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Tweed Byron Coastal Creeks Flood Study

Byron Shire Council Climate Change Assessment

Final Report

March 2010

Tweed Byron Coastal Creeks Flood Study

Byron Shire Council Climate Change Assessment Final Report

Prepared For:	Byron Shire Council
Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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GLOSSARY

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).
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 beofre 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”.
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 form 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.
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
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
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
PW (or PWD)	NSW Public Works (or Public Works Department) (now Department of Public Works and Services)
TSC	Tweed Shire Council

1 INTRODUCTION

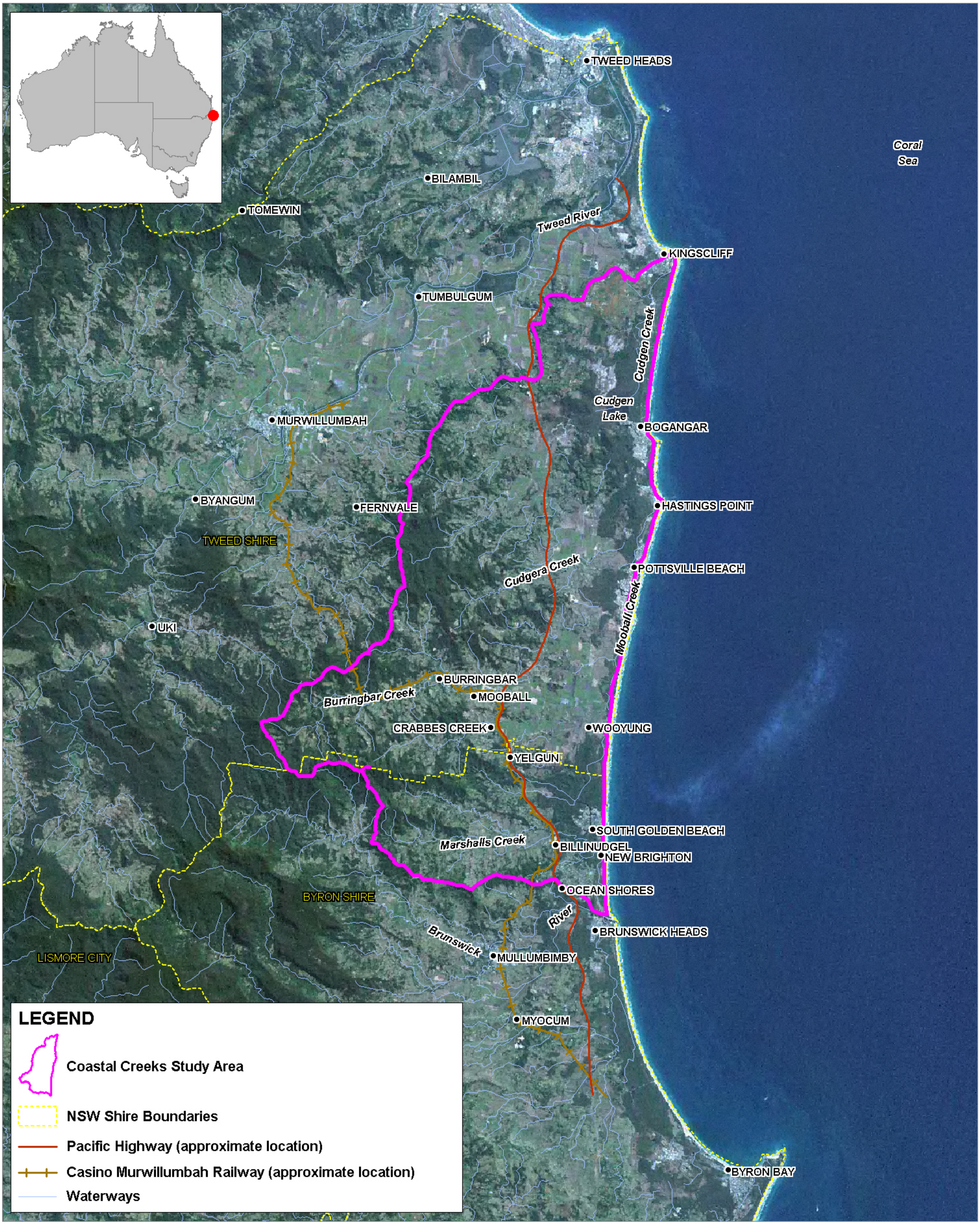
The coastal creeks of northern New South Wales between Brunswick Heads and Tweed Heads have a long history of flooding, with a major flood event occurring recently in June 2005. Flood behaviour in this area is complex due to the multitude of creeks and hydraulic connections between major floodplains, 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. Figure 1-1 presents the location and extent of this flood study.

As part of the Coastal Creeks Flood Study a RAFTS-XP hydrologic and a TUFLOW 1D/2D hydrodynamic 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. The impacts of climate change on the 100 year ARI design flood levels and behaviour were also assessed as part of the Coastal Creeks 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).

BSC however have additional requirements in terms of climate change assessment beyond the above two scenarios, with two additional climate change scenarios as follows (as defined in the June 2009 *Draft 100 Year Climate Change Flood Planning Scenarios*):

- 2050: 10% increase in rainfall intensity and peak tailwater level of 2.89m AHD; and
- 2100: 30% increase in rainfall intensity and peak tailwater level of 3.49m AHD.

This report presents the outcomes of the assessment of these two additional climate change scenarios on the ‘base case’ 100 year ARI design flood behaviour (i.e. peak flood levels, depths and velocity x depth products) as presented in the Coastal Creeks Flood Study (BMT WBM, 2009).



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Locality Plan

Figure: 1-1

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2 OVERVIEW OF FLOOD MODEL DEVELOPMENT AND CALIBRATION

This section is an extract from the Coastal Creeks Flood Study Report (BMT WBM, 2009). Please refer to this document for a full description of the catchments, data collection process, model development, calibration and results.

2.1 Hydrology

2.1.1 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.

2.1.2 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.

2.1.3 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. Only the Mooball/Marshalls model is described in the following section. Please refer to BMT WBM (2009) for description of the Cudgen-Cudgera model.

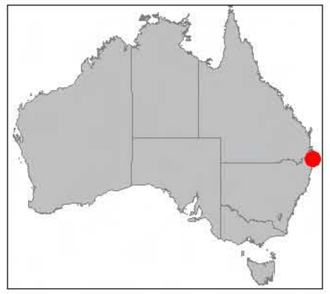
The existing Marshalls Creek RAFTS-XP model developed by SMEC (2006) was provided for use as part of this study. This model was combined with the Mooball Creek model to produce the final Mooball-Marshalls hydrological model. Note that the Marshalls Creek sub-catchment downstream of the Pacific Highway 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 2-1.

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:

Mooball-Marshalls Hydrological Model Layout

Figure: 2-1

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0 1.5 3km
Scale - Main Map

0 0.5 1km
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2.2 Hydraulic Modelling

2.2.1 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.

2.2.2 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.

2.2.3 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 the Mooball/Marshalls model are provided in the sections below. Refer to the Coastal Creeks Flood Study report (BMT WBM, 2009) for details of the Cudgen/Cudgera model. Main features of the models are also shown in Figure 2-3.

2.2.3.1 2D Domains

A total of 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.

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.

Each square grid element contains information on ground topography sampled from the DEM (developed based on Aerial Laser Survey data flow specifically for the purposes of the flood study), surface resistance to flow (Manning’s n roughness value – refer to Section 2.2.3.4) and initial water level.

Significant hydraulic controls, including the railway line, the Pacific Highway, the Tweed Coast Way, the Tweed Valley Way, Wooyung Road and the North Ocean Shore 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.

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

2.2.3.2 1D Networks

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

- 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.

These 1D networks represent the in-bank sections of the creeks, based on surveyed cross-section data available from DECC (now DECCW). 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 or natural drainage paths were also added in the 2D domains as 'gully lines' to ensure that the bed of the drains 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.

2.2.3.3 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.

2.2.3.4 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 Coastal Creeks Flood Study, BMT WBM 2009, 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 2-2 for the existing case hydraulic model.

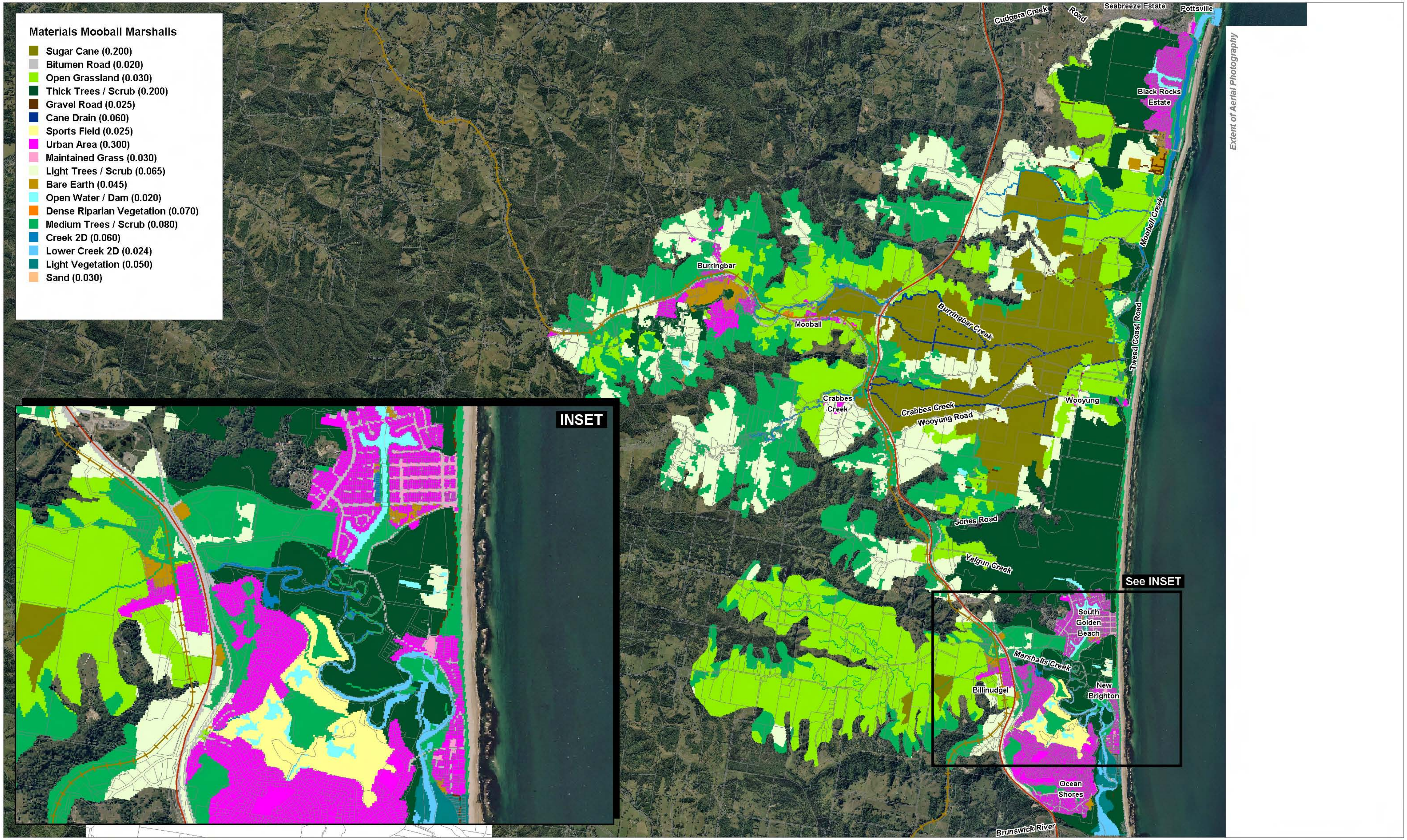
2.2.3.5 Cane Drains Representation

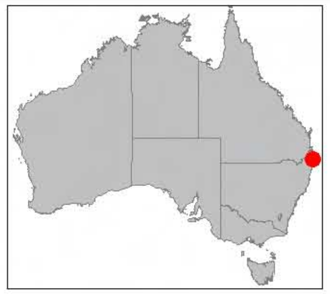
The representation of cane drains within the floodplain downstream of the Pacific Highway was one of the challenges of the study. These drains are typically relatively shallow, and don't represent significant floodplain storage in larger flood events. It is thus not appropriate to represent the cane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

2.3 Joint Model Calibration

The hydraulic and hydrologic models were calibrated to the June 2005 flood event, and subsequently validated against peak flood levels for the May 1987 and March 1974 flood events. Details of this calibration and validation process and results are reported in the Coastal Creeks Flood Study report (BMT WBM, 2009).





LEGEND

Pacific Highway (approximate location)

Casino Murwillumbah Railway (approximate location)

Cadastral Boundaries

Title:

Land Use Distribution
Mooball/Marshalls Creeks Model

Figure: 2-2

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Scale - Main Map

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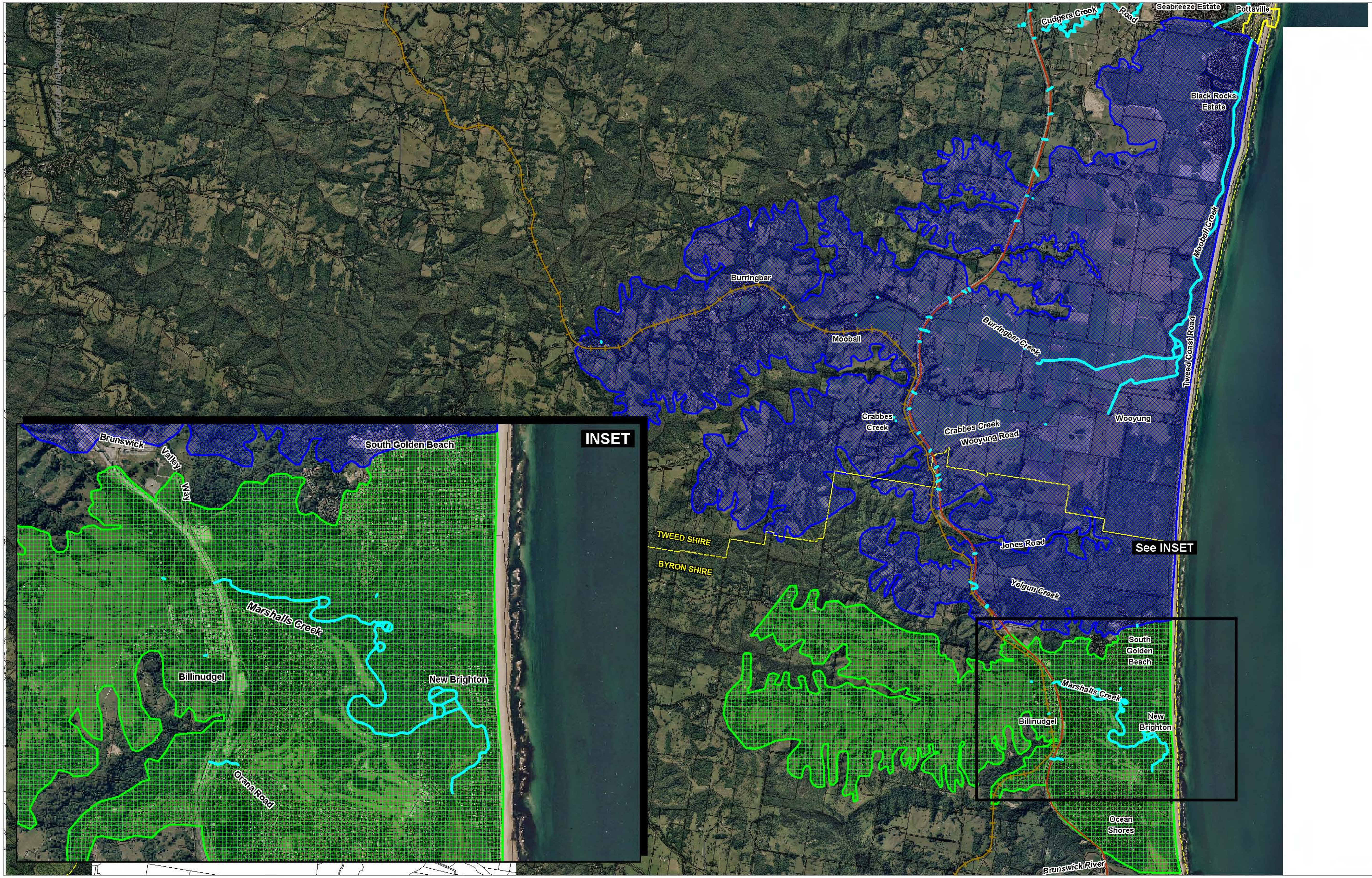

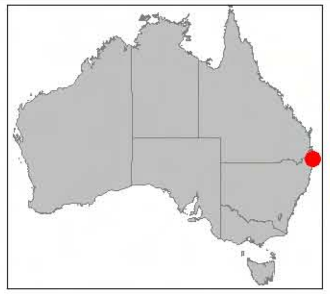

LEGEND

- 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

Figure: 2-3

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Scale - Main Map

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3 IMPACT OF CLIMATE CHANGE

3.1 Climate Change Scenarios

In addition to the climate change scenarios assessment undertaken as part of the Coastal Creeks Flood Study, BSC requested the assessment of two additional scenarios as per the June 2009 *Draft 100 Year Climate Change Flood Planning Scenarios*. The aim is to provide an assessment of the potential impacts of climate change on the 'base case' 100 year ARI design flood levels and behaviour, as defined in the Coastal Creeks Flood Study (BMT WBM, 2009).

The two additional climate change scenarios are as follows:

- **'2050':** a 10% increase in rainfall intensity, a 0.4m increase in sea level and a 0.2m increase in storm surge; and
- **'2100':** a 30% increase in rainfall intensity, a 0.9m increase in sea level and a 0.3m increase in storm surge.

These scenarios are considered to represent the latest scientific research on climate change, based on data collated by CSIRO and the Intergovernmental Panel on Climate Change (IPCC) who are both leading authorities in the field. The scenarios proposed in DECC's *Floodplain Risk Management Guideline: Practical Consideration of Climate Change* (2007) do not include the increase in storm surge, and so the above BSC scenarios are considered to be more conservative.

The proposed scenarios were applied to the 100 year ARI design flood events defined in the Coastal Creeks Flood Study, as described in Table 3-1 below. Figure 3-1 presents the resulting tailwater hydrographs. These hydrographs were applied uniformly across the study area at the TUFLOW model downstream boundaries. The downstream boundary hydrographs applied to the climate change scenarios in the Coastal Creeks Flood Study are also shown in Figure 3-1 for comparison.

Peak flood results for each 100 year ARI climate change scenario comprise an 'envelope' of three modelled storm durations for each flood event (i.e. 6, 24 and 36 hour) for both rainfall dominated and storm surge dominated flood events. 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 flood level for each climate change scenario. This is consistent with the approach to defining the 'base case' 100 year ARI design flood events in the Coastal Creeks Flood Study.

Table 3-1Climate Change Scenarios

Design Event	Catchment Inflow	Ocean Boundary	
	Rainfall Event	Storm Surge Event	Peak Tailwater Level
2050 100 year ARI (envelope)	100 year ARI + 10%	20 year ARI + 0.6m	2.60 mAHD
	10 year ARI + 10%	100 year ARI + 0.6m	2.89 mAHD
2100 100 year ARI (envelope)	100 year ARI + 30%	20 year ARI + 1.2m	3.20 mAHD
	10 year ARI + 30%	100 year ARI + 1.2m	3.49 mAHD

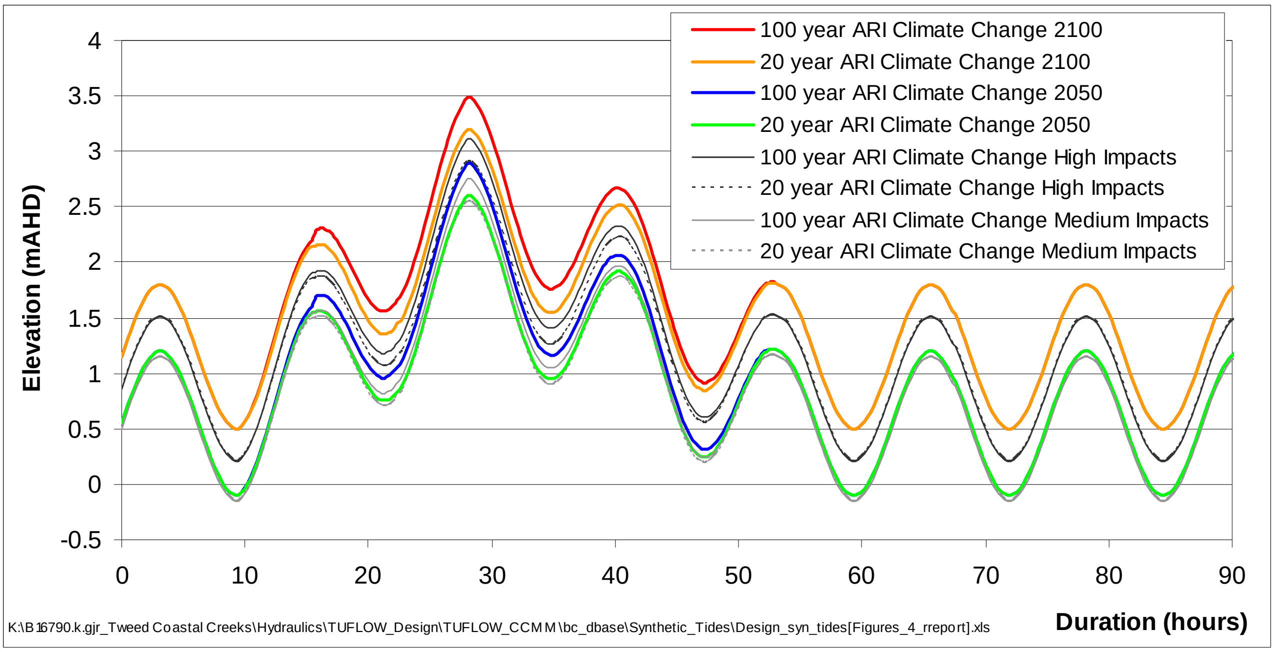


Figure 3-1 Downstream Ocean Boundary for Climate Change Scenarios

3.2 Discussion of Results

3.2.1 Results Presentation Approach

Flood maps of the peak flood levels, depths and velocity x depth products, as well as impact of climate change scenario on peak flood levels, are reported as per the following table.

Table 3-2 Flood Maps

Figure	Scenario
Figure 3-2	2050 Peak Flood Levels
Figure 3-3	2050 Peak Flood Depths
Figure 3-4	2050 Peak Velocity x Depth Product
Figure 3-5	2050 Impact on Peak Flood Level
Figure 3-6	2100 Peak Flood Levels
Figure 3-7	2100 Peak Flood Depths
Figure 3-8	2100 Peak Velocity x Depth Product
Figure 3-9	2100 Impact on Peak Flood Level

It is noted that these climate change scenarios are compared with the ‘base case’ 100 year ARI design flood, which already takes into account some allowance for sea level rise (based on a conservative 2.6 mAHD ocean tailwater, refer to the Coastal Creeks Flood Study for more details).

Peak flood levels were also extracted at a number of locations within the Marshalls Creek floodplain (see Figure 3-10 for locations). The 100 year ARI peak flood levels predicted by the TUFLOW model at these locations for the design flood, as well as all climate change scenarios are summarised in Table 3-3. A long section of Marshalls Creek is also presented in Figure 3-11, showing the 100 year peak flood levels for these same scenarios.

Table 3-3 100 year ARI Peak Flood Levels

Location	Label	100 Year ARI Design Peak Flood Level (mAHD)				
		Base Case	Medium Impacts	High Impacts	2050	2100
Marshalls Creek upstream of railway line at Billinudgel	1	4.10	4.33	4.48	4.22	4.50
Marshalls Creek upstream of Pacific Highway at Billinudgel	2	3.52	3.73	3.88	3.64	3.95
Yelgun Creek upstream of Kallaroo Circuit	3	3.11	3.42	3.60	3.27	3.63
Capricornia Canal at Berrimbilla Court	4	2.77	2.98	3.23	2.93	3.46
Capricornia Canal upstream of New Brighton Road	5	2.77	2.99	3.26	2.94	3.49
Capricornia Canal at confluence with Marshalls Creek	6	2.78	3.03	3.29	2.98	3.51
Marshalls Creek at New Brighton	7	2.55	2.86	3.17	2.88	3.49
Marshalls Creek downstream of Orana Bridge	8	2.53	2.74	3.11	2.85	3.47
Marshalls Creek at downstream end of model	9	2.60	2.75	3.11	2.89	3.49

3.2.2 2050 Climate Change Scenario

Peak flood levels predicted under the 2050 climate change scenario are generally 0.1m to 0.4m higher than the 100 year ARI design peak flood levels in the Marshalls Creek floodplain downstream of the Pacific Highway (see Figure 3-5), including:

- Approximately 0.3m higher in New Brighton;
- Approximately 0.2m higher in Capricornia Canal south of Kallaroo Circuit; and
- Approximately 0.1m higher in Billinudgel downstream of the Pacific Highway.

Compared to previous climate change assessments undertaken as part of the Coastal Creeks Flood Study, 100 year ARI peak flood levels predicted for the 2050 scenario are slightly lower than the Medium Impacts climate change scenario for all of the upper floodplain area down to around New Brighton. Downstream of New Brighton, however, the 2050 scenario is predicted to generate higher flood levels than the Medium Impacts scenario, by approximately 0.1m. This is consistent with the differences in the scenarios, as follows:

- 10% rainfall increase in the 2050 scenario compared with a 20% increase in the Medium Impacts scenario, i.e. less rainfall affecting flood levels in the upper catchment; and
- 2.89m AHD peak tailwater level in the 2050 scenario (for the storm surge dominated event), 0.29m higher than the Medium Impacts peak tailwater level, hence generally higher levels predicted in the lower floodplain.

In terms of flood hazard (see velocity x depth product maps), the 2050 climate change scenario is relatively similar to the 100 year ARI design flood event. Most areas remain in the same hazard category, with only a slight increase in the extent of the medium hazard category. High hazard areas are confined to Marshalls Creek, Capricornia Canal and the main drains in the floodplain upstream of the Pacific Highway.

3.2.3 2100 Climate Change Scenario

Peak flood levels predicted under the 2100 climate change scenario are generally 0.3m to 0.6m higher than 2050 peak flood levels, and generally 0.5m to 1m higher than the 100 year ARI design peak flood levels in the Marshalls Creek floodplain downstream of the Pacific Highway (see Figure 3-9), including:

- Approximately 0.9m higher in New Brighton;
- Approximately 0.8m higher in Capricornia Canal south of Kallaroo Circuit; and
- Approximately 0.5m higher in Billinudgel downstream of the Pacific Highway.

Compared to previous climate change assessments undertaken as part of the Coastal Creeks Flood Study, 100 year ARI peak flood levels predicted for the 2100 scenario are generally higher than the High Impacts climate change scenario across the entire Marshalls Creek floodplain. This is consistent with the differences in the scenarios, as follows:

- Same increase in rainfall (30%) for both the 2100 and High Impacts scenarios; and
- 3.49m AHD peak tailwater level in the 2100 scenario (for the storm surge dominated event), 0.38m higher than the High Impacts peak tailwater level, hence generally higher levels predicted in the Marshalls Creek floodplain.

The predicted change in hazard (see velocity x depth product maps) is also of note. High hazard areas are not predicted to change significantly in extent in the 2100 scenario, except in Billinudgel upstream of the railway line and along Marshalls Creek downstream of New Brighton. However, some 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.

Similarly, the general inundation extent is predicted to increase for the 2100 climate change scenario, with the following areas now inundated:

- Both sides of Balemo Drive in Ocean Shores;
- Between the railway line and the Pacific Highway at Billinudgel; and
- The north east and south west of South Golden Beach.

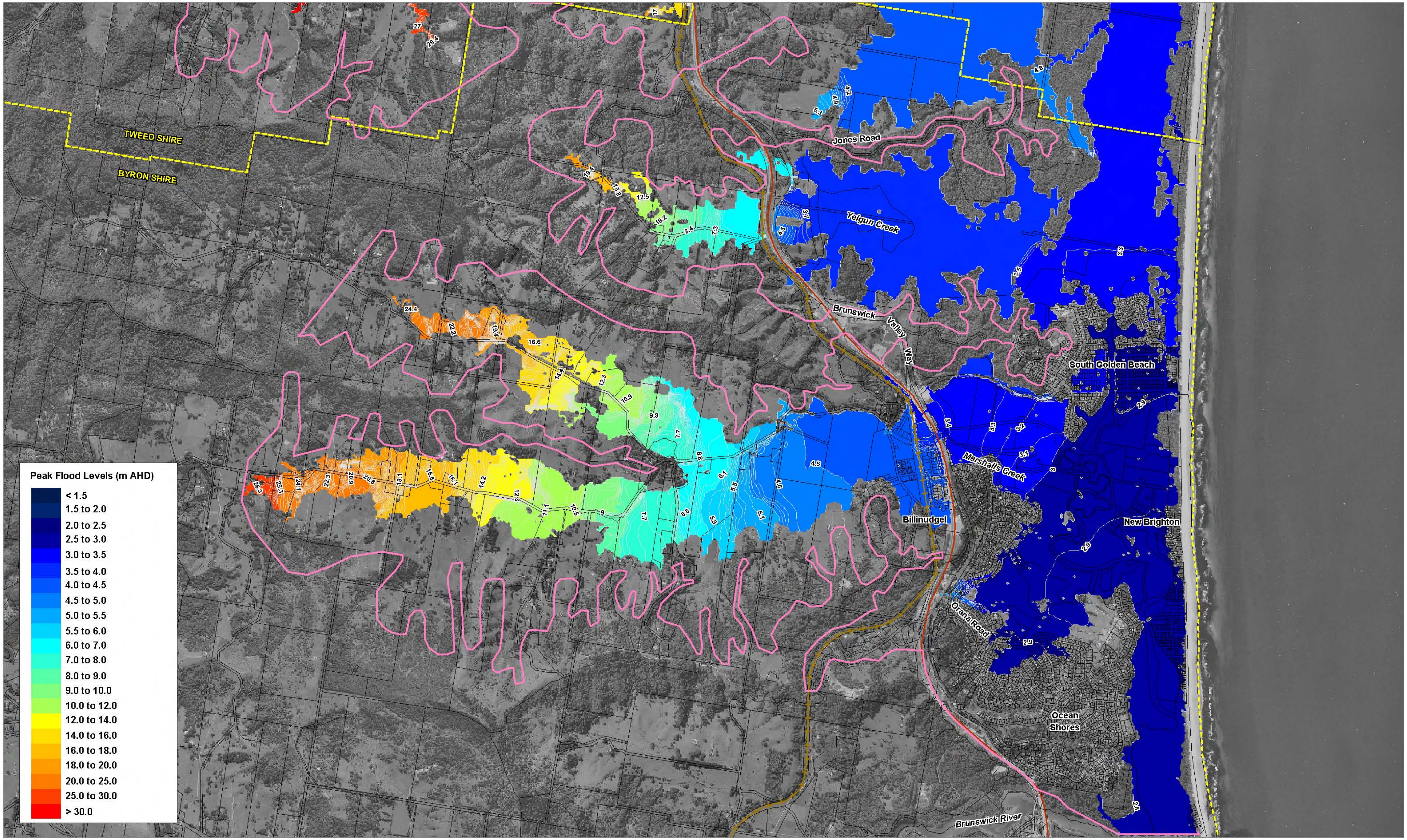
3.3 Conclusion

The additional climate change scenarios assessed for Byron Shire Council are predicted to increase the ‘base case’ 100 year ARI design peak flood levels by 0.1m to 0.9m depending on the scenario and location, with most major impacts downstream of the Pacific Highway. This is predominantly due to the high tailwater levels selected for these scenarios (i.e. up to 0.9m higher than the level adopted in the Coastal Creeks Flood Study). There are also some new areas of inundation and medium hazard in the 2100 scenario.

By comparison, the climate change scenarios assessed in the Coastal Creeks Flood Study are predicted to increase the ‘base case’ 100 year ARI design peak flood levels by 0.1m to 0.7m depending on the scenario and location. Upstream of the Pacific Highway, peak flood levels for the 2100 and High Impacts scenarios are similar. However, downstream of the highway, the 2100 scenario is predicted to increase 100 year ARI design peak flood levels by an additional 0.1m to 0.4m due to the higher tailwater assumption.

It is noted that the hydraulic model developed for the Tweed/Byron Coastal Creeks Flood Study and used in this BSC Climate Change Assessment does not take into account the lower Brunswick River, and in particular the outlet of Marshalls Creek. It is recommended that further investigation of the interactions between Marshalls Creek and the Brunswick River such as coincident Brunswick River and Marshalls Creek flooding and storm surge propagation (including climate change) be carried out to confirm flooding behaviour in the lower Marshalls Creek floodplain.

Following approval of the Tweed-Byron Coastal Creeks Flood Study and the Byron Shire Climate Change Assessment, Flood Planning Levels for the Marshalls Creek catchment should be updated. Byron Shire Council's resolution 09-704 recommended "adopting the 100 year ARI mapping for the 2100 Climate Change Scenario plus 0.5m as the new Flood Planning Level, subject to consultation", i.e. use peak flood levels presented in Figure 3-6 plus 0.5m.



LEGEND

- Model Extent
- Cadastral Boundaries
- Peak Flood Level Contours (m AHD) (0.1m interval for 1.0 to 6.0m AHD then 1.0m interval for 6.0 to 30.0m AHD)
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary

Title:

100 Year ARI Peak Flood Levels 2050 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-2

Rev: A

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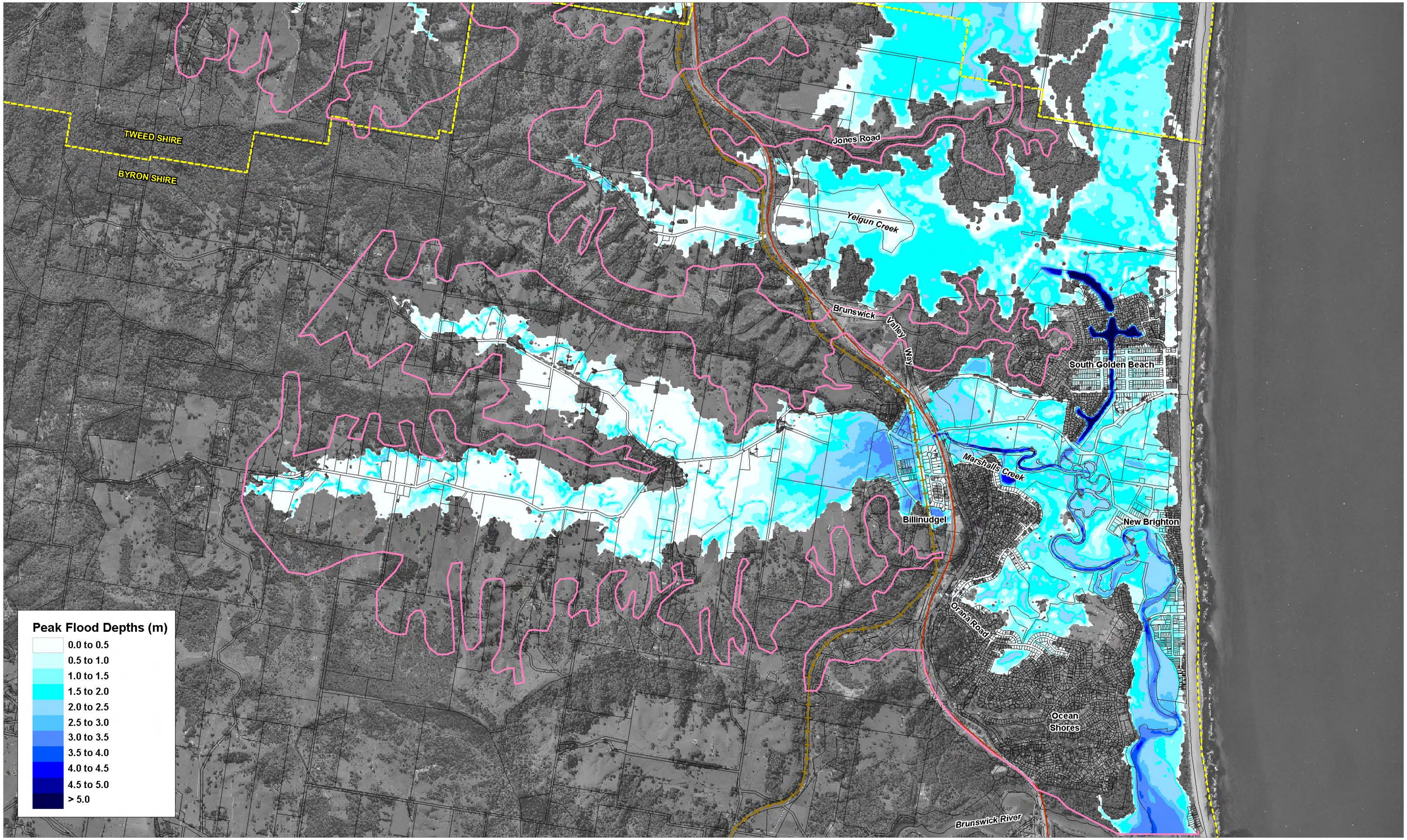

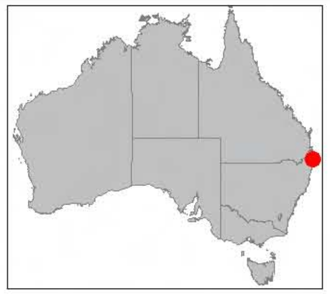

LEGEND

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

Title:

100 Year ARI Peak Flood Depths 2050 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-3

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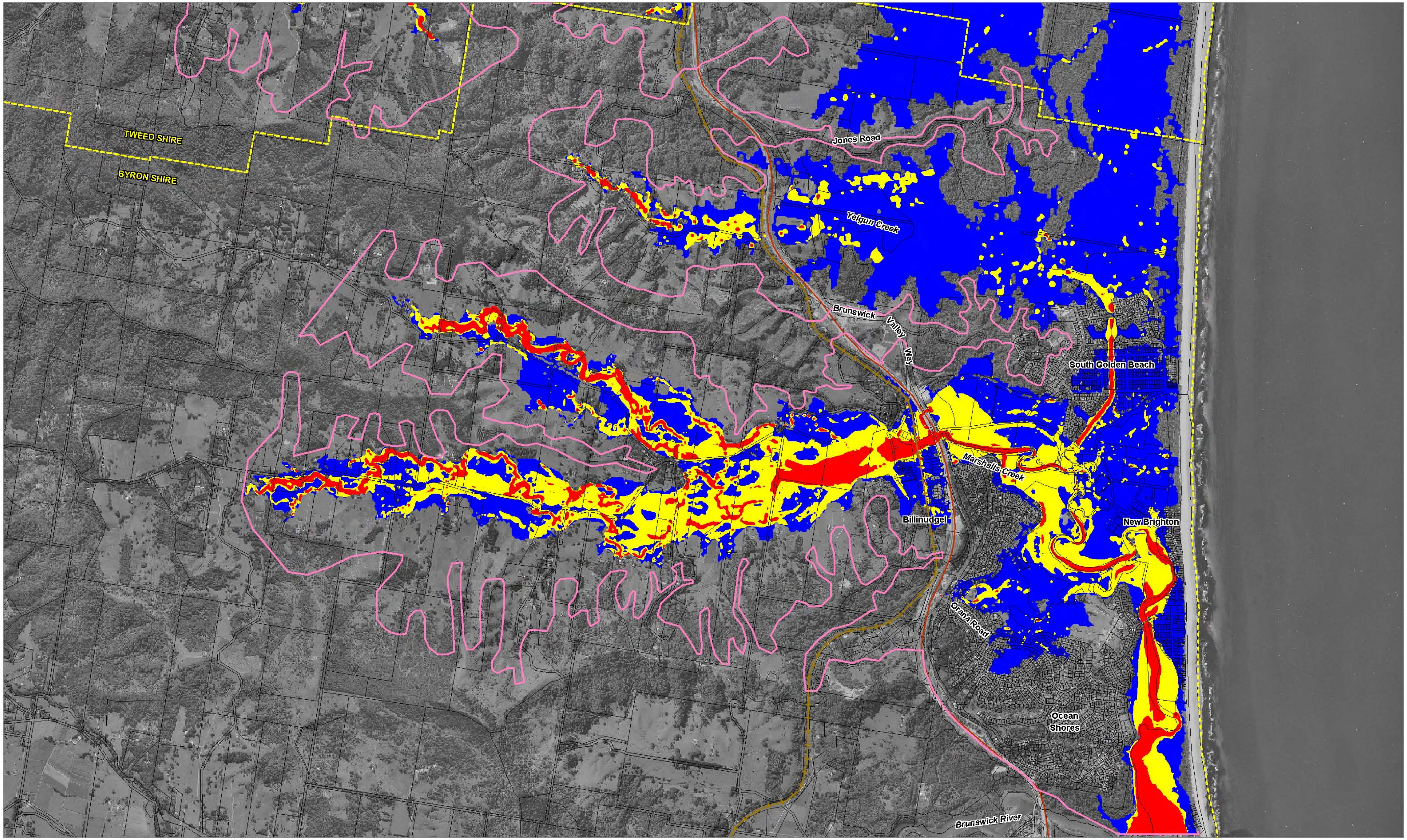

LEGEND

Model Extent

Cadastral Boundaries

Pacific Highway (approximate location)

Casino Murwillumbah Railway (approximate location)

Tweed/Byron Shire Boundary

Peak Flood Velocity x Depth (m²/s)

Low (< 0.3)

Medium (0.3 to 1.0)

High (> 1.0)

Title:

100 Year ARI Peak Flood Velocity x Depth Product
2050 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-4

Rev: A

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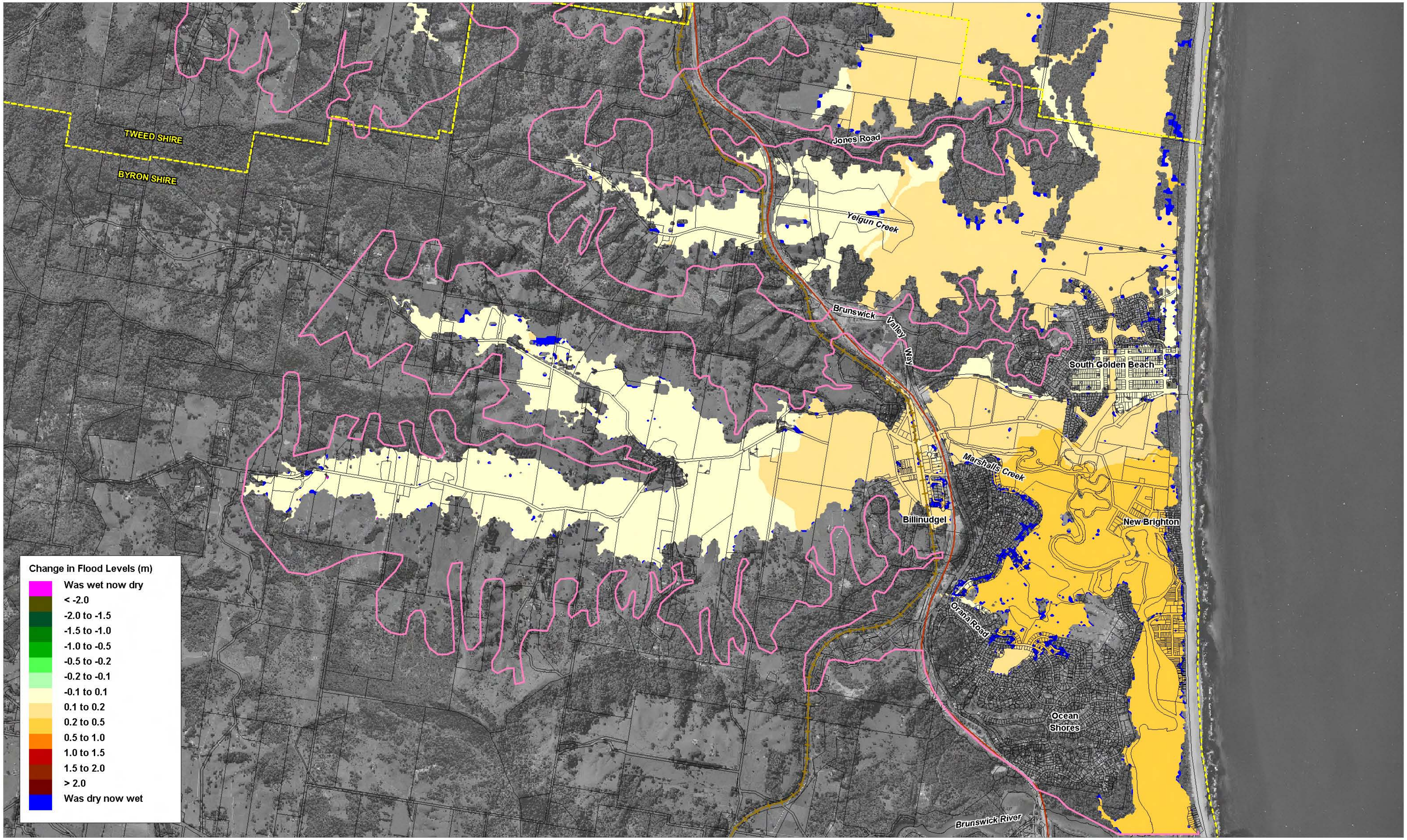

LEGEND

Model Extent

Cadastral Boundaries

Pacific Highway (approximate location)

Casino Murwillumbah Railway (approximate location)

Tweed/Byron Shire Boundary

Title:

Change in 100 Year ARI Peak Flood Levels
2050 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-5

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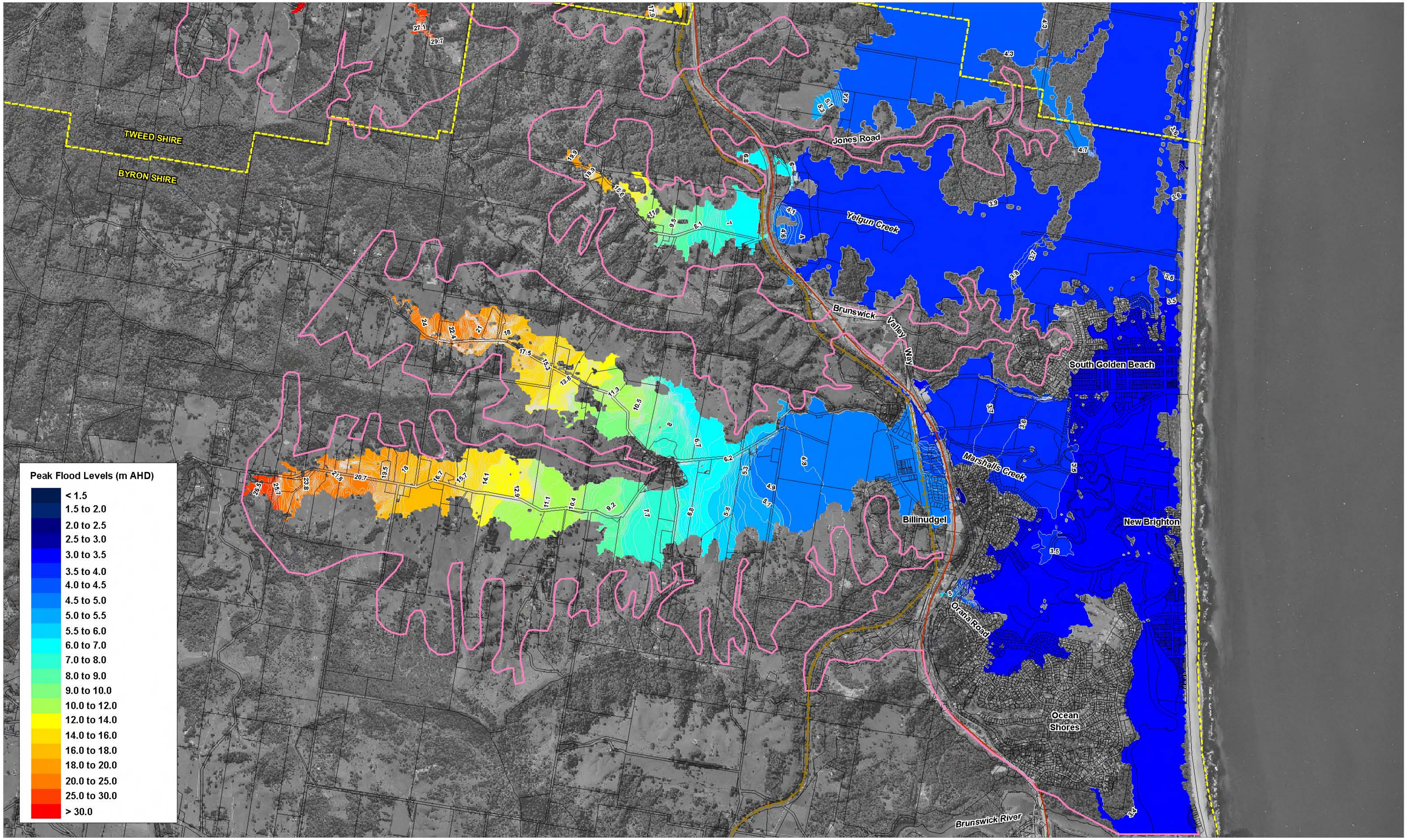

LEGEND

- Model Extent
- Cadastral Boundaries
- Peak Flood Level Contours (m AHD) (0.1m interval for 1.0 to 6.0m AHD then 1.0m interval for 6.0 to 30.0m AHD)
- Pacific Highway (approximate location)
- Casino Murwillumbah Railway (approximate location)
- Tweed/Byron Shire Boundary

Title:

100 Year ARI Peak Flood Levels 2100 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-6

Rev: A

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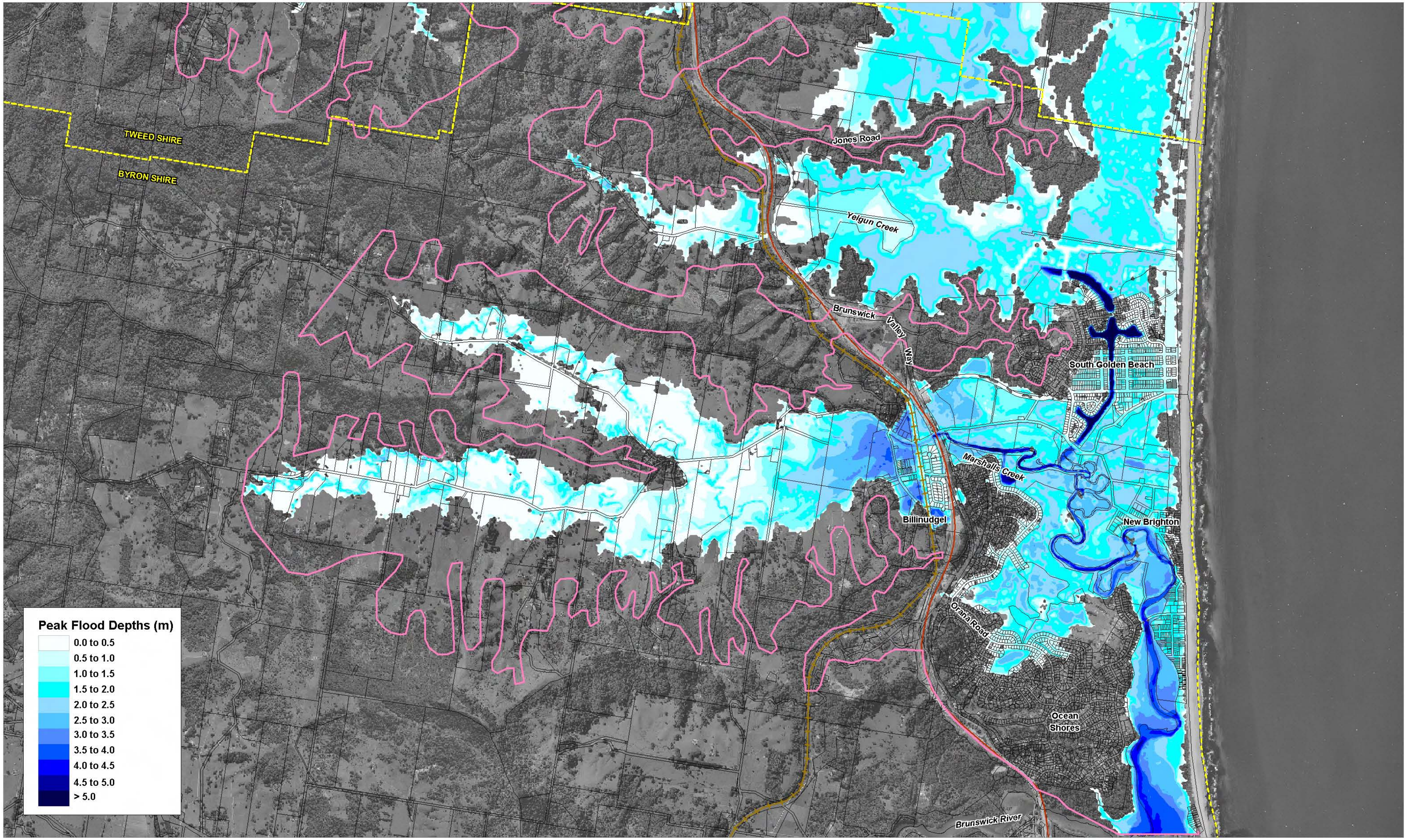

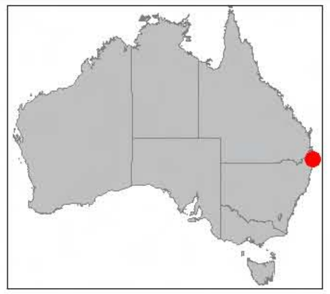

LEGEND

Model Extent

Cadastral Boundaries

Pacific Highway (approximate location)

Casino Murwillumbah Railway (approximate location)

Tweed/Byron Shire Boundary

Title:

100 Year ARI Peak Flood Depths 2100 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-7

Rev: A

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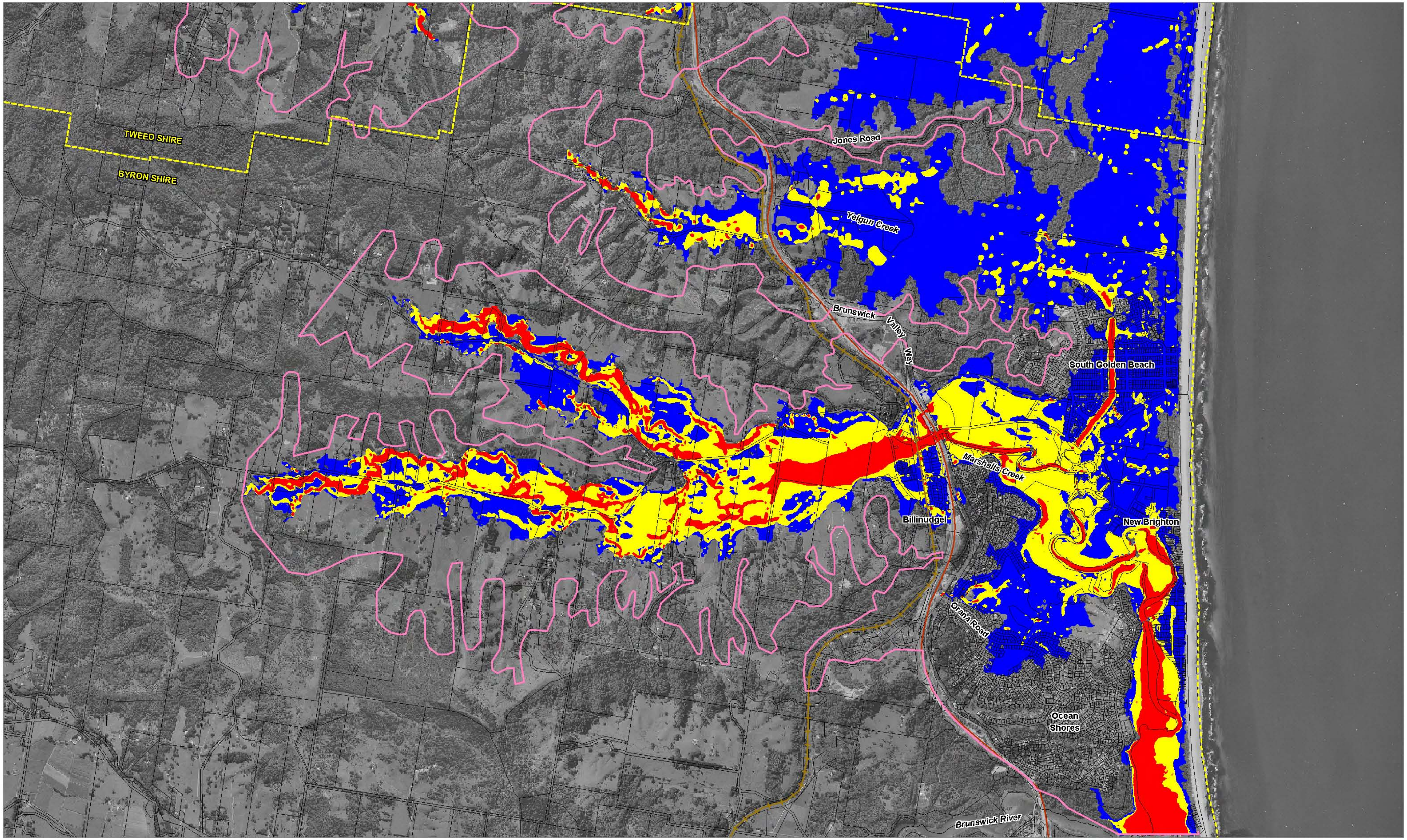

LEGEND

Model Extent

Cadastral Boundaries

Pacific Highway (approximate location)

Casino Murwillumbah Railway (approximate location)

Tweed/Byron Shire Boundary

Peak Flood Velocity x Depth (m^2/s)

- Low (< 0.3)
- Medium (0.3 to 1.0)
- High (> 1.0)

Title:

100 Year ARI Peak Flood Velocity x Depth Product
2100 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-8

Rev: A

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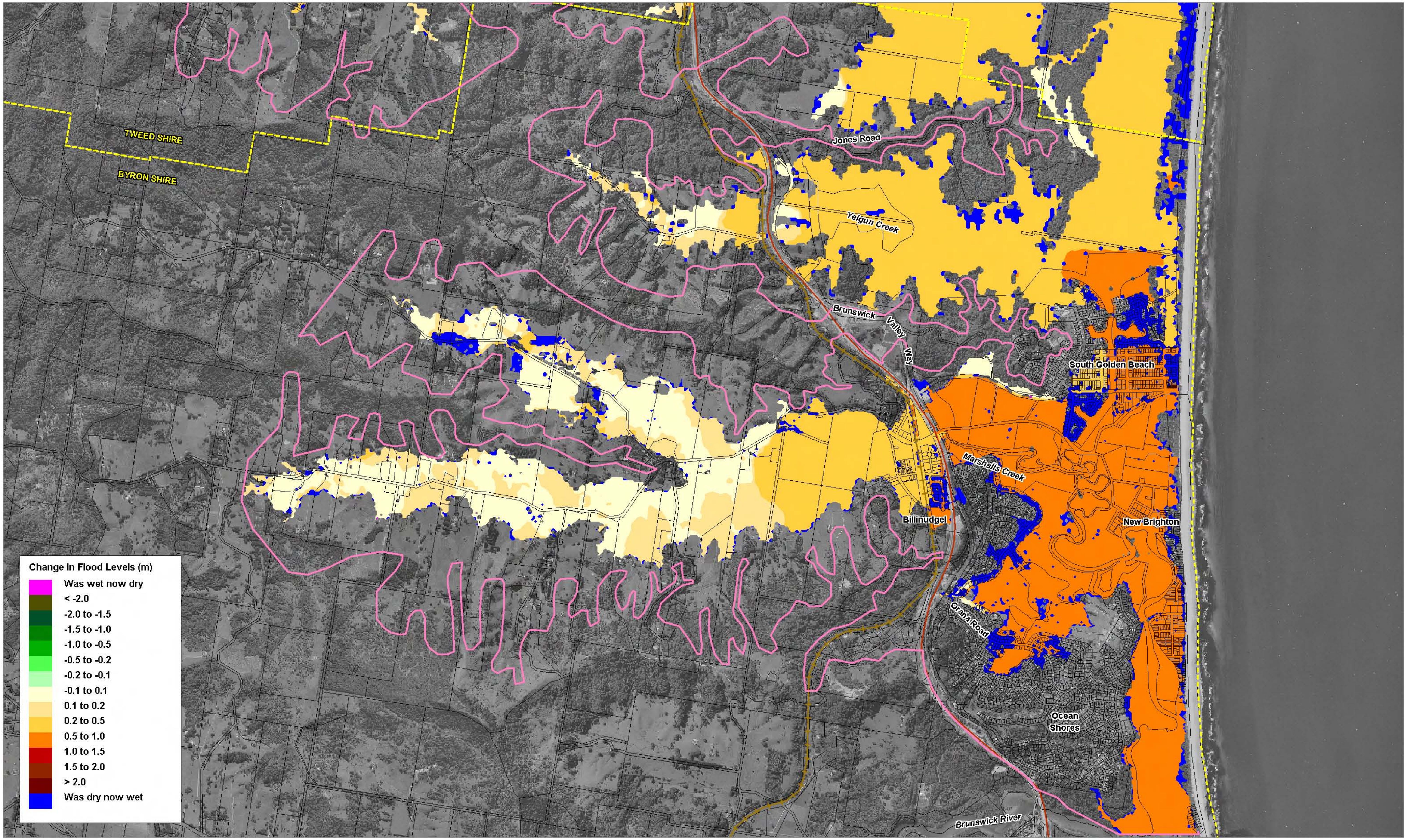

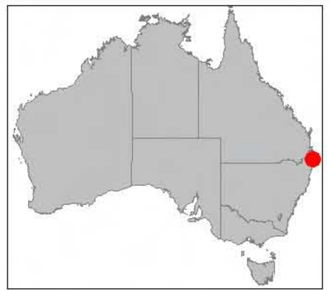

LEGEND

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

Title:

Change in 100 Year ARI Peak Flood Levels
2100 Climate Change Scenario
Marshalls Creek Catchment - Byron Shire

Figure: 3-9

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Scale - Main Map

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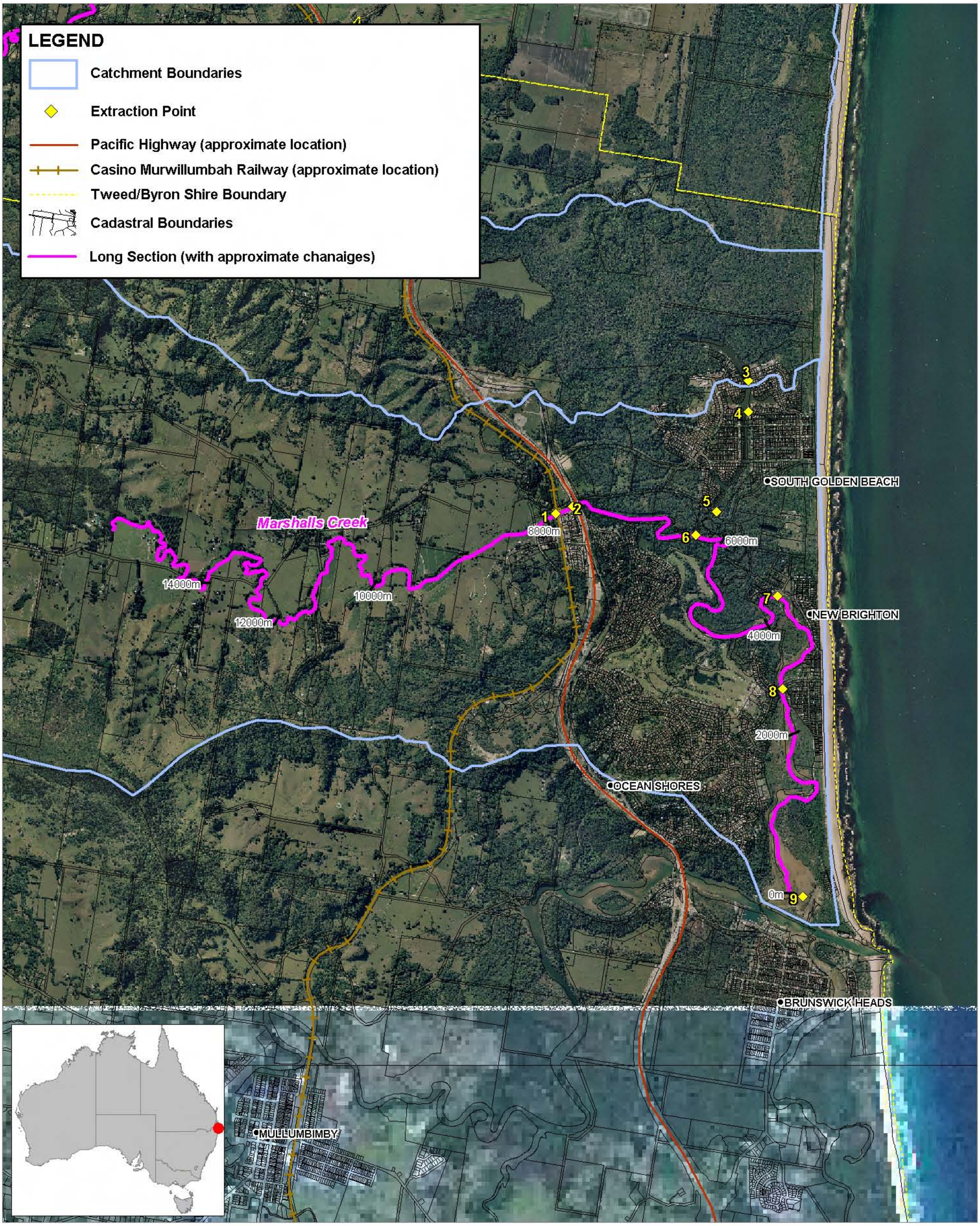

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Results Extraction Locations

Figure: 3-10

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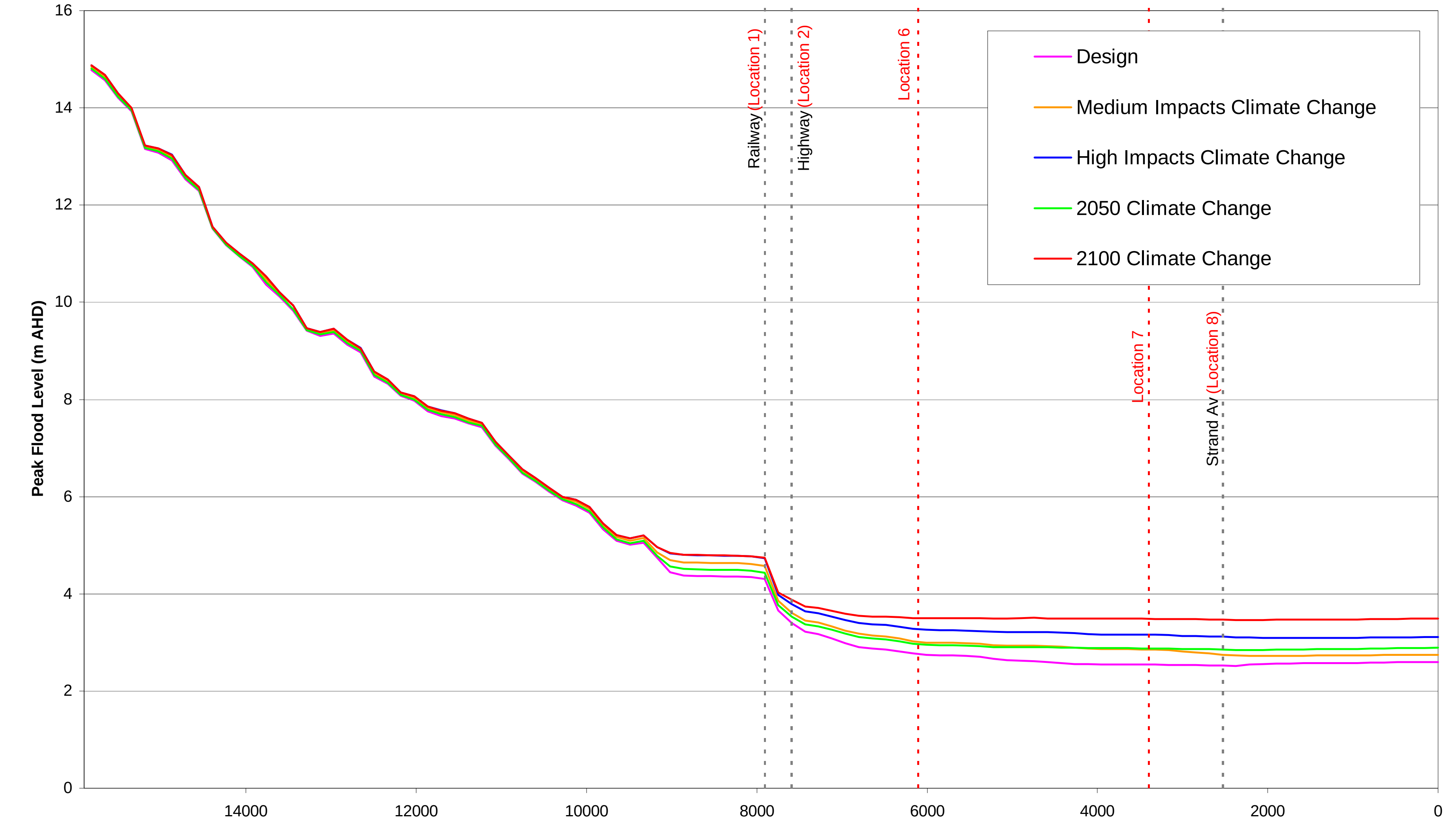

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Figure 3-11 100 Year ARI Peak Flood Levels Marshalls Creek Long Section

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