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Tweed-Byron Coastal Creeks Flood Study

Final Report

November 2009

Department of Environment, Climate Change and Water NSW

TWEED SHIRE COUNCIL

Byron SHIRE COUNCIL

Tweed Byron Coastal Creeks Flood Study Final Report

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Title :	Tweed Byron Coastal Creeks Flood Study - Final Report
Author :	Fanny Houdré, Phillip Ryan
Synopsis :	Flood study report for the coastal creeks between Kingscliff and Ocean Shores. This document covers data collection, development and calibration of computer models, establishment of design flood behaviour and flood mapping.

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FOREWORD

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

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

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

Stages of Floodplain Risk Management Process

	Stage	Description
1	Flood Study	Determines the nature and extent of the flood problem.
2	Floodplain Risk Management Study	Evaluates management options for the floodplain in consideration of social, ecological and economic factors.
3	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management with preferred options for the floodplain.
4	Plan Implementation	Implementation of flood mitigation works, response and property modification measures by Council.

This study represents the first of the four stages for the coastal creeks in the Tweed and Byron areas. It has been prepared for Tweed Shire Council and Byron Shire Council to describe and define the existing flood behaviour and establish the basis for floodplain risk management activities in the future.

EXECUTIVE SUMMARY

The coastal creeks of northern New South Wales between Brunswick Heads and Tweed Heads have a long history of flooding, with a major flood event occurring recently in June 2005. Flood behaviour in this area is complex due to the multitude of creeks and hydraulic connections between major floodplains, including the Mooball Creek catchment in Tweed Shire and the Yelgun and Marshalls Creek catchments in Byron Shire. Both Councils have therefore jointly undertaken a new flood study covering the Cudgen, Cudgera, Mooball, Yelgun and Marshalls Creeks.

This Coastal Creeks Flood Study is the first key stage in the floodplain management process as outlined in the New South Wales *Floodplain Development Manual*. The key outputs of the study, including a 1D/2D hydrodynamic TUFLOW model, design flood levels, depths, velocities and flows across the floodplains, will form the basis for the subsequent Floodplain Risk Management Studies and Plans for each of the coastal creeks.

The study area covers approximately 300 km^2, including 110 km^2 of the Mooball Creek catchment, 100 km^2 of the Cudgen Creek catchment, 40 km^2 of the Marshalls Creek catchment, and 35 km^2 of the Cudgera Creek catchment. These catchments are bisected in a north-south direction by the Pacific Highway, with predominantly agricultural and forested areas upstream and a mixture of agricultural land, sugar cane farms, forested and urban areas downstream. Cudgen, Cudgera and Mooball Creeks flow to the ocean, and Marshalls Creek flows into the Brunswick River approximately 1.2km from the mouth.

The townships of Bogangar/Cabarita Beach, Hastings Point, Pottsville, Burringbar, Mooball, Wooyung, Crabbes Creek, Billinudgel, South golden Beach and New Brighton all have frequently experienced inundation from floodwaters, originating from two typical sources: heavy rainfall over the catchments and/or high tailwater levels in the ocean due to storm surge or exceptional tidal conditions. A major flood event occurred across all catchments in June 2005, which resulted in above floor level flooding of a significant number of buildings across the study area. Other significant flood events occurred in May 1987 and March 1974, although these events were more localised (mainly Cudgen, Mooball Creek and Marshalls Creek in 1987 and Marshalls Creek in 1974).

A Digital Elevation Model was developed for the whole study area based on 2007 Aerial Laser Survey data, together with bathymetric surveys of the lower sections of the main creeks available within the lower sections of the floodplains. RAFTS-XP hydrologic and TUFLOW 1D/2D hydraulic models were developed and jointly calibrated to the June 2005 flood event, and verified against the May 1987 and March 1974 floods. The models were then used to simulate a range of design events for the existing catchment conditions. The 5, 10, 20, 50, 100 and 500 year ARI, as well as the PMF event, were simulated for three selected duration storms: 6 hours, 24 hours and 36 hours. These durations were defined as being the most critical in terms of peak flood levels across the study area. Catchment inflow and runoff were combined with downstream ocean and storm surge levels adopted in consultation with DECCW, TSC and BSC staff. The 100 year ARI design flood for the study area was adopted as the maximum envelope of two scenarios: a catchment dominated event (i.e. 100 year ARI rainfall event and 20 year ARI storm surge) and an ocean dominated event (i.e. 10 year ARI rainfall event and 100 year ARI storm surge).

The impacts of climate change on the 100 year ARI design flood levels and behaviour were also assessed as part of the Flood Study, based on two scenarios selected in consultation with DECCW, TSC and BSC staff: a 'medium' impacts scenario (i.e. 20% increase in rainfall intensity and 55cm increase in sea level) and a 'high' impacts scenario (i.e. 30% increase in rainfall intensity and 91cm increase in sea level).

Both digital and hard copy maps were generated of modelled design flood levels, depths and velocities across the range of design events. These maps will be used for the purpose of floodplain management and development planning.

Following approval of this Flood Study the following actions are recommended:

- Update Flood Planning Levels based on the results of this Flood Study, as well as Local Environmental Plans and Development Control Plans as appropriate;
- Update Councils GIS systems with the flood mapping outputs from this Flood Study;
- Update S149 certificates for properties affected by flooding;
- Proceed to the preparation of the Floodplain Risk Management Study, to determine options to manage and/or reduce the flood risk taking into consideration social, ecological and economic factors.
- Byron Shire Council should also consider the interactions between Marshalls Creek and the Brunswick River prior to undertaking the Floodplain Risk Management Study for this area.
- On completion of the Floodplain Risk Management Study, preferred options recommended by each Council will be presented in a Floodplain Risk Management Plan publicly exhibited for subsequent implementation by Council.

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GLOSSARY

Annual Exceedance Probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (i.e. a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year. (see also Average Recurrence Interval).
Australian Height Datum (AHD)	Common national survey datum corresponding approximately to mean sea level.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20 year ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also Annual Exceedance Probability)
Catchment	The area of land draining through the main stream (as well as tributary streams) to a particular site. It always relates to an area above a specific location.
Design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year 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. Refer to Part 4 of the EP&A Act for further details.
Discharge	The rate of flow water measured in terms of volume ove rtime (i.e. the amount of water moving past a point). Discharge and flow are interchangeable.
Digital Elevation Model (DEM)	A three-dimensional model of the ground surface elevation.
Digital Terrain Model (DTM)	A three-dimensional model of the ground surface (potentially including several parameters such as elevation, surface texture). Often used interchangeably with DEM.
Flood	Relatively high river, creek, estuary, lake or dam flows, which overtop the natural or artificial banks, and inundate floodplains, and/or local overland flooding associated with drainage before entering a watercourse, and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood behaviour	The pattern, characteristics and nature of a flood, including flood levels, velocities and flows.
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	Land susceptible to flooding by the PMF event. See also Flood Prone Land. Flood liable land covers the whole floodplain, not just that part below the flood planning levels.

Floodplain	Area of land subject to inundation by floods up to and including the probable maximum flood (PMF) event, i.e. flood prone land.
Floodplain management	The co-ordinated management of activities that occur on the floodplain.
Flood Planning Levels (FPL)	Combination of flood levels derived from historical flood events or floods of specific AEPs plus freeboard selected for floodplain risk management purposes, as determined in management studies and incorporated in Floodplain Risk Management Plans. Selection of these levels 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.
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 FDM (2005). 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 plan (local)	A sub-plan of a disaster plan specifically dealing with flooding at a state, division or local level. Local flood plans are prepared under the leadership of the SES.
Flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. See also flood liable land.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk is usually divided into 3 types: existing, future and continuing risks. The existing flood risk is the risk a community is exposed to as a result of its location on the floodplain. The future flood risk is the risk a community may be exposed to as a result of new development on the floodplain. The continuing flood risk is the risk a community is exposed to after floodplain risk management measures have been implemented. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
Flood storage areas	Floodplain areas that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity. Loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence it is necessary to investigate a range of flood events before defining flood storage areas.
Floodway areas	Floodplain areas carrying significant volumes (discharges) of floodwaters during a flood. They are often aligned with natural channels. Partial blockage of floodway areas would cause a significant redistribution of flood flows, or a significant increase in flood levels.

Hazard	A source of potential harm or a situation with a potential to cause loss. Flooding is a hazard which has the potential to cause damage to the community. The degree of flood hazard varies with circumstances across the full range of floods. Refer to FDM (2005) for definition of high and low hazard categories.
Historical flood	A flood that has actually occurred in the past.
Hydraulics	The term given to the study of water flow in waterways (i.e. rivers, estuaries and coastal systems).
Hydrograph	A graph showing how the discharge or stage/flood level at any particular location varies with time during a flood.
Hydrology	The term given to the study of the rainfall-runoff processes in catchments.
Left bank	Side of a river which is on the left-hand side of a person whose face is turned downstream.
Peak flood level, flow or velocity	The maximum flood level, flow (i.e. discharge) or velocity that occurs during a flood event.
Probable Maximum Flood (PMF)	An extreme flood deemed to be the largest flood that could conceivably occur at a specific location. It is generally not physically or economically possibel to provide complete protection against this flood event. The PMF defines the extent of flood prone land (i.e. the floodplain).
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
Probability	A statistical measure of the likely frequency or occurrence of flooding. See also AEP.
Right bank	Side of a river which is on the right-hand side of a person whose face is turned downstream.
Runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek, also known as rainfall excess.
Stage	Equivalent to water level. See flood level.
Stage hydrograph	A graph showing the evolution of water level at a particular location over time during a flood.
TUFLOW	Hydrodynamic modelling software package developed by BMT WBM and used in this study.
Velocity	The speed at which floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.
Water level	See flood level.

LIST OF ABBREVIATIONS

1D / 2D	One dimensional / Two dimensional
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff (1987)
BSC	Byron Shire Council
Cm	Centimetre
Cumecs	cubic metres per second
DECC	Department of Environment and Climate Change (now DECCW)
DECCW	Department of Environment, Climate Change and Water (formerly DECC and DIPNR)
DEM	Digital Elevation Model
DIPNR	Department of Infrastructure, Planning and Natural Resources (now DECCW)
DLWC	Department of Land and Water Conservation
DTM	Digital Terrain Model
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
km	kilometre
LGA	Local Government Area
m	metre
m^3/s	cubic metres per second
m AHD	Elevation in metres relative to the Australian Height Datum
PMP	Probable Maximum Precipitation
PMF	Probable Maximum Flood
PW (or PWD)	NSW Public Works (or Public Works Department) (now Department of Services, Technology and Administration)
TSC	Tweed Shire Council

1 INTRODUCTION

1.1 Background

Tweed Shire Council (TSC) is in the process of preparing a Floodplain Risk Management Plan for the Cudgen, Cudgera and Mooball Creeks. This area of the northern NSW coast has a long history of flooding, with a major flood event occurring recently in June 2005.

In large flood events, these three catchments, and specifically Mooball Creek catchment, are hydraulically connected with the catchments of Yelgun and Marshalls Creeks located south of Wooyung in Byron Shire. Catchment interactions have been observed in the past across the Yelgun Creek floodplain. Byron Shire Council (BSC) thus took the opportunity to update its Marshalls Creek Floodplain Management Plan as part of this study.

Figure 1-1 presents the location and extent of the study area.

Title:

Locality Plan

Figure: **1-1**

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1.2 Funding Arrangements

This Flood Study was undertaken as a joint study between TSC and BSC. TSC was granted a fund under the 2007-2008 Natural Disaster Mitigation Program (NDMP) to undertake this Flood Study. The total cost was thus funded in a ratio of one third (⅓) Council, one third (⅓) NSW State Government and one third (⅓) Commonwealth. A principle agreement between the Councils was made to share the Council portion of the cost based on a ratio of one quarter (¼) BSC and three quarters (¾) TSC.

1.3 General Floodplain Management Approach

Floodplain management in NSW generally follows the guidelines described in the *Floodplain Development Manual* (FDM, 2005). It states that the implementation of the flood policy requires a floodplain management plan that ensures:

- The use of flood prone land is planned and managed in a manner compatible with the assessed frequency and severity of flooding, including cumulative impact;
- Flood prone lands are managed having regard to social, economic and ecological costs and benefits, to individuals as well as the community;
- Floodplain management matters are dealt with having regard to community safety, health and welfare requirements;
- Information on the nature of possible future flooding is available to the public;
- All reasonable measures are taken to alleviate the risk and damage potential resulting from development on floodplains;
- There is no significant growth in risk and damage potential resulting from new development on floodplains; and
- Appropriate and effective flood warning systems exist, and emergency services are available for future flooding.

The steps involved in formulating a Floodplain Risk Management Plan are outlined in the Manual, and include:

1 Establishment of a Floodplain Risk Management Committee

2 Data Collection

3 Flood Study

4 Floodplain Risk Management Study

5 Floodplain Risk Management Plan

6 Implementation of Plan

Community consultation is a strong element through the entire process. The Flood Study should also address the possible impacts of climate change (e.g. increases in ocean levels, altered weather patterns including increases in rainfall) on flooding behaviour, so that it can be considered further in the Floodplain Risk Management Study.

Step 2 and step 3 of the above process are covered by this report. The specific methodology adopted is presented in Section 1.4.

1.4 Study Objectives and Methodology

The primary objective of the Coastal Creeks Flood Study is to examine and define the flood behaviour of Cudgen, Cudgera, Mooball, Yelgun and Marshalls Creeks and their main tributaries between Kingscliff and Ocean Shores. The findings will form the basis for the subsequent Floodplain Risk Management Study and Plan for each of the coastal creeks.

The general approach and methodology employed to achieve the study objectives involved the following steps (as shown in Figure 1-2):

- Compilation and review of available information;
- Acquisition of additional data, including resident survey to determine nature and extent of historical flooding;
- Development of hydrological and hydraulic models;
- Calibration and verification of models;
- Modelling of design events under existing conditions; and
- Reporting and mapping.

The above tasks are described in detail in the following sections, together with presentation and discussion of the results as appropriate.

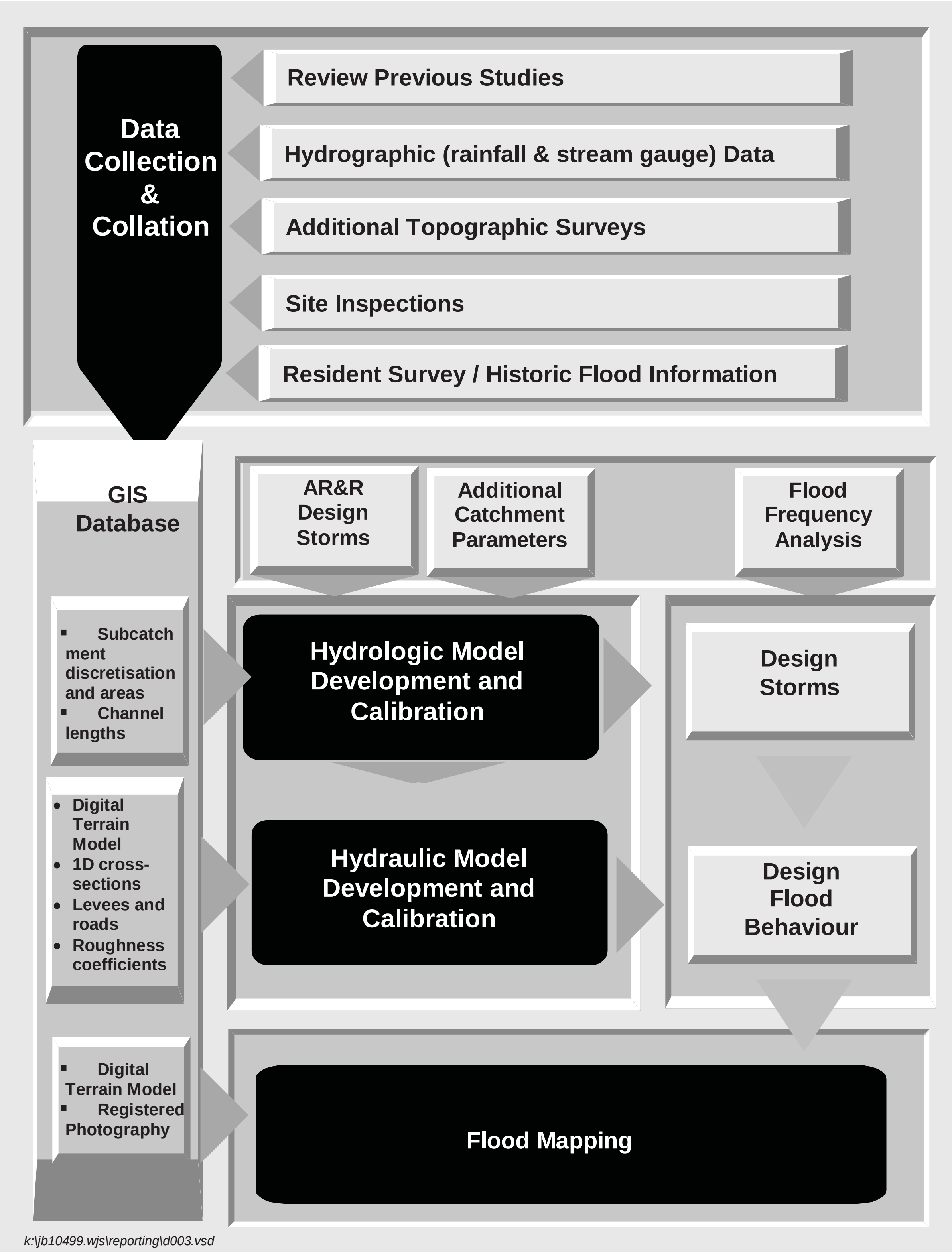


Figure 1-2 Study Approach

2 DATA COLLECTION

2.1 Catchments Description

The study area comprises four main coastal catchments; Cudgen, Cudgera, Mooball and Marshalls Creeks. The northern three catchments (Cudgen, Cudgera and Mooball Creeks) drain directly to the ocean, whereas Marshalls Creek drains into the Brunswick River just upstream of the mouth. These catchments and their main tributaries are shown in Figure 2-1. The following sections provide a brief description of each of the main catchments, as well as the Yelgun Creek catchment, which drains to both the Mooball and Marshalls Creeks catchments.

An initial site visit was undertaken on the 23rd of November 2007. This was an opportunity for BMT WBM staff members to meet with the joint Floodplain Management Committee, present the study methodology, and drive across the study area to get a broad picture of the characteristics of all catchments.

Specific features across the Cudgen, Cudgera, Mooball, Yelgun and Marshalls Creeks floodplains were also identified, such as major hydraulic structures, key topographic features influencing hydraulic connections between the different catchments, and potential areas for flood information collection during the resident survey (see Section 2.8 for further details). Photographs taken during this site visit have been collated and are presented in Appendix A.

2.1.1 Cudgen Creek Catchment

The Cudgen Creek catchment is the northern most of the catchments in this study. The Cudgen Creek catchment is approximately 100km^2 in area and is bounded by the Burringbar Range to the west. Elevations in the catchment range from greater than 350m AHD to sea level. The catchment is approximately 20km long and drains to the ocean at Kingscliff. The upper catchment is relatively steep and heavily forested.

The Cudgen catchment is linked to the Cudgera catchment via a set of culverts under Kanes Rd. Three (3) 1.05m diameter circular culverts link the Cudgen and Cudgera catchments. The catchment is bisected in a north-south direction by the Pacific Highway.

The main creeks in the Cudgen catchment include Cudgen, Reserve and Clothiers Creeks. Reserve and Clothiers Creeks combine and flow into Cudgen Lake, located west of Bogangar. Figure 2-1 shows these sub-catchments; the lower floodplains have been included in the broader Cudgen Creek floodplain.

The upper sections of the catchment are a mixture of forested and agricultural land. The lower areas of the catchment contain agricultural land, sugar cane farms, forested and urban areas.

Towns within the Cudgen Creek catchment include Bogangar, Cabarita Beach, Tanglewood, Salt, Casuarina (South Kingscliff) and Kingscliff.

2.1.2 Cudgera Creek Catchment

The Cudgera Creek catchment lies between the Cudgen and Mooball catchments. The Cudgera Creek catchment is approximately $34km^2$ in area. Elevations in the catchment range from greater than 350m AHD to sea level. The catchment is approximately 11km long and drains to the ocean at Hastings Point.

The Cudgera catchment is linked to the Cudgen catchment to the north, with Christies Creek flowing into the Cudgera Creek floodplain downstream of the Pacific Highway through three (3) 1.05m circular culverts under Kanes Rd. To the south the Cudgera catchment is linked to the Mooball catchment via three (3) 900mm circular culverts underneath Pottsville Rd. The catchment is bisected in a north-south direction by the Pacific Highway.

The main land use types in the Cudgera catchment are agricultural land, sugar cane farms, forested and urban areas.

Townships within the Cudgera Creek catchment include Pottsville, Hastings Point, as well as the Seabreeze and Koala Beach Estates.

2.1.3 Mooball Creek Catchment

The Mooball Creek catchment lies between the Cudgera and Marshalls catchments and covers an area of approximately $110km^2$. Mooball Creek drains to the ocean at Pottsville.

There are three (3) 900mm circular culverts under Pottsville Road linking the Cudgera and Mooball catchments. The Mooball Creek catchment is also linked with the Yelgun Creek catchment, with both floodplains connecting hydraulically south of Wooyung in the corridor east of the old coastal dune system.

The two main creeks within the Mooball catchment are Burringbar Creek and Crabbes Creek. Burringbar Creek and Crabbes Creek join to become Mooball Creek north of Wooyung.

The main land use types in the Mooball catchment are agricultural land, sugar cane farms, forested and urban areas.

Townships within the Mooball Creek catchment include Burringbar, Mooball and Crabbes Creek upstream of the Pacific Highway, as well as Wooyung and the Black Rock Estate towards Pottsville in the lower floodplain.

2.1.4 Yelgun Creek Catchment

The Yelgun Creek catchment lies between the Mooball and Marshalls catchments. It is approximately $11km^2$ in area.

In a flood event Yelgun Creek flows both south into Marshalls Creek and north into Mooball Creek, primarily in the low area west of the frontal dune system through Billinudgel Nature Reserve. Yelgun Creek catchment is linked to the Marshalls Creek catchment at North Ocean Shores. There are culverts underneath Kallaroo Circuit at Capricornia Canal linking the catchments. In the June 2005 flood, the Kallaroo Circuit bund caused flood waters to back up north of the bund and cut through urban areas to the east at Fern Beach and via overland flow flooded South Golden Beach. However, additional culverts have recently been constructed to resolve this issue.

Various bunds at North Ocean Shores affect the hydraulic interaction of Yelgun, Mooball and Marshalls creeks floodwaters (see Section 2.4.2 for more details on the North Ocean Shores bunds). The catchment is bisected in a north-south direction by the Pacific Highway and the railway line.

The main land use types in the Yelgun Creek catchment are agricultural land, forested and urban areas.

No major township is located within the Yelgun Creek Catchment, although South Golden Beach lies at the downstream end of the catchment at the boundary between Yelgun Creek catchment and Marshalls Creek catchment.

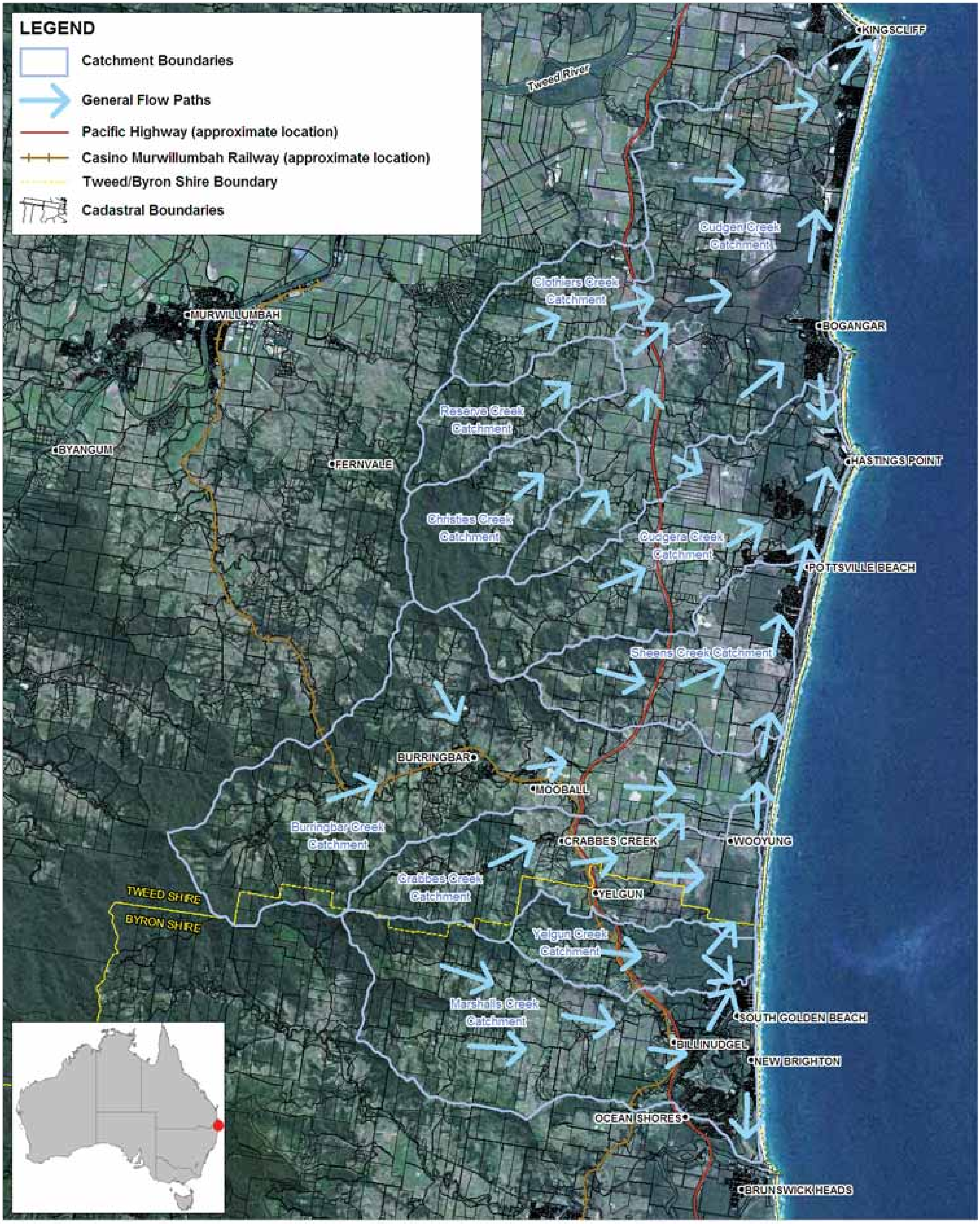
2.1.5 Marshalls Creek Catchment

The Marshalls Creek catchment is the southern most catchment in this study and it covers an area of approximately 42km^2. Marshalls Creek flows into the Brunswick River approximately 1.2km from the mouth.

Marshalls catchment is linked to the Yelgun catchment at North Ocean Shores. There are culverts underneath Kallaroo Circuit linking the catchments (see Section 2.1.4 above). The catchment is bisected in a north-south direction by the Pacific Highway and the railway line.

Upstream of the Pacific Highway the catchment is predominantly agricultural and forested land. The area downstream of the Pacific Highway is significantly developed and this part of the catchment is a mixture of urban (including golf course) and forested areas.

Townships within the Marshalls Creek catchment include Billinudgel, South Golden Beach, New Brighton and Ocean Shores.



Title:

Catchments Map

Figure: 2-1

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Approx. Scale

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2.2 Review of Previous Reports and Studies

A number of flood investigations have been carried out in the past within the study area. Relevant studies have been reviewed. They are listed in the sections below, with a summary of relevant aspects.

2.2.1 Cudgen Creek Flood Study (PWD, 1988)

BMT WBM (then trading as Oceanics Australia) developed and calibrated a one-dimensional (1D) model of Cudgen Creek for the then Public Works Department.

As part of the study, hydrological (WBNM) and hydraulic (ESTRY) models were created for the Cudgen Creek catchment. Tidal and flood versions of the hydraulic model were created. The flood model was calibrated to the May 1987 event and verified with the March 1974 event. The calibrated models were used to estimate flood levels and behaviour for a number of design rainfall events.

2.2.2 Proposed Motorway – Billinudgel to Chinderah – Hydraulics and Hydrology Working Paper (WBM, 1994)

This study investigated the hydraulic and hydrology impacts of the Pacific Highway. A number of preliminary road alignments were assessed. A more detailed analysis of the preferred option was undertaken using a modified version of the calibrated ESTRY hydraulic model described in PWD (1988). This study included sizing of waterway openings.

2.2.3 Marshalls Creek Flood Study (Webb McKeown, 1994)

This report was not available for review.

2.2.4 Marshalls Creek Flood Study (Pattersons MP, 1997)

This report was not available for review.

2.2.5 Upgrade of the Pacific Highway between Yelgun and Chinderah (WBM, 1998)

This flood impact assessment and concept design of the Yelgun to Chinderah Pacific Highway Upgrade included significant upgrades to the existing hydraulic model in the area. It also included the development of a new hydrological model using RAFTS-XP and adopting the rainfall intensities and patterns from Australian Rainfall and Runoff (1987).

A 2D/1D hydraulic model was developed to predict the impacts of the upgraded Pacific Highway on peak flood levels, velocities and flow distributions.

2.2.6 Upgrade of the Pacific Highway between Brunswick and Yelgun

This report was not available for review. A TUFLOW model was developed for the RTA as part of this study.

2.2.7 Tanglewood Flood Impact Assessment (WBM, 2005a)

This flood impact assessment of the Tanglewood development was undertaken in 2005 using a 2D / 1D TUFLOW hydraulic model.

2.2.8 Koala Beach and Seabreeze Estates Link Road Flood Impact Assessment (WBM, 2005b)

Existing hydraulics models were used to assess the impacts of the proposed link road between the Koala Beach and Seabreeze estates. This assessment also included refining the proposed design of the road.

2.2.9 Cudgera Creek Road Upgrade (WBM, 2005c)

The 1D representation was upgraded in the vicinity of the Cudgera Creek Road Upgrade to a fully two-dimensional (2D) TUFLOW representation to better analyse the flooding characteristics (e.g. flood depths, direction and velocities of flow and possible break out locations).

This 2D / 1D hydraulic model was used to define the elevation of the Cudgera Creek Road to provide immunity in a 5% AEP design event. Waterway openings were sized to minimise afflux.

2.2.10 Cudgen Creek Bridge Upgrade: Flood and Tide Assessment (WBM, 2006)

A 2D/1D model of the Cudgen Creek was developed to assess the impacts of the upgrades to the Cudgen Creek Bridge at Kingscliff. The 2D model covered the lower Cudgen Creek floodplain. This model was used to predict changes to peak flood level and tidal prism.

2.2.11 Assessment of Flooding Behaviour in the Marshalls Creek Catchment (SMEC, 2006)

This study was undertaken by SMEC to assess the behaviour of the June 2005 flood event in the Marshalls Creek catchment, in the vicinity of the South Golden Beach area. The existing RAFTS hydrological model of the Marshalls Creek catchment developed in 2002 by Connell Wagner was reviewed and updated as part of this study. Similarly, the existing one-dimensional MIKE-11 hydraulic model was updated with new survey data collected specifically for this study.

2.3 Topographical and Bathymetrical Data

Several sources of topographic data were required for the development of the hydrologic and hydraulic models. They are detailed below, with extent shown graphically in Figure 2-2.

2.3.1 Floodplain Topography

Airborne Laser Scanning (ALS) data was collected over the entire study area by FUGRO Spatial Solutions in July 2007. This data was subsequently used by FUGRO to develop a 5m gridded Digital Elevation Model (DEM) and 0.5m interval contours on 1:5000 mapsheet tiles. Typical vertical accuracy of this data is claimed to be +/- 0.25m at 90% confidence.

The DEM obtained by assembling the tiles provided is shown in Figure 2-3. Raw ALS ground returns were also provided. This allowed for creation of DEMs at finer than 5m resolution (typically 0.5m).

It is noted that ALS surveys are unable to provide ground data through sugar cane fields and other areas of thick vegetation. Topography for areas of cane fields not covered by the ALS data was thus generated subsequently by interpolating adjoining elevation values. The DEM shown in Figure 2-3 includes these areas.

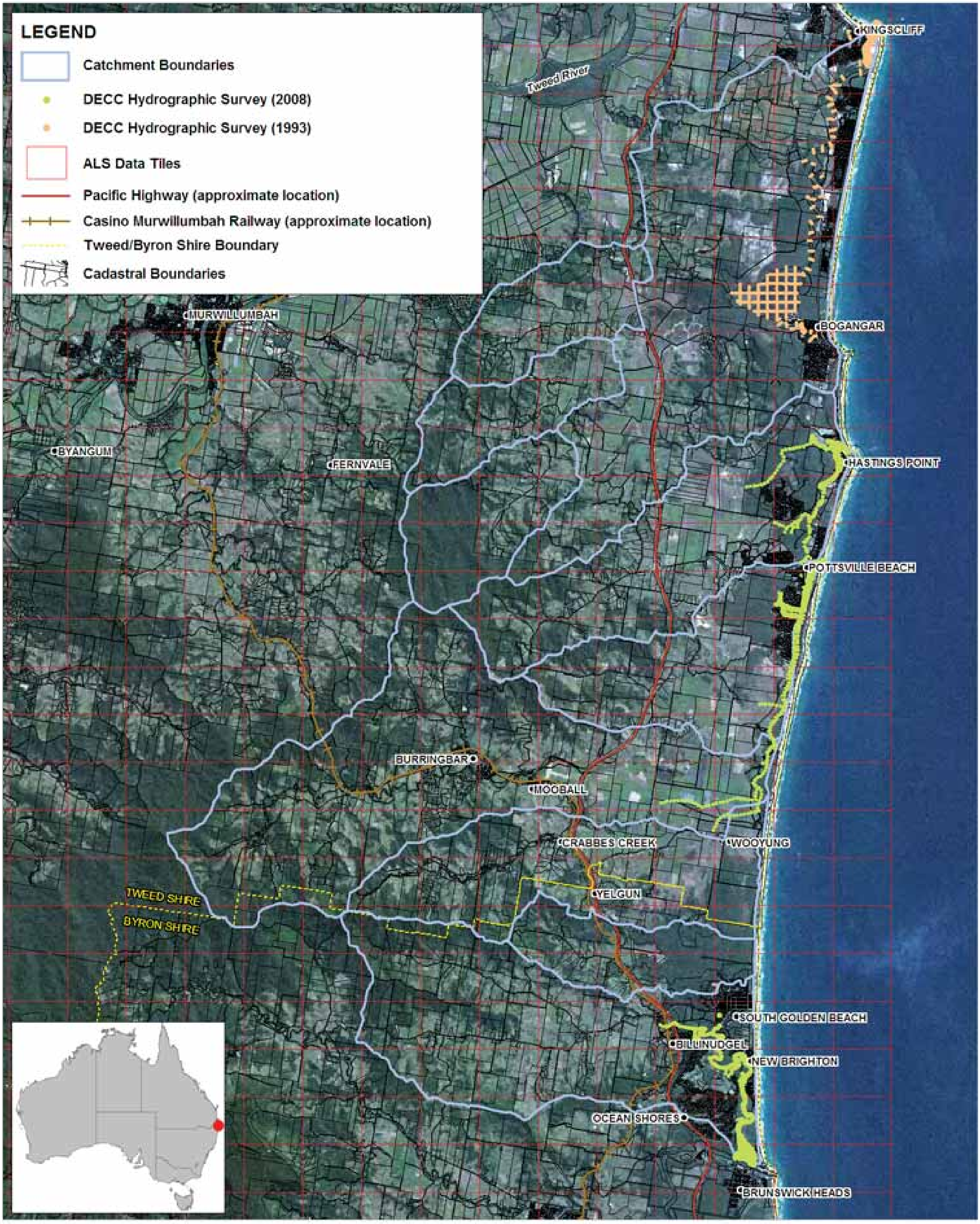
2.3.2 DECC Hydrographic Survey

Surveyed cross-sections of Cudgen Creek collected in 1993 were available from DECC (now DECCW). These covered the section of the creek downstream of Cudgen Lake, as well as the lake itself and Friday Island canal at Bogangar.

DECC also provided 2008 surveyed cross-sections for the coastal creeks. The DECC hydrographic surveys covers the following areas:

- Mooball Creek;
- Cudgera Creek; and
- Marshalls Creek.

Cross-section locations are presented in Figure 2-2.



Title:

Topographic Data Sources

Figure: 2-2

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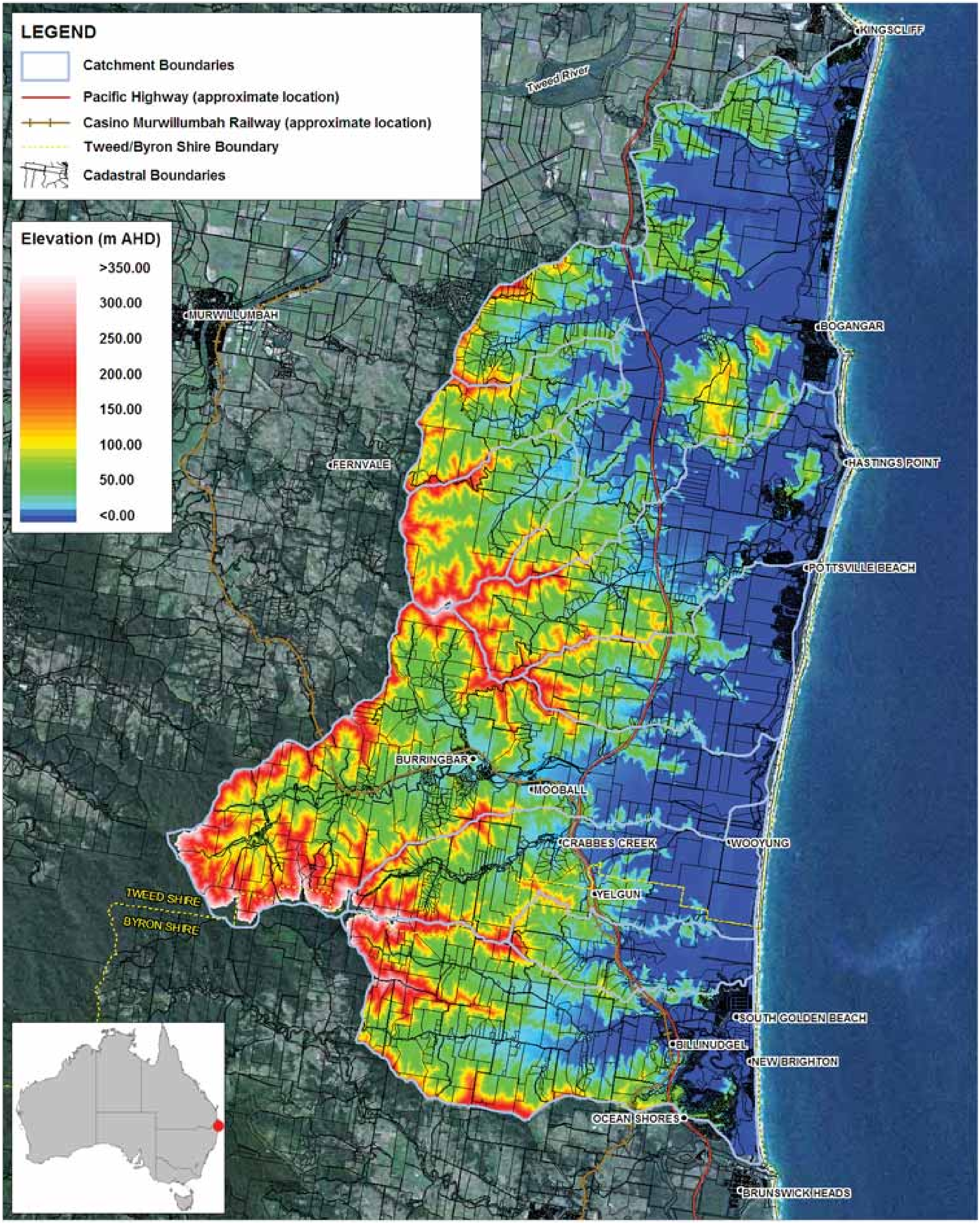
Filepath : I:\B16790_I_BRH Tweed Byron GJR\DRG\FLD_006_090710_Topographic Data Sources RevC.wor



Title:

Digital Elevation Model

Figure: 2-3

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Approx. Scale

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www.wbmpl.com.au

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2.4 Structure Data

2.4.1 Bridge Data

There are numerous bridges and culverts in the study area. The major road structures include:

- Sutherland Street over Cudgen Creek at Kingscliff;
- Old Bogangar Road Bridge over Cudgen Creek;
- Tweed Coast Road over Cudgera Creek at Hastings Point;
- Cudgera Avenue over Cudgera Creek at Pottsville (Koala Beach);
- Koala Beach / Seabreeze Link Road over Cudgera Creek;
- Cudgera Creek Road over Cudgera Creek, west of Pottsville;
- Tweed Coast Road over Mooball Creek at Pottsville;
- Overall Drive over Mooball Creek at Pottsville (Black Rocks Bridge);
- Strand Avenue Bridge over Marshalls Creek at New Brighton;
- New Brighton Road Bridge over the Capricornia Canal at North Ocean Shore;
- Pacific Highway crossings of the main creeks; and
- Kallaroo Circuit Bund culverts joining the Yelgun, Mooball and Marshalls Creeks Catchments.

Details of numerous other smaller structures were also obtained. The locations of the bridges / structures are presented in Figure 2-4. These structures were primarily modelled as 1D elements in the hydraulic model (see Section 4.2 for more details). Bridge data was obtained from the following sources:

- Tweed Shire Council;
- Byron Shire Council; and
- Roads and Traffic Authority.

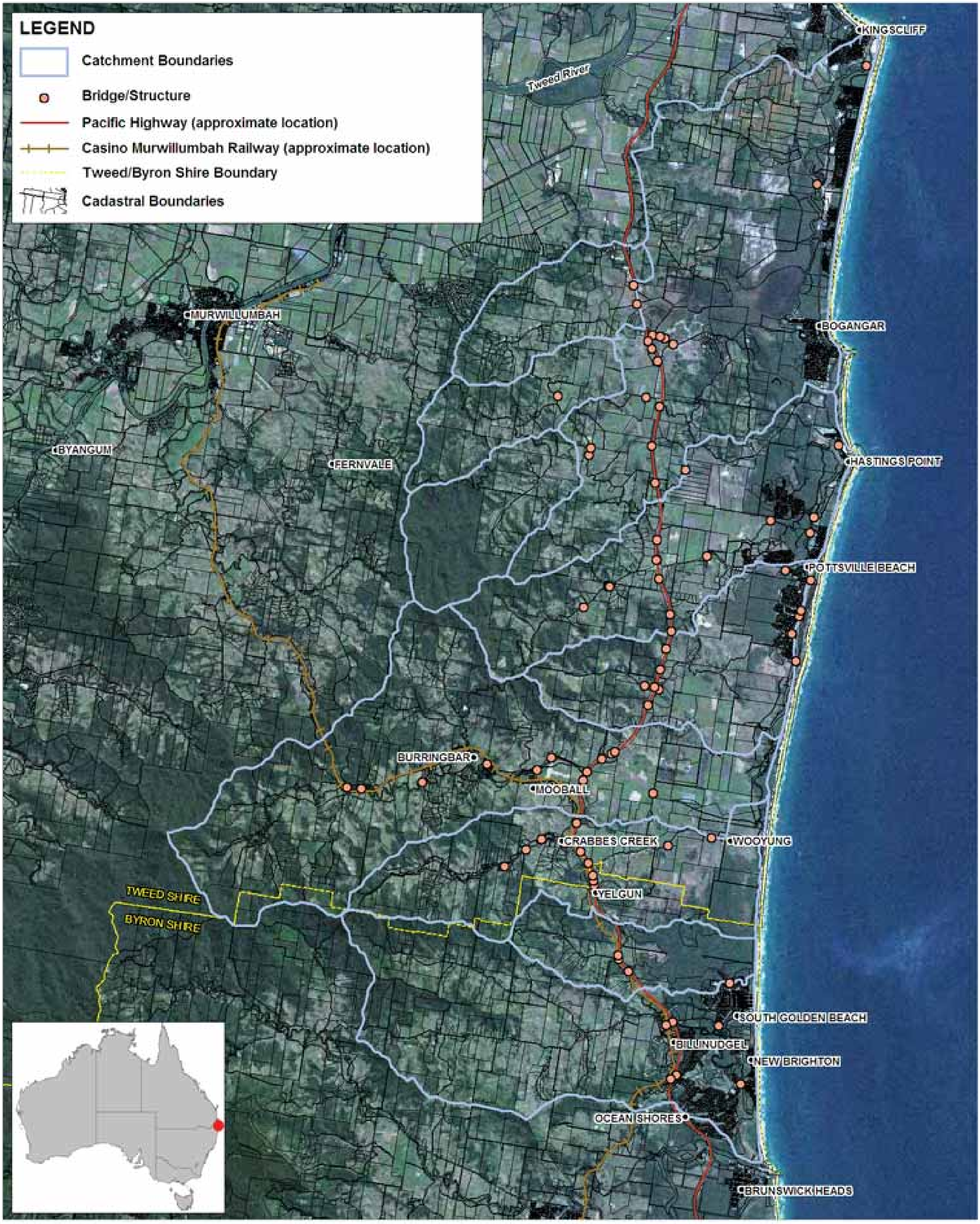
Australian Rail Track Corporation were unable to provide details of rail bridges in the study area. Some rail bridge details were obtained from previous MIKE11 modelling (SMEC), in particular details of the rail bridge at Billinudgel. Hydraulic losses for the remaining rail structures were assumed based on site visits, aerial photography and adjacent highway openings.

2.4.2 North Ocean Shores Bund Data

After extensive discussion with Matthew Lambourne on 23/05/2008, it appeared that the ALS data was not representing the North Ocean Shores bund accurately, especially in terms of location and height of the breaches along the length of the bund. This feature is an important element of the area, as it defines the hydraulic connection between the Mooball, Yelgun and Marshalls Creeks catchments.

A west-east traverse of the bund surveyed in 2003 was provided by BSC. BSC also undertook ground survey in 2008 to obtain crest levels along the length of the bund not covered by the 2003 dataset. The 2008 survey revealed two major breaches in the bund, and a constructed rock overflow on the western section of the bund. Details and location of this data are presented in Figure 2-5.

It should be noted that the breaches on the western section of the bund were created during the June 2005 flood event, after collapse of the bund at these two locations. This has been taken into account in the modelling (refer to Section 5.2.2 for further details).



Title:

Main Bridge and Culvert Locations

Figure: 2-4

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Approx. Scale

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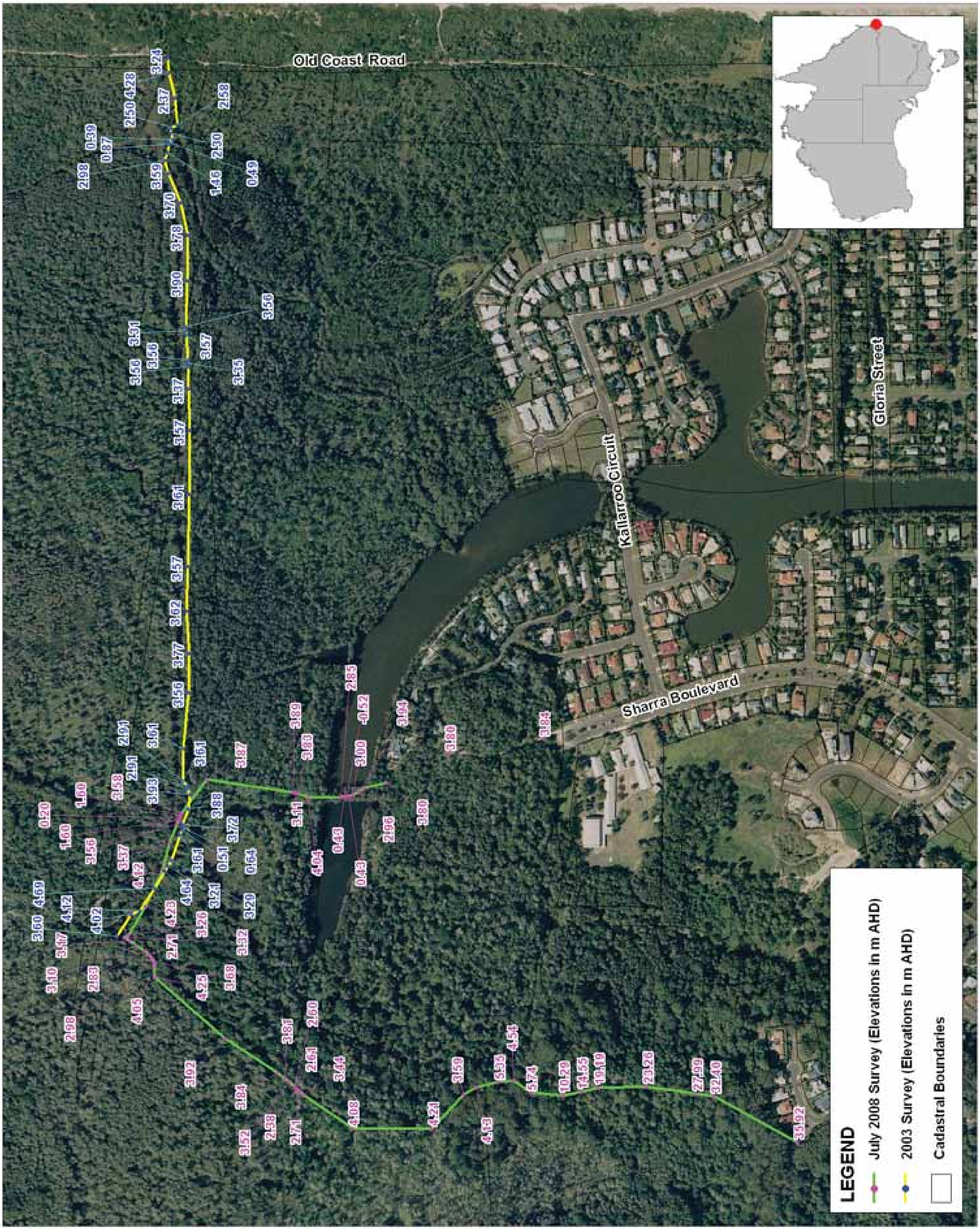

Title:

North Ocean Shores Bund Survey

Figure: 2-5

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2.5 Rainfall Data

2.5.1 Daily Rainfall Stations

Daily rainfall stations over (or close to) the study area were sourced from the Bureau of Meteorology (BoM) Water Resources Catalogue. They are shown in Figure 2-6. Not all stations have records for the events of interest (June 2005, May 1987 and March 1974), either due to non-operational periods, or failure of readings. In particular, the following observations are noted:

- The Kingscliff station doesn't have records for the 29th of June 2005 and 1st of July 2005, with a spurious reading for the 30th of June 2005; and
- Only a small number of stations have readings for the May 1987 and March 1974 events, providing limited indication of the spatial variation in the rainfall over the catchments.

2.5.2 Pluviograph Stations

There are a total of eleven pluviograph stations within or close to the coastal creeks catchments. They are shown in Figure 2-6. Details of the stations are summarised in Table 2-1.

Table 2-1 Pluviograph Stations

Pluviograph Station	Operation	Available Records Interval
Coolangatta	BoM	6-minute
Banora Point STP	TSC	10-minute
Duranbah Repeater	TSC	variable
Cudgera Creek	MHL	5-minute
Lacks Creek Middle pocket Road	BoM	1-hour
Chincogan	BoM	1-hour
Mullumbimby Creek Road	BoM	1-hour
Murwillumbah (Bray Park)	BoM	1-hour
Upper Main Arm	BoM	1-hour
Myocum	MHL	1-hour
Cape Byron Lighthouse	MHL	1-hour

These stations all have records for the June 2005 event. Only the Cudgera and Bray Park stations have records for the May 1987 event, and only the Bray Park pluviograph holds records for the March 1974 event.

2.5.3 Landholders Records

Additional rainfall information was collected within the catchments boundary during the resident consultation, as well as from previous studies in the area. In particular, daily readings were provided by Craig King, John Irby, John Harbison, Gordon Quinn and Lise Hallogan for the June 2005 event. John Irby also provided daily records for the May 1987 event.

The location of these records is reported in Figure 2-6. It is noted that this data is really valuable to analyse the spatial variation of the rainfall within the coastal creek catchments during the storm events, especially given the scarcity of the rainfall stations away from the coast in this area.

2.6 Streamflow Data

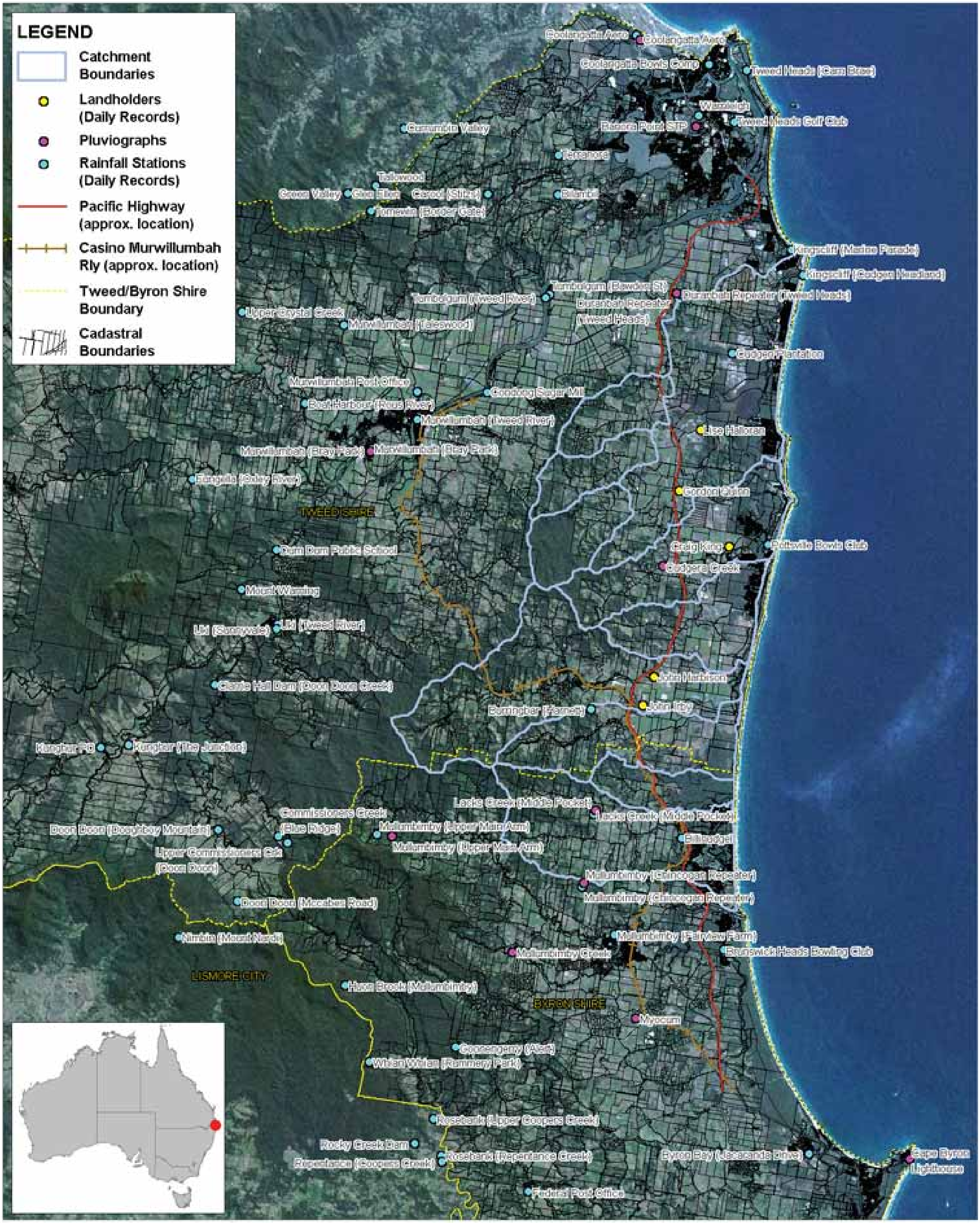
No streamflow records were available within the study area.

2.7 Water Level Recorders

A number of water level recorders are operating in the study area. The availability of water level data for various calibration events is presented in Table 2-2. This data has been subsequently used to validate the levels predicted by the model (see Section 5 for further details).

Table 2-2 Water Level Recorders

Location	March 1974 Event	May 1987 Event	June 2005 Event
Cudgen Lake at Bogangar	Limited	Yes	Yes
Cudgen Creek at Kingscliff	No	Yes	Yes
Marshalls Creek at Billinudgel	No	Yes	Yes



Title:

Rainfall Data Stations

Figure: 2-6

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2.8 Historical Flood Records

2.8.1 Resident Survey

A resident survey was conducted within the study area to gather information regarding historical floods and identification of known flood marks. This process was initiated through a notice in the local TSC newsletter (‘The Tweed Link’) in mid-December 2007, a media release from Byron Shire Council in April 2008, and diffusion of the information across both Shires. This information requested the assistance of residents in the collection of flood level information and included a free call phone number to report information. A number of residents utilised this service, providing valuable assistance to the data collection process.

Following this preliminary stage of data collection, four BMT WBM staff members conducted door-knock surveys of the area on the 16th, 17th and 18th of January 2008, and subsequently on the 15th of May 2008. These surveys sought information from the residents regarding the timing, duration and impact of historical flood events. A number of flood heights were also identified thanks to local knowledge and records of flood marks. These flood heights were then surveyed. This is detailed further in Section 2.8.2. A summary of the number of responses with flood information for various years is presented in Table 2-3.

Table 2-3 Flood Information Responses for Various Years

Year	Number of Responses
2005	44
1987	10
1974	3
2000	2
2008	1
2003	1
1995	1
1994	1
1954	1

All the information collected was then collated into a Geographic Information System (GIS) database with the following details for each resident survey point:

- Location (Easting and Northing coordinates);
- Contact details (street address, name and phone number);
- Interviewer initials;
- Flood event date;
- Flood mark description;
- Flood mark accuracy;
- Survey requirements;

- Photographs of the flood mark and/or property;
- A copy of the initial form completed during the survey; and
- Any additional comments regarding the information provided.

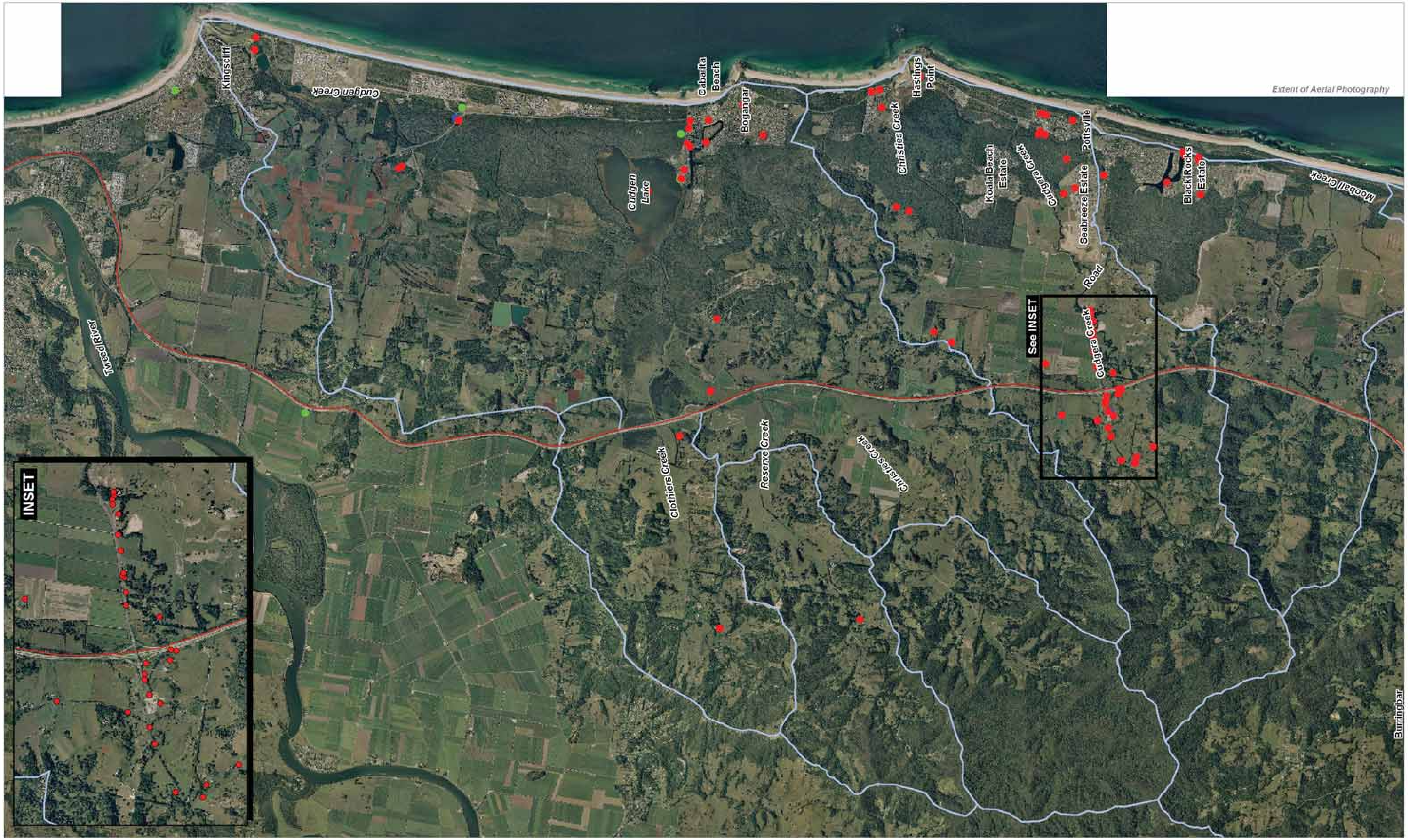
In addition to flood marks, residents were able to provide key insights into local flood behaviour, including:

- Timing of the flood events;
- Flow paths and velocities;
- Blockage of hydraulic structures;
- Geographical extent of historical flood events across the different catchments; and
- Daily rainfall readings during significant events.

These elements have been incorporated in the description of historical flood events in Section 3.

2.8.2 Survey of Flood Records

Ground survey of the flood marks was subsequently undertaken by TSC and BSC in order to provide flood levels to datum (mAHD). These levels were provided to BMT WBM in April and July 2008 respectively. They are reported in Figure 2-7 and Figure 2-8 for the three major flood events (June 2005, May 1987 and March 1974), respectively for the Cudgen/Cudgera Creeks catchments and for the Mooball/Marshalls Creeks catchments. Note that these figures also present flood mark information which was previously collated in the area.



LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- Flood Record - June 2005
- Flood Record - May 1987
- Flood Record - March 1974

Title:

Historical Flood Marks
Cudgen/Cudgera Creeks Catchments

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Figure: 2-7

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LEGEND

Catchment Boundaries
Pacific Highway (approximate location)
Casino Murwillumbah Railway (approximate location)
Tweed/Byron Shire Boundary
Flood Record - June 2005
Flood Record - May 1987
Flood Record - March 1974

Title:
Historical Flood Marks
Mooball/Marshalls Creeks Catchments

Figure: 2-8

Rev: B

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3 HISTORICAL FLOOD BEHAVIOUR AND FLOODING MECHANISMS

3.1 History of Flooding

The coastal creeks in the study area have a long history of flooding. Resident survey and interviews revealed recollection of numerous flood events of various magnitudes. The earliest flood event reported in the resident survey was 1954.

A major flood event occurred more recently in June 2005. This flood event resulted in above floor flooding for a significant number of buildings. Other significant flood events occurred in May 1987 (this event is often referred to as "the Mothers Day Flood") and March 1974. A smaller event also occurred in January 2008.

The probability for floods (i.e. flows) of a given size to be exceeded can typically be estimated with a flood frequency statistical analysis. However, without a long and extensive record of flood levels or flows it is unfeasible to carry out such a flood frequency analysis. In this case, design floods are typically determined using the Australian Rainfall & Runoff (ARR, 1987) approach. This approach has been applied for the Coastal Creeks Flood Study and it is described further in Section 6.

3.2 General Flooding Mechanisms

Developing an appreciation of the flooding processes in the creeks is an important step in defining flood behaviour and developing appropriate computer models.

A general understanding of the different patterns of flooding, or flood behaviour, was obtained based on consultations with local residents and others, as well as an understanding of flood hydraulics and a history and review of previous work in the area.

Tweed and Byron coastal creeks floods originate from one or more of the following sources:

- Heavy rainfall over the catchment;
- High tail water levels in the ocean due to storm surge or tidal conditions; and
- Localised rainfall not being able to drain because of high creek levels and or constrictions caused by the flood drainage structures.

Specific flooding behaviour of each of the major creeks is described in the following sections.

3.2.1 Cudgen Creek Flooding Behaviour

Cudgen Creek has a relatively large floodplain area as a proportion of the total catchment. The tributary catchments of Reserve Creek, Clothiers Creek and Christies Creek (upper) drain to an intermediate floodplain upstream of Cudgen Lake. This floodplain is crossed by the Pacific Highway which includes numerous large bridges to convey floodwaters.

Discharge from this upper floodplain is restricted through a floodplain area approximately 900m wide prior to discharging into the relatively shallow Cudgen Lake. Due to the shallow depth of the lake and the wide floodplain downstream of the lake, Cudgen Lake provides only minimal attenuation of the flood flows.

Downstream of Cudgen Lake, a number of smaller tributaries flow into the floodplain from the west. These catchments are much smaller and more responsive than the catchments of the upstream tributaries. The tributary immediately downstream of Cudgen Lake has a constricted floodplain outflow into the broader Cudgen Creek floodplain due to the presence of remnant coastal dune systems.

Old Bogangar Road forms a barrier to floodplain flows, except for the bridge over Cudgen Creek.

Downstream of Old Bogangar Road, the flood behaviour is influenced by tidal conditions at the creek mouth and the flood gradient between Old Bogangar Road and the ocean is relatively flat.

3.2.2 Cudgera Creek Flood Behaviour

Cudgera Creek has a complex flooding behaviour. While the upper parts of the creek have a more typical cross section with a narrow steep sided floodplain, just upstream of the Pacific Highway the floodplain widens and splits into two branches. The Cudgera Creek branch runs roughly parallel to Cudgera Creek Road, crossing from the south to the north side of the road. Cudgera Creek is constricted by natural high land upstream of Seabreeze Estate, which limits the flow capacity within the creek. Downstream of this constriction, the floodplain again widens into an estuarine creek, including large wetland areas.

With the flow limitations in Cudgera Creek, and due to changes in elevation, significant floodplain flows occur between Cudgera Creek in the south and Christies Creek in the north, across agricultural (sugar cane) land. Cudgera Creek and Christies Creek converge at Hastings Point, near the creek mouth.

3.2.3 Mooball Creek Flood Behaviour

Upstream of the Pacific Highway, Burringbar and Crabbes Creeks generally have a defined creek channel and relatively narrow floodplain. Downstream of the Pacific Highway, the floodplain becomes much wider.

Crabbes Creek splits upstream of Wooyung township with one branch flowing north into Burringbar Creek near Hulls Rd, and the remaining flow passing under/over Wooyung Rd twice. A high ridge in the sand dune system (with the same alignment as Jones Rd, Wooyung) forces flows north where the waters join Mooball Creek.

Mooball Creek, which runs parallel to the coastline, has a flat flood gradient and wide floodplain. Near Overall Drive water is confined by filled developments of Black Rock Estate and Pottsville Waters Estate, constricting the flow to a much narrower path. The area west of Pottsville has a very flat gradient with low flood velocities.

3.2.4 Yelgun Creek Flood Behaviour

Yelgun Creek has a relatively narrow floodplain upstream of the Pacific Highway, which then widens downstream of the Pacific Highway. Flows are then constrained by a small channel (approx 15m wide) through the old dune system and the North-South Bund (see Section 2.4.2).

At this point floodwaters either flow north into Mooball Creek or south into Marshalls Creek and through the Kallaroo Circuit culverts. The East-West Bund (see Section 2.4.2) also influences the interaction between the creek systems.

3.2.5 Marshalls Creek Flood Behaviour

This creek system is characterised by a complicated interaction between the Yelgun, Mooball and Marshalls Creeks.

Downstream of the Pacific Highway the Yelgun Creek floodplain is relatively large. The flow is then constrained by a small channel (approx 15m wide) through the dune and the North-South Bund (see Section 2.4.2). At this point floodwaters either flow north into Mooball Creek or south into Marshalls Creek and through the Kallaroo Circuit culverts. The East-West Bund (see Section 2.4.2) also influences the interaction between the creek systems.

Depending on the relative flood levels, flow between Mooball Creek and Marshalls Creek occurs in both directions and can change during a single flood event.

Lacks Creek and Marshalls Creek converge upstream of Billinudgel. The floodplain significantly increases in size at the confluence of the creeks. The flow is then constrained by the railway line before passing through the Pacific Highway bridges. Downstream of the Pacific Highway the floodplain is also large, with water backing up into the Golf Course area.

At Strand Avenue in New Brighton, flows are mainly constrained to the bridge opening, with a small amount of flow occurring across Strand Avenue in the vicinity of North Head Road in larger events. Downstream of Strand Avenue the floodplain is bounded by the coastal dune and the high ground to the west. The waterway is approximately 450m wide.

4 MODEL DEVELOPMENT

4.1 Hydrology

4.1.1 Purpose of Hydrologic Model

Hydrologic modelling calculates the quantity and rate of catchment runoff from rainfall during a flood event. The model produces estimates of the discharges in the river and its tributaries during the course of a flood. The amount of runoff from the rainfall and the attenuation of the flood wave as it travels down the river are dependent on:

- Catchment slope, area, vegetation and other catchment characteristics;
- Variation in the distribution, intensity and amount of rainfall; and
- The antecedent conditions of the catchment.

These factors are represented in the model by:

- Sub-dividing the catchment into a network of sub-catchments inter-connected by channel reaches representing the creeks and rivers. The sub-catchments are delineated so that they each have a general uniformity in their slope, land-use, vegetation density, etc;
- The amount and intensity of rainfall is varied across the catchment based on available information. For the historical events chosen for calibration, a reasonable amount of rainfall information was available;
- The antecedent conditions are modelled by varying the amount of rainfall that is “lost” into the ground and “absorbed” by storages. This is represented in the model by initial and continuing loss values. For very dry antecedent conditions a higher initial rainfall loss typically results. The continuing loss rate is generally a function of ground coverage and soil type.

The output from the hydrologic model is a series of flow hydrographs at selected locations such as at the boundaries of the hydraulic model. These hydrographs are then used by the hydraulic model to simulate the passage of the flood down the coastal creeks and over the floodplains (see Section 4.2 for further information).

4.1.2 Hydrological Model Selection

Prediction of flows from the coastal creek catchments has been undertaken with the runoff routing program RAFTS-XP. RAFTS-XP is used extensively throughout Australia and South-East Asia and it has been shown to work well on catchments ranging in size from a few square metres to thousands of square kilometres of both rural and urban nature.

RAFTS-XP uses the Laurenson non-linear runoff-routing procedure to develop a stormwater runoff hydrograph from either an actual event (recorded rainfall time series) or a design storm utilising rainfall intensity-frequency-duration data together with dimensionless storm temporal patterns.

4.1.3 Hydrological Model Development

Hydrological RAFTS-XP models of Cudgen, Cudgera and Mooball Creeks had previously been developed by BMT WBM as part of previous studies. However, the resolution and extent of these models was not considered to be sufficient for the purpose of the current Coastal Creeks Flood Study. Hence, new models were developed based on the available updated topography data and aerial photography. This process is described below.

Given the size of the catchments, it was decided to build two separate hydrological models to cover the entire study area. The division of the coastal creeks catchments was based on the hydraulic connection between each individual catchment as described in the previous sections (Section 2.1 and Section 3). Both models are described in the following sections.

4.1.3.1 Cudgen-Cudgera Hydrological Model

The Cudgen Creek and Cudgera Creek catchments were divided into sub-catchments along the different tributaries. For each sub-catchment, the hydrological characteristics (i.e. slopes, area, hydraulic roughness and impervious fraction) were derived from the DEM and the aerial photography covering the extent.

The hydrological model thus consists of 198 nodes representing the following sub-catchments:

- 73 sub-catchments for Cudgera Creek,
- 73 sub-catchments for Cudgen Creek,
- 20 sub-catchments for Reserve Creek,
- 19 sub-catchments for Clothier Creek, and
- 13 sub-catchments for Christies Creek.

These sub-catchments are presented graphically in Figure 4-1.

The individual nodes are connected to form the catchment drainage system using a simple translation (or lagging). Lengths of travel time from one node to the next have been specified for each link, assuming an average velocity of flow. Hydrographs are then translated on this time basis without attenuation of the peak flow.

4.1.3.2 Mooball-Marshalls Hydrological Model

A similar approach was adopted for the Mooball (Burringbar) Creek catchment.

The existing Marshalls Creek RAFTS-XP model developed by SMEC (2006) was provided for use as part of this study. This model was combined with the Mooball Creek model to produce the final Mooball-Marshalls hydrological model. Note that the Marshalls Creek sub-catchment downstream of the Pacific Highway was further refined into smaller sub-catchments to capture the hydrological patterns specifically in the vicinity of the North Ocean Shores urban development.

This model consists in a total of 146 nodes representing the following sub-catchments:

- 47 sub-catchments for Burringbar Creek,
- 33 sub-catchments for Sheens Creek,
- 29 sub-catchments for Crabbes Creek,
- 13 sub-catchments for Yelgun Creek, and
- 24 sub-catchments for Marshalls Creek.

These sub-catchments are also presented graphically in Figure 4-2.

Similarly to the Cudgen-Cudgera model, a lagging approach was adopted for the computation of hydrographs downstream of the catchments.

LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- RAFTS Subcatchments

Title:
Cudgen-Cudgera Hydrological Model Layout

Figure: 4-1

Rev: B

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Filepath : I:\B16790_I_BRH Tweed Byron GJR\DRG\FLD_014_090713_CC_RAFTS_Catchments RevB.WOR

LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- RAFTS Subcatchments

Title:

Mooball-Marshalls Hydrological Model Layout

Figure: 4-2

Rev: B

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4.2 Hydraulic Modelling

4.2.1 2D Versus 1D Modelling

Under normal flow conditions (i.e. within the creek banks), one-dimensional (1D) hydraulic modelling is typically used. However, when water levels rise above the creek banks, water starts to flow laterally onto the floodplain. Flow patterns when flooding occurs are typically more complex and the modelling assumptions of uniform channel flow associated with 1D representation of creek systems are no longer valid. Two-dimensional (2D) models are then used to capture the complexity of the flow patterns within the floodplain and the interaction between the creek systems and the floodplain. This particularly applies to the coastal creeks catchments, with complex interactions between the various floodplains downstream of the Pacific Highway.

4.2.2 TUFLOW Hydrodynamic Modelling System

The 2D hydraulic modelling software package TUFLOW has been used for all of the hydraulic modelling in this study. A brief description of the program is provided below.

TUFLOW solves the full 2D shallow water equations based on the scheme developed by Stelling (1984) and improved by Syme (1991) and Syme *et al* (1999). The solution is based around the alternating direction implicit finite difference method. A square grid is used to define the discretisation of the computational domain.

Improvements to the Stelling scheme (Stelling, 1984), including a robust wetting and drying algorithm and greater stability at oblique boundaries, and the ability to dynamically link a quasi-2D model were developed by Syme (1991). Further improvements including the insertion of 1D elements or quasi-2D models inside a 2D model, the modelling of constrictions on flow such as bridges and large culverts and automatic switching to upstream controlled weir flow have been developed subsequently.

TUFLOW models have been successfully checked against rigorous test cases (Syme 1991, Syme et al 1998 and WBM 2000), and calibrated and applied to a large range of real-world tidal and flooding applications. TUFLOW has the capability to dynamically link 2D domains to quasi-2D models as well as having numerous 2D domains with varying grid sizes dynamically nested.

Hydraulic structure flows through large culverts and bridges are modelled in 2D and include the effects of bridge decks and submerged culvert flow. Flow over roads, levees, bunds, etc is modelled using the broad-crested weir formula when the flow is upstream controlled. For smaller hydraulic structures such as pipes, 1D elements can be inserted at any points inside the 2D model area. Flow over a bridge or culvert that is modelled in 2D can be represented using a 1D weir equation.

4.2.3 Hydraulic Model Development

In the same manner as for the hydrological model development, two hydraulic models were initially developed as part of this study. The approach to model development was similar for both models, with the representation of the floodplains in 2D and the addition of a system of 1D networks ‘carved’ through the 2D domains to represent the creeks on the lower parts of the catchments (downstream of the Pacific Highway). Further details of both models are provided in the sections below. Main features of the models are also shown in Figure 4-5 and Figure 4-6.

4.2.3.1 2D Domains

Cudgen-Cudgera Hydraulic Model:

A total of three (3) 2D domains were developed for this model, as follows:

- **Cudgen Creek mouth:** A 2D domain based on a 10m x 10m square grid with a north-east orientation covering the mouth of Cudgen Creek and upstream for approximately 2km. This 2D domain was based on an existing TUFLOW model developed previously as part of the Cudgen Creek Bridge Upgrade Study (WBM, 2006);
- **Cudgen Creek floodplain:** A 2D domain based on a 30m x 30m square grid with a north-west orientation covering the remainder of the Cudgen floodplain; and
- **Cudgera Creek floodplain:** A 2D domain based on a 15m x 15m square grid with a north-west orientation covering the Cudgera Creek floodplain.

It is noted that the orientation of the two floodplain domains was based on the alignment with the Pacific Highway, in order to optimise the representation of bridges and hydraulic structures along this major feature of the floodplain.

Each square grid element contains information on ground topography sampled from the DEM (refer to Section 2.3), surface resistance to flow (Manning's n roughness value – refer to Section 4.2.3.4) and initial water level. Topography information for patches of cane fields missing from the ALS data was generated at this stage by interpolating adjoining elevation values.

Significant hydraulic controls (i.e. major road embankments, such as the Pacific Highway, Tweed Coast Road, Old Bogangar Road, Clothiers Creek Road, or Pottsville Road) have been added in the 2D domains as 3D 'breaklines' to ensure that the crests were contained within the model grids and accurately represented in the model. The height along these features was extracted from the DEM.

Main urban developments (including Koala Beach, Pottsville and Cabarita Beach/Bogangar) were also taken into account in the modelling through the representation of road crests.

Mooball-Marshalls Hydraulic Model:

Similarly, three (3) 2D domains were developed for the Mooball-Marshalls model, as follows:

- **Mooball Creek mouth:** A 2D domain based on a 10m x 10m square grid with a north-east orientation covering the mouth of Mooball Creek;
- **Mooball Creek floodplain:** A 2D domain based on a 30m x 30m square grid with a north-east orientation covering Mooball/Burringbar Creek floodplain; and
- **Marshalls Creek floodplain:** A 2D domain based on a 15m x 15m square grid with a north-east orientation covering the Marshalls Creek floodplain.

Again, the orientation chosen for those domains is based on the alignment of the Pacific Highway and the railway line in this area, in order to optimise the modelling of the hydraulic crossings along these features.

As per the Cudgen-Cudgera model, each square grid element contains information on ground topography sampled from the DEM (refer to Section 2.3), surface resistance to flow (Manning's n roughness value – refer to Section 4.2.3.4) and initial water level.

Significant hydraulic controls, including the railway line, the Pacific Highway, the Tweed Coast Road, the Tweed Valley Way, Wooyung Road and the North Ocean Shores Bund, have been added in the 2D domains as 3D 'breaklines' to ensure that the crests were contained within the model grids and accurately represented in the model. The height along these features was extracted either from the DEM or directly from survey data.

The Capricornia Canal was represented in 2D, both in the Mooball Creek 2D domain and the Marshalls Creek 2D domain, respectively for the reaches of the canal north and south of Kallaroo Circuit. Again, a 3D breakline representing the crest of this road was included to ensure an appropriate representation of the Kallaroo Circuit bund levels.

Main urban developments in Pottsville and Billinudgel were also taken into account in the modelling through the representation of road crests.

4.2.3.2 1D Networks

1D networks of the lower parts of the major creeks have also been embedded in the 2D domains as follows:

Cudgen-Cudgera Hydraulic Model:

- An 8km reach of Cudgen Creek downstream of Cudgen Lake to the Tweed Coast Way Bridge (at the transition between the 30m floodplain domain and the 10m mouth domain);
- A 3.2km reach of Christies Creek from Round Mountain to Hastings Point;
- An 8.5km reach of Cudgera Creek downstream of Cudgera Dip (New Cudgera Creek Road Bridge) to the sandy mouth of the creek just upstream of Hasting Point; and
- A 1.8km reach of Cudgera Creek draining north downstream of Cudgera Creek Road in Pottsville, joining Cudgera Creek downstream of Crown Reserve.

Mooball-Marshalls Hydraulic Model:

- A 3km reach of Burringbar Creek downstream of Hills Road Bridge;
- A 2.5km reach of Crabbes Creek downstream of Wooyung Road crossing;
- A 5.7km reach of Mooball Creek from the junction of Burringbar and Crabbes Creeks to Pottsville Bridge; and
- A 5km reach of Marshalls Creek from the Pacific Highway to Orana Road Bridge.

For both models, these 1D networks represent the in-bank sections of the creeks, based on the surveyed cross-section data (see Section 2.3). Other reaches of the creeks were modelled within the relevant 2D domains using 'gully lines' to ensure representation of the bed levels and slopes within the grid cells. Similarly, secondary flowpaths, natural drainage paths or canals were also added in the 2D domains as 'gully lines' to ensure that the bed of the drains and/or canals were contained within the model grids and accurately represented in the model. Particular attention was made to the nature reserve at the downstream end of Yelgun Creek.

It is noted that isolated 1D elements have also been used to represent hydraulic characteristics of road and railway crossings throughout the models. This is discussed further in the following section.

4.2.3.3 Structures Representation

The major bridges along the Pacific Highway were modelled as either 2D 'flow constrictions' or 1D structures using cross-sections to represent the open waterway underneath the bridge deck. The specification of additional energy losses were based on bridge drawings and/or specifications obtained from the Councils. Bridge loss coefficients (including pier characteristics, eccentricity and skew) were computed using the techniques described in *Waterway Design, A Guide to the Hydraulic Design of Bridges, Culverts and Floodways* (AustROADS, 1994).

Similarly, smaller hydraulic structures, such as culverts under minor roads, were modelled as 1D elements embedded within the 2D domains. This is the case for instance for the Kallaroo Circuit culverts or the Black Rock Estate culverts into Mooball Creek.

Hastings Point Bridge over Cudgera Creek and Sutherland St Bridge over Cudgen Creek were modelled within the 2D domains (respectively over Cudgen Creek mouth and Cudgera Creek mouth) as 2D 'flow constrictions'. This 2D representation of hydraulic structures simulates contraction and expansion losses. Further, the representation in 2D is well-suited to bridges larger than the model domain grid cell size and which will not be overtopped during a flood event. Note that additional pier losses were also defined for this type of representation when necessary, based on AustROADS (1994).

4.2.3.4 Manning's n Roughness Values

Roughness coefficients represent the resistance to flood flows in channels and floodplains. They are ultimately used in the formulation of the Manning's equation used in the computation of flow velocities.

The most important factors affecting roughness within creek systems are:

- The type and size of the bed and/or banks materials; and to some extent
- The shape of the channel (e.g. meandering, irregularity, obstruction).

In the case of the coastal creeks, there is a clear change of characteristics of the bed down the creek line, with sandy soil types close to the mouth and typically more clay-like vegetated beds upstream in the catchments. This translates into a general decrease in resistance downstream (and thus the Manning's 'n' parameter). Specifically for this study, Manning's n has been explicitly defined along the 1D networks, with typical values of 0.1 to 0.2 for the creek banks and 0.025 to 0.08 for the creek beds depending on the material (vegetated clay, sand etc).

Roughness values for floodplains are typically different from values within channels and creeks and take into account the soil type, the obstructions and the vegetation cover. A key feature of the coastal creeks floodplains is the presence of sugar cane fields, which significantly slow flood flows when fully grown. This is reflected in the Manning's n selection as presented below. It is noted that the state of the cane fields during calibration events is a key parameter in representing historical flood behaviour.

Manning's n values used in the modelling are typical for the relevant land-use categories. These were determined following consideration of site inspections, aerial photographs and the models' calibration and validation results (refer to Section 5 for further details). The roughness values applied in the modelling, together with the spatial distribution of these land-use categories across the study area are presented in Figure 4-3 and Figure 4-4 for the existing case hydraulic model.

It is noted that different roughness values were applied in some areas for historical flood events (such as May 1987 or March 1974), based on anecdotal knowledge of the area. This allows a more accurate representation of the actual land use at the time of the flood event (i.e. representation of urban developments, forested areas or sugar cane maturity).

4.2.3.5 Cane Drains Representation

The representation of cane drains within the floodplain downstream of the Pacific Highway was one of the challenges of the study. These drains are typically relatively shallow, and don't represent significant floodplain storage in larger flood events. It is thus not appropriate to represent the cane drains within the 2D domains as this would overestimate the actual storage of the drains.

The adopted approach was instead based on the definition of an equivalent Manning's n of 0.06 for the cells along the cane drains. This Manning's n typically accounts not only for the cane drain itself (usually approximately n = 0.08) but also for the side tracks running along on the banks of the drain (typically 5m on each side with a roughness of n = 0.04). This approach was validated during the calibration phase of this study.

4.2.3.6 Hydraulic Connection Between Catchments

Although two separate hydraulic models were initially developed, there is an existing bi-directional hydraulic connection between the Mooball Creek and Cudgera Creek floodplains. This connection is via three (3) 900mm diameter culverts under Coronation Avenue in Pottsville (Cudgera Creek Road).

It should be noted that the various resident surveys indicated that historical peak flood levels have never reached the crest of the road at this point (which is the low point along this road). However, the importance of taking this connection into account in the modelling has been acknowledged, especially for calibration events and subsequently for rare design events (i.e. 100 year ARI and PMF flood events). Hence, both Cudgen-Cudgera and Mooball-Marshalls hydraulic models were aggregated to constitute a single hydraulic model with representation of the hydraulic connection between all four catchments. Results were compared for simulations of the June 2005 events. Both the combined model and the separate Cudgen/Cudgera and Mooball/Marshalls models predict similar peak flood levels. The combined model has thus been used for all design simulations presented in this report.

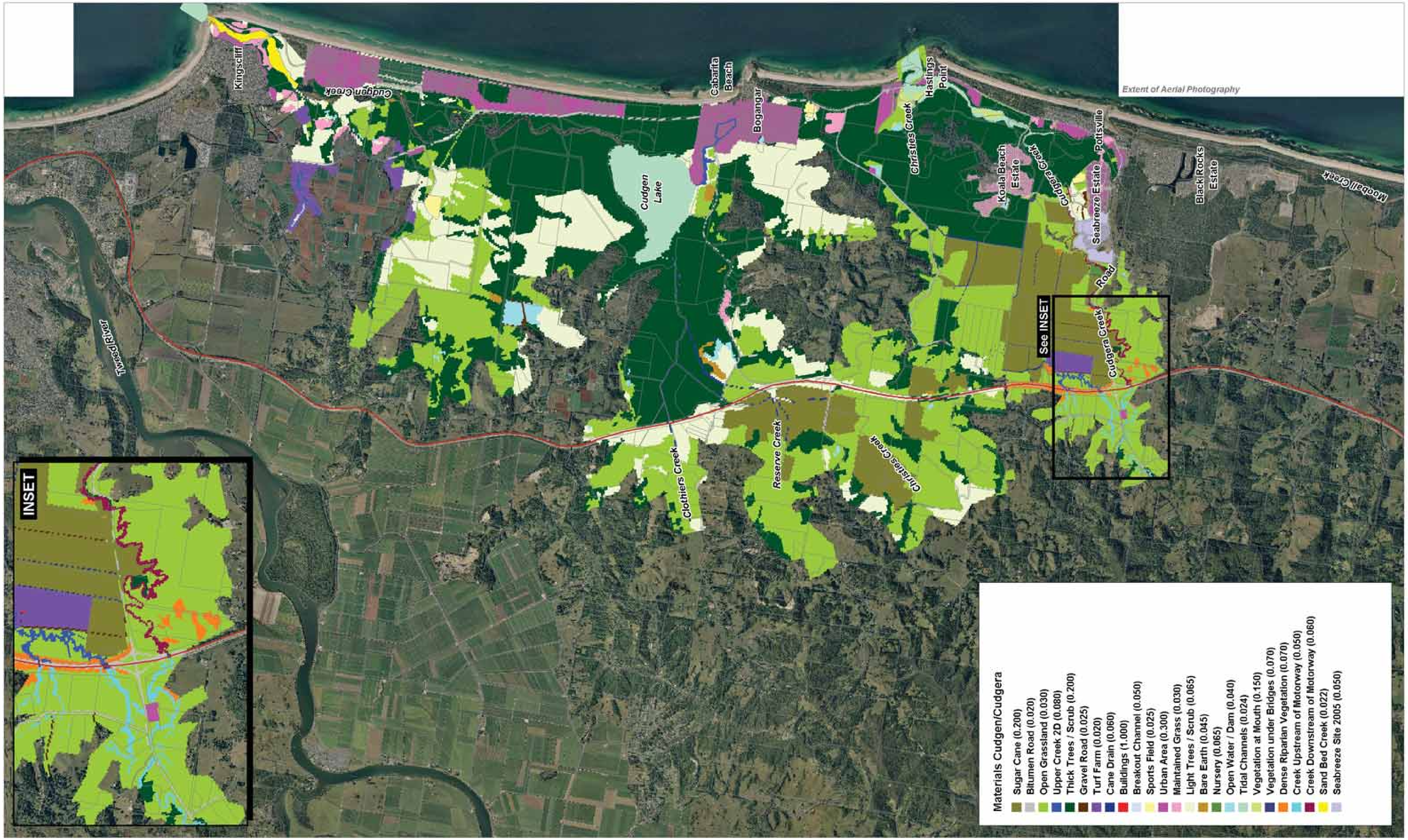
4.2.3.7 Downstream Tidal Boundaries

Four downstream boundaries were defined for the combined model, to represent water levels at the downstream end (ocean entrances) of Cudgen Creek, Cudgera Creek, Mooball Creek and Marshalls Creek. The location of these boundaries is shown in Figure 4-5 and Figure 4-6. Details of the water levels applied for the calibration events are provided in Section 5.2.

4.2.3.8 Creek Mouth Morphology

Preliminary modelling showed that model results in the lower areas are sensitive to the morpho-geological conditions of the creek entrances. The creek mouths experience significant erosion during high flows.

The morphology module in TUFLOW was used to estimate bathymetry conditions at those locations. This morphology module is a coupled hydrodynamic – sediment transport numerical model with dynamic bottom updating (i.e. bed level is computed and updated on relative small time steps). This means that gradual scouring of the creek's mouth during the flood is modelled and changes in cross-sections at the mouth are taken into account at each timestep. Sediment transport formulation used by the morphological module of TUFLOW is the method of Van Rijn (Van Rijn, 1989). The morphology module dynamically links with the TUFLOW hydrodynamic model and simulates sediment transport and bed scour based on specific parameters such as sediment grain size and transport initiation velocity.



LEGEND

Pacific Highway (approximate location)

Cadastral Boundaries

Title:
Land Use Distribution
Cudgen/Cudgera Creeks Model

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Figure:
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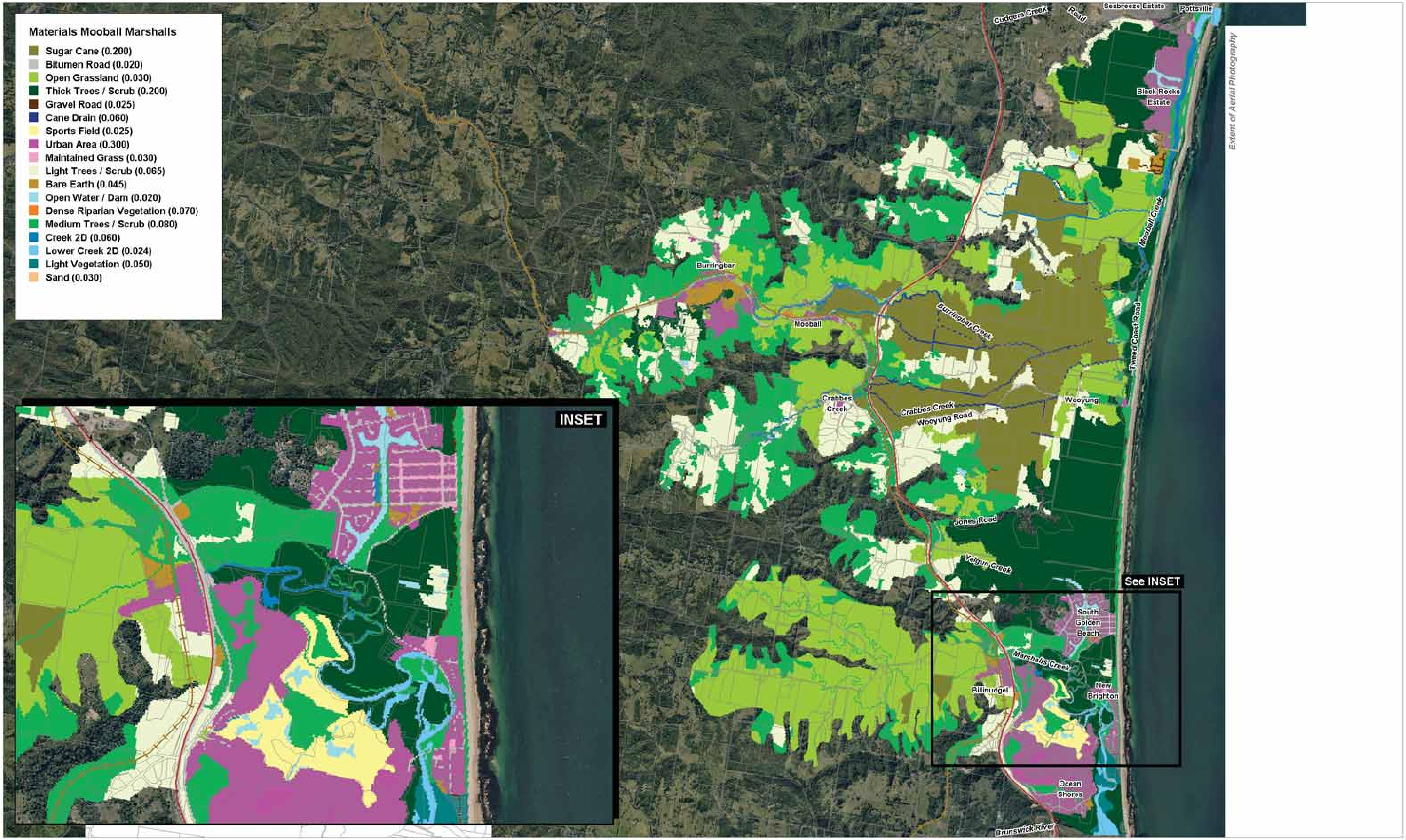

LEGEND

- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Cadastral Boundaries

Title:

Land Use Distribution Mooball/Marshalls Creeks Model

Figure: 4-4

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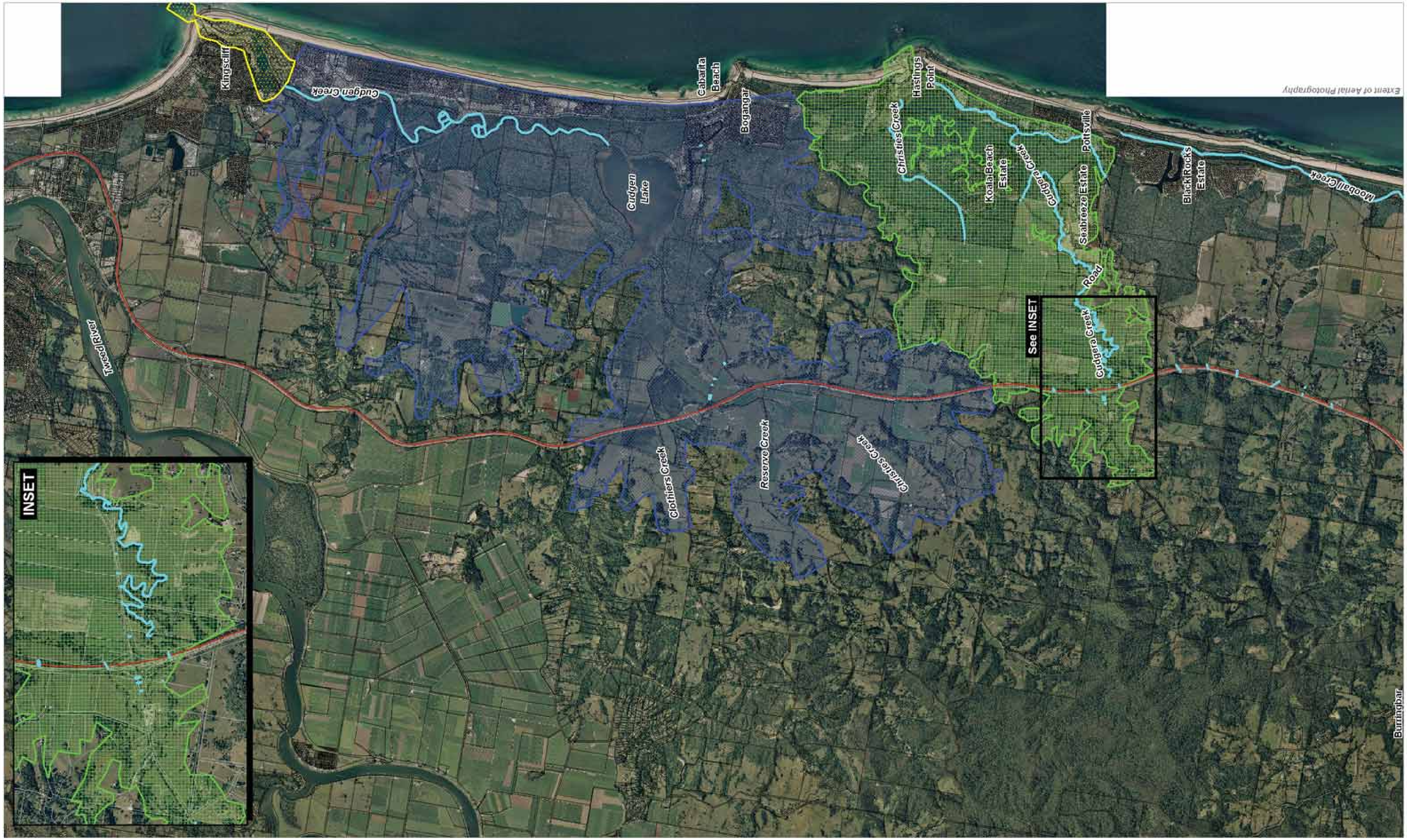

Title:
2D/1D Model Extents
Cudgen/Cudgera Creeks Model

Figure: 4-5

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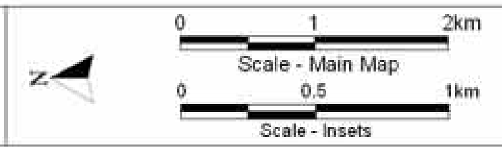

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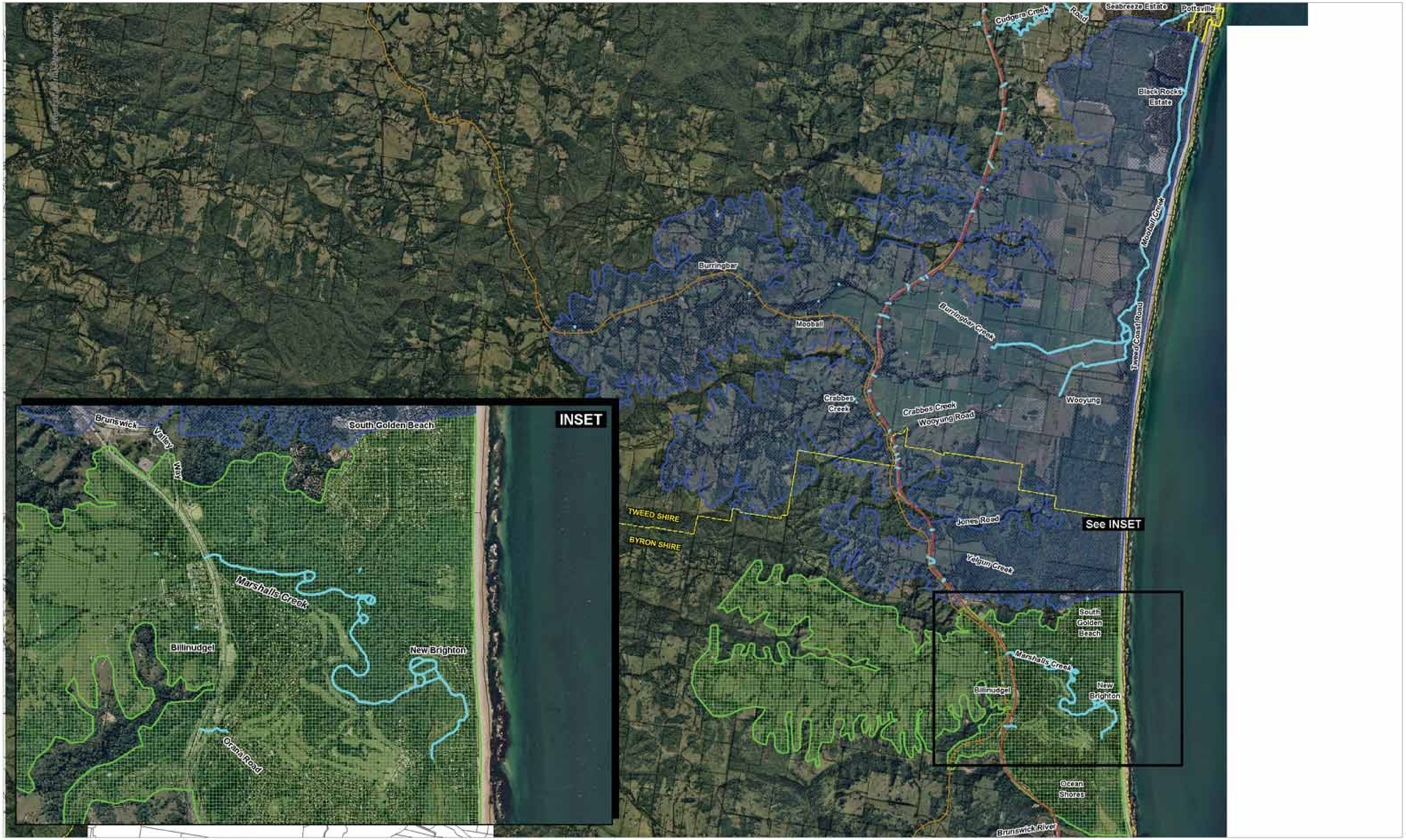

LEGEND

- Mooball 30m Model
- Marshalls 15m Model
- Lower Mooball 10m Model (Dynamic Scour)
- 1D Network
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary

Title:

2D/1D Model Extents
Mooball/Marshalls Creeks Model

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Figure: 4-6

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5 MODEL VALIDATION

5.1 Choice of Calibration / Verification Events

5.1.1 Available Records of Peak Flood Level Data

The recent large and widespread June 2005 flood event was the most recorded and remembered by Councils and residents across the entire study area. The number of peak flood level records for this event amounts to 169 records, relatively well spread over the coastal creeks catchments. See Figure 2-7 for a geographical distribution map.

Another major historical event was the May 1987 flood. Records of peak flood levels for this event are fewer (total of 62 records) and somewhat localised around the Marshalls Creek and Upper Burringbar Creek catchments.

There is not much recollection of the March 1974 flood event (more than 30 years ago), with only 15 records, principally around Mooball and the lower Cudgen Creek catchment.

No dataset was successfully collated for other recent or older flood events (including 1954, 1994 and 2000).

5.1.2 Available Rainfall and Pluviograph Data

Together with the availability of flood marks, the ability to accurately estimate the spatial and temporal rainfall distributions for each flood event is a key element of a successful model calibration. This is strongly dependent on the availability of continuous rainfall datasets at several locations across the different catchments.

Although they are a good indication of the scale of the event, daily rainfall records do not provide enough information to derive spatial and temporal rainfall distributions over the critical 24 to 72 hours of storm events. Good pluviograph information (i.e. rainfall data over shorter time steps such as hourly or six-minute intervals) is critical to a successful calibration.

Pluviograph data was collated for each of the three major flood events for which there were available flood marks (namely June 2005, May 1987 and March 1974). This is described in Section 2.5.2.

It is noted that pluviograph data is scarce for the 1974 and 1987 flood event, with only one or two pluviographs within the entire study area. This implies a greater degree of uncertainty when it comes to calibration of the hydrological and hydraulic models for these events.

5.1.3 Conclusions on Choice of Calibration / Verification Events

The sections above highlight a general lack of available calibration data for the coastal creeks historical flood events.

The June 2005 datasets is the most extensive. Hence, this event was chosen as the main calibration event for the joint calibration of the coastal creeks hydrological and hydraulic models.

Although there was few flood mark data available to some extent for the May 1987 flood event, there is also an obvious lack of accurate and detailed rainfall data across the catchments for this event. Similarly, not much information was collated for the March 1974 flood event. In such circumstances, it is advisable that these flood events be used as "verification" events rather than calibration events. This means that the May 1987 and March 1974 flood events were run through the models once these had been successfully calibrated to the June 2005 flood event.

Note that the models (and particularly the hydraulic model) were modified to represent the land uses and urban developments of the relevant period. Any potential discrepancies with the available flood level data is typically weighted with uncertainties associated with the simulation of these validation floods. This is presented and discussed further in the following Section 5.2.

5.2 Joint Model Calibration

5.2.1 General Approach

Due to the difficulty of accurately estimating the spatial and temporal rainfall distributions of the chosen events and the absence of stream flow data across the coastal creeks catchments, a joint calibration of hydrologic and hydraulic model was undertaken, rather than a two-step calibration of each model individually. This approach has been previously applied on a number of different flood studies and has proven to provide an accurate representation of flooding behaviour. An iterative process was thus carried out in this phase of the flood study, in order to ensure that the models provide an adequate representation of historical events, based on the available information. The main outcomes of this joint model calibration are detailed in the following sections for each of the three selected historical flood events (namely June 2005, May 1987 and March 1974).

5.2.2 June 2005 Flood

5.2.2.1 Rainfall Data

Cumulative rainfall depths and daily rainfall totals were analysed for the period from 28th of June to 1st of July 2005. The aim of this analysis was to define spatial and temporal rainfall patterns applicable across the coastal creeks catchments for this event.

Five areas were defined during the calibration process, with five corresponding pluviograph patterns. Figure 5-1 and Figure 5-2 present those patterns, and the areas are shown in Figure 5-3. The following key points are noted in relation to these rainfall patterns:

- All catchments experienced about a 1 year ARI rainfall event to the 28th of June 2005;
- This was followed by roughly a 5 year ARI rainfall event on the 29th of June 2005 for the upper parts of the catchments. This second day of rainfall was not very significant in the coastal areas;
- The situation then worsened with a major rainfall event on the 30th of June 2005, homogeneously across all catchments. Heavy rainfalls amounted to a cumulative depth of 200mm in 4 hours (from 6am to 10am); and
- In the previous 2 hours, the northern catchments received substantially more than the southern catchments (100mm in the north compared to 50mm in the south).

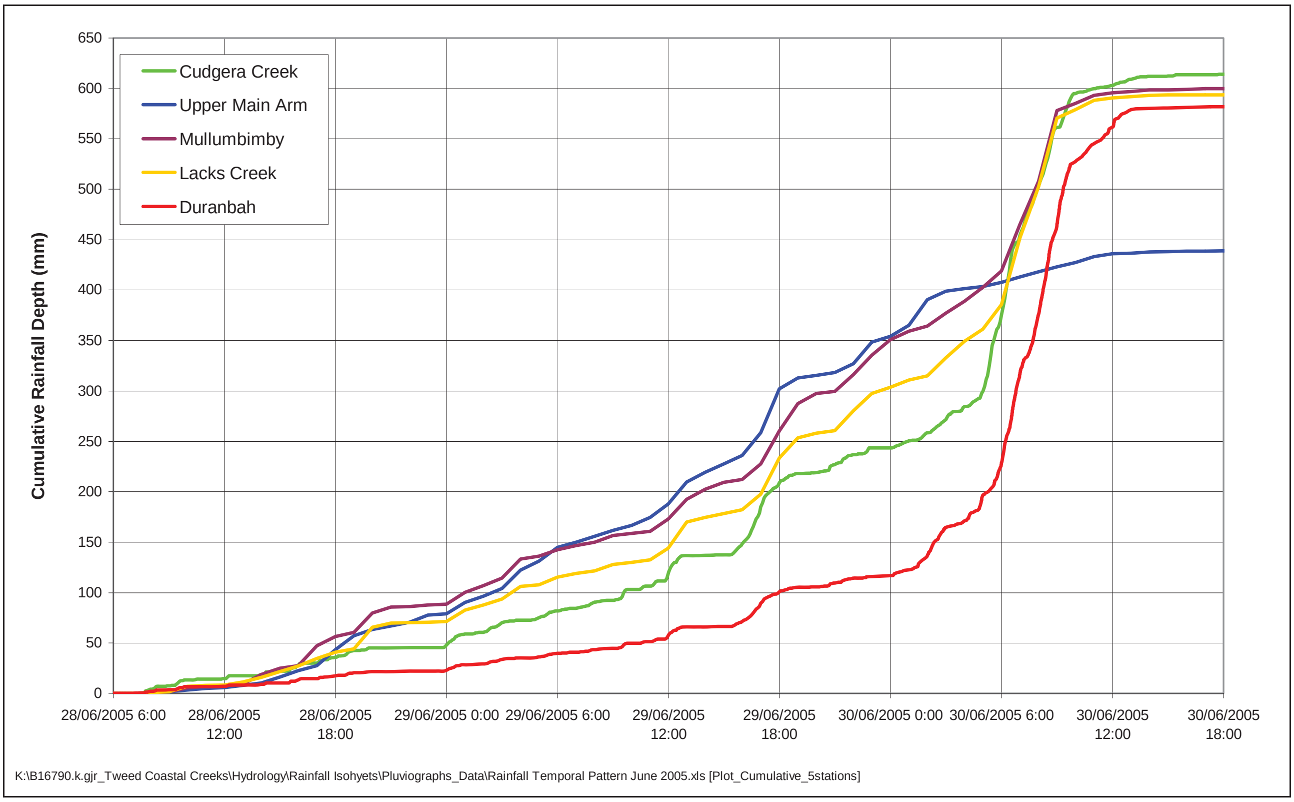


Figure 5-1 Cumulative Pluviograph Patterns – June 2005 Event

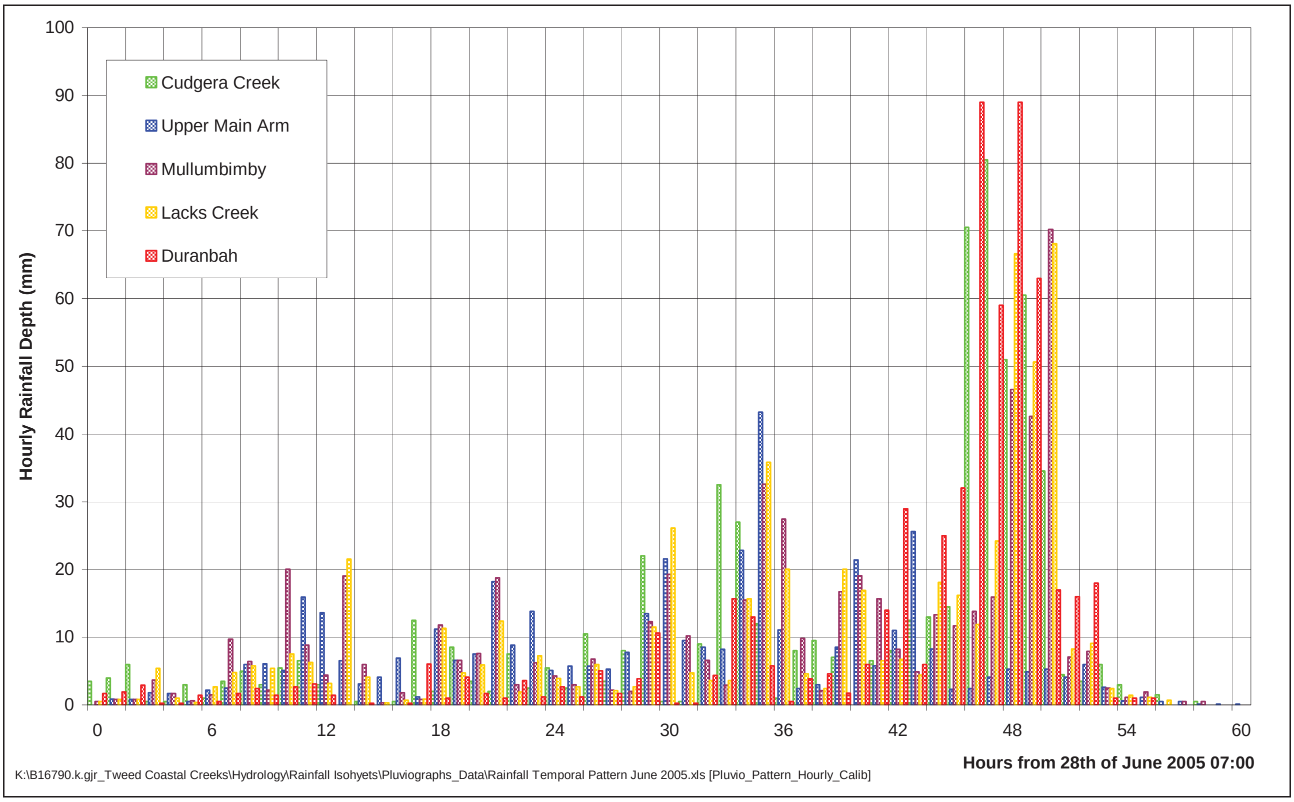
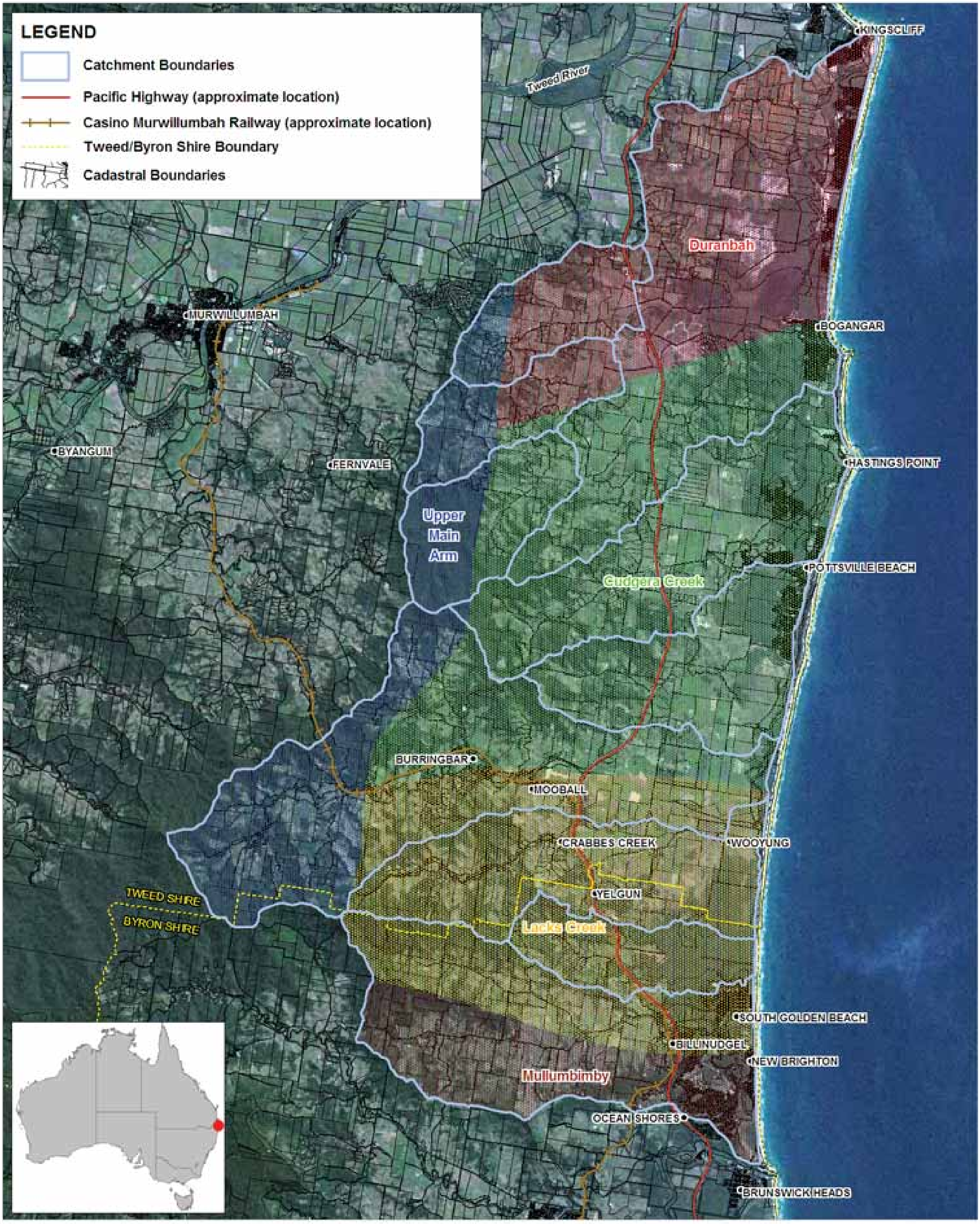


Figure 5-2 Hourly Pluviograph Patterns – June 2005 Event



Title:
Pluviograph Patterns Application Areas

Figure: 5-3

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Approx. Scale

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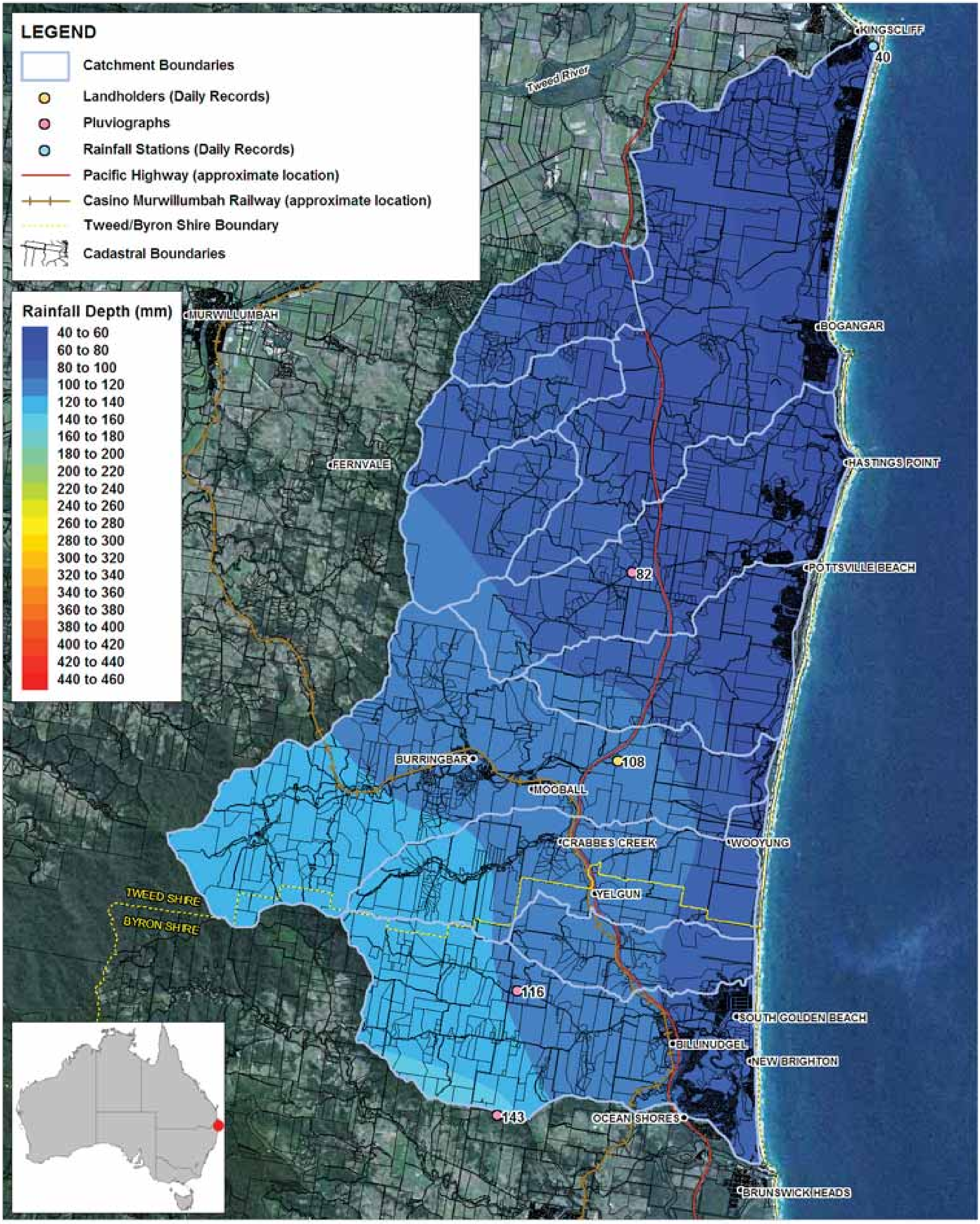
Daily isohyets were derived from the available records across the catchments for each of the three days of the rainfall event. These isohyets were used to generate rainfall surfaces for the entire study area, from which a total daily rainfall depth for each subcatchment was subsequently derived for both hydrological models. These surfaces are shown in Figure 5-4 to Figure 5-6.

Pluviograph patterns as defined previously were then assigned to the subcatchments, with corresponding hydrographs scaled across the catchment using the daily rainfall depth values. The resultant scaling factors were used to weight the pluviograph data in the RAFTS models.



Title:

Total Rainfall Depth Surface
24 Hours to 29th June 2005 6am

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Approx. Scale

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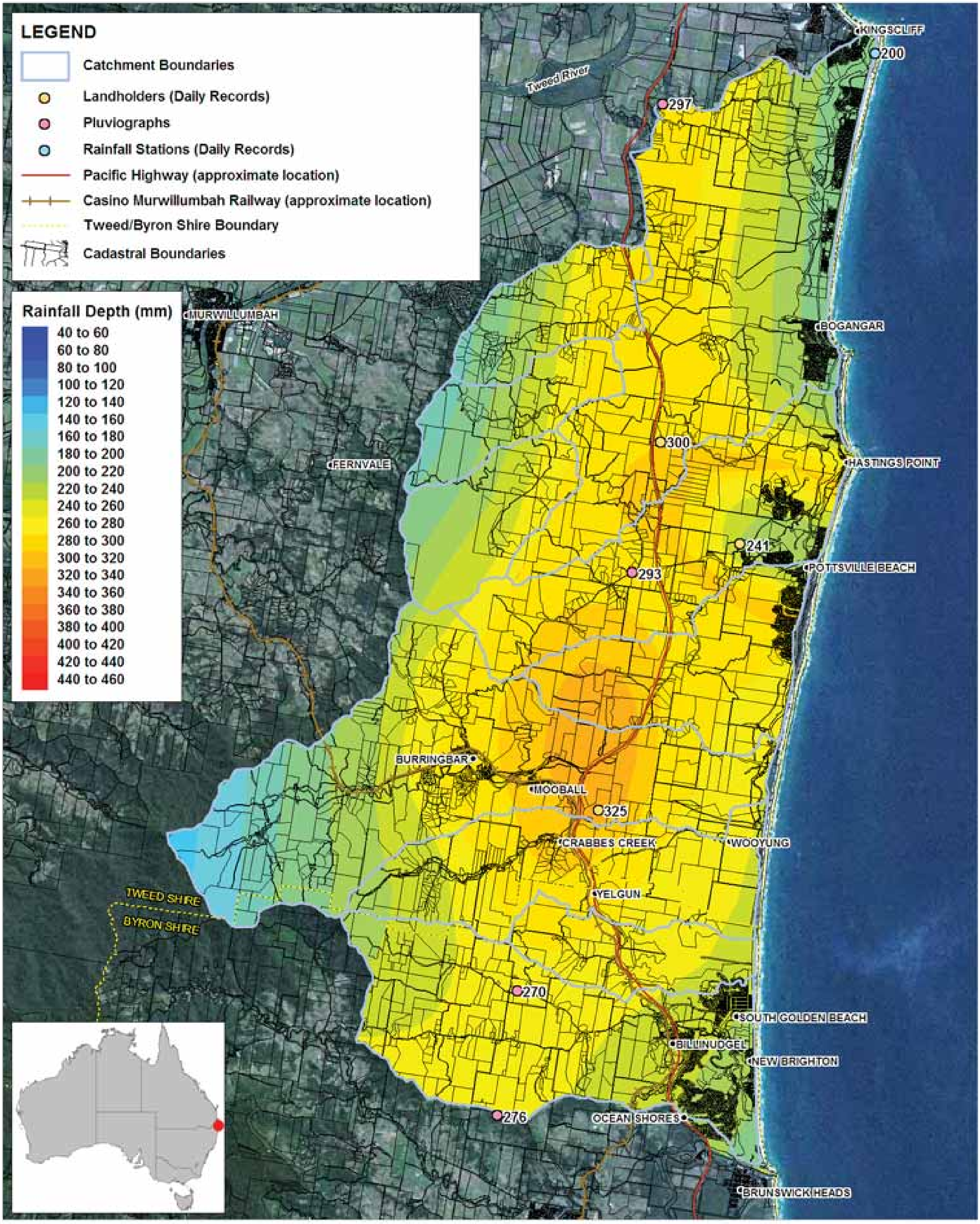

Title:

Total Rainfall Depth Surface 24 Hours to 30th June 2005 6am

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Approx. Scale

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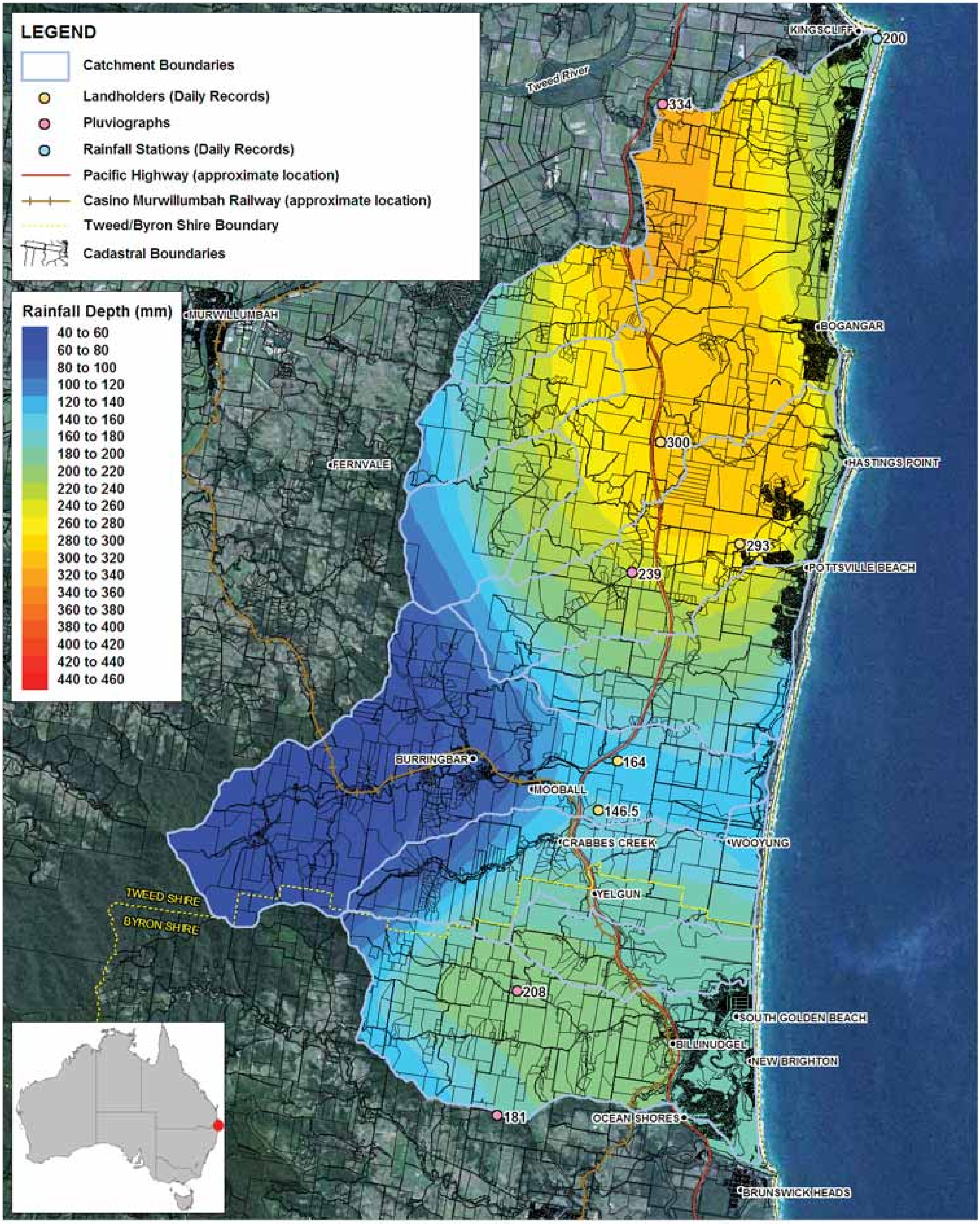

Title:

Total Rainfall Depth Surface
24 Hours to 1st July 2005 6am

Figure: 5-6

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5.2.2.2 Hydrological Modelling Results

In the absence of any records at the Kingscliff station, the hydrological modelling of the June 2005 event was challenging, especially to capture the spatial variation of the rainfall over the northern part of the Cudgen Creek catchment.

Adopted loss parameters for the June 2005 storm event are as follows:

- Initial Loss = 0 mm over rural areas;
- Initial Loss = 0 mm over urban areas;
- Continuing Loss = 2 mm/hr over rural areas; and
- No continuing losses were taken into account for urban areas.

The predicted discharge hydrographs downstream of the main coastal creek systems are shown in Figure 5-7.

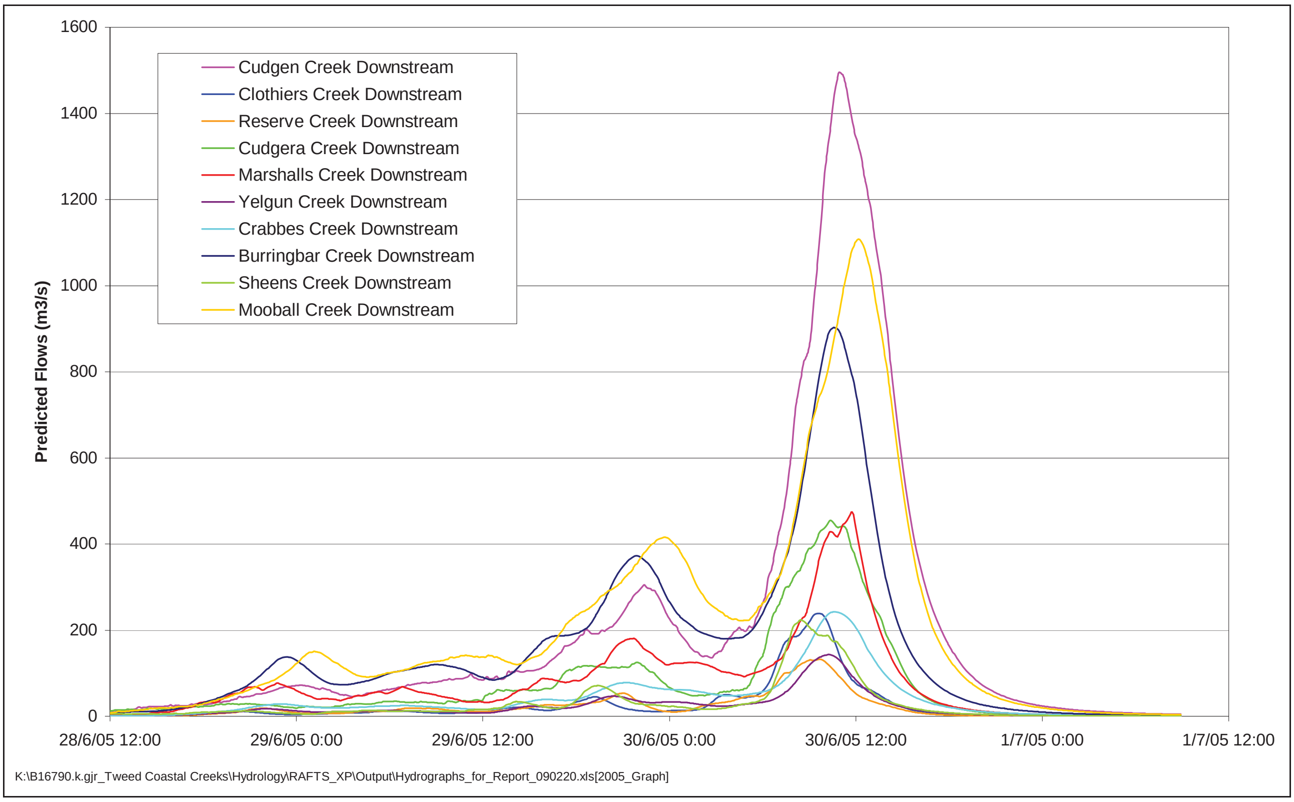


Figure 5-7 RAFTS-XP Discharge Hydrographs – June 2005 Event

5.2.2.3 Tidal Boundary Conditions

Two water level recorders were operating during the June 2005 event: in Cudgen Creek at Kingscliff (inside the training walls) and in the Brunswick River at Brunswick Heads. Data for these stations was obtained from Manly Hydraulics Laboratory (MHL).

The downstream boundary conditions used for the June 2005 event are presented in Figure 5-8 and discussed below.

For the purpose of this calibration, the Cudgen Creek model developed previously was shortened from the ocean boundary back into the training walls at Kingscliff (where the water level recording station is located). Tidal levels recorded during the June 2005 event could then be applied directly to downstream boundary of this shortened model.

These records show that there was no significant storm surge at Kingscliff for the June 2005 event. Figure 5-8 also present synthetic tidal predictions at Kingscliff. The difference in water levels between the recorded data (inside the training walls) and the predicted data (out to the sea) at Kingscliff during the high flow period highlights the effect of hydraulic losses through the training walls.

No water level recordings were available for Cudgera and Mooball Creeks. Given the lack of storm surge at Kingscliff, the predicted synthetic tide at Kingscliff was applied to these models, which both extend offshore.

The water level recorder in the Brunswick River is located at Brunswick Heads. The Marshalls Creek hydraulic model developed previously does not extend this far downstream. Hence, the recorded level in the Brunswick River was modified to match peak flood levels recorded within the downstream section of Marshalls Creek. This modification was only applied at the peak of the flood flows, consistently with recorded water levels at Kingscliff. As the model is calibrated to peak flood levels this representation is considered sufficient for the purposes of this study.

It is noted that the accuracy of the model in this area, and the ability to represent the connection between Marshalls Creek and the Brunswick River would significantly be improved by extending the model downstream to include the lower Brunswick River (including training walls). This is out of the scope of the current flood study, but should be considered in the future to enhance the representation of the complex flow patterns around the breakwalls at the outlet of Marshalls Creek and enable simulation of coincident Brunswick River and Marshalls Creek flooding and storm surge propagation (including climate change).

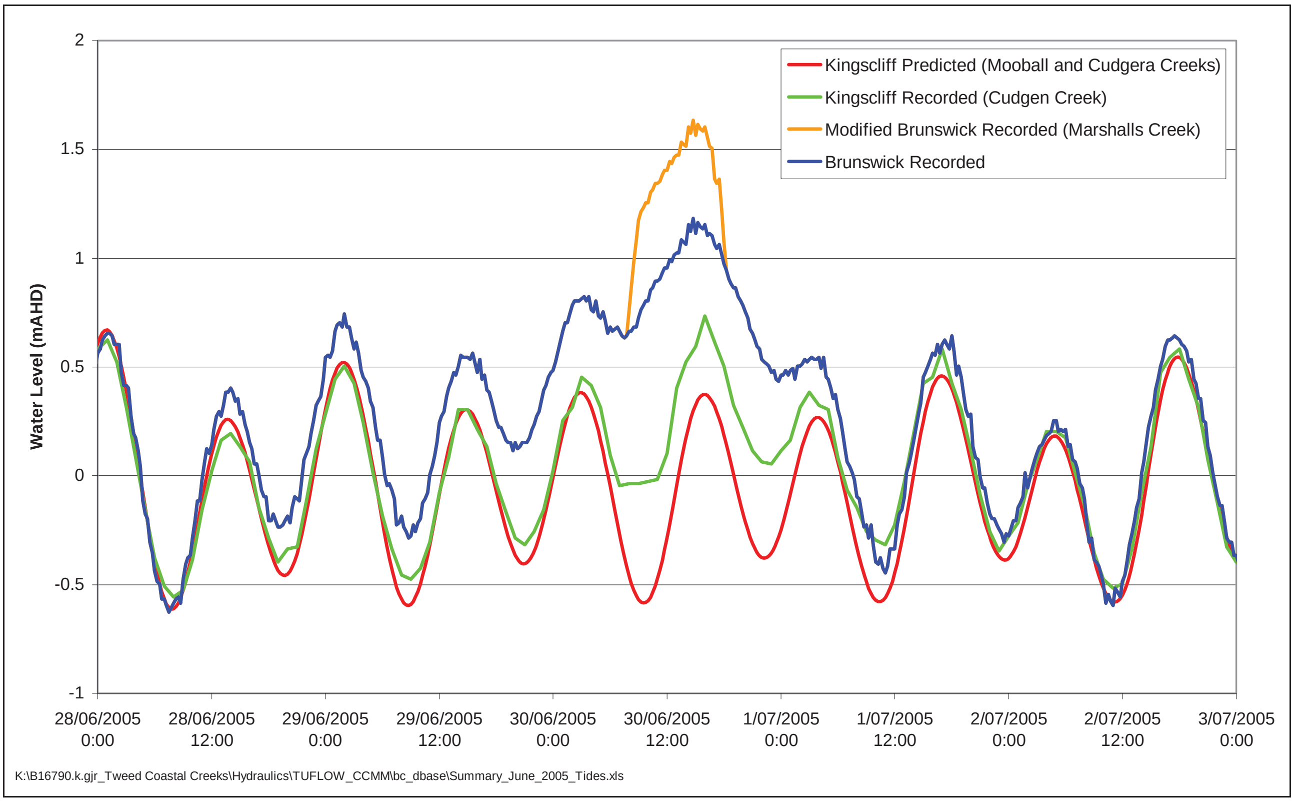


Figure 5-8 Downstream Boundary Conditions – June 2005 Event

5.2.2.4 Hydraulic Modelling Results

The performance of the hydraulic models to replicate recorded peak flood levels for the June 2005 flood event is presented in Figure 5-9 (Cudgen/Cudgera Creeks catchments) and Figure 5-10 (Mooball/Marshalls Creeks catchments). In particular, these figures show the predicted peak flood surface across the study area, as well as observed and modelled peak flood levels for the June 2005 records.

It is noted that a number of flood marks collected represent localised runoff and drainage issues and, hence, no inundation is predicted using the regional scale model used in the current study. This is typically the case in the upper parts of the catchments.

Two time series recorders were operational in the study area during the June 2005 event: at Billinudgel and at Bogangar (Cudgen Lake). Both recorders are operated by MHL. The Billinudgel recorder is located on Marshalls Creek, upstream of the Pacific Highway and railway. The predicted and observed hydrographs at this location are presented in Figure 5-11. The Bogangar recorder provides Cudgen Lake levels during the flood event. Similarly, the predicted and observed hydrographs at this location are presented in Figure 5-12. The model provides a good representation of the timing and shape of both hydrographs.

The main effort of the hydraulic calibration was in varying Manning's n values (within reasonable ranges) to provide the optimal calibration with recorded data.

A key area in calibrating the hydraulic model in the Cudgera catchment was the top of bank level for Cudgera Creek north of Cudgera Creek Road. In this area flows break out of the creek and flow through the sugar cane farms. Tweed Shire Council surveyed the top of bank in this area.

The results for the lower Cudgen and Mooball Creeks were sensitive to the conditions at the creek mouth. The morphology module in TUFLOW was used to estimate the scour, based on the predicted velocities. With the morphology estimates, the model matches the 1.15mAHD observed upstream of the Cudgen Creek bridge at Kingscliff. The predicted water level at the bridge is low in comparison to the level of 1.09mAHD observed at the bridge. Given the significant velocities of up to 2m/s through this bridge, there is likely to have been a backwater effect at the upstream of the bridge pylons. This could lead to an increase in predicted water level of up to 0.2m as velocity head is converted to an increase in water level [$V^2/2g$, $(2.0^2)/ (2x9.81)$].

In order to match the level recorded at the Old Bogangar Bridge, north of Cudgen Lake, it was necessary to lower the bed levels downstream of the bridge. Surveyed levels in the area were lowered by 0.5m. Prior to reducing bed levels, velocities in the channel were 1 to 1.5m/s and hence, well above the threshold at which sand will begin to transport. It is noted that the model is still slightly over predicting the recorded levels in this area and this could reflect a greater scour during the June 2005 flood event.

The model is under predicting peak flood levels near the Hasting Point Sewage Treatment Plant. The area is densely vegetated and the ALS is unlikely to accurately measure ground levels in the area. There are also few rainfall records in this area and it is possible that greater rainfall occurred in this area than assumed.

There are a significant number of calibration points in the South Golden Beach area. The observed water levels vary from 2.59mAHD to 3.17mAHD. The modelling predicts a relatively flat flood gradient in this area. The observed flood levels to the west of the canal system are higher than the observed levels within the canal. This is due to a flood gradient caused by local hydraulic effects not represented in this study.

5.2.2.5 Flood Recession Modelling

Discussions held with the Floodplain Committee highlighted the availability of additional flood level data upstream (north) and downstream (south) of the Kallaroo Circuit culverts for the June 2005 event. These flood levels were collected during the event by Matthew Lambourne, and are particularly valuable to assess the ability of the model to accurately reproduce the recession of the flood. Although a secondary focus of the current flood study (the primary focus being peak flood levels), it is understood that flood recession plays a major role in the sustainability of local ecosystems (e.g. Yelgun Creek/Billinudgel Nature Reserve).

The June 2005 simulation was thus extended to cover a 10-day period following the peak of the flood. For this purpose, the following assumptions were made:

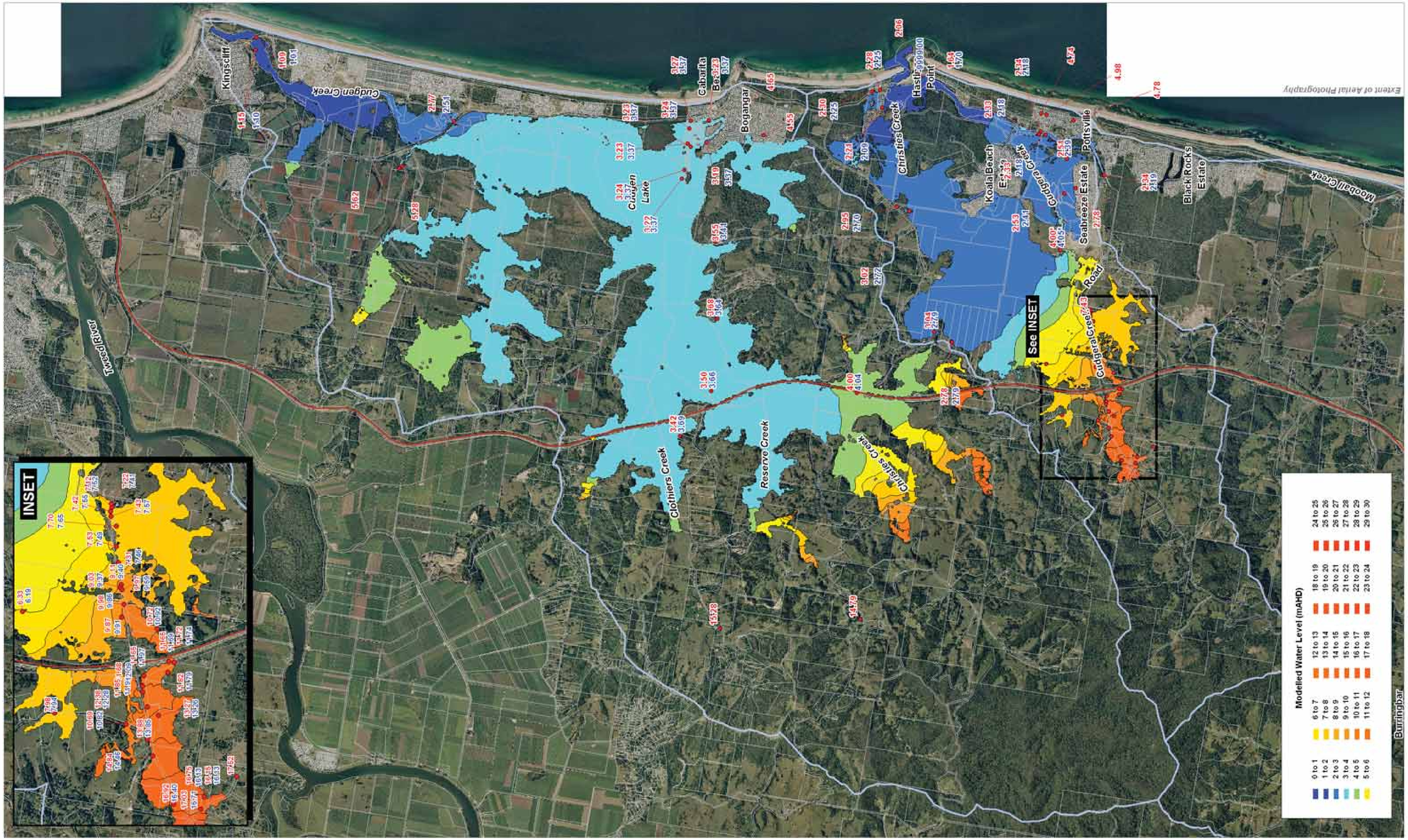
- No rainfall was considered after the 1st of July 2005. This is consistent with available rainfall records in the area;
- The downstream boundary at the mouth of Marshalls Creek was derived based on the recorded level in the Brunswick River at the Brunswick Heads Station. As discussed in Section 5.2.2.3

the levels were modified at the times of peak flow in Marshalls Creek. The levels are increased to match peak levels recorded at the downstream end of Marshalls Creek. After the peak has passed, the levels used for the downstream boundary are those recorded in the Brunswick River.

Results are presented in Figure 5-13, together with the levels recorded by Matthew Lambourne. This figure shows that the model is reliably reproducing the June 2005 flood levels both upstream and downstream of the Kallaroo Circuit culverts for the first 5 days of the recession of the flood. This figure also shows that once the bulk of the flood event has passed through the system, flood levels in the area are controlled by the downstream tidal levels at the mouth of Marshalls Creek.

It is recognised that the model presents some lack of robustness in the representation of the downstream connection between Marshalls Creek and the Brunswick River (see Section 5.2.3.3 for details on the downstream boundary conditions). This is important in representing the recession of the flood, as well as frequent hydrological events, when flood levels downstream of the Pacific Highway are controlled by the levels within the Brunswick River, rather than by the hydrological inflows from the upper catchments. However, these boundary conditions do not impact on flood levels during major events. Further improvements in the downstream boundary representation (in particular modelling of the downstream section of Marshalls Creek and the Brunswick River, as discussed in Section 5.2.2.3) would overcome this issue.

It is noted that only one level was recorded at the start of the flood event (on the 29th of June 2005). Although the model results match those records, a single point is not sufficient to conclude about the capacity of the model to reproduce the flood rise. However, this has been validated previously with flood level gauge records at Billinudgel and Cudgen Lake (see Figure 5-11 and Figure 5-12).



LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary

Observed Water Level
Modelled Water Level

* Indicates Water Level Not at Flood Peak

Title:
June 2005 Calibration Cudgen/Cudgera Creeks Model

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Figure: 5-9

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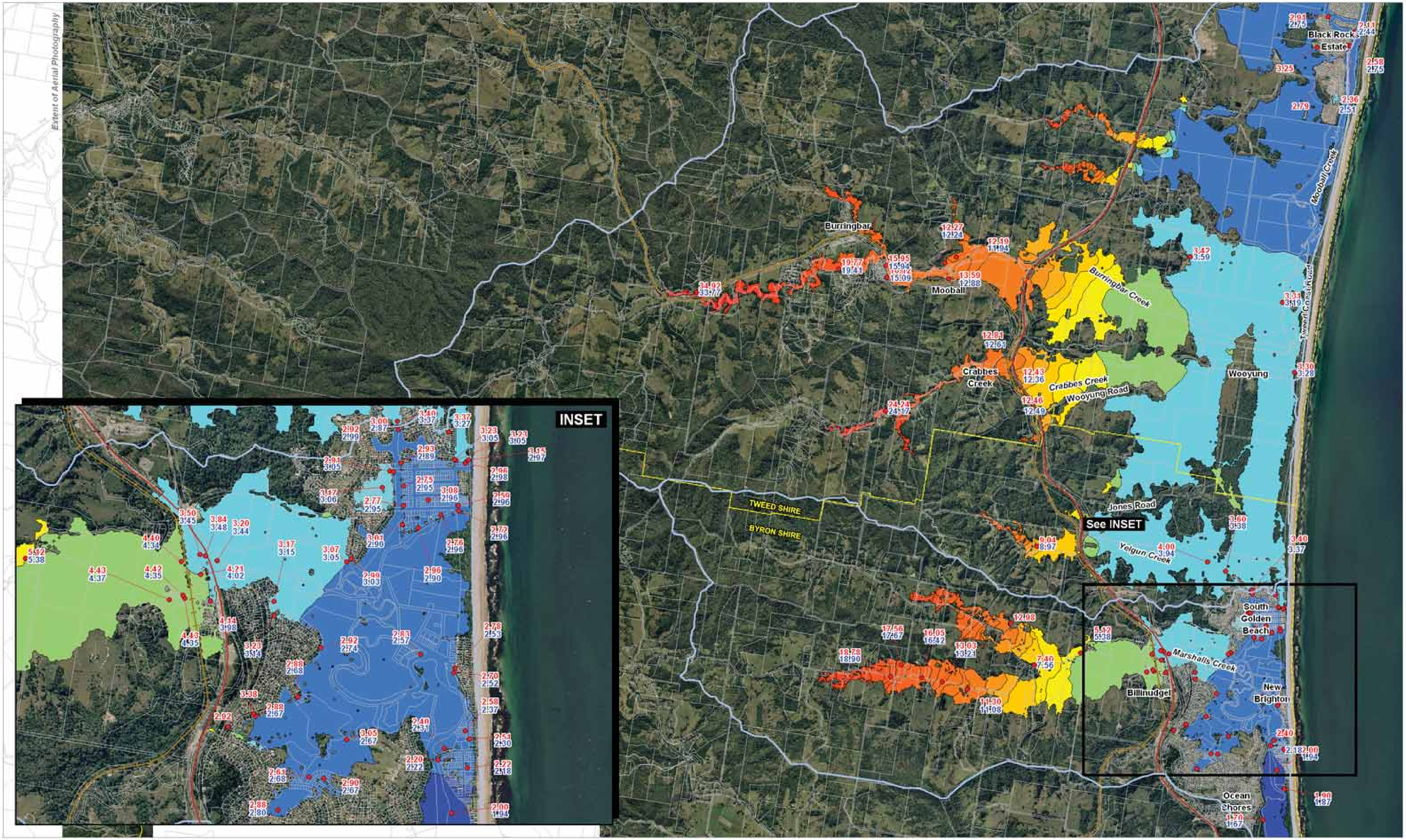

LEGEND

- Catchment Boundaries
- Tweed/Byron Shire Boundary
- Observed Water Level
- Modelled Water Level
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)

Modelled Water Level (mAHD)

0 to 1	6 to 7	12 to 13	18 to 19	24 to 25
1 to 2	7 to 8	13 to 14	19 to 20	25 to 26
2 to 3	8 to 9	14 to 15	20 to 21	26 to 27
3 to 4	9 to 10	15 to 16	21 to 22	27 to 28
4 to 5	10 to 11	16 to 17	22 to 23	28 to 29
5 to 6	11 to 12	17 to 18	23 to 24	29 to 30

Title:

June 2005 Calibration
Mooball/Marshalls Creeks Model

Figure: **5-10**

Rev: **C**

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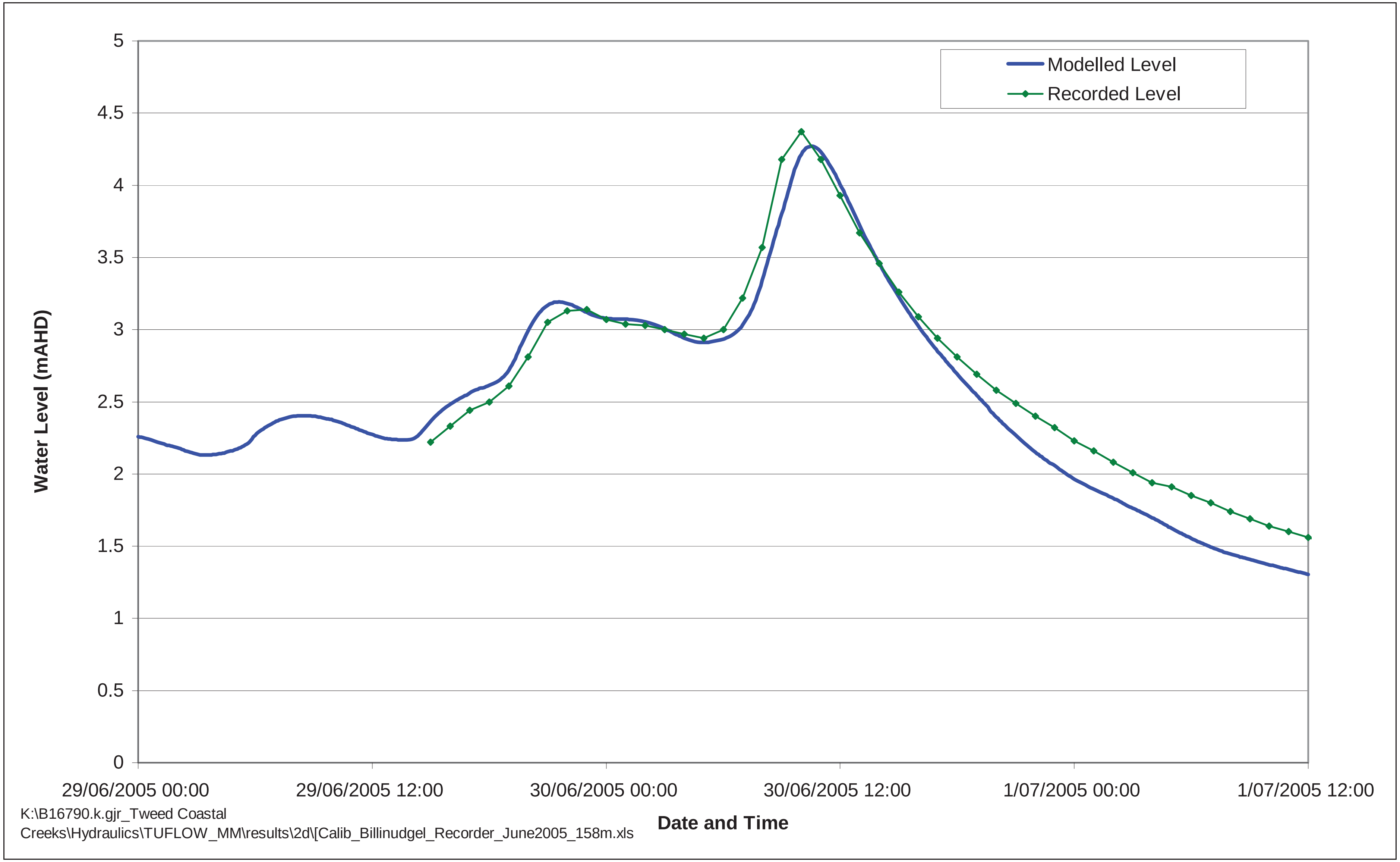


Figure 5-11 June 2005: Billinudgel Gauge Comparison with Hydraulic Model Results

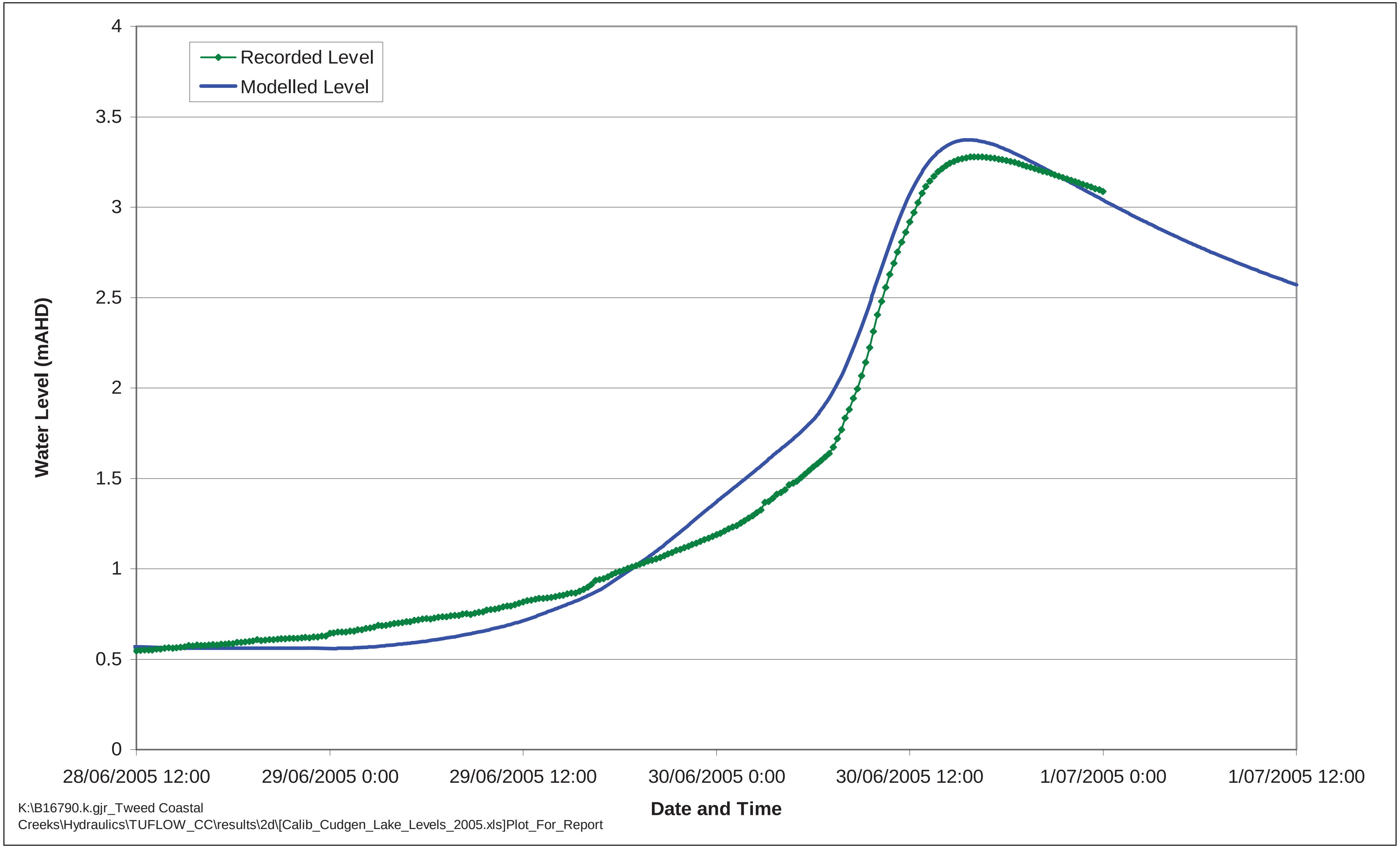


Figure 5-12 June 2005: Cudgen Lake Gauge Comparison with Hydraulic Model Results

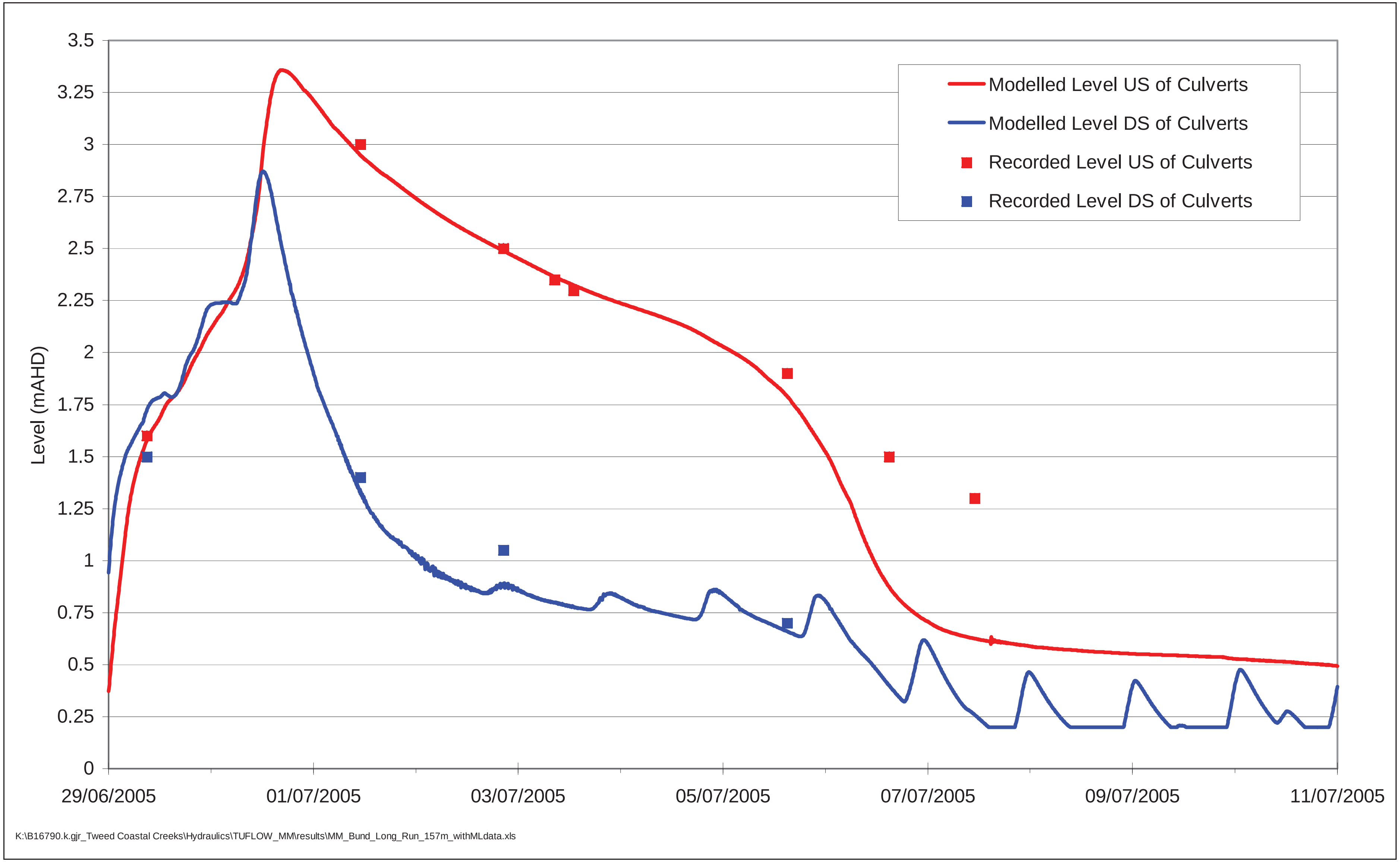


Figure 5-13 June 2005: Kallaroo Circuit Culverts Comparison with Hydraulic Model Results

5.2.3 May 1987 Flood

5.2.3.1 Rainfall Data

Rainfall distribution for this event was retrieved from previous studies (PWD, 1988). Pluviograph records were available from two stations within the catchment: Cudgera and Murwillumbah (Bray Park). The Cudgera pluviograph record was used for the rainfall temporal pattern. It is illustrated in Figure 5-14. Adopted rainfall isohyets are reported in Figure 5-15.

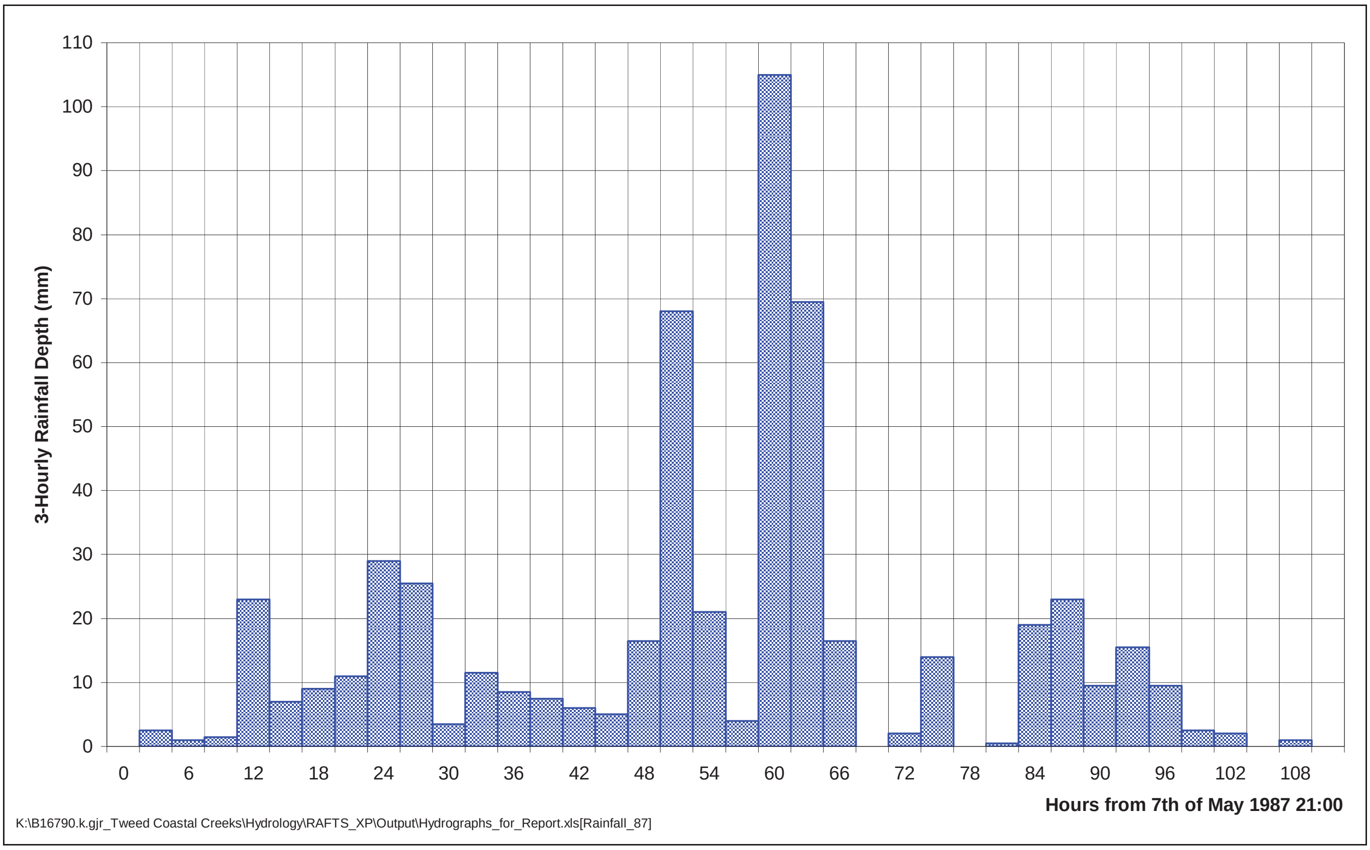
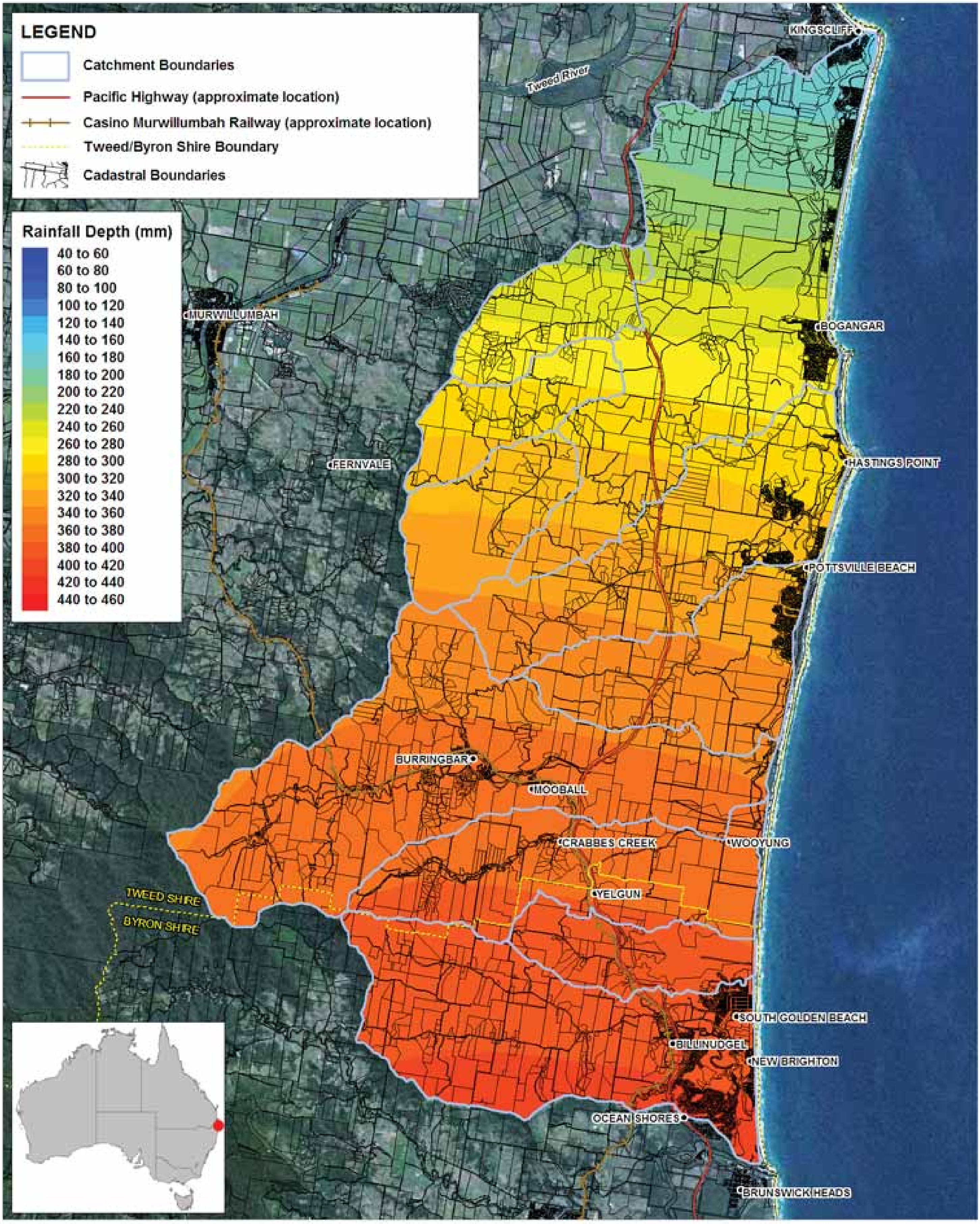


Figure 5-14 Rainfall Temporal Pattern – May 1987 Event



Title:

Total Rainfall Depth Surface
48 Hours to 11th May 1987 9am

Figure: **5-15**

Rev: **B**

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Approx. Scale

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5.2.3.2 Hydrological Modelling

In order to reproduce recorded flood levels in the Cudgen Creek and Mooball Creek floodplains, no losses (initial or continuing) were assumed in the hydrological modelling for the May 1987 storm event. Although this might not be representative of real processes in the catchments for this particular event, this allowed for the lack of accurate rainfall data across the coastal creeks study area.

The predicted discharge hydrographs downstream of the main coastal creek systems are shown in Figure 5-16.

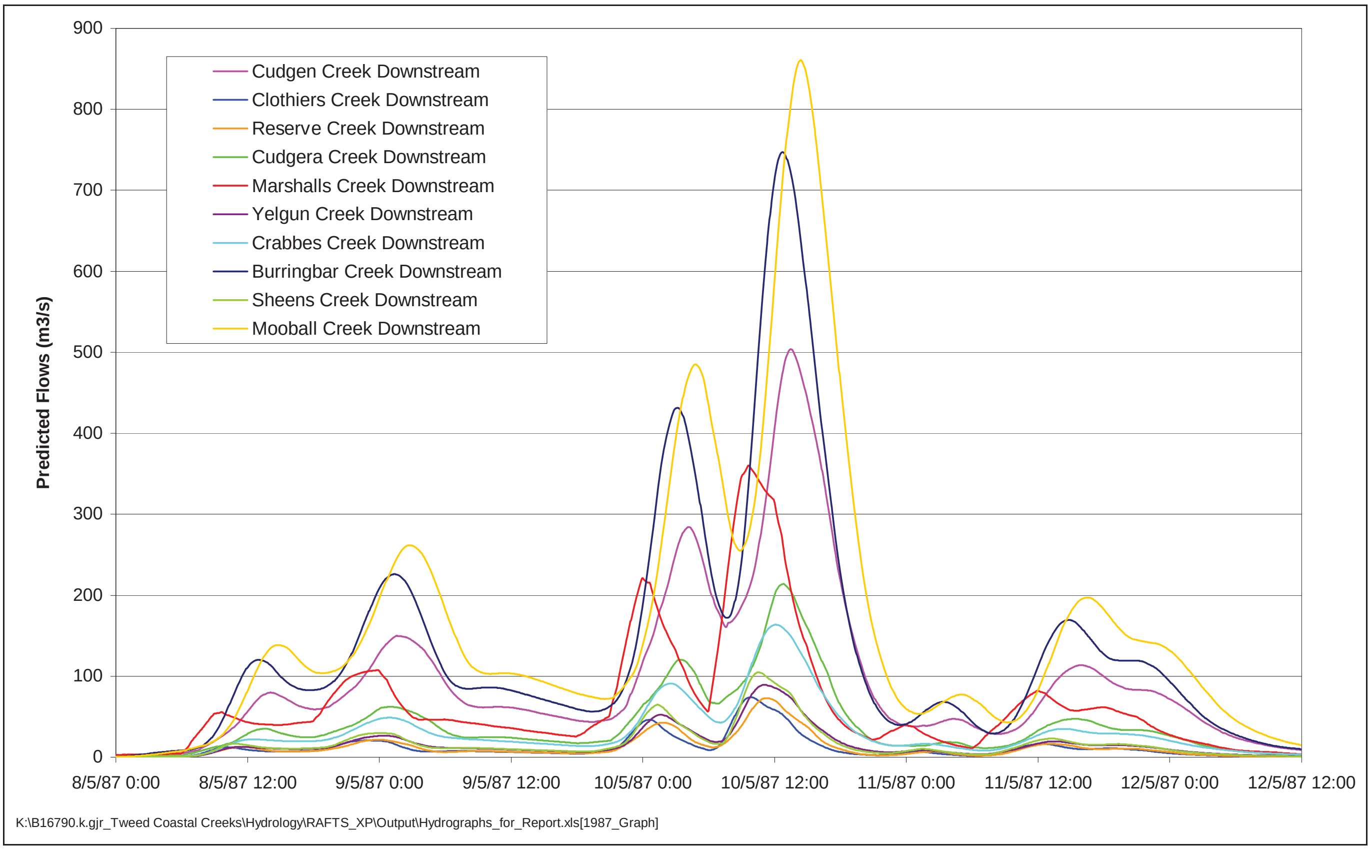


Figure 5-16 RAFTS-XP Discharge Hydrographs – May 1987 Event

5.2.3.3 Tidal Boundary Conditions

The tidal boundaries for the May 1987 event are based on water level recordings at two locations similar to the June 2005 event: Cudgen Creek at Kingscliff and Brunswick River at Brunswick Heads. The data recorded at Kingscliff was used as a downstream boundary for Cudgen, Cudgera and Mooball Creeks. It is presented in Figure 5-17.

The water level recorder in the Brunswick River is located at Brunswick Heads. The Marshalls Creek hydraulic model developed previously does not extend this far downstream. Hence, the recorded level in the Brunswick River was modified to match peak flood levels recorded within the downstream section of Marshalls Creek. This is the same method that was used for the June 2005 event (see

Section 5.2.2.3). The recorded and modified Brunswick River timeseries are illustrated in Figure 5-17.

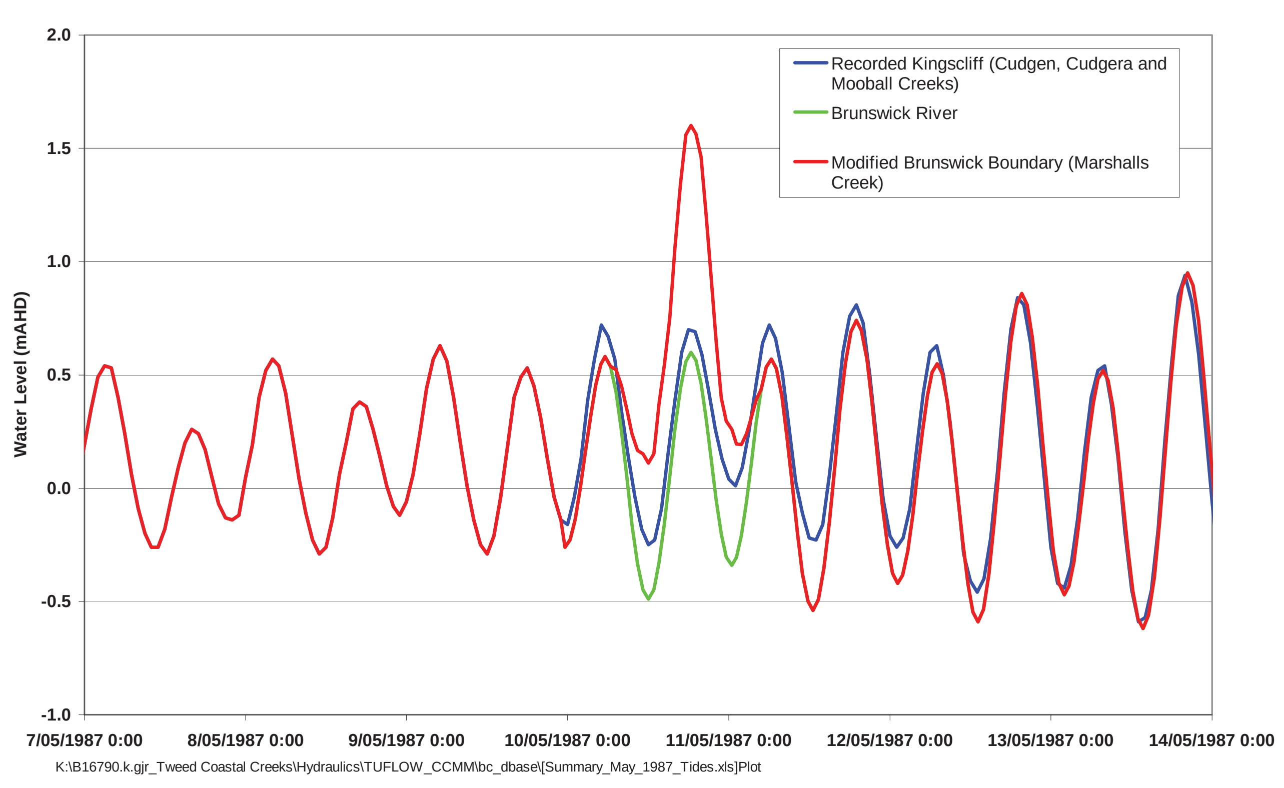
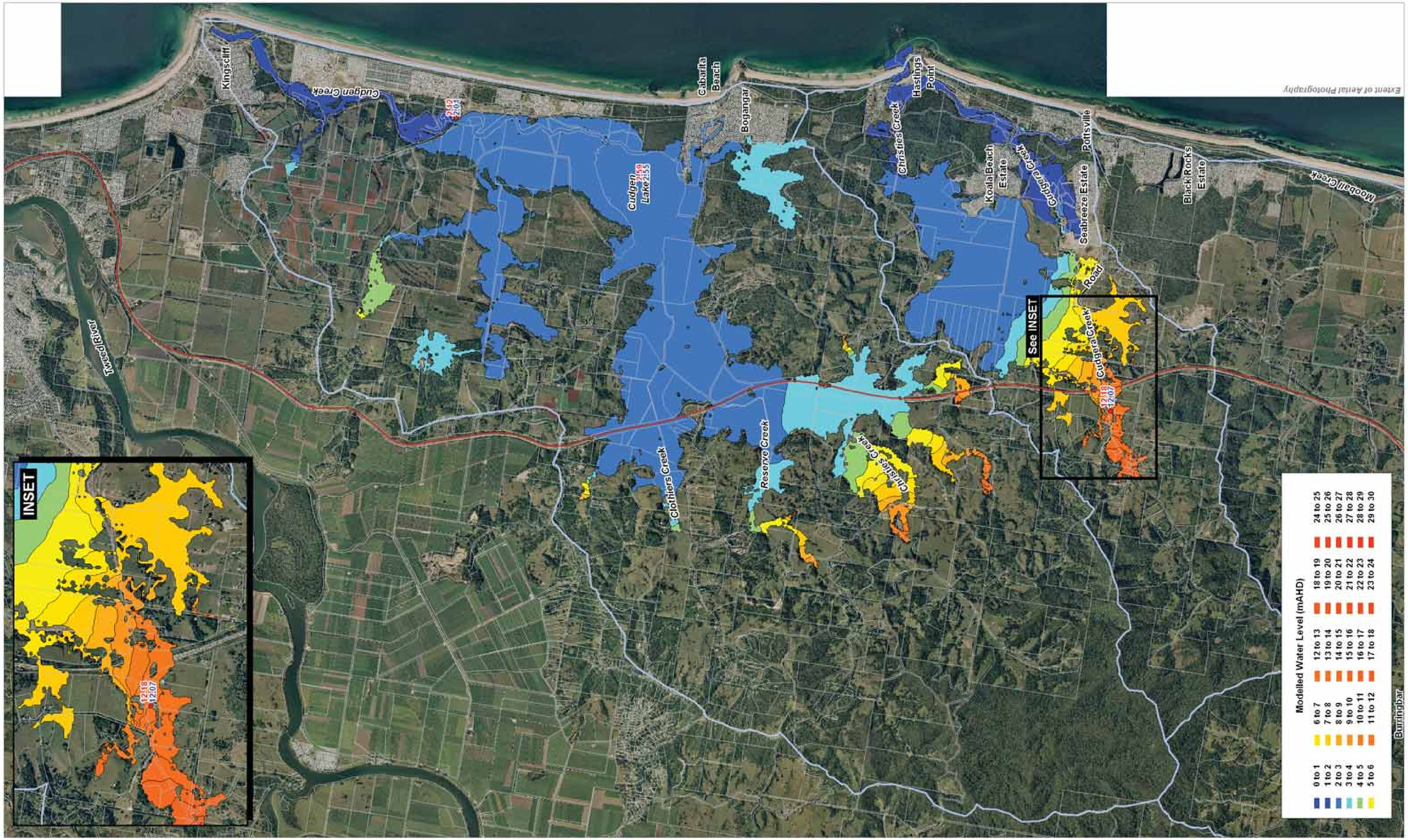


Figure 5-17 Downstream Boundary Conditions – May 1987 Event

5.2.3.4 Hydraulic Modelling

The performance of the hydraulic models to replicate recorded peak flood levels for the May 1987 flood event is presented in Figure 5-18 (Cudgen/Cudgera Creeks catchments) and Figure 5-19 (Mooball/Marshalls Creeks catchments). In particular, these figures show the predicted peak flood surface across the study area, as well as observed and modelled peak flood levels for the May 1987 records.

Due to the lack of available data, this event was used as a verification of model performance after calibration to the June 2005 event. Discrepancies between recorded peak levels and modelled peak levels are considered to be due to the uncertainties in the data input to the model, primarily the lack of rainfall data.



LEGEND

Catchment Boundaries
Pacific Highway (approximate location)
Casino Murwillumbah Railway (approximate location)
Tweed/Byron Shire Boundary

Observed Water Level
Modelled Water Level

* Indicates Water Level Not at Flood Peak

Title:
May 1987 Calibration Cudgen/Cudgera Creeks Model

Figure: 5-18

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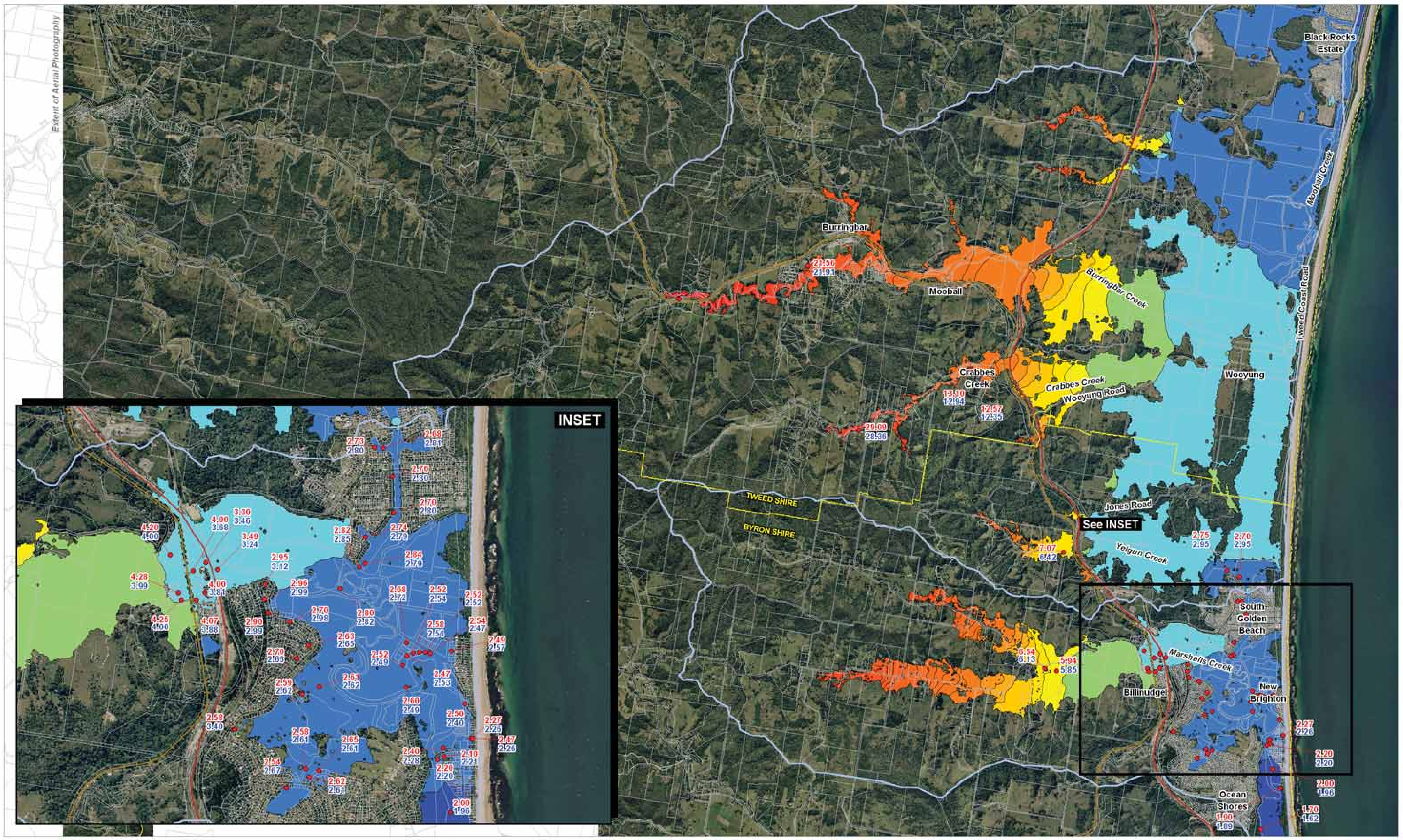

LEGEND

- Catchment Boundaries
- Tweed/Byron Shire Boundary
- Observed Water Level
- Modelled Water Level
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)

Modelled Water Level (mAHD)

0 to 1	6 to 7	12 to 13	18 to 19	24 to 25
1 to 2	7 to 8	13 to 14	19 to 20	25 to 26
2 to 3	8 to 9	14 to 15	20 to 21	26 to 27
3 to 4	9 to 10	15 to 16	21 to 22	27 to 28
4 to 5	10 to 11	16 to 17	22 to 23	28 to 29
5 to 6	11 to 12	17 to 18	23 to 24	29 to 30

Title:

May 1987 Calibration
Mooball/Marshalls Creeks Model

Figure: **5-19**

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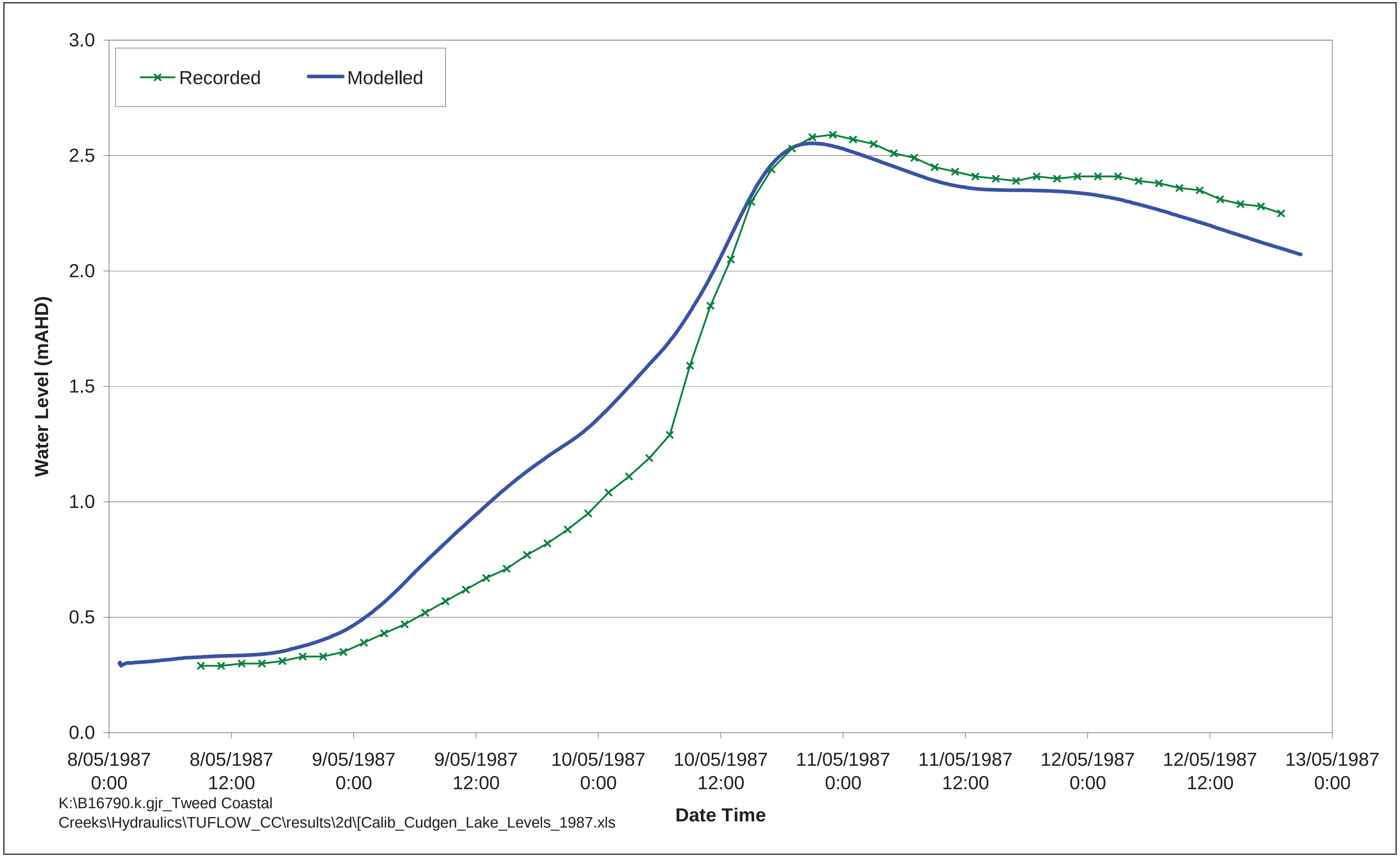


Figure 5-20 May 1987: Cudgen Lake Gauge Comparison with Hydraulic Model Results

5.2.4 March 1974 Flood

5.2.4.1 Rainfall Data

Rainfall distribution for this event was retrieved from previous studies (PWD, 1988). The only pluviograph data available for this event was the Murwillumbah (Bray Park) record. Although outside of the catchment area, this record was used to define the rainfall temporal pattern across the study area. It is illustrated in Figure 5-21. Adopted rainfall isohyets are reported in Figure 5-22. It should be noted that this is the best available data for this event. However, it has a high degree of uncertainty to represent the actual rainfall event on the coastal creeks catchments. Results of the hydrological and hydraulic modelling for this event should thus be interpreted accordingly.

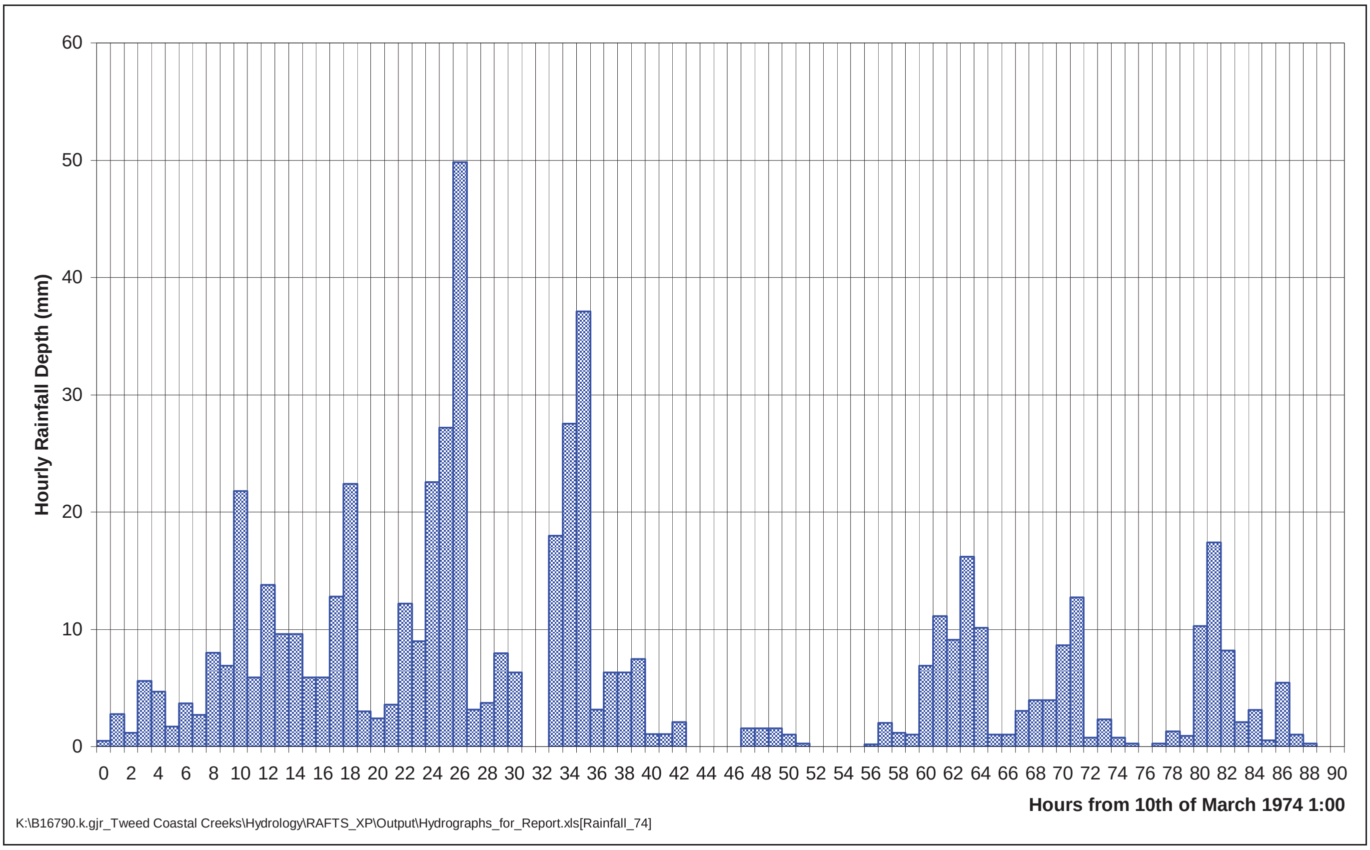
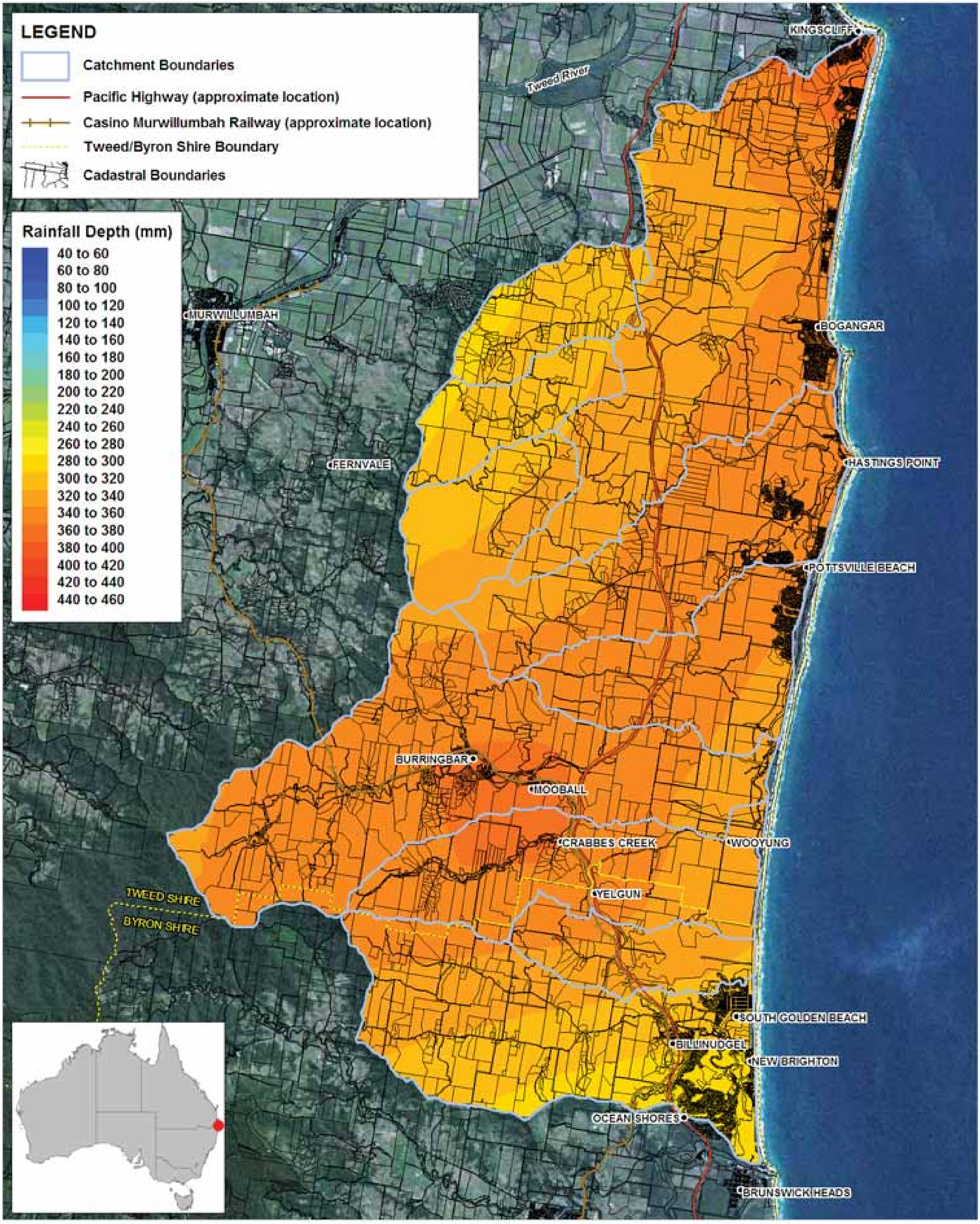


Figure 5-21 Rainfall Temporal Pattern – March 1974 Event



Title:
Total Rainfall Depth Surface 24 Hours to 11th March 1974 9am

Figure: 5-22

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5.2.4.2 Hydrological Modelling

Adopted losses parameters for the March 1974 storm event are as follows:

- Initial Loss = 20 mm over rural areas;
- Initial Loss = 10 mm over urban areas;
- Continuing Loss = 2 mm/hr over rural areas; and
- No continuing losses were taken into account for urban areas.

The predicted discharge hydrographs downstream of the main coastal creek systems are shown in Figure 5-23.

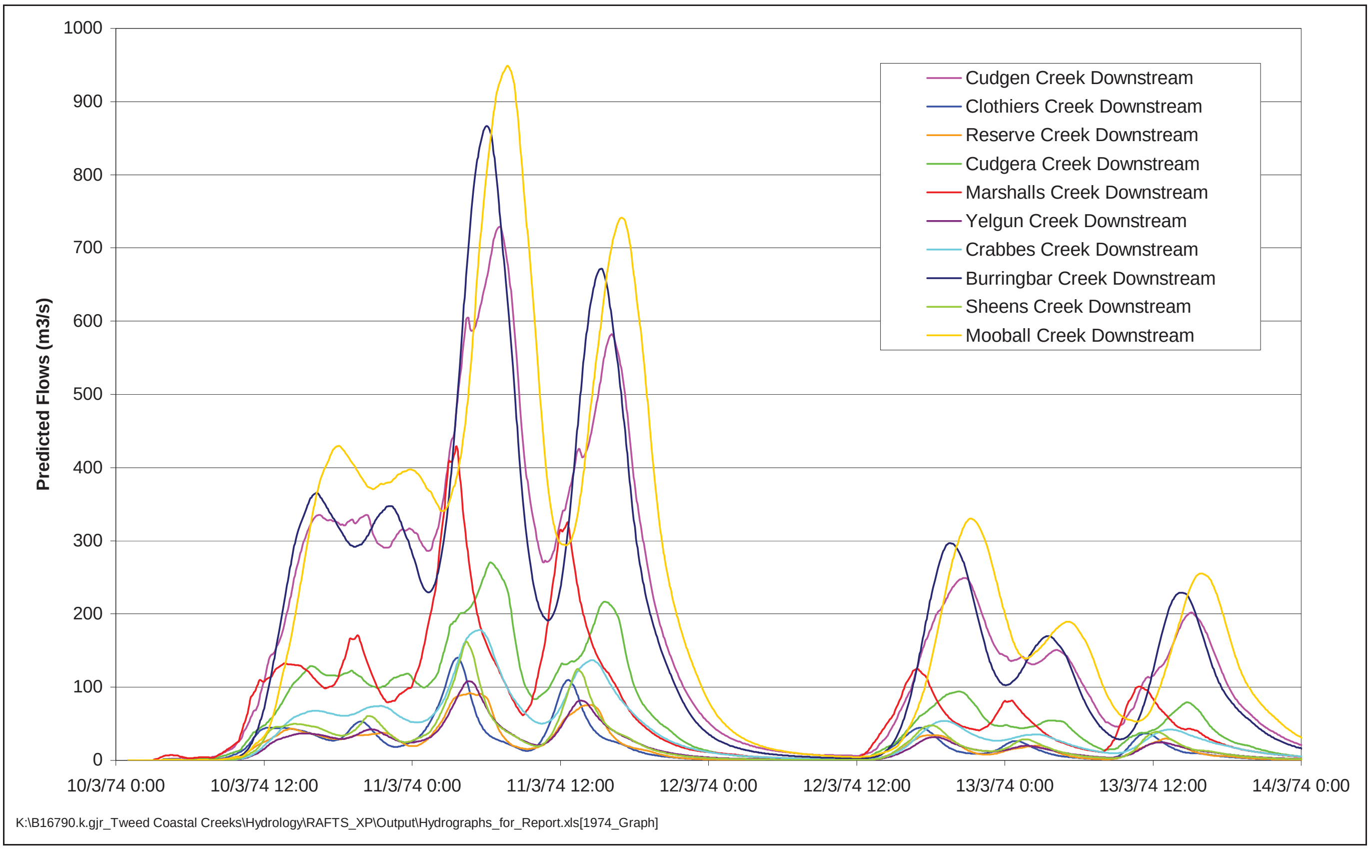


Figure 5-23 RAFTS-XP Discharge Hydrographs – March 1974 Event

5.2.4.3 Tidal Boundary Conditions

No ocean boundaries were available for the March 1974 flood event for any of the modelled creeks. The ocean level boundaries were taken from the Cudgen Creek Flood Study (PWD, 1988). This boundary was originally derived from predicted synthetic tide levels.

The downstream boundary condition applied to all creeks is presented in Figure 5-24.

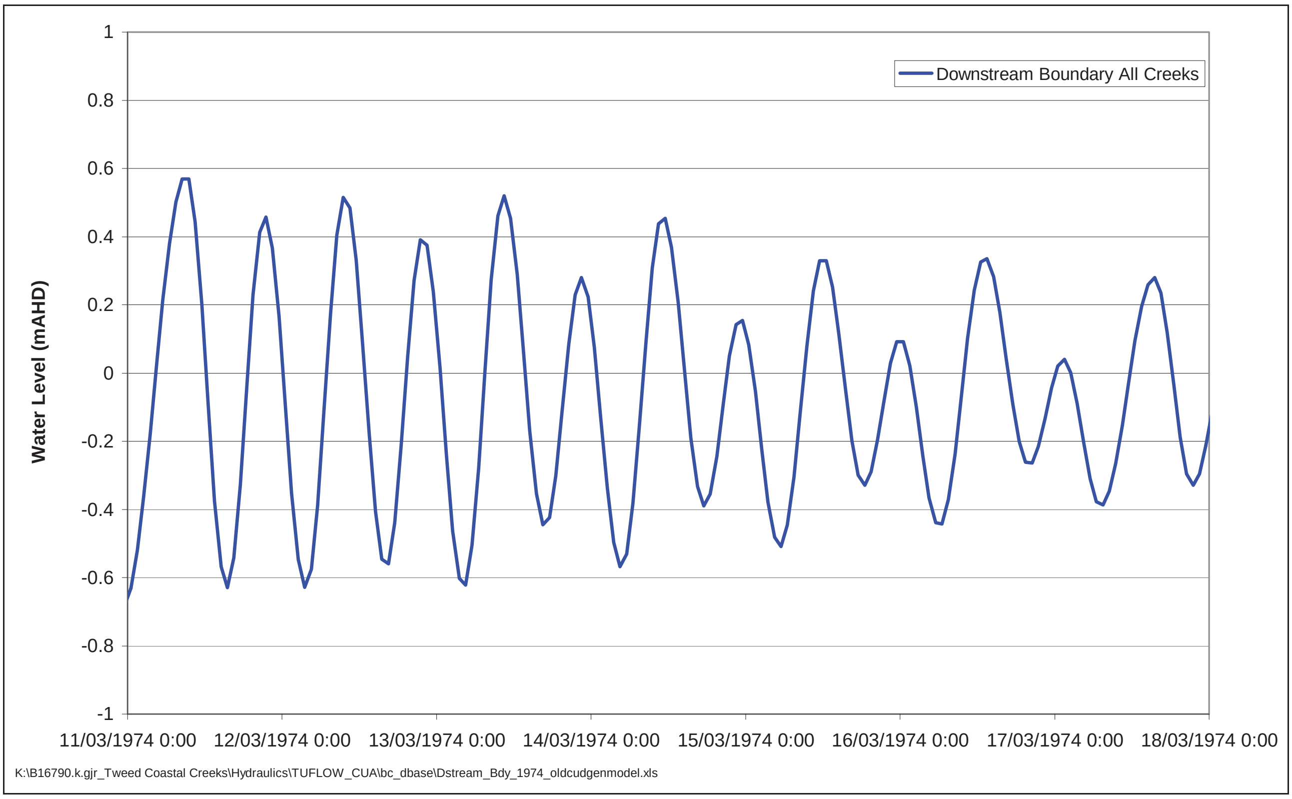
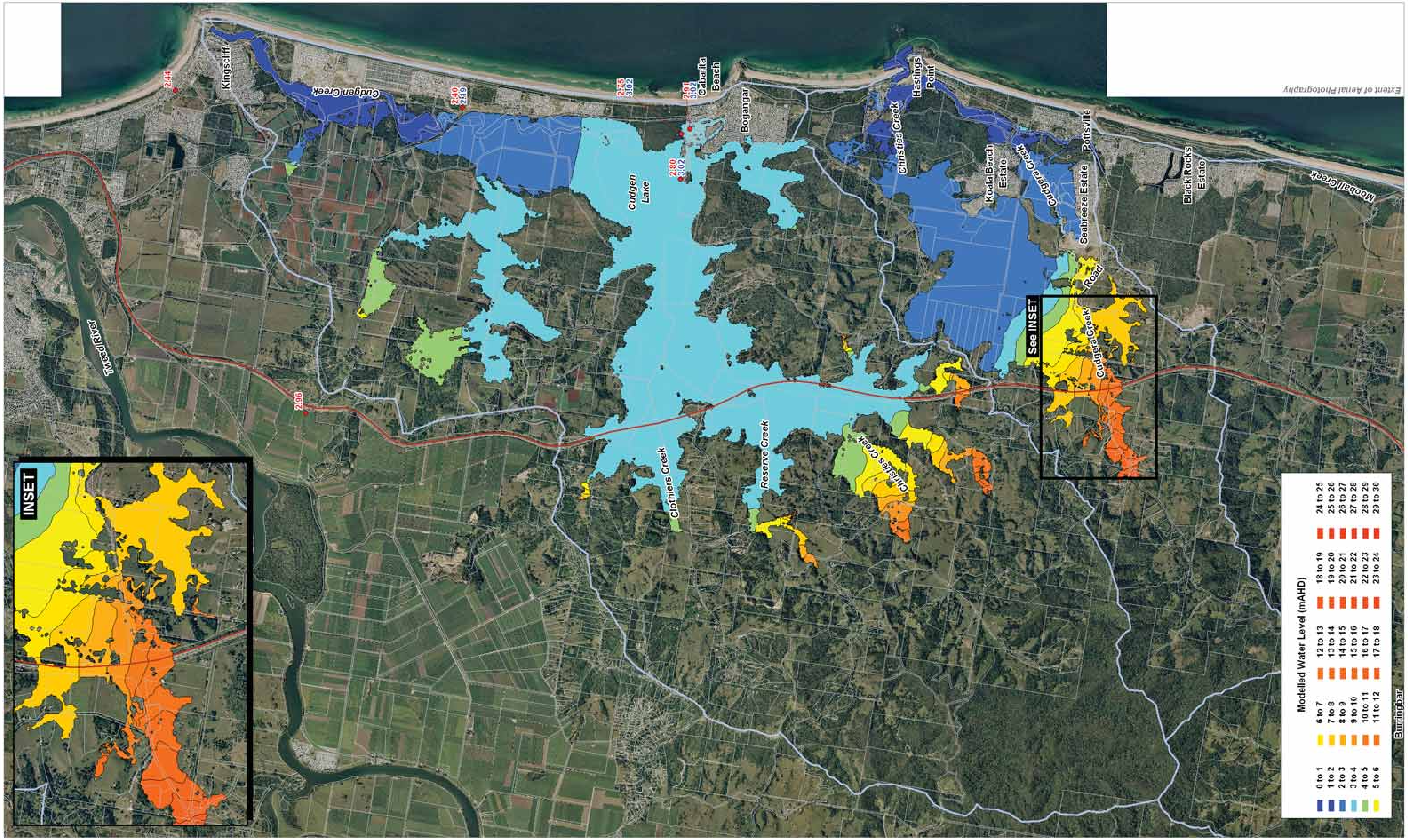


Figure 5-24 Downstream Boundary Condition – March 1974

5.2.4.4 Hydraulic Modelling

The performance of the hydraulic models to replicate recorded peak flood levels for the March 1974 flood event is presented in Figure 5-25 (Cudgen/Cudgera Creeks catchments) and Figure 5-26 (Mooball/Marshalls Creeks catchments). In particular, these figures show the predicted peak flood surface across the study area, as well as observed and modelled peak flood levels for the March 1974 records.

Due to the lack of available data, the March 1974 event was used as a verification of model performance after calibration to the June 2005 event. Discrepancies between recorded peak levels and modelled peak levels are considered to be due to the uncertainties in the data input to the model, primarily the lack of rainfall data.



LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- Observed Water Level
- Modelled Water Level

* Indicates Water Level Not at Flood Peak

Title:
March 1974 Calibration Cudgen/Cudgera Creeks Model

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Figure: 5-25

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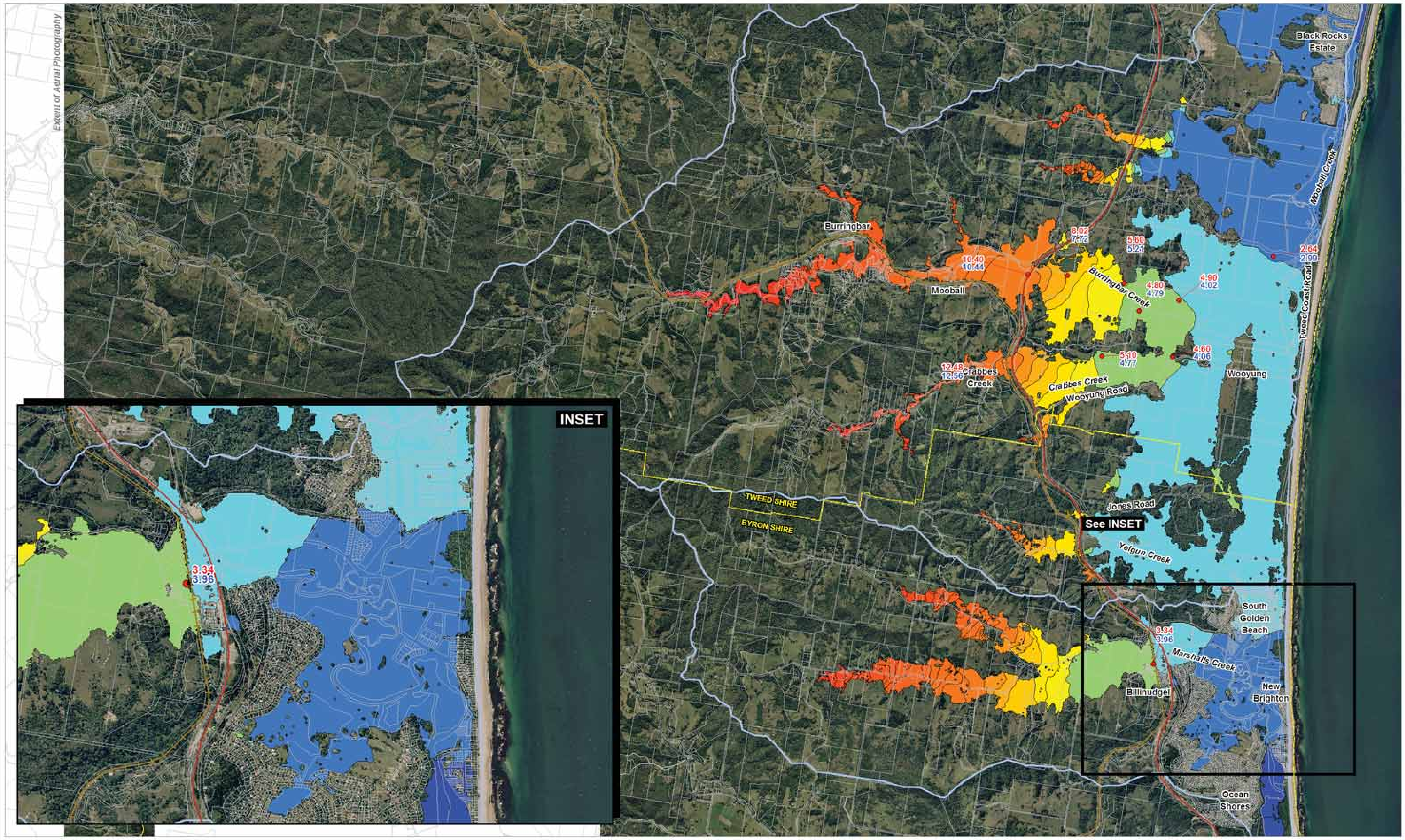

LEGEND

Catchment Boundaries

Tweed/Byron Shire Boundary

Observed Water Level

Modelled Water Level

Pacific Highway (approximate location)

Casino Murwillumbah Railway (approximate location)

Modelled Water Level (mAHD)

0 to 1	6 to 7	12 to 13	18 to 19	24 to 25
1 to 2	7 to 8	13 to 14	19 to 20	25 to 26
2 to 3	8 to 9	14 to 15	20 to 21	26 to 27
3 to 4	9 to 10	15 to 16	21 to 22	27 to 28
4 to 5	10 to 11	16 to 17	22 to 23	28 to 29
5 to 6	11 to 12	17 to 18	23 to 24	29 to 30

Title:

March 1974 Calibration
Mooball/Marshalls Creeks Model

Figure: **5-26**

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5.2.5 Conclusion

In summary, the hydraulic and hydrologic models provide an adequate representation of the dynamic flood behaviour in the study area for the purposes of this study and subsequent floodplain management studies.

The shape of the hydrograph and the speed of propagation of the flood wave along the river are considered acceptable given the uncertainties in the input data. This is demonstrated by the calibration to the Billinudgel and Cudgen Lake hydrographs for both the June 2005 and May 1987 flood events.

The ability of the models to replicate peak water levels in the creeks and floodplains are considered acceptable given the uncertainties in the input data. The Committee supported these calibration results and agreed that the project proceed to design runs.

6 DESIGN FLOOD MODELLING

6.1 Introduction

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

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

This report uses the ARI terminology. Table 6-1 provides a definition of AEP and the ARI equivalents simulated in this study.

Table 6-1 Terminology for Design Flood Events

	AEP	ARI	Comments
Medium to Large Floods	20%	5 year	A hypothetical flood or combination of floods which is likely to have a 20% chance of occurring in any one year or, in other words, is likely occur once every 5 years on average.
	10%	10 year	A hypothetical flood or combination of floods which is likely to have a 10% chance of occurring in any one year or, in other words, is likely occur once every 10 years on average.
	5%	20 year	A hypothetical flood or combination of floods which is likely to have a 5% chance of occurring in any one year or, in other words, is likely occur once every 20 years on average.
	2%	50 year	A hypothetical flood or combination of floods which is likely to have a 2% chance of occurring in any one year or, in other words, is likely occur once every 50 years on average.
	1%	100 year	A hypothetical flood or combination of floods which is likely to have a 1% chance of occurring in any one year or, in other words, is likely occur once every 100 years on average.
Rare to Extreme Floods	0.2%	500 year	A hypothetical flood or combination of floods which is likely to have a 0.2% chance of occurring in any one year or, in other words, is likely occur once every 500 years on average.
Probable Maximum Flood	0%	1,000,000 year[1]	A hypothetical flood or combination of floods which represent a theoretical 'worst case' scenario. It is only used for special purposes (e.g. design of a dam spillway) where a high factor of safety is recommended, or in consideration of floodplain planning (e.g. evacuation and isolation of communities).

[1] The return period of the PMF for the Coastal Creeks catchments has been estimated as approximately one million years in accordance with AR&R.

6.2 Critical Storm Duration

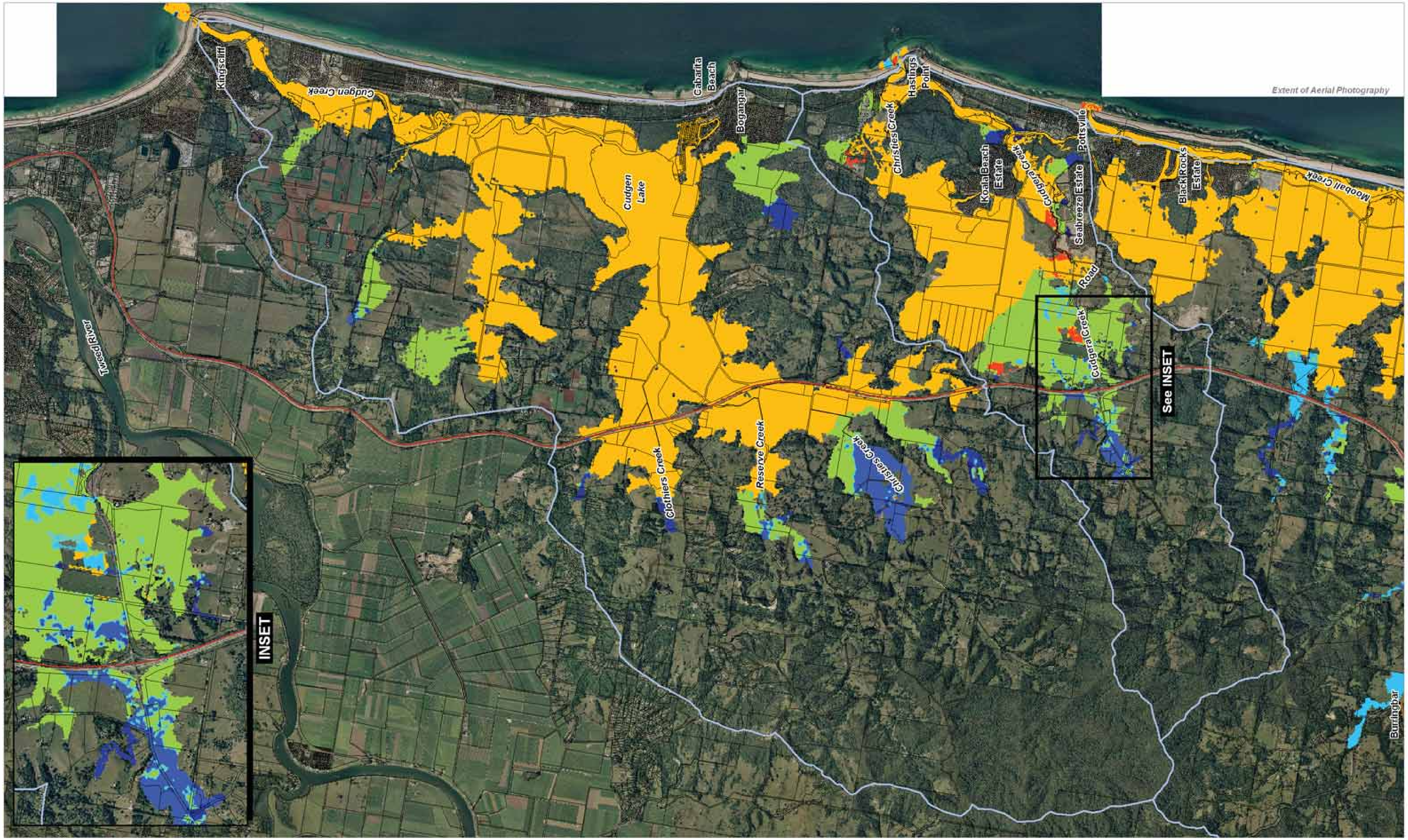
In determining the design floods, it is necessary to take into account the critical storm duration of the catchment. Small catchments are typically more prone to flooding during short duration storms while for larger catchments longer durations will be more critical. Similarly, the upper parts of the creeks catchments are likely to have significantly shorter durations than those for the floodplain areas. For example, the Cudgen Creek floodplain will have a critical duration in the order of 36 hours, while the upper parts of the Christies Creek, Reserve Creek and Clothiers Creek catchments will have critical durations in the order of 2 to 6 hours.

A range of 8 durations between 1 hour and 72 hours were initially simulated for the 100 year ARI design event using the calibrated hydrologic and hydraulic models in order to determine the spatial variation of the critical storm duration and inform the selection of the storm durations producing the highest water levels over the coastal creeks catchments. Critical duration simulations were run using inflows generated by applying AR&R (1987) parameters to the hydrological models and a constant downstream ocean boundary of 0.6m AHD (i.e. a Mean High Water Spring tide).

Figure 6-1 and Figure 6-2 present the resulting critical storm durations respectively for the Cudgen/Cudgera and the Mooball/Marshalls areas. These durations represent the duration of rainfall storms that will generate the highest flood levels within the study area. These figures highlight the following:

- The 36-hour storm duration is critical for the lower parts of the floodplains across the entire study area;
- The 6-hour storm duration is generally critical for the upper parts of the catchments in the Mooball/Marshalls areas (i.e. Burringbar Creek, Crabbes Creek and Marshalls Creek upstream of the Pacific Highway); and
- The 24-hour storm duration is generally critical for intermediate parts of the catchments in the Mooball/Marshalls area, as well as for the upper parts of the catchments in the Cudgen/Cudgera area.

These three storm durations were selected for the design flood simulations. Figure 6-3 and Figure 6-4 present the differences in peak flood levels between the envelope of the three selected storm durations results (i.e. surface of maximum 100 year ARI flood levels predicted for any of the 6-hour, 24-hour and 36-hour duration storms) and the envelope of the eight simulated storm durations results (i.e. surface of maximum 100 year ARI flood levels for all simulated duration storms). In other words, these figures highlight areas where peak flood levels may be underestimated by selecting only the 6-hour, 24-hour and 36-hour durations. As seen on the figures, only a few localised areas generally within the upper part of the catchments, are potentially underestimated in a 100 year ARI flood event by 0 to 50mm (and by no more than 100mm). This was deemed acceptable by both Councils as these areas were generally not major areas of focus for future development and/or urbanisation.



LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- Cadastral Boundaries

100 Year Design Events (hours)

- 1
- 2
- 3
- 6
- 12
- 24
- 36
- 72

Title:
100 Year ARI Critical Durations Cudgen/Cudgera Creeks Catchments

Figure: 6-1

Rev: C

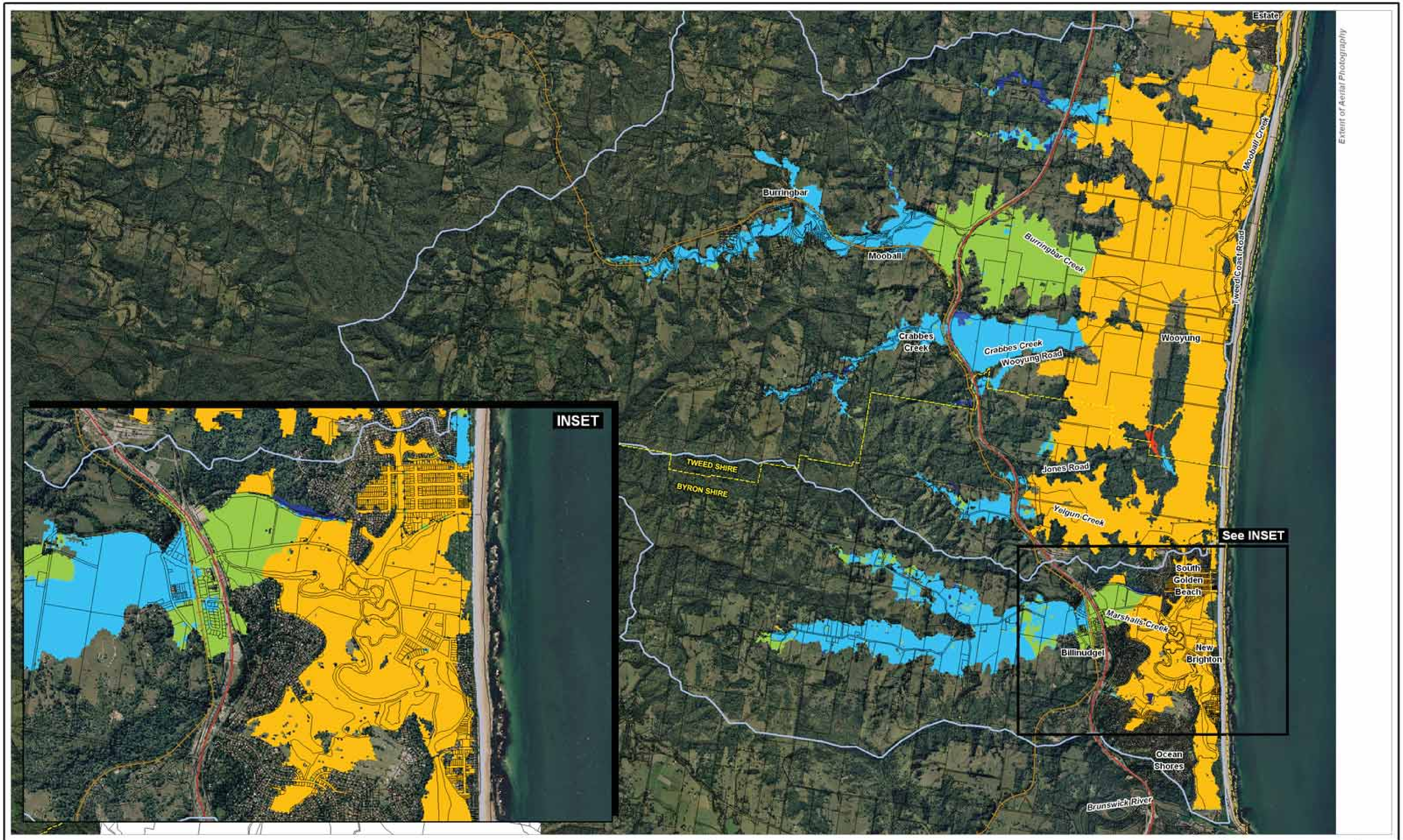
N

0 1 2km
Scale - Main Map

0 0.5 1km
Scale - Insets

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16790_I_BRH Tweed Byron GJR\DRG\FLD_035_090713_CC 100Y Critical Durations RevC.WOR



Title:

100 Year ARI Critical Durations
Mooball/Marshalls Creeks Catchments

Figure: 6-2

Rev: C

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16790_I_BRH Tweed Byron GJR\DRG\FLD_037_090713_MM 100Y Critical Durations RevC.WOR

LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- Cadastral Boundaries

Difference in Design Envelopes (m)

-3.00 to -2.00	-0.50 to -0.30
-2.00 to -1.50	-0.30 to -0.10
-1.50 to -1.00	-0.10 to -0.05
-1.00 to -0.75	-0.05 to -0.02
-0.75 to -0.50	-0.02 to 0.00

Title:
100 Year ARI Sensitivity of Three Selected Durations Cudgen/Cudgera Creeks Catchments

Figure: 6-3

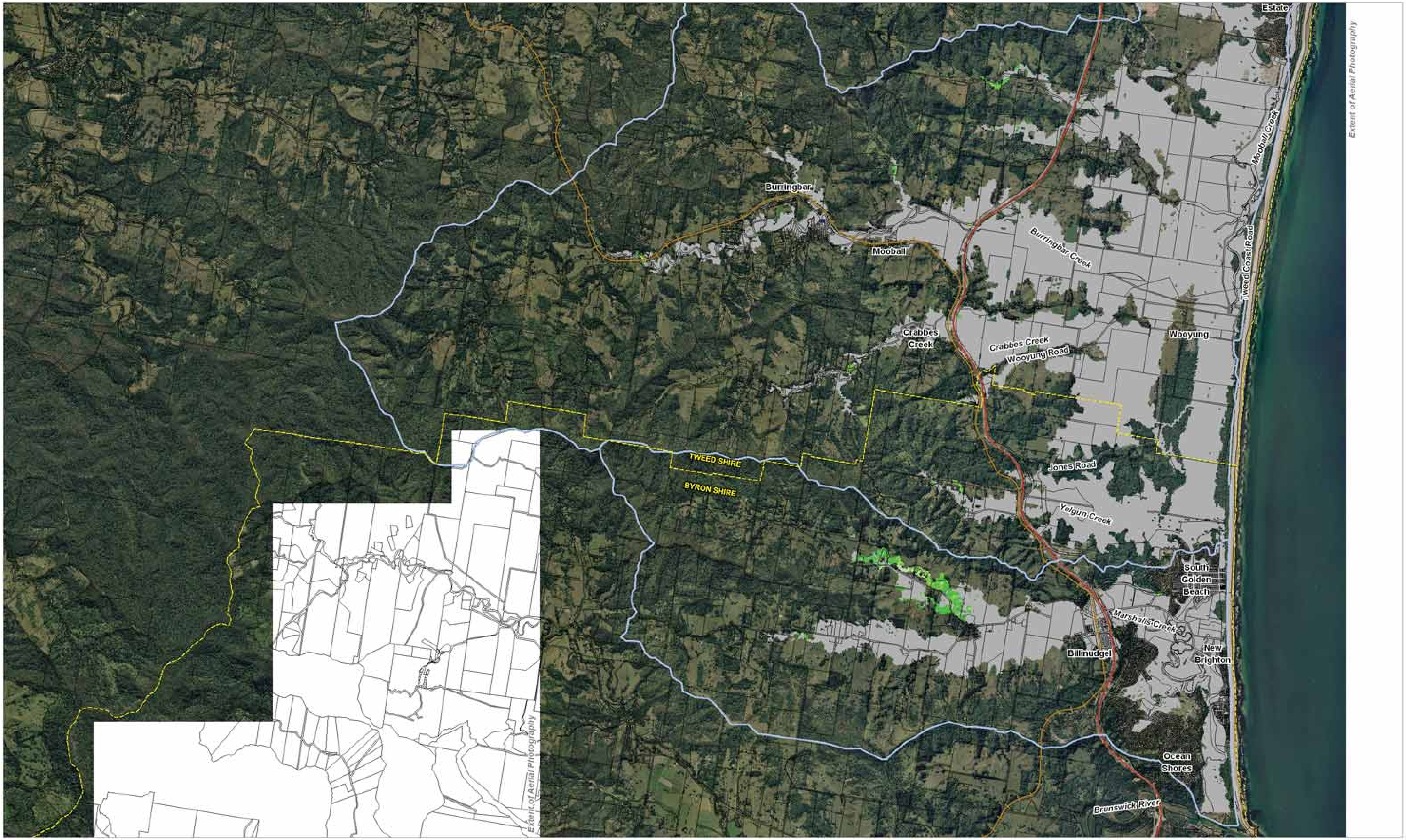
Rev: C

N

0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16790_I_BRH Tweed Byron GJR\DRG\FLD_036_090713_CC 100Y Sensitivity 3 Durations RevC.WOR



LEGEND

- Catchment Boundaries
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- Cadastral Boundaries

Difference in Design Envelopes (m)

-3.00 to -2.00	-0.50 to -0.30
-2.00 to -1.50	-0.30 to -0.10
-1.50 to -1.00	-0.10 to -0.05
-1.00 to -0.75	-0.05 to -0.02
-0.75 to -0.50	-0.02 to 0.00

Title:

100 Year ARI Sensitivity of Three Selected Durations Mooball/Marshalls Creeks Catchments

Figure: 6-4

Rev: C

N

0 1.5 3km

Approx. Scale

BMT WBM

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Filepath : I:\B16790_I_BRH Tweed Byron GJR\DRG\FLD_038_090713_MM 100Y Sensitivity 3 Durations RevC.WOR

6.3 Design Rainfall

6.3.1 Approach

The design flood inflows to the hydraulic 2D / 1D model of the coastal creeks were derived from the validated hydrological models (as described in Section 4.1 and Section 5.2). In accordance with current best practice, different methodologies were required for estimating design rainfall depending on the magnitude of the flood event:

- For the medium to large floods (i.e. the 5, 10, 20, 50 and 100 year ARI) rainfall depths were estimated from AR&R (1987).
- For the rare to extreme floods (i.e. the 500 year ARI) rainfall depths were based on an interpolation between the 100 year ARI and the probable maximum flood (see next bullet point) in accordance with AR&R (1987).
- For the probable maximum flood (or PMF) rainfall depth was estimated based on the BoM's Revised Generalised Tropical Storm Method (GTSMR) and Generalised Short Duration Method (GSDM), depending on the duration. Refer to Section 6.3.3.2 for further details.

The derivation of design rainfall depths, spatial variation and temporal patterns is outlined in more detail in the following sections.

6.3.2 Medium to Large Floods

In accordance to the general hydrological modelling approach, and in order to represent the variability in rainfall within the hydrological model, two rainfall Intensity-Frequency-Duration (IFD) parameter regions were identified for the computation of rainfall depths as follows:

- The Cudgen/Cudgera area; and
- The Mooball/Marshalls area.

The resulting design rainfall intensities are presented for both regions in Table 6-2 and Table 6-3. These rainfall depths are point rainfall intensities; i.e. to apply to a catchment, areal reduction factors are used to account for the spatial variability of rainfall, as defined in AR&R (1987).

Table 6-2 Cudgen/Cudgera Average Rainfall Intensities (AR&R 1987)

Duration (hours)	Average Rainfall Intensity (mm/hr)				
	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI
6	22.0	24.8	28.5	33.4	37.1
24	9.8	11.2	13.0	15.4	17.2
36	7.7	8.9	10.4	12.4	13.9

Table 6-3 Mooball/Marshalls Average Rainfall Intensities (AR&R 1987)

Duration (hours)	Average Rainfall Intensity (mm/hr)				
	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI
6	23.8	27.1	31.4	37.1	41.4
24	10.9	12.6	14.7	17.6	19.8
36	8.7	10.0	11.8	14.2	16.1

AR&R (1987) Zone3 temporal patterns were adopted across the entire study area. They are presented in Figure 6-5 to Figure 6-7 for the three selected durations. These patterns define two separate rainfall bursts (one major burst at the beginning and one smaller towards the end) for both the 24 and 36 hour duration storms.

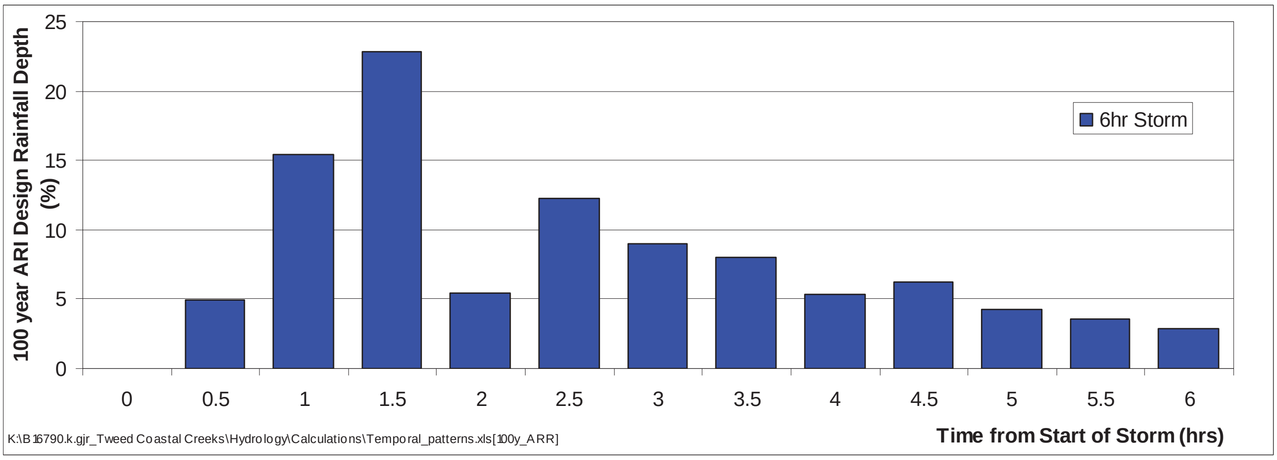


Figure 6-5 AR&R Zone 3 Temporal Pattern – 6hr Storm

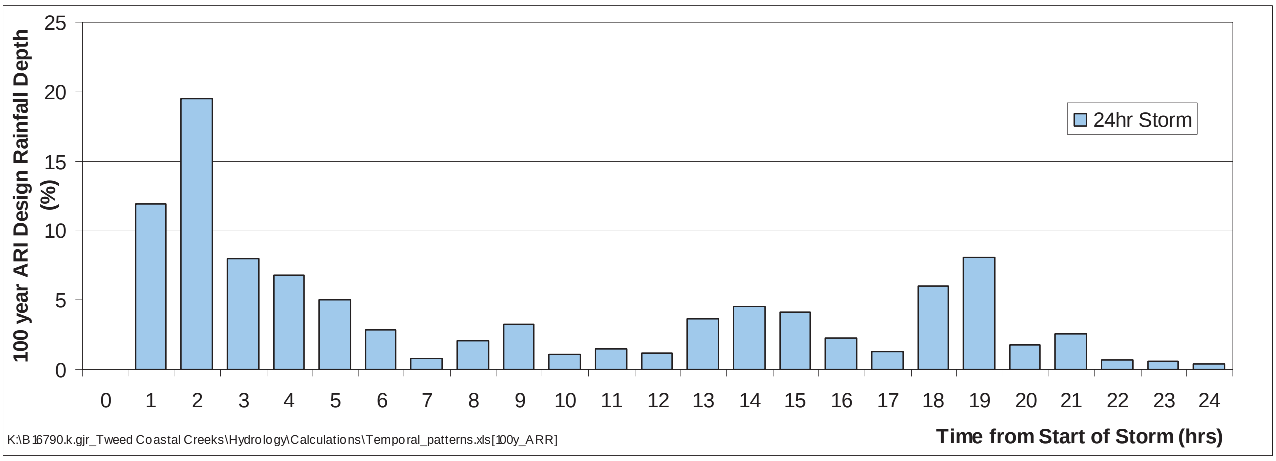


Figure 6-6 AR&R Zone 3 Temporal Pattern – 24hr Storm

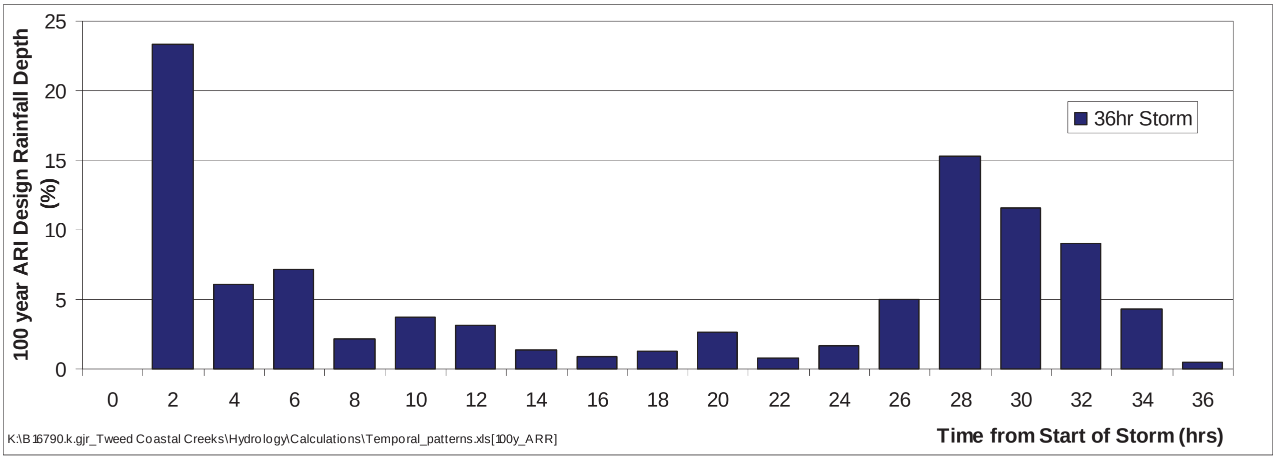


Figure 6-7 AR&R Zone 3 Temporal Pattern – 36hr Storm

6.3.3 Rare Flood and Probable Maximum Flood Estimates

6.3.3.1 500 Year ARI Flood

Estimation of the 500 year ARI rainfall depths were based on an interpolation between the 100 year ARI and the PMF in accordance with AR&R (1987). Figure 6-8 shows the large to PMP design rainfall depths for the 36 hour duration storm. Similar plots were derived for the 6 and 24 hour duration storms, and the 500 year ARI design rainfall depths were then interpolated from those plots. The resulting rainfall intensities are reported in Table 6-4. Temporal and spatial patterns similar to the PMP were used for the 500 year ARI event. These are described in the following section.

Table 6-4 Average Rainfall Intensities - 500 Year ARI Event

Catchment	Average Rainfall Intensity (mm/hr)		
	6hr	24hr	36hr
Marshalls Creek	50.6	25.7	21.4
Mooball Creek	45.2	25.4	21.2
Cudgen Creek	43.7	22.0	18.5
Cudgera Creek	47.6	22.9	18.9

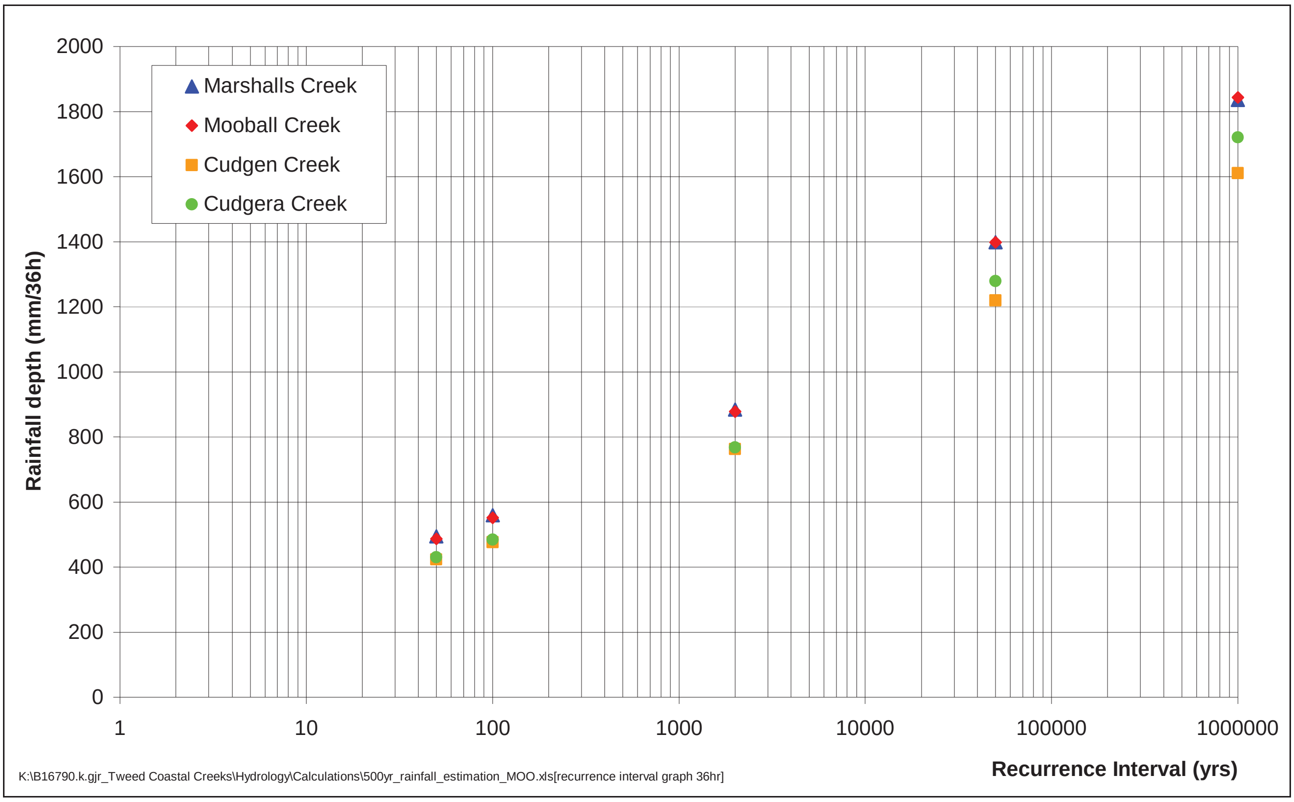


Figure 6-8 Design Rainfall Depths for a 36-hour Storm

6.3.3.2 Probable Maximum Flood

The PMF is the largest flood that could reasonably be expected to occur in a catchment based on the Probable Maximum Precipitation (PMP). The theoretical definition of the PMP is the greatest depth of precipitation meteorologically possible for a given duration and size storm area at a particular location and time of year (WMO, 1986).

Estimation of the PMP was based on BoM's Generalised Short Duration Method (GSDM) for the 6 hour storm duration and Revised Generalised Tropical Storm Method (GTSMR) for the 24 and 36 hour storm duration, as per AR&R (1987) recommendations. Average rainfall intensities were defined for four different areas across the coastal creeks catchments, as reported in Table 6-5. Temporal patterns were derived from the GSDM and GTDMR methods and are shown in Figure 6-9 and Figure 6-10.

Table 6-5 Average Rainfall Intensities - PMP

Catchment	Average Rainfall Intensity (mm/hr)		
	6hr	24hr	36hr
Marshalls Creek	138.3	63.8	51.9
Mooball Creek	105.0	64.6	52.5
Cudgen Creek	125.0	56.3	45.8
Cudgera Creek	141.7	59.6	48.6

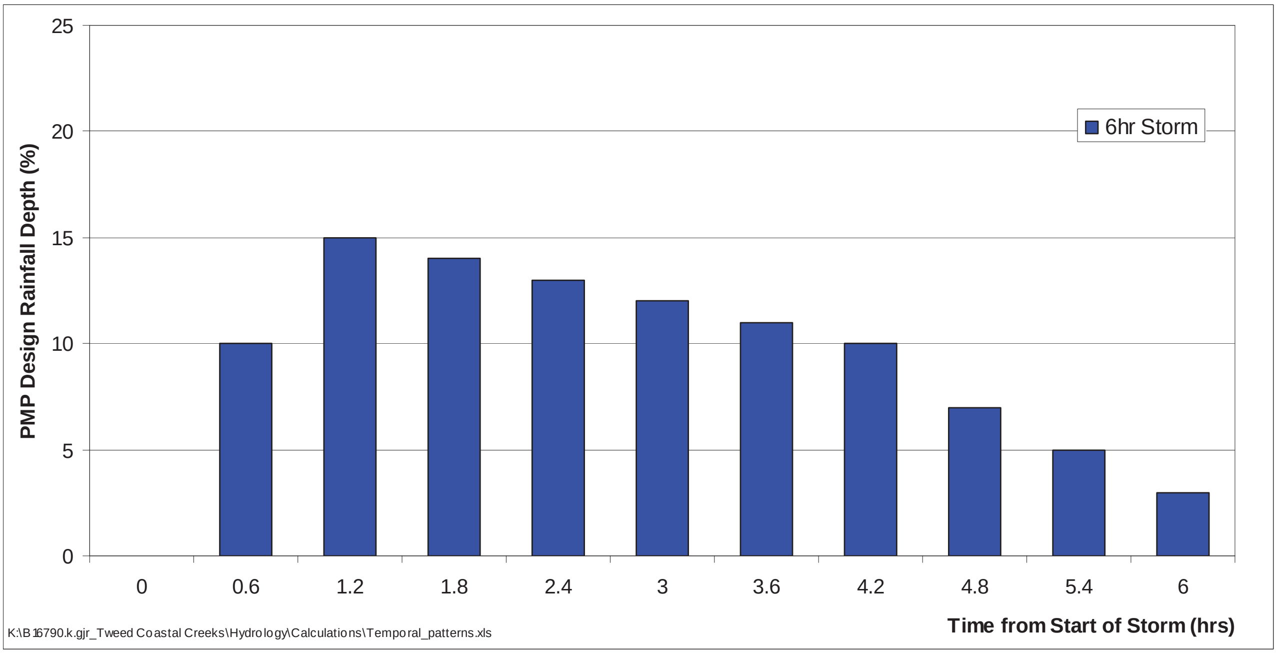


Figure 6-9 PMP Temporal Distribution – Short Duration Storm

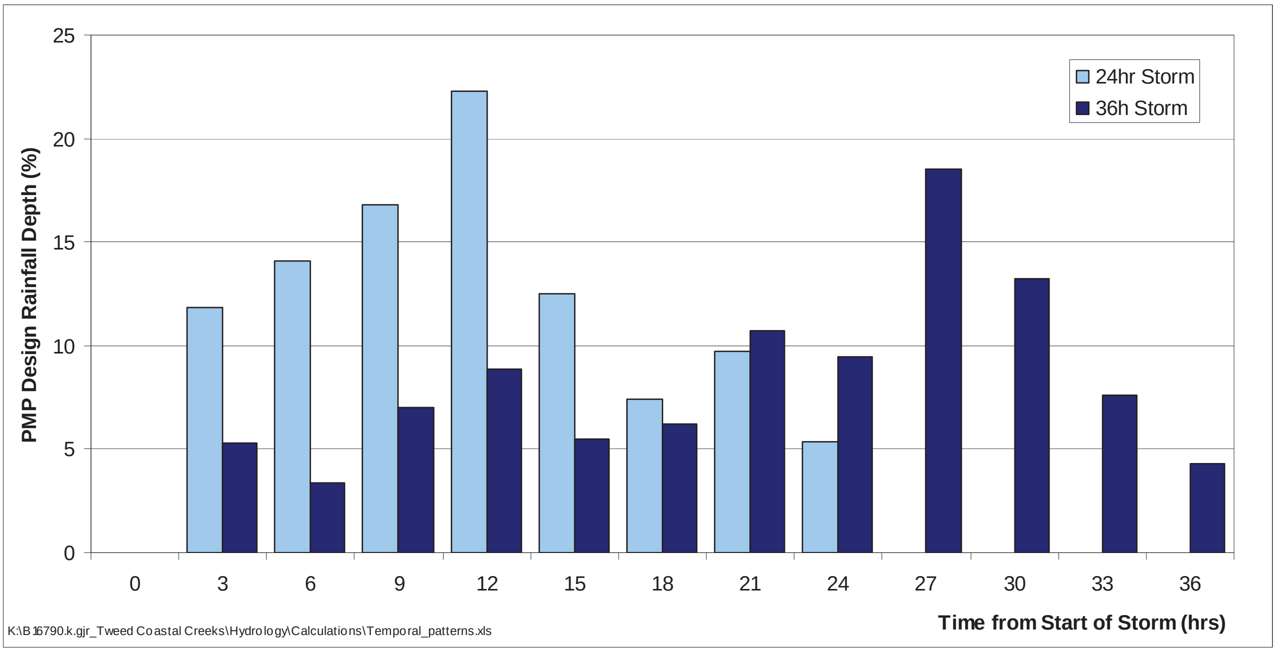


Figure 6-10 PMP Temporal Distribution – Long Duration Storm

6.3.4 Rainfall Losses

Rainfall losses for the hydrological modelling for all design events were as follows:

- 0mm initial loss over entire model area – this is a conservative loss reflecting catchments being saturated with rainfall prior to the design event; and
- 2mm continuing loss over rural areas and no continuing losses over urban areas based on model calibration to the June 2005 event.

6.4 Design Inflows

The validated RAFTS models were used to simulate catchment rainfall-runoff routing processes (as described in Section 4.1) based on the design rainfall depths, temporal and spatial patterns derived above. Table 6-6 to Table 6-8 summarise the resulting peak inflows from the RAFTS-XP models at the hydraulic model boundaries for the three selected storm durations respectively. In addition to these inflows, runoff generated by rainfall falling directly onto the hydraulic model area is also input as local runoff hydrographs applied at each RAFTS-XP subcatchment within the 2D TUFLOW domains. This direct rainfall is not tabulated here. It is noted that the 500 year ARI peak flows are of similar magnitude (or smaller) than the 100 year ARI peak flows. The temporal patterns are however different, with a much longer rainfall burst for the 500 year ARI storm, which will generate a larger volume of runoff. This is illustrated in Figure 6-11, which presents flow hydrographs at the upstream boundary for Burringbar Creek for the 6-hour duration storm. This figure shows that, although the predicted peak flow is smaller for the 500 year ARI rainfall storm, the total volume of water for this event is bigger than for the 100 year ARI storm event.

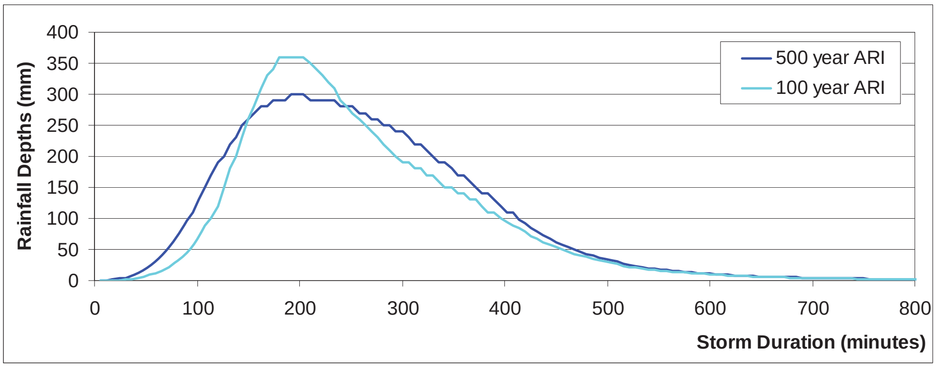


Figure 6-11 Flow Hydrographs

Table 6-6 Peak Design Inflows – 6hr Duration Storm

Upstream Boundary	Peak Flow (m^3/s)						
	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	500 year ARI	PMF
Clothiers Creek	61	70	82	93	110	110	340
Reserve Creek	64	73	87	98	110	110	340
Christies Creek	110	130	150	180	200	210	630
Cudgera Creek	73	84	98	110	130	150	470
Sheens Creek	15	17	20	23	33	25	62
Burringbar Creek	160	190	230	260	350	300	730
Crabbes Creek	31	36	43	49	70	53	130
Yelgun Creek	12	15	17	20	27	23	57
Marshalls Creek	51	59	71	82	110	110	320

Table 6-7 Peak Design Inflows – 24hr Duration Storm

Upstream Boundary	Peak Flow (m^3/s)						
	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	500 year ARI	PMF
Clothiers Creek	71	83	100	110	120	62	200
Reserve Creek	68	79	93	100	120	63	200
Christies Creek	130	150	180	200	230	110	370
Cudgera Creek	85	100	120	130	150	77	250
Sheens Creek	18	22	26	29	33	16	50
Burringbar Creek	200	230	280	310	350	190	600
Crabbes Creek	38	45	55	60	70	33	100
Yelgun Creek	14	17	21	23	26	15	48
Marshalls Creek	55	66	81	90	110	62	200

Table 6-8 Peak Design Inflows – 36hr Duration Storm

Upstream Boundary	Peak Flow (m^3/s)						
	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	500 year ARI	PMF
Clothiers Creek	55	65	79	86	96	53	210
Reserve Creek	51	60	72	78	89	53	200
Christies Creek	99	120	140	150	180	97	380
Cudgera Creek	66	78	94	100	120	64	260
Sheens Creek	14	17	21	23	27	13	50
Burringbar Creek	150	190	220	240	280	160	610
Crabbes Creek	30	36	44	47	55	27	110
Yelgun Creek	11	15	17	18	22	12	48
Marshalls Creek	43	59	65	72	85	52	200

6.5 Downstream Boundary Conditions

Downstream ocean level boundaries were based on *Floodplain Management Guidelines No.5* (DIPNR, 2004) and consultation with DECCW, TSC and BSC. Table 6-9 outlines the combination of rainfall and storm surge events adopted for the Coastal Creeks Flood Study. Peak storm surge levels are also specified for each design event in that table, and full hydrographs are provided in Figure 6-12. These levels account for a tide surge interaction with the storm surge and wave setup superimposed upon normal variations in water level estimates.

The 100 year ARI peak ocean level of 2.6m AHD was based on coastal assessments undertaken some 20 years ago, taking into account a 100 year ARI storm surge (i.e. wind and barometric setup) with wave setup. Although more recent assessments along NSW coast have shown that this level is conservative, this boundary condition has been used in previous studies in the area and can be considered to take into account some allowance for sea level rise due to climate change.

It is noted that although the TUFLOW model does not extend into the ocean at the Brunswick River mouth, these peak storm surge levels were also applied to the downstream Marshalls Creek hydraulic model boundary. This approach is likely to be conservative for the ocean dominated events, as it will not simulate any propagation effects through the training walls at the Brunswick River entrance or the Marshalls Creek outlet. On the other hand, it is likely to under-estimate tailwater levels for the catchment dominated events, as it will not represent the head drop across the training walls at the Marshalls Creek outlet. However, levels in these downstream areas are likely to be dictated by the ocean events mentioned above. The joint probability of a Marshalls Creek flood event and a Brunswick River flood event was not addressed as part of this study.

An ‘envelope’ approach was used for the 20, 50 and 100 year ARI design events in order to ensure that peak flood levels from both catchment dominated events (i.e. in the upper parts of the catchments, typically upstream of the Pacific Highway) and storm surge dominated events (i.e. in the lower floodplains) were captured in the definition of design flood levels (as outlined in Table 6-9).

Each design event was simulated for the three selected storm durations (refer to Section 6.2). The timing of peak inflows and storm surge is more likely to coincide for the 6 hour duration storm events. In the longer events, it is likely that ocean levels will have passed their peak by the time catchment inflows reach the lower floodplain. Hence, the timing of design events was selected so that the storm tide peaks with the 6 hour rainfall flood peak for the major catchments (i.e. Cudgen Creek, Cudgera Creek, Mooball Creek and Marshalls Creek).

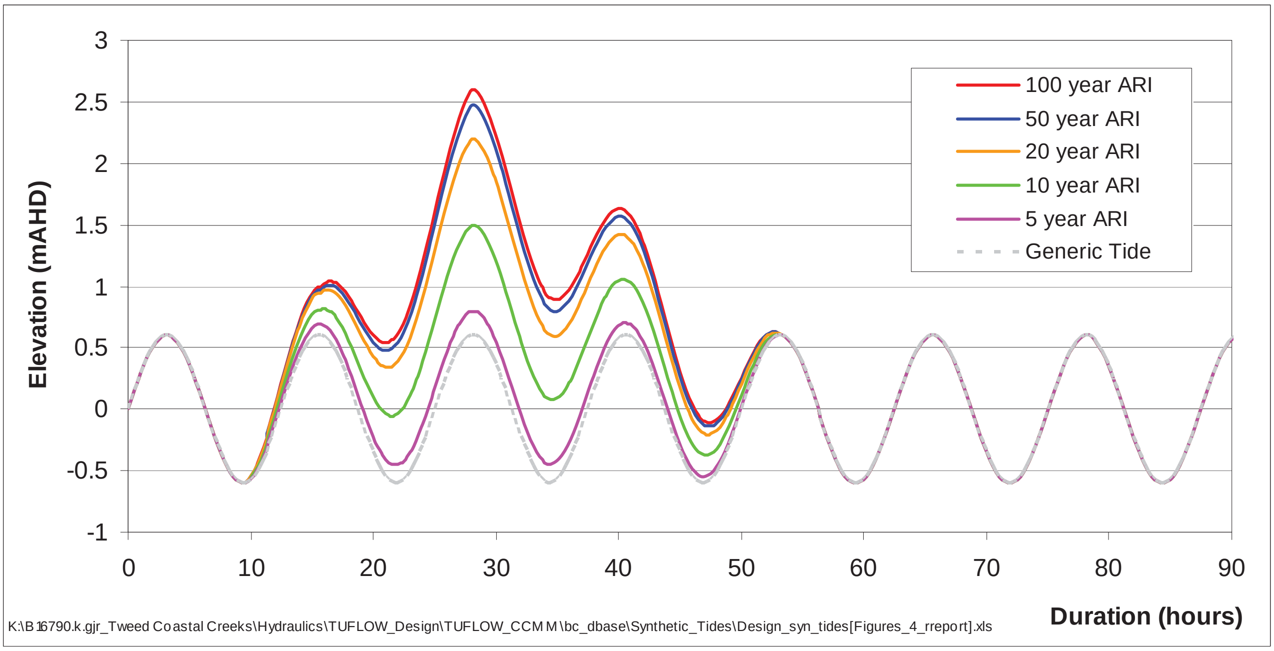


Figure 6-12 Downstream Ocean Boundary for Design Events – Cudgen/Cudgera Creeks

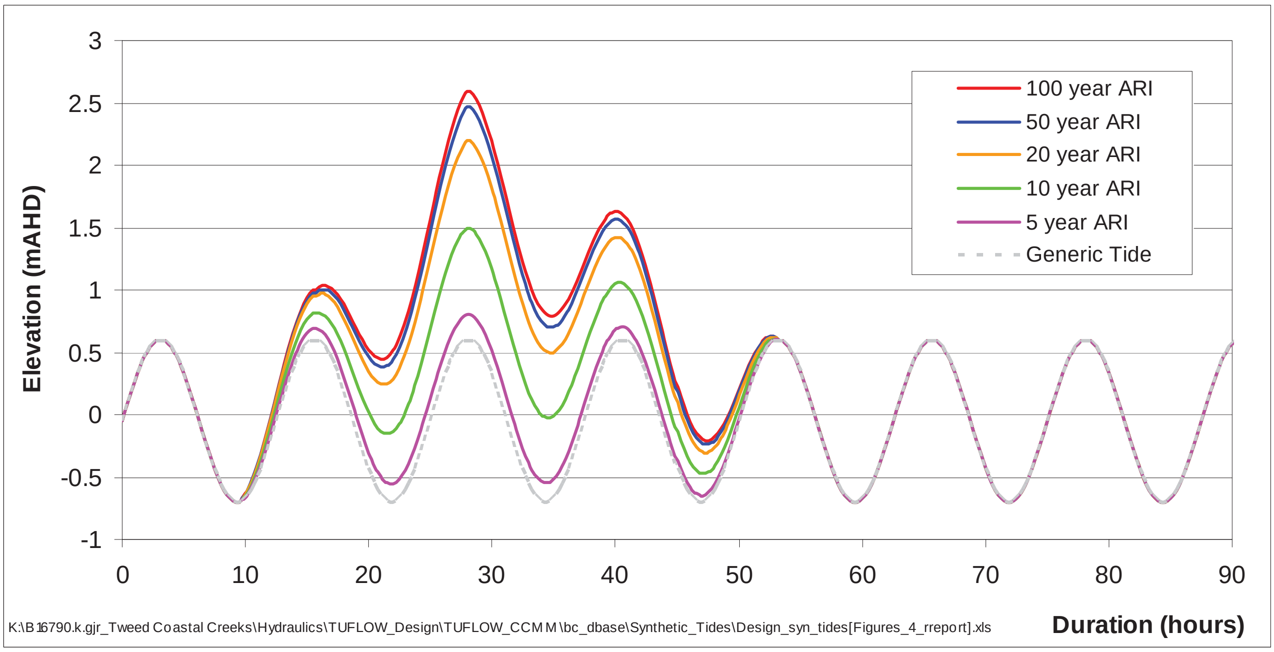


Figure 6-13 Downstream Ocean Boundary for Design Events – Mooball/Marshalls Creeks

Table 6-9 Design Combination of Rainfall and Storm Surge Events

Design Event	Catchment Inflow Rainfall Event	Ocean Boundary Storm Surge Event	Ocean Boundary Peak Tailwater Level (mAHD)
5 year ARI	5 year ARI	5 year ARI	0.8
10 year ARI	10 year ARI	10 year ARI	1.5
20 year ARI (envelope)	20 year ARI	10 year ARI	1.5
	10 year ARI	20 year ARI	2.2
50 year ARI (envelope)	50 year ARI	10 year ARI	1.5
	10 year ARI	50 year ARI	2.4
100 year ARI (envelope)	100 year ARI	20 year ARI	2.2
	10 year ARI	100 year ARI	2.6
500 year ARI	500 year ARI	100 year ARI	2.6
PMF	PMF	100 year ARI	2.6

6.6 Design Model Geometry

The hydraulic model geometry used for the June 2005 calibration was modified to account for post-2005 changes in the floodplain as follows:

- The proposed development for the Seabreeze Estate in the lower Cudgera Creek floodplain was included in the design model. Design fill levels as well as the proposed levee along Cudgera Creek were added to the model geometry as per the latest available design (as of 15th of June 2009). This also includes the proposed Koala Beach / Seabreeze link road and associated bridge over Cudgera Creek;
- The Kallaroo Circuit culverts in North Ocean Shores were upgraded in the model to include the new 3 x 4.8m wide x 1.5m high box culverts in addition to the existing 2 x 900mm pipes. It is noted that the purpose of the current Coastal Creeks Flood Study was NOT to assess the impacts of the culvert upgrade at this location. Specific hydraulic assessments were previously undertaken by SMEC (2006) in this regard. Further assessments with the newly developed TUFLOW Coastal Creeks model were also undertaken in parallel and reported separately to BSC in July 2009; and
- Sections of the Pacific Highway located near the vicinity of the Billinudgel Golf Course were finalised after the June 2005 flood event. The base topography was thus raised in these sections in order to represent the final (and current) state of the Pacific Highway embankments and bridges.

This updated model geometry was considered representative of the existing configuration of the floodplain and was used for all design runs, including simulations undertaken to inform the critical duration selection (refer to Section 6.2).

7 DESIGN FLOOD BEHAVIOUR

7.1 General Issues and Uncertainty

The interpretation of the flood maps and other design modeling results presented in this report should be done with an appreciation of any limitations in their accuracy. While the points below highlight these limitations, it is important to note that the results presented provide an up-to-date reliable and accurate prediction of design flood behaviour in the Coastal Creeks floodplains. Key elements are:

- Recognition that no two floods behave in exactly the same manner;
- Design floods are a best estimate of an 'average' flood for their probability of occurrence;
- The DEM has been generated from ALS data with a reported vertical accuracy of +/- 0.25 metre and interpolated in areas of dense vegetation such as sugarcane (see Section 2.3.1). As flood depths and flood extents are determined using the DEM, their accuracy should be interpreted accordingly;
- The purpose of the Coastal Creeks Flood Study is to represent regional flooding behaviour. Hence the resolution of the model is limited in urban areas. In particular, the flood model generally does not account for minor stormwater drainage infrastructure, such as street drainage. As such, urban areas may also experience local stormwater flooding in addition to the regional flooding presented in the flood maps addendum; and
- The results are based on available data and numerical tools at the time of this study. Changes in technology and improved data collection may provide more accurate modelling in the future.

Design floods are typically based on statistical analyses of recorded rainfall data. The longer the period of recordings, the greater the certainty. For example, derivation of the 100 year ARI rainfall from 5 years of recordings would have a much greater error margin than from 100 years of recordings.

Similarly, the accuracy of the hydrologic and hydraulic computer models is dependent on the amount and range of reliable rainfall and flood level recordings for model calibration. An uncalibrated model's results have a greater error margin than a calibrated model.

The error margin in the Coastal Creeks Flood Study is regarded as 'moderate' based on the following factors:

- The flood models were calibrated to one historical flood event and verified against another two events;
- Limited rainfall data was available for the three historical events and limited flood level data was available for the two verification flood events;
- The calibration flood event occurred recently and so catchment conditions and flood behaviour are well known;
- The model parameters are generally typical of those used elsewhere; and
- The vertical accuracy of the ALS data used to develop the DEM.

7.2 Design Flood Results

Unless otherwise specified, results are presented in the following sections in terms of peak values of flood level, depth and flow/velocity. These peak values do not represent an instantaneous point in time across the entire study area, but rather an envelope of the maximum values which occurred at each computational point in the model during the entire flood event.

In addition, the peak values presented comprise an envelope of the three modelled storm durations for each flood event and, in the case of the 20, 50 and 100 year ARI flood events, as an envelope of both catchment dominated and storm surge dominated flood events. Figure 7-1 presents an example of a flood profile for the 100 year ARI design event, which illustrates this approach of flood envelope. At each computational point in the model, the maximum of all 6 flood events modelled (i.e. 3 storm durations x 2 rainfall/storm surge combinations) are combined to define the peak 100 year ARI design flood level.

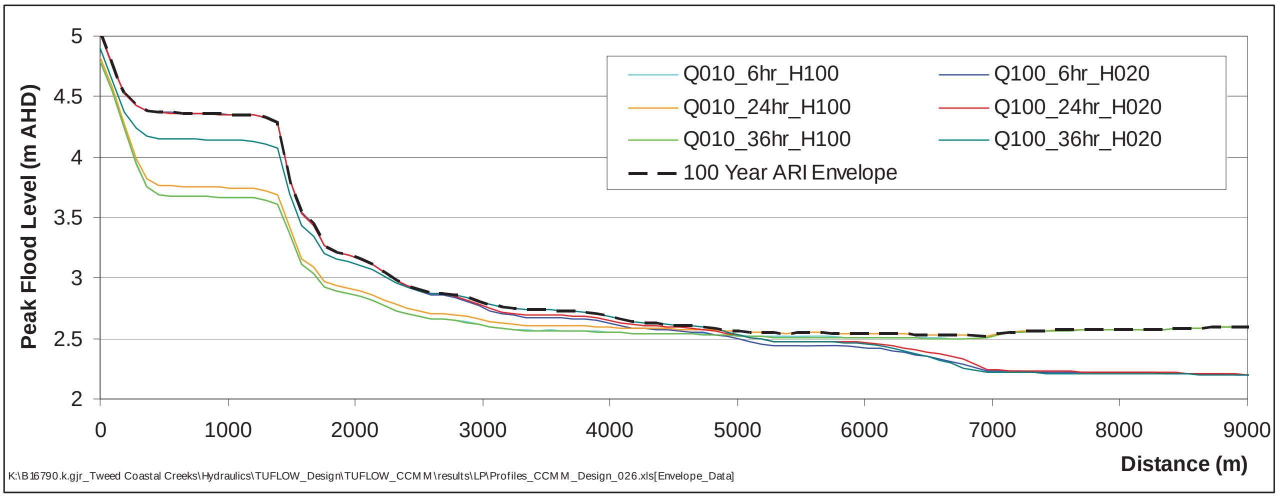


Figure 7-1 Envelope Approach Example

7.2.1 Peak Design Levels at Selected Locations

Table 7-1 presents the peak design levels at selected locations for all the design flood events. These locations are shown in Figure 7-2.

7.2.2 Flood Profiles

Peak flood level profiles were extracted along the major creeks as per the lines shown in Figure 7-2. They are reported in Figure 7-3 to Figure 7-11. Peak design levels extraction locations as defined in the previous section are also reported along the profiles.

These profiles show the significant change in flood gradient at the Pacific Highway and other structures (road and rail), with generally steep flood gradients in the upper creeks, and relatively flat flood gradient downstream in the lower floodplains. These characteristics of the flood gradient are consistent across the full range of flood events from the medium to large floods up to the rare flood.

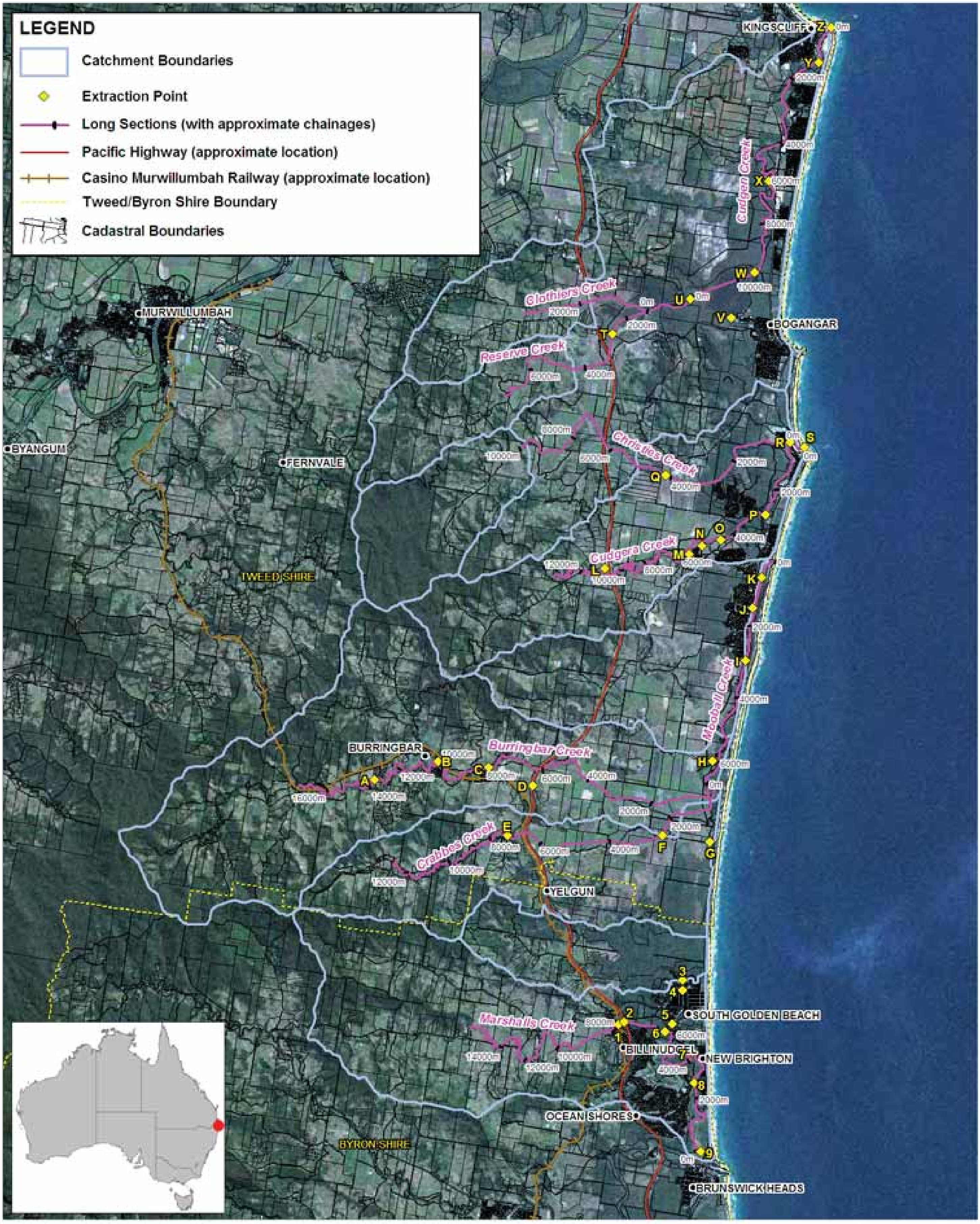
For the PMF, this tends to be attenuated, with major hydraulic controls within the floodplain (e.g. road embankments, bridges) being submerged for this flood event.

7.2.3 Floodplain Mapping

The flood behaviour is presented graphically separately in the Flood Maps Addendum. This addendum comprises maps of the peak flood levels, depths, and velocity x depth products for the 7 design flood events: 5, 10, 20, 50, 100 and 500 year ARI and PMF events. Digital results in a gridded format have also been generated and provided to both Councils to allow detailed interrogation of the mapped outputs.

Table 7-1 Peak Design Flood Levels at Selected Locations

Location	Label	Peak Flood Level (m AHD)						
		5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	500 year ARI	PMF
Marshalls Creek								
Marshalls Ck u/s of railway line at Billinudgel	1	3.41	3.59	3.80	3.96	4.13	4.38	5.88
Marshalls Ck u/s of Pacific Highway at Billinudgel	2	2.90	3.05	3.23	3.36	3.51	3.74	5.42
Yelgun Ck upstream of Kallaroo Circuit	3	2.29	2.34	2.66	2.93	3.11	3.61	5.63
Capricornia Canal at Berrimbilla Court	4	2.24	2.25	2.49	2.65	2.77	2.99	5.29
Capricornia Canal upstream of New Brighton Rd	5	2.24	2.26	2.50	2.66	2.77	2.99	5.18
Capricornia Canal at confluence with Marshalls Ck	6	2.23	2.27	2.50	2.66	2.78	3.04	5.18
Marshalls Ck at New Brighton	7	1.64	1.72	2.20	2.43	2.55	2.86	5.02
Marshalls Ck downstream of Orana Bridge	8	1.41	1.53	2.18	2.42	2.53	2.68	4.60
Marshalls Ck at downstream end	9	0.80	1.50	2.20	2.47	2.60	2.60	2.60
Mooball Creek								
Greenvale Court Bridge at Burringbar	A	25.68	26.04	26.60	26.84	27.15	26.88	28.66
Tweed Valley Way Bridge at Burringbar	B	17.76	18.09	18.57	18.79	19.01	18.94	20.70
Quinns Bridge at Mooball (Pottsville Mooball Rd)	C	12.77	12.87	12.98	13.09	13.21	13.19	14.38
Burringbar Creek Crossing at Pacific Highway	D	10.53	10.72	10.92	11.09	11.35	11.45	13.07
Crabbes Creek General Store	E	12.32	12.46	12.62	12.72	12.79	12.67	13.26
Wooyung Rd West of Tea Tree Rd (Canal Crossing)	F	3.30	3.27	3.62	3.80	3.94	4.16	5.90
Wooyung Caravan Park	G	2.60	2.63	2.89	3.09	3.25	3.67	5.79
End of Warwick Park Road	H	2.23	2.28	2.54	2.77	2.98	3.54	5.73
Black Rocks Bridge	I	1.54	1.68	2.08	2.39	2.68	3.38	5.61
Pottsville Water Estate	J	1.38	1.57	2.07	2.26	2.56	3.25	5.47
Tweed Coast Road Bridge at Pottsville	K	1.20	1.51	2.17	2.43	2.55	2.86	4.90
Cudgera Creek								
Cudgera Creek Road Interchange	L	11.73	11.82	11.91	11.94	12.02	12.03	12.76
Newcastle Drive at Seabreeze Estate	M	4.98	5.00	5.02	5.03	5.04	5.05	5.17
Lennox Circuit at Seabreeze Estate	N	2.91	2.94	2.98	3.01	3.03	3.09	4.52
Link Road Bridge at Koala Beach	O	1.99	1.98	2.18	2.35	2.42	2.51	4.60
Cudgera Avenue Bridge at Koala Beach	P	1.26	1.53	2.13	2.34	2.42	2.51	4.40
Christies Creek Channel West of Quarry	Q	1.67	1.83	1.99	2.17	2.34	2.70	4.55
Tweed Coast Road Bridge	R	0.86	1.51	2.17	2.40	2.51	2.56	3.23
Cudgera Creek Outlet to Ocean	S	0.80	1.50	2.20	2.47	2.59	2.60	2.60
Cudgen Creek								
Clothiers Creek Road Crossing	T	2.40	2.55	2.74	2.99	3.19	3.54	6.01
Cudgen Lake Inlet (Clothiers Creek)	U	2.08	2.26	2.48	2.72	2.92	3.36	5.74
Cudgen Lake at Willow Avenue	V	2.08	2.26	2.47	2.72	2.92	3.36	5.73
Cudgen Lake Outlet	W	2.08	2.26	2.47	2.72	2.92	3.36	5.73
Tweed Coast Road Bridge at Casuarina	X	0.93	1.54	2.10	2.30	2.38	2.90	5.39
Sutherland St Bridge at Kingscliff	Y	0.84	1.52	2.13	2.36	2.45	2.53	4.81
Cudgen Creek Outlet to Ocean	Z	0.80	1.50	2.16	2.41	2.52	2.56	2.80



Title:

Design Results Extraction Locations

Figure: 7-2

Rev: B

N

0 3 6km

Approx. Scale

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Filepath : I:\B16790_I_BRH Tweed Byron GJR\DRG\FLD_101_090908_Results_Extraction.wor

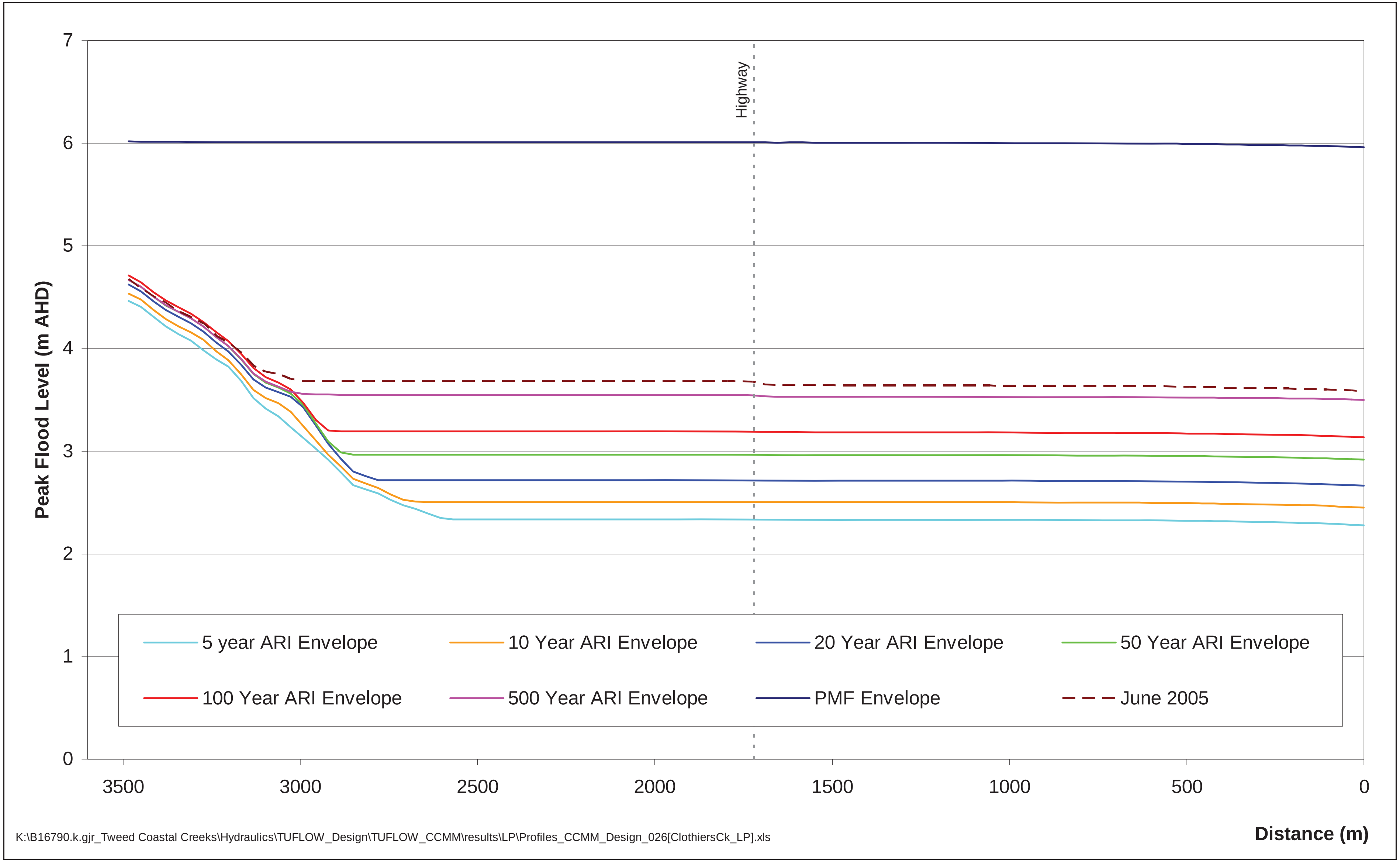


Figure 7-3 Clothiers Creek Flood Profile

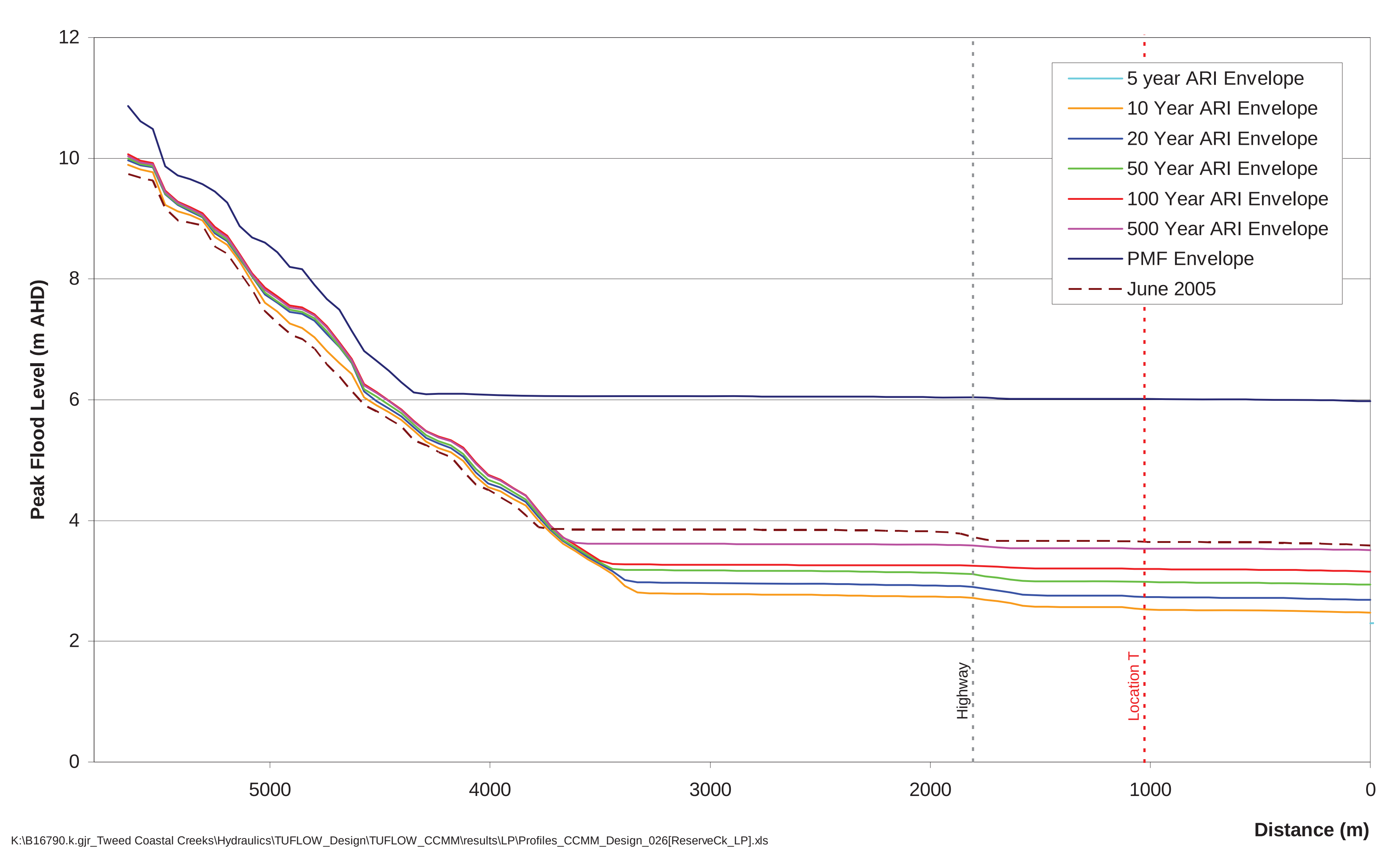


Figure 7-4 Reserve Creek Flood Profile

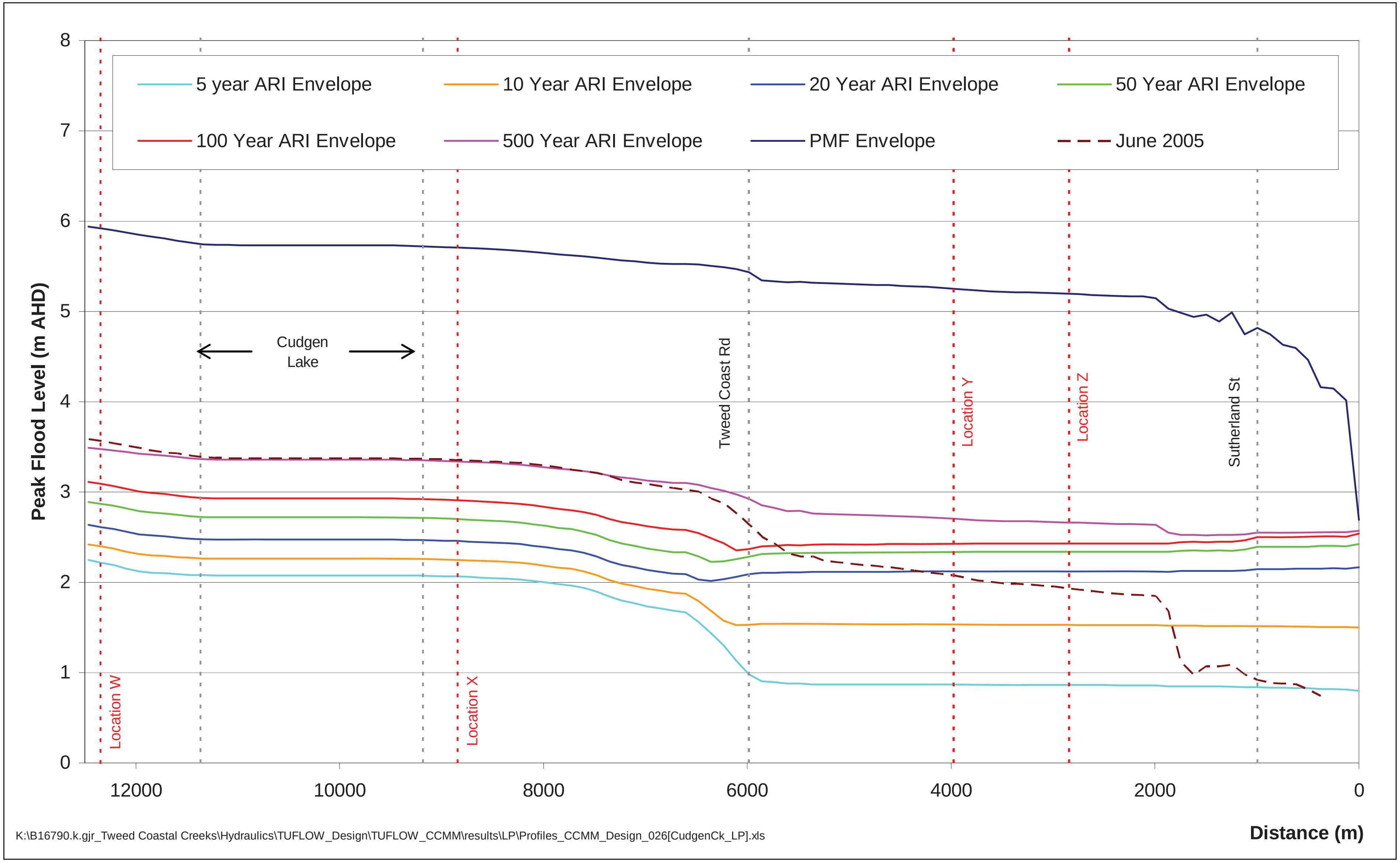


Figure 7-5 Cudgen Creek Flood Profile

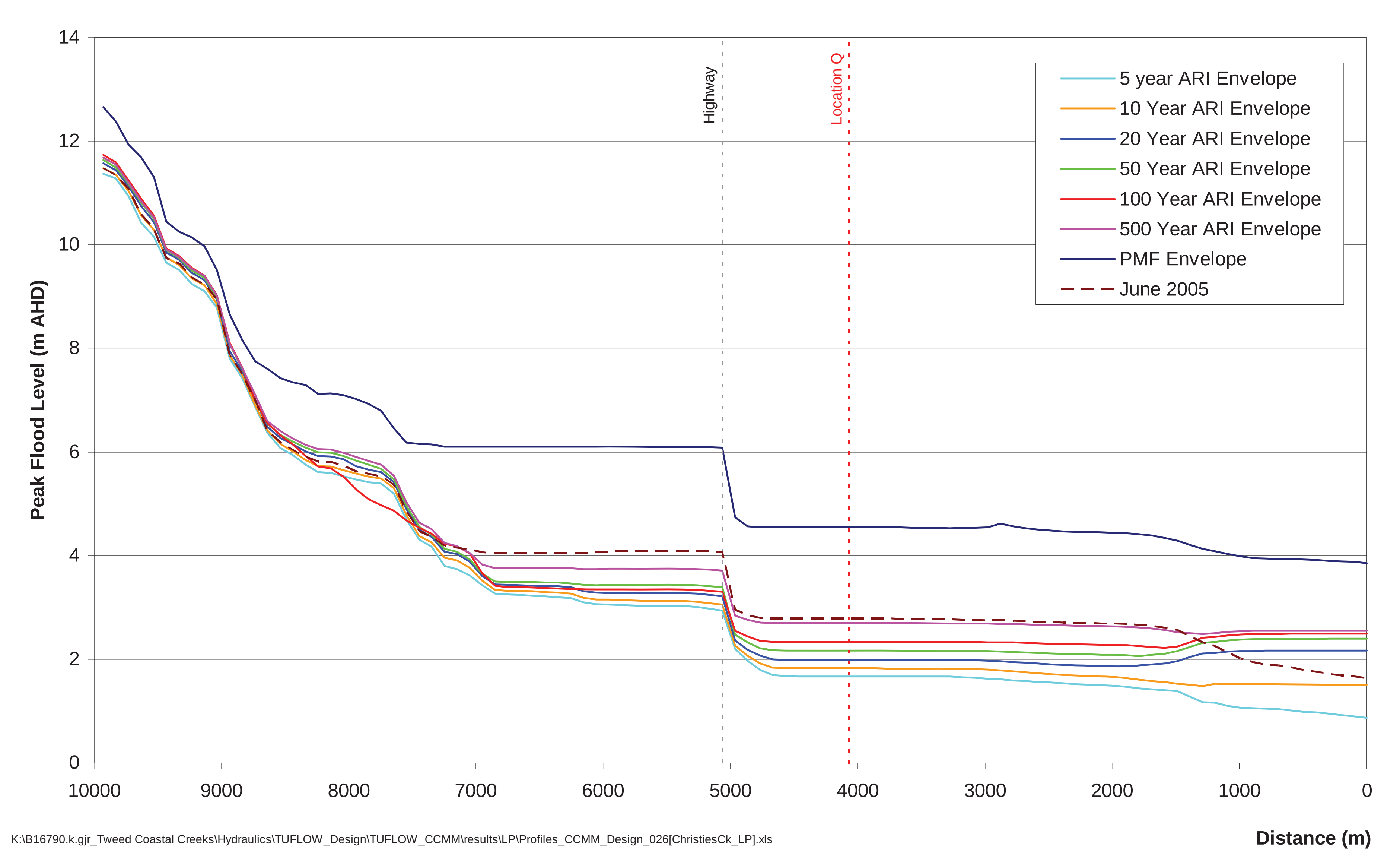


Figure 7-6 Christies Creek Flood Profile

BMT WBM

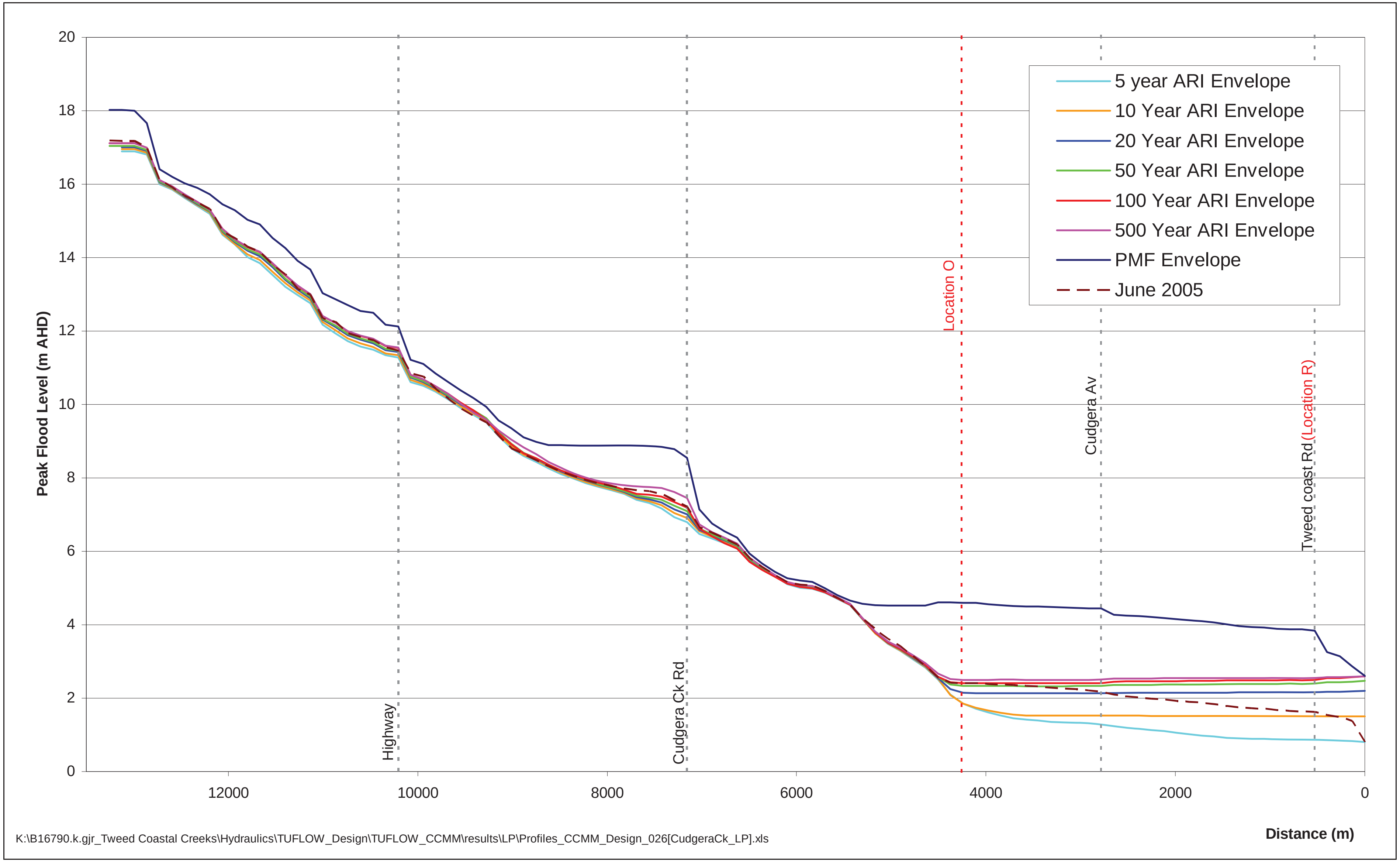


Figure 7-7 Cudgera Creek Flood Profile

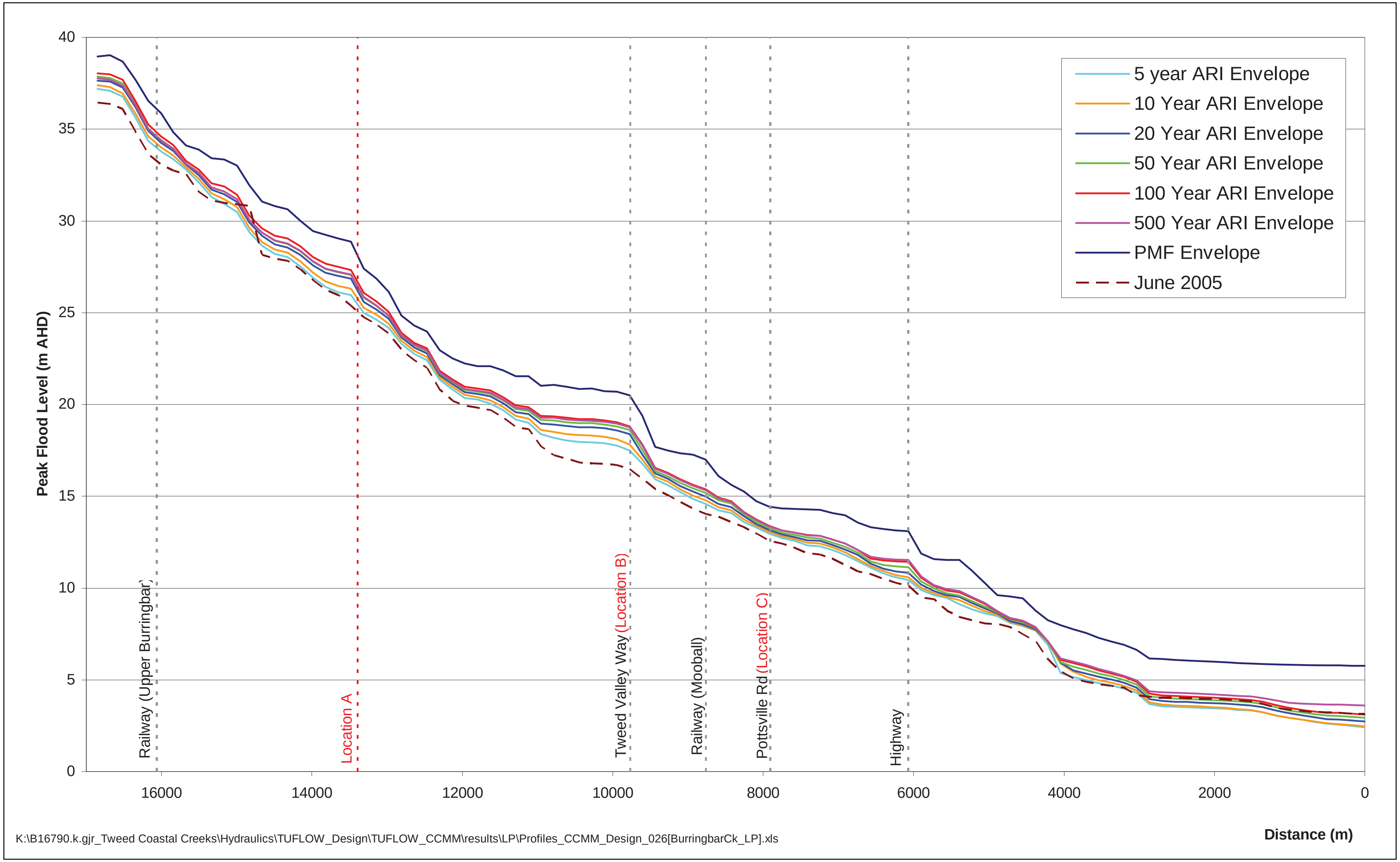


Figure 7-8 Burringbar Creek Flood Profile

BMT WBM

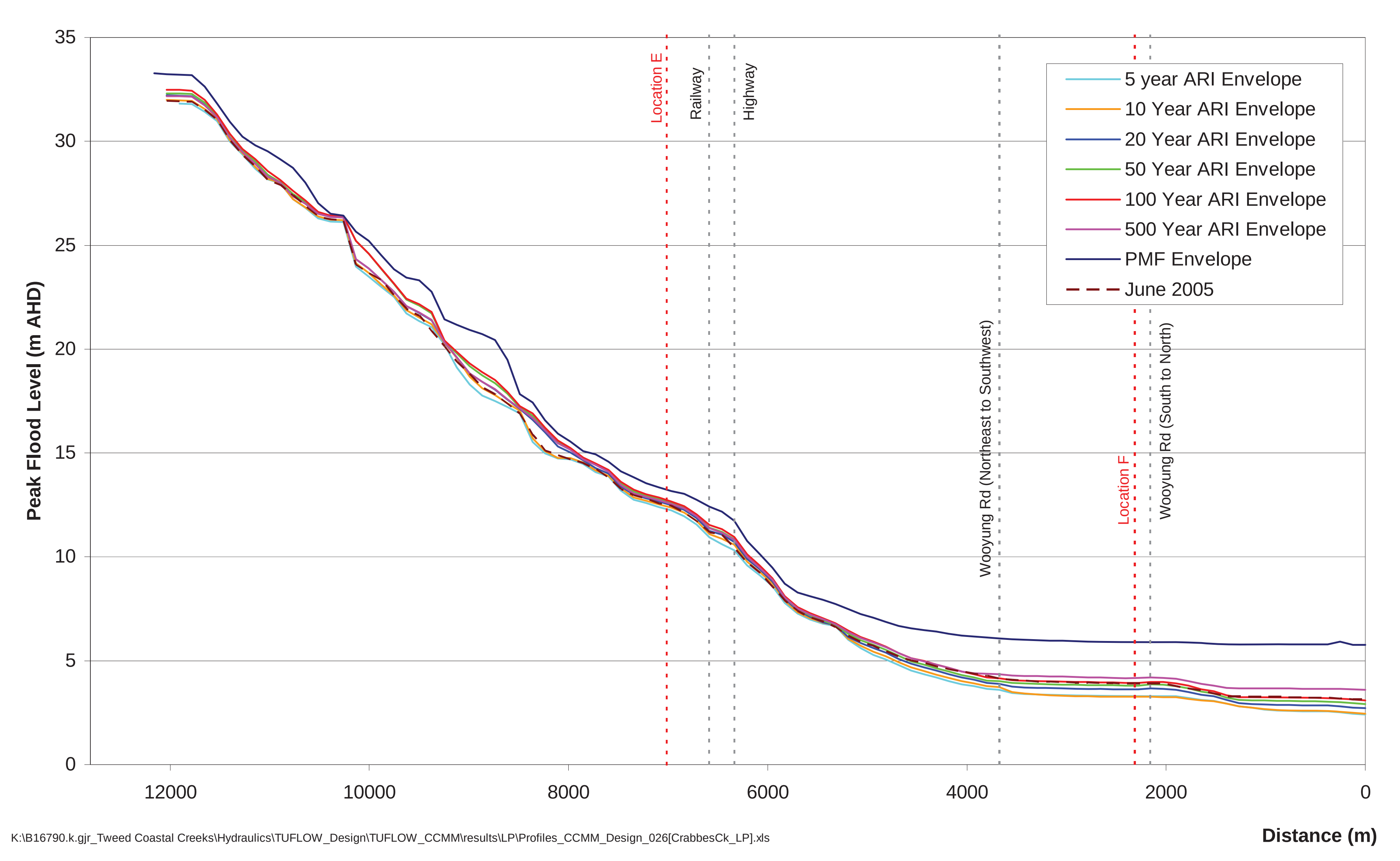


Figure 7-9 Crabbes Creek Flood Profile

BMT WBM

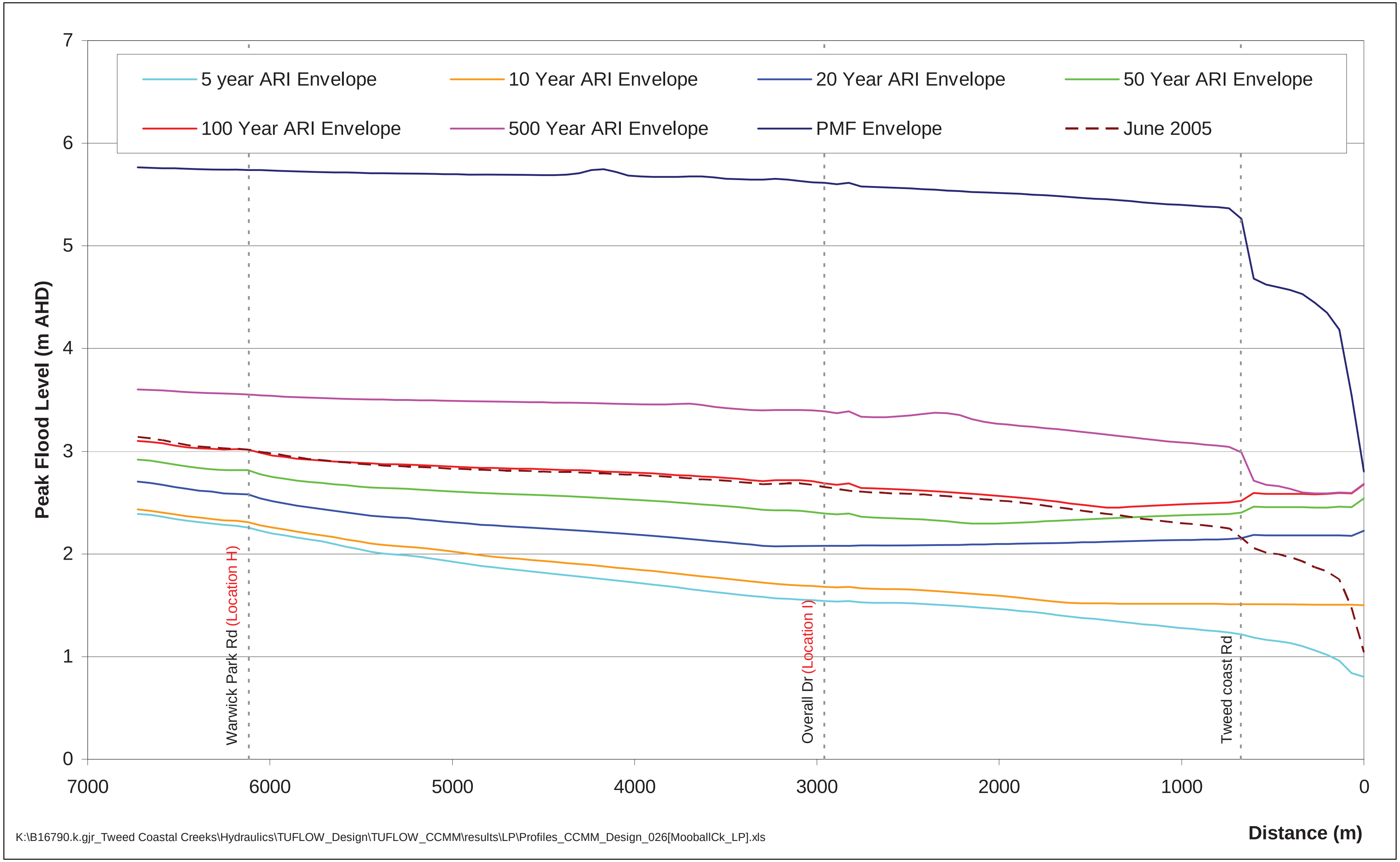


Figure 7-10 Mooball Creek Flood Profile

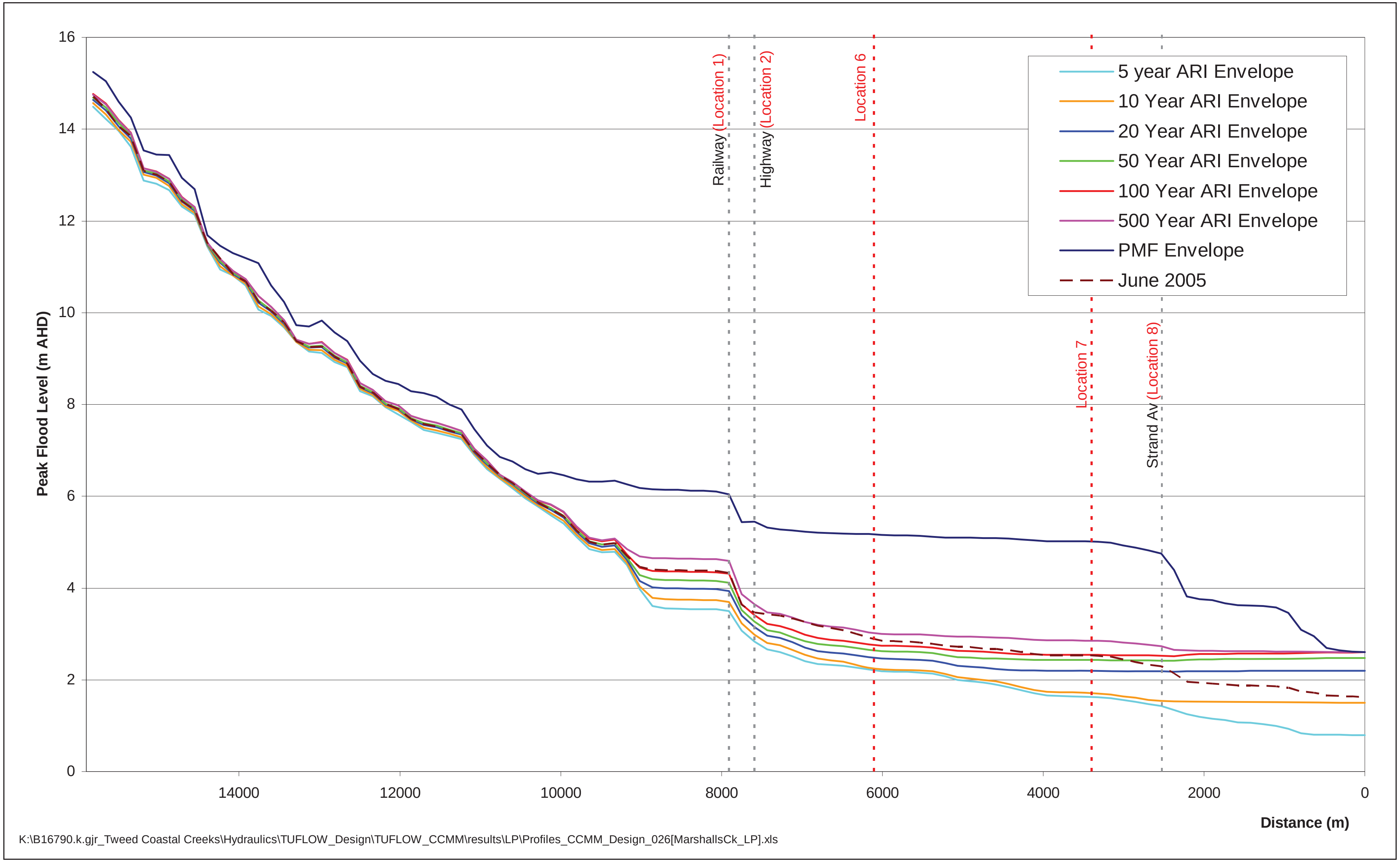


Figure 7-11 Marshalls Creek Flood Profile

BMT WBM

7.3 Flood Behaviour

This section describes the design flood behaviour for the major urban centres across the Coastal Creeks study area. Flood maps for the 100 year ARI design flood event are provided for each area in Figure 7-12 to Figure 7-21, with references to the streets and landmarks discussed in the following sections.

7.3.1 Bogangar / Cabarita Beach

Parcels along Tamarind Avenue start to be inundated from backwaters from Cudgen Lake and the Cudgen Creek floodplain in events less than the 20 year ARI design event. In a 50 year ARI design event, the inundation also covers the area between Rosewood Avenue and Mimosa Avenue and into Hastings Road, with waters predicted to break out of the Friday Island canal across Rosewood Avenue. In a 100 year ARI design event, most of the area to the north of Rosewood Avenue is predicted to be inundated, with depths generally below 0.5m. Flood waters are also predicted to cross over east of Hastings Road towards commercial land in the Cabarita Beach CBD for this event.

Clothiers Creek Road is predicted to be inundated at the creek crossing west of Cabarita Road from a 10 year ARI design flood event. Access to the Pacific Motorway via Clothiers Creek Road however is lost in flood events less than the 5 year ARI design event on the Tanglewood floodplain.

In a PMF event, peak flood levels are predicted to reach 5.7m AHD in this area, generating flooding for most of the area north of Sandalwood Drive and west of the Tweed Coast Road, (this floodplain area was filled for residential development).

Cabarita Beach (i.e. east of the Tweed Coast Road) is located on the high coastal dune, so is predicted to remain flood free.

7.3.2 Hastings Point

Parcels along Creek Street are predicted to be inundated in a 20 year ARI design flood event. Overland flooding is also predicted for this event at the bend of Cudgera Creek in Young Street. Peak flood levels of approximately 2.2m AHD are predicted for this event, reaching up to 2.5m AHD in a 100 year ARI design event (i.e. up to 1m of water in places) and up to 3.9m AHD in a PMF event (i.e. up to 2.5m of water). In a PMF event, the area south of Peninsula Street and east of the Tweed Coast Road is also predicted to be inundated.

The Tweed Coast Road bridge is predicted to remain flood free for all flood events except the PMF with overtopping of up to 0.3m.

7.3.3 Koala Beach Estate

Koala Beach Estate is predicted to remain flood free over nearly the entire area for all floods up to the 500 year ARI design event. Only the reserve to the east of Muskheart Circuit is predicted to start being inundated in a 50 year ARI design event, with peak depths still below 0.5m in a 500 year ARI design event.

In a PMF event, the estate is isolated by road, with Cudgera Avenue inundated. Properties on the eastern half of Muskheart Circuit and west of Lomandra Avenue are predicted to be inundated with depths of water of up to 2m in a PMF event. Local streets such as Muskheart Circuit, Bandicoot Street and Sugar Glider Drive are predicted to become major flow paths during this event.

7.3.4 Seabreeze Estate

Inundation of low lying open space areas and roadways in Seabreeze Estate is predicted for events similar or greater than a 100 year ARI design flood event, including flooding of the north eastern corner of Lennox Circuit and the intersection of Seabreeze Boulevard and Ballina Street. This flooding extends eastward along Seabreeze Boulevard for the 500 year ARI design event, with depths of water of more than 0.5m (but less than 1m) at the Koala Beach Link Road.

In a PMF event, peak flood levels are predicted to reach up to 4.6m AHD in this area, generating up to 2m of flooding in the estate north of Mylestom Circle and Korora Parkway. The northern part of Lennox Circuit is also predicted to be flooded in this extreme event, but depths are predicted to remain below 1m. Seabreeze Boulevard is predicted to become a major flow path in this event.

7.3.5 Pottsville

In a 50 year ARI design flood event, the creek linking Mooball Creek and Cudgera Creek catchments is predicted to break out downstream of Pottsville Road. This is predicted to generate minor flooding in the parcels along and to the north of Coronation Avenue (Pottsville Village CBD).

In a 50 year ARI design flood event, Mooball Creek is also predicted to break out and inundate residential land along Philip Street. In a 100 year ARI design event, inundation extends northward across the village green area between Phillip St and Tweed Coast Road.

Pottsville Road and Coronation Avenue are predicted to be inundated along several sections in a 500 year ARI event, with floodwaters from Mooball Creek and Cudgera Creek connecting overland through the CBD area.

Almost the entire area of Pottsville Village is predicted to be inundated in a PMF event, with depths of water of up to 2m. This area is also predicted to become a major flow path with the connection of floodwaters from Mooball Creek and Cudgera Creek in a PMF event, with velocity x depth product higher than 1 m^2/s in some sections.

7.3.6 Pottsville Waters & Black Rocks Estates

Pottsville Waters and Black Rocks Estates are predicted to remain flood free for all flood events up to (and including) the 100 year ARI design event. In a 500 year ARI design event, floodwaters are predicted to inundate most of these filled estates north of McKenzie Avenue as water from the Sheens Creek floodplain to the west join waters from Mooball Creek to the east. The entire area is predicted to be underwater in a PMF event, with peak flood levels of up to 5.6m AHD at the southern end of the development. Peak flood depths of up to 3m in places are predicted, across the estates, although flow velocities remain low (i.e. the area is acting as a flood storage area rather than major conveyance flow path).

7.3.7 Burringbar

Overland flooding is predicted in relatively frequent flood events (i.e. 5 year ARI design event) along Burringbar Creek, and affecting residential properties around Hunter Street and Tweed Valley Way south of the Burringbar Creek bridge. Depths of up to 2m are predicted for the 5 year ARI design flood event at the back of parcels east of the Tweed Valley Way, where creek break-outs create a major flow path.

Properties on the southern side of the Broadway begin to be affected in the 10-20 year ARI design flood event, as the creek breaks out and water travels northwards.

In a 100 year ARI design event, many parts of the township are predicted to be inundated by flooding from Burringbar Creek, including rural residential development in Greenvale Court. This area is predicted to remain subject to low flood flows, whereas the other inundated areas are located within the floodwater conveyance paths and as such are characterised by medium to high flows (particularly east of Tweed Valley Way).

In a PMF event, the entire area between Burringbar Creek and Burringbar Road is predicted to be inundated, and the railway line is predicted to be overtopped in two sections: near Greenvale Court entrance, and north of the Hunter Street / Tweed Valley Way junction.

It is noted that Burringbar Creek is relatively constrained by the topography in this area, so that the extent of flooding does not vary much between the different flood events (except for extreme events like the PMF). This also means that the floodwaters cannot spread out, thus high velocities and/or depths are predicted. This implies that most of the floodplain is subject to medium to high flood flows in this area.

7.3.8 Mooball

The above observation is applicable to the township of Mooball as well, especially north of the railway line. In fact this area lies within the ‘active’ floodplain of Burringbar Creek, where secondary flow paths develop during flood events.

Similarly to Burringbar township, extensive developed areas are predicted to be inundated in the 5 year ARI design flood event. It is noted that backwater flooding is also predicted to the south of the railway line and Tweed Valley Way. However, this area is characterised by low velocities and depths of less than 0.5m. In a 100 year ARI flood event, the entire floodplain north of the railway line is inundated, with depths up to 2m in places. Ponding of backwater on the southern side of the Tweed Valley Way is also predicted to increase to depths of about 2m locally.

In a PMF event, the entire township of Mooball is predicted to be inundated, extending some 250m south of the Tweed Valley Way. High peak depths and velocities are predicted to the north of the railway line, with most of the floodplain subject to high flood flows. The area south of the Tweed Valley Way is predicted to be subject to medium flood flows.

7.3.9 Crabbes Creek

Although Crabbes Creek is predicted to break out at the Crabbes Creek Road bridge in a 5 year ARI design flood event, the inundation is not predicted to reach the school and general store (at the road) up to the 100 year ARI design flood event. This flooding is mainly due to the constrictions of flow downstream at the Tweed Valley Way. In a PMF event, the entire township is predicted to be underwater, with the main path to convey flood waters (high to medium flows) breaking out of the creek and into the back of the school and general store parcels.

7.3.10 Wooyung

For all design floods, Wooyung Road is predicted to be inundated first at the canal crossing west of Tea Tree Road by floodwaters from the Crabbes Creek and Burringbar Creek catchments. It is then predicted to be overtopped east of Tea Tree Road when floodwaters from Mooball Creek backup to the South in the vicinity of the Wooyung Caravan Park.

In a 100 year ARI design flood event, the canal crossing flow path is predicted to change from low flow to medium flow, as velocities increase across the road.

The floodplain east of Tea Tree Road is constrained by the coastal dune system. Hence, the extent of flooding does not vary much from the relatively frequent floods to the 500 year ARI design flood event. Peak flood levels are however predicted to go up by approximately 1m between the 5 year and the 500 year ARI flood event. About another 1m depth is predicted in a PMF flood event. In this event, the entire length of Wooyung Road east of the high ground (where it turns eastwards) is predicted to be overtopped with depths of up to 4m in some places.

7.3.11 South Golden Beach

Although the levee around Capricornia Canal provides more than 500 year ARI flood protection, it does not protect South Golden Beach from overland flooding from Yelgun Creek / Mooball Creek. The area between Gloria Street and Helen Street is predicted to be inundated in a 5 year ARI flood event, from local ponding and/or overland flow coming from the north, as occurred in the June 2005 flood. It is noted that local drainage mechanisms to convey rainfall/runoff water into the Capricornia Canal have not been considered in this study (e.g. floodgated drainage pipes).

The area to the north of Gloria Street remains flood free up to a 100 year ARI design flood event. In a 500 year ARI design flood event, peak flood levels in this area are dictated by floodwater from the Mooball and Yelgun Creek catchments, with a hydraulic gradient across Redgate Road as well as the bunds around Capricornia Canal into the Marshalls Creek floodplain.

The South Golden Beach area is predicted to become a medium hazard area in a PMF flood event; with peak flood levels of up to 5.5m AHD on the southern side of the Kallaroo Circuit bund and 5.6m AHD on the northern side.

7.3.12 Billinudgel

The area upstream of the railway line and the land between Shara Boulevard and New Brighton Road are predicted to be inundated in a 5 year ARI design event, with depths of up to 2.5m. In a 100 year ARI design flood event, the area between the railway line and the Pacific Highway is also predicted to be inundated, although the railway line is still a hydraulic control generating a significant head drop of approximately 0.3m. The area between Balemo Drive and the Brunswick Valley Way remains mostly flood free in this major flood event and even in the 500 year ARI design flood event.

Peak flood levels are predicted to increase by more than 2m from the 100 year ARI flood to the PMF event. In a PMF event, most of the floodplain downstream of the Pacific Highway and north and east of Balemo Drive is predicted to be a major flow path for the flood, with high (greater than 1 m^2/s) velocity x depth product.

7.3.13 New Brighton

The northern section of New Brighton (i.e. west of Byron Street) is predicted to be fully inundated in a 20 year ARI design flood event. Peak flood depths and velocities are predicted to remain low up to the 500 year ARI design flood event. The park area between Byron Street and Park Street is predicted to convey floodwaters towards South Golden Beach, and is predicted to become a medium hazard area in a 500 year ARI flood event.

In a PMF event, the entire area east of Marshalls Creek is also predicted to be inundated, with only the parcels east of River Street remaining as low hazard.

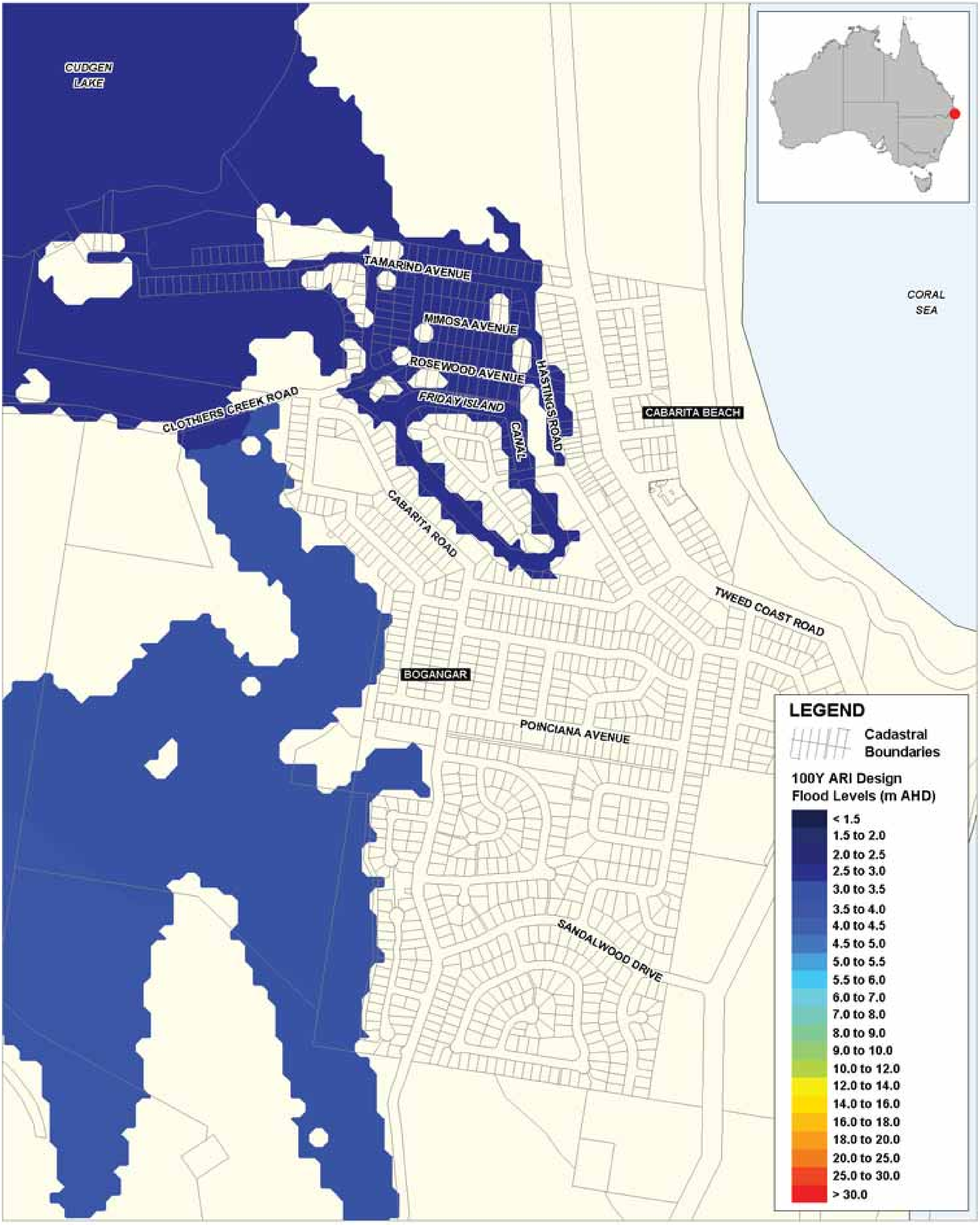
7.3.14 Ocean Shores

Ocean Shores is predicted to remain flood free in all design flood events for most of the area. Only parcels to the north of Orana Road are predicted to start being inundated in a 50 year ARI design flood event, with the inundation extending into Kiah Close and Narooma Drive as well as around the edges of Water Lily Park in a PMF event. This area remains in a low hazard category up to the 500 year ARI event.

7.4 Comparison with the June 2005 Flood

Flood profiles for the June 2005 event were also extracted along the major creeks and are reported together with the peak design flood levels in Figure 7-3 to Figure 7-11. These figures highlight the variability of this flood event across the study area in terms of magnitude. Generally, these profiles show that the June 2005 flood event was:

- Less than the 100 year ARI design flood event in the lower floodplains, mostly due to the absence of storm surge during this event;
- Between the 100 and 500 year ARI design flood events for the Mooball Creek, Marshalls Creek and Cudgera Creek catchments;
- Above the 500 year ARI design flood levels for the Cudgen Creek catchment; and
- Less than the 5 year ARI design flood in Burringbar Creek upstream of the Pacific Highway, due to relatively low rainfall in the upper catchment during this event.



Title:

Bogangar and Cabarita Beach

Figure: **7-12**

Rev: **A**

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Approx. Scale

BMT WBM

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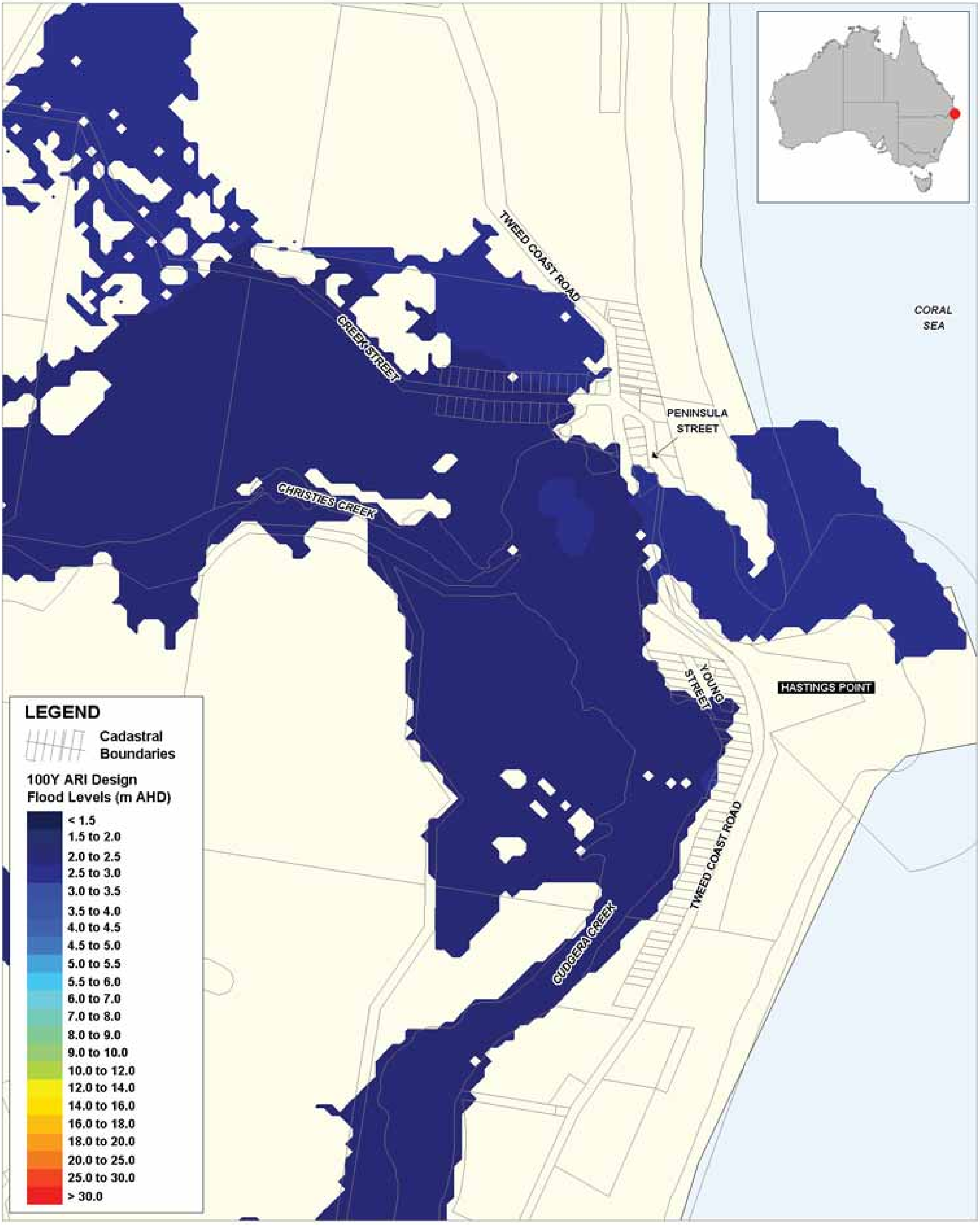

Title:
Hastings Point

Figure: 7-13

Rev: A

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Approx. Scale

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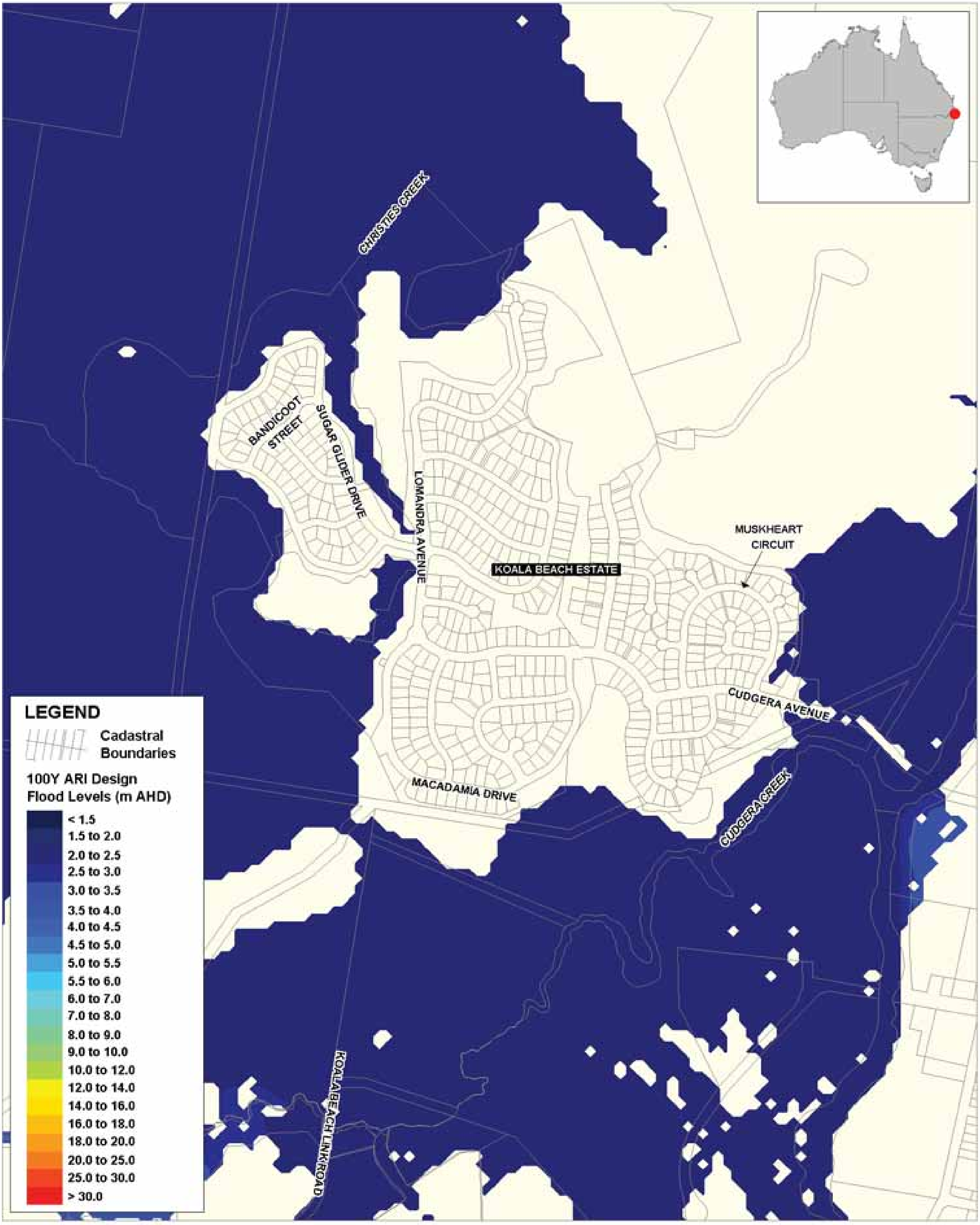

Title:

Koala Beach Estate

Figure: 7-14

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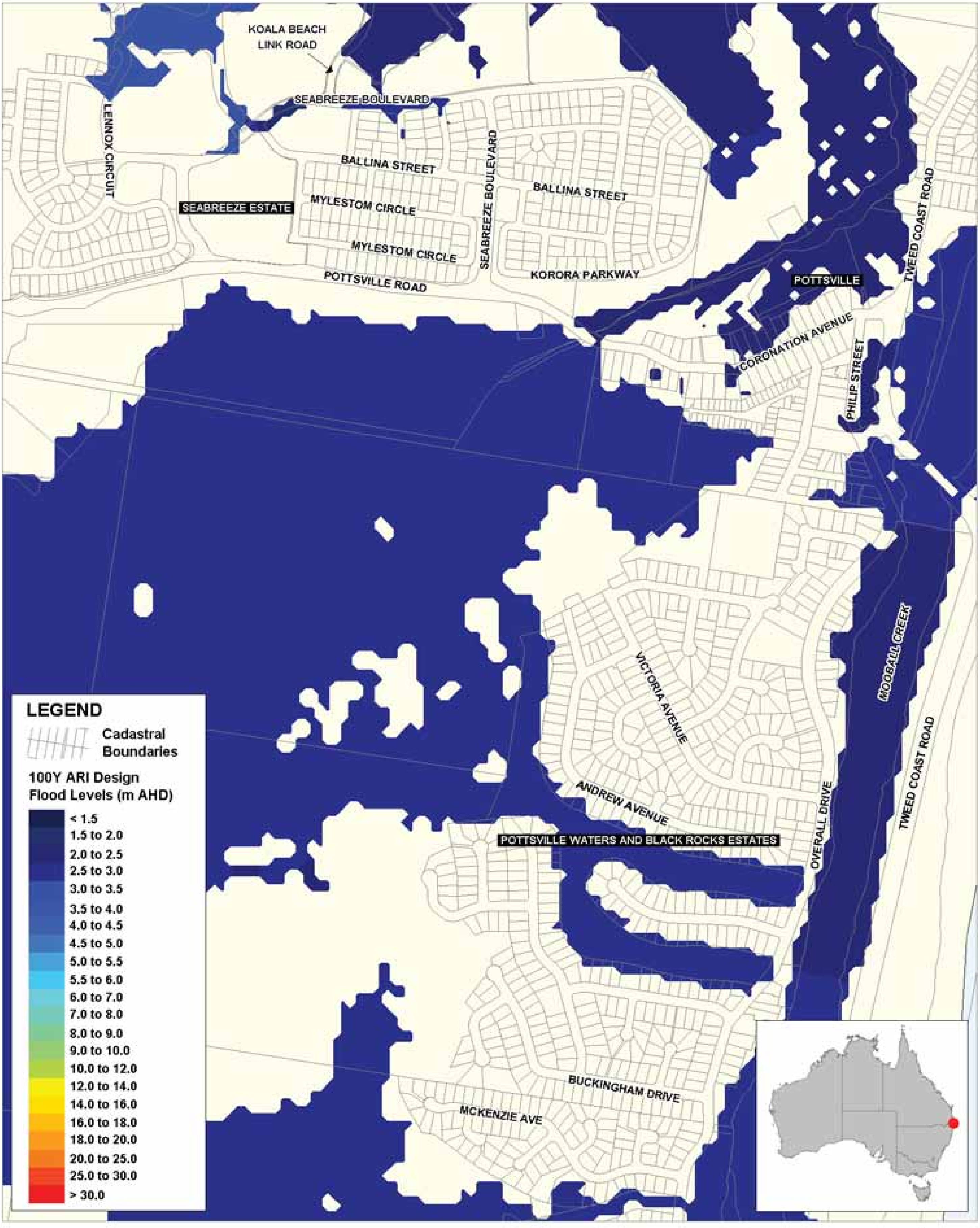

Title:

Seabreeze, Pottsville Waters and Black Rocks Estates and Pottsville

Figure: **7-15**

Rev: **A**

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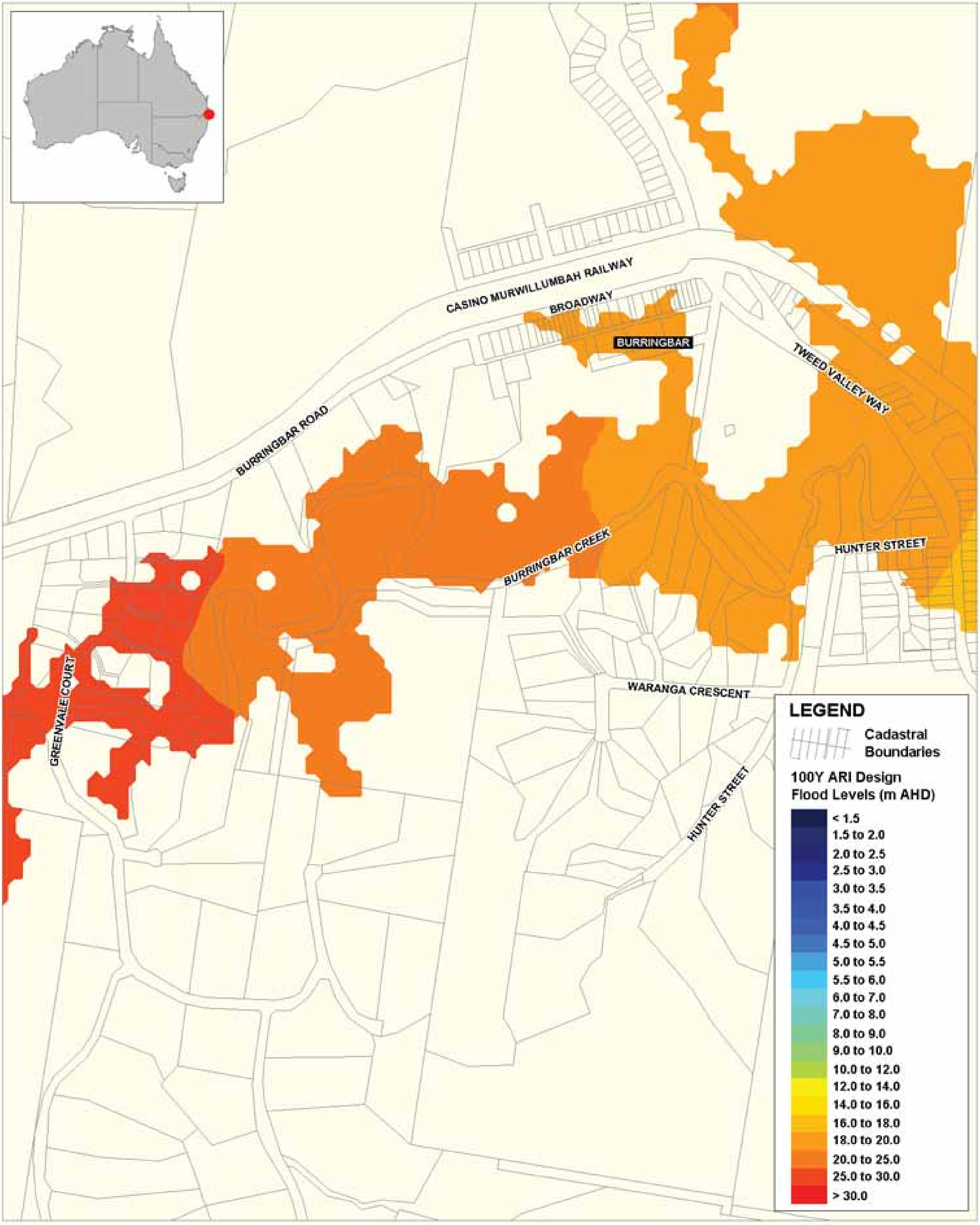

Title:
Burringbar

Figure:
7-16

Rev:
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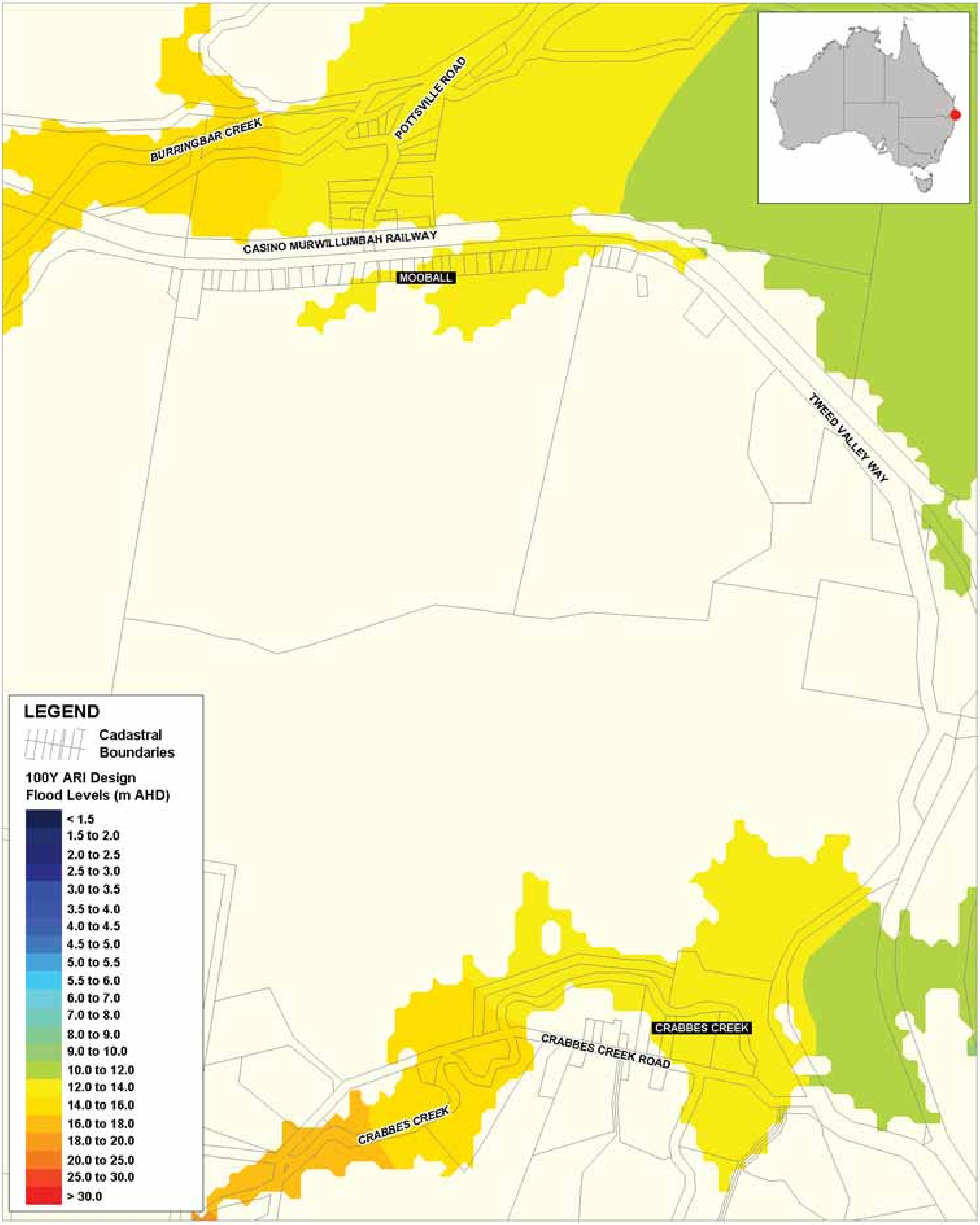

Title:

Mooball and Crabbes Creek

Figure: 7-17

Rev: A

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Approx. Scale

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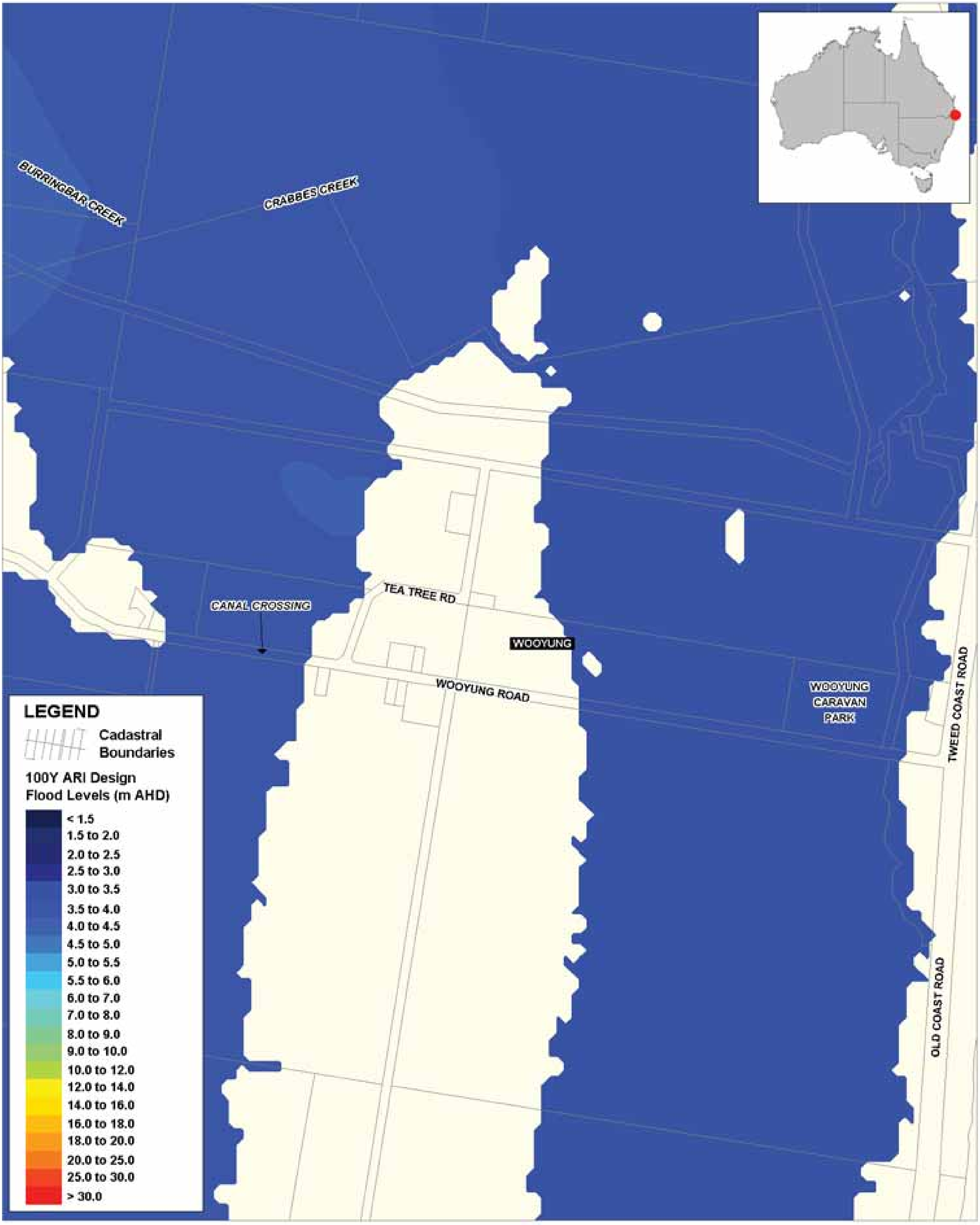

Title:
Wooyung

Figure:
7-18

Rev:
A

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Approx. Scale

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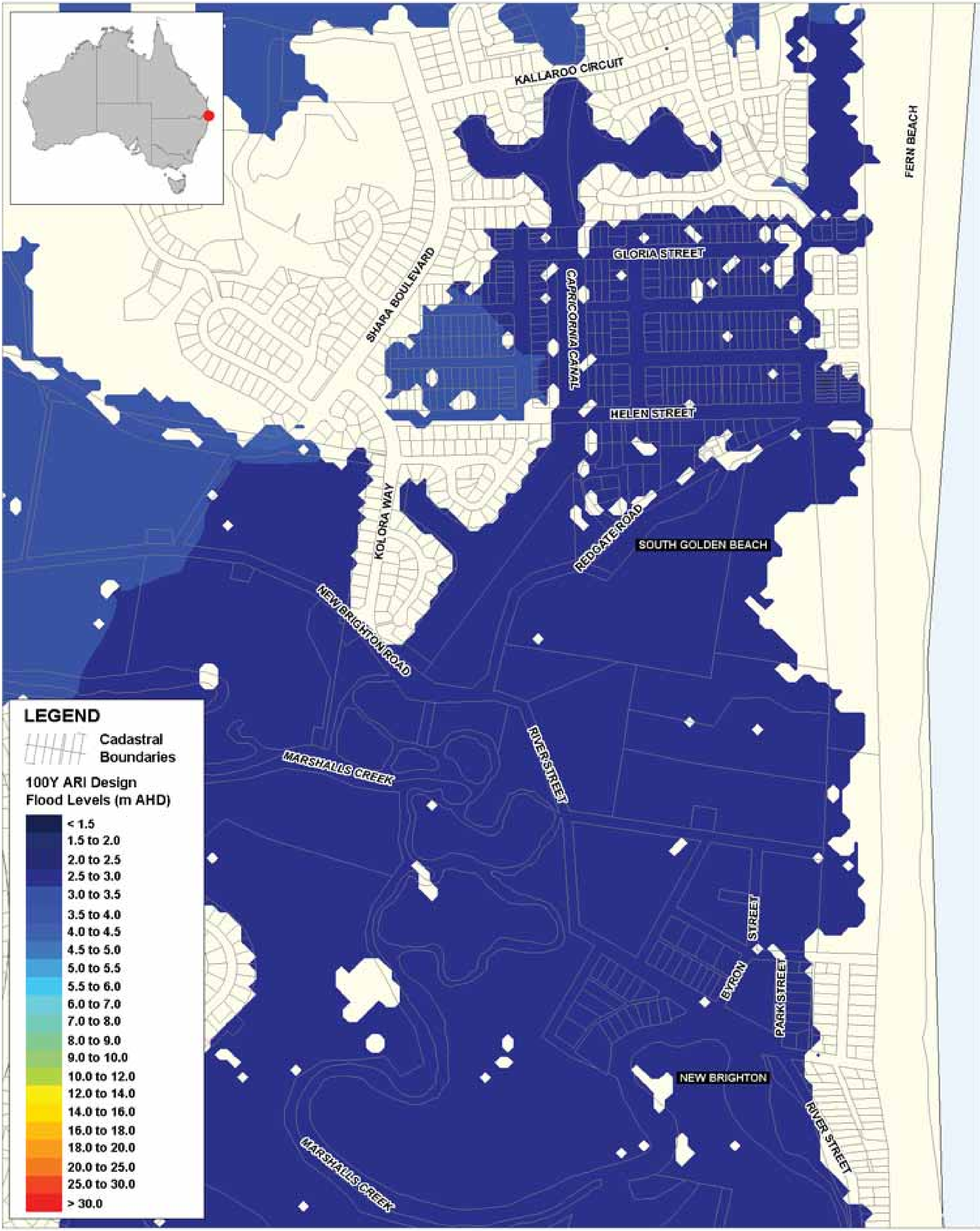

Title:

South Golden Beach and New Brighton

Figure: 7-19

Rev: A

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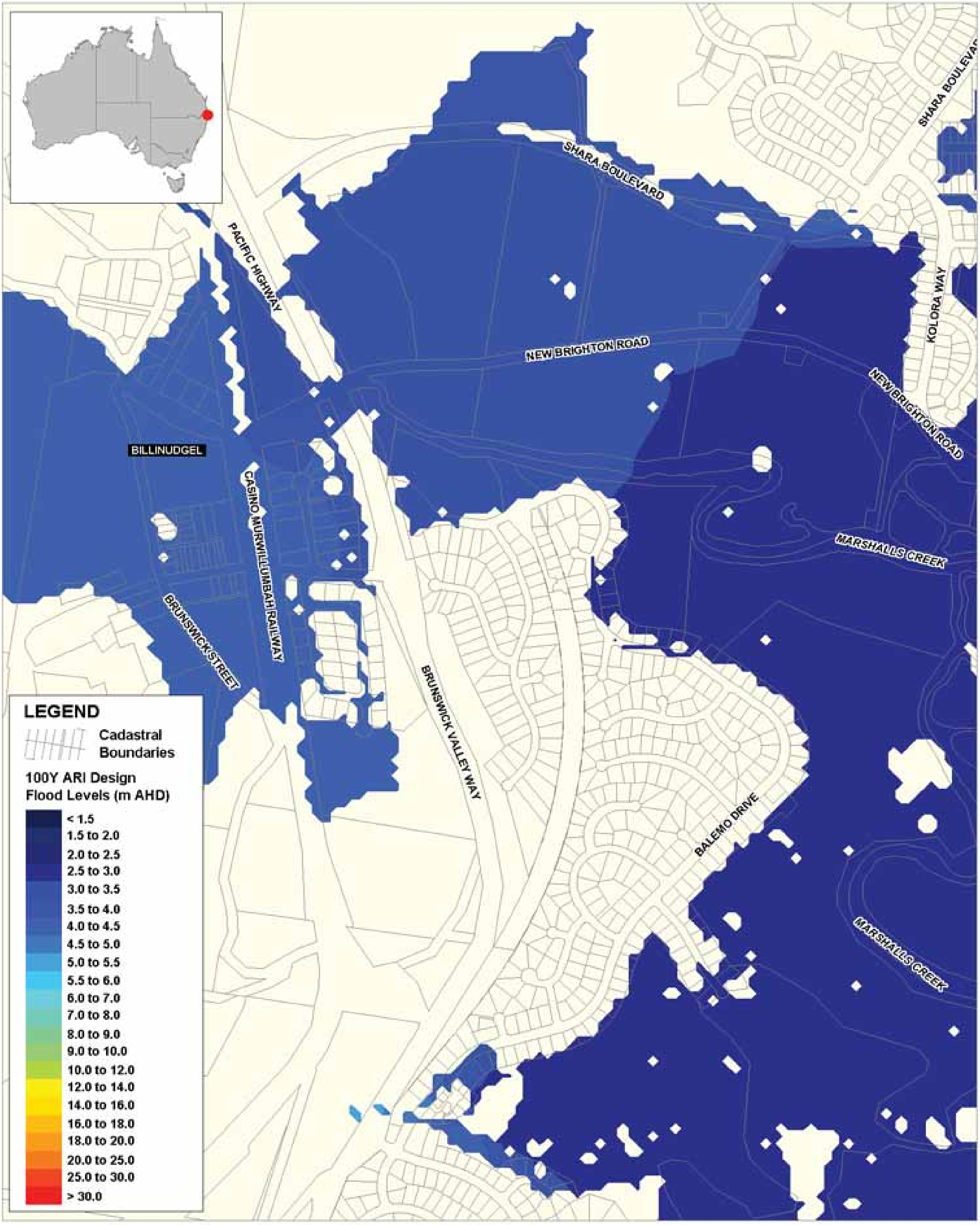

Title:
Billinudgel

Figure: 7-20

Rev: A

N

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Approx. Scale

BMT WBM

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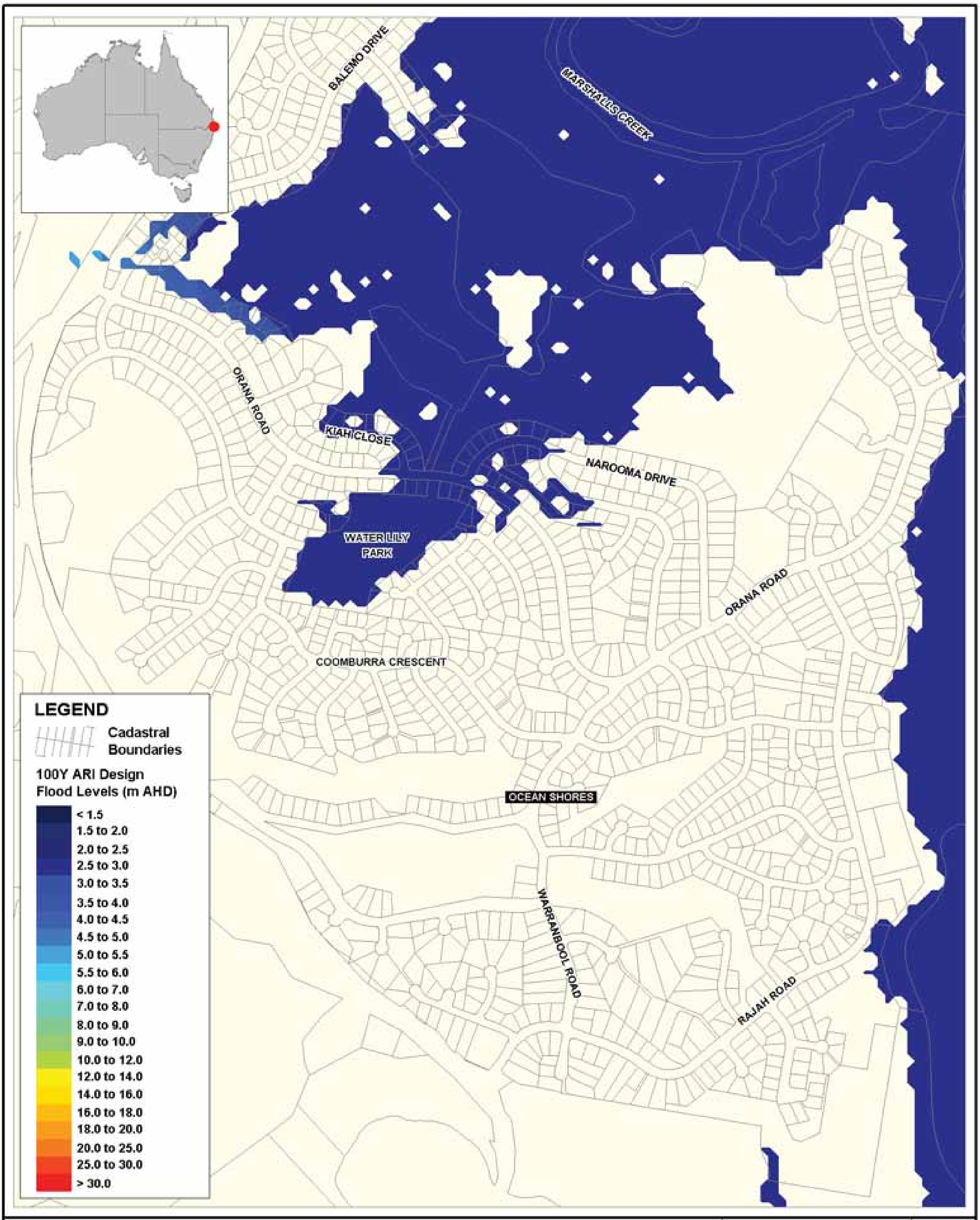

Title:
Ocean Shores

Figure: 7-21

Rev: A

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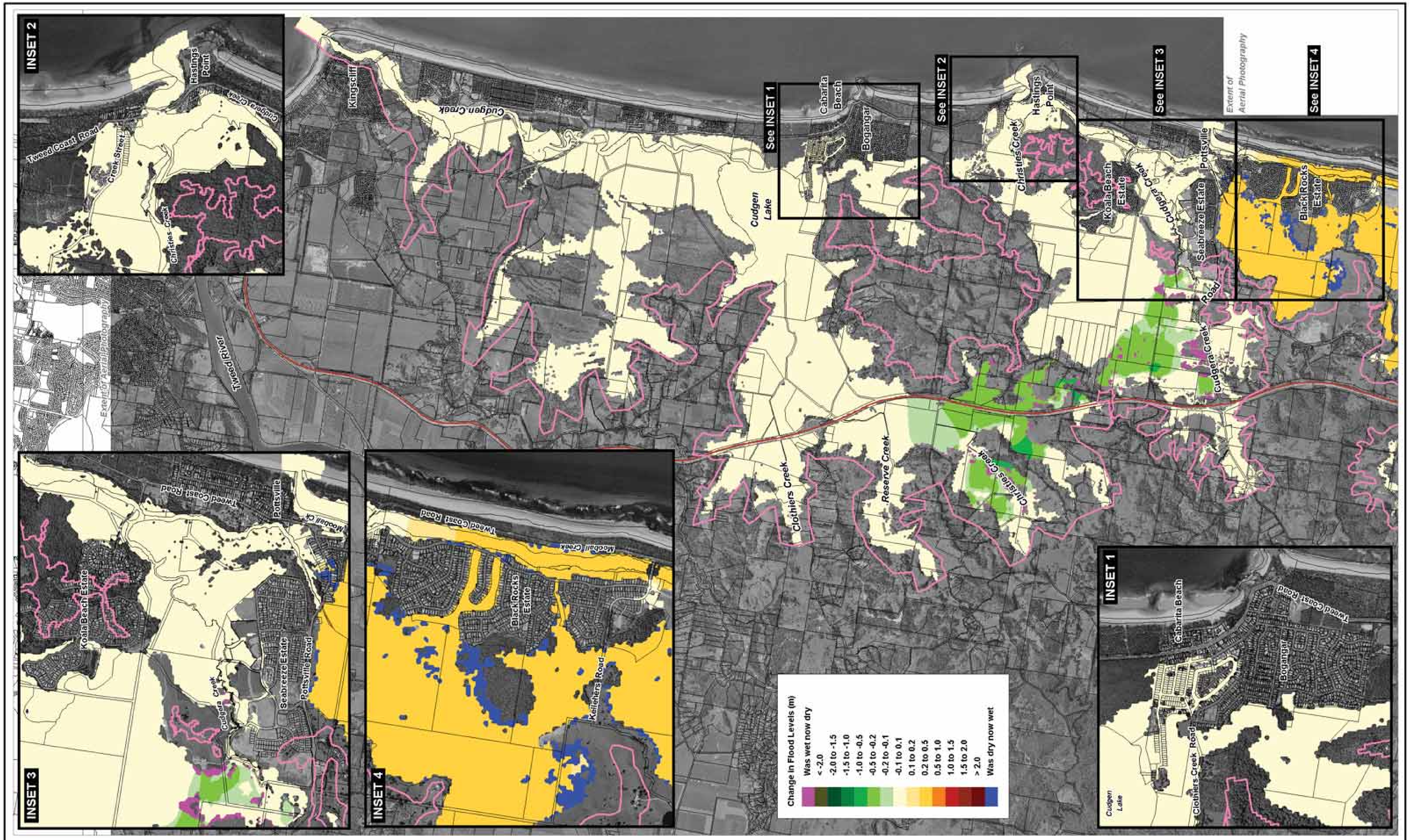
8 SENSITIVITY ANALYSES

Sensitivity analyses are typically undertaken to assess the sensitivity of model results to various assumptions and boundary conditions in the modelling. In particular, as discussed in Section 4.2.3.4, a key feature of the Coastal Creeks floodplains is the presence of sugar cane fields, which can comprise a significant obstruction to flows when fully grown. Design runs were carried out based on the roughness values calibrated to the June 2005 event (i.e. an adopted Manning's n of 0.20), representing the fully matured cane fields during this calibration event.

However, the status of the sugar cane crop on the floodplain is a variable that affects the behaviour of floods in the vicinity of the site. If a flood occurs when the sugar cane has been harvested or when a change in land use has occurred, then the efficiency of the floodplain may increase (i.e. conveyance floodwaters downstream more quickly) and generally lowering flood levels in these areas and increasing levels downstream. Sensitivity analyses were thus undertaken to assess the impact of harvested conditions (i.e. an adopted Manning's n of 0.04) on the 100 year ARI design flood behaviour.

Figure 8-1 and Figure 8-2 present the impacts of this change in roughness on peak flood levels respectively for the Cudgen/Cudgera and Mooball/Marshalls floodplains. These figures show that the change in land use has more impact on modelled flood behaviour in the lower Burringbar Creek and Crabbes Creek floodplains and the Mooball Creek floodplain, with 100 year ARI peak flood levels predicted to decrease by up to 1m for some 2 to 3km downstream of the Pacific Highway. Conversely, flood levels are predicted to increase by up to 0.5m further downstream in the lower Mooball Creek floodplain downstream of Wooyung to Pottsville. This behaviour is consistent with an increase in flood velocities (and thus conveyance) across the cane fields, resulting in a flattening of the flood gradient in this area. Minor impacts are also predicted in the upper Cudgera Creek and Christies Creek catchments, although the amplitude of these impacts is less; decreases of up to 0.5m in the vicinity of the cane fields and increases downstream limited to 0.1m. This is reflective of the lesser extent of cane fields in these catchments.



LEGEND

- Model Extent
- Pacific Highway (approximate location)
- Cadastral Boundaries

Title:
Change in 100 Year ARI Peak Flood Levels
Sugar Cane Fully Harvested (n=0.04)
Cudgen/Cudgera Creeks Catchments

Figure: 8-1

Rev: B

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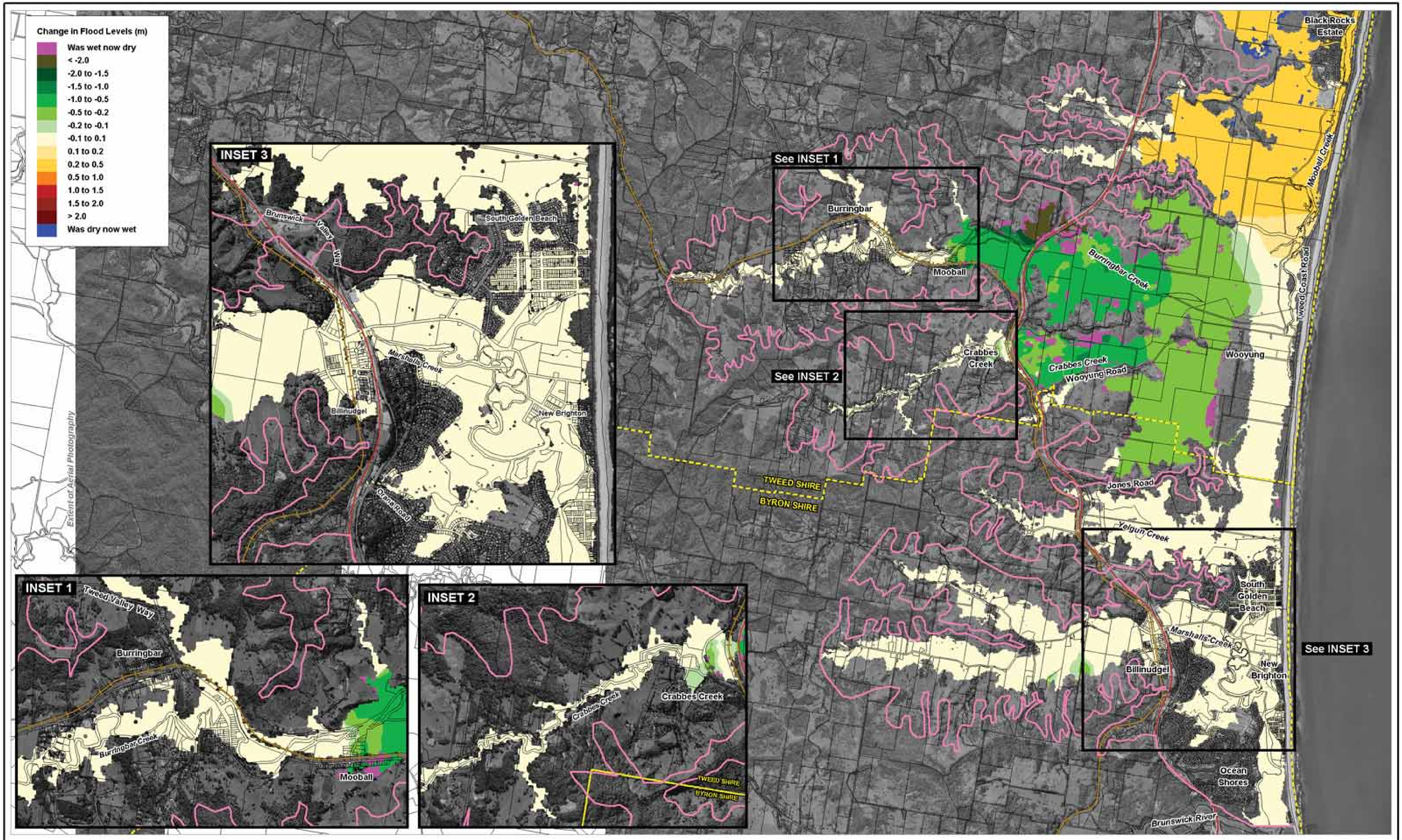

LEGEND

- Model Extent
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- Cadastral Boundaries

Title:
Change in 100 Year ARI Peak Flood Levels
Sugar Cane Fully Harvested (n=0.04)
Mooball/Marshalls Creeks Catchments

Figure: **8-2**

Rev: **B**

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9 IMPACT OF CLIMATE CHANGE

9.1 Climate Change Scenarios

The *Floodplain Development Manual* (FDM, 2005) recognises the need for analysis of the consequences of climate change on flood levels and behaviour. In the Coastal Creeks Flood Study, sensitivity of the results to increases in rainfall intensity and downstream water level conditions were assessed for the 100 year ARI design flood event.

Based on DECC (now DECCW) guidelines and recommendations outlined in *Floodplain Risk Management Guideline: Practical Consideration of Climate Change* (October 2007) and *Draft Sea Level Rise Policy Statement* (February 2009), two climate change scenarios were selected, as follows:

- **'Medium' impacts:** a 20% increase in rainfall intensity and a 55cm increase in sea level; and
- **'High' impacts:** a 30% increase in rainfall intensity and a 91cm increase in sea level.

It is noted that DECC guidelines are based on data from CSIRO and the Intergovernmental Panel on Climate Change (IPCC), which are both leading authorities in this field and provide comprehensive and up-to-date assessments of the current state of knowledge on climate change.

The selected increases were applied to the 100 year ARI design flood events (i.e. 3 storm durations x 2 rainfall/storm surge combinations)) as described in Table 9-1 below. Details of the tailwater levels assumptions are provided in Section 9.2. Figure 9-1 present the resulting tailwater hydrographs. As per the design runs, these hydrographs were applied uniformly across the study area, i.e. for Cudgen Creek, Cudgera Creek, Mooball Creek and Marshalls Creek downstream boundaries.

Table 9-1 Climate Change Scenarios

Design Event	Catchment Inflow Rainfall Event	Ocean Boundary Storm Surge Event	Ocean Boundary Peak Tailwater Levels (mAHD)	Ocean Boundary Total Peak Tailwater Levels (mAHD)
Medium Impacts 100 year ARI (envelope)	100 year ARI + 20%	20 year ARI + 0.55m	2.0 + 0.55	2.55
	10 year ARI + 20%	100 year ARI + 0.55m	2.2 + 0.55	2.75
High Impacts 100 year ARI (envelope)	100 year ARI + 30%	20 year ARI + 0.91m	2.0 + 0.91	2.91
	10 year ARI + 30%	100 year ARI + 0.91m	2.2 + 0.91	3.11

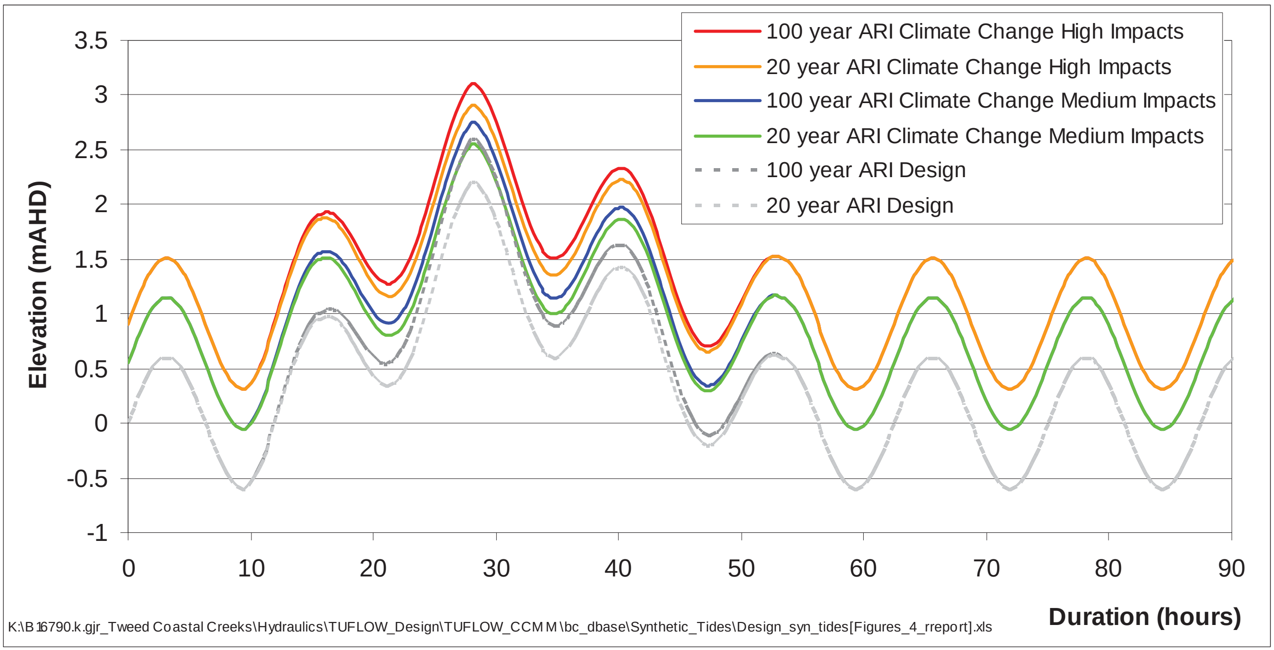


Figure 9-1 Downstream Ocean Boundary for Climate Change Scenarios – Cudgen/Cudgera Creeks

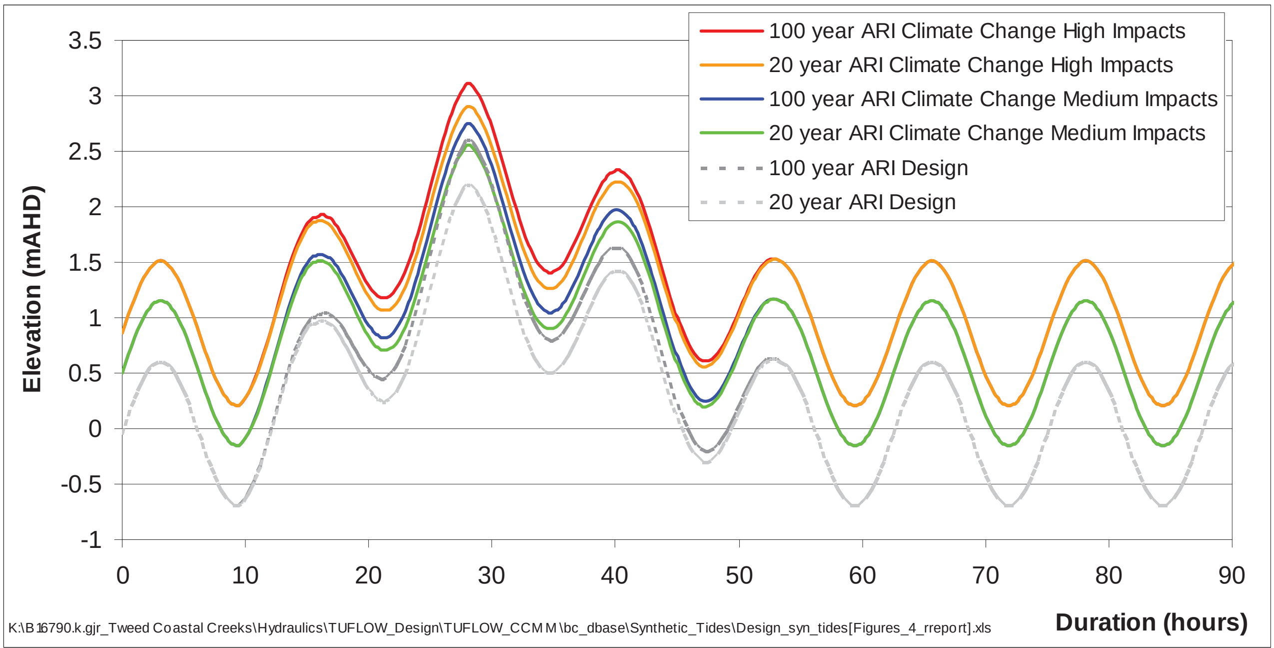


Figure 9-2 Downstream Ocean Boundary for Climate Change Scenarios – Mooball/Marshalls Creeks

9.2 Tailwater Levels Selection

As discussed previously (refer to Section 6.5), the downstream ocean levels specified in DIPNR (2004) and adopted for the design runs were based on coastal assessments undertaken some 20 years ago, and are typically considered conservative, even potentially taking into account some allowance for sea level rise due to climate change. In order not to duplicate the allowance for climate change impacts, a literature review of more recent estimates of ocean levels along the northern NSW coast was undertaken to inform the selection of tailwater levels for the climate change scenarios.

The following studies were reviewed for this purpose:

- Ballina Flood Assessments (Lawson and Treloar, 1994);
- Byron Coastline Hazard Study (WBM, 2000);
- Gold Coast Broadwater Study (CSIRO, 2000);
- Cobaki Lakes Ocean Water Level Study (Cardno, 2004); and
- Belongil Creek Impact of Climate Change on Tailwater Level (SMEC, 2007).

Each of these is briefly described below in the context of their use in the current flood study. Table 9-2 provides a summary of estimated tailwater levels.

Table 9-2 Tailwater Levels Review

Study Reviewed	Tailwater Level (m AHD)	
	20 year ARI	100 year ARI
DIPNR (2004)	2.2	2.6
Lawson and Treloar (1994)	1.8	1.9
WBM (2000)	n/a	1.95
CSIRO (2000)	n/a	2.05 ±0.15
Cardno (2004)	2.06	2.17
SMEC (2007)	1.92	2.15

Lawson and Treloar (1994) included a study of elevated ocean water levels (i.e. from cyclones and east-coast tropical lows) for the Richmond River entrance. This study considered the probability of elevated ocean water levels due to low pressure systems and wave forces. Extended investigations of that study in 1995 produced a set of water level hydrographs over the duration of a flood event for various probabilities of recurrence.

WBM (2000) aimed at identifying the coastal hazards relevant to Byron Shire. Although it defined hazards related to climate change and associated coastal inundation, its purpose was not to derive tailwater levels and, as such, the assessment wasn't based on a probability / recurrence interval approach. Estimations of elevated ocean water levels considered five main components (astronomical tide, inverted barometric setup, wind setup, wave setup and wave runup), and assumed a coincident high tide (Highest Astronomical Tide) and storm surge, which is considered conservative for the purpose of deriving a 100 year ARI tailwater level. Estimated ocean water level components were as follows:

- Tide (HAT) = 1.1m AHD;
- Barometric pressure setup = 0.33m at 980 hectoPascals;
- Wind setup = 0.2m; and
- Wave setup = 3% of offshore wave height for the Brunswick River; i.e. 0.32m for a 100 year ARI storm and wave conditions (this value was derived from MHL wave rider buoys datasets).

CSIRO (2000) focused on evaluating the likelihood of storm tide levels within the Broadwater of the Gold Coast using a deterministic modelling of coastal sea levels and statistical models of cyclone and east coast low occurrences. Storm tide levels were defined as the elevation of water from mean sea level resulting from the effects of tides, wind and waves (including wave setup). The 50 and 100 year ARI sea levels were quantified at the Seaway based on a broad range of combination of possible events (e.g. waves from an east coast low combining with a spring tide, or significant storm surge combining with a neap tide).

The Cobaki Lakes Flood Assessment (Cardno, 2004) was undertaken to investigate ocean levels suitable for modelling of the 100 year ARI Cobaki Creek and Tweed River Estuary flood. Both east coast low and cyclone records were considered, and the 20 year ARI ocean boundary level was estimated from the joint probability analysis of the recorded data. This study showed that the peak ocean water level for a 20 year ARI event is controlled by east coast low storms rather than cyclones. The levels estimated for the ocean boundary included astronomical tide and storm tide (i.e. inverse barometer effect, onshore wind setup and a shelf wave component).

SMEC (2007) investigated the impact of climate change on tailwater levels for Belongil Creek. Estimates of the 20 and 100 year ARI ocean levels were derived based on cyclone records analysis. Typical components of the ocean levels were derived as follows:

- Astronomical tide = 0.8m AHD;
- Barometric pressure setup = 0.6m at 950 hectoPascals;
- Wind setup = 0.3m; and
- Wave setup = 0.45m for an open entrance.

It is noted that both the Belongil Creek Study (SMEC, 2007) and the Broadwater Study (CSIRO, 2000) considered cyclones up to latitudes of 26 to 25.5 degrees. This lies some 250km north of the Coastal Creeks study area. Hence, tailwater levels and recurrence intervals estimated during those earlier studies should be considered carefully before being applied to the coast string between Tweeds Heads and Brunswick Heads.

Based on a review of these studies, the following median values were adopted for base design tailwater levels for the climate change assessment:

- 2.0m AHD in a 20 year ARI event; and
- 2.2m AHD in a 100 year ARI event.

It is noted that, although some consideration was given to entrance morphology in the different studies reviewed above, the selected approach for the current study does not directly take into account potential impact of river entrance conditions or bathymetry on wave setup and subsequently on tailwater levels. However, selected tailwater levels are still considered conservative estimates for the purpose of the climate change assessment.

9.3 Discussion of Results

Flood maps of the peak flood levels, depths and velocity x depth products are reported in the Flood Maps Addendum for both the medium and high impact climate change scenarios.

For each scenario, peak flood levels were also compared to the 100 year ARI peak design flood levels. These comparisons are shown in Figure 9-3 and Figure 9-4 for the medium impacts scenario, and Figure 9-5 and Figure 9-6 for the high impacts scenario. As discussed previously, the comparison of these climate change scenarios with the 100 year ARI design flood is not straight forward as the design floods were based on a conservative 2.6 m AHD ocean tailwater, which already takes into account some allowance for sea level rise. This should be noted when considering the comparisons below.

In the medium impacts climate change scenario (i.e. 20% increase in rainfall and 0.55m sea level rise), increases in peak flood levels of up to 0.5m are predicted for most of the floodplains downstream of the Pacific Highway. Burringbar Creek, Reserve Creek and Clothiers Creek upstream of the Pacific Highway are also predicted to be impacted by an increase of up to 0.5m. Peak flood levels in the lower sections of the floodplains (i.e. Marshalls Creek downstream of New Brighton, Mooball Creek downstream of the Tweed Coast Road Bridge in Pottsville, Cudgera Creek downstream of Seabreeze Estate, and Cudgen Creek downstream of the Tweed Coast Road Bridge) are predicted to increase to a lesser extent, by up to 0.2m.

In the high impacts climate change scenario (i.e. 30% increase in rainfall and 0.91m sea level rise), peak flood levels are predicted to increase even more as follows:

- By up to 1.0m in the Marshalls Creek floodplain downstream of the Capricornia Canal junction;
- By up to 1.0m in the lower Mooball Creek floodplain downstream of Warwick Park Road; and
- By up to 1.0m upstream of hydraulic structures and/or constrictions including the Pacific Highway in Mooball, the Tweed Coast Road downstream of Cudgen Lake, and the Tweed Valley Way in Burringbar.

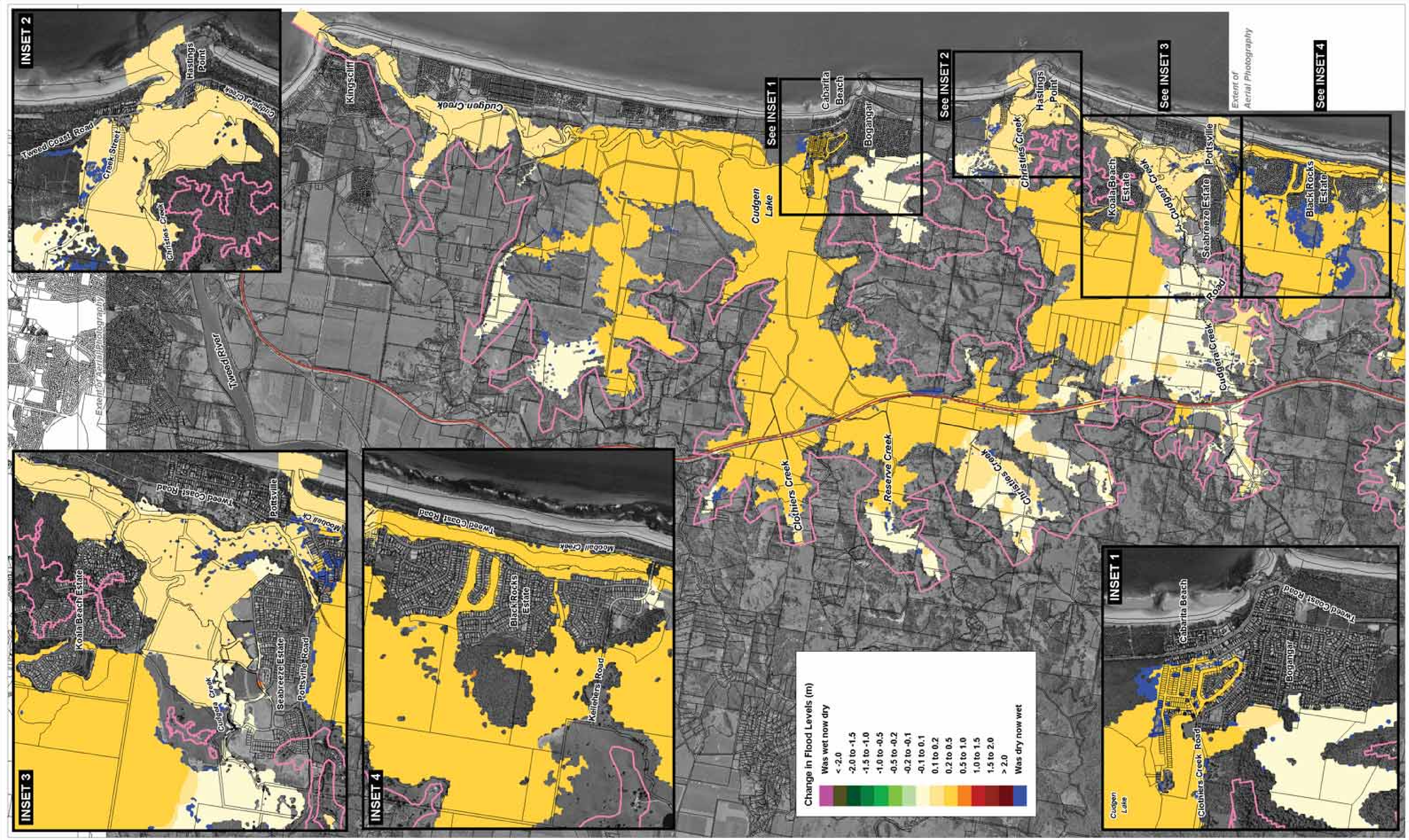
The predicted change in hazard (i.e. high flows or high depths or a combination of both) shown in the velocity x depth product flood maps is also of note. High hazard areas are not predicted to change significantly in extent in the high impacts scenario, except in Billinudgel upstream of the railway line and along Marshalls Creek downstream of New Brighton. However, a number of areas are predicted to change from low to medium hazard, in particular:

- Most of the land between Sharra Boulevard and New Brighton Road in Billinudgel;
- The junction of the Burringbar Creek and Crabbes Creek floodplains;
- The floodplain on the left bank of Mooball Creek downstream of Wooyung; and

- The main flow path downstream of Reserve Creek into Cudgen Lake.

Similarly, the general inundation extent is predicted to increase for the climate change scenarios, with the following areas now inundated in the high impacts scenario:

- Both sides of Balemo Drive in Billinudgel;
- Between the railway line and the Pacific Highway at Billinudgel;
- The north east end of South Golden Beach
- Along Upper Burringbar Road ;
- Along the canal in Black Rock Estate; and
- The southern side of Pottsville Road in Pottsville.



LEGEND

Model Extent

Pacific Highway (approximate location)

Cadastral Boundaries

Title:
Change in 100 Year ARI Peak Flood Levels
Medium Impacts Climate Change
Cudgen/Cudgera Creeks Catchments

Figure: 9-3

Rev: C

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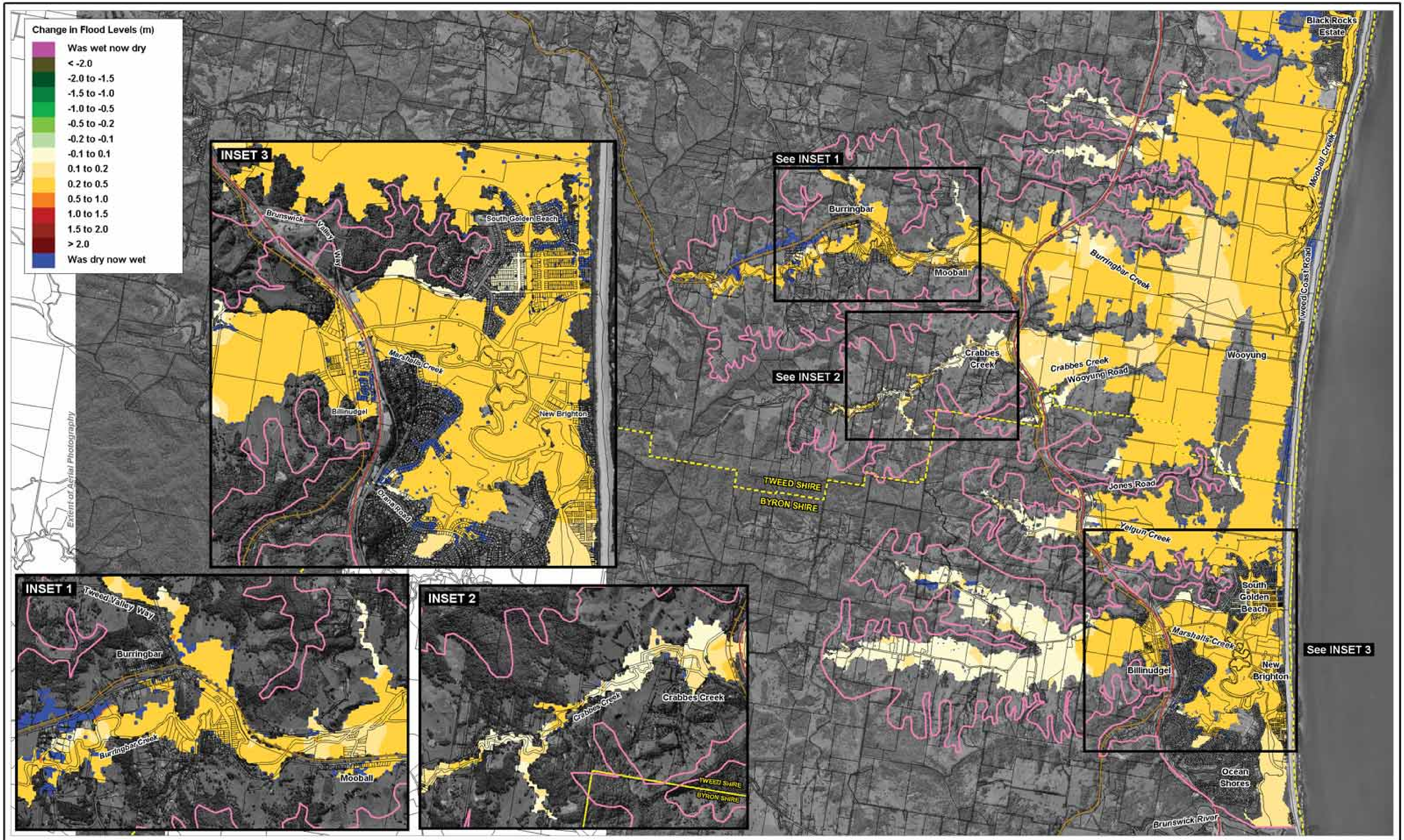

LEGEND

- Model Extent
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary
- Cadastral Boundaries

Title:
Change in 100 Year ARI Peak Flood Levels Medium Impacts Climate Change Mooball/Marshalls Creeks Catchments

Figure: 9-4

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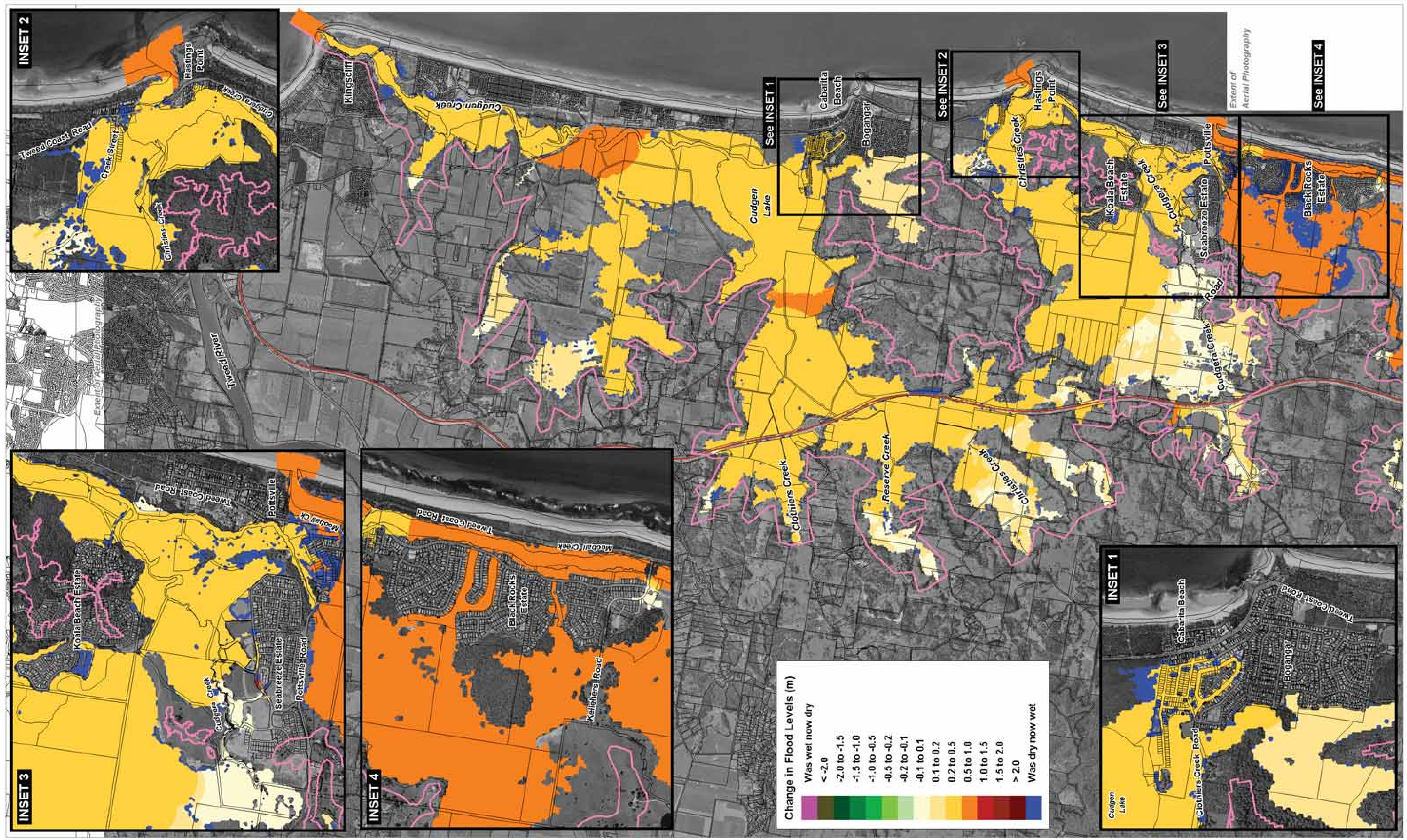

LEGEND

Model Extent

Pacific Highway (approximate location)

Cadastral Boundaries

Title:
Change in 100 Year ARI Peak Flood Levels
High Impacts Climate Change
Cudgen/Cudgera Creeks Catchments

Figure: 9-5

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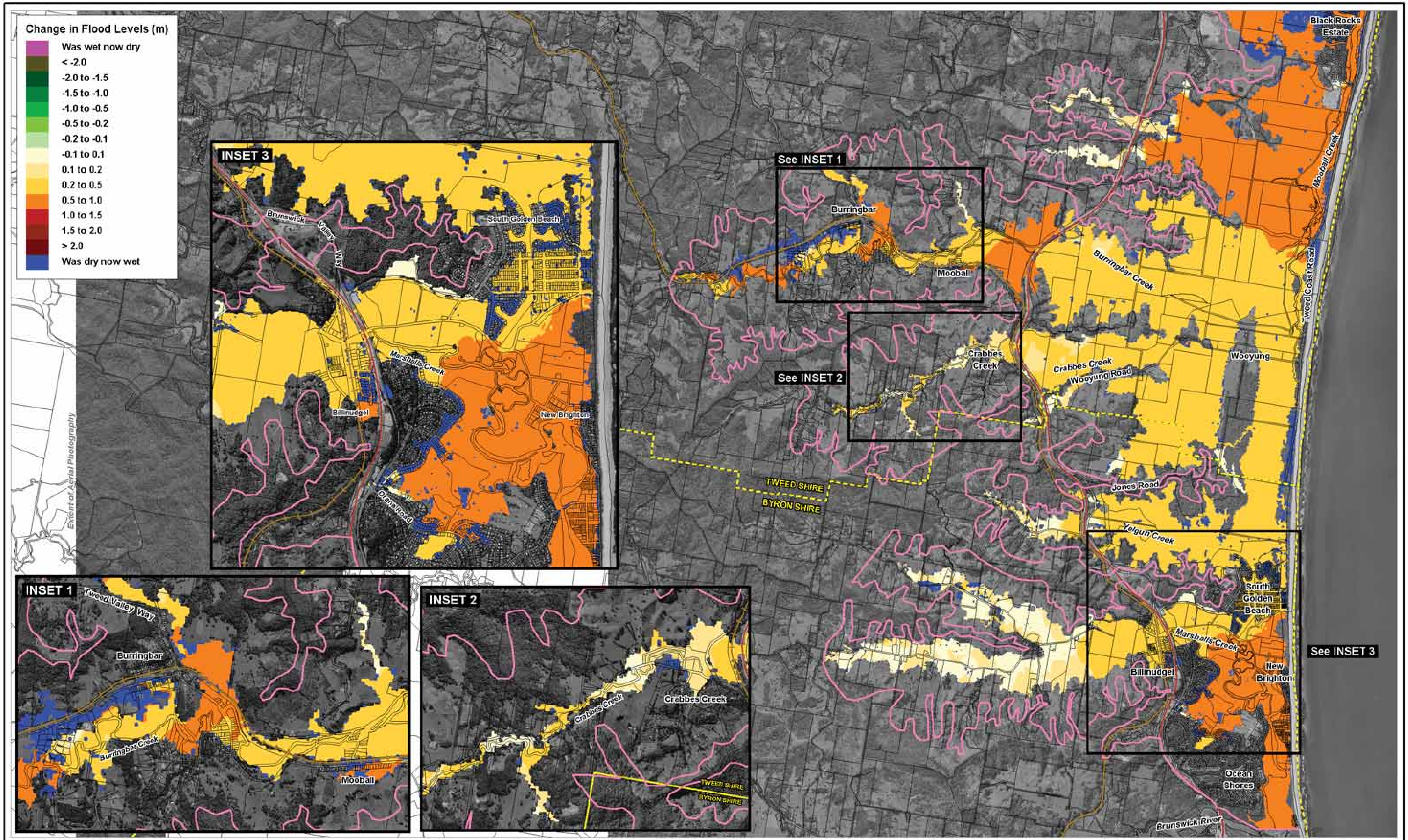

LEGEND

Model Extent

Pacific Highway (approximate location)

Casino Murwillumbah Railway (approximate location)

Tweed/Byron Shire Boundary

Cadastral Boundaries

Title:
Change in 100 Year ARI Peak Flood Levels
High Impacts Climate Change
Mooball/Marshalls Creeks Catchments

Figure: **9-6**

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10 CONCLUSION

This Flood Study defines the existing flooding behaviour for the Tweed/Byron Coastal Creeks area and it is the first stage of the overall floodplain risk management process. The computer models developed and the results determined as part of this Flood Study will form the basis of investigations and advice provided within the next stage of the process, the Floodplain Risk Management Study.

Following approval of this Flood Study the following actions are recommended:

- Update Flood Planning Levels based on the results of this Flood Study, as well as Local Environmental Plans and Development Control Plans as appropriate;
- Update Councils GIS systems with the flood mapping outputs from this Flood Study;
- Update S149 certificates for properties affected by flooding;
- Proceed to the preparation of the Floodplain Risk Management Study, to determine options to manage and/or reduce the flood risk taking into consideration social, ecological and economic factors.
- Byron Shire Council should also consider the interactions between Marshalls Creek and the Brunswick River prior to undertaking the Floodplain Risk Management Study for this area. The results of the Coastal Creeks Flood Study do not take into account coincident Brunswick River and Marshalls Creek flooding and storm surge propagation.
- It is noted that the Floodplain Risk Management Study can be undertaken separately by each Council for their respective area. However, both Councils should ensure that management and mitigation options do not adversely impact on flood behaviour elsewhere where floodplains are connected.
- On completion of the Floodplain Risk Management Study, preferred options recommended by each Council will be presented in a Floodplain Risk Management Plan publicly exhibited for subsequent implementation by Council.

11 REFERENCES

AustROADS (1994) *Waterway Design - A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*, AustROADS, Sydney, 1994.

Cardno (2004) *Cobaki Lakes Flood Assessment Ocean Water Level Study*, prepared for LEDA Design & Construction (Qld) Pty Ltd, Report J8469/R2159, Cardno Lawson Treloar Pty Ltd, November 2004.

CSIRO (2000) *Gold Coast Broadwater Study - Storm Tide Return Periods and 1974 Floodwater Modelling*, prepared for Gold Coast City Council, CSIRO Atmospheric Research, May 2000.

DIPNR (2004) *Floodplain Management Guidelines No.5 – Ocean Level Boundary*, New South Wales Government, Department of Infrastructure, Planning and Natural Resources, February 2004.

DECC (2007) *Floodplain Risk Management Guideline: Practical Consideration of Climate Change*, New South Wales Government, Department of Environment and Climate Change, October 2007.

DECC (2009) *Draft Sea Level Rise Policy Statement, New South Wales Government*, Department of Environment and Climate Change, February 2009.

FDM (2005) *Floodplain Development Manual*, New South Wales Government, Department of Infrastructure, Planning and Natural Resources, April 2005.

PWD (1988) *Cudgen Creek Flood Study*, Oceanics Australia, November 1988.

SMEC (2006) *Assessment of Flooding Behaviour in the Marshalls Creek Catchment*, SMEC Australia, February 2006.

SMEC (2007) *Belongil Creek Impact of Climate Change on Tailwater Level (Sea Level Rise) – Discussion Paper*, SMEC, July 2007.

Stelling, G.S. (1984) *On the Construction of Computational Methods for Shallow Water Flow Problems*. Rijkswaterstaat Communications, no. 35/1984, The Hague, The Netherlands.

Syme, W.J. (1991) *Dynamically Linked Two-Dimensional/One-Dimensional Hydrodynamic Modelling Program for Rivers, Estuaries and Coastal Waters,* William Syme, M.Eng.Sc (Research) Thesis, Dept of Civil Engineering, The University of Queensland, May 1991.

Syme, W.J., Nielsen, C.F., Charteris, A.B. (1998) *Comparison of Two-Dimensional Hydrodynamic Modelling Systems: Part One - Flow Through a Constriction,* Conference on Hydraulic in Civil Engineering, Adelaide, 1998.

Syme, W.J., Rogencamp, G.J., Nielsen, C.F. (1999) *Two-Dimensional Modelling of Floodplains - A Powerful Floodplain Management Tool,* NSW Flood Mitigation Conference, Tamworth, 1999.

WBM (1994) *Proposed Motorway – Billinudgel to Chinderah – Hydraulics and hydrology Working Paper*, WBM Oceanics Australia, February 1994.

WBM (1998) *Upgrade of the Pacific Highway between Yelgun and Chinderah*, WBM Oceanics Australia, July 1998.

WBM (2000) *Byron Shire Coastline Hazard Definition Study – Final Report*, WBM Oceanics Australia, November 2000.

WBM (2005a) *Tanglewood Flood Impact Assessment*, WBM Oceanics Australia, November 2005.

WBM (2005b) *Koala Beach and Seabreeze Estates Link Road Flood Impact Assessment*, WBM Oceanics Australia, August 2005.

WBM (2005c) *Cudgera Creek Road Upgrade - Hydrology/Hydraulics Working Paper,* WBM Oceanics Australia, 2005.

WBM (2006) *Cudgen Creek Bridge Upgrade: Flood and Tide Assessment*, WBM Oceanics Australia, July 2006.

APPENDIX A: SITE VISIT PHOTOGRAPHS


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Site Visit Photographs Location Map

Figure: **Appendix A**

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