEP Events

Design Rainfall Depths

Design rainfall depths for other probability events, based on a rainfall frequency analysis of 7 day totals at Bulahdelah are presented in Table 6-4. Two extreme events are also presented in place of the PMF as the GSAM method is only applicable for durations up to 72 hours. They include the 1 in 10000 year FFA event of 787.5 mm and 3 x 100 year (1% AEP) event which is 1436.4 mm.

The GSAM PMP method was used to provide some insight into the extreme event analysis. The 72 hour GSAM PMP method (AR&R87) predicts a PMP of 1158 mm. If this depth is scaled from a 3 day event to the 7 day event using a ratio of 1% AEP depths (from Table 6-2) a 7 day PMP estimate of 1412 mm is obtained which is in close agreement with the extreme event (3 x 100 yr) estimate of PMP (1436 mm).

Table 6-4 Adopted Design Rainfall Depths for 7 Day Storm

Design Event Frequency (AEP)	Rain Depth (mm)
50%	208.6
20%	281.8
10%	329.7
5%	375.4
2%	434.4
1%	478.8
0.5%	523.5
Extreme Event (10000 yr)	787.5
Extreme Event (3 x 100yr)	1436.4

6.1.2 Temporal Patterns

The design rainfall depth data presented in Table 6-4 provides for the total rainfall depth for the 7 day storm duration. Temporal patterns are required to define what percentage of the total rainfall depth occurs over a given time interval throughout the storm duration. The temporal patterns adopted in the current study are based on a linear extrapolation of the 72 hour temporal pattern presented in AR&R (2001). A comparison of the adopted temporal pattern against a constant (average) rainfall event is presented in Figure 6-2.

The same temporal pattern has been applied across the whole catchment. This assumes that the design rainfall occurs simultaneously across each of the modelled sub-catchments. The direction of a storm and relative timing of rainfall across the catchment may be determined for historical events if sufficient data exists, however, from a design perspective the same pattern across the catchment is generally adopted.

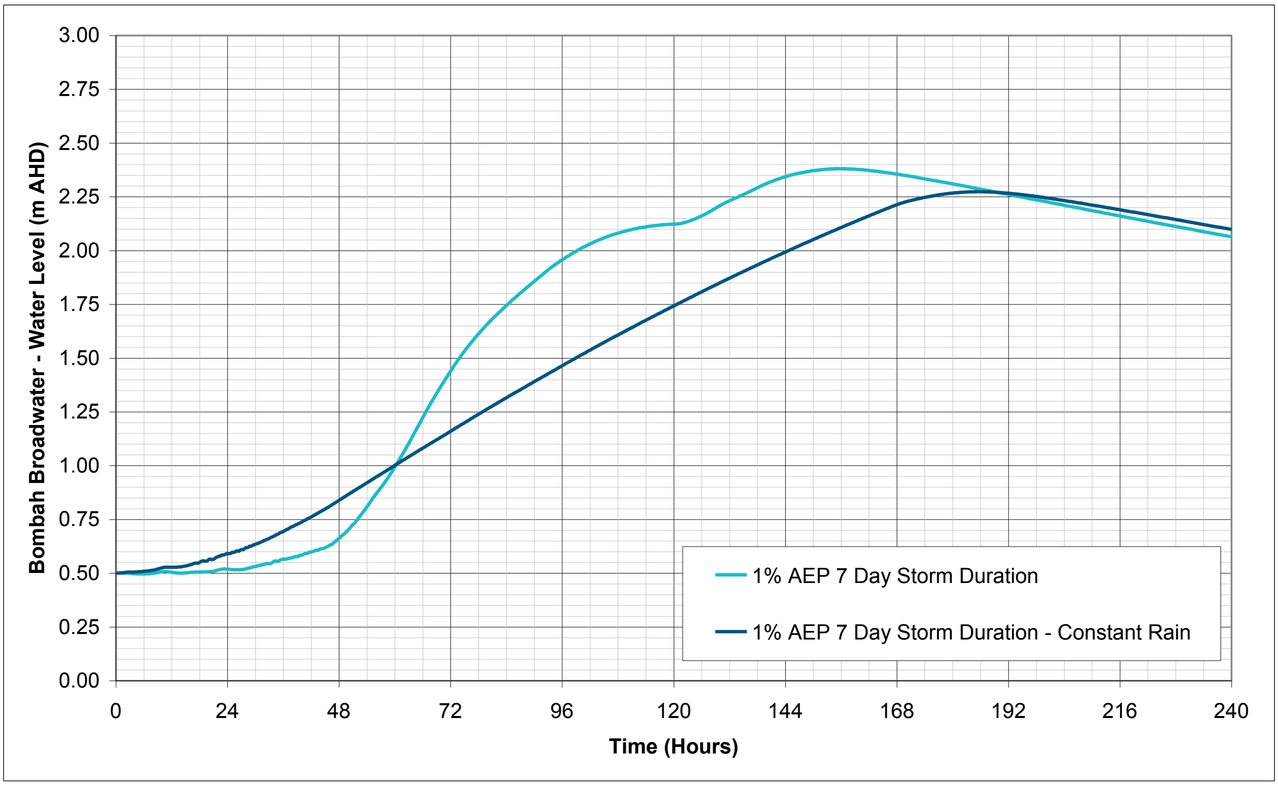

Figure 6-2 Influence of Adopted Temporal Pattern on Predicted Water Levels

6.1.3 Rainfall Losses

The rainfall loss parameters adopted for the design floods were based on those determined during the model calibration and validation. For the initial and continuing rainfall losses, values of 15 mm and 0.5 mm/hr were used for pervious areas. A lower than typical (2.5 mm/hr) continuing loss was required due to the long storm duration.

6.2 Design Ocean Boundary

Design ocean boundaries adopted for use in the Lower Myall Flood Study are based on observed tidal data for Tomaree and design peak water levels presented in WMA (2010).

6.2.1 Catchment Derived Flood Events

The adopted tidal boundary for catchment derived flood events was based on observed tide data from 18th April to 5th March, 2008 as presented in Figure 6-3. This period appears to be fairly representative of a typical spring, neap period.

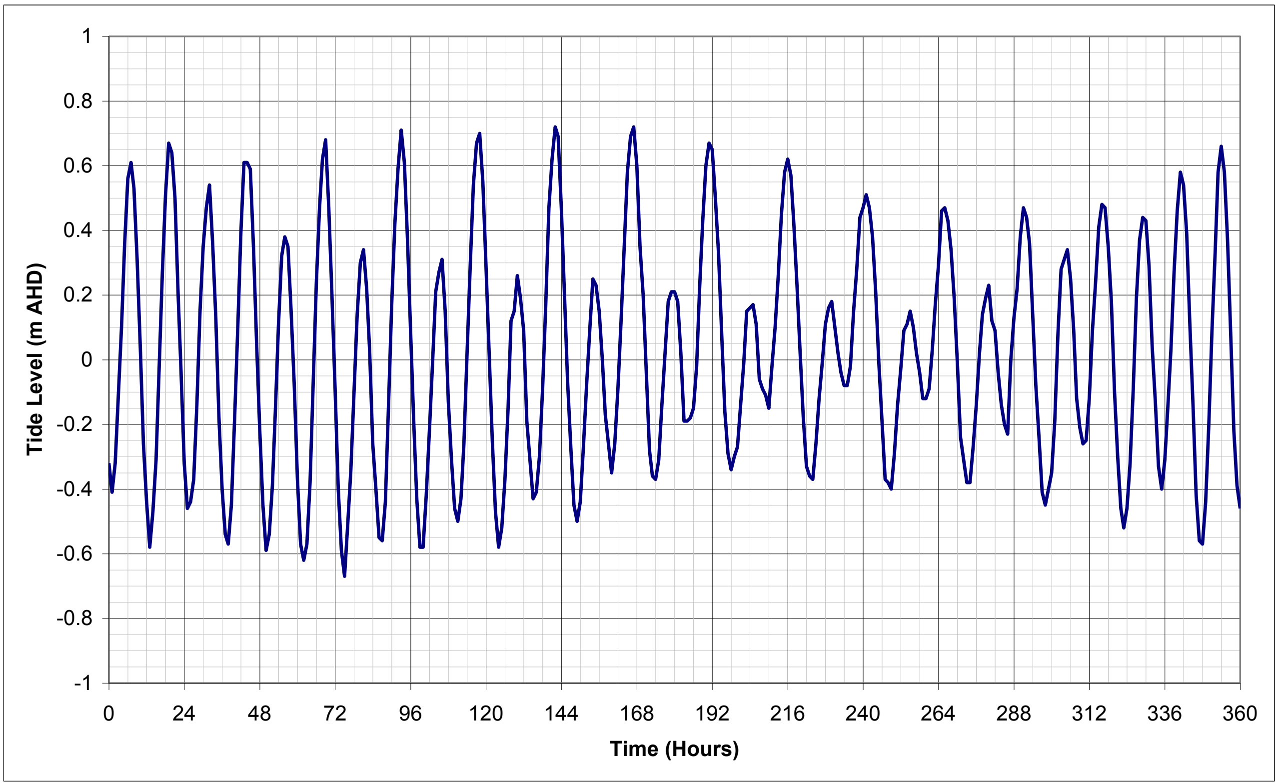

Figure 6-3 Design Tide for Catchment Flooding Simulations

6.2.2 Ocean Derived Flood Events

The adopted tidal boundary for ocean derived flood events was based on raising an observed spring tide event to the design peak ocean water levels for Port Stephens presented in WMA (2010).

Adopted peak ocean boundary water levels for various magnitude storm events are presented in Table 6-5. It should be noted that WMA (2010) only provided data for the 1%, 2% and 5% with log-linear extrapolation used to determine the remaining design events. The adopted extreme tide of 1.8 m AHD was defined in consultation with OEH.

Table 6-5 Design Peak Ocean Water Levels

Event Magnitude	Water Level (m)
50% AEP	1.33
20% AEP	1.37
10% AEP	1.40
5% AEP	1.43
2% AEP	1.47
1% AEP	1.50
0.5% AEP	1.53
Extreme Tide	1.80

The design storm tides were generated by applying a four day storm surge profile to an observed spring tide. The selected observed Tomaree tide is from the 18th to 24th April 2011 which had a peak of 1.04 m AHD on 20th April 2011 at 10pm. A four day sinusoidal storm surge with the required amplitude to raise the observed tide to the corresponding design peak ocean level was added to the observed spring tide signal to develop the design tide time series. The observed tide, and design tide and storm surge time series for the 0.5% AEP, 5% AEP and 50% AEP ocean events are presented in Figure 6-4.

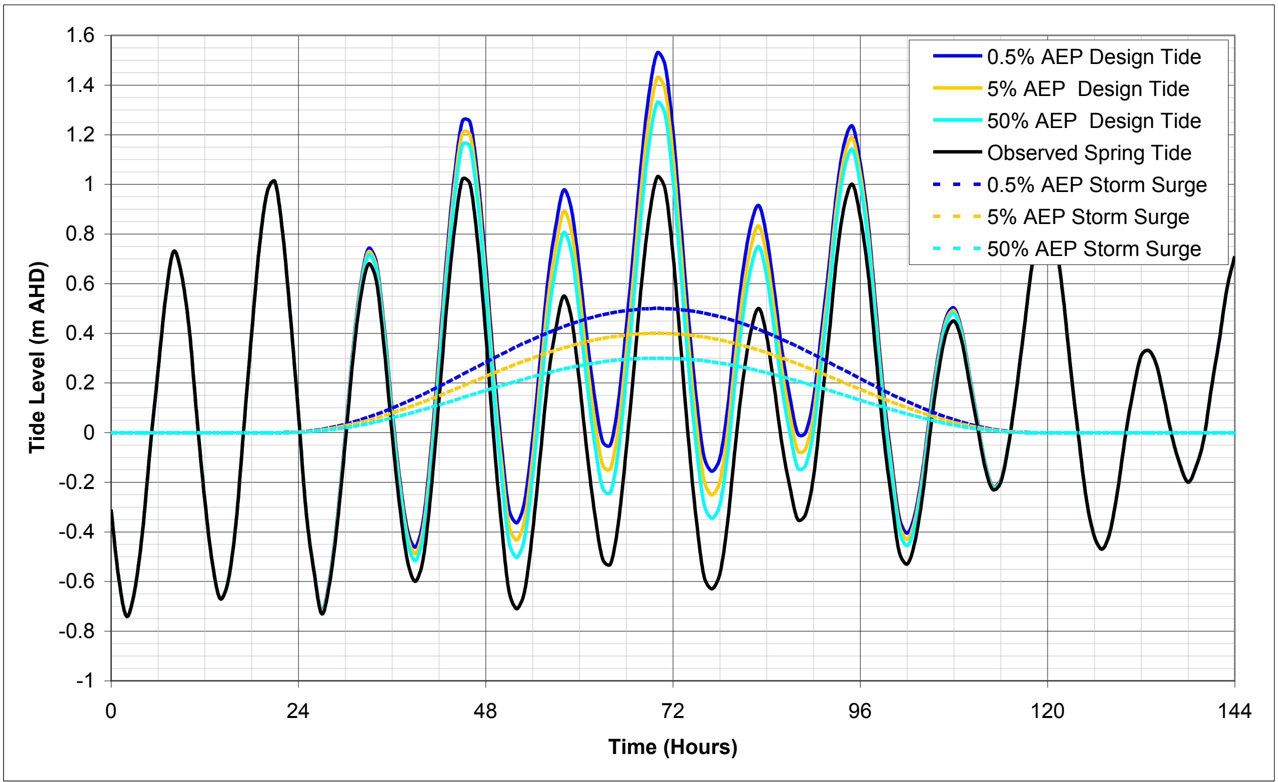

Figure 6-4 Design Ocean Boundary – Storm Surge Elevated Tides

6.3 Initial Water Levels

Initial water levels in the Myall Lakes system for design flood events have been derived based on an analysis of water level statistics at Bombah Point between July 2001 and April 2012. The lake level statistics are presented in Table 6-6. An initial lake level of 0.5 m AHD was selected (for both catchment and ocean events) in consultation with OEH and GLC and matches the lake level exceeded only 10% of the time. A lake level of 0.5 m AHD is likely to be representative of lake levels immediately following a minor storm event or several weeks after a more significant rain event.

Sensitivity testing of the influence of initial lake level is presented in Section 7.11.3. A more detailed investigation into the selection of an appropriate design initial water level including additional sensitivity testing is presented in Appendix C. The additional investigation provides information on rates of lake drainage, an analysis of longer term lake levels (based on processed Bulahdelah data) and the correlation between maximum annual 7 and 30 day cumulative rainfall totals. The cumulative rainfall analysis provides some information on the likelihood of two large rain events occurring in a short period of time which may result in a high initial lake level.

Table 6-6 Bombah Point Water Level Exceedance Statistics

Percent Exceedance	Lake Level (mAHD)
99	-0.09
90	-0.01
75	0.06
50	0.15
25	0.30
20	0.35
15	0.41
10	0.50
5	0.68
1	1.05
average	0.21

6.4 Modelled Design Events

As requested by GLC a suite of design event scenarios were defined that were considered suitable for future floodplain management planning for the Lakes and Lower Myall. Consideration was given to design flood events driven by both catchment and ocean processes. The potential impact of climate change on flood behaviour within the study area is presented in Section 8.

6.4.1 Catchment Derived Flood Events

A range of design events were defined to model the behaviour of catchment derived flooding within the Lower Myall system including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and extreme events. The catchment derived flood events were based on the following:

- Design rainfall parameters derived from site specific rainfall frequency analysis;
- A typical tide for the ocean boundary;
- Initial lake level of 0.5 m AHD.

6.4.2 Ocean Derived Flood Events

A range of design events were defined to model the behaviour of ocean derived flooding within the Lower Myall including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and extreme tide events. The ocean derived flood events were based on the following:

- No catchment rainfall;
- Peak ocean water levels as presented in WMA (2010).
- Initial water level of 0.5 m AHD.

6.4.3 Joint Catchment and Ocean Derived Flood Events

Two model simulations were undertaken to consider the coincidence of catchment and ocean flooding conditions. The events considered the occurrence of a 1% AEP design catchment rainfall coinciding with 1% AEP design ocean condition. The difference between the two combined simulations is the timing on the peak tide level and the peak flood level. The two joint catchment and ocean derived flood events include:

- No lag - the peak storm surge occurring at the same time as the peak rainfall. In this case the storm (meteorological event) causing the high rainfall is assumed to occur at the same time as high winds that cause the peak of the storm surge.
- 90 hour lag - the peak storm surge occurs at the same time as peak lake level.

Because of the catchment size and available lake storage, the peak storm surge is unlikely to occur at the same time as the peak lake level; however, the simulation is informative as it provides peak flood levels for what could be considered a worse case situation. It is important to understand that has different meteorological conditions drive the catchment and ocean flooding, such that a combined 1% AEP catchment event combined with a 1% AEP ocean event represents an extremely rare occurrence and that lagging the events to produce a worst case situation will represent an even more rare flood situation.

7 DESIGN FLOOD RESULTS

A range of design flood conditions were modelled, the results of which are presented and discussed below. The simulated design events included the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, and 0.5% AEP events for catchment or ocean derived flooding. An extreme (similar to PMF) flood event has also been modelled for the catchment and ocean flood events. A series of design flood maps for these events are provided in Appendix B.

7.1 Peak Flood Conditions

7.1.1 Catchment Derived Flood Events

Predicted flood levels at selected locations are shown in Table 7-1 for the full range of design event magnitudes considered. The locations of reported flood levels are shown in Figure 7-1.

7.1.2 Ocean Derived Flood Events

Predicted flood levels at selected locations are shown in Table 7-2 for the full range of design event magnitudes considered.

7.1.3 Combined Design Flood Results

Peak flood levels for the catchment and ocean events have been combined to produce a single (combined) peak flood level as presented in Section 7.6. Maps of combined peak flood depth and velocity for each of the design events are presented in Appendix B.

7.1.4 Joint Catchment and Ocean Derived Flood Events

Predicted peak flood levels at selected locations for the coincident catchment and ocean flooding scenario is shown in Table 7-3. The coincident flooding scenarios are for: a combined 1% AEP catchment rainfall with 1% AEP design ocean condition (with and without a 90 hour lag), a combined 5% AEP catchment rainfall with 1% AEP design ocean condition and a combined 1% AEP catchment rainfall with 5% AEP design ocean condition . The results show that the combined ocean and catchment event does not produce flood levels significantly higher than either event separately with water levels for the combined event typically being only a few centimetres higher than either the catchment or ocean 1% AEP event. The river reach 5 km either side of Monkey Jacket is most significantly influenced by combined ocean and catchment events especially where the ocean event is lagged by approximately 90 hours so that the peak tide coincides with peak lake level.

Table 7-1 Modelled Peak Flood Levels (m AHD) for Catchment Derived Design Events

Design Event Frequency (AEP)	Myall Lake	Bombah Broadwater	Brasswater	Monkey Jacket	Tea Gardens	Corrie Island	Tidal Boundary
50%	1.22	1.22	1.13	0.77	0.75	0.74	0.72
20%	1.56	1.56	1.47	0.80	0.75	0.74	0.72
10%	1.78	1.77	1.68	0.82	0.76	0.74	0.72
5%	1.97	1.97	1.88	0.86	0.76	0.74	0.72
2%	2.21	2.21	2.12	0.94	0.77	0.74	0.72
1%	2.38	2.38	2.29	1.01	0.78	0.75	0.72
0.5%	2.54	2.54	2.45	1.08	0.80	0.75	0.72
Extreme Event (10000 yr)	3.38	3.37	3.25	1.56	1.06	0.87	0.72
Extreme Event (3 x 100yr)	4.86	4.85	4.68	2.76	2.24	1.69	0.72

Table 7-2 Modelled Peak Flood Levels (m AHD) for Ocean Derived Design Events

Design Event Frequency (AEP)	Tidal Boundary	Corrie Island	Tea Gardens	Monkey Jacket	Brasswater	Bombah Broadwater	Myall Lake
50%	1.33	1.26	1.25	1.20	0.64	0.50	0.50
20%	1.37	1.30	1.28	1.24	0.65	0.50	0.50
10%	1.40	1.33	1.31	1.26	0.66	0.50	0.50
5%	1.43	1.36	1.34	1.29	0.67	0.50	0.50
2%	1.47	1.40	1.37	1.32	0.67	0.50	0.50
1%	1.50	1.42	1.40	1.35	0.68	0.50	0.50
0.5%	1.53	1.45	1.42	1.38	0.69	0.50	0.50
Extreme Tide	1.80	1.71	1.67	1.62	0.76	0.52	0.52

Table 7-3 Modelled Peak Flood Levels (m AHD) for Combined Catchment and Ocean Event

Design Event Frequency (AEP)	Myall Lake	Bombah Broadwater	Brasswater	Monkey Jacket	Tea Gardens	Corrie Island	Tidal Boundary
1% AEP Catchment and 1% AEP Ocean*	2.40	2.40	2.31	1.44	1.45	1.45	1.50
1% AEP Catchment and 1% AEP Ocean (90 hour lag)	2.38	2.38	2.30	1.58	1.53	1.51	1.50
1% AEP Catchment and 5% AEP Ocean*	2.40	2.40	2.31	1.38	1.39	1.39	1.43
5% AEP Catchment and 1% AEP Ocean*	2.00	2.00	1.91	1.41	1.43	1.44	1.50

* indicates adopted value for design runs

Title:

Design Event Peak Water Level Reporting Locations and Long-Section

Figure: 7-1

Rev: B

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Approx. Scale

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7.2 Design Flood Hydrographs

A number of key catchment inflows hydrographs as well as a time-series of lake outflow for the 1% AEP (seven day) catchment event is presented in Figure 7-2. The hydrographs show the relative contribution of the three key catchments but do not show the volume attributed to direct rainfall on the lake surface. The influence of storage along the Myall River between Bulahdelah and it's confluence with Bombah Broadwater is also evident. A peak outflow of 225 m^3/s (at a peak lake level of 2.38 m AHD) from the Broadwater into the Lower Myall is in reasonable agreement with PWD (1980) which calculated a peak outflow of 210 m3/s for a peak lake level of 2.56 mm AHD.

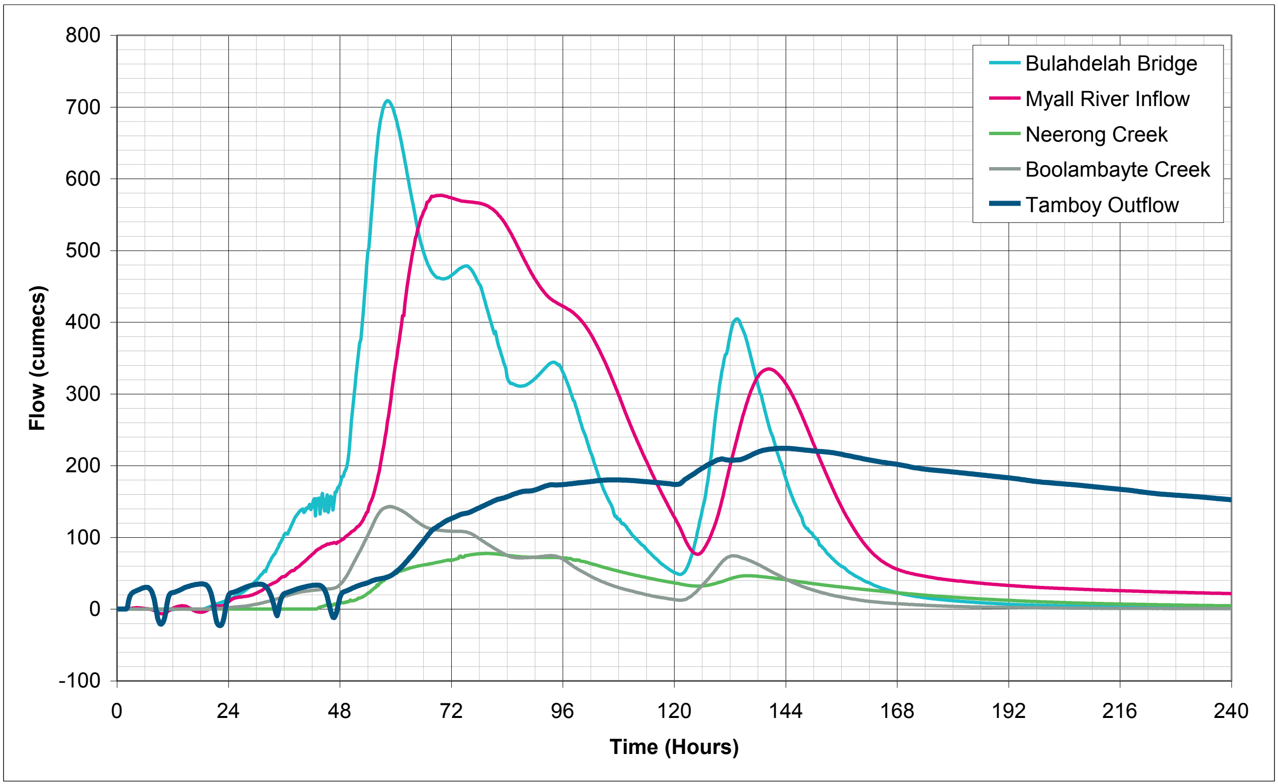

Figure 7-2 Predicted Lower Myall Flows for 1% AEP Catchment Event

7.3 Design Flood Behaviour for Catchment Events

The design flood mapping in Appendix B presents the peak design flood condition throughout the catchment for the 1% AEP catchment derived event. Further discussion on the general nature of catchment derived flooding within the Lower Myall system is provided below.

7.3.1 Lake and Channel Water Levels

Figure 7-3 shows examples of the relative response of water level in the Lower Myall and three lake water bodies for the 1% AEP design catchment event. A rapid increase in lake water levels between 48 and 96 hours is evident and is in response to the Myall River inflow hydrograph presented in Figure 7-2. During this time water levels in Bombah Broadwater rise more rapidly then Boolambayte and Myall Lakes indicating that significant flows from the Broadwater to the Lake would occur until the three lakes reach an equal level approximately 108 hours into the event. Lake levels rise again between 120 and 156 hours has a second burst of rainfall further fills the lake system. Peak lake levels occur around 156 hours into the event when lake outflow exceeds lake inflow. For the remaining 84 hours lake outflow begin to reduce lake levels which fall at approximately 0.4 m/day.

The catchment derived flood event results in only minor increases in tidal water levels in the downstream reaches of the Lower Myall. The 1% AEP catchment flood only increases high tide levels by ~0.1 m while increase to low tide levels of 0.3-0.4 m may occur during high river discharge.

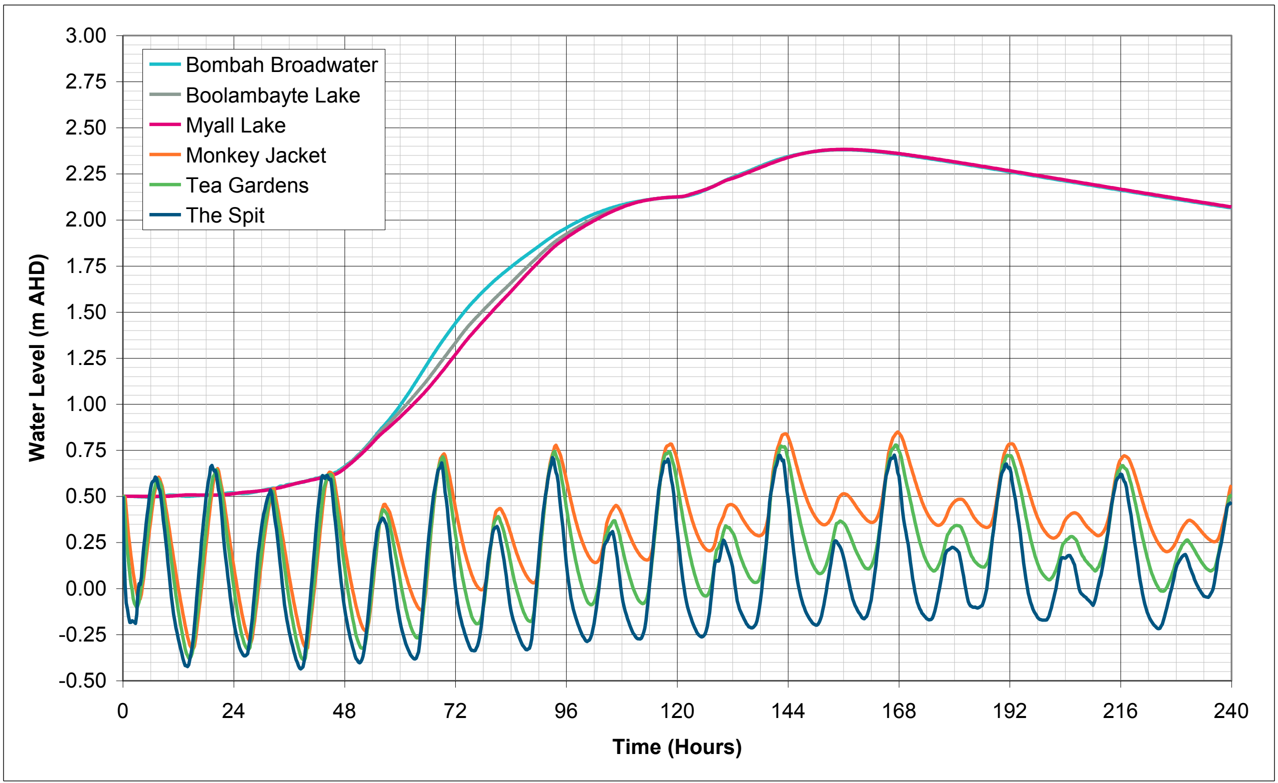

Figure 7-3 Predicted Water Levels 1% AEP Catchment Event

7.3.2 Peak Water Level Profile

Peak flood level profiles along the Lower Myall for the extreme (3 x 100 yr), 1% AEP, 5% AEP and 20% AEP catchment design events are shown in Figure 7-4. The profiles of peak flood level are taken along the channel of the Lower Myall from Port Stephens to Bombah Broadwater as shown in Figure 7-1.

The shape of the long-section profile reflects the hydraulic capacity of the Lower Myall channel and floodplain and the storage capacity (stage-volume relationship) of the lakes system. Peak floodplain discharge for the four events presented in Figure 7-4 is: Extreme event, 1250 m^3/s; 1% AEP, 225 m^3/s; 5% AEP, 155 m^3/s and 20% AEP, 101 m^3/s. For the catchment derived 1% AEP (and smaller) event, the channel capacity downstream of Monkey Jacket is sufficient to carry flood flows with minimal inundation of the floodplain.

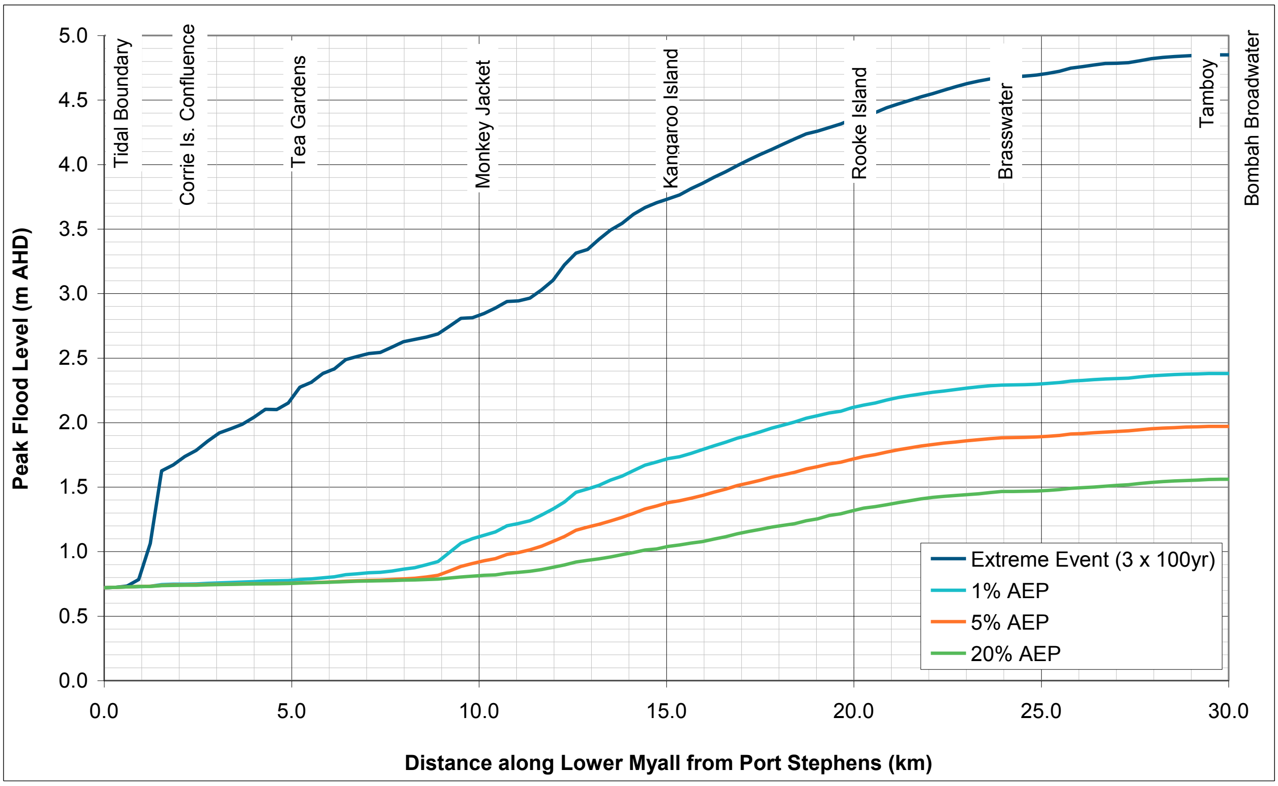

Figure 7-4 Peak Flood Water Level Profile for the Lower Myall Catchment Events

7.4 Design Flood Behaviour for Ocean Events

The design flood mapping in Appendix B presents the peak design flood condition throughout the catchment, for the 1% AEP ocean derived event. Further discussion on the general nature of ocean derived flooding within the Lower Myall system is provided below.

7.4.1 Lake and Channel Water Levels

Figure 7-5 shows examples of the relative response of water levels along the Lower Myall for the 1% AEP design ocean event. Peak high-tide water levels at Tea Gardens and even Monkey Jacket appear to only be 5 – 10 cm below the Port Stephens peak water level indicating efficient tidal penetration in the lower reaches of the Lower Myall River. Further upstream at Rooke Island and Brasswater the penetration of the peak tide is significantly reduced due to the availability of significant overbank floodplain storage. The influence of floodplain storage along the Lower Myall and the large waterway area of the Lakes system results in a negligible water level response at Bombah Broadwater due to the 1% AEP ocean event.

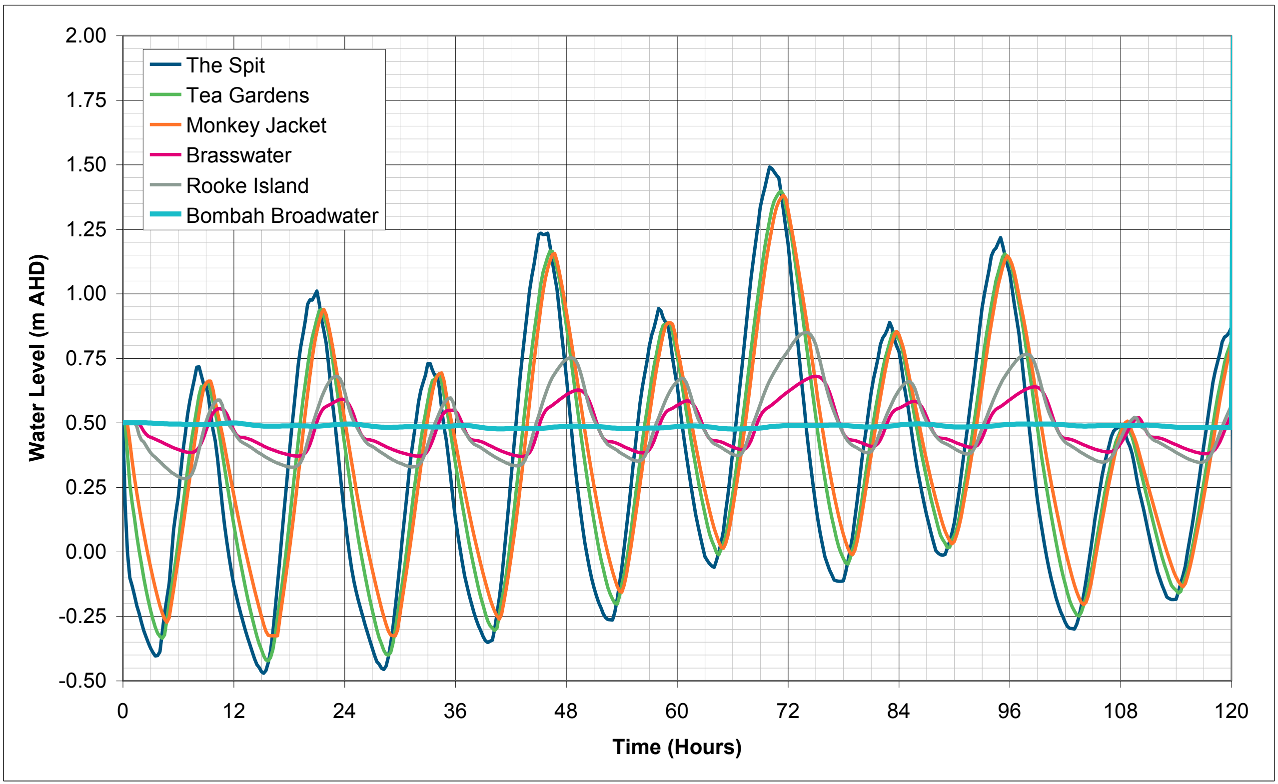

Figure 7-5 Predicted Water Levels 1% AEP Ocean Event

7.4.2 Peak Water Level Profile

Typical peak flood level profiles along the Lower Myall are shown in Figure 7-6. The long-section data indicates a reduction in peak tide level of 5-10 cm along both the Eastern and Northern Channels with lower hydraulic gradients through Tea Gardens. More significant hydraulic gradients exist from just downstream of Monkey Jacket to Tamboy. The drop in peak flood levels between Monkey Jacket and Tamboy occurs as water flows from the channel out on to the floodplain. The bank heights of the

Lower Myall are typically 0.7 – 0.9 m AHD and floodplain widths range from 500 – 1000 m resulting in significant floodplain storage. The low bank heights and high volumes of floodplain storage mean that upstream of Kangaroo Island ocean derived flood levels are unlikely to exceed 1.3 m AHD and catchment derived flood events will produce more significant flooding than ocean events.

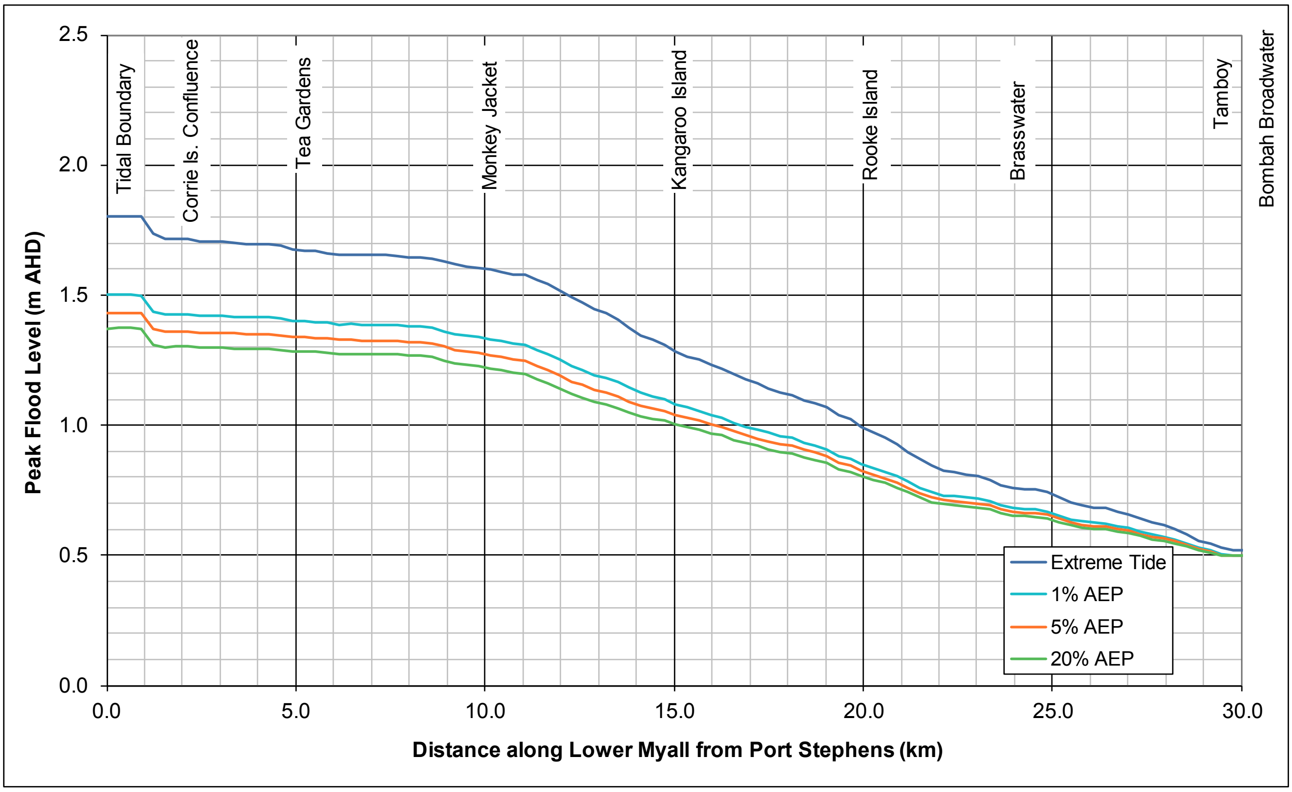

Figure 7-6 Peak Flood Water Level Profile for the Lower Myall Ocean Events

7.5 Design Flood Behaviour Coincident Catchment and Ocean Derived Flood Events

The flood behaviour of a coincident catchment and ocean flood event, as expected is a combination of the separate events (as previously reported) with the addition of a region of overlapping influence, where the result of a coincident event is worse than the individual sum of the component events. This region of combined influence is generally restricted to the 10 km reach between Tea Gardens and Kangaroo Island, with the greatest area of impact being centred a few kilometres upstream of Monkey Jacket (see Figure 7-9). Due to the rare nature of the coincident 1% AEP catchment and ocean event no flood mapping has been undertaken, however, a description of flooding and peak water levels is provided below.

The relative response of water levels in the Lower Myall system to the two coincident catchment and ocean derived flood scenarios is presented in Figure 7-7 (no lag) and Figure 7-8 (90 hour lag). The two figures highlight the difference in the timing of peak tides and lake water levels between the no lag and 90 hour lag scenarios. A long section of peak flood water levels for the two coincident scenarios as well as the individual 1% AEP catchment and ocean derived flood events is presented in Figure 7-9.

In the no lag scenario, when the peak tidal level occurs, there is a negative water level gradient (i.e. downstream water levels are greater than upstream water levels) at Tea Gardens, whereas in the 90 hour lag scenario there is a positive water level gradient, with upstream levels being higher then downstream levels. For the no lag coincident event, peak lake levels are 2 cm higher than the catchment only event, which is due to the tidal inundation reducing available floodplain storage. For the coincident event, 90 hour lag scenario, there is no increase in peak lake level, however, tide locking reduces floodplain discharge resulting in a positive water level gradient for the peak flood level along the Lower Myall which could be up to 0.3 m greater than either the peak catchment or ocean 1% AEP flood level. However, it is important to note that the occurrence of a simultaneous 1% AEP catchment and 1% AEP ocean event is significantly rarer than the 1% AEP event.

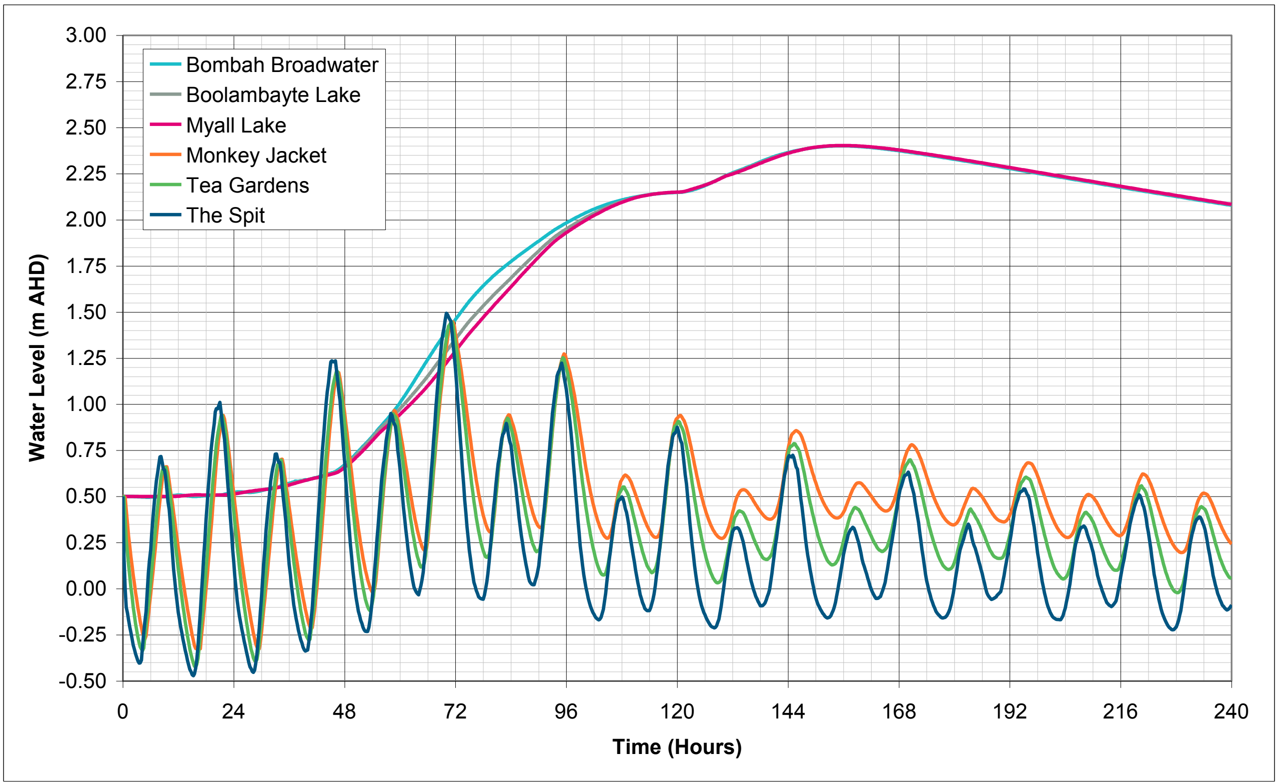

Figure 7-7 Predicted Water Levels Coincident 1% AEP Catchment and Ocean Event – no lag

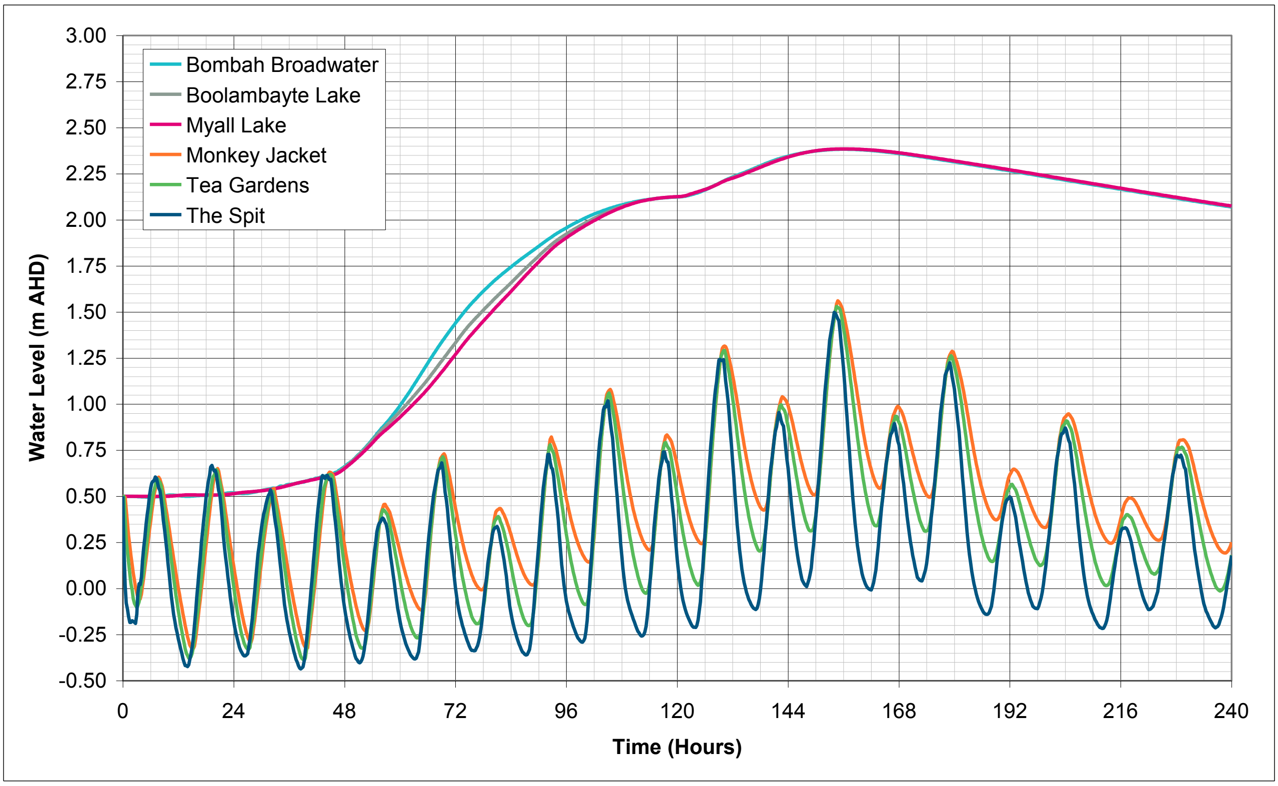

Figure 7-8 Predicted Water Levels Coincident 1% AEP Catchment and Ocean Event – 90 hour lag

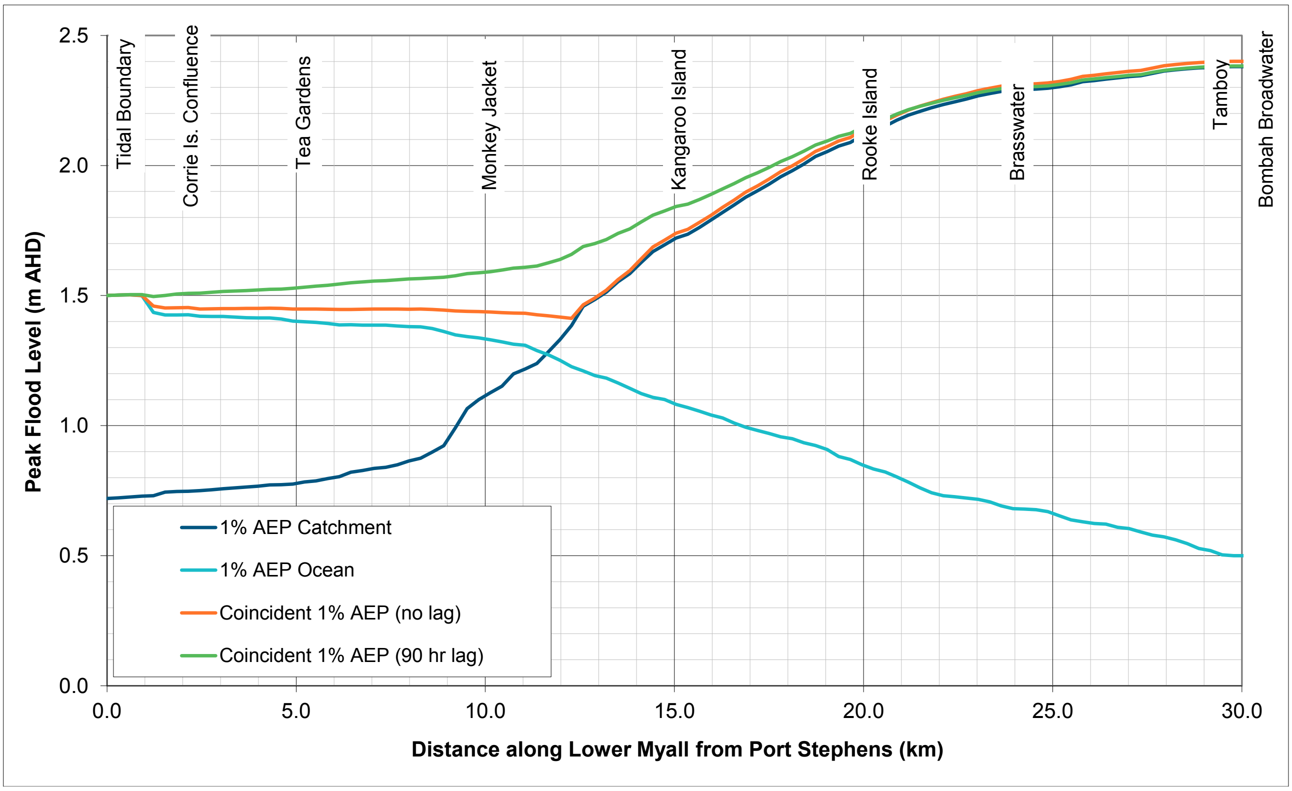

Figure 7-9 Peak Flood Water Level Profile for the Lower Myall Coincident 1% AEP Events

7.6 Design Flood Profiles: Peak Combined Flood Levels

Peak flood levels for the catchment and ocean events have been combined to produce a single (combined) peak flood level. This single combined (envelope) flood level is presented for each design event in Table 7-4 and Figure 7-10. Maps of combined peak flood depth and velocity for each of the design events are presented in Appendix B.

Table 7-4 Peak Flood Levels (m AHD) for Combined Catchment & Ocean Design Events

Design Event Frequency (AEP)	Myall Lake	Bombah Broadwater	Brasswater	Monkey Jacket	Tea Gardens	Corrie Island	Tidal Boundary
50%	1.22	1.22	1.13	1.20	1.25	1.26	1.33
20%	1.56	1.56	1.47	1.24	1.28	1.30	1.37
10%	1.78	1.77	1.68	1.26	1.31	1.33	1.40
5%	1.97	1.97	1.88	1.29	1.34	1.36	1.43
2%	2.21	2.21	2.12	1.32	1.37	1.40	1.47
1%	2.38	2.38	2.29	1.35	1.40	1.42	1.50
0.5%	2.54	2.54	2.45	1.38	1.42	1.45	1.53
Extreme Event	4.86	4.85	4.68	2.76	2.24	1.71	1.80

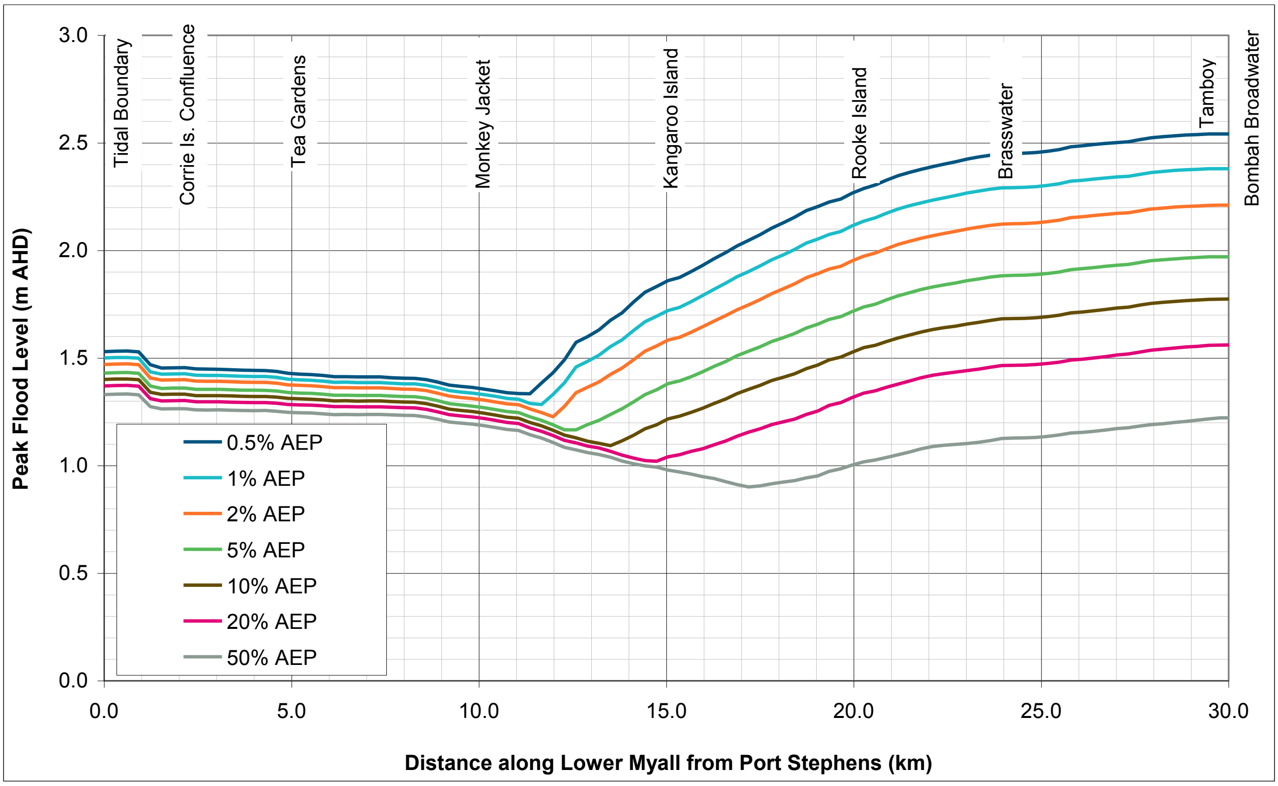

Figure 7-10 Peak Water Level Profiles for Combined Design Catchment and Ocean Floods

7.7 Comparison with Previous Studies and Historic Data

7.7.1 Comparison to MHL (1980)

A comparison of the peak flood levels from the current study with those of the previous PWD (1980) flood study indicates a substantial change for the predicted flood levels as presented in Table 7-5.

Table 7-5 Comparison to Previous Catchment Derived Flood Study

	Current			PWD (1980)	
	0.5% AEP	1% AEP	5% AEP	1% AEP	5% AEP
Optimal Duration (days)	7	7	7	7 to 10	7 to 10
Rainfall Depth (mm)	523[1]	479[1]	375[1]	605[2]	487[2]
Peak Lake Level (m AHD)	2.54	2.38	1.97	3.00	2.56
Peak Lake Outflow (m^3/s)	256	225	155	290	210

1 Note – an areal reduction factor applied of 0.95 is applied to this rainfall depth
2 Note – no areal reduction factor was used in the PWD (1980) study

The key difference between the two studies is due to the adoption of different design rainfall depths. When the PWD (1980) was undertaken, digital daily rainfall data for local rainfall gauges was only available from 1970 so site specific IFD analysis was not undertaken and Sydney IFD data was used instead. For the current study long term digital records of daily data of local gauges allowed site specific IFD data to be calculated. The differences in IFD data source between the two studies means that in the PWD (1980) study a 1%AEP design rainfall depth of 605 mm was adopted, whereas in the current study a design rainfall depth of 455 mm (after areal reduction) was adopted. The difference in design rainfall depth is the key reason why the PWD (1980) report predicted a 1% AEP peak flood level in the lakes of 3.0m AHD, whereas the current study predicts a 1% AEP flood level of 2.38m AHD.

It should also be noted that a difference in initial and continuing losses will also have an influence on the design hydrology. The PWD (1980) study adopted an initial loss of 30 mm and a continuing loss of 0 mm/hr, whereas the current study adopted an initial loss of 15 mm and a continuing loss of 0.5 mm/hr based on the model calibration.

In order to check there were no significant other differences in the models, the current model was used to simulate a 7 day event using a rainfall depth of 605 mm and continuing loss of 0 mm/hr. Using the PWD (1980) 1% AEP hydrology the current model calculated a peak lake level of 3.05 m AHD which is in close agreement to the PWD (1980) study.

It is also apparent that there is a difference in the outflow rating between PWD (1980) and the current study. The PWD (1980) study outflow rating was based on a backwater analysis of 25 1D-cross-section. These cross-sections were based on 1:25000 1 m contour data and hydro-survey with limited vertical datum control which is likely to introduce significant uncertainty into the analysis. In the current study, lake outflow is calculated based on the fully dynamic 2D hydrodynamic solution using

LiDAR data and detailed hydrosurvey which is considered to be a more accurate method than that used in the PWD (1980) study.

7.7.2 Comparison to MHL (1996)

A comparison of the peak flood levels from the current study with those of the previous MHL (1996) flood study indicates a substantial change for the predicted flood levels as presented in Table 7-6. The MHL results are most comparable to the current study's co-incident 1% AEP event with a 90hr lag. The difference in peak level at Winda Woppa is because the current study does not include an assessment of wind setup, which was included in the MHL (1996) study. The significant (0.19m) water level gradient between Port Stephens (Winda Woppa) and Tea Gardens is due to the application of lake discharge (as derived from PWD (1980)) at the model boundary, which for the MHL (1996) study was immediately upstream of Tea Gardens. By applying the lake discharge immediately upstream of Tea Gardens, the significant hydraulic gradient that exists along the Lower Myall floodplain between Tamboy and Tea Gardens was not represented by the MHL flood model. This is why the peak flood level from the MHL study is significantly higher than the current predicted 1% AEP flood level.

Table 7-6 Comparison to Previous Ocean Derived Flood Study

Location / Peak Level (m AHD)	Current			MHL (1996)
	1% AEP (Ocean)	1% AEP (Co-incident)	1% AEP (Co-incident 90hr lag)	1% AEP
Tea Gardens	1.42	1.45	1.52	1.79[1]
Hawks Nest	1.43	1.45	1.51	1.67[1]
Winda Woppa	1.5	1.5	1.5	1.6

Note 1: Affected by Myall River flow

7.7.3 Comparison to Observed Historic Water Levels

A comparison of observed historic peak water levels (as presented in Section 2.2.3) matches reasonable well with design flood levels presented in Table 7-1. The design 50, 20 and 10% AEP (2, 5 & 10 year ARI) levels are in reasonable agreement with the peak observed levels recorded at the Bombah Point water level gauge between July 2001 to May 2012 (see Table 2-8).

The more extreme design level for 2% AEP (~50 year ARI) is in good agreement with the 1963 peak flood level of 2.21 m AHD. A comparison of the design flood levels to the 1927 and 1890's historic flood levels reported in PWD (1980) indicate that the accuracy of datum's used to record these flood levels is likely to be questionable. Flood frequency analysis of the observed rainfall for the 1927 event indicates that the observed event depth of 713 mm for Bulahdelah PO is representative of an event rarer than a 0.5% AEP (~1 in 200 year ARI) event. The lower estimate of observed flood level (2.7 m AHD) is only ~ 0.2 m above this studies 0.5% AEP (1 in 200 year ARI) design flood level. This difference could be attributed to differences in initial lake level between the design and observed 1927 event. However, the high lake level for the 1927 event may be due to a short event duration with 503 mm being recorded at the Bulahdelah PO gauge on the 16th April 1927.

The reported peak flood level of 3.7 m AHD for the 1890's event is above the estimated 1 in 10000 year ARI event. An analysis of available rainfall data shows that in August 1899, four gauges recorded monthly totals ranging from 494 mm to 631 mm. This rainfall depth is lower than the 1 in 10000 year ARI rain depth (Table 6-4) and therefore, it is likely that the event water level should also be lower than the 1 in 10000 year ARI peak lake level, indicating a possible error in the 1890's observed flood level.

7.8 Hydraulic Classifications

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

The hydraulic categories as defined in the Floodplain Development Manual (NSW Government, 2005) are:

Floodway - Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.

Flood Storage - Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it would result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.

Flood Fringe - Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

A number of approaches were considered when attempting to define flood impact categories across the Lower Myall catchment. Approaches to define hydraulic categories that were considered for this assessment included partitioning the floodplain based on:

- Peak flood velocity;
- Peak flood depth;
- Peak velocity * depth (sometimes referred to as unit discharge);
- Cumulative volume conveyed during the flood event; and
- Combinations of the above.

The definition of flood impact categories that was considered to best fit the application within the Lower Myall catchment, was based on a combination of velocity*depth and depth parameters. The adopted hydraulic categorisation is defined in Table 7-7.

Preliminary hydraulic category mapping for the 5% AEP and 1% AEP design events is included in Appendix B. It is also noted that mapping associated with the flood hydraulic categories may be amended in the future (e.g. a change from floodway to flood storage), at a local or property scale, subject to appropriate analysis that demonstrates no additional impacts to upstream, downstream or adjacent properties. From the definitions provided in the Floodplain Development Manual, it should be noted that filling would generally only be permissible in flood fringe areas. Filling would generally not be permitted in Floodways or Flood Storage Areas.

Table 7-7 Hydraulic Categories

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

7.9 Provisional Hazard Categories

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

High hazard – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and

Low hazard – should it be necessary, trucks could evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

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

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

Figures L1 and L2 in the Floodplain Development Manual (NSW Government, 2005) are used to determine provisional hazard categorisations within flood liable land. These figures are reproduced in Figure 7-11.

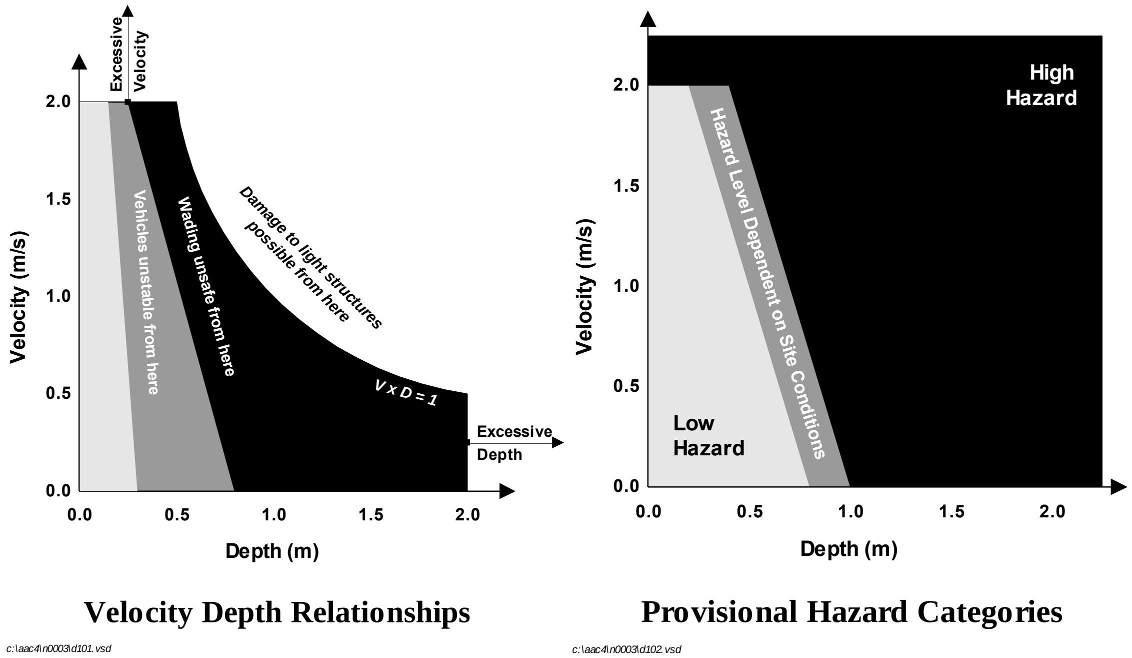

Figure 7-11 Provisional Flood Hazard Categorisation

The provisional hydraulic hazard is included in the mapping series provided in Appendix B for the 20% AEP, 5% AEP, 1% AEP and PMF events.

7.10 Flood ERP Classifications of Communities

Delineation of floodplain communities into Flood Emergency Response Planning (FERP) categories has been undertaken based on the guidelines provided in DECC (2007). The floodplain risk management (FRM) guideline was developed in conjunction with the State Emergency Service (SES) to provide a basis for the flood emergency response categorisation of floodplain communities (both existing and future). Classification provides an indication of the relative vulnerability of the community in flood emergency response and when used with FRM guideline SES information requirements from the FRM process, it identifies the type and scale of information needed by the SES to assist with emergency response planning (ERP).

Separate emergency response planning has been considered for catchment and ocean derived flood events. The influence of sea level rise on ERP has also been considered. A description of proposed ERP and community classification is provided below with associated mapping provided in Appendix B).

7.10.1 Catchment Derived Flooding ERP

Catchment derived flooding will produce lake levels of: 2.0, 2.4 and 4.9 m AHD for the 5% AEP, 1% AEP and Extreme Event (~PMF) design events. These lake levels may result in the flooding of a number of camp sites surrounding the lakes and also the community of Bombah Point and Nerong. Due to the nature of the topography surrounding the lakes these areas are considered: “Areas able to be Evacuated, Rising Road Access Area” for the 5% and 1% AEP events. In the PMF event it is possible that the Lakes Road is flooded, creating a “High Flood Island” for the Bombah Point community.

The 5% AEP and 1% AEP catchment floods do not cause flooding downstream of Monkey Jacket (see Figure ERP_Rain). However, in the Extreme Event (~PMF) design catchment event, flood levels up to 2.4 m AHD will flood low lying land in Tea Gardens and Hawks Nest. Due to the large storage volume in the Lakes flooding of the Lakes and Lower Myall could last for several days.

In the design PMF catchment event the Tea Gardens peninsula would be classified as a “Low Lying Flood Island” requiring evacuation to prevent the potential loss of life due to the occurrence of high risk (i.e. deep, high velocity), flood conditions. Evacuation of the Tea Gardens peninsula should be considered if lake levels are above 3 m AHD and continued rainfall is predicted.

In the design PMF catchment event the Hawks Nest is classified as a “Rising Road Access Area” due to the ability to evacuate to the higher ground to the east of the River, while Winda Woppa is classified as a “High Flood Island” as access along Tuloa Av may be lost.

7.10.2 Ocean Derived Flooding ERP

Ocean derived flooding will produce peak water levels at Tea Gardens of: 1.35, 1.4 and 1.7 m AHD for the 5% AEP, 1% AEP and Extreme Event (~PMF) design events. These peak storm tide levels will cause minor flooding (up to a depth of ~0.5 m) of a number of streets and blocks surrounded by Charles St., Maxwell St., Witt St., Myall St., and Marine Drive (see Figure ERP_Tide). Due to the tidal nature of the flooding, inundation would occur for less than three hours either side of storm influenced a high tide.

During the PMF ocean flood event a small “High Flood Island” will be occur on the Tea Gardens Peninsula (between Odgen Street and Maxwell Street), however, all other areas are “Rising Road Access Areas” and can be evacuated to higher ground.

7.10.3 Impact of Climate Change on ERP

Climate Change will increase the frequency and severity of flooding though increases in storm (rainfall) intensity and also sea level rise (SLR).

An SLR of 0.9 m will result in the 1% AEP catchment event producing a 1.66 m AHD flood level at Tea Gardens creating a small “High Flood Island” area (see Figure ERP_SLR_Tide).

For the 1% AEP ocean event, 0.5 m of SLR will produce a peak flood level of 1.87 m AHD at Tea Gardens, while 0.9 m of SLR will produce a peak flood level of 2.29 m AHD at Tea Gardens. In both of these events a large proportion of Tea Gardens will be inundated, with evacuation of the peninsula likely to be required to reduce the potential risk to residents (see Figure ERP_SLR_Rain).

7.11 Sensitivity Tests

A number of sensitivity tests have been undertaken on the modelled flood behaviour along the Lower Myall. In defining sensitivity tests, consideration is given to the most appropriate tests taking into account catchment properties and simulated design flood behaviour. The tests undertaken have included:

- hydrological initial and continuing loss parameters;
- rainfall intensity / depth;
- initial water level;
- downstream boundary condition;
- eastern channel closure;
- hydraulic roughness;
- floodplain LiDAR accuracy;

The rationalisation for each of these sensitivity tests along with adopted model configuration/parameters and results are summarised in the following sections. The impact of the sensitivity tests on the standard design 1% AEP flood condition (7-day duration) is presented in Table 7-8.

Table 7-8 Peak 1% AEP Lake Flood Levels for Sensitivity Tests

Parameter	Value	Peak Tuflow Lake Level (mAHD)	Difference to Adopted 1% AEP Event
Initial Losses (CL=0.5mm/hr)	**(mm)**		
	0	2.409	0.028
	15*	2.381	0
	30	2.346	-0.035
Continuing Losses (IL=15mm)	**(mm/hr)**		
	0	2.576	0.195
	0.5*	2.381	0
	1	2.202	-0.179
	2.5	1.738	-0.643
Initial Lake Levels (m AHD)			
	0	2.15	-0.231
	0.5*	2.381	0
	1	2.608	0.227
Increased Rain Depth/Intensity	**(% increase)**		
	0*	2.381	0
	10	2.554	0.173
	20	2.72	0.339
	30	2.877	0.496
Floodplain elevation (i.e. LiDAR Accuracy)	**(m)**		
	-0.25	2.32	-0.061
	0*	2.381	0
	0.25	2.44	0.059
Mannings Sensitivity (Hydraulic Roughness)	**(% change)**		
	-0.25	2.316	-0.065
	0*	2.381	0
	0.25	2.432	0.051
Downstream Boundary Condition			
	fixed 0mAHD	2.37	-0.011
	normal	2.381	0
	100yr Tide	2.401	0.02
	Block Eastern Channel	2.381	0

* indicates adopted value for design runs

7.11.1 Initial Rainfall Loss

Sensitivity tests on the initial loss value were undertaken by running an additional two scenario's, one with 0 mm and the other with 30 mm initial loss in addition to the design run which adopted a typical

15 mm initial rainfall loss value. The results as presented in Table 7-8 indicate that the predicted design 1% AEP flood level is relatively insensitive to the selection of initial rainfall losses with results varying by less than 6 cm across the range of typical values.

7.11.2 Continuing Rainfall Loss

Sensitivity tests on the continuing loss parameter were undertaken by running an additional three scenario's, with 0, 1.0 and 2.5 mm/hr losses being compared to the adopted 0.5 mm/hr for the design simulations. The tests show that peak lake levels are quite sensitive to the selected continuing loss value. This sensitivity is due to the long duration of the critical event (168 hours (7 days)), which means that even small differences in the selection of continuing loss can result in large changes to the total effective rainfall depth.

The results as presented in Table 7-8 indicate that the predicted design 1% AEP flood level is very sensitive to the selection of continuing loss rate. If a typical (as recommended in AR&R87) value of 2.5 mm/hr was selected, the 1% AEP design peak lake level would be 0.64 m lower than the adopted design event which uses a 0.5 mm/hr continuing loss which was based on model calibration as presented in Section 5. If a conservative value continuing loss of 0 mm/hr was adopted (as per PWD (1980), the peak lake level for the 1% AEP event could be nearly 0.2 m higher than the adopted design level.

7.11.3 Initial Lake Level

Sensitivity tests on the influence of initial lake level were undertaken by running an additional two scenario's, one with the initial lake level at 0 m AHD and the other at 1.0 m AHD. This represents sensitivity tests of +/- 0.5m about the adopted design initial lake level of 0.5 m AHD. The results, as presented in Table 7-8, indicate that the peak lake levels are sensitive to the initial lake level, though moderate lake outflow and a relatively long event duration (7 days) mean that resultant change in peak lake level is less than half the magnitude of change in initial water level (i.e. the +/- 0.5 m change to initial lake level generated only a +/- 0.23 m change in peak flood level). A discussion of the adoption of the 0.5 m AHD initial water level is presented in Section 6.3.

7.11.4 Increased Rain Intensity

Sensitivity tests on the adopted 1% AEP rainfall intensity (or event total rainfall depth) where undertaken to help understand the potential changes to design peak flood levels that may occur as a result to changes to design rainfall depth resulting from updates to methods used to estimate design rainfall depths (including new IFD data associated with the forthcoming release of updates to AR&R) or potential changes due to climate change (see Section 8.1.2 & 8.2).

An additional three simulations investigating increases in rainfall intensity (or rainfall depth) of 10% , 20% and 30% result in predicted increases to peak lake flood levels of 0.17, 0.34 and 0.5 m respectively (see Table 7-8).

7.11.5 Floodplain elevation (LiDAR accuracy)

Sensitivity tests investigating the influence of LiDAR accuracy to adequately define floodplain elevations were undertaken. Two additional runs in which floodplain depths along the Lower Myall were raised or lowered by 0.25 m (the usual accuracy associated with LiDAR data) were used to simulate the 1% AEP catchment event. The results as presented in Table 7-8 indicate that the peak lake levels are relatively insensitive to minor changes in floodplain elevation with a +/- 0.25 m change in floodplain elevation only resulting in a +/- 6 cm change in predicted peak lake level.

7.11.6 Hydraulic Roughness

Sensitivity tests on the hydraulic roughness (Manning's 'n') were undertaken by applying a 25% decrease and a 25% increase in the adopted values for the baseline design conditions. While a calibration process has been undertaken with respect to available data, and adopted design parameters are within typical ranges, the inherent variability/uncertainty in hydraulic roughness warrants consideration of the relative impact on adopted design flood conditions.

The sensitivity tests have been undertaken for the 1% AEP catchment rainfall event. The results of the sensitivity tests on hydraulic roughness for the 1% AEP design event are summarised in Table 7-8 and show that a 25% reduction in hydraulic roughness reduces the predicted peak lake level by 6.5 cm whereas a 25% increase in hydraulic roughness increases the predicted peak lake level by 5.1 cm. This indicates that the model is relatively insensitive to the adopted hydraulic roughness which further highlights the importance of flood storage in the Lower Myall system.

7.11.7 Downstream Boundary Condition

Three additional scenario runs were undertaken to examine the sensitivity of model predictions to changes in the adopted downstream boundary condition. The three tests included running the 1% AEP catchment model with:

- a fixed 0 m AHD downstream water level;
- a 1% AEP (1.5m AHD peak level) tidal condition; and
- the Eastern Channel (Paddy Marr Inlet) completely blocked such that flood discharge can only occur through the Northern Channel (Corrie Island Channel).

The results of the sensitivity tests on downstream boundary condition for the 1% AEP design catchment event are summarised in Table 7-8 and show that peak lake levels are not sensitive to changes in the design downstream boundary condition. The results show that there is less than +/- 2 cm in predicted 1% AEP peak lake level if the model is run in conjunction with a 1% AEP ocean event or a fixed 0 m AHD tide level. This suggests that the selection of a design tide condition will not influence the peak lake level.

The sensitivity results also show that dredging of the Eastern Channel will not have significant influence on catchment derived flood behaviour along the Lower Myall, with an extreme case of the Eastern Channel being completely blocked having no influence on peak lake flood levels.

7.11.8 Fluvial Influence on Tidal Flooding

In addition to the four co-incident ocean and catchment events (see Section 7.1.4), two additional scenario runs were undertaken to examine the sensitivity of fluvial conditions on tidal flooding. The two additional tests included running the 1% AEP catchment model with:

- an initial lake water level of 1.0 m AHD and
- an initial lake water level of 1.4 m AHD.

A compilation of results showing the sensitivity of predicted tidal flooding to different fluvial conditions is presented in in Table 7-9. The results show that unless deliberate lagging of the peak tide to match peak fluvial discharge there is less than 5 cm difference in peak tidal levels at Tea Gardens for the 1% ocean design event.

Table 7-9 Sensitivity of Tidal Flooding to Fluvial Conditions

Design Event Frequency (AEP)	Tidal Boundary	Corrie Island	Tea Gardens	Monkey Jacket	Brasswater	Bombah Broadwater	Myall Lake
1% AEP Catchment and 1% AEP Ocean (no lag)	1.50	1.45	1.45	1.44	2.31	2.40	2.40
1% AEP Catchment and 1% AEP Ocean (90 hour lag)	1.50	1.51	1.53	1.58	2.30	2.38	2.38
5% AEP Catchment and 1% AEP Ocean (no lag)	1.50	1.44	1.43	1.41	1.91	2.00	2.00
1% AEP Ocean 1mAHD IWL	1.50	1.43	1.41	1.37	1.00	1.00	1.00
1% AEP Ocean 1.4mAHD IWL	1.50	1.44	1.43	1.41	1.40	1.40	1.40
1% AEP (Separate Combined Maximums, 0.5mAHD IWL)*	1.50	1.42	1.40	1.35	2.29	2.38	2.38

* adopted for design run

8 CLIMATE CHANGE ANALYSIS

The NSW Government has incorporated consideration of potential climate change impacts into relevant planning guidelines. The NSW Sea Level Rise Policy Statement (DECCW, 2009a) was prepared to support consistent adaptation to projected sea level rise impacts. The Policy Statement includes sea level rise planning benchmarks for use in assessing potential impacts of sea level rise in coastal areas, including in flood risk and coastal hazard assessments. The benchmarks are a projected rise in sea level, relative to the 1990 mean sea level, of 0.4 metres by 2050 and 0.9 metres by 2100.

While the Policy Statement defining the benchmarks was repealed by the NSW Government on 8 September 2012, the science behind the Policy was deemed as adequate by the NSW Chief Scientist. The benchmarks are considered the best available information at the time of preparation of this report. Great Lakes Council has adopted their own set of sea level rise benchmarks (which are based on DECCW, 2009a) which include a projected rise in sea level, relative to the 1990 mean sea level, of 0.5 metres by 2060 and 0.9 metres by 2100.

Worsening coastal flooding impacts as a consequence of sea level rise in lowland areas such as around the Lower Myall are of particular concern for the future. Regional climate change studies (e.g. CSIRO, 2004) indicate that aside from sea level rise, there will also be an increase in the maximum intensity of extreme rainfall events. This is likely to include increased frequency, duration and magnitude of flooding and consequently increased number of emergency evacuations and associated property and infrastructure damage.

The NSW Floodplain Development Manual (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).

Key elements of future climate change (sea level rise, rainfall intensity) have been incorporated into the assessment of future flooding conditions in the Lower Myall catchment for consideration in the ongoing floodplain risk management.

8.1 Potential Climate Change Impacts

The impacts of future climate change are likely to lead to a wide range of environmental responses in the Lower Myall. These are likely to manifest throughout the physical, chemical and ecological processes that drive local estuarine ecosystems.

The following changes in the physical characteristics of the Lower Myall system have potential influence on the flood behaviour of the system and implications for medium and long term floodplain management:

- Increase in initial Lagoon water level – linked to changes in ocean water levels;
- Increase in ocean boundary water level – sea level projections provide for a direct increase in tidal and storm surge water level conditions; and
- Increase in rainfall intensity – the frequency and severity of extreme rainfall events is expected to increase.

The model configuration and assumptions adopted for each of these potential climate change impacts are discussed in the following sections.

8.1.1 Adopted Sea Level Rise Benchmarks

GLC has adopted a sea level rise benchmark with projected increases in mean sea level of 0.5m and 0.9m, by the years 2060 and 2100 respectively. Based on this benchmark the design ocean boundaries have been raised by 0.5m and 0.9m to assess the potential impact of sea level rise on flood behaviour in the Lower Myall catchment.

8.1.2 Design Rainfall Intensity

Current research predicts that a likely outcome of future climatic change will be an increase in flood producing rainfall intensities. Climate Change in New South Wales (CSIRO, 2007) provides projected increases in 2.5% AEP 24h duration rainfall depths for Sydney Metropolitan catchments of up to 12% and 10%, for the years 2030 and 2070 respectively.

The NSW Government has also released a guideline (DECC, 2007) for Practical Consideration of Climate Change in the floodplain management process that advocates consideration of increased design rainfall intensities of up to 30%. In line with this guidance note, additional tests incorporating 10%, 20% and 30% increases in design rainfall have been undertaken.

8.2 Catchment Events with Increased Rainfall Intensity

To determine possible changes to flood risk that may occur due to potential increases in rainfall intensity associated with climate change, three additional model runs have been simulated. The runs examine a: 10, 20 and 30% increase in rainfall intensity (depth) for the 1% AEP catchment event.

A summary of the peak flood levels is presented in Table 8-1 while a long-section of the three climate change and the base case 1% AEP peak flood levels is presented in Figure 8-1. The results show that a 30% increase in rainfall intensity could increase lake flood levels by 0.5 m above the current base case 1% AEP design flood level of 2.38 m AHD. However, the hydraulic gradient along the

Lower Myall means that an increase rainfall intensity of 30% would only result in a 0.24 m increase in predicted 1% AEP flood level at Monkey Jacket.

Table 8-1 Modelled Peak Flood Levels (m AHD) for Catchment Derived Climate Change (Intensity) Events

Catchment Event	Myall Lake	Bombah Broadwater	Brasswater	Monkey Jacket	Tea Gardens	Corrie Island	Tidal Boundary
1% AEP (base case)	2.38	2.38	2.29	1.01	0.78	0.75	0.72
1% AEP, +10% intensity	2.56	2.55	2.46	1.09	0.80	0.75	0.72
1% AEP, +20% intensity	2.72	2.72	2.62	1.17	0.83	0.76	0.72
1% AEP, +30% intensity	2.88	2.88	2.77	1.25	0.86	0.78	0.72

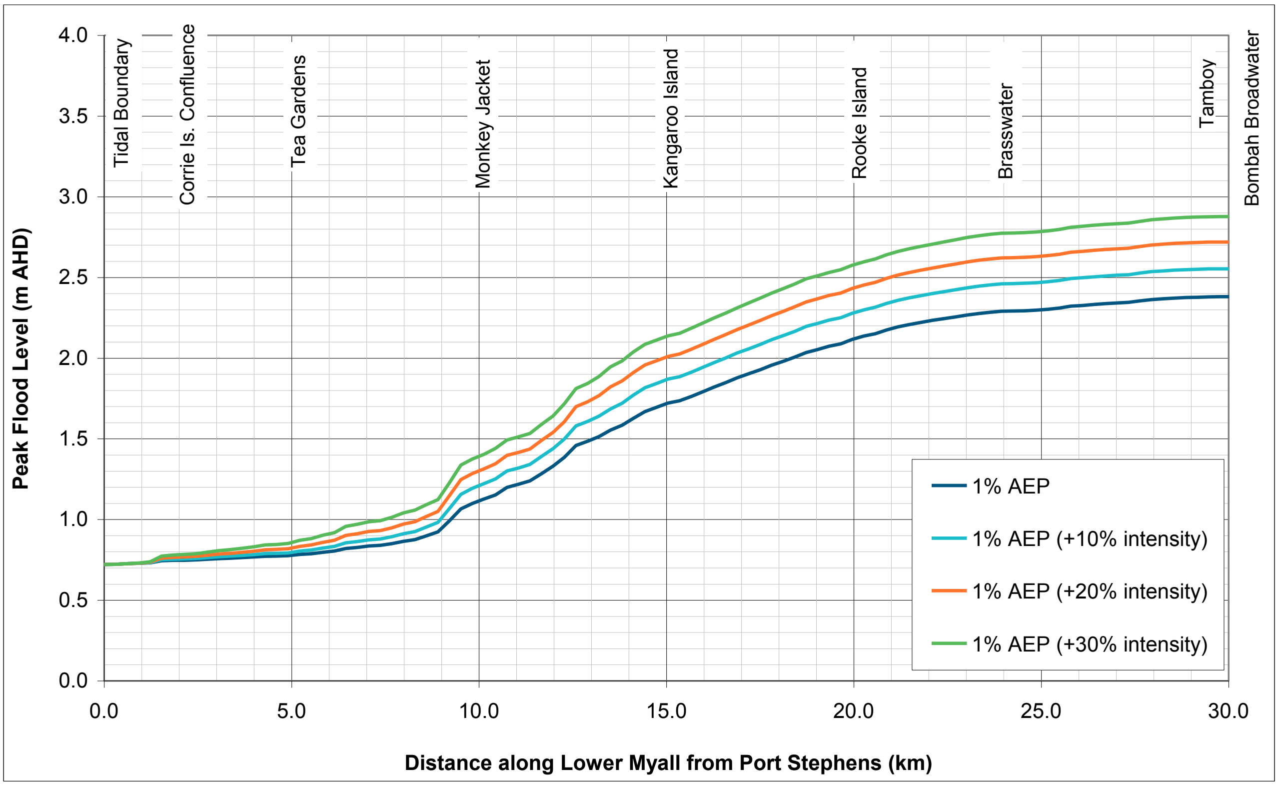

Figure 8-1 Peak Flood Level Profiles for the Lower Myall Climate Change (Intensity) Events

8.3 Catchment Events with Sea Level Rise and Increased Rainfall Intensity

Four additional model runs have been simulated, to determine possible changes to catchment derived flood risk that may occur due to potential increases in mean sea level (MSL) and rainfall intensity that have been associated with climate change. These four runs include:

- 1% AEP catchment design event combined with 0.5 m SLR (expected to occur by 2060);
- 1% AEP catchment design event combined with 0.9 m SLR (expected to occur by 2100);
- 1% AEP catchment design event combined with 0.5 m SLR and a 10% increase in rainfall intensity; and
- 1% AEP catchment design event combined with 0.9 m SLR and a 30% increase in rainfall intensity.

The influences of SLR were incorporated in the model scenarios by increasing the initial water level and MSL position of the downstream boundary by the required amount of SLR (i.e. 0.5 & 0.9m).

A summary of predicted peak flood levels along the Lower Myall for the base case 1% AEP design catchment event and four climate change scenarios is presented in Table 8-2 while a long-section of peak flood levels is presented in Figure 8-2. An increase in MSL of 0.5 m and 0.9 m will increase peak 1% AEP flood levels in the Myall Lakes by 0.25 m and 0.44 m respectively. While an increase in MSL of 0.5 m, combined with a 10% increase in rainfall intensity could increase peak 1% AEP lake levels by 0.41 m. An increase in MSL of 0.9 m, combined with a 30% increase in rainfall intensity, could increase peak 1% AEP lake levels by 0.87 m.

Table 8-2 Modelled Peak Flood Levels (m AHD) for Catchment Derived Climate Change Events

Catchment Event	Myall Lake	Bombah Broadwater	Brasswater	Monkey Jacket	Tea Gardens	Corrie Island	Tidal Boundary
1% AEP, 0 m SLR	2.38	2.38	2.29	1.01	0.78	0.75	0.72
1% AEP, 0.5 m SLR	2.63	2.63	2.54	1.39	1.27	1.24	1.22
1% AEP, 0.9 m SLR	2.82	2.82	2.73	1.74	1.66	1.64	1.62
1% AEP, 0.5 m SLR & 10% increase in rainfall intensity	2.79	2.79	2.69	1.44	1.28	1.25	1.22
1% AEP, 0.9 m SLR & 30% increase in rainfall intensity	3.25	3.25	3.13	1.86	1.71	1.65	1.62

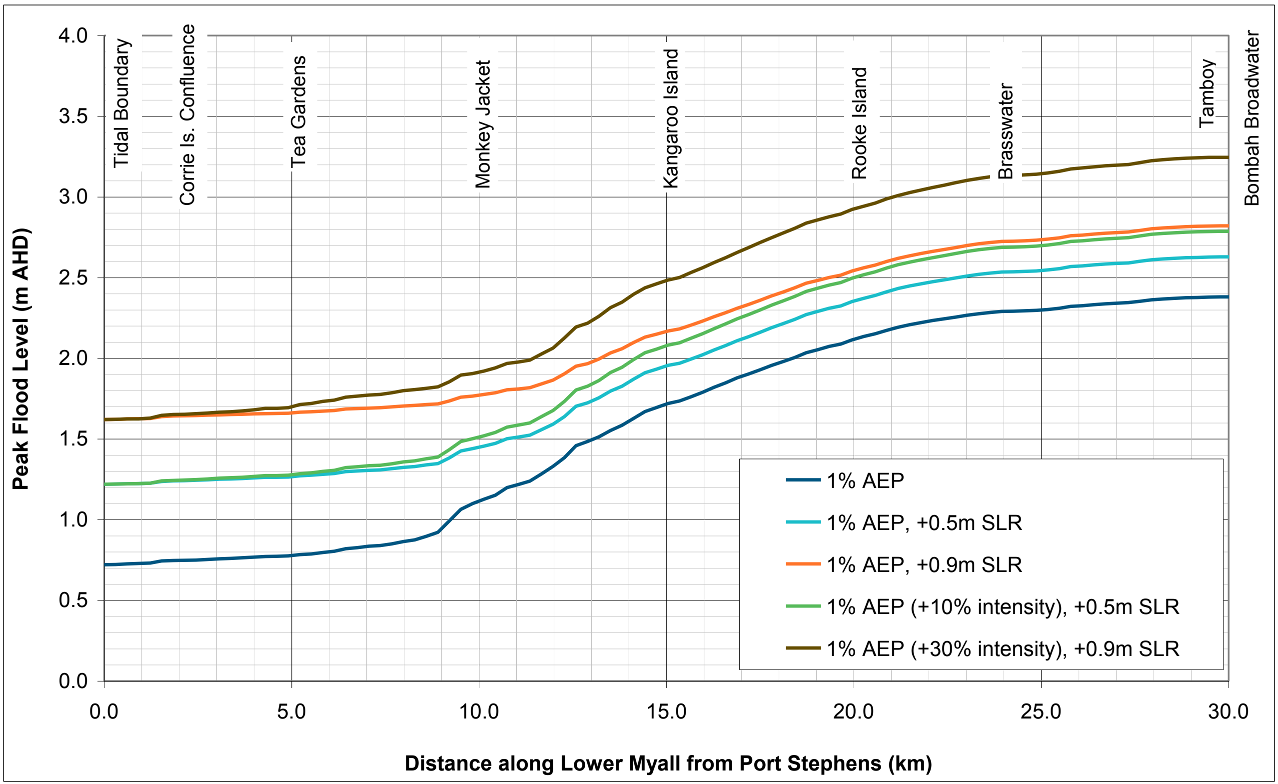

Figure 8-2 Peak Flood Level Profiles for the Lower Myall Catchment Climate Change Events

8.4 Ocean Events with Sea Level Rise

Two additional model runs have been simulated to determine possible changes to ocean derived flood risk that may occur due to potential increases in mean sea level (MSL). These runs include:

- 1% AEP ocean design event combined with 0.5 m SLR (expected to occur by 2060);
- 1% AEP ocean design event combined with 0.9 m SLR (expected to occur by 2100);

The influences of SLR were included in the model scenarios by increasing the initial water level and MSL position of the downstream boundary by the required amount of SLR (i.e. 0.5 & 0.9m).

A summary of predicted peak flood levels along the Lower Myall for the base case 1% AEP design ocean event and two climate change scenarios is presented in Table 8-3 while a long-section of peak flood levels is presented in Figure 8-3. An increase in MSL of 0.5 m and 0.9 m will increase peak 1% AEP ocean flood levels in the Myall Lakes by 0.5 m and 0.9 m respectively.

Table 8-3 Modelled Peak Flood Levels (m AHD) for Ocean Derived Climate Change Events

Ocean Event	Tidal Boundary	Corrie Island	Tea Gardens	Monkey Jacket	Brasswater	Bombah Broadwater	Myall Lake
1% AEP, 0 m SLR	1.50	1.42	1.40	1.35	0.68	0.50	0.50
1% AEP, 0.5 m SLR	2.00	1.91	1.87	1.83	1.13	1.00	1.00
1% AEP, 0.9 m SLR	2.40	2.33	2.29	2.25	1.54	1.40	1.40

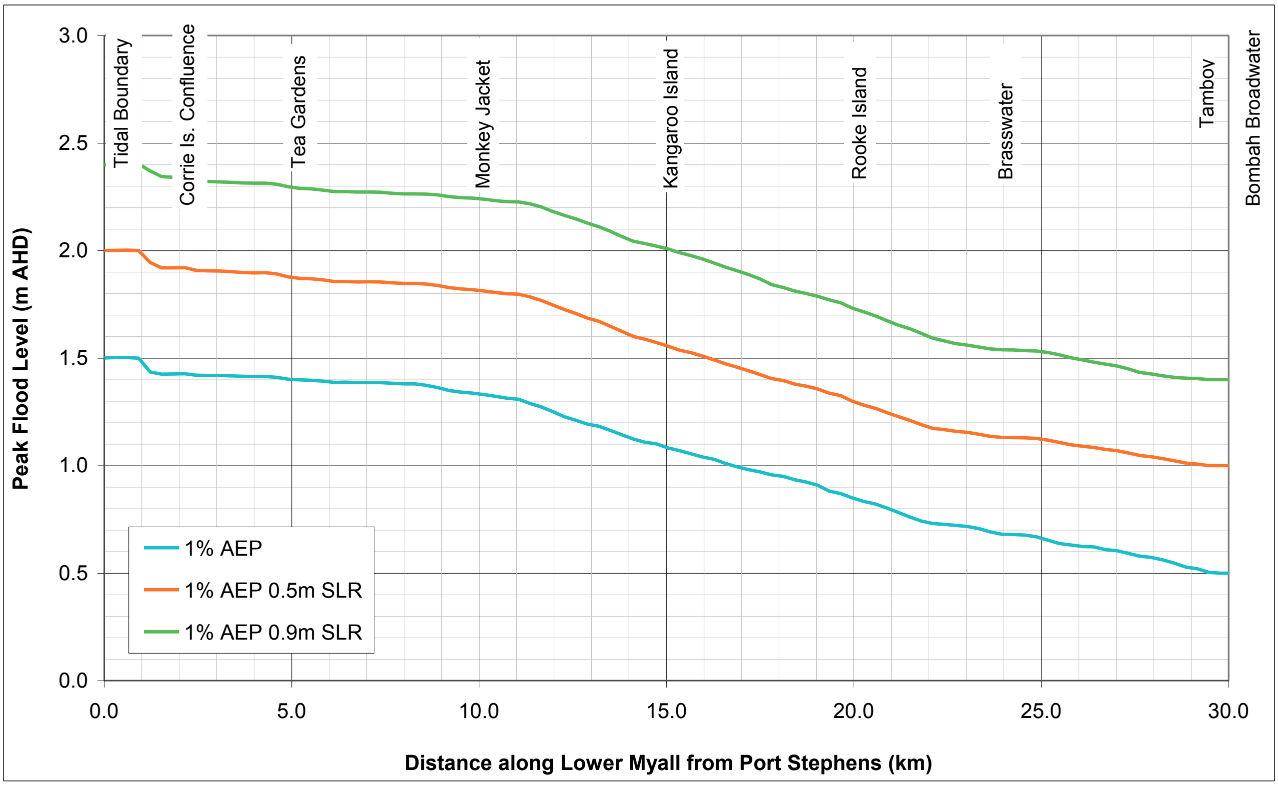

Figure 8-3 Peak Flood Level Profiles for the Lower Myall Ocean Climate Change Events

8.5 Flood Profiles: Peak Combined Flood Levels with Sea Level Rise

Peak flood levels for the catchment and ocean events with sea level rise (SLR) have been combined to produce a single (combined) peak flood level. This single combined flood level is presented for the 1% design event in Table 8-4 and Figure 8-4. A map of combined peak flood depth and flood extent for the 1% AEP design event with SLR and maps showing hydraulic hazard (as defined in Section 7.9) for the 1% AEP with 0.5 m SLR and 1% AEP with 0.9 m SLR are presented in Appendix B.

Table 8-4 Modelled Peak Flood Levels (m AHD) for Combined 1% AEP, SLR Events

Ocean Event	Tidal Boundary	Corrie Island	Tea Gardens	Monkey Jacket	Brasswater	Bombah Broadwater	Myall Lake
1% AEP, 0 m SLR	1.50	1.42	1.40	1.35	2.29	2.38	2.38
1% AEP, 0.5 m SLR	2.00	1.91	1.87	1.83	2.54	2.63	2.63
1% AEP, 0.9 m SLR	2.40	2.33	2.29	2.25	2.73	2.82	2.82

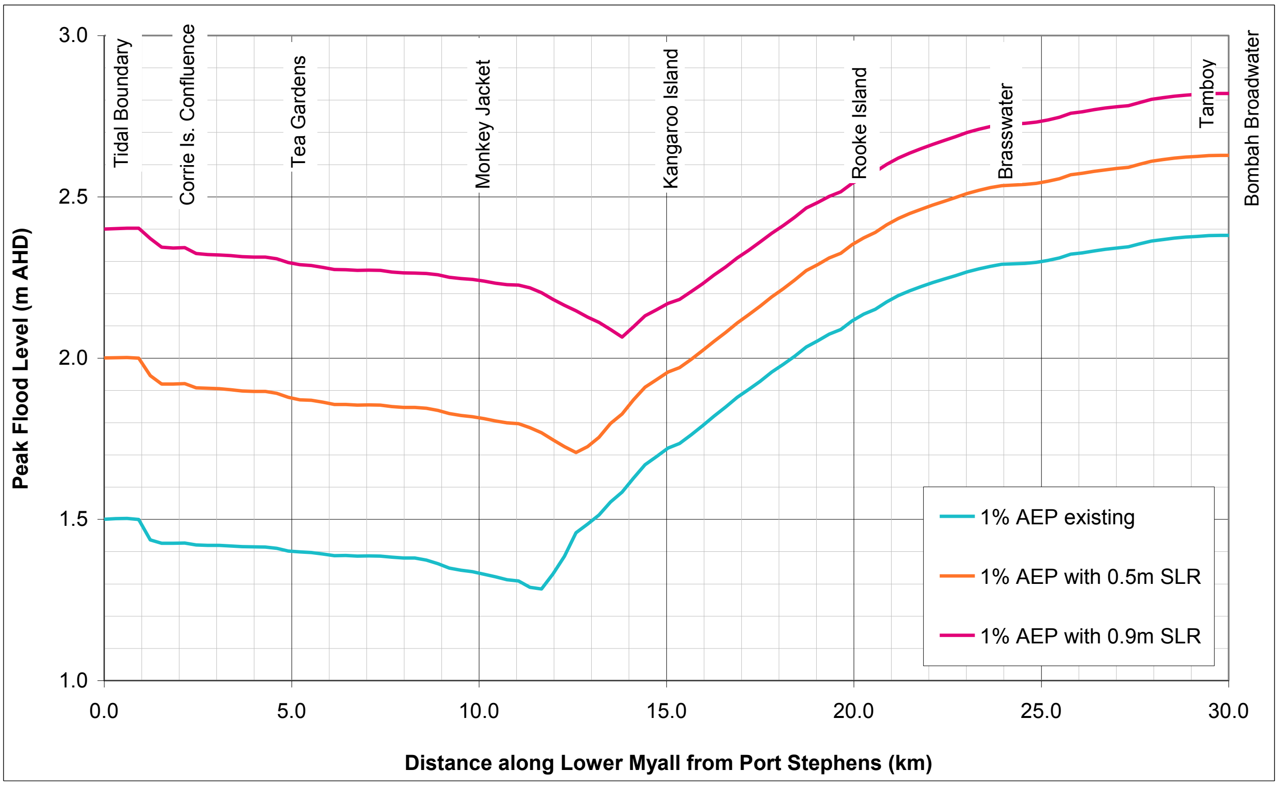

Figure 8-4 Peak Flood Level Profiles for the Lower Myall 1% AEP SLR Events

9 CONCLUSION

The objective of the Lower Myall Flood Study has been to undertake a detailed flooding assessment of the Lower Myall and establish models as necessary for accurate flood level prediction. Central to this is the development of appropriate hydrological and hydraulic models.

The study program provided for a staged approach in undertaking the Flood Study, incorporating:

- Stage 1 - Collection, Compilation and Review of Available Information;
- Stage 2 – Acquisition of Additional Data
- Stage 3 – Develop Hydrologic and Hydraulic Models;
- Stage 4 – Calibration and Verification of Models
- Stage 5 – Design Flood Assessment including Climate Change Analysis; and
- Stage 6 - Final Reporting including Flood Hazard Assessment and Mapping.

This Draft Flood Study incorporates all of the above stages and has been produced for comment by GLC and OEH prior to Public Exhibition. In completing the flood study, the following activities have been undertaken:

- Compilation and review of existing information pertinent to the study and acquisition of additional data including survey as required;
- Undertaking of a community consultation and participation program engage the community in the on-going floodplain management process;
- Development and calibration of appropriate hydrological and hydraulic models;
- Determination of design flood conditions for a range of design events including the Extreme Event (~ PMF), 0.5%, 1%, 2%, 5%, 10%, 20% and 50% AEP events for catchment derived and ocean derived flooding; and
- Assessment of the potential impact of climate change using the latest guidelines.

The key study outputs include a full suite of design flood mapping incorporating peak flood inundation extent, flood depth, flood velocity and flood hazard for the full range of return period magnitudes assessed. This report and the key mapping outputs help to define the flood behaviour in the Lower Myall and establish the basis for subsequent floodplain management activities.

Provided below is a summary of the key findings of the Flood Study, in particular some of the important considerations for future floodplain risk management in the Lower Myall:

- A hydrologic and 2D flood model has been developed to assist in the prediction of flood behaviour in the Lower Myall. A good degree of model calibration and validation to three historic events has been achieved providing confidence in model predictions.

- The key area of interest of the flood study is the Lower Myall system comprising of the Myall Lakes and Myall River downstream of Bombah Broadwater. The Myall River upstream of Bombah Broadwater has been incorporated into the model to suitably account for floodplain storage; however critical design conditions have not been calculated along this reach.

- Due to the significant volume of flood storage afforded by the Myall Lakes system, critical durations were found to be greater than the 72 hour design event. The current IFD data set provided under the current AR&R guidelines only includes events up to the 72 hour event, therefore site specific rainfall frequency analysis was required to determine appropriate critical design storm rainfall depths.

- Over 100 years of daily rainfall data at the Bulahdelah Post Office gauge was used to determine annual maximums for 3, 5, 7 and 10 day cumulative totals. These series of annual maximums were then analysed using the flood frequency analysis package *Flike* to determine rainfall depth probability statistics for the 3, 5, 7 and 10 day duration events. These four duration events were then used to simulate design flood conditions for the 1% AEP catchment event. The results show that the 7 day storm event produces the highest peak lake level and hence is deemed the critical duration for the lakes system.

- The current AR&R revision process includes the development of updated IFD data which extends design storm duration up to seven days should be released in 2013. When this updated IFD data is made available it is recommended that a comparison be made between the current site specific design data and the revised IFD product which includes the region of influence approach to provide a better estimate of design rainfall events.

- The design flood conditions documented in the report are significantly lower than those previously calculated in the PWD (1980) study. The current study calculated design rainfall depth based on site specific flood frequency analysis, whereas the PWD (1980) study was based on IFD data for Sydney. The current study also calculated lake outflow using a sophisticated 2D numerical model based on LiDAR data, whereas the PWD (1980) used a simple backwater analysis utilising low-resolution cross-section data.

- Model results show that peak flood levels upstream of Monkey Jacket are attributed to catchment derived design flood events, while below (downstream of) Monkey Jacket ocean derived flood events are more significant.

- Coincident ocean and catchment flood events cause a negligible increase in peak lake levels; however, depending on the timing of peak tides may increase peak flood levels below Kangaroo Island by up to 0.2 m.

- Results have been presented showing peak flood levels, depths, velocity, hazard and hydraulic categorisation from either a ocean or catchment source. These combined (or envelope) results show total flood risk at a given location.

- Current flood impact appears to be limited to a small area in Tea Gardens that is inundated (typically to less than 0.4 m depth) by ocean events above the 20% AEP level. The inundated area includes a number of streets and blocks surrounded by Charles St., Maxwell St., Witt St., Myall St., and Marine Drive.

- Sensitivity testing has been undertaken to increase confidence in design event flood levels. The testing has shown that the prediction of peak lake level is (as expected) quite sensitive to the selected design rainfall depth and selection of continuing loss. The peak lake level is also moderately sensitive to the selection of initial lake level. The model predictions appear to be less sensitive to the selection of hydraulic roughness (Mannings, ‘n’), initial loss value, downstream boundary and LiDAR accuracy.

- Changes to flood risk along the Lower Myall due to climate change (including increases in rainfall intensity and sea level rise) have also been investigated. An increase in mean seal level due to sea level rise may pose a significant flood risk problem along the Tea Gardens peninsula, where ground elevations of only 1.5 m AHD are common. Low lying areas in Hawks Nest (with ground elevations below 2.0 m AHD) will also be affected by predicted SLR. Robust land use planning and development policies will be required to ensure future flood risks are not unduly exacerbated in light of predicted flood behaviour under potential climate change scenarios

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APPENDIX A: SURVEY CHECK DATA

Ground survey was undertaken at a number of transects along the Lower Myall Floodplain to check the accuracy of the LiDAR data under the relatively dense forest canopy. Carmen Surveyors undertook ground survey using a Total Station along 4 Transects of the Lower Myall Floodplain as presented in Figure A-2. Due to the dense forest canopy RTK GPS survey could not be used. The additional effort required for Total Station survey resulted in only four out of the six transects being able to be survey for the available project scope but resulted in sufficient data to adequately check the LiDAR data.

A total of 86 survey points were received and were compared to the LiDAR data. Figure A-1 presents data showing the accuracy of the LiDAR data at the 86 locations where ground survey was collected. The figure also presents the accuracy of the 36 points on the active floodplain (defined as being below 1 m AHD and being the primary area of interest) compared to the entire data set. In general the LiDAR data was found to closely match the ground survey data as indicated by the following statistics:

- 76 out of 86 points were +/- 0.3m (i.e. within 0.3m of the ground survey level)
- 65 out of 86 points were +/- 0.2m
- 50 out of 86 points were +/- 0.1m

The LiDAR data indicates a slight 0.05m to 0.1m bias to overestimate the ground level on the floodplain. Because this slight overestimate will produce a minor degree of conservatism in the model prediction a correction to the LiDAR has not been applied. Model sensitivity testing indicated that if the LiDAR overestimated floodplain elevations by 0.25m this would increase the 1% AEP design Lake level by approximately 5 cm.

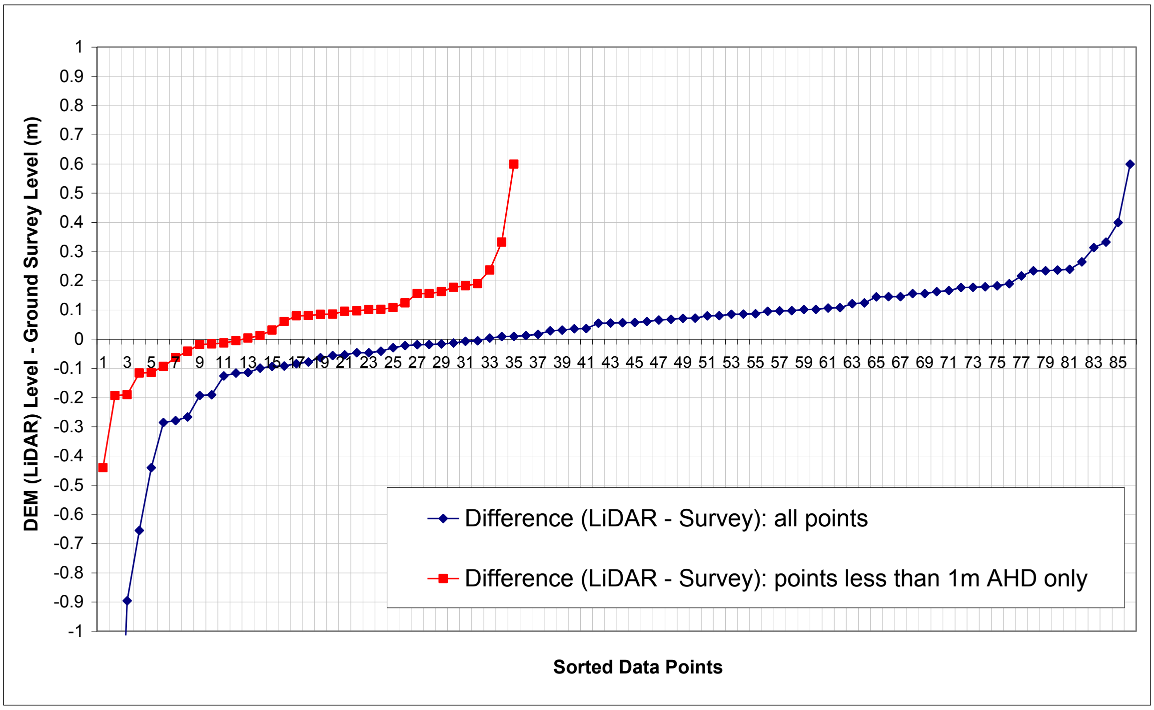
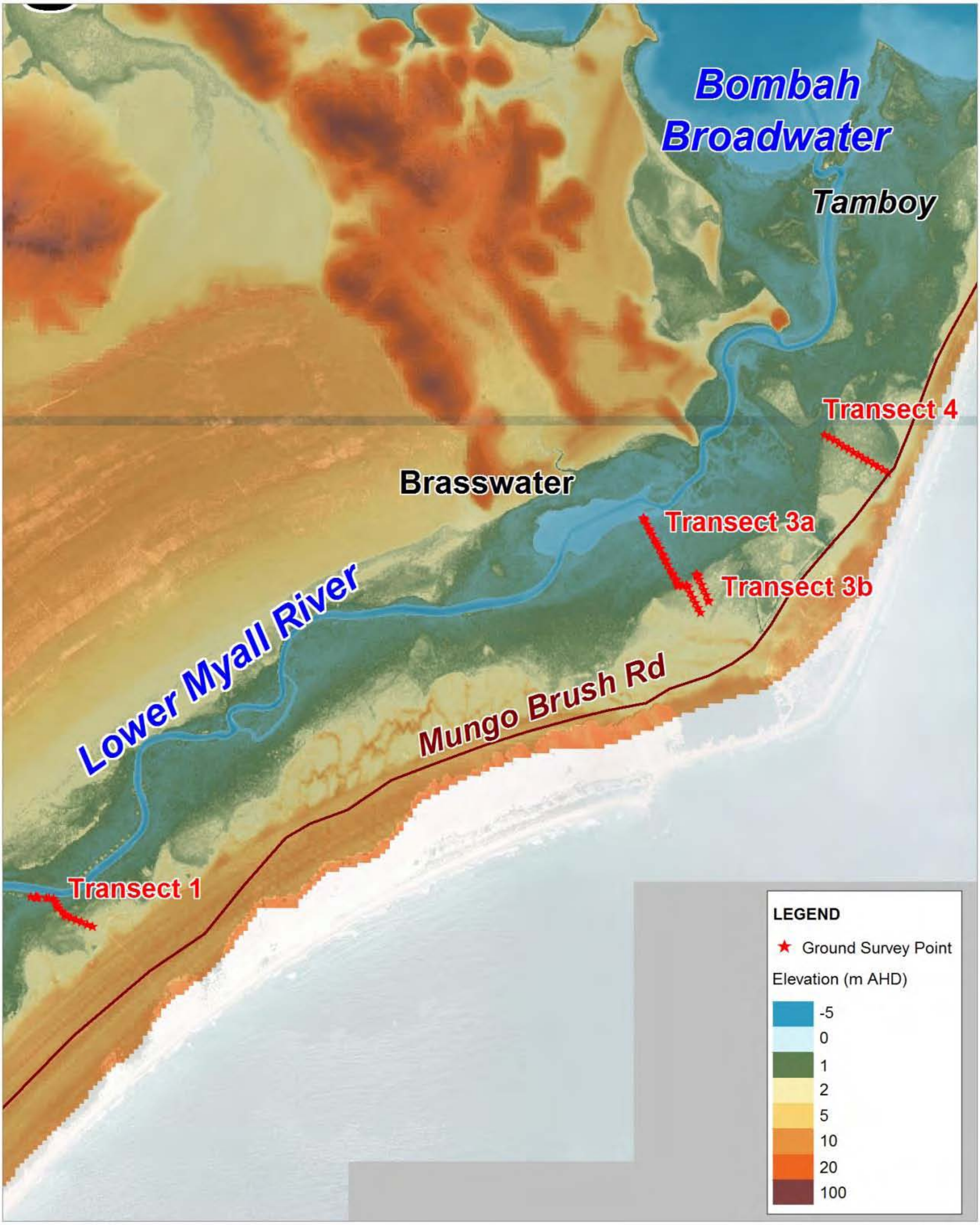


Figure A-1 Comparison of Ground Survey to LiDAR Data



Title:

Lower Myall LiDAR and Survey Check Data

Figure: **A-2**

Rev: **A**

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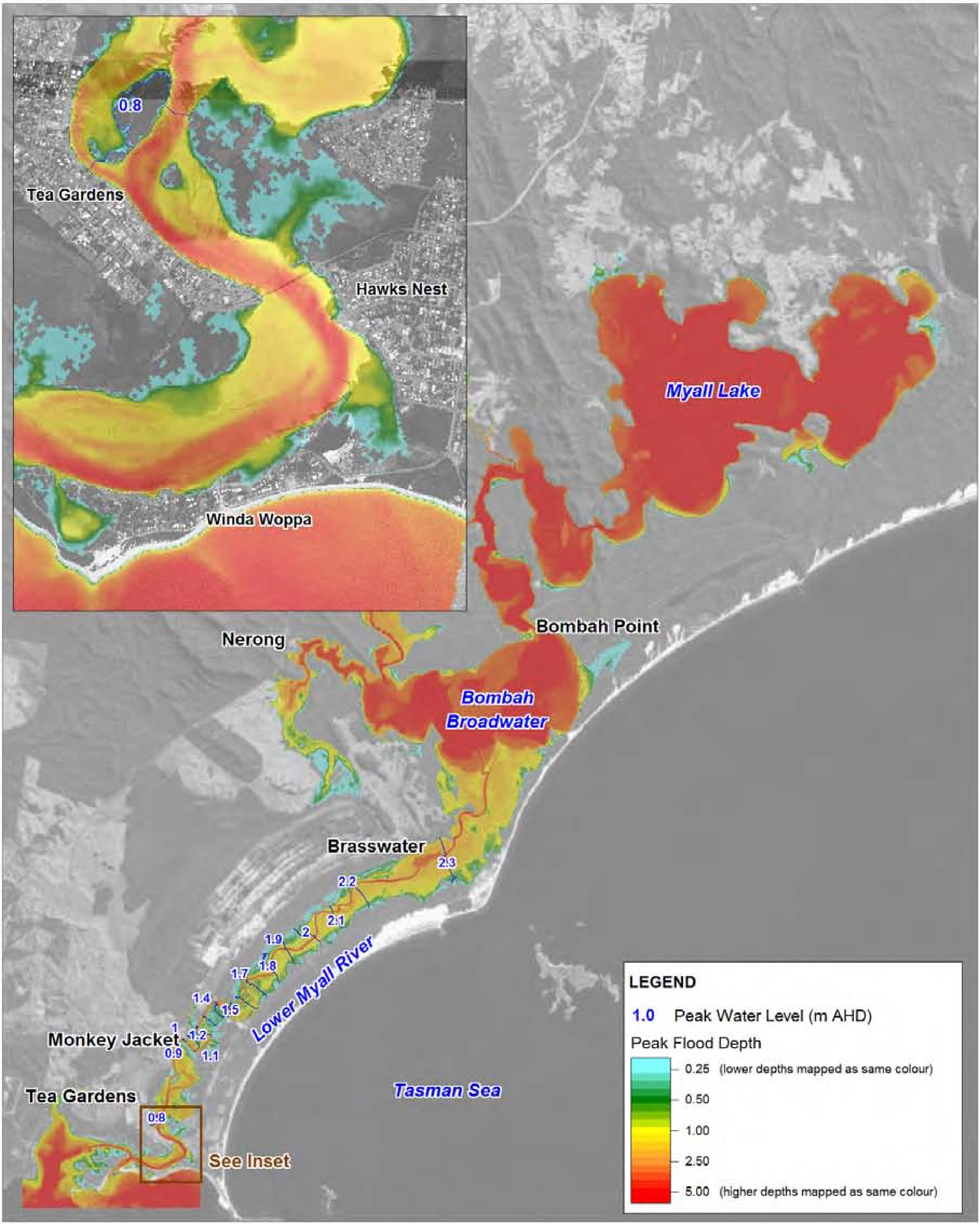
APPENDIX B: DESIGN FLOOD MAPPING

List of Maps in Compendium:

Figure Reference	Title
Dep_1%rain	Peak Flood Depths and Water Levels - 1% AEP Catchment Event
Dep_1%tide	Peak Flood Depths and Water Levels - 1% AEP Ocean Event
Dep_Extreme	Extreme Event - Peak Flood Depths and Water Levels
Dep_0.5%	Peak Flood Depths and Water Levels - 0.5% AEP Flood Event
Dep_1%	Peak Flood Depths and Water Levels - 1% AEP Flood Event
Dep_2%	Peak Flood Depths and Water Levels - 2% AEP Flood Event
Dep_5%	Peak Flood Depths and Water Levels - 5% AEP Flood Event
Dep_10%	Peak Flood Depths and Water Levels - 10% AEP Flood Event
Dep_20%	Peak Flood Depths and Water Levels - 20% AEP Flood Event
Dep_50%	Peak Flood Depths and Water Levels - 50% AEP Flood Event
Vel_Extreme	Peak Flood Velocity - Extreme Event
Vel_0.5%	Peak Flood Velocity - 0.5% AEP Event
Vel_1%	Peak Flood Velocity - 1% AEP Event
Vel_2%	Peak Flood Velocity - 2% AEP Event
Vel_5%	Peak Flood Velocity - 5% AEP Event
Vel_10%	Peak Flood Velocity - 10% AEP Event
Vel_20%	Peak Flood Velocity - 20% AEP Event
Vel_50%	Peak Flood Velocity - 50% AEP Event
Haz_Extreme	Peak Flood Hazard - Extreme Event
Haz_1%	Peak Flood Hazard - 1% AEP Event
Haz_5%	Peak Flood Hazard - 5% AEP Event
Haz_20%	Peak Flood Hazard - 20% AEP Event
Haz_0.5mSLR	Peak Flood Hazard - 1% AEP with 0.5m Sea Level Rise Event
Haz_0.9mSLR	Peak Flood Hazard - 1% AEP with 0.9m Sea Level Rise Event
HydCat_1%	Hydraulic Categories - 1% AEP Event
HydCat_5%	Hydraulic Categories - 5% AEP Event
Des_In_Ex	Design Flood Inundation Extents
SLR_In_Ex	Design 1% AEP Flood Inundation Extents with SLR
Dep_1%_0.5mSLR	Peak Flood Depths and Water Levels - 1% AEP Flood Event with 0.5m Sea Level Rise Event
Dep_1%_0.9mSLR	Peak Flood Depths and Water Levels - 1% AEP Flood Event with 0.9m Sea Level Rise Event
ERP_Rain	Emergency Response Planning Community Classification for Catchment Flood Events
ERP_Tide	Emergency Response Planning Community Classification for Ocean Flood Events
ERP_SLR_Rain	Emergency Response Planning Community Classification for SLR Catchment Flood Events
ERP_SLR_Tide	Emergency Response Planning Community Classification for SLR Ocean Flood Events



Title:

Lower Myall Flood Study: 1% AEP Catchment Event Peak Flood Depths and Water Levels

Figure: **Dep_1%rain**

Rev: **A**

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Approx. Scale

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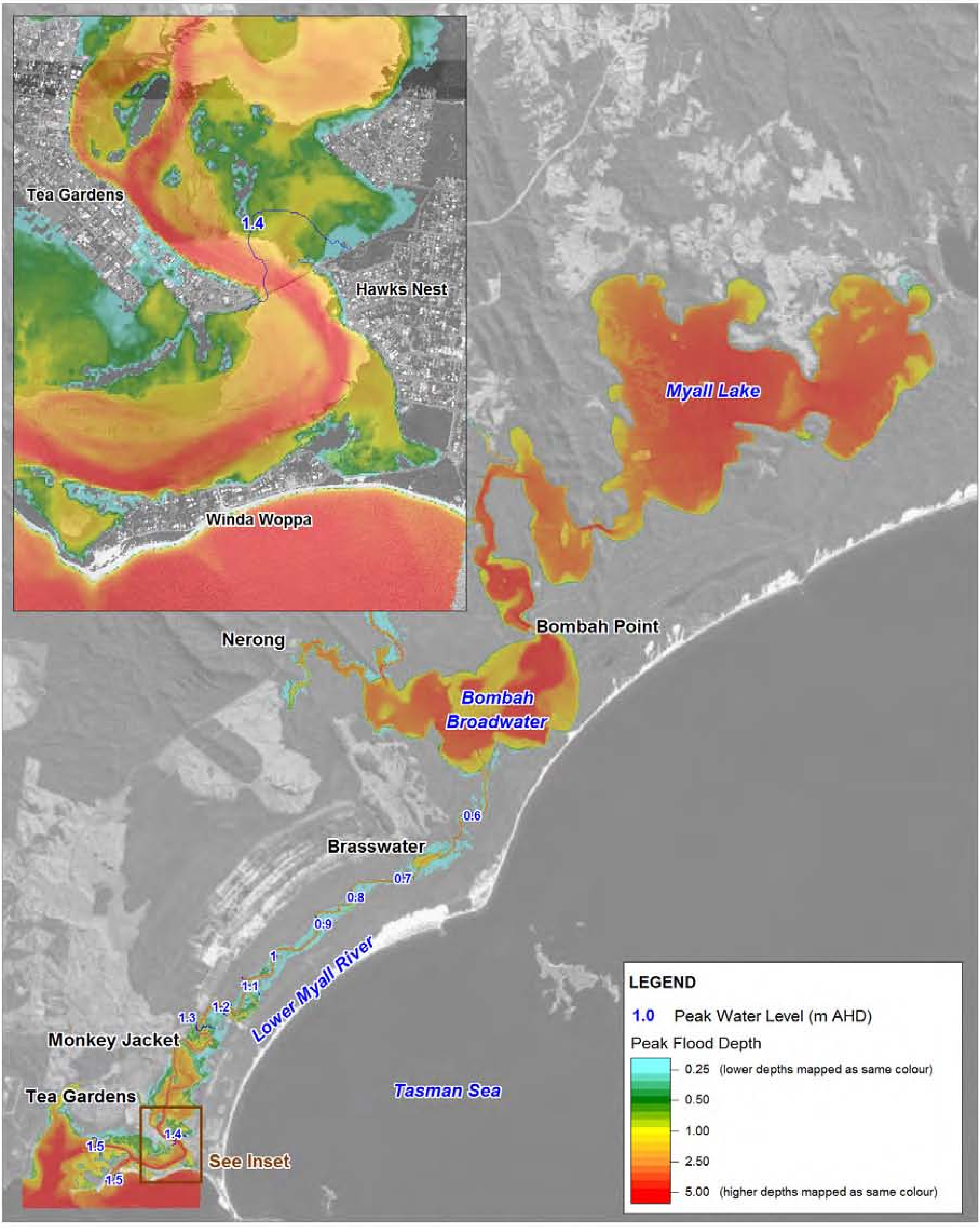

Title:

Lower Myall Flood Study: 1% AEP Ocean Event Peak Flood Depths and Water Levels

Figure: **Dep_1%tide**

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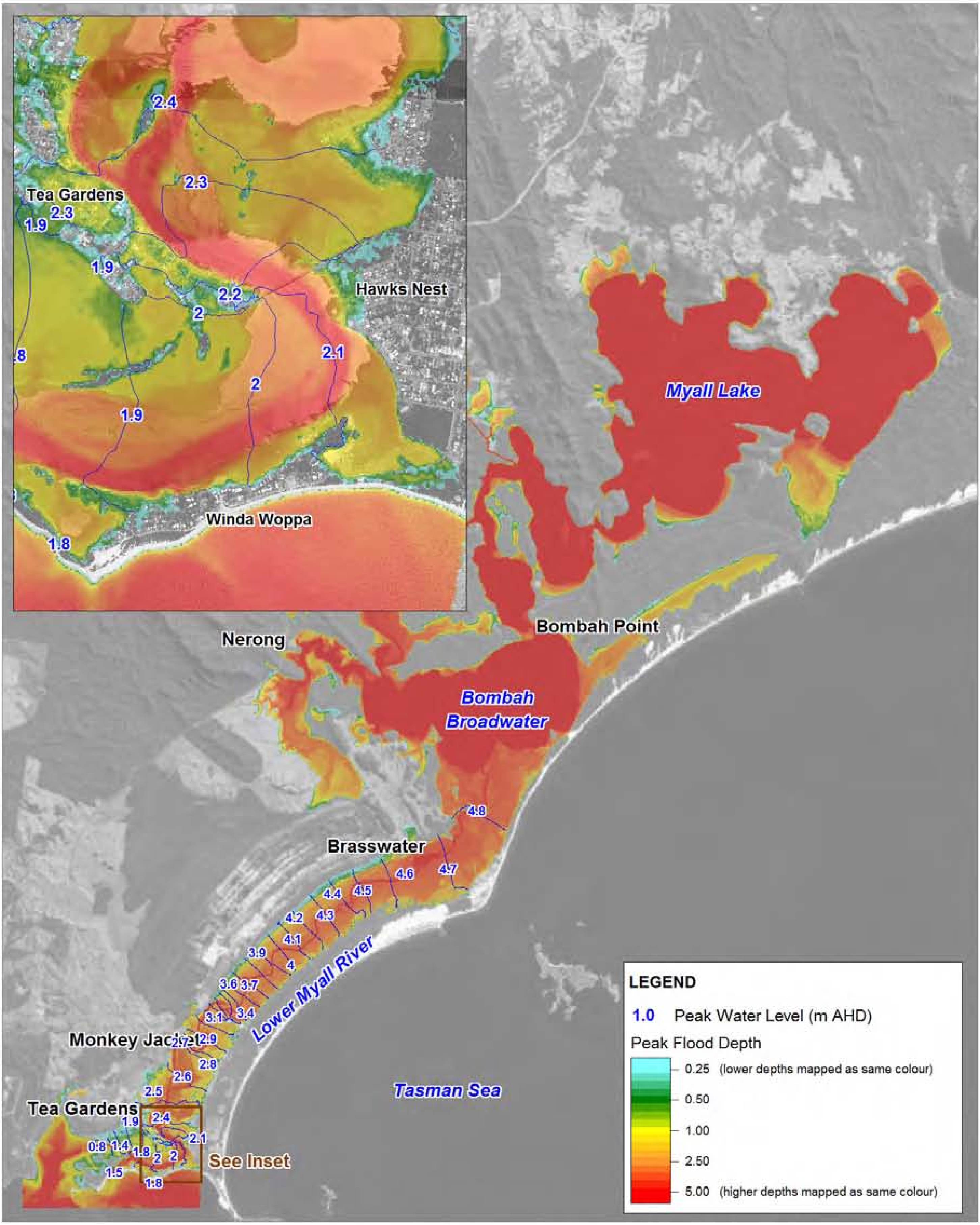

Title:

Lower Myall Flood Study: Extreme Catchment Event Peak Flood Depths and Water Levels

Figure: Dep_Extreme

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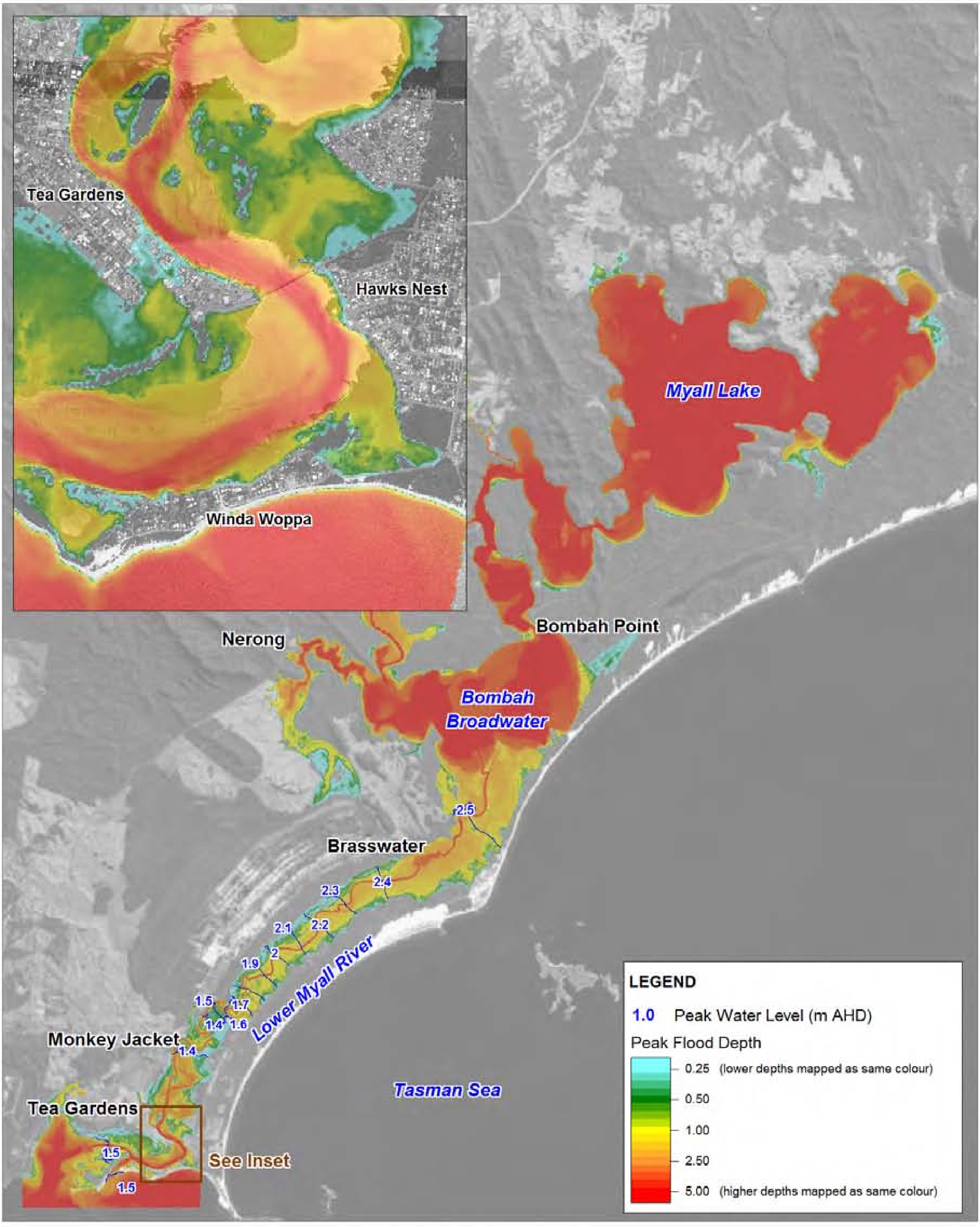

Title:

Lower Myall Flood Study: 0.5% AEP Flood Event
Peak Flood Depths and Water Levels

Figure: **Dep_0.5%**

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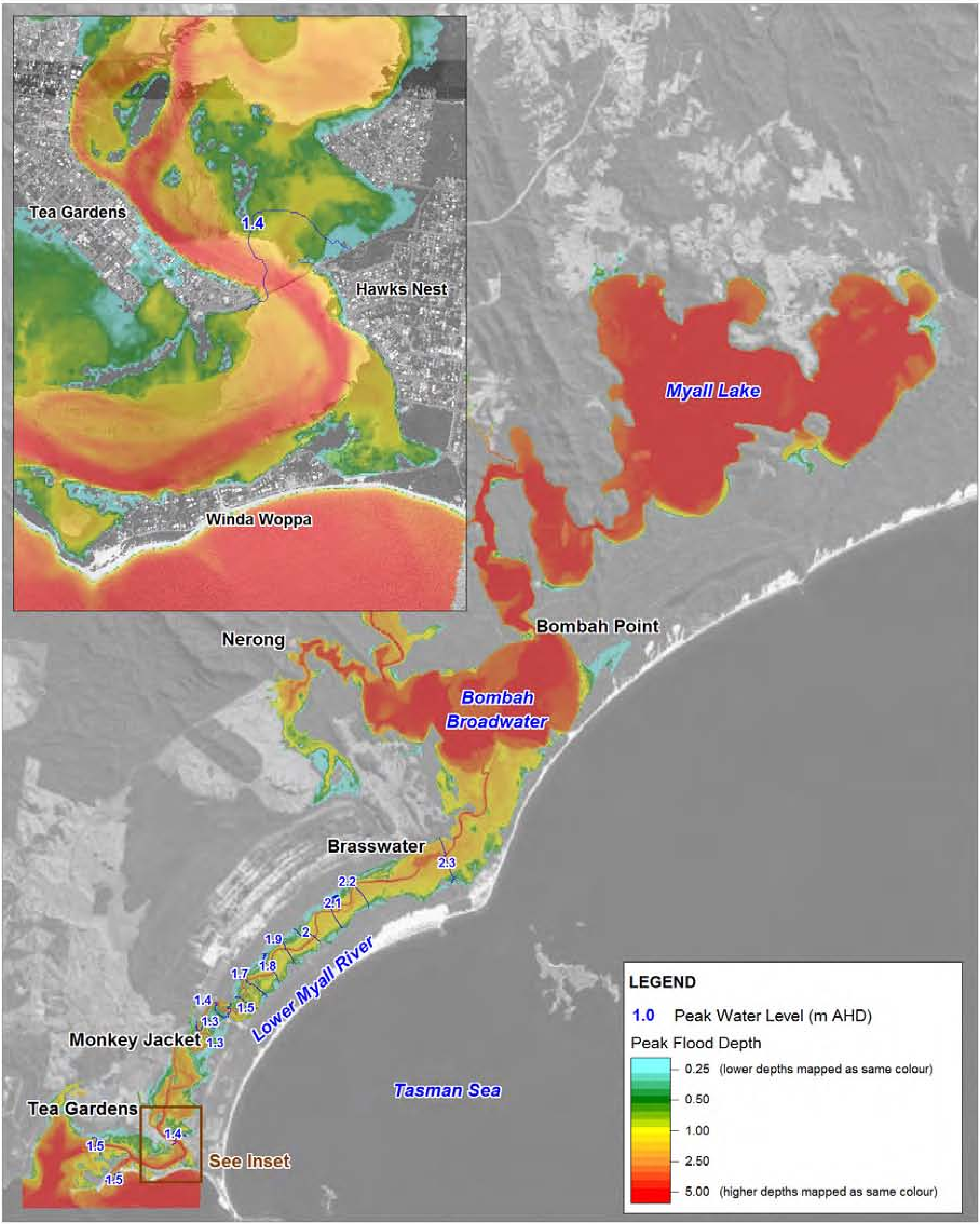

Title:

Lower Myall Flood Study: 1% AEP Flood Event
Peak Flood Depths and Water Levels

Figure: **Dep_1%**

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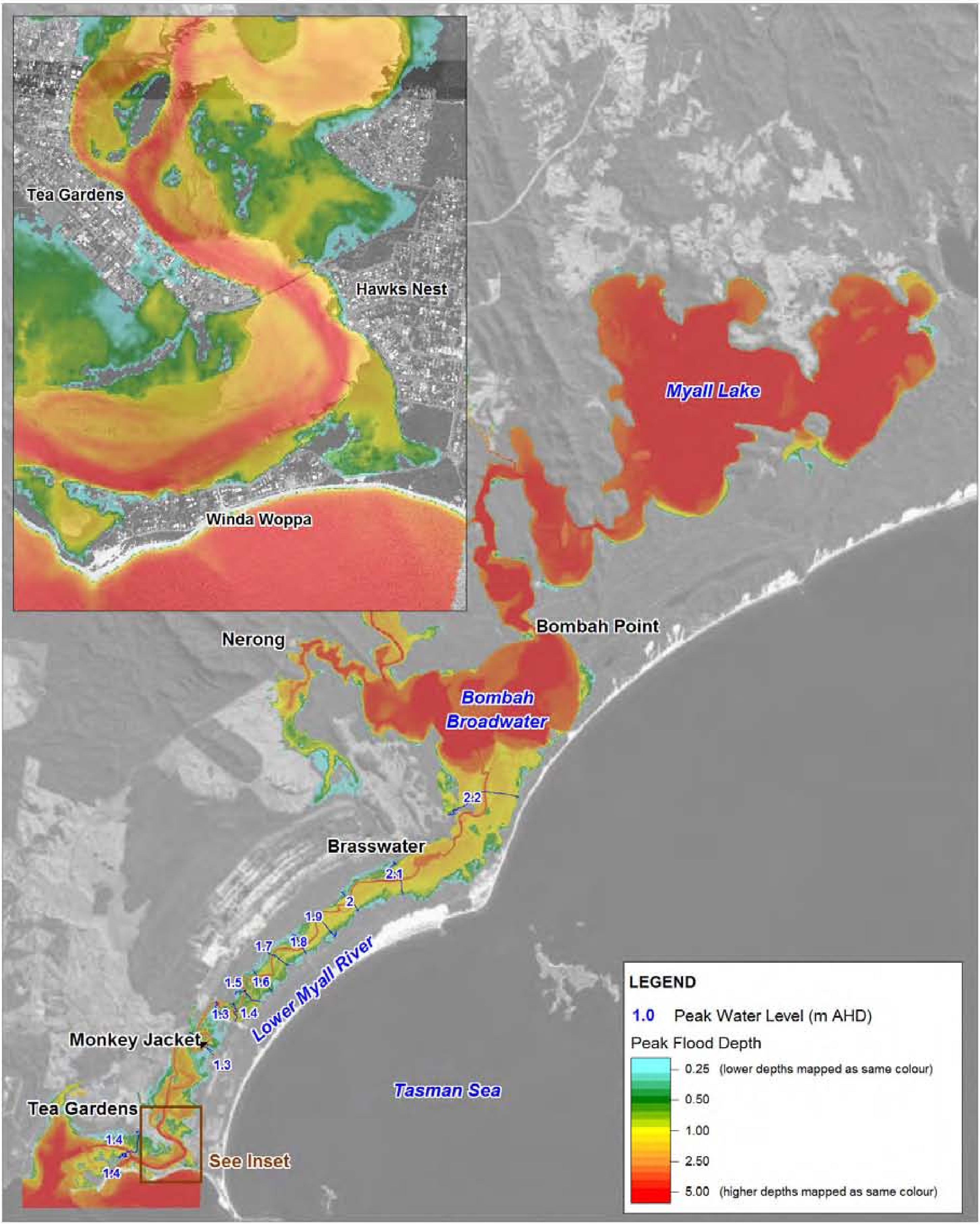

Title:

Lower Myall Flood Study: 2% AEP Flood Event Peak Flood Depths and Water Levels

Figure: **Dep_2%**

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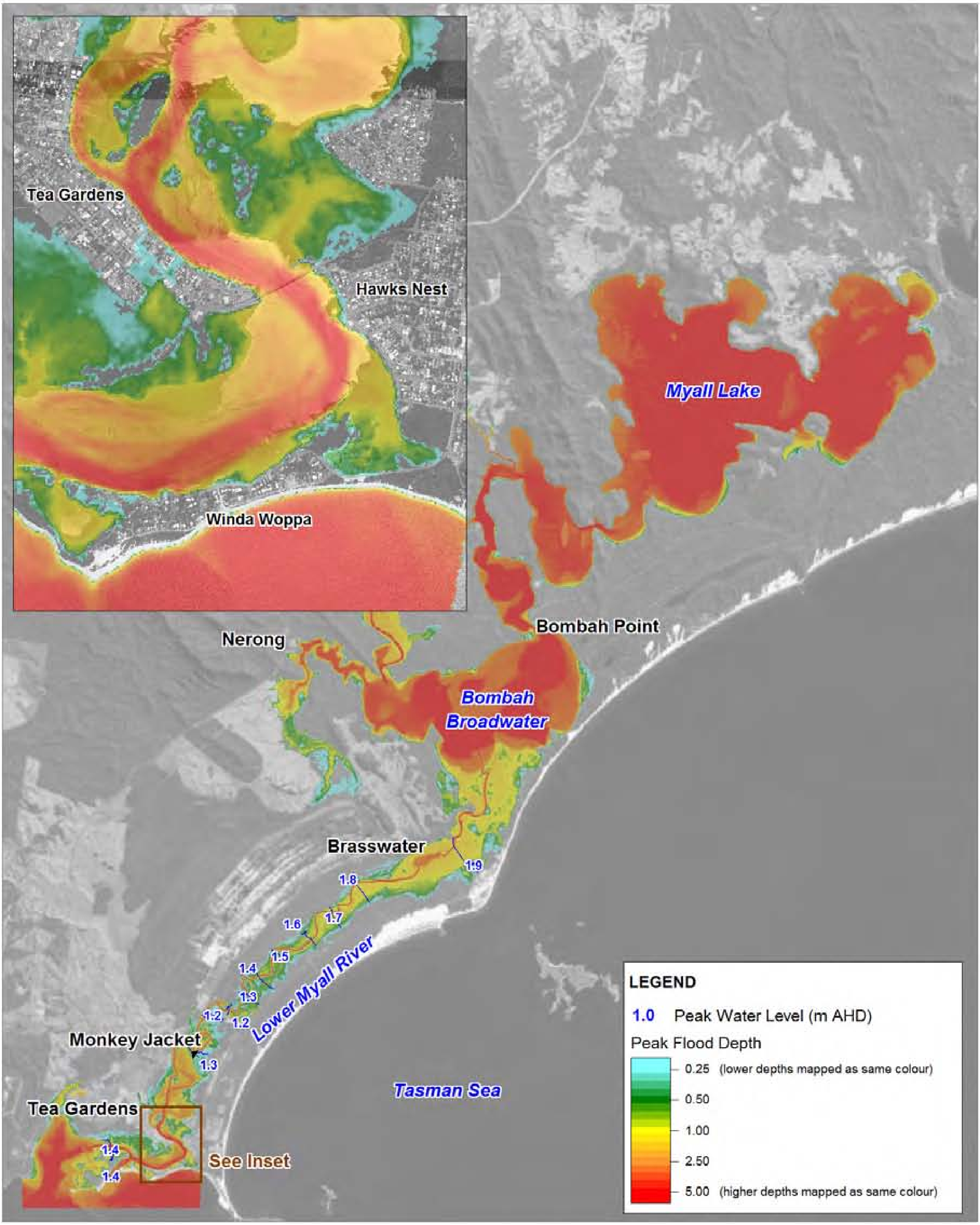

Title:

Lower Myall Flood Study: 5% AEP Flood Event Peak Flood Depths and Water Levels

Figure: Dep_5%

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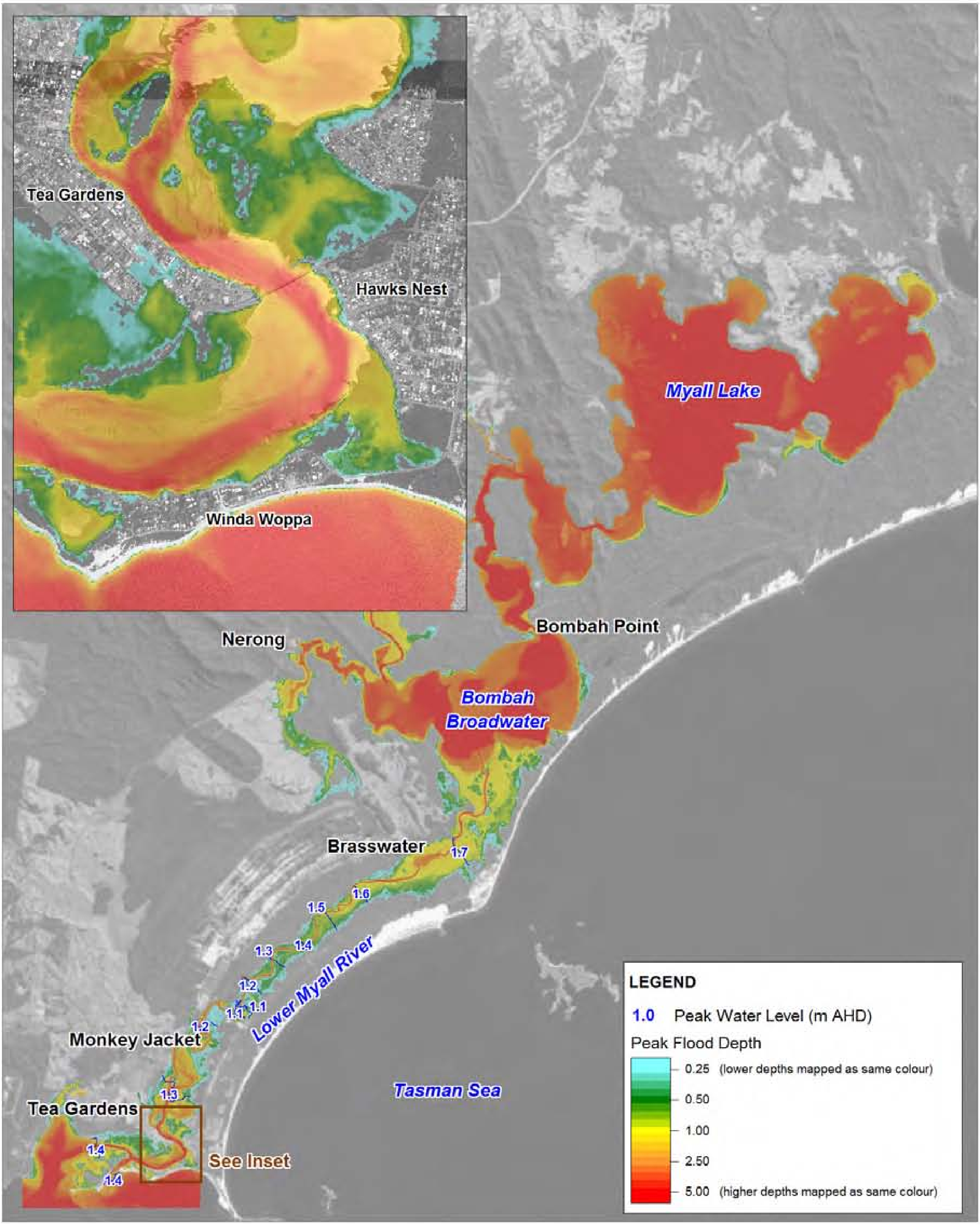

Title:

Lower Myall Flood Study: 10% AEP Flood Event Peak Flood Depths and Water Levels

Figure: **Dep_10%**

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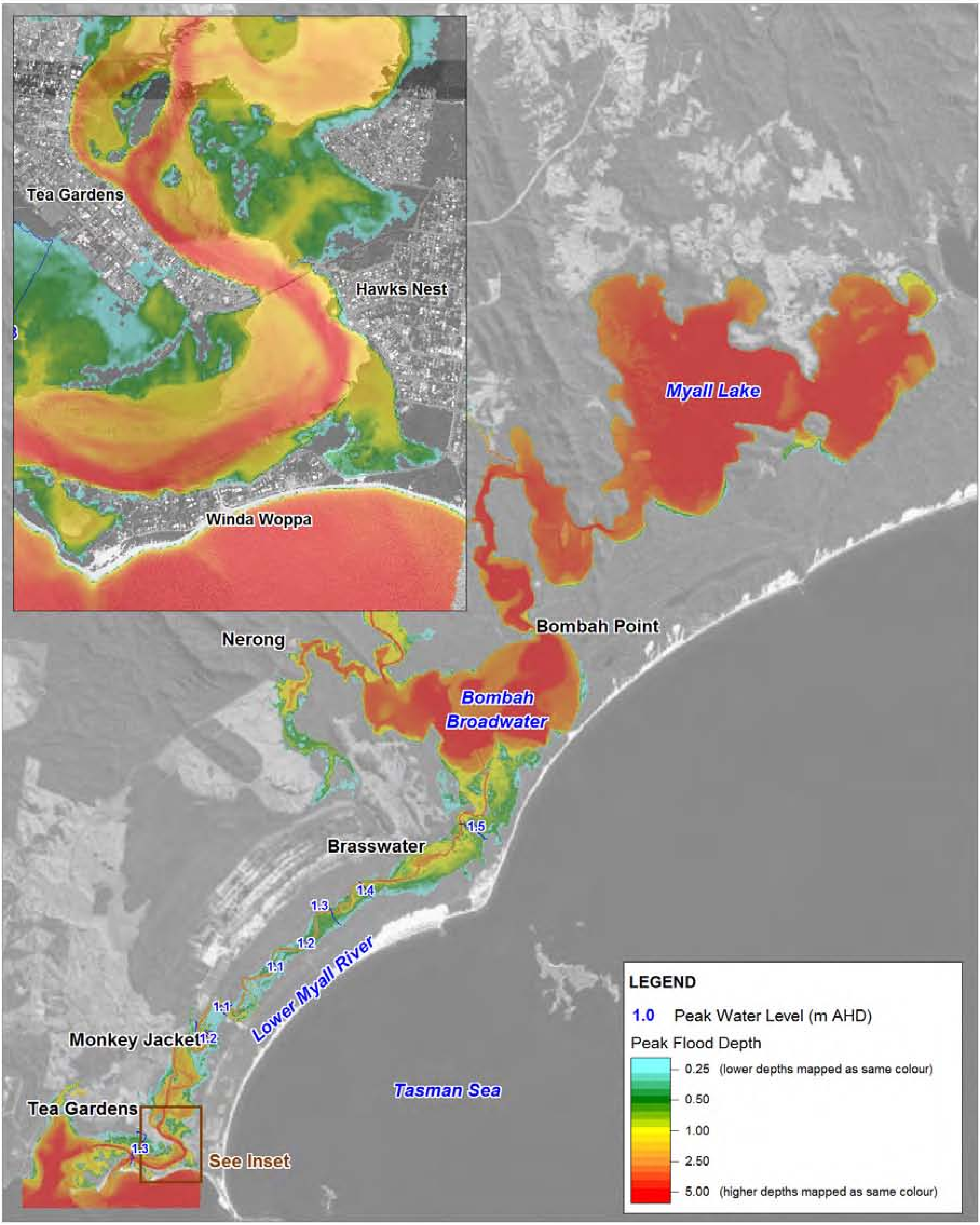

Title:

Lower Myall Flood Study: 20% AEP Flood Event Peak Flood Depths and Water Levels

Figure: Dep_20%

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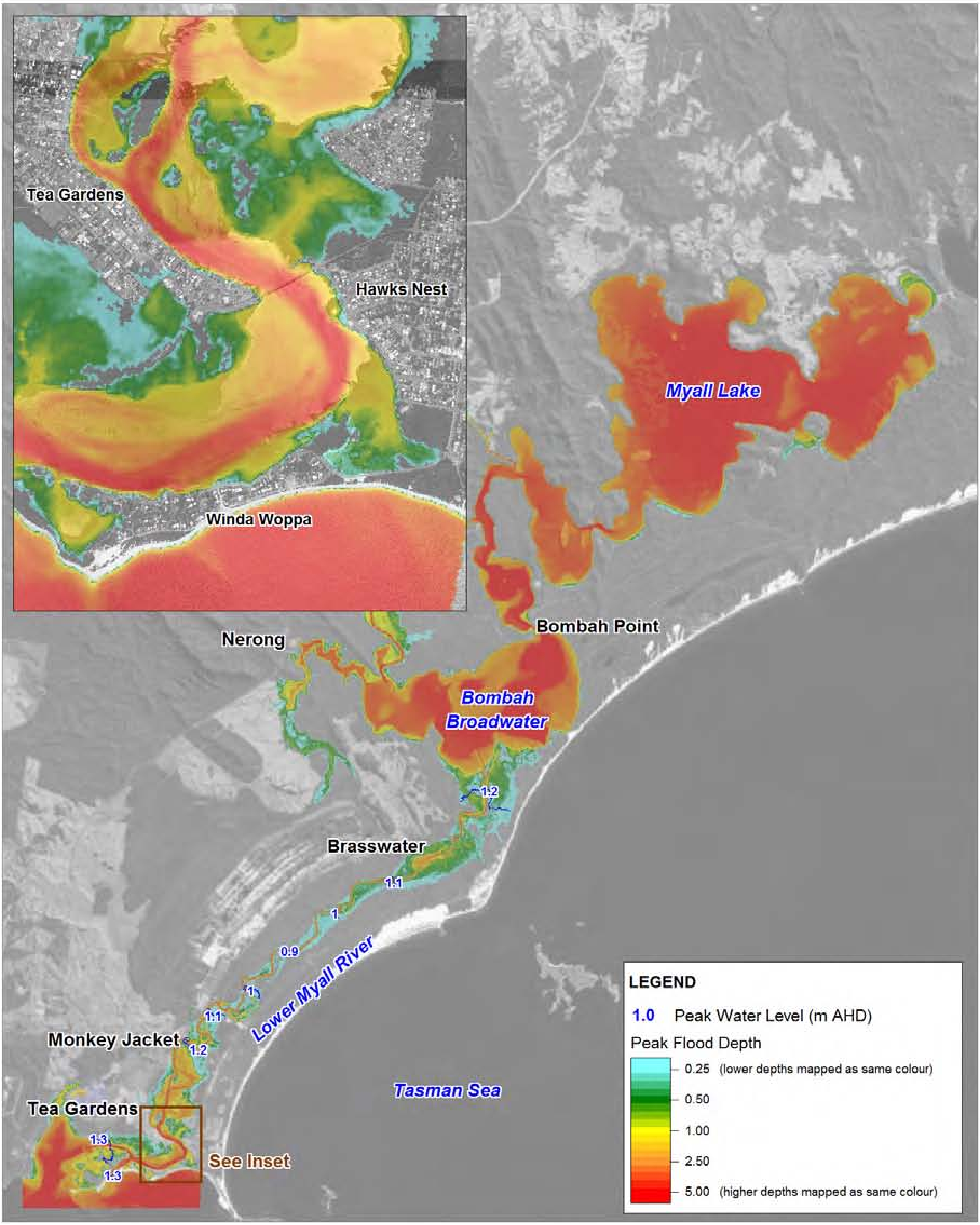

Title:

Lower Myall Flood Study: 50% AEP Flood Event
Peak Flood Depths and Water Levels

Figure: Dep_50%

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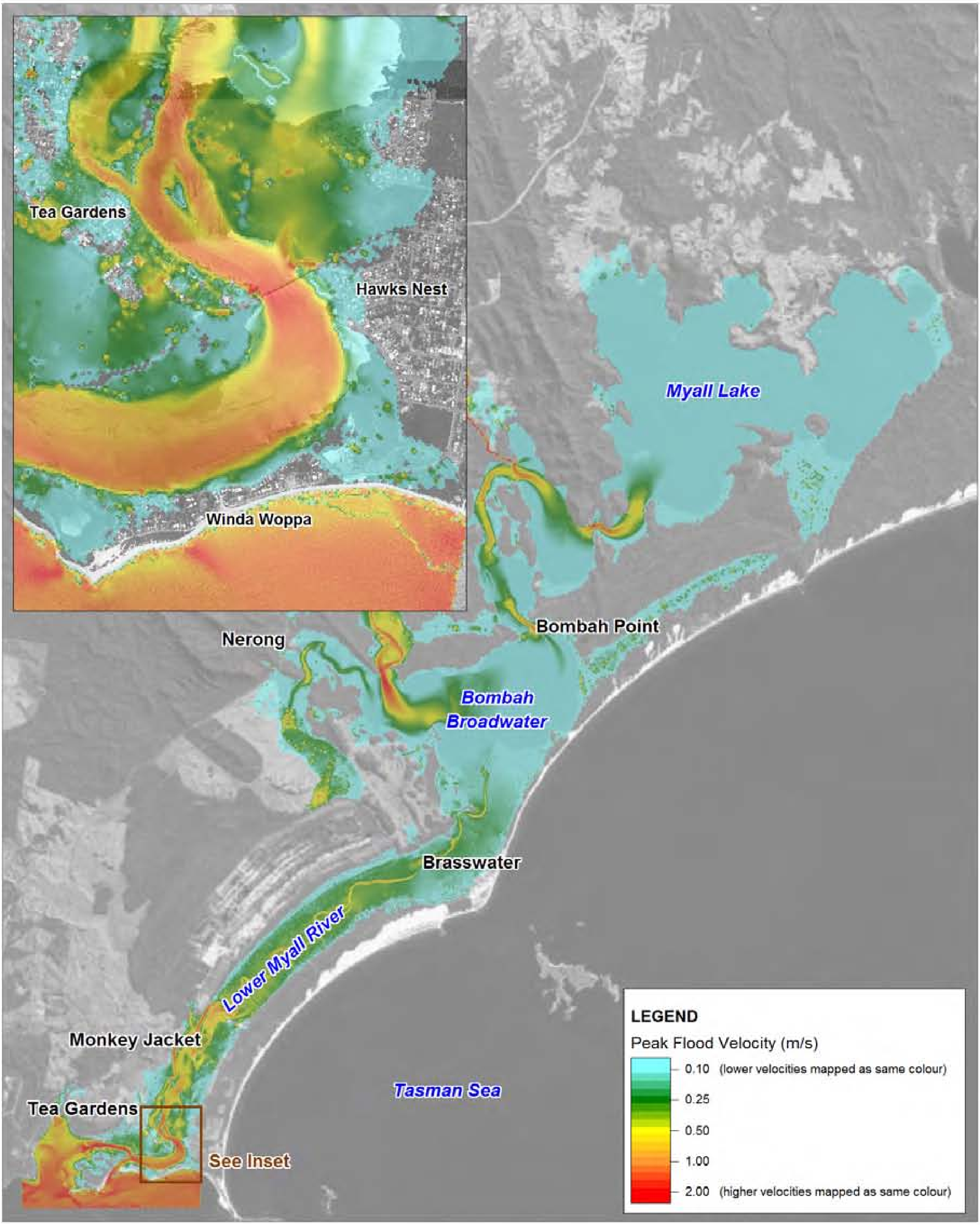

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Lower Myall Flood Study - Peak Flood Velocity: Extreme Catchment Derived Event

Figure: **Vel_Extreme**

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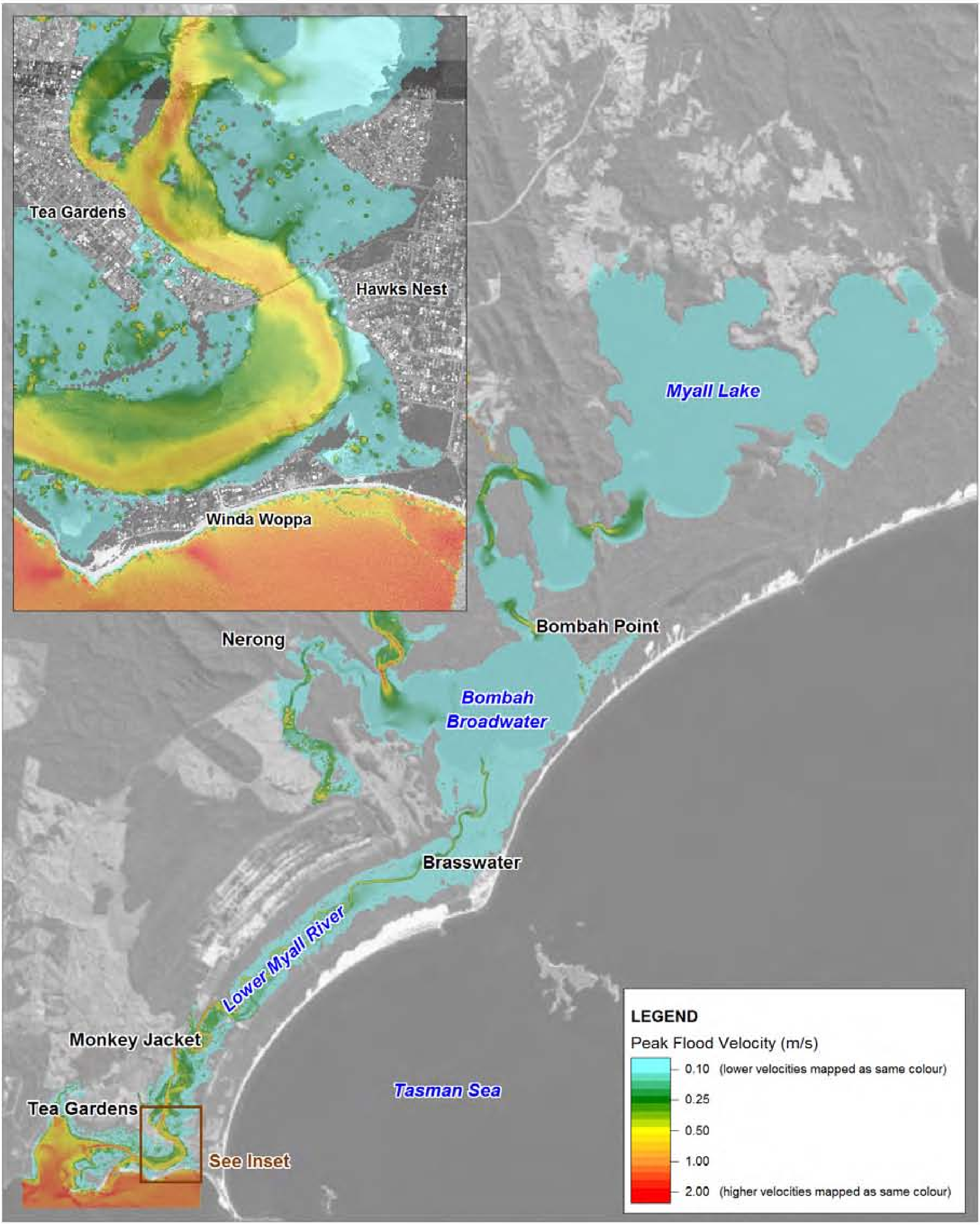

Title:

Lower Myall Flood Study - Peak Flood Velocity: 0.5% AEP Event

Figure: **Vel_0.5%**

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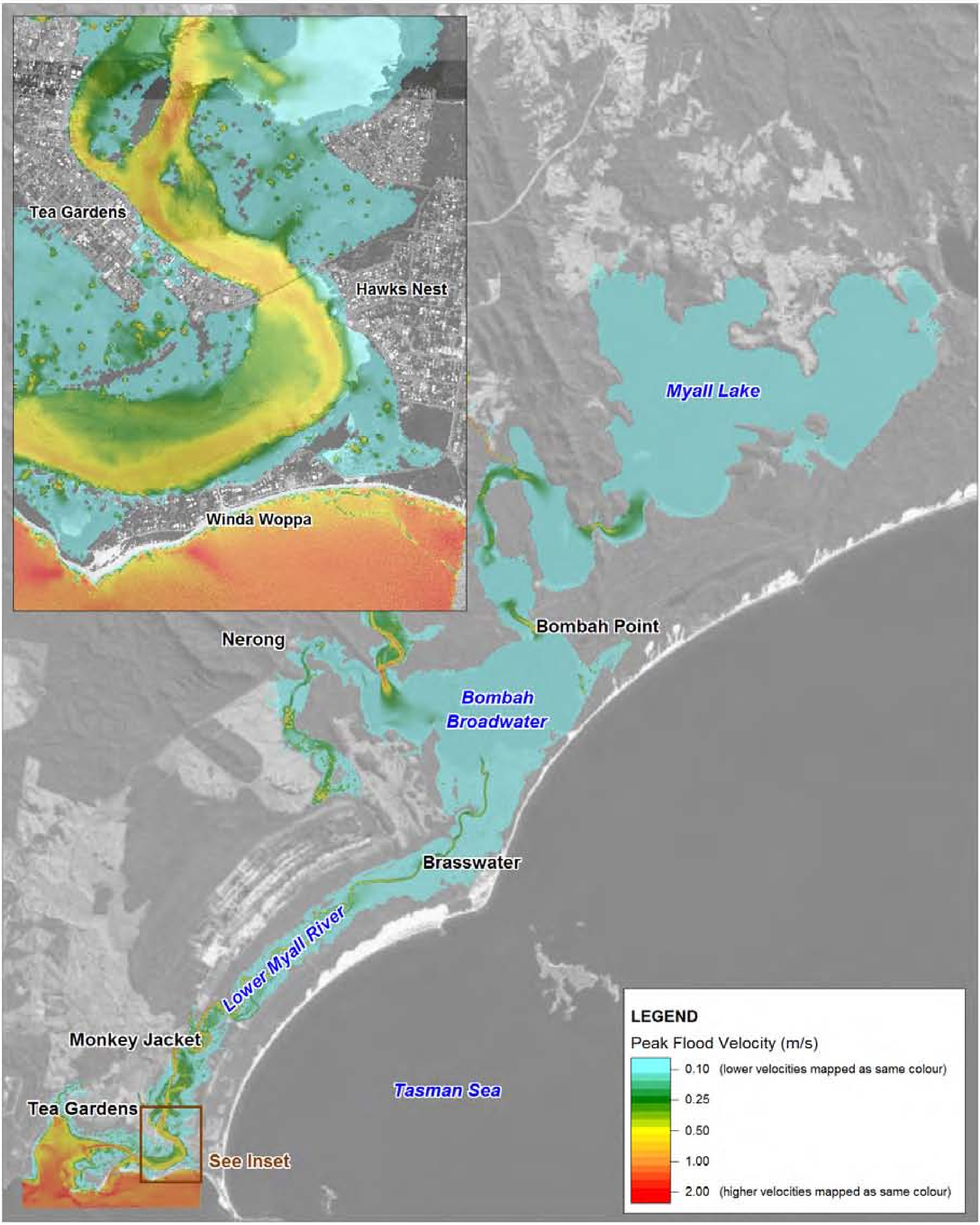

Title:

Lower Myall Flood Study - Peak Flood Velocity: 1% AEP Event

Figure: **Vel_1%**

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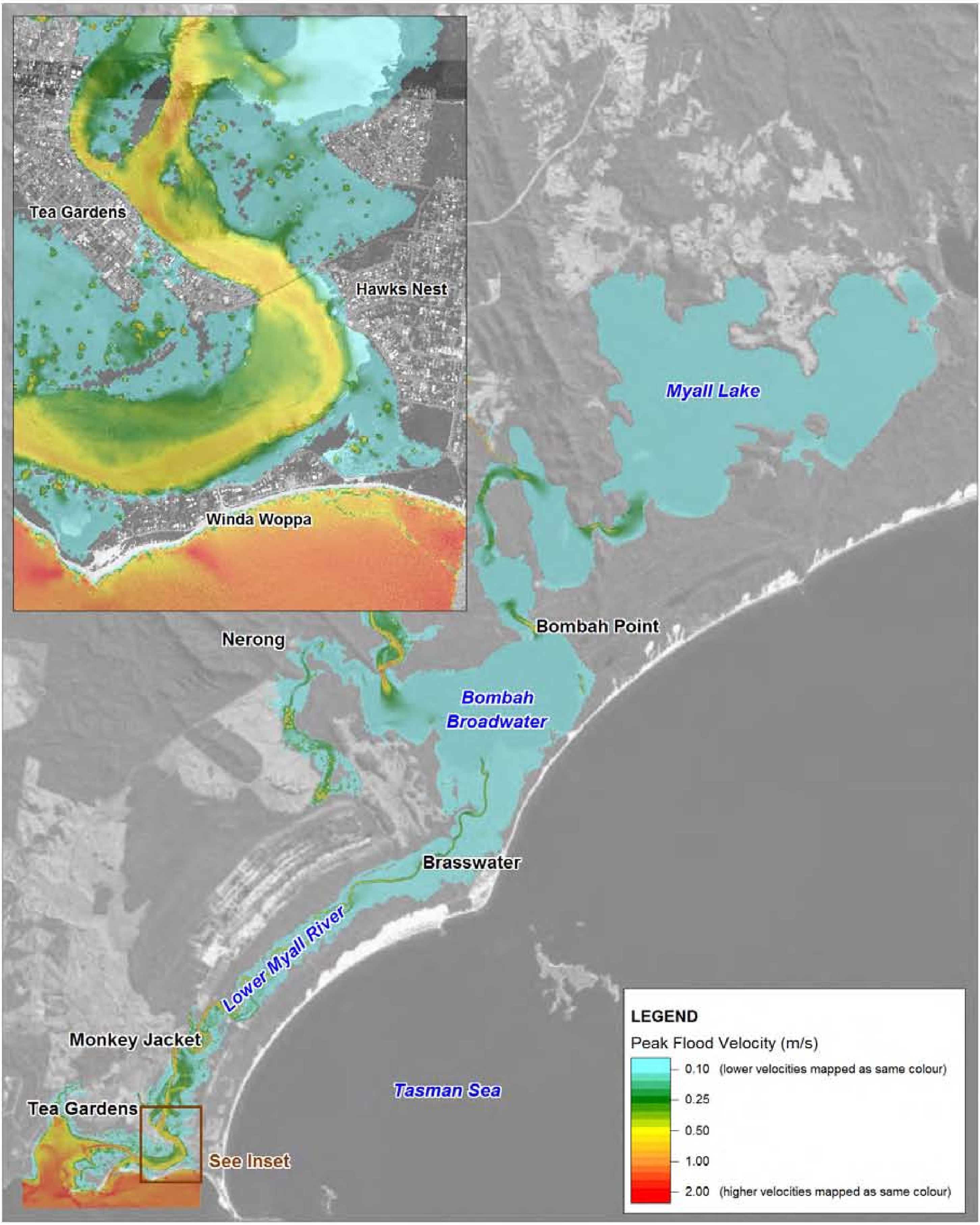

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Lower Myall Flood Study - Peak Flood Velocity: 2% AEP Event

Figure: **Vel_2%**

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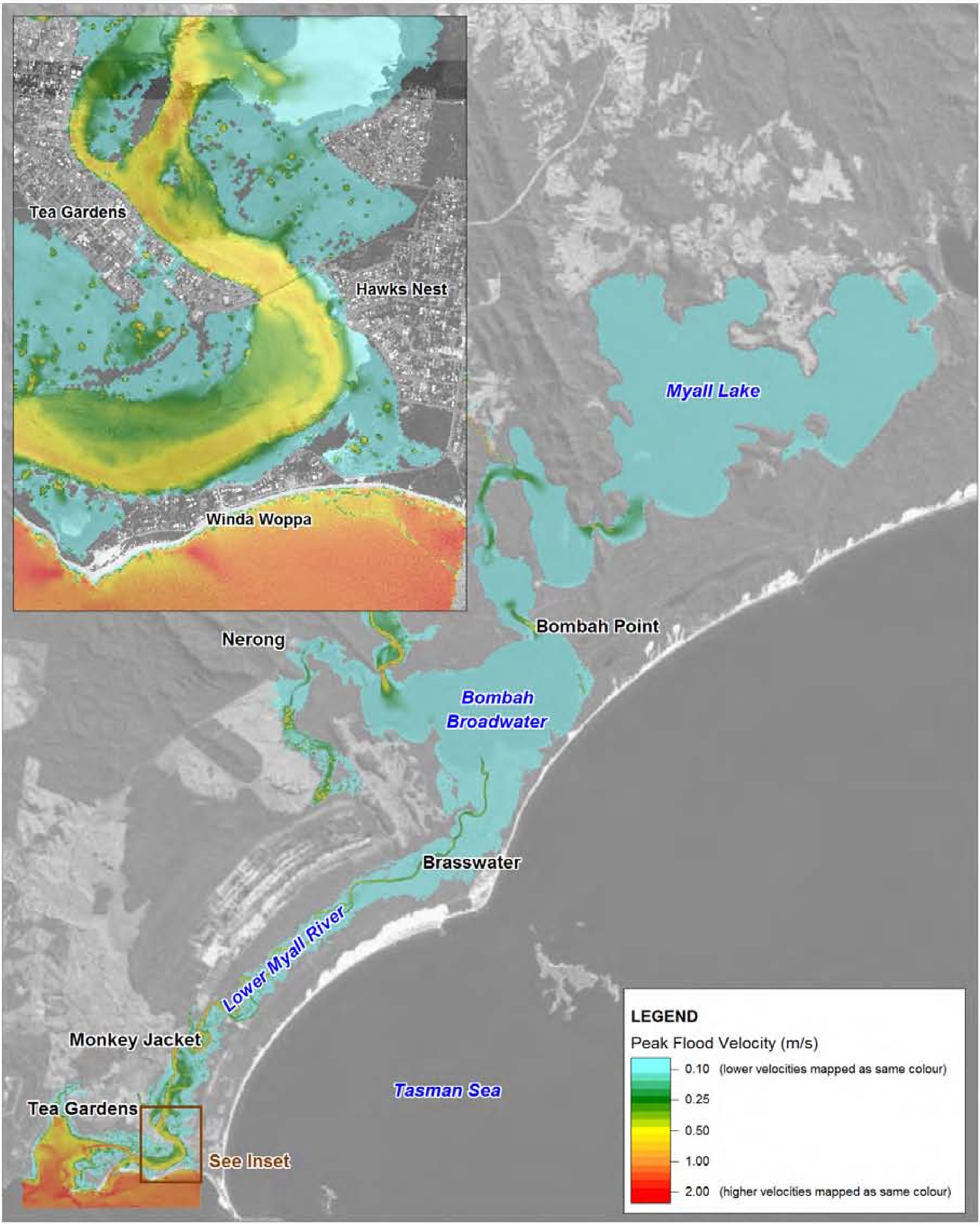

Title:

Lower Myall Flood Study - Peak Flood Velocity: 5% AEP Event

Figure: **Vel_5%**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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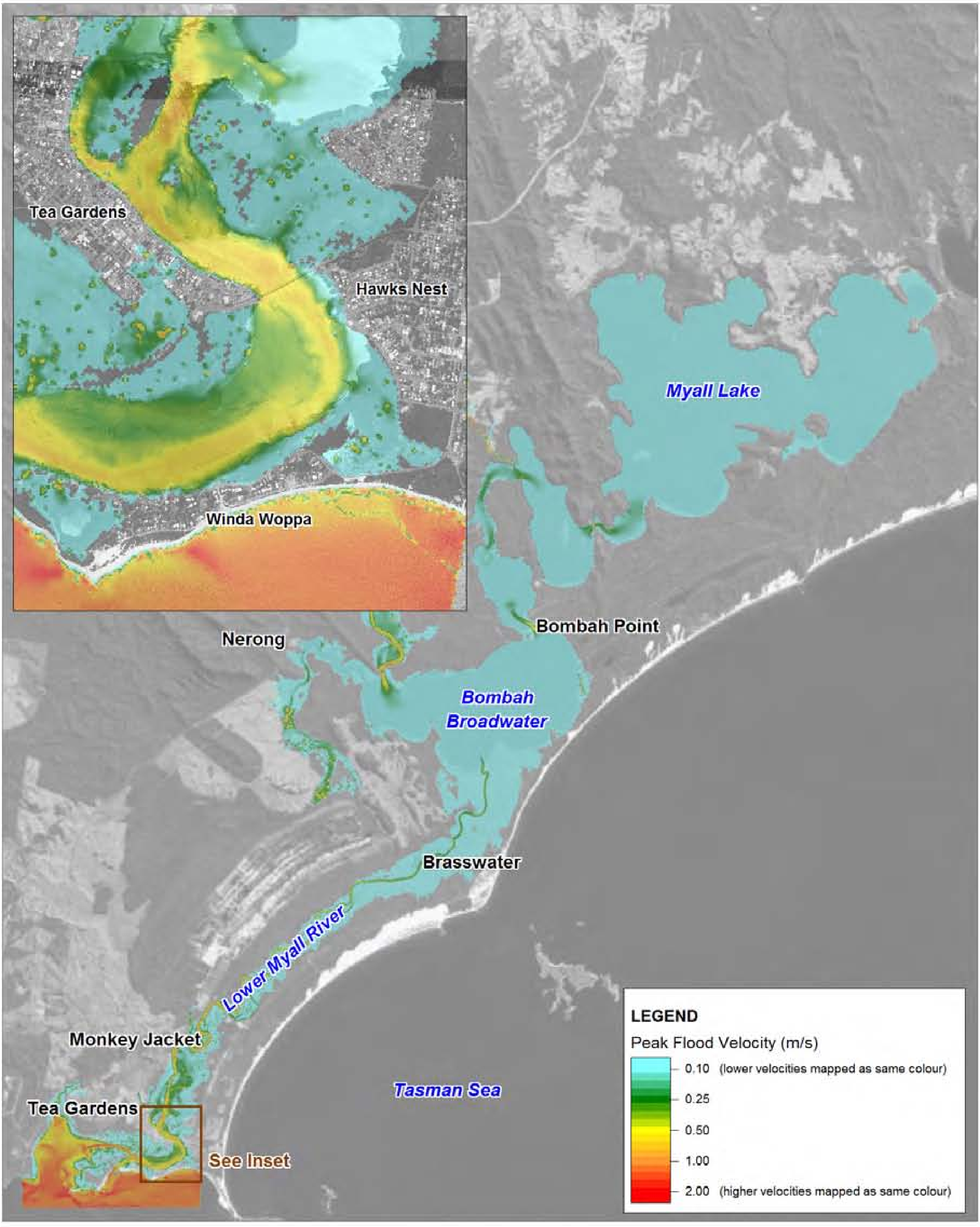
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_115_PeakVelocity_5%AEP.WOR



Title:
Lower Myall Flood Study - Peak Flood Velocity: 10% AEP Event

Figure: **Vel_10%**

Rev: **A**

N

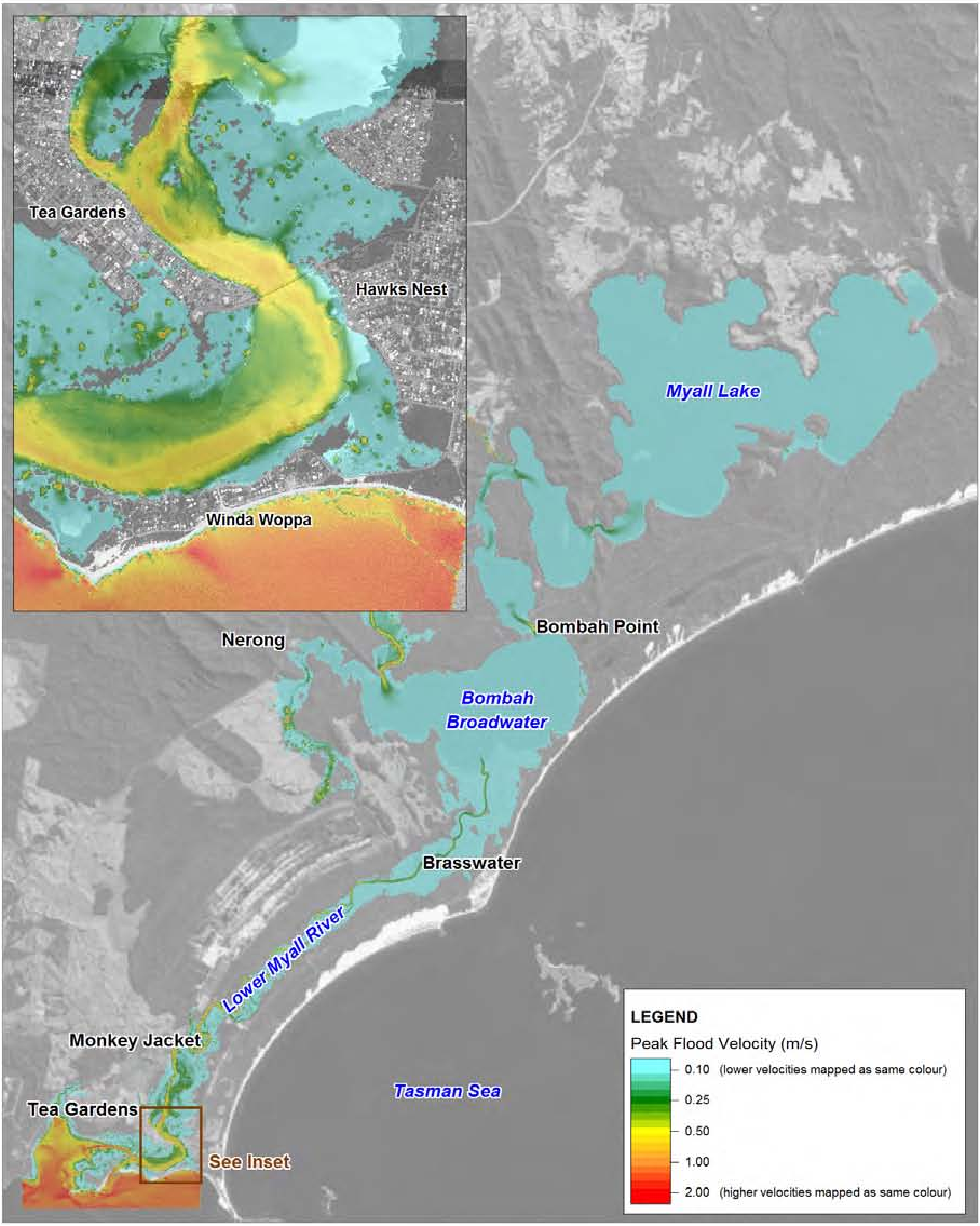
0 3.75 7.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_116_PeakVelocity_10%AEP.WOR



Title:

Lower Myall Flood Study - Peak Flood Velocity: 20% AEP Event

Figure: **Vel_20%**

Rev: **A**

N

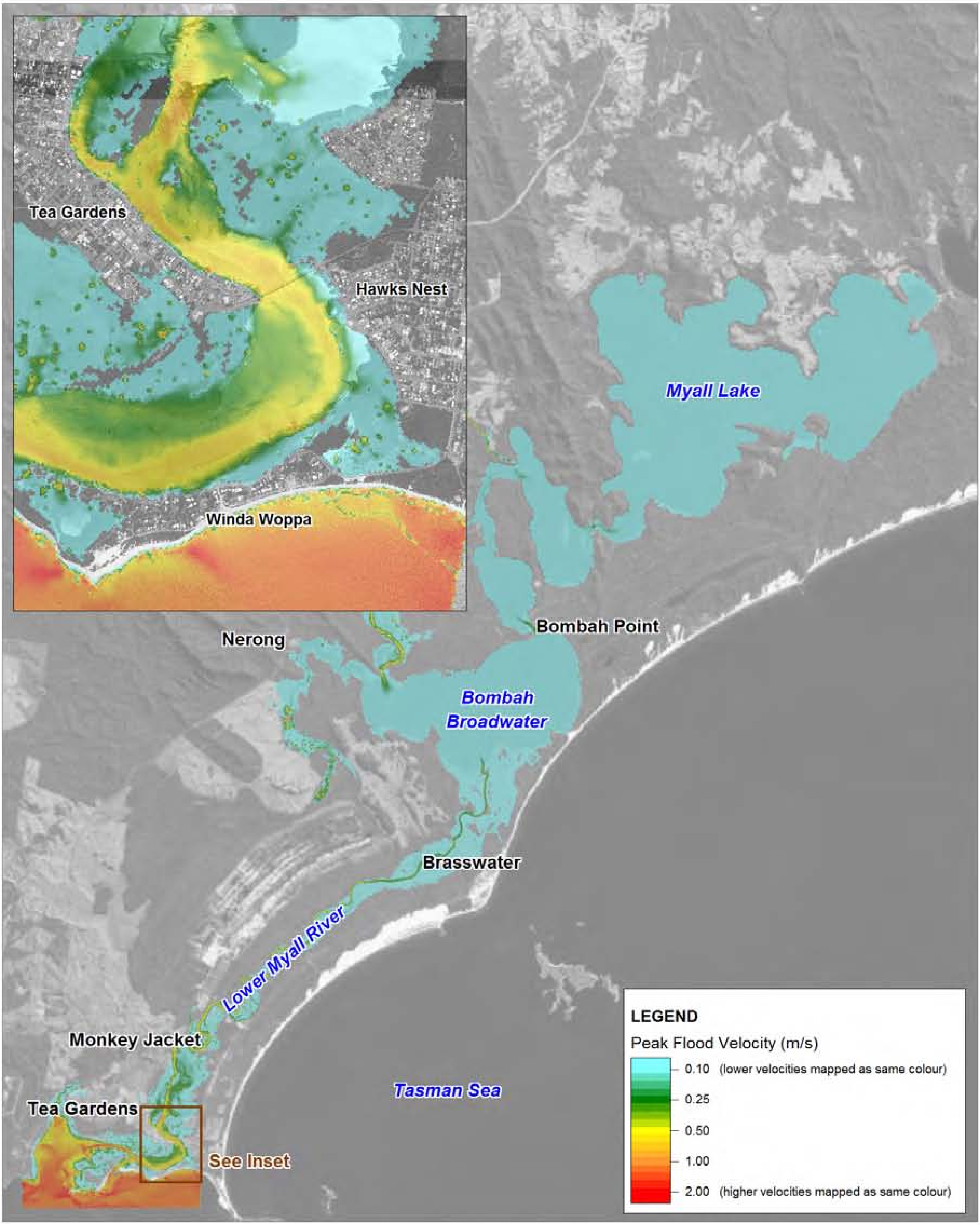
0 3.75 7.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_117_PeakVelocity_20%AEP.WOR



Title:

Lower Myall Flood Study - Peak Flood Velocity: 50% AEP Event

Figure: **Vel_50%**

Rev: **A**

N

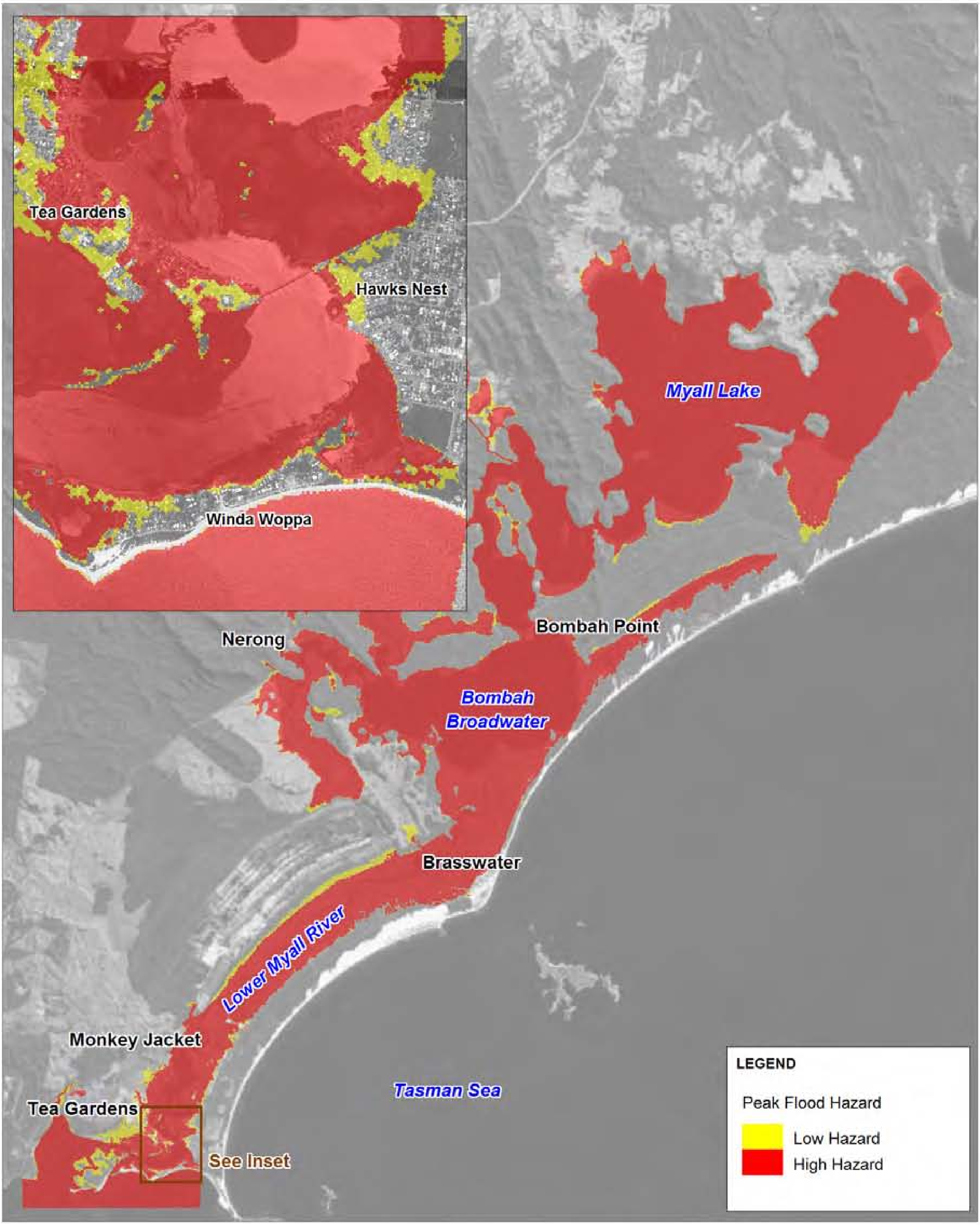
0 3.75 7.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_118_PeakVelocity_50%AEP.WOR



Title:

Lower Myall Flood Study - Peak Flood Hazard: Extreme Catchment Event

Figure: **Haz_Extreme**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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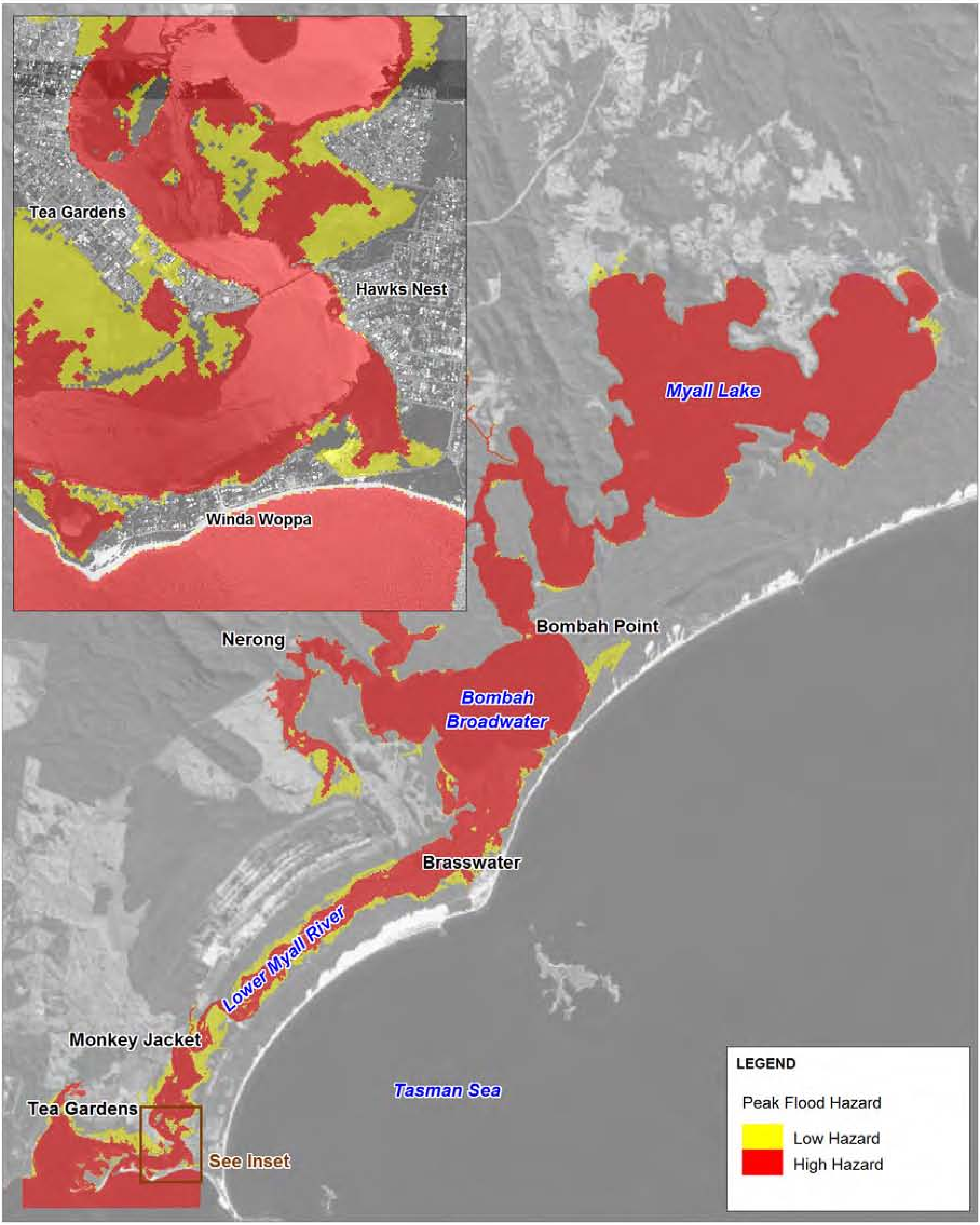
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_119_Hazard_ExtremeCatchment.WOR



Title:

Lower Myall Flood Study - Peak Flood Hazard: 1% AEP Event

Figure: **Haz_1%**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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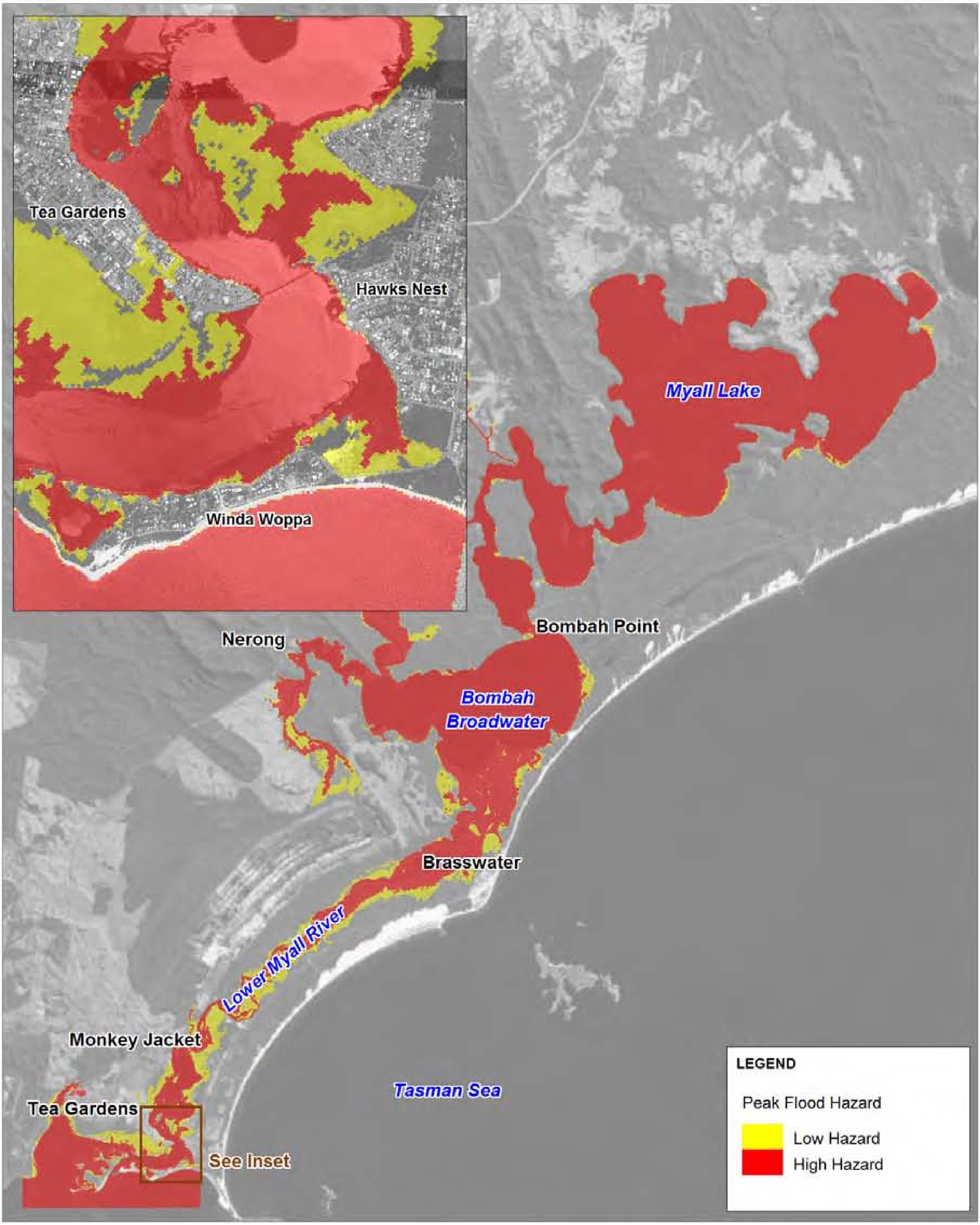
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_120_Hazard_1%AEP.WOR



Title:
Lower Myall Flood Study - Peak Flood Hazard: 5% AEP Event

Figure: **Haz_5%**

Rev: **A**

N

0 3.75 7.5km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

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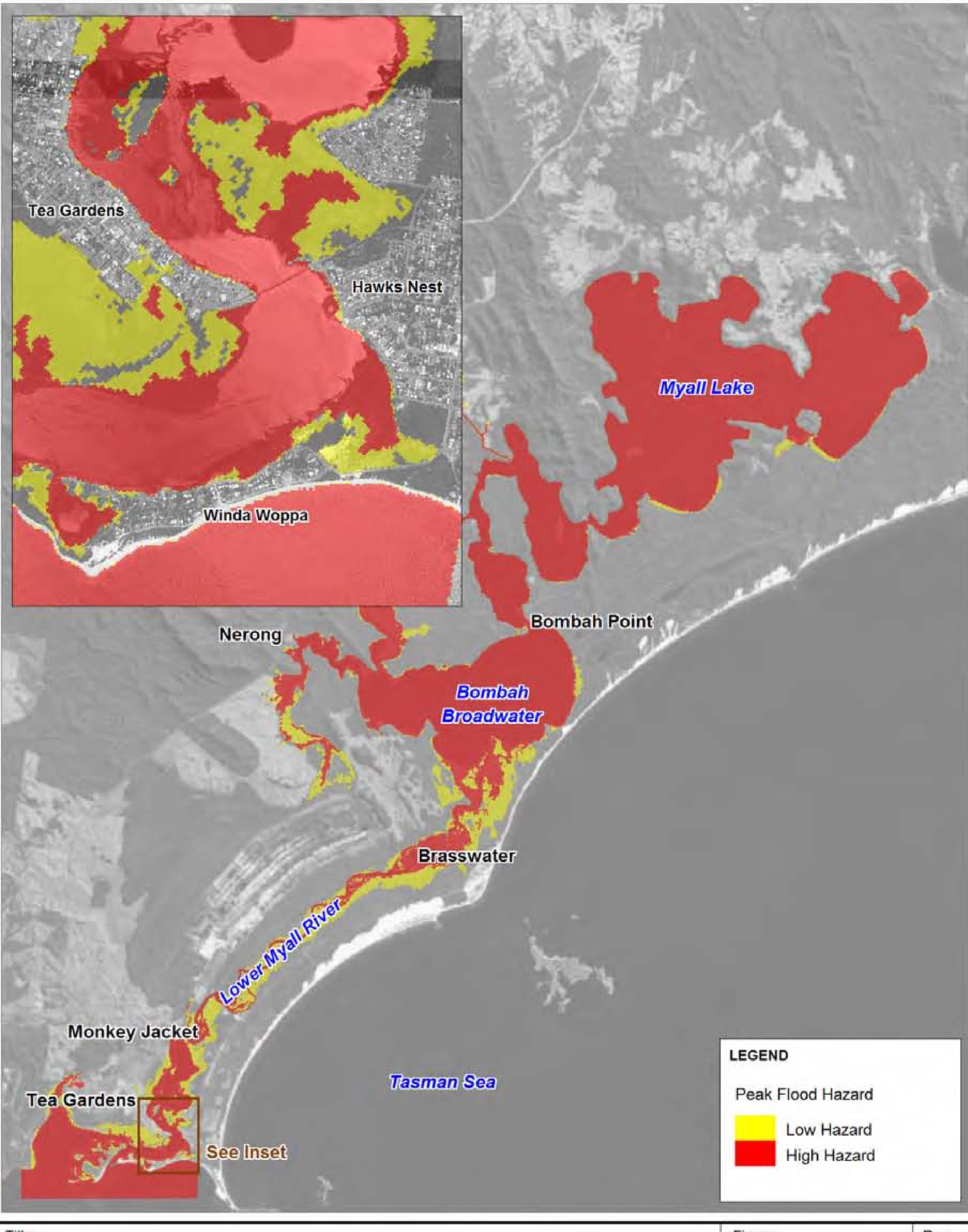


Title:

Lower Myall Flood Study - Peak Flood Hazard: 20% AEP Event

Figure: **Haz_20%**

Rev: **A**

N

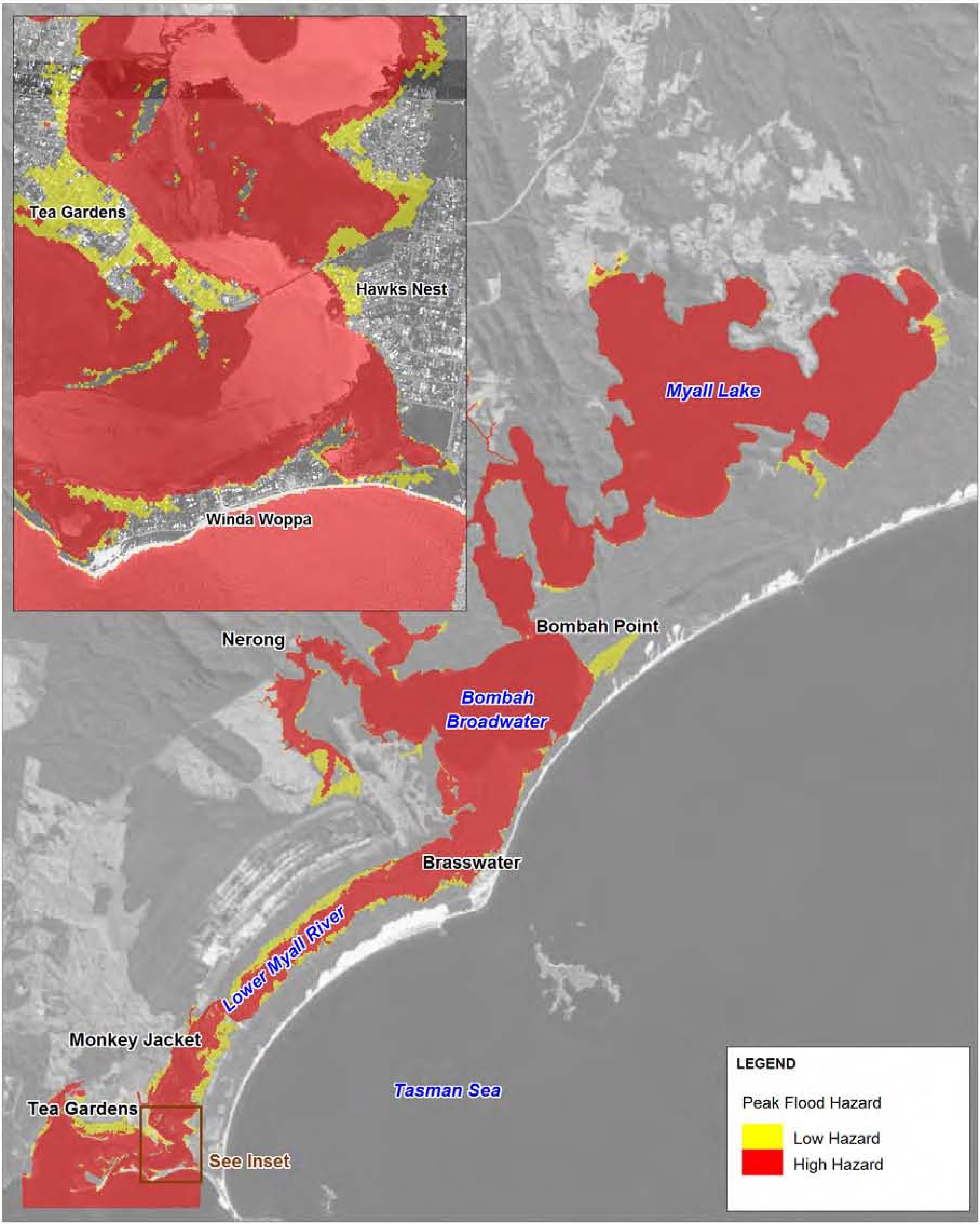
0 3.75 7.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_122_Hazard_20%AEP.WOR



Title:

Lower Myall Flood Study - Peak Flood Hazard: 1% AEP with 0.5m Sea Level Rise Event

Figure: **Haz_0.5mSLR**

Rev: **A**

BMT WBM
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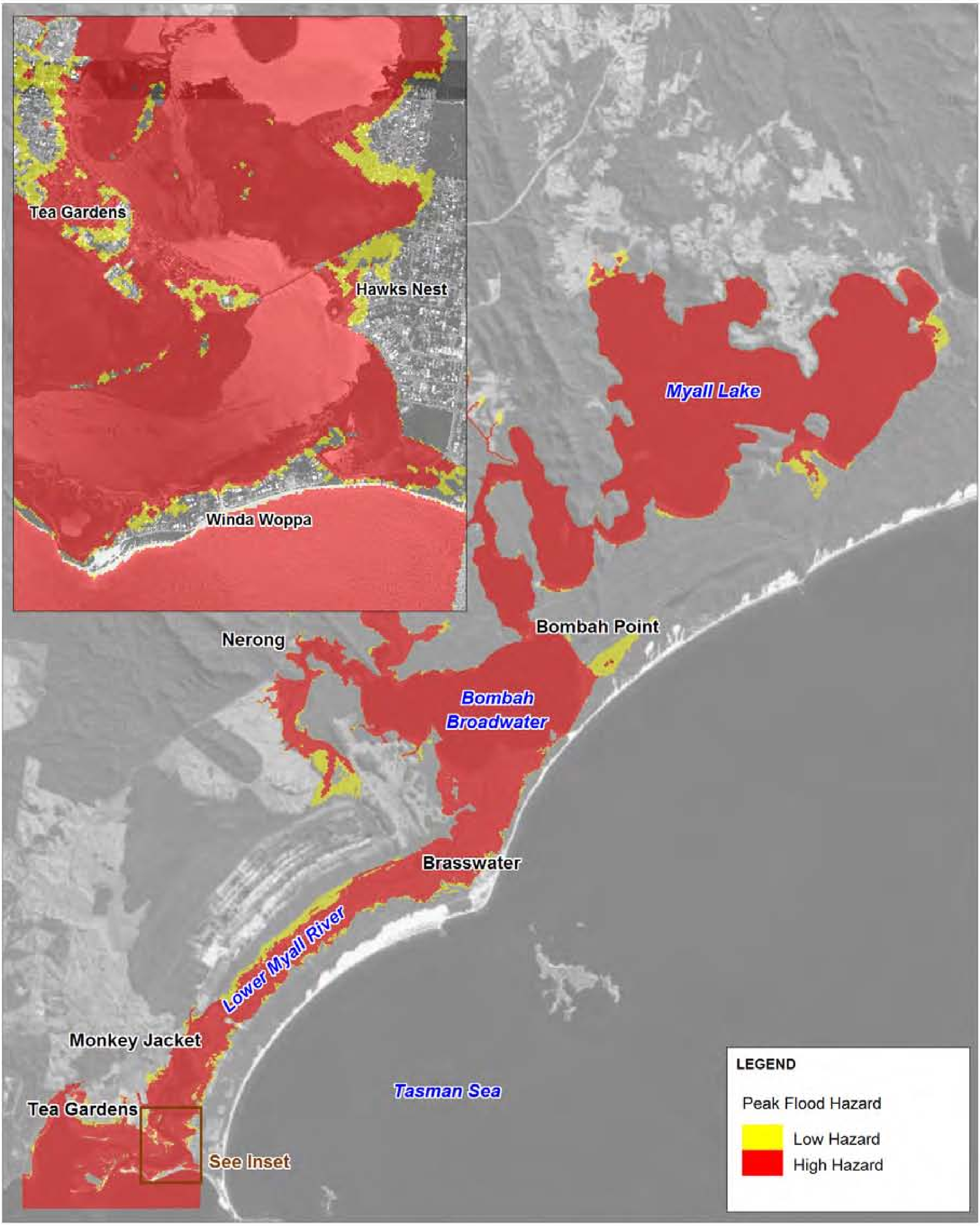
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_123_Hazard_1%_0.5mSLR.WOR



Title:

Lower Myall Flood Study - Peak Flood Hazard: 1% AEP with 0.9m Sea Level Rise Event

Figure: **Haz_0.9mSLR**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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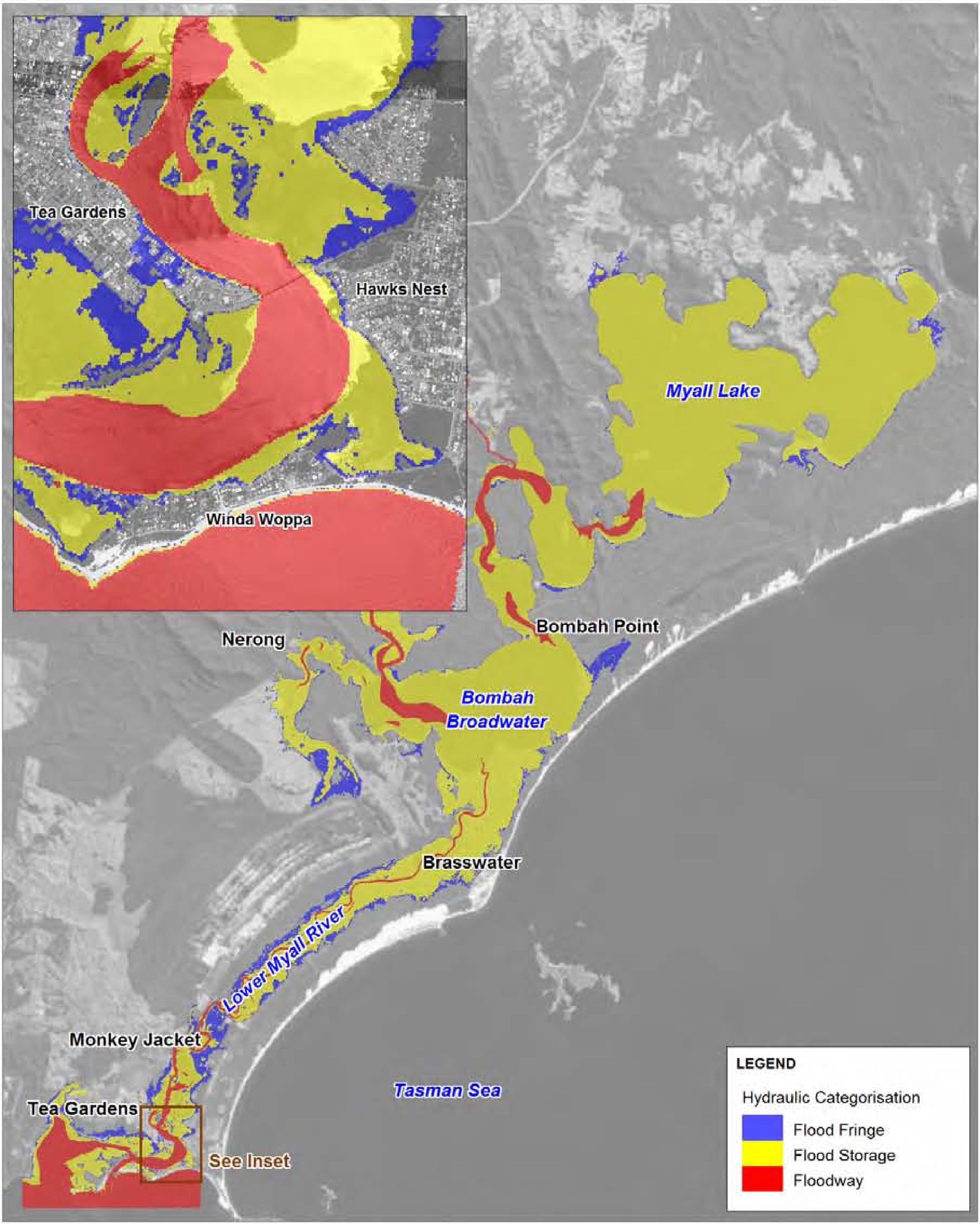
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_123_Hazard_1%_0.9mSLR.WOR



Title:

Lower Myall Flood Study - Hydraulic Categories: 1% AEP Event

Figure: HydCat_1%

Rev: A

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N

0 3.75 7.5km

Approx. Scale

BMT WBM

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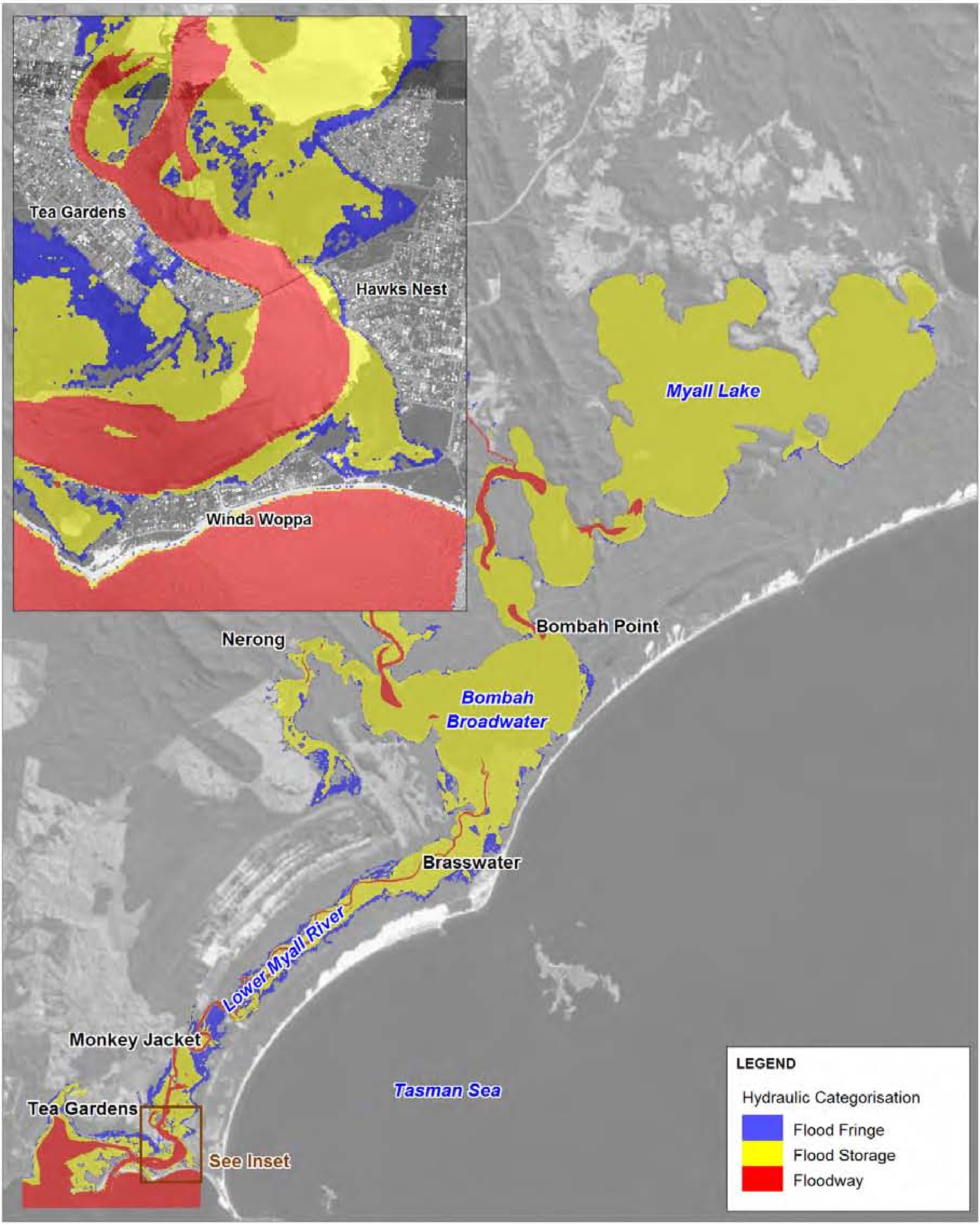
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_125_HydCat_1%AEP.WOR



Title:

Lower Myall Flood Study - Hydraulic Categories: 5% AEP Event

Figure: **HydCat_5%**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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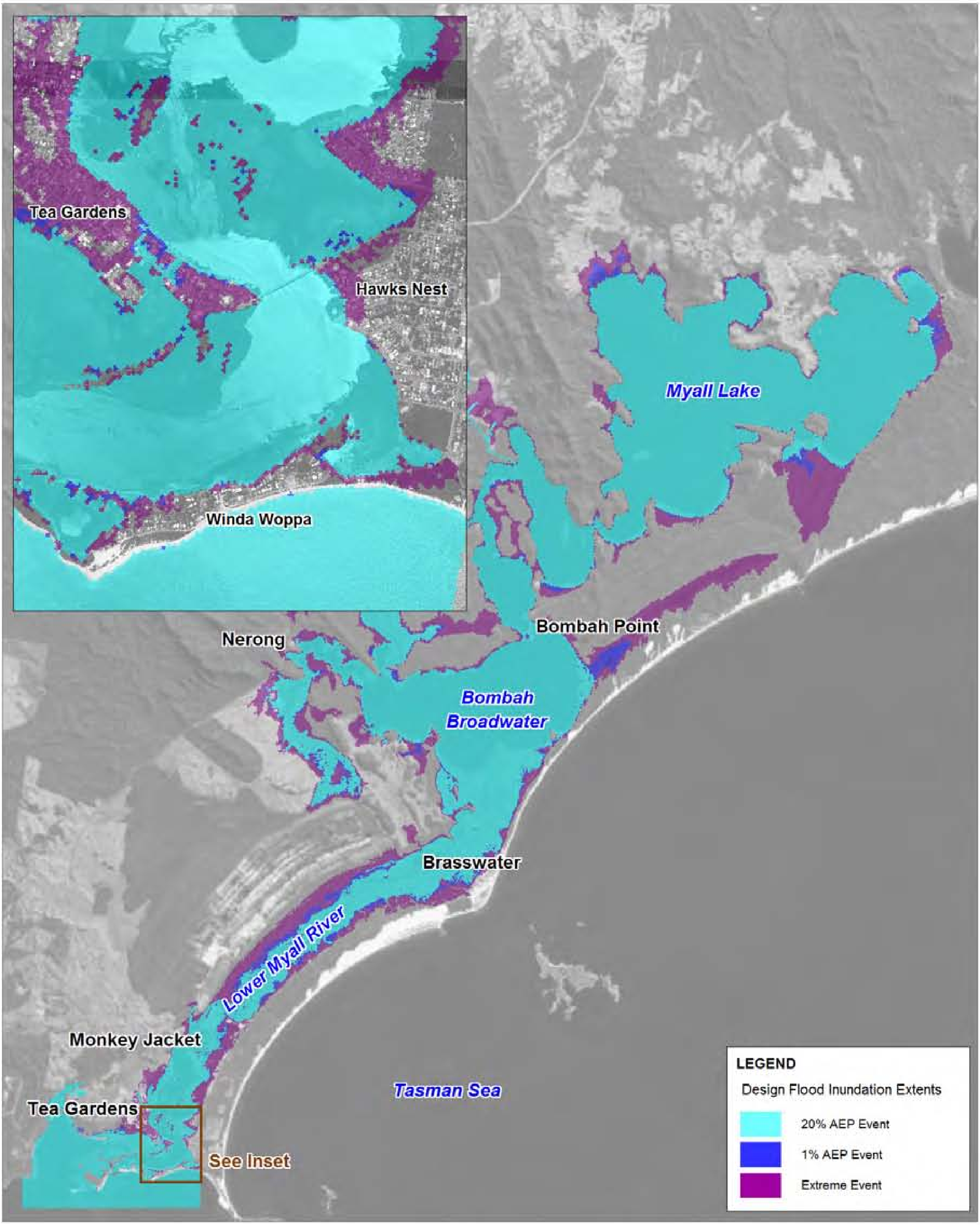

Title:

Lower Myall Flood Study - Design Flood Inundation Extents

Figure: **Des_In_Ex**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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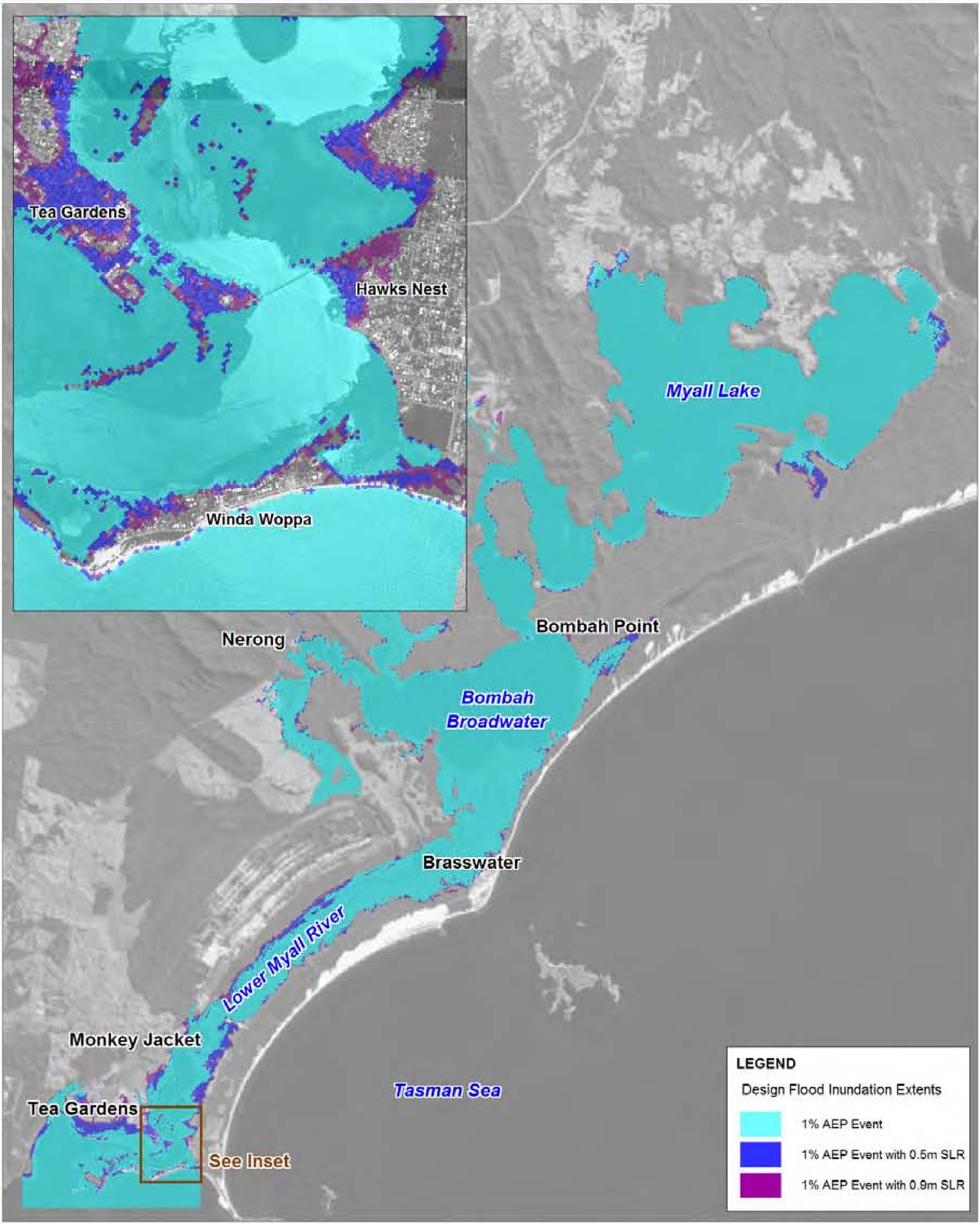

Title:

Lower Myall Flood Study - Design 1% AEP Flood Inundation Extents with SLR

Figure:	Rev:
SLR_In_Ex	A

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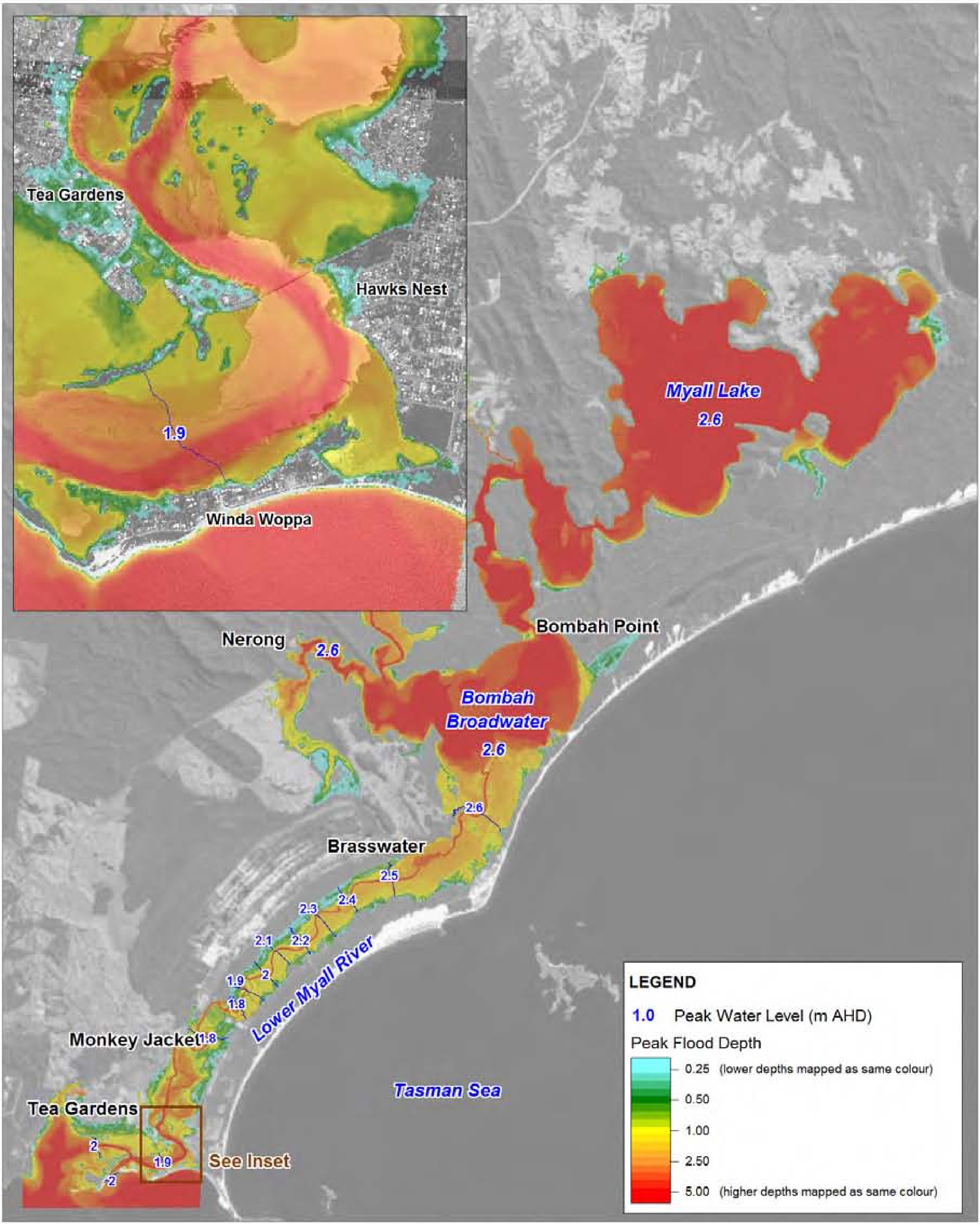
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_128_DesignExtents_1%wSLR.WOR



Title:

Lower Myall Flood Study: 0.5m SLR, 1% AEP Flood Event Peak Flood Depths and Water Levels

Figure: **Dep1% 0.5mSLR**

Rev: **A**

N

0 3.75 7.5km

Approx. Scale

BMT WBM

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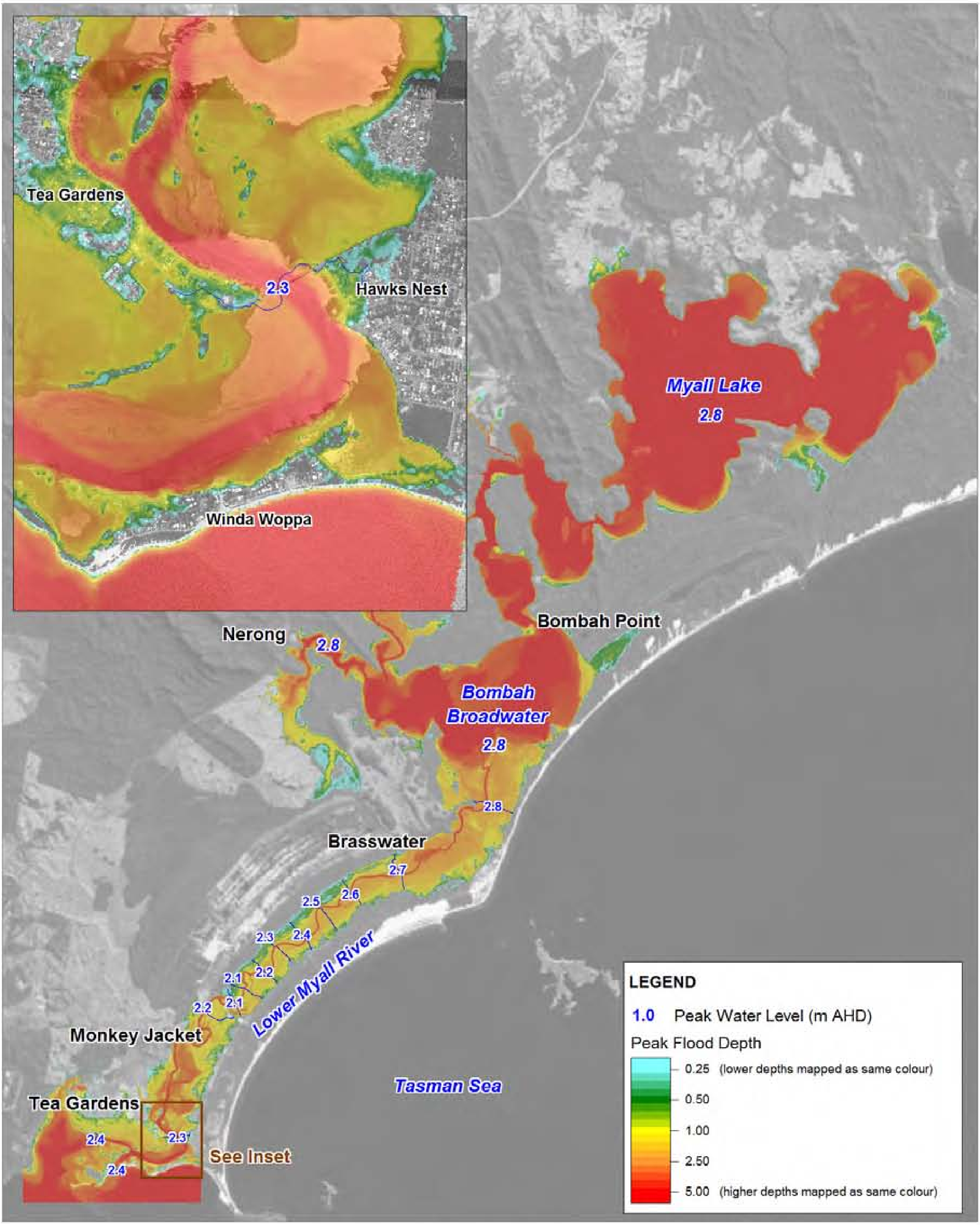


Title:

Lower Myall Flood Study: 0.9m SLR, 1% AEP Flood Event
Peak Flood Depths and Water Levels

Figure: **Dep1% 0.9mSLR**

Rev: **A**

N

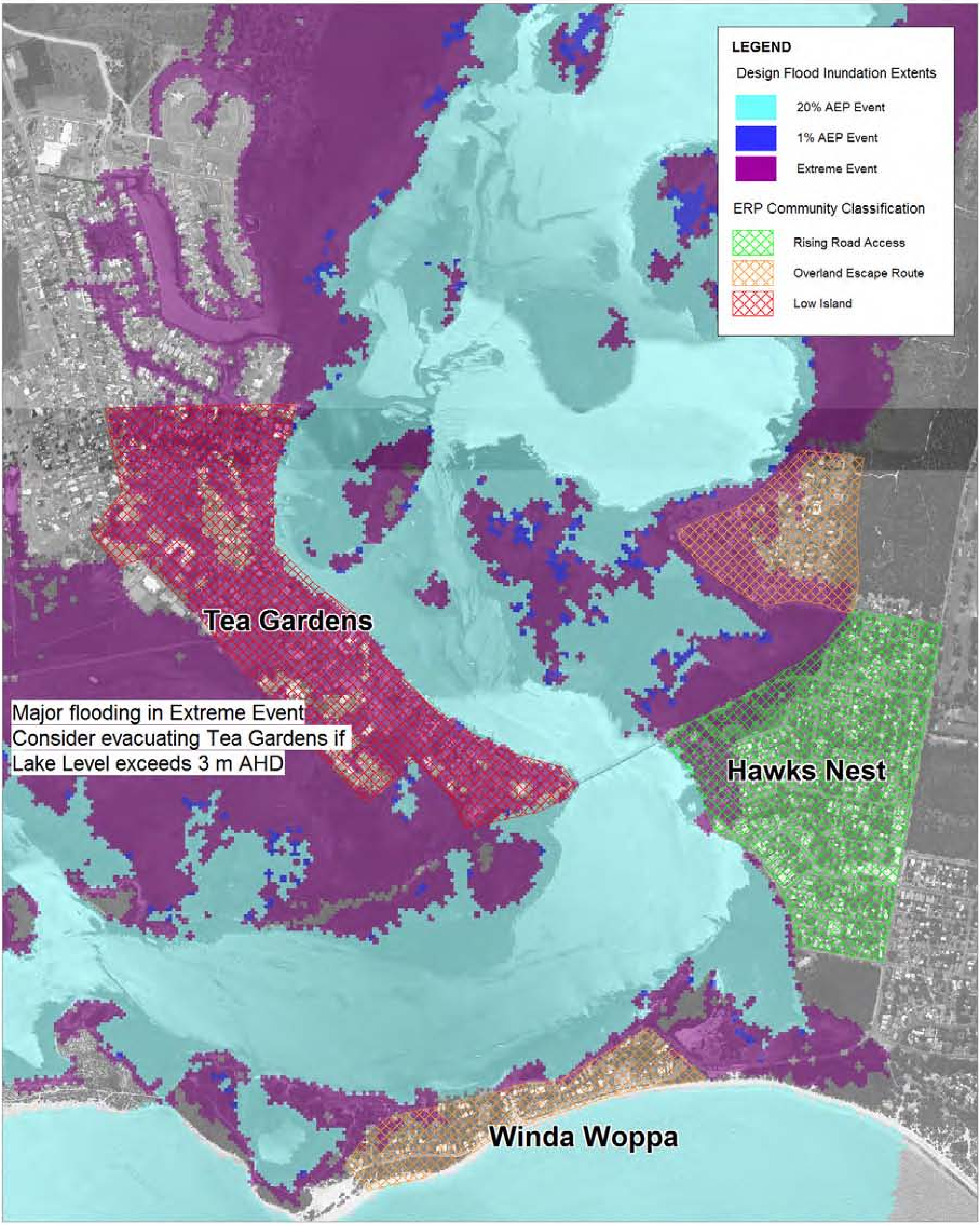
0 3.75 7.5km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_132_PeakDepth&WL_1%AEP_0p9mSLR.WOR



Title:

Lower Myall Flood Study: Emergency Response Planning Community Classification for Catchment Flood Events

Figure: **ERP_Rain**

Rev: **A**

N

0 250 500m

Approx. Scale

BMT WBM

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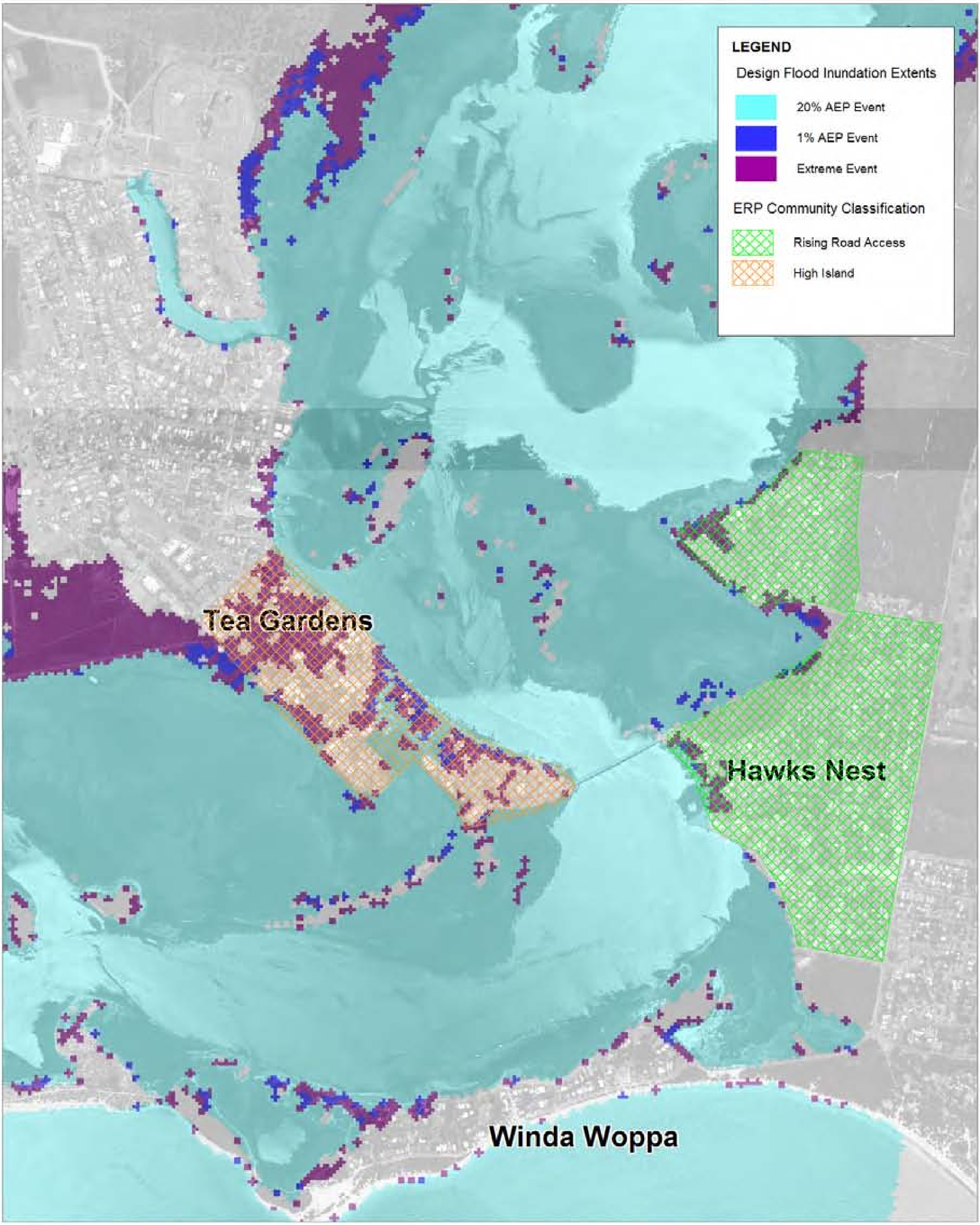
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_129_ERP_Rain_DesignExtents.WOR



Title:

Lower Myall Flood Study: Emergency Response Planning Community Classification for Ocean Flood Events

Figure: ERP_Tide

Rev: A

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N

0 250 500m

Approx. Scale

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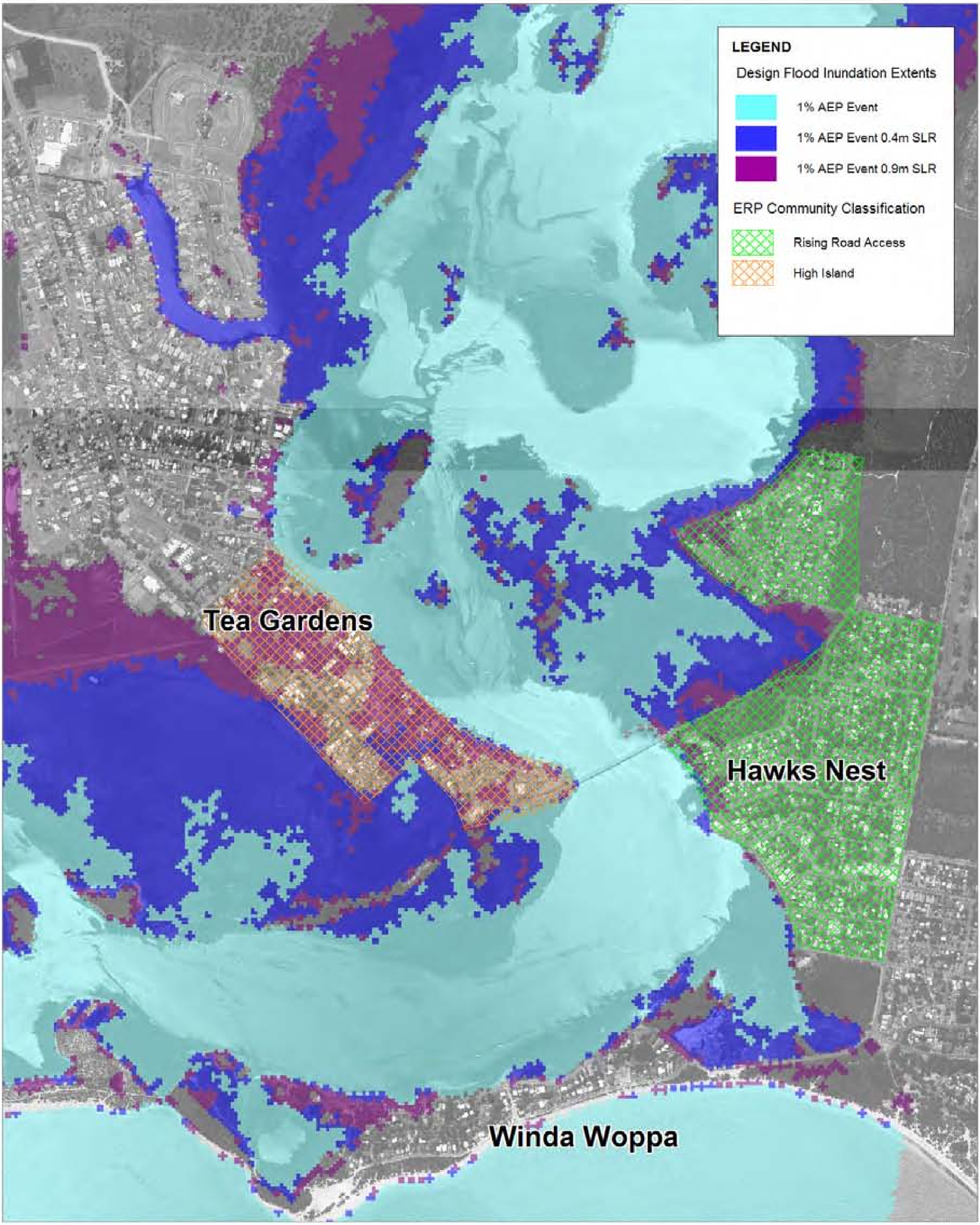
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_130_ERP_Tide_DesignExtents.WOR



Title:
Lower Myall Flood Study: Emergency Response Planning Community Classification for SLR Catchment Flood Events

Figure: ERP_SLR_Rain

Rev: A

BMT WBM
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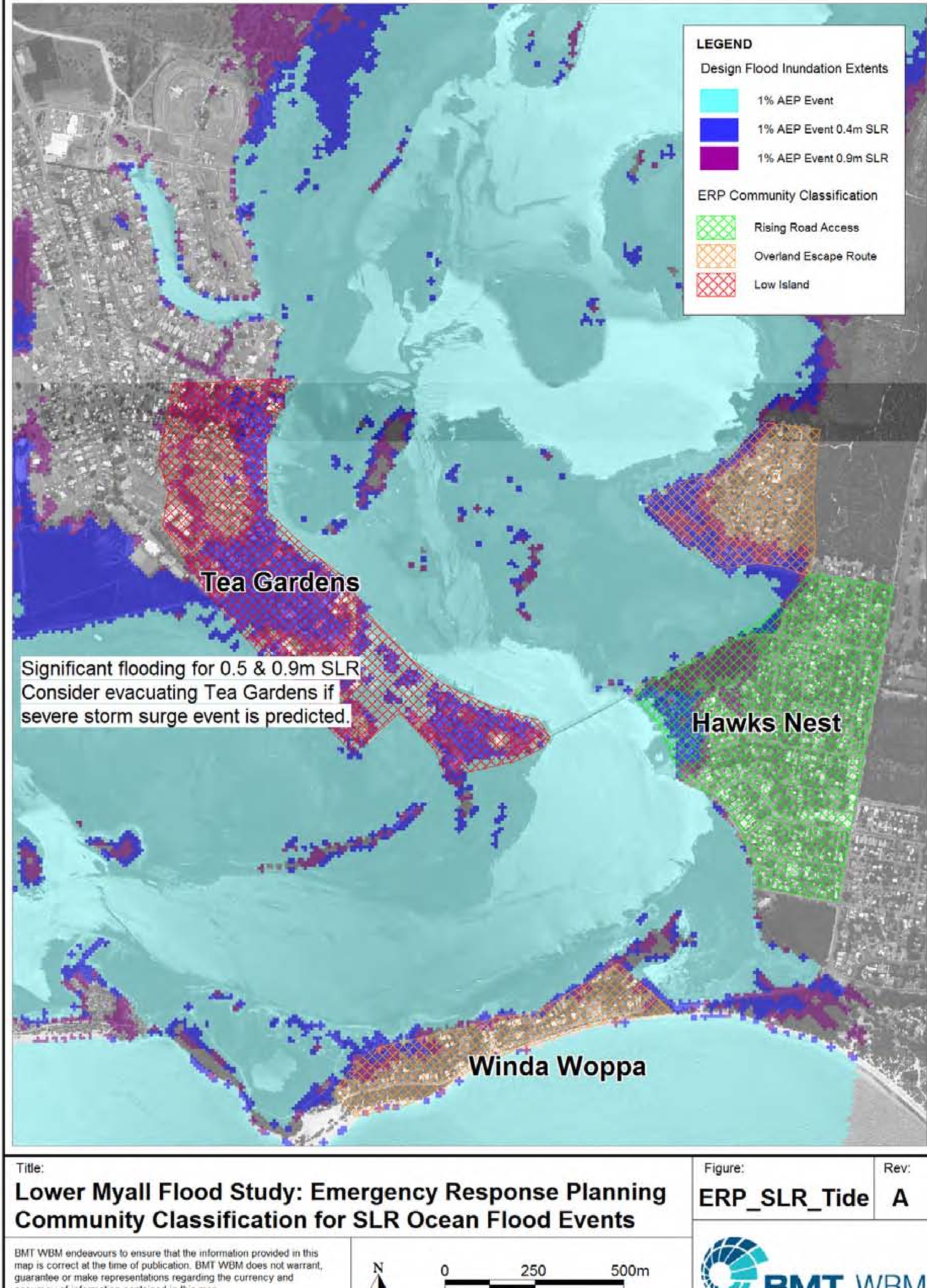
Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_131_ERP_SLR_Rain_DesignExtents.WOR



Title:

Lower Myall Flood Study: Emergency Response Planning Community Classification for SLR Ocean Flood Events

Figure: ERP_SLR_Tide

Rev: A

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Filepath : K:\N2247_Lower_Myall_Lakes_Flood_Study\MI\Workspaces\DWG_132_ERP_SLR_Tide_DesignExtents.WOR

APPENDIX C: DESIGN INITIAL WATER LEVEL INVESTIGATIONS

C.1 Introduction

An investigation into the appropriate setting of a design initial water level (IWL) was undertaken to ensure appropriate design conditions were adopted in the flood study. The additional analysis included investigations into:

- the rate at which lake levels fell;
- extending the lake level data series using Bulahdelah water level data;
- examining rainfall data to determine the occurrence of multiple significant events in a short space of time; and
- the influence of IWL conditions on design levels.

C.2 Rate of Lake Level Fall

A series of model runs were used to determine the rate of water level fall in the lakes. By understanding the rate at which the water level falls, the influence of a number of storms in close succession on initial lake level can be better understood.

A graph showing the modelled rate of lake level fall is presented in Figure C-1. The data was generated using the numerical model to run two events. The first model run was for 30 days from an IWL of 3.4 m AHD while the second model run was from an IWL of 1.2 m AHD (no additional inflows assumed). Below approximately 0.5 m AHD the tide begins to influence the rate of lake drainage.

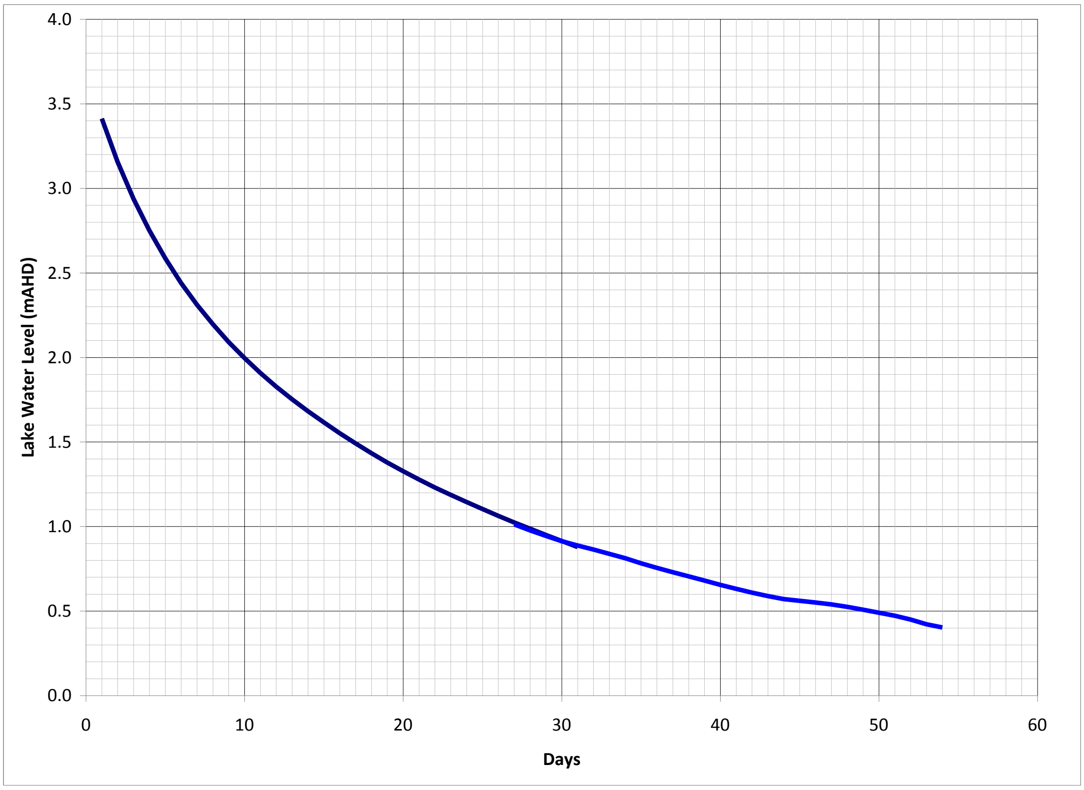

Figure C-1 Modelled Lake Level Fall

The modelled lake level fall data has been analysed to produce data showing the rate of lake fall (m/day) for a range of lake levels (Table C-1) and also the length of time (i.e. days) it takes for the lake to drain from a given level (Table C-2). The data shows that the lake drains much more rapidly at higher levels than at lower levels. Below approximately 1.0 m AHD tides begin to influence lake drainage such that by a lake level of 0.5 m AHD water level decreases can range between 1 and 3 cm per day.

The drainage duration data presented in Table C-2 show that while it only takes 10 days for the lake to fall from 1.5 to 1.0 m AHD it will take 21 days to drain from 1.0 to 0.5 m AHD and nearly two weeks to drain from 0.75 to 0.5 m AHD.

Table C-1 Rate of Lake Level Fall (Modelled)

Level (mAHD)	Daily Lake Fall (m/day)
3.5	0.26
3.0	0.19
2.5	0.13
2.0	0.09
1.5	0.06
1.1	0.04
0.7	0.03

Table C-2 Summary of Lake Level Fall (Modelled)

Level (mAHD)	Duration (days)
3.0 to 2.0	7
2.0 to 1.5	7
1.5 to 1.0	10
1.0 to 0.75	8
0.75 to 0.5	13

C.3 Extend Lake Level Record using Bulahdelah WL Data

The MHL water level gauge at Bombah Point was installed on 17/7/2001 (see Section 2.2.2) while the Bulahdelah gauge was installed on 15/11/1984. While the Bulahdelah gauge is located in a backwater channel of the lake (and hence can be used to provide lake level data), water levels at this location are also influenced by channel discharge and hence the data must be processed in order to provide a good estimate of lake water levels. A suitable procedure was determined (as described below) and was used to extend the lake level record by an additional 17 years. This procedure was checked using the period when both gauges were operational and found to provide a good estimate of lake levels.

An analysis of typical Myall Channel inflows during a flood event (i.e. see Figure 5-10, Figure 5-16, Figure 5-21 and Figure 5-27) indicated that for most events high channel levels (above lake levels) only lasted for 2-3 days. Therefore, by taking a rolling 3 day minimum, the majority of fluvially influenced water levels could be removed from the Bulahdelah record. By further removing any daily water level changes greater than 0.1 m/day a good match to observed lake levels was achieved.

Lake water level exceedance statistics based on the 28 years of corrected Bulahdelah data is presented in Table C-3 alongside the statistics based on 11 years of available Bombah Point data. Comparison of the exceedance statistics based on the 11 and 28 years water level series show that the additional data only changes the exceedance levels by a few centimetres and that the 10% exceedance lake level is still approximately 0.5 m AHD.

Table C-3 Lake Water Level Exceedance Statistics

Percent Exceedance	Bombah Point Lake Level (mAHD) 11 Years Data	Bulahdelah Lake Level Estimate (mAHD) 28 Years Data	Days/Year
99	-0.09	-0.10	361
90	-0.01	-0.01	329
75	0.06	0.05	274
50	0.15	0.14	183
25	0.30	0.30	91
20	0.35	0.35	73
15	0.41	0.42	55
10	0.50	0.52	37
5	0.68	0.67	18
1	1.05	0.97	3.7
average	0.21	0.21	n/a

C.4 Investigate Long Term Cumulative Rainfall Totals

An analysis of long term daily rainfall data at Bulahdelah was used to see if any information on the likely occurrence of multiple events in a short period of time could be determined from the data. Daily rainfall data at the Bulahdelah PO rain gauge was available from 1905 to 2012. The data was analysed to produce the maximum annual cumulative 7 and 30 day rainfall totals. This data was then plotted (see Figure C-2) to investigate the relationship between 7 and 30 days totals. A 7 day cumulative rainfall total is significant because (as presented in Section 6.1.1) this is the critical duration for the lake. Cumulative totals beyond 30 days were not investigated as lake drainage rates indicate that the lake can be significantly drained over a 30 day period.

From Figure C-2 we can see that there is a reasonable amount of scatter in the data, however, between 40% and 80% of maximum annual 30 day cumulative totals fall in a 7 day (event) period. A regression analysis (with a R^2 of 0.74) on the 107 years of data indicates that, on average, 60% of maximum annual 30 day cumulative totals fall in a 7 day period. This analysis indicates that a substantial amount of rainfall may fall in short succession to a large flood event. An example of this would be if there was a 300 mm design 7 day event, it would be likely that an additional 0.4 x 300 mm = 120 mm may fall in the 23 days before or after the event. If the majority of rain fell before the 7 day design event a higher initial lake level may occur. However, the analysis cannot tell us whether the additional rainfall will have fallen before or after the 7 day event and is therefore of limited use to the initial water level analysis.

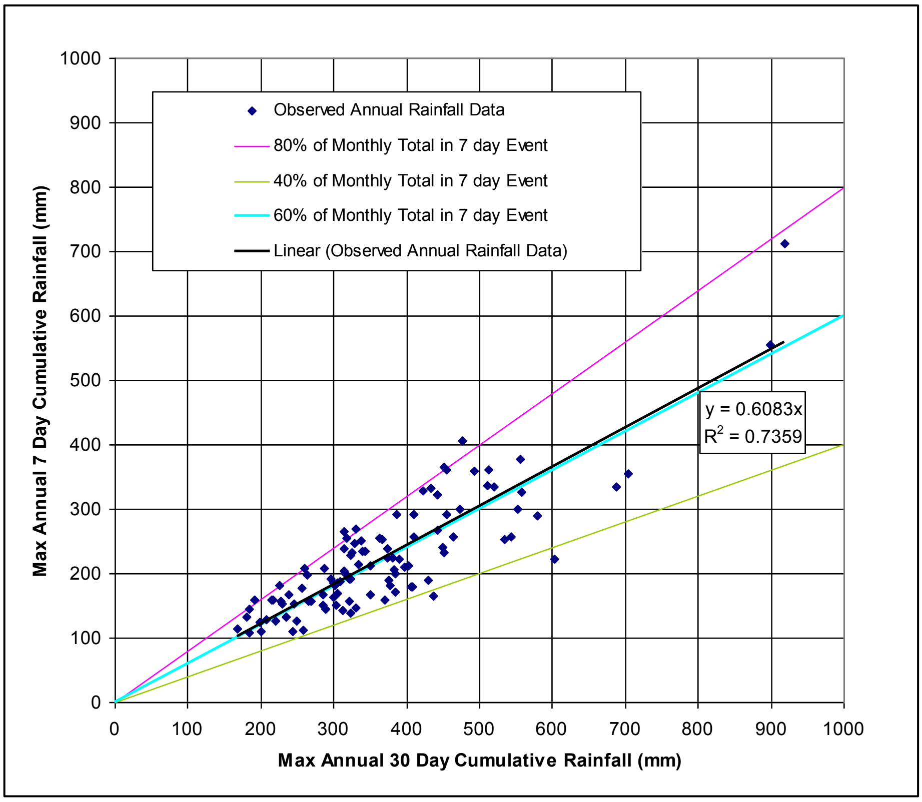

Figure C-2 7 Day vs 30 Day Max Cumulative Rainfall Totals

C.5 Additional Sensitivity Tests of IWL on 1% AEP Event

In addition to the sensitivity testing of initial water level (IWL) presented in Section 7.11, two additional 1% AEP catchment events were modelled. These investigated initial lake levels of 0.25 and 0.75 m AHD and have been compared to the adopted design IWL of 0.5 m AHD as presented in Figure C-5. From the figure we can see that a difference in initial lake of 25 cm results in a difference in peak level of approximately 10 cm along the Lower Myall, above Kangaroo Island reducing to less than 5 cm below Monkey Jacket.

A summary of peak lake levels for the 1% AEP catchment events for five different initial lake levels is presented in Table C-4.

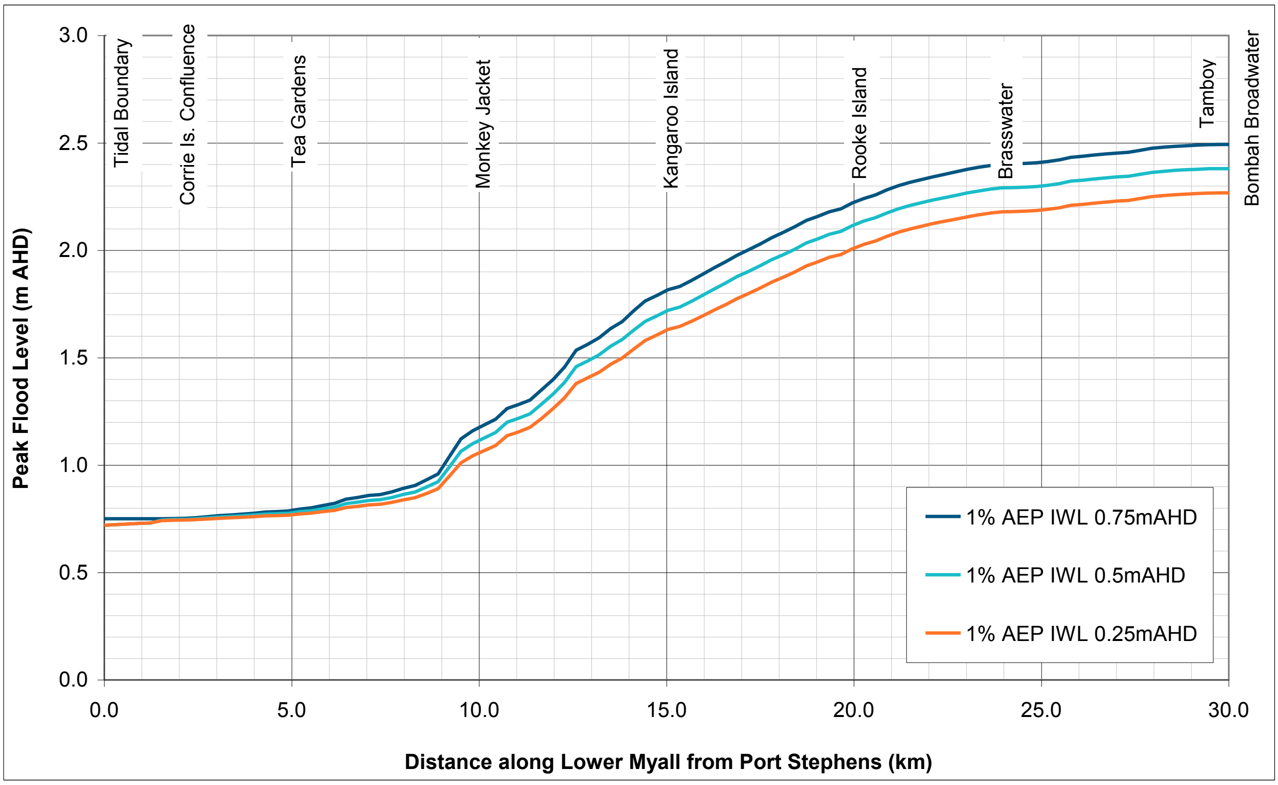

Figure C-3 Peak Water Level Profiles for IWL Sensitivity Tests (1% AEP Catchment Event)

Table C-4 IWL and Peak 1% AEP Lake Level

Initial Water Level (mAHD)	Peak Lake Level (mAHD)	Difference Compared to Design IWL
1.00	2.61	+0.23
0.75	2.49	+0.11
0.50	2.38	0.00
0.25	2.27	-0.11
0.00	2.15	-0.23

C.6 Discussion of Adopted Design IWL

The previous Lower Myall Flood Study (PWD, 1980) adopted an initial water/lake level (IWL) of 0.5 m AHD. Analysis of 11 years of Bombah Point water level data shows that a lake level of 0.5 m AHD is exceeded for less than 10% of the time (i.e. less than 37 days/year). By extending the lake water level record to 28 years (using corrected Bulahdelah data) a similar 10% exceedance value is obtained (Table C-3).

It is important to remember that a high initial lake level would have been generated by a fairly significant rainfall event, the occurrence of two storms in short succession needs to be considered. By analysing the rate of lake drainage (Section C-2) we can see from Table C-3 that it takes 8 days for the lake to drain from 1.0 m AHD to 0.75 m AHD and a further 13 days to drain from 0.75 m AHD to 0.5 m AHD. The rate of lake drainage indicates that it would be pointless to analyse cumulative rainfall totals beyond about 30 days. 107 years of daily rainfall data was analysed to produce annual maximums for cumulative 7 and 30 day rainfall totals. It was found that maximum annual 7 day rainfall totals typically account for 60% of maximum annual 30 day rainfall totals. This indicates that a significant volume of rain (and hence runoff) could fall within 23 days of a large 7 day rain event, producing a reasonable high initial lake level. However, given the reasonable amount of scatter in the data and that rain may equally occur before or after the shorter duration event no firm conclusions could be drawn from the rainfall analysis.

Examination of the March 2013 validation event shows that while an initial water level of 0.8 m AHD was used for the validation exercise (Section 5.6), a longer (9 day) duration event coupled with an initial lake level of 0.4 m AHD (see Figure 10-1) would also have been possible. Comparing a catchment average rainfall in the order of 350 mm to design rainfall depths presented in Table 6-4 indicates that this event is likely to be associated with a 10% AEP design rain event (allowing for a slightly longer duration). This event produced a peak lake level of 1.75 m AHD which is in agreement with results presented in Table 7-1 which calculate a 10% AEP design lake level of 1.78 m AHD.

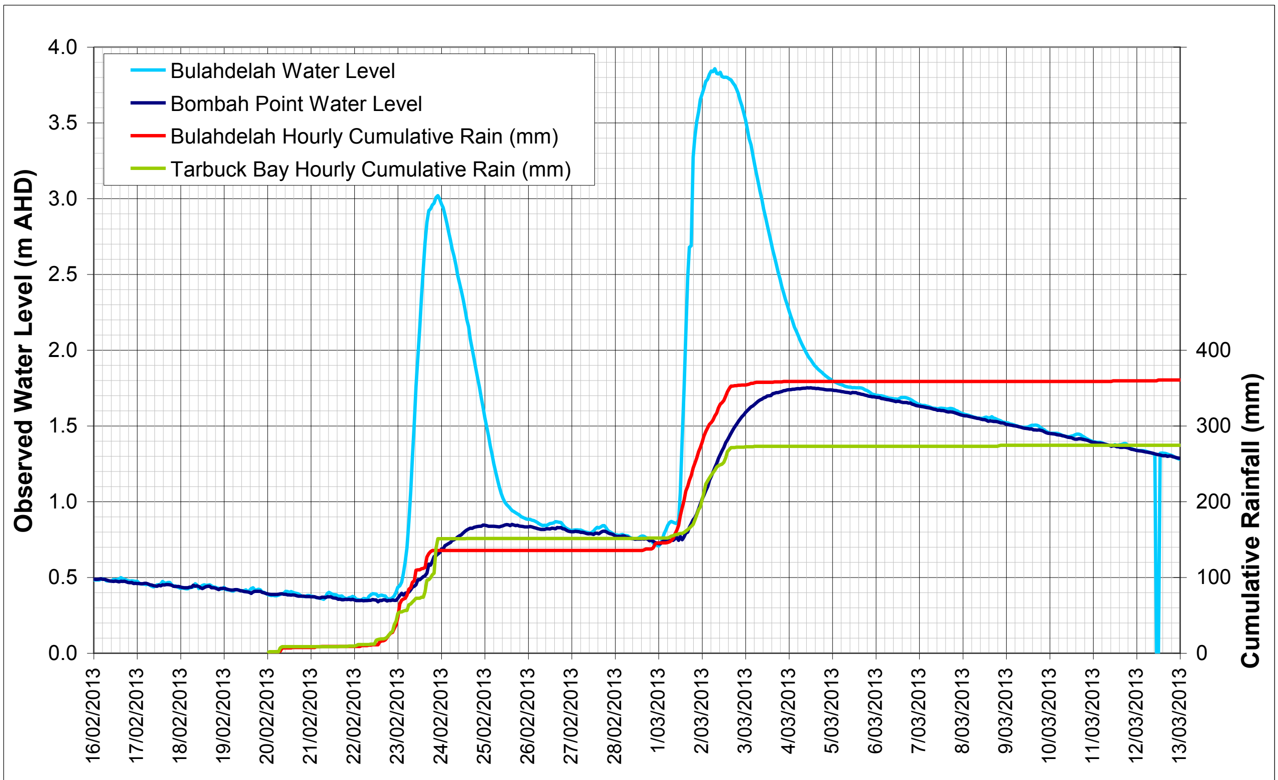

Figure 10-1 Observed Water Levels and Cumulative Rainfall – Feb - March 2013

A consideration of the rate of lake level drainage and lake water level exceedance statistics indicate that a design IWL of between 0.25 and 0.75 m AHD could be applicable. Sensitivity testing of a range of IWL's indicates that peak lake levels are only likely to vary by ~0.1 m from the adopted design IWL of 0.5 m AHD for the range of likely lake initial water levels. This analysis indicates that the adoption of a 0.5 m AHD initial lake level is likely to be a good and practical estimate of IWL for design conditions.