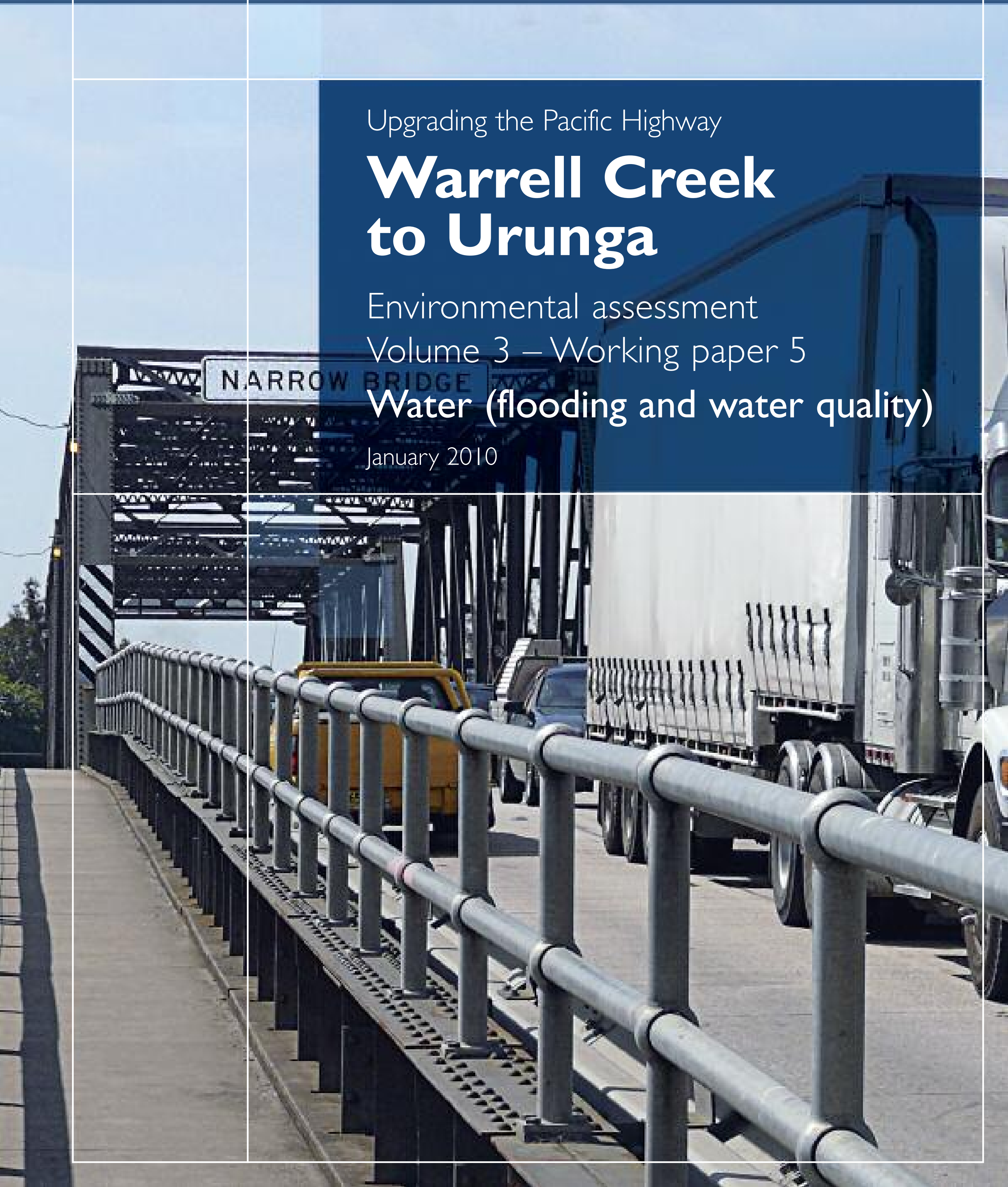
Upgrading the Pacific Highway

Warrell Creek to Urunga

Environmental assessment
Volume 3 – Working paper 5
Water (flooding and water quality)

January 2010



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WORKING PAPER NO 5 - FLOODING

Final Rev J

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Executive summary

Sinclair Knight Merz (SKM) has been commissioned by the New South Wales (NSW) Roads and Traffic Authority (RTA) to conduct an environmental assessment (EA) of the Proposal for the Pacific Highway upgrade between Warrell Creek and Urunga, which forms part of the RTA's Pacific Highway Upgrading (PHU) Program. The Proposal corridor is located in the Mid-North Coast region of NSW and extends for approximately 42 km from the northern end of the existing Allgomera deviation, south of Warrell Creek, to the existing Waterfall Way interchange at Raleigh.

Water, including flooding, is identified as a key issue in the Department of Planning (DoP) (now part of the Department of Planning and Local Government) Director-General's requirements. A detailed hydrological assessment of the Proposal was undertaken as part of the broader EA process and to assist with the concept design and is presented in this Working Paper.

The purpose of the flood modelling was to assess changes to the existing flooding regime, in accordance with the Floodplain Development Manual (DIPNR 2005) including impacts on existing property and infrastructure and the future development of affected land. Following receipt of the Director- General's Requirements for the EA, the RTA and the Department of Environment, Climate Change and Water (DECCW) agreed on the proposed assessment methodology and that the impacts of the Proposal for the 10, 100 and 2,000 year Average Recurrence Interval (ARI) flood events would be assessed for the five key waterways within the study area. From south to north these are:

- Upper Warrell Creek;
- Warrell Creek;
- Nambucca River;
- Deep Creek; and
- Kalang River.

The existing flooding regime for the Nambucca River is characterised by widespread flooding in the low lying areas of Macksville and surrounds, particularly in Gumma Swamp. Flooding of these areas occurs as a result of a lack of conveyance of the river, and flood water backing up into the low-lying Gumma Swamp.

The existing flooding regime of the Kalang River is characterised by a narrow floodplain in the upper reaches of the study area. The Kalang River splits into two arms which surround Newry Island, creating an extensive floodplain. The flow patterns across Newry Island are complex.

The Warrell Creek, Upper Warrell Creek and Deep Creek existing flooding regime was characterised by a well defined channel and confined floodplain in the study area. Once the existing flood regimes were defined, developed conditions hydraulic models were built to assess the potential impacts of the Proposal including the proposed road alignment and associated infrastructure.

A climate change sensitivity analysis was also undertaken to assess the potential changes to the flooding regime and potential impacts to the Proposal resulting from climate change. The sensitivity analysis for climate change was undertaken for two potential affects being; flooding with consideration of the expected rise in sea level and increased flooding from an expected increase in rainfall intensity and depth due to climate change.

The modelling exercise identified that development of the Proposal has potential impacts on the flooding regimes of the five major waterways being transversed. These potential impacts have been mitigated or minimised with the following measures:

- sensitive route selection;
- vertical and horizontal alignment of the Proposal; and
- design of floodplain structures.

With the mitigation measures in place the following flooding impacts are predicted for the five major waterways:

- Upper Warrell Creek – maximum increase in flood levels of 30 mm for the 100 year ARI flood event upstream of the Proposal, with no existing dwellings located within the area of increased flood levels;
- Warrell Creek – maximum increase in flood levels of 10 mm for the 100 year ARI flood event upstream of the Proposal, with no existing dwellings located within the area of increased flood levels;
- Nambucca River – less than 20 mm increase in flood levels for the 100 year ARI flood event upstream of the Proposal, with less than 20 mm increase in 100 year ARI flood levels at existing dwellings;
- Deep Creek – maximum increase in the flood levels of 10 mm for the 100 year ARI flood event upstream of the Proposal, with no existing dwellings located within the area of increased flood levels;
- Kalang River – 60 mm increase in flood levels for the 100 year ARI flood event upstream of the Proposal, with one dwelling affected with an increase in the 100 year ARI flood level of 50 mm.

For the Proposal, the RTA considers that an adaptive approach provides the most appropriate methodology for the management of the impact of future climate change on flood behaviour and the performance of the highway drainage structures. This approach would involve:

- Designing and constructing the Proposal to achieve the Proposal objective of providing flood immunity on at least one carriageway for a 1 in 100 year flood event.
- Monitoring the performance of the installed drainage structures.
- Periodic reviews of published rainfall and ocean level data and advices / guidelines issued by appropriate organisations.
- Determine, based on the above data, the actual and/or predicted performance of the highway drainage structures and compare this performance against the Proposal objective of providing flood immunity on at least one carriageway for a 1 in 100 year flood event.
- Identify any location(s) where the performance of the highway drainage structures does not satisfy the Proposal objective and identify and assess measures to manage these areas.
- Implement the adopted management measure.

Glossary

Term	Definition
Average Recurrence Interval (ARI)	The average or expected value of the period between exceedance of a given rainfall intensity or peak flow. ARI is another way of expressing the likelihood of occurrence of a flood event.
Balancing Structure	A structure that provides for the balancing of flood waters on the floodplain from one side of the infrastructure to the other. Required if a road transverses a floodplain or ponded area.
Catchment	The land area draining to a specific location.
Conveyance	The ability of a stream to pass flows.
Critical Storm Duration	The storm duration which results in the peak flow rate or peak flood level at a given location. Longer storms give the critical duration for larger catchments and vice versa.
DECC	NSW Department of Environment and Climate Change.
DECCW	NSW Department of Environment, Climate Change and Water.
Flood	The temporary inundation of land by water that has overtopped the natural or artificial banks of the watercourse.
Flood Frequency Analysis	A statistical analysis to determine the relationship between peak flow and the likelihood of the occurrence of the peak flow. This is undertaken based on recorded historical data.
Floodplain Structure	A structure that passes flow from minor watercourses in the floodplain such as a bridge or culvert.
Fraction Impervious	The part of the catchment which is impervious due to roof areas, roads and hardstand areas etc.
Freeboard	The difference in height between the calculated water surface level and the crest of the road. Provided for the purpose of ensuring a safety margin above the deign level and to allow for the affects of wind and waves.
Hydraulic	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
Hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
Hydrology (hydrologic)	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

Term	**Definition**
Impervious	A surface or area within the catchment where the majority of the rainfall becomes runoff eg roads, carparks and roofs etc. as the water is not able to infiltrate into the ground
k_c	Parameter used to characterise the catchment in the RORB hydrologic model. This parameter relates to the storage of water in catchment.
m	Parameter used to characterise the catchment in the RORB hydrologic model. This parameter relates to the travel time of water dependant on the flow.
Manning’s ‘n’	A parameter that relates to the surface roughness. Used in the Manning’s equation.
Peak Flow	The maximum flow rate during or following a rainfall event.
Pervious	A surface or area within a catchment where some of the rainfall will infiltrate, resulting in a reduced rate of runoff eg grassed areas, pasture, lawns etc.
Pluviograph	An instrument that automatically records the amount of rainfall as a function of time normally at sub-daily interval.
Probabilistic Rational Method	A simplified method of determining peak flow from a catchment.
Resistance	A measure of the roughness of the surface roughness.
RORB	RORB is a hydrologic modelling software package used to characterise the flows in a catchment. The RORB model uses rainfall patterns and depths as well as parameters to represent catchment characteristics to estimate catchment flow.
Sheet Flow	Runoff that flows over the ground as a shallow, even layer rather than concentrated in a channel.
Storm Duration	The period of which the design rainfall occurs in the catchment.

Contents

1. Introduction

Sinclair Knight Merz (SKM) has been commissioned by the NSW Roads and Traffic Authority (RTA) to conduct an environmental assessment (EA) of the Proposal for the Pacific Highway upgrade between Warrell Creek and Urunga, which forms part of the RTA's Pacific Highway Upgrading (PHU) Program. The Proposal corridor is located in the Mid-North Coast region of NSW and extends for approximately 42 km from the northern end of the existing Allgomera deviation, south of Warrell Creek, to the existing Waterfall Way interchange at Raleigh.

Water, including flooding, is identified as a key issue in the Department of Planning (DoP) Director-General's Requirements. A detailed hydrological assessment of the Proposal was undertaken as part of the broader environmental assessment process and to assist with the concept design and is presented in this working paper.

1.1. Objectives

The Director-General requirements for the Proposal specify that environmental assessment (EA) for the Proposal must include an assessment of the changes to the existing flooding regimes, in accordance with the Floodplain Development Manual including impacts to existing property and infrastructure and future development of affected land.

Following receipt of the Director General Requirements for the environmental assessment, the RTA and the Department of Environment and Climate Change (DECC) (now part of the Department of Environment, Climate Change and Water (DECCW) agreed on the proposed assessment methodology and that the impacts of the Proposal for the 10, 100 and 2,000 year Average Recurrence Interval (ARI) flood events would be assessed for the five key waterways within the study area. From south to north these are:

- Upper Warrell Creek;
- Warrell Creek;
- Nambucca River;
- Deep Creek; and
- Kalang River.

Hydrologic and hydraulic modelling of these waterways has been undertaken in consultation with the DECCW, Nambucca Shire Council and Bellingen Shire Council.

Modelling of the waterways in the study area has been undertaken previously and information from this was used as a reference in this assessment. These studies are outlined in **Section 2.1.1**.

The five waterways investigated for this report are of significant size and have complex flooding patterns, therefore assessment of impacts required the use of detailed flood modelling methods as discussed in **Section 2.2**. The information provided in this report has been used to inform the concept design and has also been used to determine the potential for impacts and to develop mitigation measures which have been included in Chapter 16 of the EA.

1.2. Investigation area

The Proposal is located in the mid-north coast region of NSW and extends for approximately 42 km from the northern end of the existing Allgomera deviation, south of Warrell Creek, to existing Waterfall Way interchange at Raleigh. The alignment traverses two key rivers, the Nambucca to the south and the Kalang at the north, both of which have broad systems with extensive floodplains. Warrell Creek, Upper Warrell Creek and Deep Creek are significant waterways with a well defined channel and confined floodplain. All of these waterways would be crossed by the Proposal.

The study area has been split into four sections as shown in **Figure 1-1**. These include:

- Section 1 – Allgomera Deviation to Nambucca River.
- Section 2 – Nambucca River to Nambucca Heads.
- Section 3 - Nambucca Heads to Ballards Road.
- Section 4 - Ballards Road to Waterfall Way interchange.

FIGURE 1-1 | THE PROPOSAL

Warrell Creek to Urunga - Upgrading the Pacific Highway

0 2 4 Kilometres

2. Description of existing environment

2.1. Existing environment flood modelling

2.1.1. Previous studies undertaken in the study area

Flood modelling was undertaken over all of the five major watercourses of the study area. Previous studies had been completed for both the Kalang River and the Nambucca River. These studies include:

- Lower Nambucca River Flood Study NSW Department of Public Works (February, 1994);
- Lower Nambucca River Floodplain Management Study, Resource Design and Management (1999);
- Bellingen Shire Floodplain Risk Management Study, Bellingen Shire Council (2001); and
- Lower Bellinger River Flood Study Department of Public Works, NSW (September 1991).

A thorough review of these studies was completed with the support of DECCW and it was concluded that new modelling should be developed for the concept design for which the environmental assessment is based. This decision was made on the basis that:

- the previous studies were aged and more recent technology was available to undertake the modelling;
- over 17 years had passed since the previous studies and a greater length of climatic data was available for the analysis; and
- new hydrologic modelling standards had been developed since the time of the previous studies.

2.1.2. Previous studies undertaken for the Proposal

There have been previous studies undertaken for the Proposal. In 2004, the route options assessment was undertaken to determine the preferred route. One of the major issues for the selection of the preferred route for the Proposal was the potential impact on the nature and extent of flooding.

Hydrologic and hydraulic modelling was undertaken for a number of different route options and a preliminary flooding assessment was undertaken. These results were incorporated into the overall Options assessment to determine the preferred route.

2.1.3. Studies undertaken for the environmental assessment

The model extents and layouts from the previous studies were used as a reference for the Proposal investigations, so that the results of the new modelling could be checked against to the previous modelling results. Where practical, the investigations for the Proposal adopted the modelling software package used for the previous studies for consistency. The following sections describe the existing conditions adopted in the flood modelling for each of the five major crossings of the Proposal as described in **Section 1.1**.

2.2. Modelling methods

The five waterways within the investigation area are of significant size and have complex flooding patterns. The impact assessment, therefore, required the use of detailed flood modelling methods.

There are two stages to the flooding assessment:-

- the hydrologic assessment that determines flood flows, and
- the hydraulic assessment that determines the flood levels under existing conditions, after the implementation of the Proposal, and under climate change conditions.

The hydrologic assessment involved converting rainfall to flows based on the catchment characteristics. Two hydrologic models, RAFTS and RORB, were used to determine the flows for the hydraulic assessment. These models were selected to be consistent with previous studies undertaken in the area.

The hydraulic assessment involved predicting flood levels based on the flows as determined in the hydrologic assessment. Three hydraulics models, MIKE21, MIKEFLOOD and HEC-RAS, were used to predict the flood levels. These models were selected as the most appropriate representation of flooding for the Proposal.

2.2.1. RAFTS – Hydrologic modelling

RAFTS is a hydrologic modelling software package used to characterise the flows in a catchment. The RAFTS model uses rainfall patterns and depths as well as physical catchment characteristics to estimate catchment flow. The catchment characteristics are described by parameters such as catchment area, average slope and resistance. Catchment response to rainfall can be described in the form of a loss model with initial and continuing rainfall losses.

The primary parameters to be defined in the RAFTS hydrologic model are:

- catchment slope;
- resistance; and
- fraction impervious.

2.2.2. RORB – Hydrologic modelling

RORB is a hydrologic modelling software package used to characterise the flows in a catchment. The RORB model uses rainfall patterns and depths as well as parameters to represent catchment characteristics to estimate catchment flow. The catchment characteristics are described by parameters such as catchment area, k_c and m. Catchment response to rainfall can be described in the form of a loss model with initial and continuing rainfall losses.

The primary parameters to be defined in the RORB hydrologic model are:

- k_c;
- m; and

- fraction impervious.

The parameter k_c expresses the speed of the catchment response to rainfall. The 'm' describes the degree of non-linearity of catchment response to rainfall.

2.2.3. MIKE21 – Hydraulic modelling

MIEK21 is a hydraulic modelling software package (version 2007) developed by the Danish Hydraulics Institute (DHI). MIKE is a two-dimensional model which is used to predict flooding including depth, flood level and velocity. The MIKE21 model represents the study area topography as a terrain grid, with the following parameters input to the model to define flow behaviour:

- design or historical inflow time series;
- tidal boundary conditions; and
- terrain resistance.

2.2.4. MIKEFLOOD – Hydraulic modelling

MIKEFLOOD is a hydraulic modelling software package developed by the Danish Hydraulics Institute (DHI) (version 2007). MIKEFLOOD links the two-dimensional hydraulic modelling package, MIKE21, to the one dimensional hydraulic modelling package MIKE11. This allows for detailed 1-D modelling of specific hydraulic structures inside a 2-D flood model of the river and floodplain.

2.2.5. HEC-RAS – Hydraulic modelling

HEC-RAS is a hydraulic modelling software package developed US Army Engineering Corp which is used to predict flooding including depth, flood level and velocity. The HEC-RAS model characterises the study area with a series of cross sections to represent the topography and design peak flows to define flow behaviour. The model is parameterised by hydraulic roughness as the primary parameter.

2.3. Nambucca River flood modelling

The Nambucca River is a large river with a catchment of approximately 1,000 km^2 upstream of the town of Macksville and the Proposal. Taylors Arm is a major tributary and joins the Nambucca River immediately upstream of Macksville. Macksville and the low-lying surrounds, have been identified as flood prone and have suffered flood damage with higher than desirable frequency.

Flood modelling was completed to the same extent as a previous study titled *Lower Nambucca River Flood Study* (DPW, 1994). This extent was selected to remain consistent with the modelling that Nambucca Shire Council used as the basis for its floodplain planning.

The focus of the modelling was the area of the proposed bridge crossing of the river and road crossing of the floodplain at the location of the Proposal.

The following sub-sections describe both the hydrologic and hydraulic modelling that was completed to describe the existing flooding regime of the Nambucca River.

2.3.1. Hydrologic modelling

A RAFTS hydrologic model (refer **Section 2.2.1**) for the Nambucca River catchment was used to characterise the flows in the Nambucca River. The RAFTS model from the previous study was used as the basis for this investigation and it was updated based on current information including available aerial photography and terrain information. **Figure 2-1** shows the catchment boundary and catchment delineation for the Nambucca River catchment.

2.3.2. Hydrologic model parameterisation

The Nambucca River catchment ranged in slope from very steep (40 %) in the upper catchment to relatively flat (1.4 %) in the lower catchment near the Proposal site and the coast. The slope data for the catchment was generated from the available contour information which had a resolution of 20 metres.

The catchment resistance was represented in the model as Manning's 'n' and was applied to the model based on the land use, determined from a site inspection and aerial photography. A Manning's 'n' of 0.1 was applied for the pervious areas of the catchment and 0.015 for impervious areas.

Impervious areas were specified for the towns in the catchment due to the presence of hard developed areas such as roads and roofs. This was determined from available aerial photography.

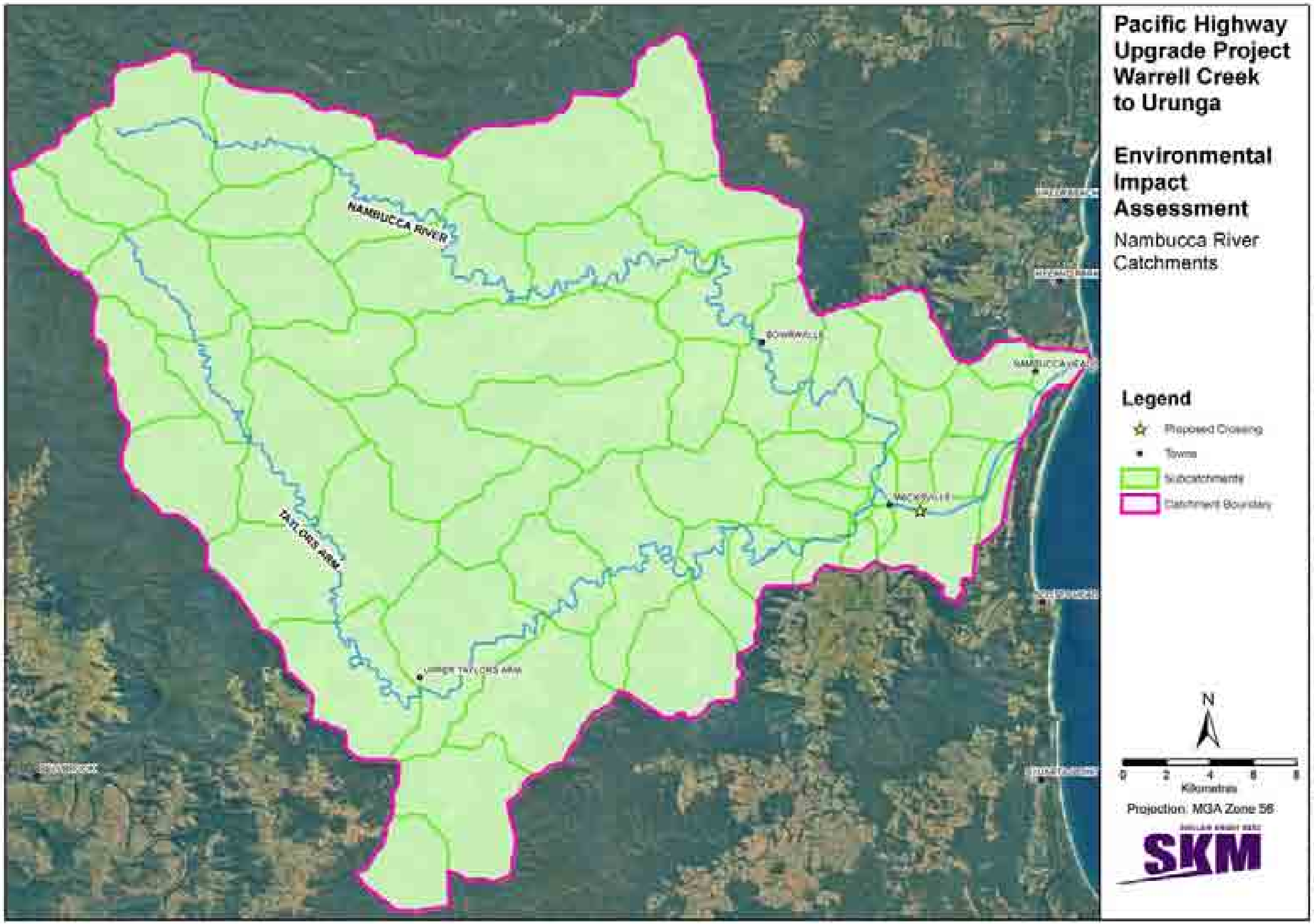
2.3.3. Hydrologic model calibration

Model calibration is normally sought to produce a model that can be used to estimate the flows in the design rainfall events.

Calibration of the hydrologic model to historical storm events was attempted on the basis of the Nambucca River streamflow gauge record at Bowraville (205006). This gauge had a period record from 1971 to 2005. However, there were no pluviograph rainfall gauges within the catchment and such gauging would add much quality to the calibration confidence. The closest pluviograph with a suitable data record was Bellbrook (59000) which was approximately 50 km from the catchment. The rainfall depth at the Bellbrook pluviograph for various rainfall events was compared to the daily rainfall depths for a number of rainfall gauges in the catchment of the Bowraville gauge. There was found to be a poor correlation between the Bellbrook rainfall gauge and the gauges within the catchment. Therefore, calibration to historic storm events was not able to be achieved.

In lieu of calibration to historic events, validation of the design flood hydrology was undertaken to a flood frequency analysis. The flood frequency analysis provides an estimate of the peak discharge expected for a range of flood events and also provides an estimate of the volume that would pass in the same range of events. Therefore, the hydrologic model can be established to mimic these results. This is considered to be good practice when historic calibration is not possible. It is a process that would be undertaken as part of a common calibration and validation process to ensure that the hydrologic model can replicate a full range of flood events.

■ **Figure 2-1 Nambucca River catchment**



2.3.4. Flood frequency analysis

A single site flood frequency analysis (FFA) was undertaken for the Nambucca River streamflow gauge at Bowraville (205006). The aim of the FFA was to estimate the flows of the design flood events based on the historical record from the stream flow gauge. The Bowraville gauge has a catchment of 430 km^2 and a period record from 1971 to 2005. This gauge had 34 years of record which gave confidence in the FFA up to 50 year ARI event. After the 50 year ARI event predicted by the FFA the confidence limits widen. The results of the FFA were validated up to the 50 year ARI event and the parameters were used to predict the 100 and 2,000 year ARI event.

The FFA was undertaken for the peak flow and flood volume. The results of the FFA are outlined in **Table 2-1**.

- **Table 2-1 FFA Nambucca River at Bowraville**

ARI (years)	Peak flow (m^3/s)	1 day volume (ML)	2 day volume (ML)	3 day volume ML)
10	1,264	69,700	107,800	129,100
100	2,163	113,500	174,500	240,300
2,000	3,087	152,100	231,100	379,000

2.3.5. Hydrologic design flood estimation

Design flood estimation was undertaken using the hydrologic model, incorporating design rainfall depths and rainfall patterns. The design rainfall depths and patterns were based on the *Australia Rainfall &Runoff Volume 2* (IEAust, 1987) zones. Australia has been divided into eight zones of varying rainfall depth and patterns based on recorded climatology. The Nambucca River catchment is within Zone 1. Design rainfall depths were spatially varied across the catchment to capture the variation in rainfall due to the catchment terrain in accordance with methods described in *Australia Rainfall &Runoff Volume 2* (IEAust, 1987).

The first estimation of design flood flows was undertaken using the design rainfall depths and rainfall patterns for Zone 1. This assessment found the predicted peak flow was significantly higher than the FFA predicted as well as producing an unrealistic critical storm duration. The comparison of the flow estimation from the design rainfall and the FFA lead to the conclusion that the hydrologic model would overestimate design flood flows if these rainfall patterns were adopted.

Based on further investigation and input from specialists hydrologist involved in the authorship of AR&R, it was determined that the rainfall patterns for Zone 1 are centred around Sydney and are known to be difficult to translate into the northern rivers of NSW. It was advised that it was more appropriate to use the rainfall patterns for Zone 3, which are centred in southern Queensland and borders Zone 1 at the Clarence River catchment.

The hydrologic model was rerun using the Zone 3 rainfall patterns and Zone 1 rainfall depths. The revised rainfall patterns produced a much better representation of the flood flow in the hydrologic modelling and was adopted for the Proposal.

The methodology, as described above, was reviewed by DECCW who were concurrently undertaking other studies in the region. DECCW were aware of the representation of local rainfall patterns by AR&R and accepted the methodology and suitable for the Proposal.

2.3.6. Validation to flood frequency analysis

The purpose of the flood frequency analysis (FFA) validation was to determine hydrologic model parameters of catchment storage and the initial and continuing losses. The hydrologic model was run for a number of storm durations to validate to the FFA and to determine the critical storm duration.

The parameters adopted for the design flood estimation are outlined in **Table 2-2**.

▪ **Table 2-2 Design flood estimation parameters Nambucca River**

ARI (Years)	Initial loss (mm)	Continuing loss (mm/h)	Catchment storage (Bx)
10	30	3	5.1
100	30	3	5.1
2,000	30	3	5.1

Table 2-3 presents the design peak flow and volume at Bowraville and the validation to the FFA.

▪ **Table 2-3 Design peak flows at Bowraville**

ARI (Years)	Design – Hydrologic model			FFA	
	Peak flow (m^3/s)	Storm duration (h)	2 Day volume (ML)	Peak flow (m^3/s)	2 Day volume (ML)
10	1,083	36	96,950	1,264	107,800
100	2,260	36	190,200	2,163	174,500
2,000	4,395	36	341,200	3,087	231,100

The results of the hydrologic model predicted peak flows 4 % greater than those estimated in the FFA for the 100 year ARI event. This was considered appropriate for the purpose of the concept design and is within the limits of confidence in the modelling.

The design peak flow and critical storm duration, as predicted by the hydrologic model, at the Proposal site are presented in **Table 2-4**.

- **Table 2-4 Design peak flows at the Proposal site**

ARI (Years)	Peak flows (m^3/s)	Storm duration (h)
10	2,230	36
100	4,873	36
2,000	9,440	36

2.3.7. Summary of hydrologic model findings

The hydrologic modelling was completed for use in the hydraulic modelling. The key findings from the hydrologic modelling were:

- the RAFTS hydrologic model was developed for the Nambucca River catchment based on the previous study catchment delineation and updated slope, resistance and fraction impervious parameters;
- hydrologic model calibration as not possible due to a lack of pluviograph rainfall gauges in the catchment;
- a flood frequency analysis was undertaken for the Nambucca River streamflow gauge at Bowraville;
- the hydrologic model was validated to the FFA to develop the design flow estimates; and
- the methodology and results of the hydrologic modelling was reviewed and endorsed by DECCW.

2.3.8. Hydraulic modelling

A MIKE21 hydraulic model (refer **Section 2.2.3**) for the study area was used to characterise the flows in the Nambucca River. **Figure 2-2** shows the extent of the Nambucca River hydraulic model.

2.3.9. Hydraulic model parameterisation

The hydraulic model represents the topography of the study area including rivers, creeks, roads, railway and variation in terrain elevation. The terrain for the hydraulic model was developed as a nine metre grid from two sources being:

- a digital elevation model produced from a photogrammetric survey; and
- a river survey for the Proposal which captured the river bed and banks.

The terrain resistance was represented as Manning's 'n' which was estimated based on land use, determined from site investigation, aerial photography and in accordance with reference guidance (Chow, 1959). **Table 2-5** presents the adopted Manning's 'n' parameters for the hydraulic modelling.

- **Figure 2-2 Nambucca River hydraulic model extent**

- **Figure 2-3 Nambucca River 1977 event calibration**

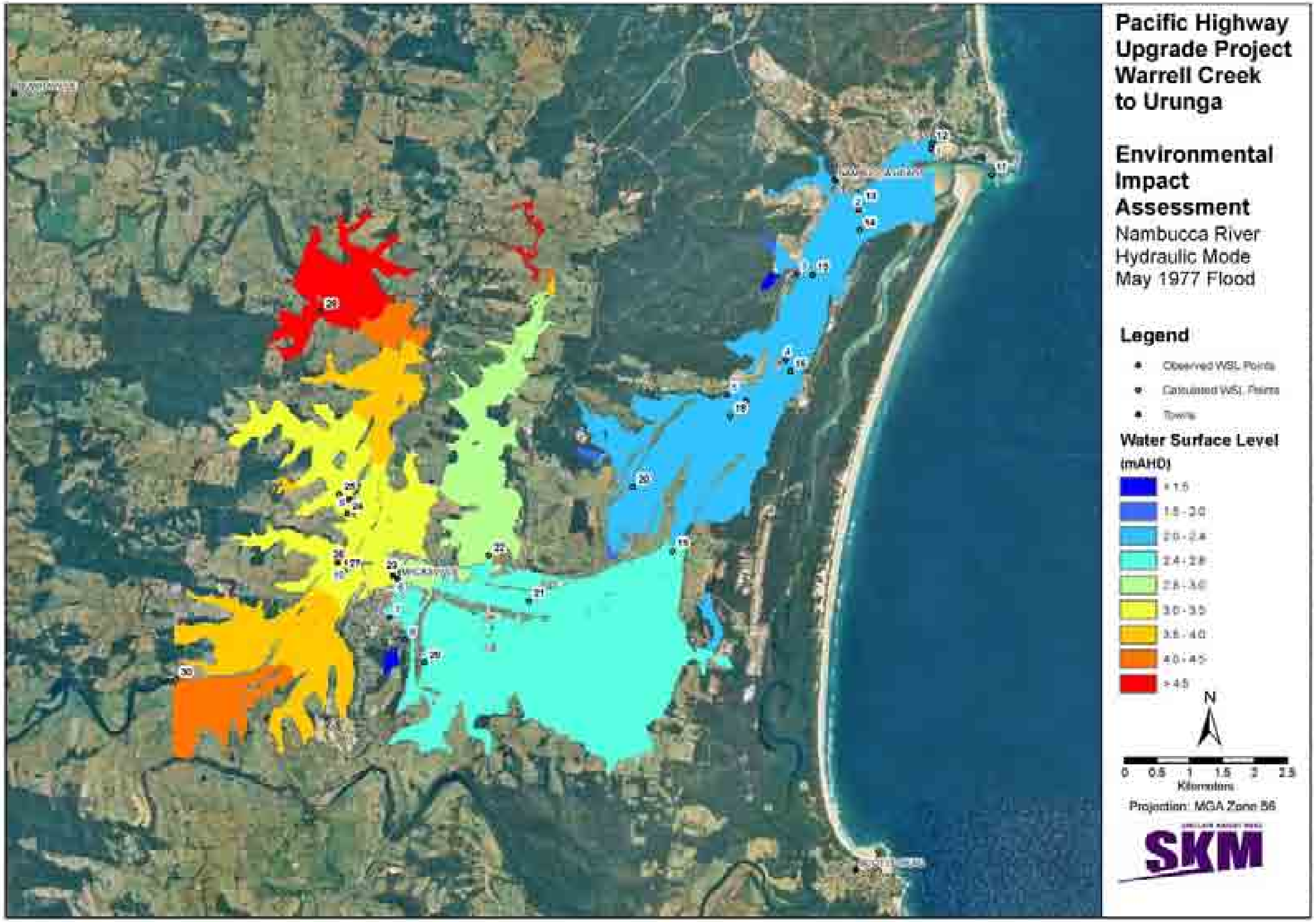


Table 2-5 Manning's 'n' parameters

Classification	Manning's 'n'
Waterway	0.015
Rural pasture	0.05
Medium brush on floodplain	0.06
Urban area	0.08
Dense brush on floodplain	0.10

2.3.10. Hydraulic model calibration

The purpose of the model calibration was to validate the model parameters selected. Calibration of the hydraulic model was undertaken for a flood event which occurred in May 1977. The May 1977 event was selected as it was also a calibration event from the previous study. The event was well recorded with data for flood flows available as well as a record of flood levels in the river and floodplain.

Figure 2-3 shows the flooding for the May 1977 flood event, as predicted by the flood modelling. A number of comparison points are provided and these are points of recorded flood levels from that 1977 event. **Table 2-6** shows the comparison of the event floods levels and the modelled results.

Table 2-6 Comparison of May 1977 flood levels to modelled flood levels

Point No.	Location	Type of reading	Reading level (m AHD)	Model level (m AHD)	Difference (m)
6	Nambucca River at Macksville	Observed	2.65	3.00	0.35
7	Macksville	Observed	2.40	2.68	0.28
8	South of Macksville near Town Drain	Observed	2.41	2.48	0.07
19	Nambucca River at Gumma Gumma Creek Confluence	Calculated	2.49	2.46	-0.03
21	Nambucca River 2km downstream of highway bridge at Macksville	Calculated	2.65	2.68	0.03
22	Newee Creek Upstream of Numbucca River confluence	Calculated	2.71	2.81	0.10
23	Nambucca River at Macksville	Calculated	2.77	2.92	0.15

The modelling showed a good calibration with the flood levels of the May 1977 flood event. The calibration also showed that to achieve the flood levels of the May 1977 event there was required to be some water in Gumma Swamp at the start of the flood event. This would be caused by the rainfall in the days preceding the main flood. There was 30 mm of rainfall in the 10 days preceding the rainfall event.

The results reported in **Table 2-6** are key points near the Proposal. The calibration of points downstream of the study area also showed a good calibration. However the points upstream of the study area differed from the historical values. This is likely to be a result of infrastructure changes upstream of the Macksville after 1977 including upgrades at Joffre Street Bridge.

2.3.11. Hydraulic design flood estimation

The calibrated hydraulic model was run for a number of durations of storms to determine the critical duration. The critical duration was deemed to be the storm event which produced the highest flood levels in the area of the Proposal. The critical duration for the Nambucca River in the area of interest was 36 hours. This was consistent with the hydrologic estimates.

The primary aim of the flood modelling was to determine the 100 year ARI flood level at the Proposal site and it was recognised that the 100 year ARI flood level could occur through one of two mechanisms. The first mechanism being a 100 year ARI river flood. The second being a 100 year ARI storm surge. It was recognised that it was unlikely that the two mechanisms would occur in isolation and that both flooding mechanisms were likely to contribute to flooding at the Proposal site in the event of a large flooding rain event.

The combination of flood flows and tidal conditions used to describe the 100 year flood for the Proposal were agreed through consultation with the DECCW and are as shown on in **Table 2-7**.

- **Table 2-7 Nambucca River 100 year ARI flood level hydraulic model boundaries**

Flooding mechanism	Boundary conditions
100 year ARI River flood	100 year ARI river flood with Normal tide (peak of 0.55 m AHD)
100 year ARI Storm surge	10 year ARI river flood with 100 year ARI ocean level (peak of 2.6 m AHD)

Another important flood event for the study was the 2000 year ARI flood event. This event was used to assess the impact of debris loading and shear forces on the bridge structures in design. The 2000 year ARI flood event with the highest flow velocities was required and therefore, the option with the lowest tailwater condition (Normal tide (peak of 0.55 m AHD)) was selected.

2.3.12. Hydraulic modelling results

The mapped results of the hydraulic assessment for the existing conditions are presented in **Appendix A - A.1**. The existing conditions flood levels at the proposed bridge crossing are presented in **Table 2-8**.

- **Table 2-8 Nambucca River hydraulic model results – existing conditions**

Flood event	Flood level (m AHD)
100 year ARI River flood	3.77
100 year ARI Storm surge	2.66
2,000 year ARI River flood	5.71

The 100 year ARI flood level at the Proposal site is 3.77m AHD as a result of river flooding.

2.3.13. Description of flooding regime

The flooding regime predicted by the model was widespread flooding in the low lying areas of Macksville and the surrounds particularly in Gumma Swamp. The flooding is caused by three flooding mechanisms.

Early in the rising stage of the flood, flood waters backed up Gumma Gumma Creek into Gumma Swamp. The low areas of the river bank east of the town overtopped broadly in the larger 100 year ARI flood event and caused widespread and deep flooding in the Proposal area. Importantly, the majority of the flood volume in Gumma Swamp flowed east to west, towards Macksville. The flow in the Gumma Swamp floodplain did not reach Macksville townsite in the 100 year ARI flood event.

At the time that Gumma Swamp was is filling, the urban drainage system was unable to drain the urban areas with the amount of flow coming from its local catchments. This was worsened by the river and floodplain flood levels being high and stopping free drainage of the high system.

At the peak of the river flood, the southern bank of the River was overtopped below the confluence of the Nambucca River and Taylors Arm.

2.3.14. Summary of hydraulic model findings

The key findings from the hydraulic modelling were:

- a good calibration of the hydraulic model was achieved for the May 1977 flood event;
- the calibrated hydraulic model was used to predicted the design flood levels for the 100 and 2,000 year ARI flood events;
- widespread flooding was predicted for the 100 year ARI flood event for the low lying areas of Macksville and the surrounds;
- flooding in Macksville and upstream of Macksville was caused by a lack of conveyance of the flood in the river channel, that is the river channel is not large enough to carry the flood;
- flooding in Gumma Swamp occurs via backwater effects through Gumma Gumma Creek, which caused flood water from the Nambucca River to flow in a westerly direction to fill Gumma Swamp; and

- the flooding of Macksville and the Gumma Swamp were hydraulically independent, that is the flooding in Gumma Swamp does not reach Macksville in the 100 year ARI event.

2.4. Warrell Creek flood modelling

Warrell Creek has a catchment of approximately 300 km^2 upstream of the town of Nambucca Heads. Warrell Creek joins the Nambucca River at Nambucca Heads. There are two river crossings proposed for Warrell Creek, approximately 4 km south of Macksville and 10 km south of Macksville (Upper Warrell Creek).

Flood modelling was completed to the same extent as a previous study titled *Lower Nambucca River Flood Study* (DPW, 1994). This extent was selected to remain consistent with the modelling that Nambucca Shire Council used as the basis for floodplain planning.

The focus of the modelling was the area of the proposed bridge crossing of the creek and floodplain.

The following sub-sections describe both the hydrologic and hydraulic modelling that was completed to describe the existing flooding regime of Warrell Creek.

2.4.1. Hydrologic modelling

A RAFTS hydrologic model (refer **Section 2.2.1**) for the Warrell Creek catchment was used to characterise the flows in the Warrell Creek. **Figure 2-4** shows the catchment boundary and catchment delineation for the Warrell Creek Catchment.

2.4.2. Hydrologic model parameterisation

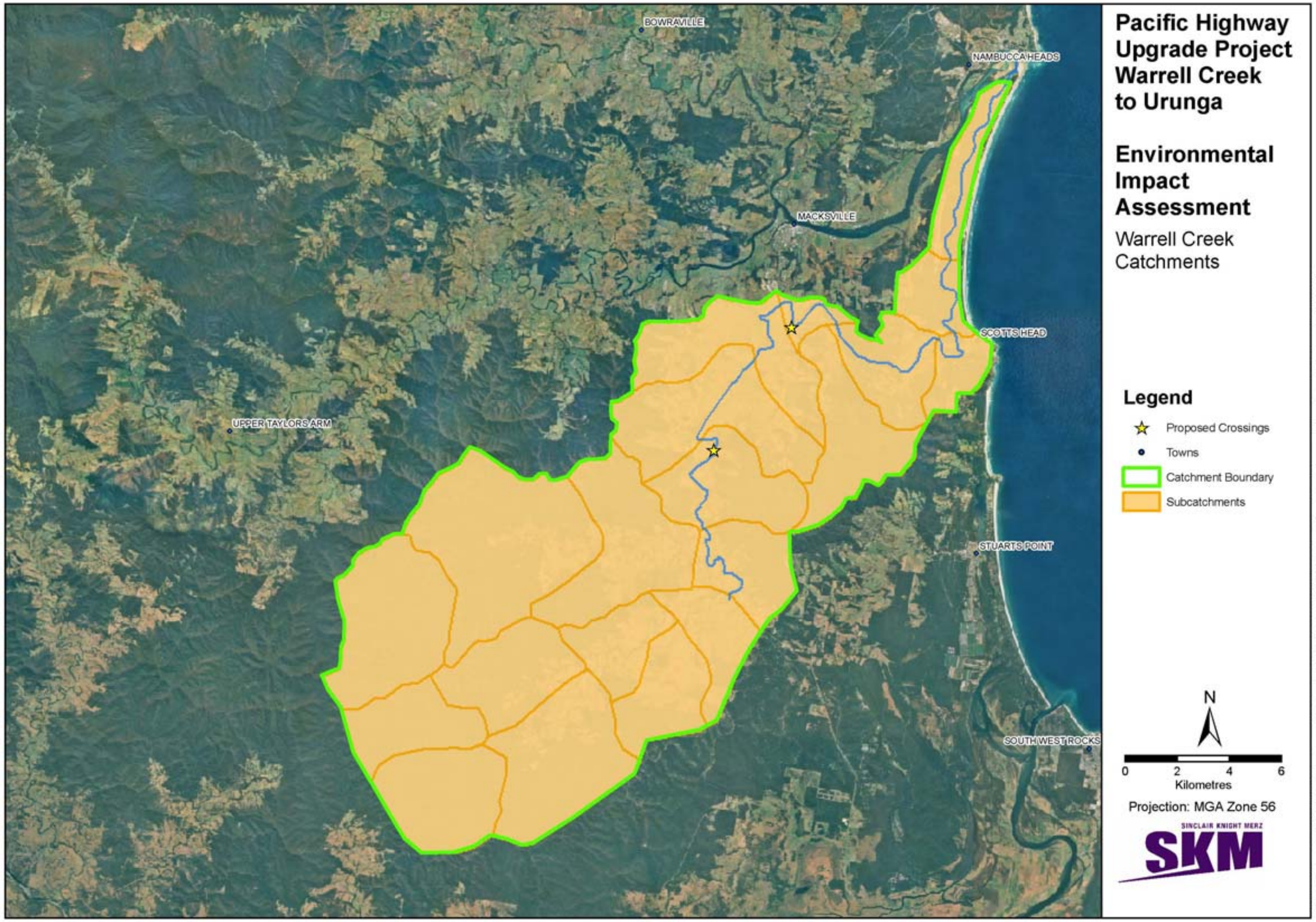
The Warrell Creek catchment ranged in slope from relatively steep (18 %) in the upper catchment to relatively flat (2 %) in the lower catchment near the coast. The slope data for the catchment was generated from the available contour information which had a resolution of 20 metres.

The catchment characteristics for Warrell Creek was similar to Nambucca River and therefore the same Manning’s ‘n’ and impervious area definition was adopted, as outlined in **Section 2.3.2**.

2.4.3. Hydrologic model calibration

There was a streamflow gauge located on Warrell Creek at Warrell Creek (205009) township. However, this gauge only had a period of record from 1980 to 1985. Calibration of the hydrologic model to historical storm events was attempted for the streamflow gauge at Warrell Creek (205009). However, there were no pluviograph rainfall gauges within the catchment as discussed in **Section 2.3.3**. Therefore calibration to historic storm events was not able to be achieved.

■ **Figure 2-4 Warrell Creek catchment**



2.4.4. Flood frequency analysis

A flood frequency analysis (FFA) was not undertaken for the Warrell Creek streamflow gauge at Warrell Creek (205009) as the gauge only had five years of data. Therefore, a regional FFA was undertaken to validate the hydrologic model.

A regional FFA was undertaken for the gauges in the surrounding catchments and the flows for Warrell Creek were interpolated based on catchment area. The regional FFA was undertaken including three gauges as outlined in **Table 2-9**.

- **Table 2-9 Regional FFA Warrell Creek**

Gauge	Period of record	Length of record (years)
Bellinger River at Thora (205002)	1982 – 2005	23
Nambucca River at Bowraville (205006)	1971 – 2005	34
Never Never at Glennifer Bridge (205014)	1982 – 2005	23

These gauges used in the regional FFA gave confidence up to 20 year ARI event. After the 20 year ARI event predicted by the FFA the confidence limits widen. The results of the FFA were validated up to the 20 year ARI event and the parameters were used to predict the 100 and 2,000 year ARI event. The results of the regional FFA are presented in **Table 2-10**.

- **Table 2-10 Regional FFA Warrell Creek**

ARI (Years)	Peak flow (m^3/s)
10	405
100	1,038
2,000	3,085

2.4.5. Hydrologic design flood estimation

The Warrell Creek catchment is adjacent to the Nambucca River catchment and therefore, the same method of Design Flood Estimation was adopted, as outlined in **Section 2.3.10**.

2.4.6. Validation to flood frequency analysis

The purpose of the FFA validation was to determine catchment storage, the initial and continuing losses. The hydrologic model was run for a number of storm durations to validate to the FFA and to determine the critical storm duration.

The parameters adopted for the design flood estimation are outlined in **Table 2-11**. These parameters were selected based on the regional FFA and adjacent the Nambucca River catchment parameters, as discussed in **Section 2.3.6**.

- **Table 2-11 Design flood estimation parameters Warrell Creek**

ARI (Years)	Initial loss (mm)	Continuing loss (mm/h)	Catchment storage (Bx)
10	30	3	3.3
100	30	3	3.3
2,000	30	3	3.3

The design peak flows and critical storm duration for Proposal site as well as the validation to the FFA are presented in **Table 2-12.**

- **Table 2-12 Design peak flows at the Proposal site**

ARI (years)	Design				FFA
	Peak flow Warrell Creek (m^3/s)	Storm duration (h)	Peak flow Upper Warrell Creek (m^3/s)	Storm duration (h)	Peak flow Warrell Creek (m^3/s)
10	445	12	383	12	405
100	970	12	832	12	1,038
2,000	2,025	12	1,732	12	3,085

The results of the hydrologic model predicted peak flows approximately 6 % lower than those estimated in the FFA for the 100 year ARI event. This was considered appropriate for the purpose of the concept design and was within the confidence limits of the FFA.

2.4.7. Summary of hydrologic model findings

The hydrologic modelling was completed for use in the hydraulic modelling. The key findings from the hydrologic modelling were:

- the RAFTS hydrologic model was developed for the Warrell Creek catchment based on the previous study catchment delineation and updated slope, resistance and fraction impervious parameters;
- hydrologic model calibration was not completed due to a lack of pluviograph rainfall gauges in the catchment;
- a regional FFA was undertaken to validate design losses and catchment storage parameters;
- design loss and catchment storage parameters were adopted based on the regional FFA and the parameters from the adjacent Nambucca River catchment; and
- the methodology for the hydrologic modelling was reviewed and endorsed by DECCW.

2.4.8. Hydraulic modelling

A MIKE21 hydraulic model (refer **Section 2.2.3**) for the study area was used to characterise the flows in the Warrell Creek. **Figure 2-5** shows the extent of the Warrell Creek hydraulic model. A HEC-RAS hydraulic model (refer **Section 2.2.5**) for the study area was used to characterise the flows in the Upper Warrell Creek.

2.4.9. Hydraulic model parameterisation

The terrain for the MIKE21 hydraulic model for Warrell Creek represents the topography of the study area including creeks, roads, railway and variation in terrain elevation. The terrain for the MIKE21 hydraulic model was developed as a nine metre grid from two sources being:

- a digital elevation model produced from a photogrammetric survey; and
- a river survey for the Proposal area which captured the river bed and banks.

The cross sections for the HEC-RAS model for Upper Warrell Creek were extracted from the digital elevation model produced from Aerial Laser Scanning Survey (ALS).

The terrain resistance was represented as Manning's 'n' which was estimated based on land use, determined from site investigation, aerial photography and in accordance with reference guidance (Chow, 1959). A Manning's 'n' of 0.05 was applied for the hydraulic modelling for both Warrell and Upper Warrell Creek which was equivalent to rural pasture.

2.4.10. Hydraulic model calibration

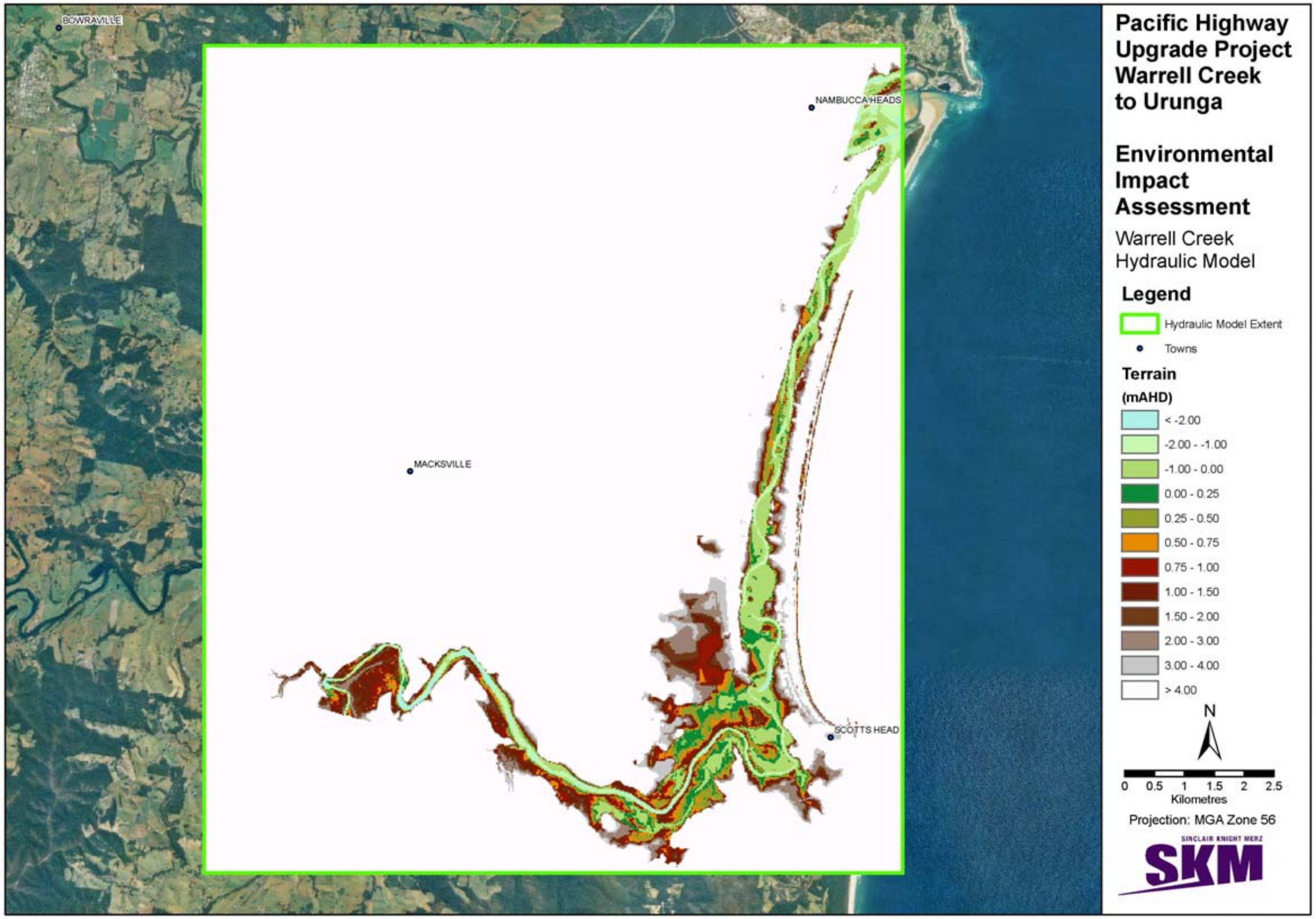
Calibration was not undertaken for the Warrell Creek as there was no set of recorded flood levels and flows for an historic flood.

2.4.11. Hydraulic design flood estimation

The hydraulic model was run for a number of storm durations to determine the critical duration. The critical duration was deemed to be the storm event which produced the highest flood levels. The critical duration for the Warrell Creek crossing was 36 hours and 12 hours for the Upper Warrell Creek Crossing.

Warrell Creek combines with the Nambucca River before discharging to the ocean and therefore the same downstream hydraulic model boundary conditions were adopted as discussed in **Section 2.3.11**.

- **Figure 2-5 Warrell Creek hydraulic model extent**



2.4.12. Hydraulic modelling results

The results of the hydraulic assessment for the existing conditions for Warrell Creek are presented in **Appendix A - A.2**. The existing conditions flood levels at the proposed bridge crossing are presented in **Table 2-13**.

- **Table 2-13 Warrell Creek hydraulic model results – existing conditions**

Flood event	Flood level (m AHD)
100 year ARI River flood	4.62
100 year ARI Storm surge	3.40
2,000 year ARI River flood	6.87

The 100 year ARI flood level at the Proposal site is 4.62m AHD as a result of river flooding.

The hydraulic assessment for Upper Warrell Creek was undertaken using the HEC-RAS model and was reported at a number of locations as shown in **Figure 2-6** and described in **Table 2-14**.

The results for the hydraulic assessment for the existing conditions for Upper Warrell Creek are presented in **Table 2-15**.

- **Table 2-14 Upper Warrell Creek reporting locations**

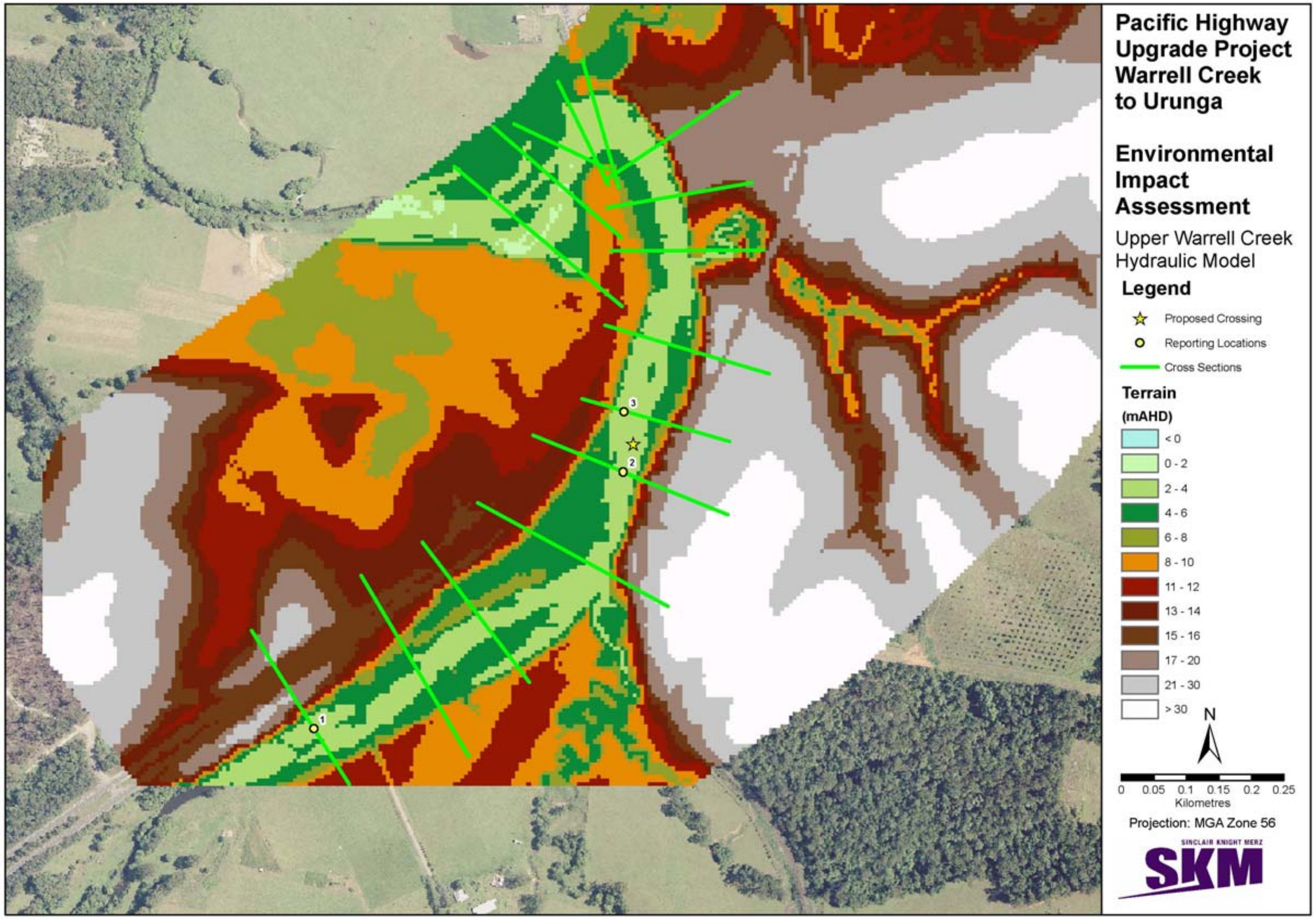
Location No.	Description
1	700 m upstream of proposed bridge
2	25 m upstream of the proposed bridge
3	25 m downstream of the proposed bridge

- **Table 2-15 Upper Warrell Creek hydraulic model results – existing conditions**

Location No.	Flood level (m AHD)		
	100 Year ARI river Flood	100 Year ARI storm surge	2,000 Year ARI river flood
1	9.76	7.91	12.35
2	9.36	7.53	11.96
3	9.28	7.46	11.88

The 100 year ARI flood level at the Proposal site is approximately 9.32m AHD as a result of river flooding.

■ **Figure 2-6 Upper Warrell Creek reporting locations**



2.4.13. Description of flooding regime

The flooding regime predicted by the hydraulic modelling for Warrell Creek was a well defined channel with a narrow floodplain. The lower reaches of Warrell Creek were tidal influenced however the flooding around the Proposal was influenced primarily by the conveyance of the waterway.

2.4.14. Summary of hydraulic model findings

The key findings from the hydraulic modelling were:

- calibration was not completed for Warrell Creek hydraulic model due to a lack of flood records;
- parameters for the design hydraulic model were based on site investigation, aerial photography and reference values;
- Warrell Creek had a well defined channel and narrow floodplain; and
- the hydraulic model was used to predict the design flood levels for the 100 and 2,000 year ARI flood events.

2.5. Deep Creek flood modelling

Deep Creek has a catchment of approximately 70 km^2 upstream of the proposed crossing. It is a minor tidal creek at the proposed crossing with a well defined bank and little floodplain.

The following sub-sections describe both the hydrologic and hydraulic modelling that was completed to describe the existing flooding regime of Deep Creek.

2.5.1. Hydrologic modelling

A RAFTS hydrologic model (refer **Section 2.2.1**) for the Deep Creek catchment was used to characterise the flows in the Deep Creek. **Figure 2-7** shows the catchment boundary and catchment delineation for the Deep Creek Catchment.

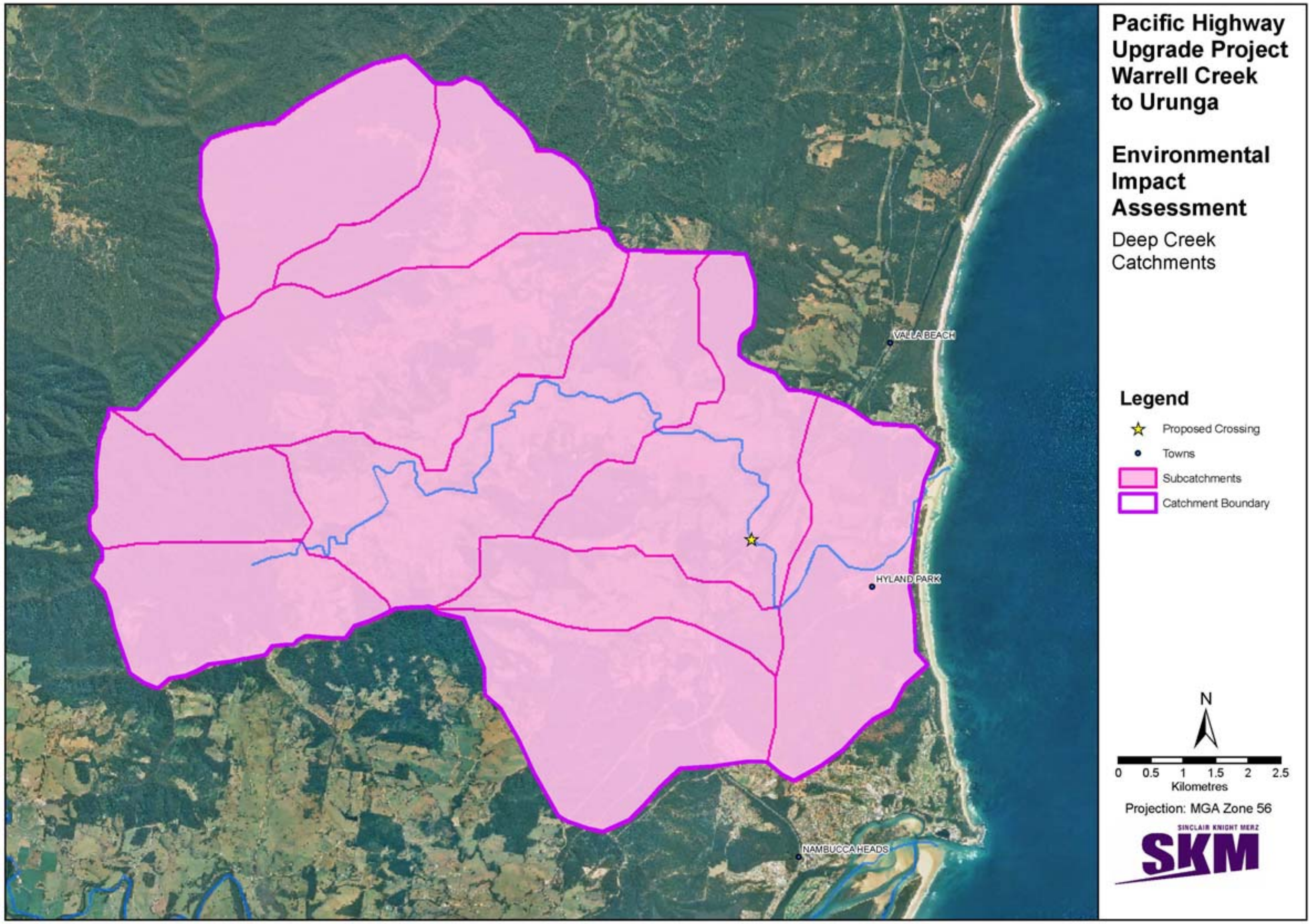
2.5.2. Hydrologic model parameterisation

The Deep Creek catchment ranged in slope from relatively steep (22 %) in the upper catchment to relatively flat (3 %) in the lower catchment near the Proposal site and the coast. The slope data was generated from the available contour information.

The resistance was represented in the model as Manning's 'n' and was applied to the model based on the land use. A Manning's 'n' of 0.1 was applied for the pervious areas of the catchment.

The catchment was assumed to be 100 % pervious due to the low level of urban development through the catchment as determined from the available aerial photography.

■ **Figure 2-7 Deep Creek catchment**



2.5.3. Hydrologic model calibration

There was no streamflow gauging within the Deep Creek catchment. Therefore, no hydrologic model calibration could be undertaken for Deep Creek.

2.5.4. Flood frequency analysis

A FFA was not undertaken for the undertaken for Deep Creek as there was no streamflow gauging in the catchment. The regional FFA was not applied to Deep Creek as the Deep Creek catchment is smaller than the catchments used in the regional FFA for Warrell Creek and Nambucca River.

2.5.5. Hydrologic design flood estimation

The Deep Creek catchment is adjacent to the Nambucca River catchment and therefore the same method of Design Flood Estimation was adopted, as outlined in **Section 2.4.10**.

2.5.6. Validation to Probabilistic Rational method

As there was no streamflow gauging in the Deep Creek catchment, a calculation of the 100 year ARI flood event peak flow was undertaken using the Probabilistic Rational Method (PRM) from *AR&R Volume 1* (IEAust, 1987). This calculation determined the 100 year ARI flood event peak flow was 480 m^3/s with a critical duration of 4 hours. Validation was undertaken with the hydrologic model incorporating the parameters from the Nambucca River catchment, which was adjacent to the Deep Creek catchment, and a comparison to PRM calculation.

The PRM calculation is considered to give a conservative estimate of the flow for a catchment as it is a simplified method of assessment. Previous assessment suggest the PRM calculation results in a 10 – 20 % overestimation.

The hydrologic model was run for a number of storm durations to determine the critical storm duration.

The parameters adopted for the design flood estimation are outline in **Table 2-16**.

- **Table 2-16 Design flood estimation parameters Deep Creek**

ARI (Years)	Initial loss (mm)	Continuing loss (mm/h)	Catchment storage (Bx)
10	30	3	2.5
100	30	3	2.5
2,000	30	3	2.5

The critical storm duration predicted was 36 hour which was longer than expected based on the catchment size. This was due to the rainfall pattern adopted however, the 6 hour duration storm produced only slightly smaller peak flow for Deep Creek. A 6 hour duration storm is considered appropriate for the size of the Deep Creek catchment. The design peak flow and critical storm duration at the Proposal site are presented in **Table 2-17.**

- **Table 2-17 Design peak flows at the Proposal site**

ARI (years)	Peak Flows Deep Creek (m^3/s)	Storm duration (h)
10	196	6
100	398	6
2,000	886	6

The hydrologic model predicted flows slightly lower than that predicted by the PRM. The hydrologic estimate was 18 % lower. This was considered to be appropriate for use in the conceptual design and is with the confidence limits of the PRM.

2.5.7. Summary of hydrologic model findings

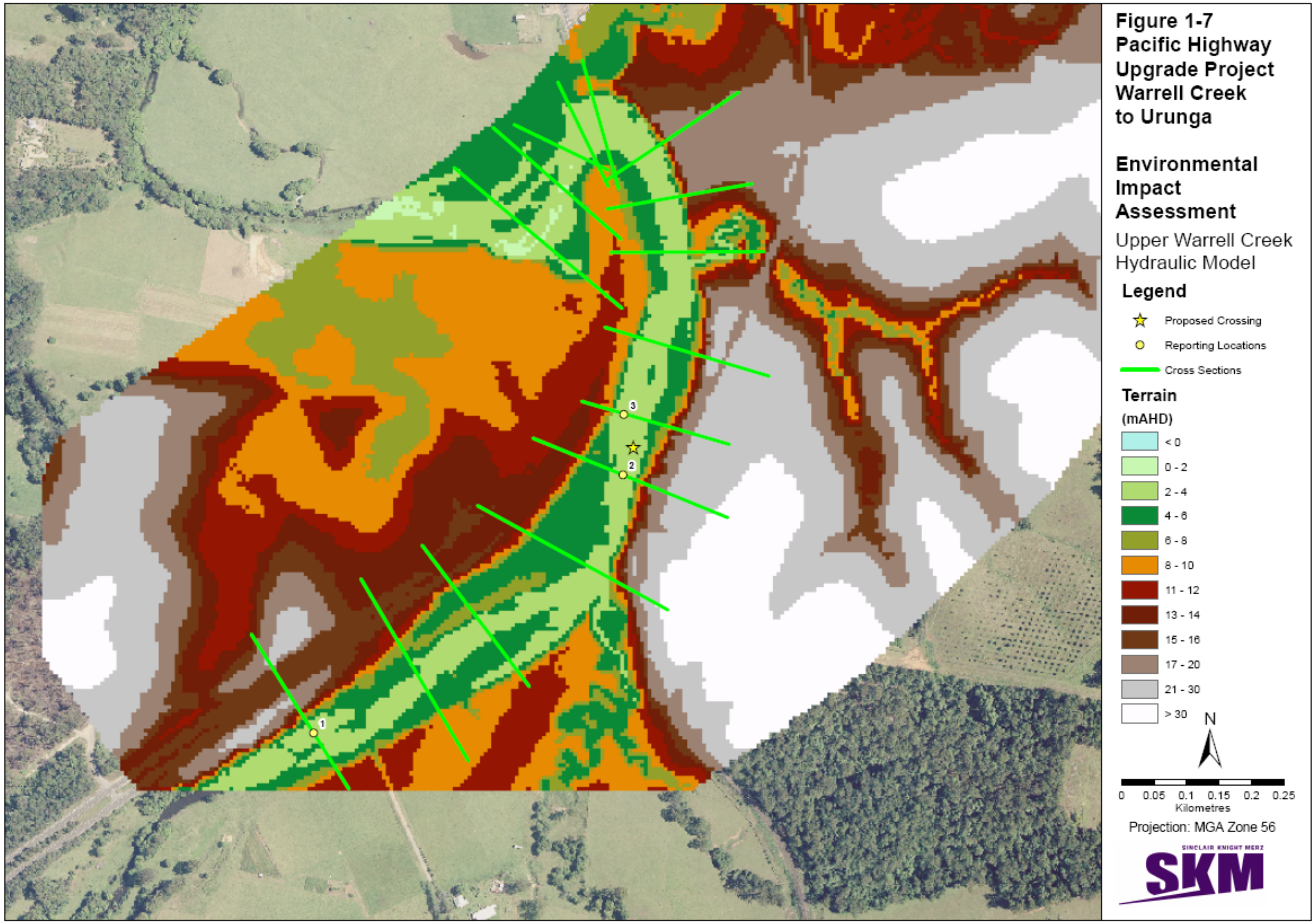
The hydrologic modelling was completed for use in the hydraulic modelling. The key findings from the hydrologic modelling were:

- the RAFTS hydrologic model was developed for the Deep Creek catchment and included slope, resistance and fraction impervious parameters;
- hydrologic model calibration and FFA was not completed due to a lack of streamflow gauges in the catchment; and
- validation of the hydrologic model was undertaken using the Probabilistic Rational Method.

2.5.8. Hydraulic modelling

A HEC-RAS hydraulic model (refer **Section 2.2.3**) for the study area was used to characterise the flows in the Deep Creek. **Figure 2-8** shows the extent of the Deep Creek hydraulic model.

■ **Figure 2-8 Deep Creek hydraulic model extent**



2.5.9. Hydraulic model parameterisation

The cross sections for the HEC-RAS model for Deep Creek were based on river and structure survey completed for the Proposal.

The terrain resistance was represented as Manning's 'n' which was estimated based on land use, determined from site investigation, aerial photography and in accordance with reference guidance (Chow, 1959). **Table 2-18** presents the adopted Manning's 'n' parameters for the hydraulic modelling for Deep Creek.

- **Table 2-18 Manning's 'n' parameters**

Classification	Manning's 'n'
Waterway	0.03
Floodplain	0.05

2.5.10. Hydraulic model calibration

Calibration was not undertaken for the Deep Creek as there were no recorded flood levels and flows for an historic flood.

2.5.11. Hydraulic design flood estimation

The hydraulic model was run with the design flows as determined by the hydrologic modelling. Through consultation with the DECCW, the boundary conditions were determined for each of the design flood events. The adopted boundary conditions are the same as the Nambucca River as discussed in **Section 2.3.11**.

2.5.12. Hydraulic modelling results

The hydraulic assessment for Deep Creek was undertaken using the HEC-RAS model and are reported at a number of locations as shown in **Figure 2-9** and described in **Table 2-19**.

The results for the hydraulic assessment for the existing conditions for Deep Creek are presented in **Table 2-20** for 10, 100 and 2,000 year ARI flood events.

- **Table 2-19 Deep Creek reporting locations**

Location No.	Description
1	200 m upstream of the proposed bridge
2	20 m upstream of the proposed bridge
3	10 m upstream of existing bridge
4	At existing railway bridge

Figure 2-9 Deep Creek reporting locations

Table 2-20 Deep Creek hydraulic model results existing conditions

Location No.	Flood Level (m AHD)		
	100 Year ARI River flood	100 Year ARI storm surge	2,000 Year ARI River flood
1	1.92	2.66	3.64
2	1.62	2.65	3.45
3	1.53	2.63	3.30
4	1.09	2.61	2.78

The 100 year ARI flood level at the Proposal site is 2.63m AHD as a result of storm surge.

2.5.13. Description of flooding regime

The flooding regime of Deep Creek is characterised by a well defined channel and narrow floodplain. The flooding was predicted to be controlled at the downstream boundary by the existing railway bridge in the 100 year ARI flood event. The existing downstream railway bridge acts as a constriction to the flow for larger flood events.

The area around the proposed bridge was tidally influenced and high ocean levels would impact flooding.

2.5.14. Summary of hydraulic model findings

The key findings from the hydraulic modelling were:

- calibration was not possible for Deep Creek due to a lack of flood records;
- the hydraulic model was used to predict the design flood levels for the 10, 100 and 2,000 year ARI flood events; and
- flood levels in the area are affected by the tidal level and the affects of the existing downstream railway bridge.

2.6. Kalang River flood modelling

The Kalang River is a large river with a catchment of approximately 310 km^2 upstream of Urunga. The Kalang River bifurcates into two channels approximately 3.5 km upstream of the railway bridge.

Flood modelling was completed to the same extent as a previous study titled *Lower Bellinger River Flood Study* (DPW,1991). This extent was selected to remain consistent with the modelling that Bellingen Shire Council used as the basis for floodplain planning.

The focus of the modelling was the area of the proposed bridge crossing of the river and road crossing of the floodplain.

Sections 2.6.1 to **2.6.13** describe both the hydrologic and hydraulic modelling that was completed to describe the existing flooding regime of the Kalang River.

2.6.1. Hydrologic modelling

A RORB hydrologic model (refer Section **2.2.2**) for the Kalang River catchment was used to characterise the flows in the Kalang River. The RORB model from the previous study was used as a foundation for the Proposal investigations. The catchment delineation of the previous study was adopted and catchment characteristics were updated based on current information and knowledge. **Figure 2-10** shows the catchment boundary and catchment delineation for the Kalang River Catchment.

2.6.2. Hydrologic model parameterisation

A k_c of 53 was selected based on the catchment area of the Kalang River catchment. The parameter 'm' of 0.8 was selected as recommended by the RORB users manual and was used in the previous model by the Department of Public Works (DPW).

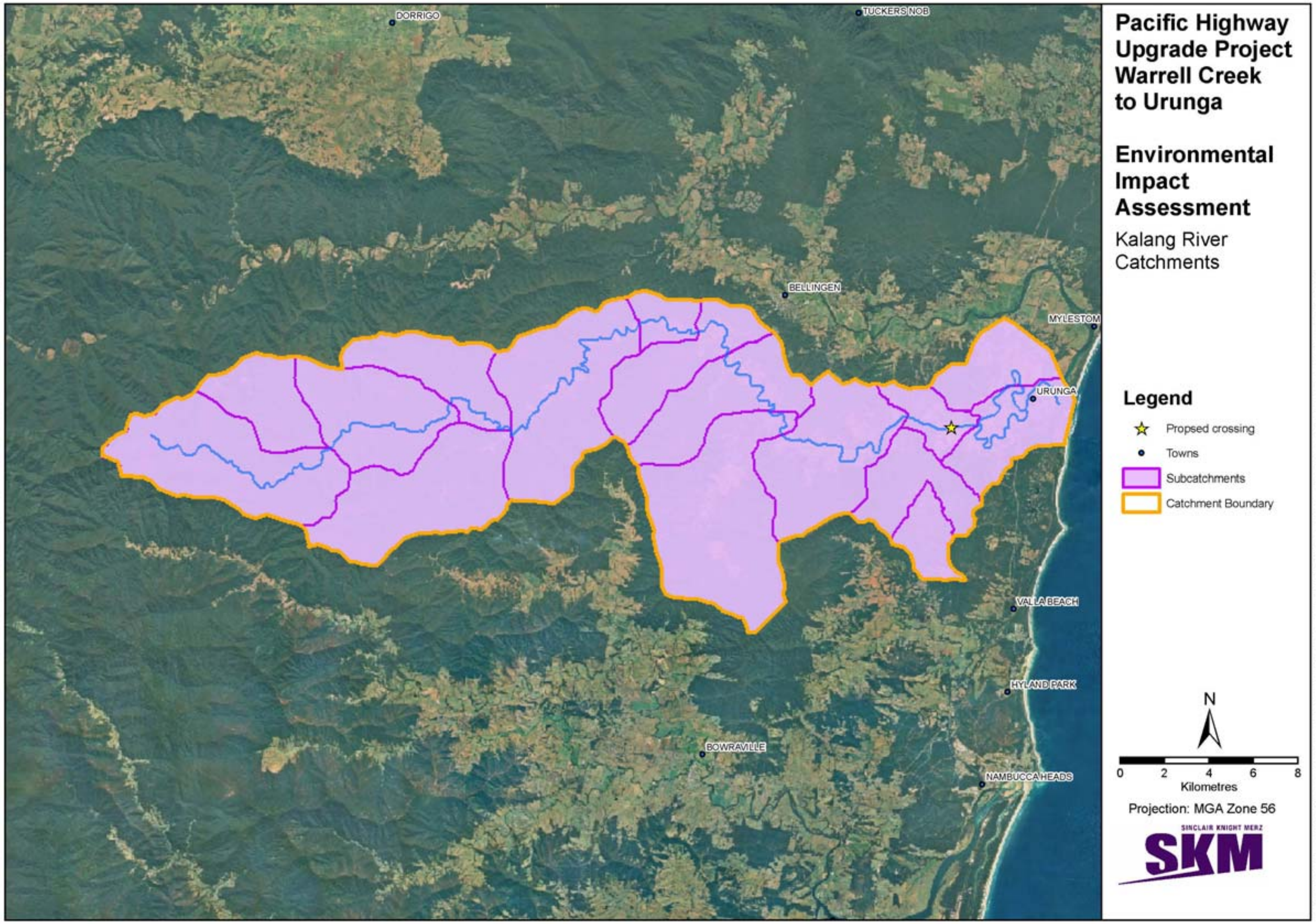
Impervious areas were specified for the towns in the catchment due to the presence of hard developed areas such as roads and roofs. This was determined from available aerial photograph and site inspection.

2.6.3. Hydrologic model calibration

There were streamflow gauges located on Kalang River, at Scotchman (205004) and at Kooroowi (205013). These gauges only had a period of record of three and nine years respectively. There were no pluviograph rainfall gauges within the catchment. The closest pluviograph gauge with a reasonable data record was Bellbrook (59000) which is approximately 100 km from the catchment. The lack of a local pluviograph rainfall gauge meant that calibration of the hydrologic model could only be done to gauges in adjacent catchments and thus, the calibration would have limitations to its accuracy. As further assessment, the recorded rainfall depth at the Bellbrook pluviograph gauge for various rainfall events was compared to the daily rainfall depths for a number of rainfall gauges within the Kalang River catchment. There was found to be a poor correlation between the Bellbrook gauge and the gauges within the catchment, therefore calibration to historic storm events was not achieved.

In lieu of calibration of the hydrologic model to historic recorded events, model validation was undertaken to a flood frequency analysis (FFA).

▪ **Figure 2-10 Kalang River catchment**



2.6.4. Flood frequency analysis

A single site FFA was undertaken for the Bellinger River streamflow gauge at Thora (205002). The Thora gauge has a catchment of 442 km^2 and a period record from 1990 to 2005. This gauge had 15 years of record which gave confidence in the FFA up to 20 year ARI event. After the 20 year ARI event predicted by the FFA the confidence limits widen. The results of the FFA were validated up to the 20 year ARI event and the parameters were used to predict the 100 and 2,000 year ARI event.

The Bellinger River catchment is adjacent to the Kalang River catchment. The FFA was undertaken for the peak flow and is presented in **Table 2-21**.

- **Table 2-21 FFA Bellinger River at Thora**

ARI (Years)	Peak flow (m^3/s)
10	1,015
100	2,634
2,000	6,596

2.6.5. Design flood estimation

Design flood estimation was undertaken using the hydrologic model incorporating design rainfall depths and rainfall patterns. The design rainfall depths and patterns were based on the *AR&R Volume 2* (IEAust, 1987) zones. The Kalang River catchment is within Zone 1 and therefore the same method of Design Flood Estimation as the Nambucca River has been adopted, as outlined in Section **2.3.5**.

2.6.6. Validation to flood frequency analysis

The purpose of the FFA validation was to determine the initial and continuing losses. The hydrologic model was run for a number of storm durations to validate to the FFA and to determine the critical storm duration.

The parameters adopted for the design flood estimation are outlined in **Table 2-22**.

- **Table 2-22 Design flood estimation parameters Kalang River**

ARI (Years)	Initial loss (mm)	Continuing loss (mm/h)
10	25	2.5
100	25	2.5
2,000	25	2.5

Table 2-23 presents the design peak flow at Thora and the validation to the FFA.

- **Table 2-23 Design peak flows at Thora**

ARI (years)	Design		FFA
	Peak flow (m^3/s)	Storm duration (h)	Peak flow (m^3/s)
10	1,260	36	1,015
100	2,649	36	2,634
2,000	5,074	36	6,596

The results of the hydrologic model predicted peak flows approximately 1% greater than those of the FFA for the 100 year ARI flood event. This was considered appropriate for the purpose of the concept design and is within the limits of confidence in the modelling.

These parameters when adopted for use in the Kalang River Model. The design peak flow and critical storm duration at Proposal site are presented in **Table 2-24.**

The critical duration at the Proposal site was less than at the Thora gauge. The catchment for the Thora gauge, which is adjacent to the catchment to the Proposal site, is larger than the catchment to the Proposal site. As these two catchments have similar characteristics, it is expected that the larger catchment would have a longer critical duration storm event, and this is the case here.

- **Table 2-24 Design peak flows at the Proposal site**

ARI (Years)	Peak flow (m^3/s)	Storm duration (h)
10	651	24
100	1,325	24
2,000	2,397	24

2.6.7. Summary of hydrologic model findings

The hydrologic modelling was completed for use in the hydraulic modelling. The key findings from the hydrologic modelling were:

- the RORB hydrologic model was developed for the Kalang River catchment based on the previous study catchment delineation and updated parameters;
- hydrologic model calibration was not possible due to a lack of pluviograph rainfall gauges in the catchment;
- a FFA was undertaken for the Bellinger River streamflow gauge at Thora;
- the hydrologic model was validated to the FFA to develop the design flow estimates;
- the methodology and results of the hydrologic modelling was reviewed and endorsed by DECCW.

2.6.8. Hydraulic modelling

A hydraulic model was developed for the Kalang River with the same extent as the previous modelling for the *Working Paper No. 8 Hydrology and Hydraulics Assessment (SKM,2004).* **Figure 2-11** shows the extent of the Kalang River Hydraulic Model.

2.6.9. Design flood estimation

The hydraulic model was run with the design flows as determined by the hydrologic modelling. Through consultation with the DECCW the boundary conditions were determined for each of the design flood events. These boundary conditions were advised by DECCW based on studies being undertaken concurrently in this area. **Table 2-25** presents a summary of the downstream boundary conditions for the each of the design flood events.

- **Table 2-25 Kalang River hydraulic model downstream boundaries**

ARI (Years)	Downstream boundary condition
10	10 year ARI flood level at railway bridge (peak 2.0 m AHD)
100	100 year ARI flood level at railway bridge (peak 3.1 m AHD)
2,000	2,000 year ARI flood level at railway bridge (peak 4.8 m AHD)

2.6.10. Hydraulic modelling results

The mapped results of the hydraulic assessment for the existing conditions for Kalang River are presented in **Appendix A - A.3** for 10, 100 and 2,000 year ARI flood events. The existing conditions flood levels at the proposed bridge crossing are presented in **Table 2-26**.

- **Table 2-26 Kalang River hydraulic model results – existing conditions**

ARI (Years)	Flood level (m AHD)
10	2.79
100	4.11
2,000	4.67

2.6.11. Description of flooding regime

The flooding regime predicted by the model was a narrow floodplain in the upper reaches of the study area. The Kalang River splits into two arms, which surround Newry Island, creating an extensive floodplain. The flow patterns across Newry Island are complex.

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- **Figure 2-11 Kalang River hydraulic model extent**

2.6.12. Inflows sensitivity

There is ongoing work by Bellingen Shire Council to develop a final adopted hydrologic model for the Kalang River for land planning purposes.. These investigations were incomplete at the time of this study. The ongoing work being completed by was required as previous studies by Bellingen Shire Council had predicted higher flows than those predicted in this study. The higher flows were the result of problems with hydrologic methods as described in **Section 2.6.3** and the ongoing work was proceding along the methods used in this study.

It is important to note that the previous studies predicted approximately 35% higher inflows for the 100 year ARI flood event. This is a large variance.

At the request of DECCW, and in response to the ongoing uncertainty about the area's design hydrology, a sensitivity analysis was undertaken in the hydraulic model. The model was tested to determine the sensitivity of the flood levels to inflows in the range of the 100 year ARI flood flow. To achieve this, the hydraulic model was run with the previous study's hydrology (approximately +35% on inflows) so that DECCW could gain an understanding of the sensitivity of the modelling to stream inflow.

The results of the hydraulic assessment for the sensitivity for Kalang River are presented in **Appendix A - A.3** for the 100 year ARI flood event. The sensitivity assessment predicted a 100 year ARI flood level approximately 600 mm higher than the level shown in Table 1-26. Due to the topography of the Kalang River valley, the additional area inundated by the increased flood levels predicted in the sensitivity assessment was estimated to be minor and localised. The maximum increase in the width of the area of inundation was estimated to be 40 m. No dwellings are located in the additional area inundated by the increased flood levels predicted in the sensitivity assessment.

2.6.13. Summary of hydraulic model findings

The key findings from the hydraulic modelling were:

- the hydraulic model was used to predicted the design flood levels for the 10, 100 and 2,000 year ARI flood events;
- flooding patterns for the Kalang River are very complex; and
- the flood level is sensitive to the inflows however the extent of inundation is not.

3. Proposal impact assessment and mitigation

3.1. Impact assessment

The Proposal could potentially affect the existing flooding regime by:

- reducing flood storage due to road embankment being constructed in floodplain areas;
- affecting flood conveyance due to bridges over primary waterways; and
- affecting flood behaviour through interfering with existing flow patterns.

Each of these impacts on the flooding regime has the potential to impact on floodplain properties. The design for the Proposal has been developed to mitigate such impacts by minimising increases in flood and property impacts

The impact assessment has been undertaken for a number of scenarios to guide the design, mitigation measures and adaptation strategies for the Proposal. These assessments included a range of events up to the 2,000 year ARI flood event. The scenarios assessed were:

- flooding impacts of the Proposal in the current climate (**Section 3.1.1**);
- flooding impacts of the Proposal under a changed climate (**Section 3.1.2**); and
- impacts of climate change on the Proposal (**Section 3.1.3**).

The following sections outline the concept design flooding considerations for the Proposal and how the impacts were mitigated for each of the primary watercourses.

3.1.1. Developed conditions flood modelling – current climate

The purpose of this scenario was to assess the impacts of the Proposal on flooding under the existing climatic conditions. The hydraulic models for the existing conditions for the waterways were updated to include the proposed road alignment and infrastructure. The hydrology for the existing conditions was used in the developed conditions flood modelling.

3.1.2. Developed conditions flood modelling – changed climate

The purpose of this scenario was to assess the impacts of the Proposal on flooding under the changed climatic conditions. Climate change was has the potential to affect flooding by either increasing rainfall intensity and depth or by increasing ocean levels. Therefore, two climate change scenarios were undertaken to assess the impacts of the Proposal are outlined in **Table 3-1**. These scenarios were developed based on the *Practical Consideration for Climate Change* (DECC, 2007) and advice from DECCW.

Table 3-1 Climate change scenarios

Scenario	Purpose	Description
1	Test impact of increase in rainfall depth and intensity due to climate change	100 year ARI flood event + 10 % increase in rainfall with a normal tide (peak of 0.55 m AHD)
2	Test impact of sea level rise due to climate change	10 year ARI flood event with a 100 year ARI ocean level (peak of 2.6 m AHD) + sea level rise (0.55 m)

This existing and developed conditions flood modelling was tested for the impacts of climate change. The results of these models were compared to determine the impact of the proposed development under a changed climate.

3.1.3. Impacts of climate change

The purpose of this scenario was to assess the impacts of climate change on the Proposal. The impacts of climate change on the Proposal were assessed using the same two scenarios as outlined in **Table 3-1.** The developed conditions flood model and the developed conditions flood model including climate change were compared to assess this impact. The results of this assessment would assist in the development of a climate adaptation strategy.

3.2. Nambucca River flood modelling

3.2.1. Hydraulic modelling

The hydraulic model developed for the existing conditions Nambucca River, as described in **Section 2.3.8**, was modified to include the proposed road alignment and river crossing. This included the addition of a number of structures and was modelled using MIKEFLOOD, as discussed in **Section 2.2.4**. The purpose of these structures is to facilitate the movement of floodwaters in a similar manner to the existing regime.

There are currently two options being considered for the crossing of the Nambucca River at Macksville. The options are similar and only vary on the northern side of the Nambucca River. The two options are:

- Option 1 – the road to built on an embankment across the northern floodplain with culverts to pass flood water; and
- Option 2 – the road to be built on a structure (viaduct) across the northern floodplain.

The structures represented in the hydraulic modelling for the Nambucca River and floodplain are presented in **Table 3-2** and **Table 3-3**. **Table 3-2** presents the floodplain structures for both Options 1 and 2, the Nambucca River Crossing details presented in **Table 3-3** are the same for both options. The structure type and size would be subject to further refinement in the detailed design stage.

It is of interest to note that the southern floodplain structures are actually larger in the case of the northern viaduct, Option 2. This option allows a freer flow of flood water downstream of the river crossing. The impact of this freer flow is that more flow then returns back up Gumma Swamp which, in turn, requires a greater waterway area to manage the southern floodplain.

- **Table 3-2 Nambucca floodplain structures**

Option	Chainage	Type	Waterway area (m^2)	Waterway opening (m)
Option 1	8100	Balancing	3	
	8300	Passes flows from Town Drain	90	
	9000	Southern floodplain	20	
	9200	Southern floodplain	100	
	9500	Southern floodplain	150	
	10700	Northern floodplain	135	
Option 2	8100	Balancing	3	
	8300	Passes flows from Town Drain	90	
	9000	Southern floodplain	20	
	9200	Southern floodplain	100	
	9500	Southern floodplain	220	
	10700-11200	Viaduct across Northern floodplain		500

- **Table 3-3 Nambucca River crossing**

Deck level (m AHD)	Waterway opening (m)
10 - 13	330

3.2.2. Results – developed conditions – current climate

The hydraulic model results for the developed conditions were compared to the existing conditions results. From this comparison, the impact of the road development was calculated and mapped.

The impact assessment results for the Nambucca River crossing are presented in **Appendix B - B.1** for the 10, 100 and 2,000 year ARI flood events. The red shades indicate an increase in flood level and the blue shades indicate a reduction in flood level.

It should be noted that Nambucca Shire Council has identified an area of land which has been approved for a combination of residential and industrial development in Macksville on Taylors Arm. This development has not been included in the modelling. However the development in this area would not impact the flood levels for the proposed road. Also the development of the road would not impact flood levels at the proposed development site.

Option 1

The results showed that Option 1 for the development of the Proposal at the Nambucca River and floodplain would have a limited impact on flood levels. The development of the road is predicted to increase flood levels on the upstream side of the road by less than 20 mm for the 100 year ARI flood event. The maximum increase in the level of the 100 year ARI flood event at any existing residence on the floodplain is less than 20 mm. The flood modelling predicted that properties adjacent to Town Drain on the western fringe of Gumma Gumma Swamp floodplain may experienced flood levels increased by only 15mm in a flood that was over 1000mm deep in this area.

The impacts in the 2000 year ARI flood event were considered to quantify what impacts occur in larger, very rare flood events and to check that the road alignment does not create a catastrophic outcome in such an event. The comparison found that the impact of the road alignment in a 2000 year ARI flood event was less than 50mm increase in flood levels through the Macksville town site area and less than 75mm at the confluence of Newee Creek and the Nambucca River.

Option 2

The results showed that Option 2 for the development of the Proposal at the Nambucca River and floodplain would have a very limited impact on flood levels. The development of the road is predicted to result in a very localised increase flood levels on the upstream side of the road by 15 mm for the 100 year ARI flood event. The maximum increase in the level of the 100 year ARI flood event at any existing residence on the floodplain is less than 15 mm. As for Option 1, the flood modelling predicted that properties adjacent to Town Drain on the western fringe of Gumma Gumma Swamp floodplain may experienced flood levels increased by only 15mm in a flood that was over 1000mm deep in this area.

The impacts in the 2000 year ARI flood were slightly higher than the impacts in the 100 year ARI event. This is the same outcome as noted for the previous option. Again, the comparison found that the impact of the road alignment in a 2000 year ARI flood event was less than a 50mm increase in flood levels through the Macksville town site area and less than 75mm at the confluence of Newee Creek and the Nambucca River.

3.2.3. Results – developed conditions – changed climate

The hydraulic model results for the developed conditions with climate change were compared to the existing conditions results with climate change, as discussed in **Section 3.1.2**. From this comparison, the impact of the Proposal was calculated and mapped.

The impact assessment results for the Nambucca River crossing are presented in **Appendix C - C.1** for the 10 and 100 year ARI flood events. The red shades indicate an increase in flood level and the blue shades indicate a reduction in flood level.

Option 1

The results showed that Option 1 for the development of the Proposal at the Nambucca River and floodplain would have a limited impact on flood levels. The development of the road is predicted to increase flood levels on the upstream side of the road by less than 40 mm for the 100 year ARI flood event. The affected area is urban area and the agricultural land. The maximum increase in the level of the 100 year ARI flood event at any existing residence on the floodplain is less than 40 mm.

Option 2

The results showed that Option 2 for the development of the Proposal at the Nambucca River and floodplain would have a limited impact on flood levels. The development of the road is predicted to increase flood levels on the upstream side of the road by less than 30 mm for the 100 year ARI flood event. The affected area is urban area and the agricultural land. The maximum increase in the level of the 100 year ARI flood event at any existing residence on the floodplain is less than 30 mm.

3.2.4. Results – impacts of climate change on the Proposal

The hydraulic model results for the developed conditions were compared to the developed conditions with climate change conditions results, as discussed in **Section 3.1.3**. From this comparison the impact of the climate change on the Proposal was calculated and mapped. The results of the analysis for the Nambucca River crossing are presented in **Appendix D - D.1** for the 10 and 100 year ARI flood events. The results of the climate change impacts assessment were similar for both Options 1 and 2.

The results for Scenario 1, increased rainfall for a 100 year ARI flood event, predicted a flood level at the proposed bridge of RL 4.16 m AHD – an increase of 430 mm above the predicted 100 year ARI flood level for developed conditions, current climate. The results for Scenario 2, sea level rise, predicted a flood level at the proposed bridge of RL 4.08 m AHD – an increase of 350 mm above the predicted 100 year ARI flood level for developed conditions, current climate. Based on this assessment, climate change impacts on the road development are predicted to be more significant from increased rainfall (Scenario 1) than an increase in sea level (Scenario 2).

The climate change impacts would have minimal impact on the flood immunity or structural integrity of the proposed bridge as the bridge deck level is higher than the 100 year ARI flood event level with climate change. The deck level for the Nambucca River crossing ranges from 10 to 13 m AHD which is at least five to eight metres above the predicted climate change Scenario 1 flood level.

The road over the Gumma Swamp floodplain south of the Nambucca River is predicted to be overtopped by approximately 170 mm under climate change Scenario 1. The road over the floodplain north of the Nambucca River would be 7.5 m – 8 m above the climate change Scenario 1 flood level.

3.3. Warrell Creek flood modelling

3.3.1. Hydraulic modelling

The hydraulic model for the existing conditions, as discussed in **Section 2.4.8**, was updated with the road crossing. **Table 3-4** presents the details of the crossings for Warrell Creek and Upper Warrell Creek.

- **Table 3-4 Warrell Creek crossing**

	Warrell Creek	Upper Warrell Creek
Deck Level (m AHD)	8.5 – 9.5	22 – 27
Opening Width (m)	180	100

3.3.2. Results – developed conditions – current climate

The hydraulic model results for the developed conditions were compared to the existing conditions results. From this comparison, the impact of the road development was calculated and mapped. The impact assessment results for the Warrell Creek crossing are presented in **Appendix B - B.2** for the 10, 100 and 2,000 year ARI flood events. The red shades indicate an increase in flood level and the blue shades indicate a reduction in flood level.

The results showed the development of the Proposal at Warrell Creek would have a limited impact on flood levels. The development of the Proposal is predicted to increase flood levels on the upstream side of the bridge by approximately 10 mm for the 100 year ARI flood event. The area of impact extends 1.5 km upstream of the proposed road and does not affect any existing dwellings. The affected area is agricultural land.

The impact assessment results for the Upper Warrell Creek crossing are presented in **Table 3-5** for the 100 and 2,000 year ARI flood events.

- **Table 3-5 Upper Warrell Creek results developed conditions – current climate**

Location No.	Existing flood level (m AHD)		Change in flood level (mm)	
	100 Year ARI	2,000 Year ARI	100 Year ARI	2,000 Year ARI
1 - 700 m upstream of proposed bridge	9.78	12.38	20	30
2 – 25m upstream of proposed bridge	9.39	12.00	30	40
3 – 25m downstream of proposed bridge	9.28	11.88	0	0

The results showed the Proposal would have a minimal impact on flood levels at Upper Warrell Creek. There was predicted to be a 30 mm increase in flood levels for the 100 year ARI flood event upstream of the proposed bridge and no increase downstream of the proposed bridge. The area of impact extends 700 m upstream of the proposed road and does not affect any existing dwellings. The affected area is a combination of dense vegetation and agricultural land.

In the 2000 year ARI flood event, the impact of the structure was predicted to be slightly greater that in the 100 year ARI event. The impact was predicted to be less than a 100mm increase in flood levels in the 2000 year ARI flood. The extent of the impact confined and similar to the extent of the impact in the 100 year ARI flood and did not affect any existing dwellings.

3.3.3. Results – developed conditions – changed climate

The hydraulic model results for the developed conditions with climate were compared to the existing conditions with climate change results, as discussed in **Section 3.1.2**. From this comparison, the impact of the Proposal under a change climate was calculated and mapped. The impact assessment results for the Warrell Creek crossing are presented in **Appendix C - C.2**. The red shades indicate an increase in flood level and the blue shades indicate a reduction in flood level.

Table 2-8 identified that 100 year ARI flood levels are determined by 100 year ARI River flooding. Based on this, climate change impacts on the road development are predicted to be more significant from increased rainfall (Scenario 1) than an increase in sea level (Scenario 2) and this is presented in **Table 3-6**.

The results showed the development of the road at Warrell Creek would have a limited impact on flood levels. The development of the Proposal is predicted to increase flood levels on the upstream side of the bridge by 15 mm for the 100 year ARI flood event. The area of impact extends 1.5 km upstream of the Proposal and does not affect any existing dwellings. The affected area is agricultural land.

The impact assessment results for the Upper Warrell Creek crossing are presented in **Table 3-6** for the year ARI flood event.

- **Table 3-6 Upper Warrell Creek results developed results – changed climate**

Location No.	Existing conditions flood level with climate change (m AHD)	Developed conditions flood level with climate change (m AHD)	Change in flood level (mm)
	100 Year ARI	100 Year ARI	100 Year ARI
1 - 700 m upstream of proposed bridge	10.20	10.23	30
2 – 25m upstream of proposed bridge	9.81	9.84	30
3 – 25m downstream of proposed bridge	9.73	9.73	0

The results showed the Proposal would have a minimal impact on flood levels at Upper Warrell Creek under a changed climate. There was predicted to be a 30 mm increase in flood levels for the 100 year ARI flood event upstream of the proposed bridge and no increase downstream of the proposed bridge. The area of impact extents 700 m upstream of the proposed road and does not affect any existing dwellings. The affected area is a combination of dense vegetation and agricultural land.

3.3.4. Results – impacts of climate change on the Proposal

The hydraulic model results for the developed conditions were compared to the developed conditions with climate change conditions results as discussed in **Section 3.1.3**. From this comparison the impact of the climate change on the Proposal was calculated and mapped. The results of the analysis for the Warrell Creek crossing are presented **Appendix D - D.2**.

The results for Scenario 1, increased rainfall for a 100 year ARI flood event, predicted an increase flood levels at the proposed bridge by 350 mm. For Scenario 2, sea level rise, there was a predicted increase in floods level of 240 mm at the proposed bridge.

The climate change impacts would have minimal impact on the flood immunity or structural integrity of the proposed bridge as the bridge deck level is approximately 3- 4 m above the predicted climate change Scenario 1 flood level.

The climate change sensitivity was undertaken for Scenario 1, as outlined in **Section 3.1.3** for the Upper Warrell Creek crossing. This scenario was undertaken as the dominant flooding mechanism at the crossing is riverine flooding and the modelling undertaken for the Warrell Creek crossing, which is downstream of the Upper Warrell Creek crossing, showed that climate change Scenario 1 resulted in higher flood levels than Scenario 2. The results of the change in flood level for the Upper Warrell Creek crossing are presented in **Table 3-7** for the 100 year ARI flood event with climate change.

- **Table 3-7 Upper Warrell Creek results impacts of climate change**

Location No.	Developed conditions flood level (m AHD)	Developed conditions flood level with climate change (m AHD)	Change in flood level (mm)
1 - 700 m upstream of proposed bridge	9.78	10.23	450
2 – 25m upstream of proposed bridge	9.39	9.84	450
3 – 25m downstream of proposed bridge	9.28	9.73	450

The results show a 450 mm increase is predicted for the 100 year ARI flood event. The changes due to climate change would have minimal impact on the flood immunity or structural integrity of the proposed bridge as the deck level for the Upper Warrell Creek crossing is 22 - 27 m AHD, which is more than 10 m above the predicted climate change Scenario 1 flood level.

3.4. Deep Creek flood modelling

3.4.1. Hydraulic modelling

The hydraulic model for the existing conditions, as discussed in **Section 2.5.8**, was updated with the road crossing. **Table 3-8** presents the details of the crossing for Deep Creek.

- **Table 3-8 Deep Creek crossing**

	Bridge
Deck Level (m AHD)	4.4
Opening Width (m)	85

3.4.2. Results – developed conditions – existing climate

The hydraulic model results for the developed conditions were compared to the existing conditions results. From this comparison, the impact of the Proposal was calculated.

The impact assessment results are presented in **Table 3-9** for the 100 and 2,000 year ARI flood events for the Deep Creek crossing.

Table 3-9 Deep Creek hydraulic model results – developed conditions

Location No.	Flood level (m AHD)		Change in flood level (mm)	
	100 Year ARI	2,000 Year ARI	100 Year ARI	2,000 Year ARI
1 - 200 m upstream of the proposed bridge	2.67	3.76	10	120
2 - 20 m upstream of the proposed bridge	2.66	3.61	10	90
3 - 10 m upstream of existing bridge	2.63	3.30	0	0
4 - At existing railway bridge	2.61	2.78	0	0

The results showed the Proposal would have little impact on flood levels. There was predicted to be a 10 mm increase in the 100 year ARI flood level upstream of the proposed crossing. The area of impact does not affect any existing dwellings and is contained in the existing floodplain. The affected area currently supports a combination of dense vegetation and agricultural land.

3.4.3. Results – developed conditions – changed climate

The hydraulic model results for the developed conditions with climate change were compared to the existing conditions with climate change results, as discussed in **Section 3.1.2**. From this comparison, the impact of the road development under a change climate was calculated.

Table 1-20 identified that 100 year ARI flood levels are determined by 100 year ARI storm surge. Based on this, climate change impacts on the road development are predicted to be more significant from an increase in sea level (Scenario 2) than an increased rainfall (Scenario 1). The impact assessment results are presented in **Table 3-10** for the 100 year ARI flood events for the Deep Creek crossing.

Table 3-10 Deep Creek results – developed conditions – changed climate

Location No.	Existing conditions flood level with climate change (m AHD)	Developed conditions flood level with climate change (m AHD)	Change in flood level (mm)
	100 Year ARI	100 Year ARI	100 Year ARI
1 - 200 m upstream of the proposed bridge	3.19	3.20	10
2 - 20 m upstream of the proposed bridge	3.18	3.19	10
3 - 10 m upstream of existing bridge	3.17	3.17	0
4 - At existing railway bridge	3.16	3.16	0

The results showed the Proposal would have a minimal impact on flood levels at Deep Creek under a changed climate. There was predicted to be a 10 mm increase in 100 year ARI flood level upstream of the crossing. The area of impact does not affect any existing dwellings. The affected area currently supports a combination of dense vegetation and agricultural land.

3.4.4. Results – impacts of climate change on the Proposal

The hydraulic model results for the developed conditions were compared to the developed conditions with climate change conditions results, as discussed in **Section 3.1.3**. From this comparison the impact of the climate change was calculated.

The results of the analysis for the Deep Creek crossing are presented in **Table 3-11** for the 10 and 100 year ARI flood events with climate change.

- **Table 3-11 Deep Creek results – climate change impact**

Location No.	Developed conditions flood level (m AHD)	Developed conditions flood level with climate change (m AHD)	Change in flood level (mm)
	100 Year ARI	100 Year ARI	100 Year ARI
1- 200 m upstream of the proposed bridge	2.67	3.20	530
2 - 20 m upstream of the proposed bridge	2.66	3.19	540
3 - 10 m upstream of existing bridge	2.63	3.17	540
4 - At existing railway bridge	2.61	3.16	540

The results showed that for Scenario 2, sea level rise, climate change was predicted to increase floods level by approximately 540 mm.

The climate change impacts would have minimal impact on the flood immunity or structural integrity of the proposed bridge as the bridge deck level is higher than the 100 year ARI flood event level under climate change. The deck level for the Deep Creek crossing was 4.4 m AHD which is approximately 1.2 m above the 100 year ARI flood level with climate change. Under climate change, the soffit of the bridge would be submerged in the 100 year ARI flood. Consideration of this was made by the bridge structural designers to ensure structural integrity into the future.

3.5. Kalang River flood modelling

3.5.1. Hydraulic modelling

The hydraulic model developed for the existing conditions Kalang River, as described in **Section 2.6**, was modified to include the proposed road alignment and river crossing. This included the addition of a number of structures and was modelled using MIKEFLOOD, as discussed in **Section 2.2.4**.

The purpose of these structures was to mitigate potential flooding impacts which are primarily due to interfering with existing flow patterns. These structures aim to enable movement of floodwaters through the floodplain similar to the existing regime.

The structures represented in the hydraulic modelling for the Kalang River and floodplain are presented in **Table 3-12** and **Table 3-13**. The structure type and size would be subject to further refinement in the detailed design stage.

- **Table 3-12 Kalang River structures**

Chainage	Type	Waterway area (m^2)
34500	Balancing	20
35000	Floodplain	238
36000	Floodplain	96
38100	Balancing	51
40000	Balancing	101
40500	Balancing	55

- **Table 3-13 Kalang River crossing**

Chainage	Deck level (m AHD)	Waterway opening (m)
35750	9.8 – 10.8	130

3.5.2. Results – developed conditions – current climate

The hydraulic model results for the developed conditions were compared to the existing conditions results. From this comparison, the impact of the road development was calculated and mapped.

The impact assessment results for the Kalang River crossing are presented in **Appendix B - B.3** for the 10, 100 and 2,000 year ARI flood events. The red shades indicate and increase in flood level and the blue shades indicate a reduction in flood level.

The results show the development of the Proposal at Kalang River would have a limited impact on flood levels. The development of the Proposal is predicted to increase flood levels on the upstream side of the bridge up to 60 mm for the 100 year ARI flood event. The affected area currently supports a combination of dense vegetation and agricultural land and one dwelling. The one affected dwelling is located on the floodplain and on land which is highly vulnerable to flooding. The Proposal would increase flooding by approximately 50mm in a flood that is over

1000mm deep and thus make a small incremental increase in the damages experienced at the dwelling.

The 2000 year ARI flood event was tested to confirm that larger, very rare flood events did not cause a disproportionately large increase in flood impacts. It was predicted that the Proposal would increase flood levels by less than 50mm in the 2000 year ARI flood event.

There is predicted to be localised changes in flooding in the centre of the study area. This is due to the culvert structure and unrefined representation of the road drainage in that area. There is predicted to be minimum impact in this area with the detailed design of the road drainage is undertaken.

3.5.3. Results – developed conditions – changed climate

The hydraulic model results for the developed conditions with climate change were compared to the existing conditions results with climate change, as discussed in **Section 3.1.2**. From this comparison, the impact of the road development was calculated and mapped.

The impact assessment results for the Kalang River crossing are presented in **Appendix C - C.3** for the 10, and 100 year ARI flood events. The red shades indicate and increase in flood level and the blue shades indicate a reduction in flood level.

The results showed the development of the Proposal at Kalang River would have a limited impact on flood levels, similar to the impacts under the existing climate. The development of the Proposal is predicted to increase flood levels on the upstream side of the bridge up to 60 mm for the 100 year ARI flood event. The affected area currently supports a combination of dense vegetation and some agricultural land. There is predicted to be one dwelling affected with an increase in the 100 year ARI flood level of 50 mm.

There is predicted to be localised changes in flooding in the centre of the study area. This is due to the culvert structure and unrefined representation of the road drainage in that area. There is predicted to be minimum impact in this area with the detailed design of the road drainage is undertaken.

3.5.4. Results – impacts of climate change on the Proposal

The hydraulic model results for the developed conditions were compared to the developed conditions with climate change conditions results, as discussed in **Section 3.1.3**. From this comparison the impact of the climate change on the road development was calculated and mapped.

The climate change impacts for the Kalang River crossing are presented in **Appendix D - D.2** for the 100 year ARI flood event.

The results for Scenario 1, increased rainfall for a 100 year ARI flood event, predicted an increase flood levels at the proposed bridge by 220 mm.

The impacts due to climate change would have minimal impact on the flood immunity or structural integrity of the proposed bridge as the road deck is higher than the 100 year ARI flood event level. The deck level for the Kalang River crossing ranges from 9.8 to 10.8 m AHD which is more than 5 m above the 100 year ARI flood level with climate change. The impacts of climate change would also lessen the freeboard on the road across the floodplain. The lowest level of the road on the embankment over the floodplain is 5.4 m AHD which is 1.1 m above the 100 year ARI flood level with climate change.

3.6. Construction impacts and mitigation measures

The construction of the Proposal would need to occur with awareness of the flooding risks of the site. Construction activities would need to be staged to avoid increasing the flooding risks on the floodplain. Also, the construction contractor would be obliged to mitigate the impacts of the construction on surface water quality as part of the Construction Environmental Management Plan. In particular current good practice erosion and sediment control measures would be provided as outlined in the following publications:

- Landcom (2004) *Managing Urban Stormwater: Soils and Construction*, Volume 1, 4th edition.
- Landcom (2006), *Managing Urban Stormwater: Soils and Construction*, Volume 2 Book 4, Main Road Construction.
- DECC (2008) *Managing Urban Stormwater: Soils and Construction*, Volume 2D - Main Road Construction.
- RTA (2000) *RTA Road Design Guide*, Section 8 “Erosion and Sedimentation.

Specific mitigation measures to address flooding and hydraulic impacts include:

- ensure adequate drainage of the construction works with provision for large events; and
- provision of adequate waterway areas through embankment constructed on the floodplains, with consideration given to impacts of large flood events that would pass over the top of the final formation but be restricted by preloaded embankments.

3.7. Operational impacts and mitigation measures

3.7.1. Current climate conditions

The development of the Proposal has potential impacts on the flooding regimes of the five major waterways within the study area. These potential impacts have been mitigated with the following measures:

- route selection to minimise where possible the number of crossings of major waterways, and to avoid sensitive areas;
- vertical and horizontal alignment of the Proposal to take into consideration flood levels and floodplain storage;
- inclusion of floodplain structures to minimise changes to existing flood regimes including culverts and bridges which would be sized for a 100 year flood event;
- 100 year ARI flood immunity for the Proposal across floodplains;
- sufficient clearances below major waterways bridges to enable the free passage of river traffic; and
- implementation of an adaptive management approach to manage changes to flood behaviour due to climate change.

With the mitigation measures in place the following flooding impacts are predicted for the five major waterways under current climatic conditions:

- Upper Warrell Creek – maximum increase in flood levels of 30 mm for the 100 year ARI flood event immediately upstream of the Proposal, with no existing dwellings located within the area of increased flood levels;
- Warrell Creek – maximum increase in flood levels of 10 mm for the 100 year ARI flood event immediately upstream of the Proposal, with no existing dwellings located within the area of increased flood levels;
- Nambucca River – less than 20 mm increase in flood levels for the 100 year ARI flood event immediately upstream of the Proposal, with less than 20 mm increase in 100 year ARI flood levels at existing dwellings;
- Deep Creek – maximum increase in the flood levels of 10 mm for the 100 year ARI flood event immediately upstream of the Proposal, with no existing dwellings located within the area of increased flood levels;
- Kalang River – maximum 60 mm increase in flood levels for the 100 year ARI flood event immediately upstream of the Proposal, with the land around one dwelling affected with an increase in the 100 year ARI flood level of 50 mm over and above the 1000mm of flooding at the location in the event. .

3.7.2. Climate change conditions

According to current knowledge of climate change science, the future climate that the Proposal will operate in will be one different from the current. According to the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the future climate is likely to be characterised by an increased temperature and more intense storm events that occur less frequently. Although the storms will be more intense, the spells between large rainfall events are expected to be longer and this will coincide with increasing sea levels over time.

More intense storms have ramifications to the proposal in terms of higher winds and more intense rainfall. They are also expected to create larger storm surge that will build over a base of higher sea levels. The flooding regime for the Proposal is therefore expected to change with time.

Current knowledge suggests that rainfall events that would cause the current 1 in 100 year ARI flood may occur more frequently in the future. The 1 in 100 year flood will therefore be redefined over time to be a larger and more damaging event.

The science behind climate change predictions is currently in a period of rapid development. The predictions of rainfall intensity increases over the coming years are published on the CSIRO climate change website (http://www.climatechangeinaustralia.gov.au/index.php) and relate the change in rainfall intensity to the range of probable increases in carbon dioxide emissions.

Development of the Proposal must therefore be planned with an awareness of the potential for climate change impacts on the Proposal and the range of the potential impacts. For the Proposal, the RTA considers that an adaptive approach provides the most appropriate methodology for the management of the impact of future climate change on flood behaviour and the performance of the highway drainage structures. This approach would involve:

- Designing and constructing the proposal to achieve the Proposal objective of providing flood immunity on at least one carriageway for a 1 in 100 year flood event.
- Monitoring the performance of the installed drainage structures to identify and record details of any inundation of the highway.
- Periodic reviews of published rainfall and ocean level data and advices / guidelines issued by appropriate organisations, eg. DECCW, CSIRO and Institution of Engineers, Australia. The documentation would assist in the identification of changes in rainfall intensity and duration and in ocean levels due to climate change.
- Determine, based on the above data, the actual and/or predicted performance of the highway drainage structures and compare this performance against the Proposal objective of providing flood immunity on at least one carriageway for a 1 in 100 year flood event.
- Identify any location(s) where the performance of the highway drainage structures does not satisfy the Proposal objective and identify and assess measures to manage these areas. Potential management measures could include, but would not be limited to:
  - Augmentation of the drainage structures and/or undertaking other works to provide flood immunity on at least one carriageway for a 1 in 100 year flood event.

  - Accept a reduced level of flood immunity at these locations and implement appropriate measures to any impacts of the reduced flood immunity.
  - A combination of the above.
- Implement the adopted management measure.

4. References

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Appendix A Hydraulic results – existing conditions

A.1 Nambucca River

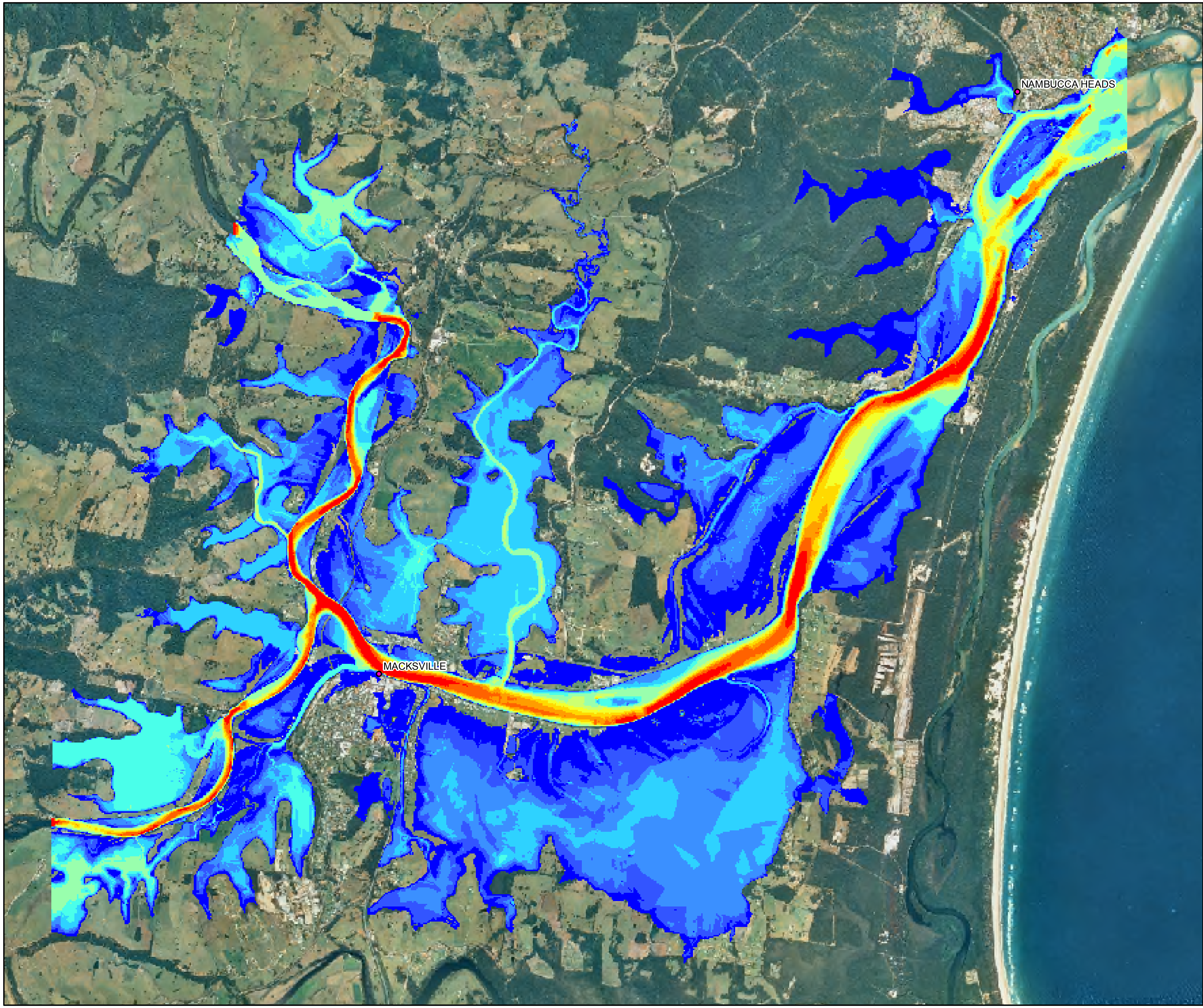

Fig A1-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Existing Conditions
10 year ARI Flooding

Legend

Towns

Inundation (m)

- < 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- 5.0 - 5.5
- 5.5 - 6.0
- 6.0 - 7.0
- > 7.0

N

0 0.4 0.8 1.2 1.6 2
Kilometres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

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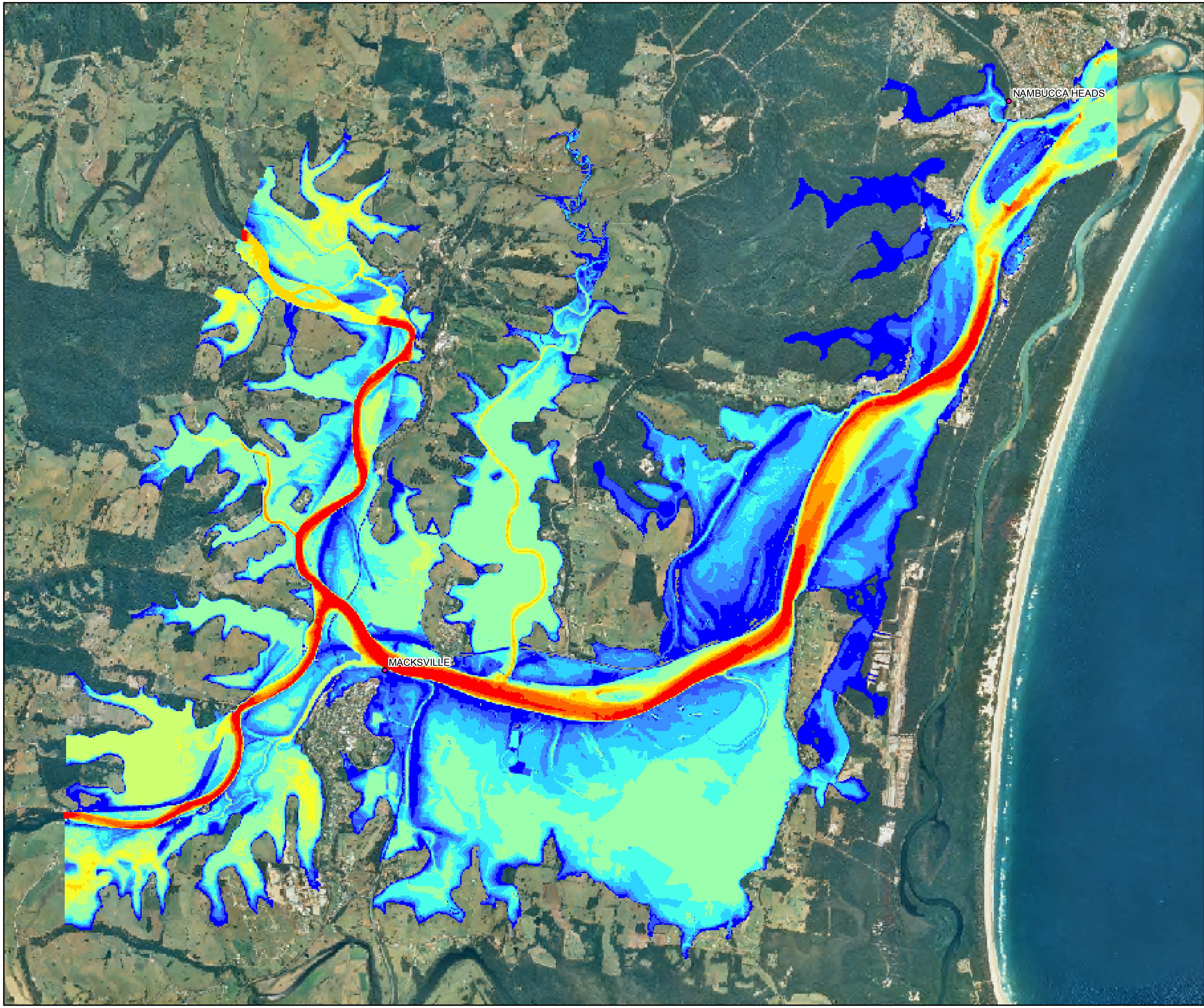

Figure A1-2 Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Existing Conditions
100 year ARI Flooding

Legend

Towns

Inundation (m)

- < 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- 5.0 - 5.5
- 5.5 - 6.0
- 6.0 - 7.0
- > 7.0

N

0 0.4 0.8 1.2 1.6 2
Kilometres

Projection: MGA Zone 56

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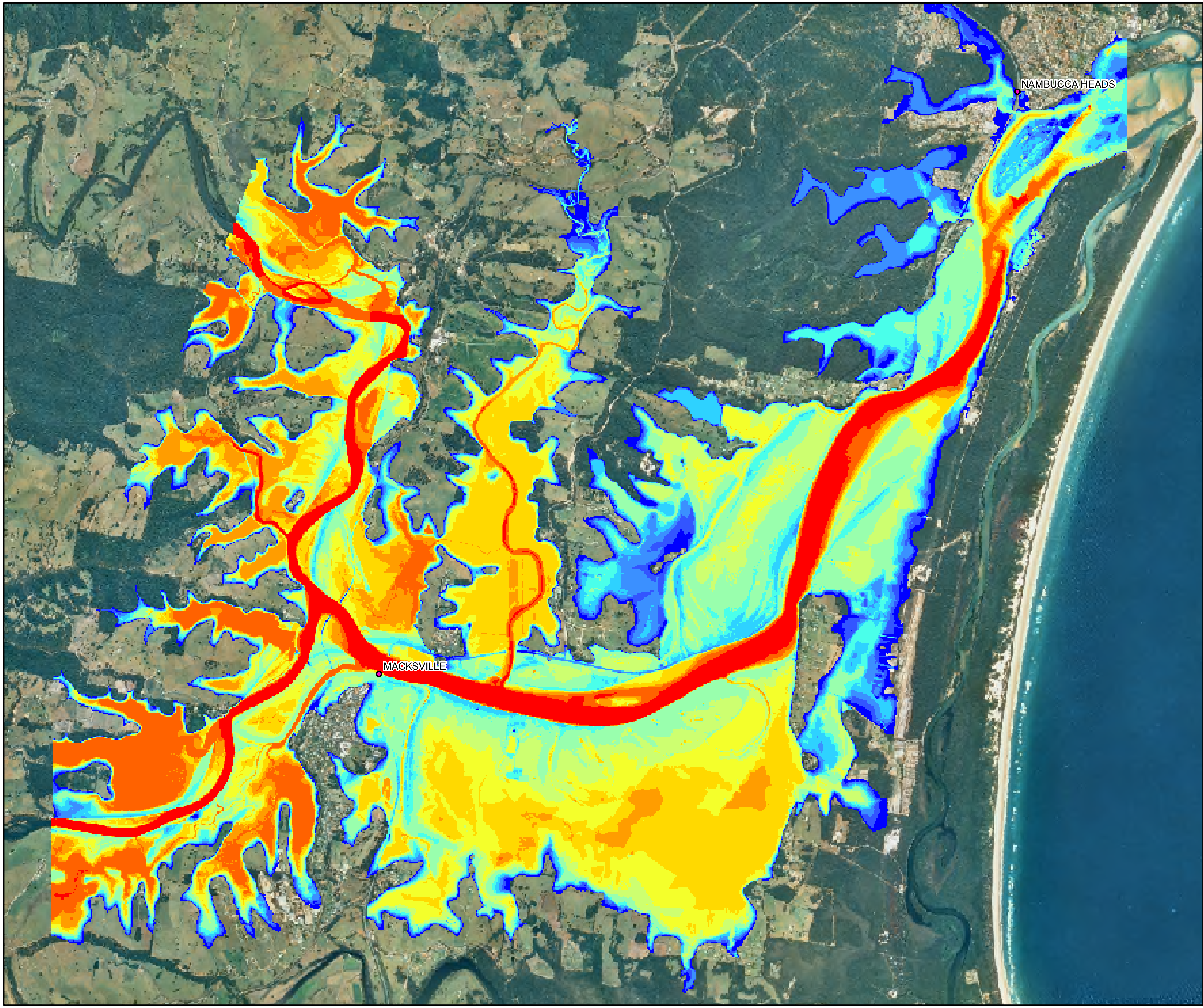

Figure A1-3
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Existing Conditions
2000 year ARI Flooding

Legend

Towns

Inundation

Depth (m)

- < 1
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- 5.0 - 5.5
- 5.5 - 6.0
- 6.0 - 7.0
- > 7.0

N

0 0.4 0.8 1.2 1.6 2
Kilometres

Projection: MGA Zone 56

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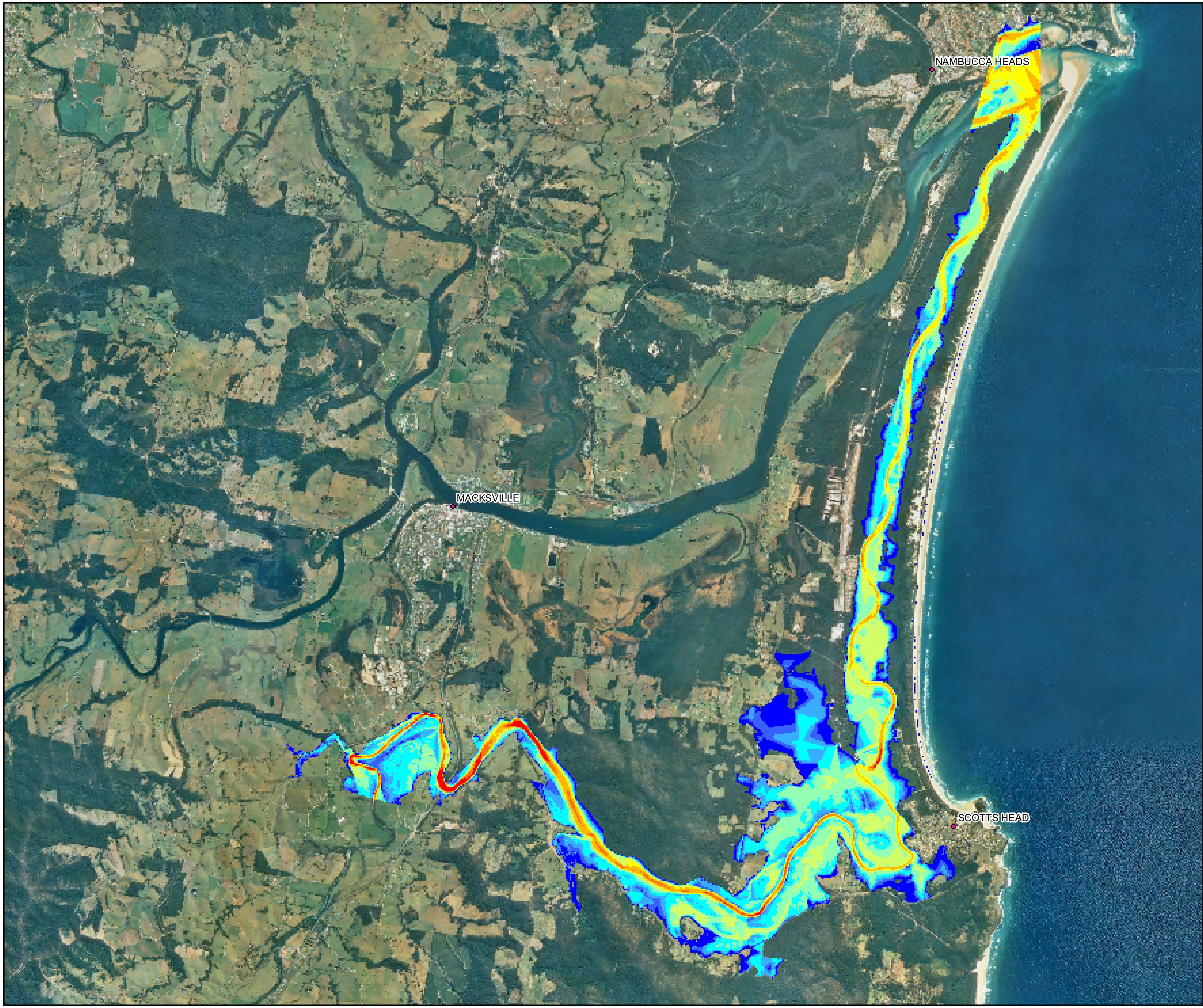
A.2 Warrell Creek

Figure A2-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Existing Conditions
10 year ARI Flooding



Legend

- Towns

Inundation

Depth (m)

- < 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- >6.0

N

0 0.5 1 1.5 2 2.5
Kilometres

Projection: MGA Zone 56

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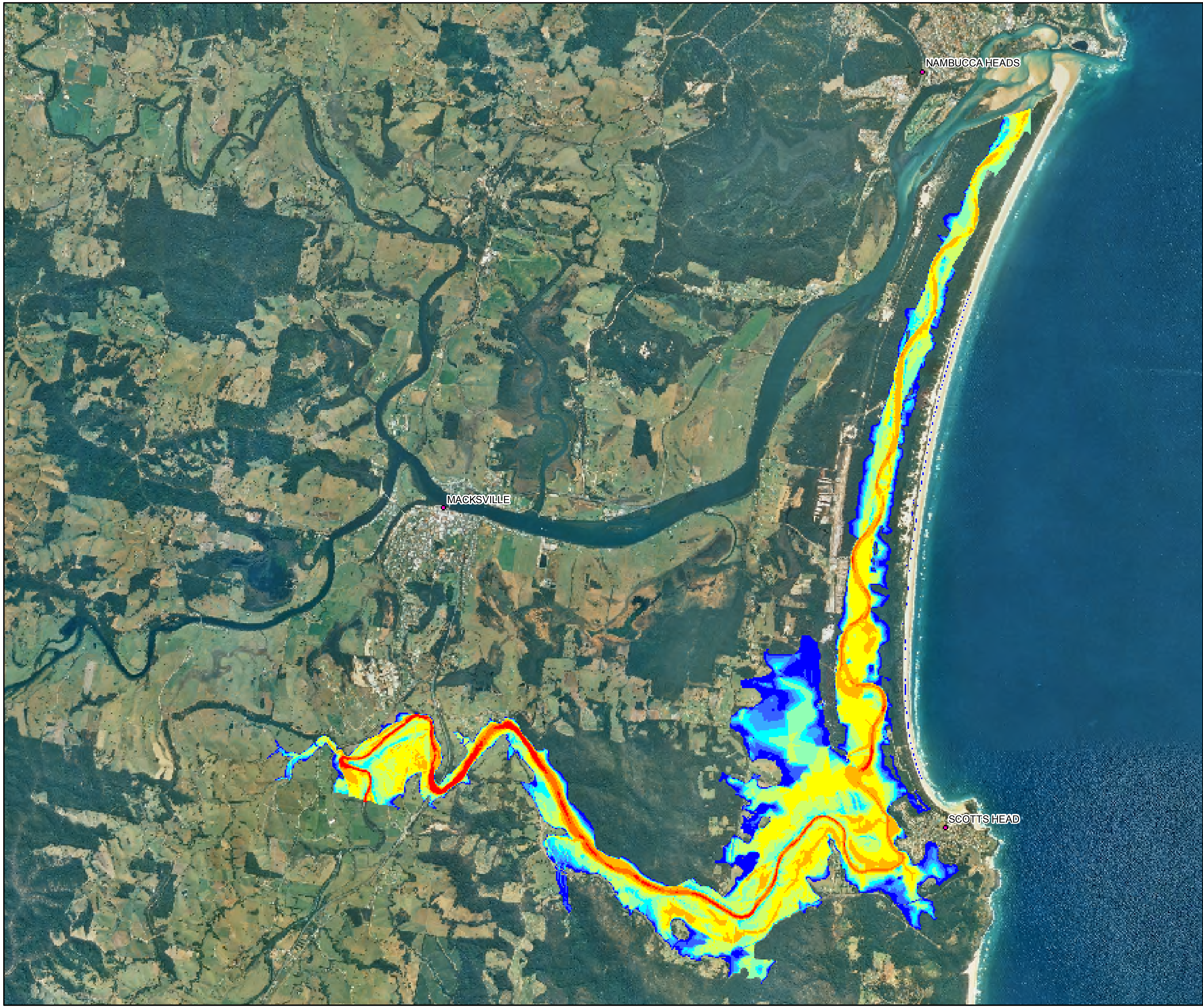

Figure A2-2 Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Existing Conditions
100 year ARI Flooding

Legend

Towns

Inundation

Depth (m)

- < 1.0
- 1.0 - 1.5
- 1.56 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- >6.0

N

0 0.5 1 1.5 2 2.5
Kilometres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
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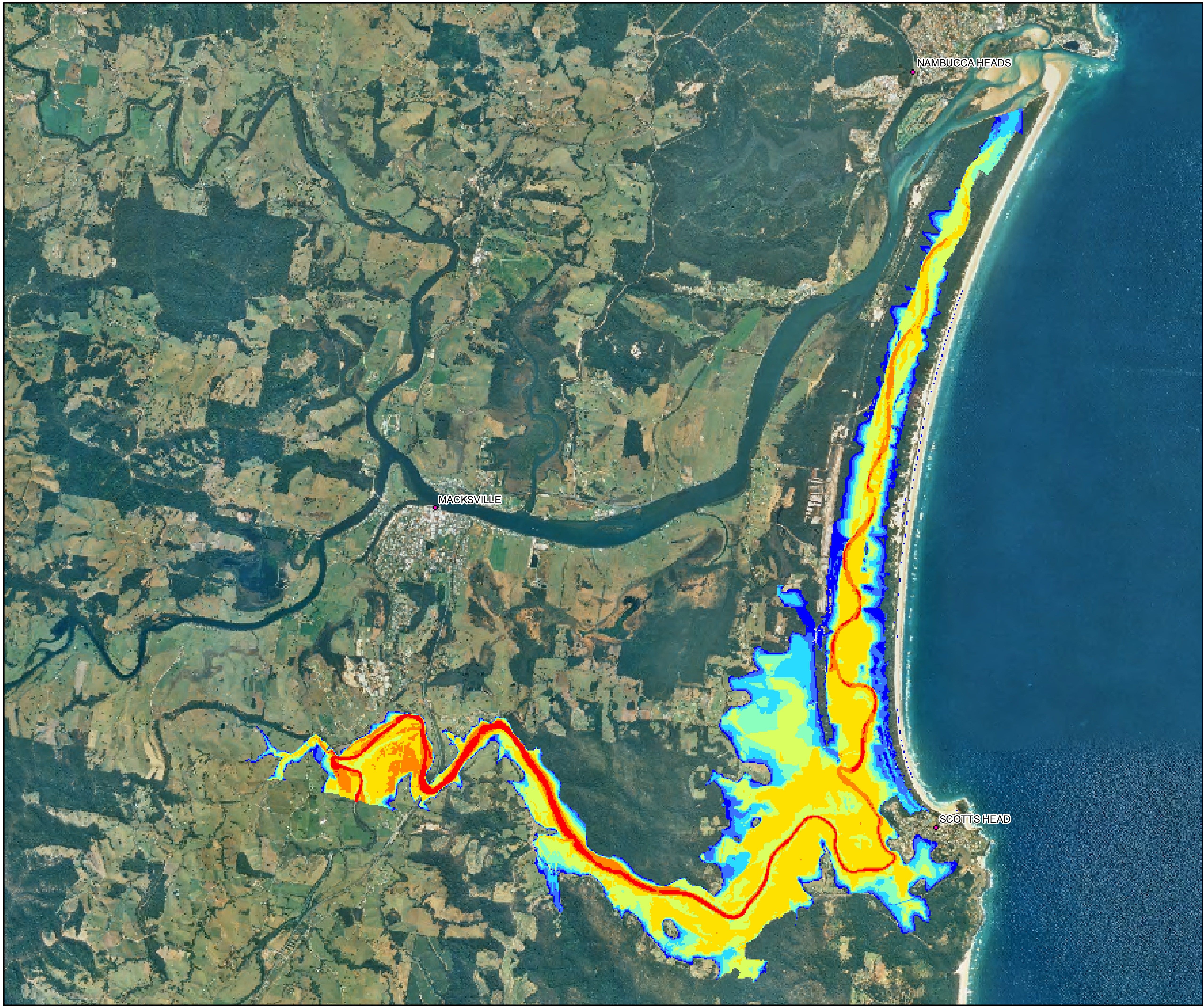

Figure A2-3
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Existing Conditions
2000 year ARI Flooding

Legend

Towns

Inundation Depth (m)

- < 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- 6.0 - 7.0
- > 7.0

N

0 0.5 1 1.5 2 2.5
Kilometres

Projection: MGA Zone 56

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A.3 Kalang River

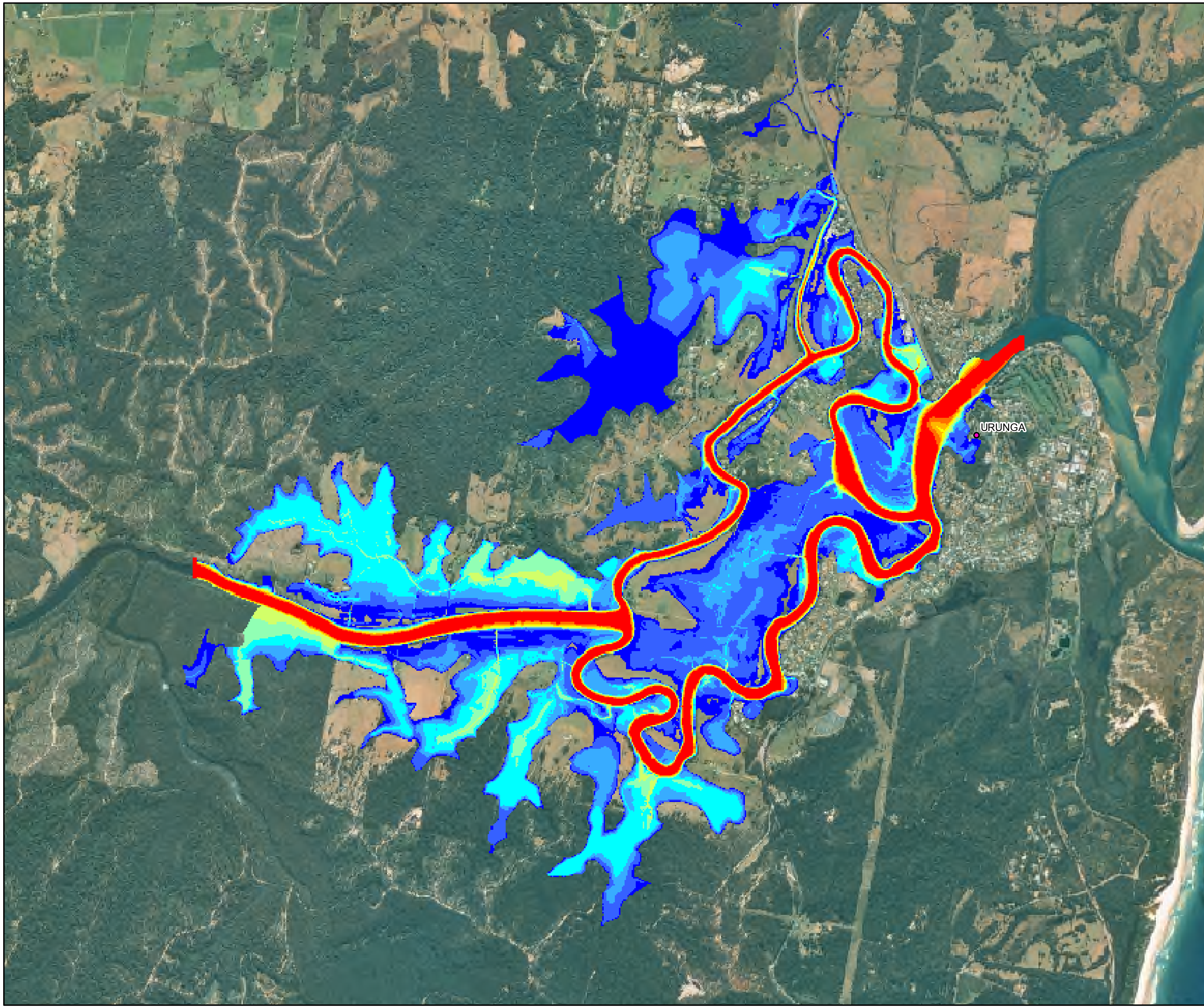

Figure A3-1 Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Kalang River
Existing Conditions
10 year ARI Flooding

Legend

Towns

Inundation Depth (m)

- < 0.5
- 0.51 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- > 4.5

N

0 0.25 0.5 0.75 1 1.25
Kilometres

Projection: MGA Zone 56

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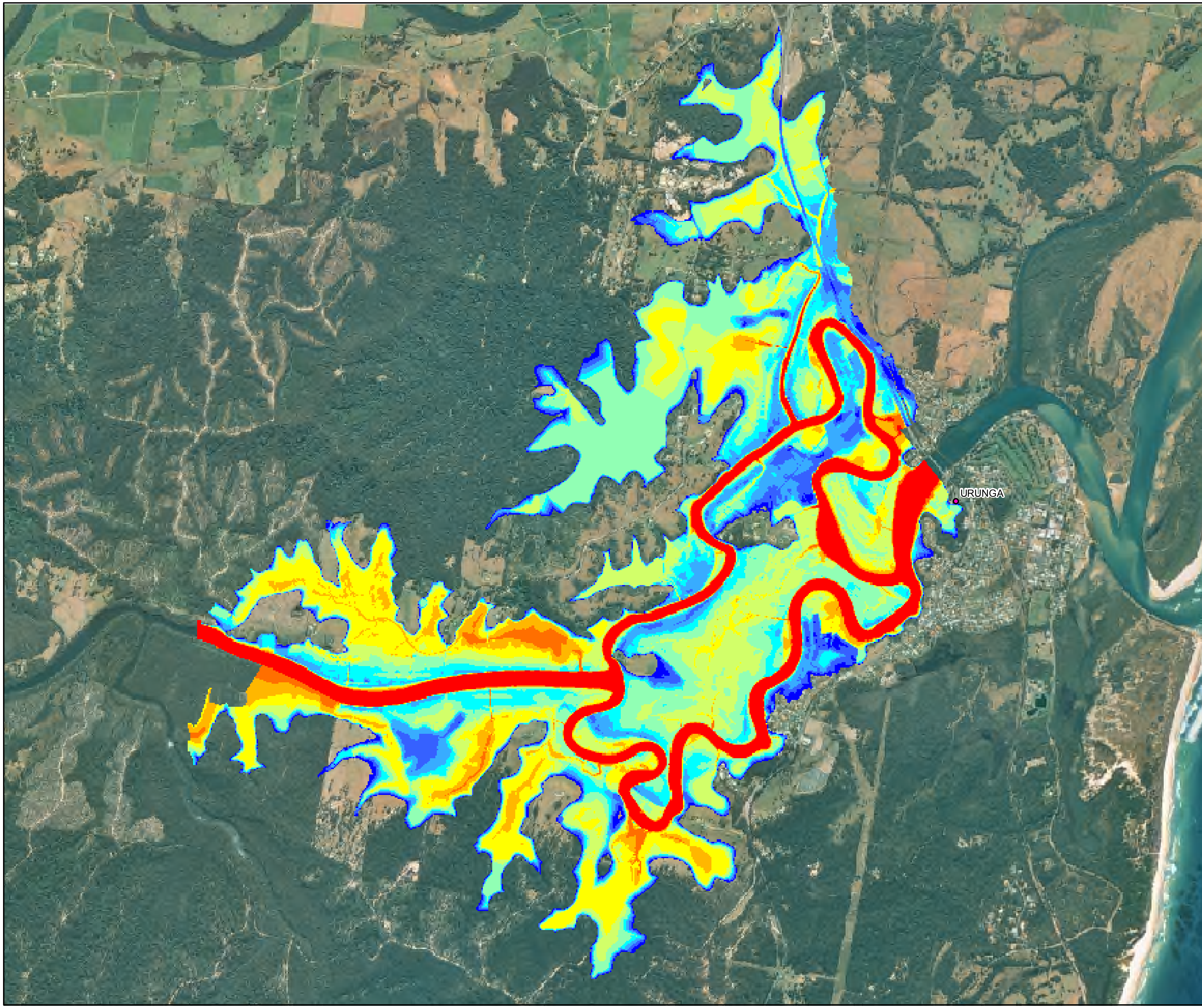

Figure A3-2 Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Kalang River
Existing Conditions
100 year ARI Flooding

Legend

- Towns

Inundation

Depth (m)

- < 0.5
- 0.51 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- > 4.5

N

0 0.25 0.5 0.75 1 1.25
Kilometres

Projection: MGA Zone 56

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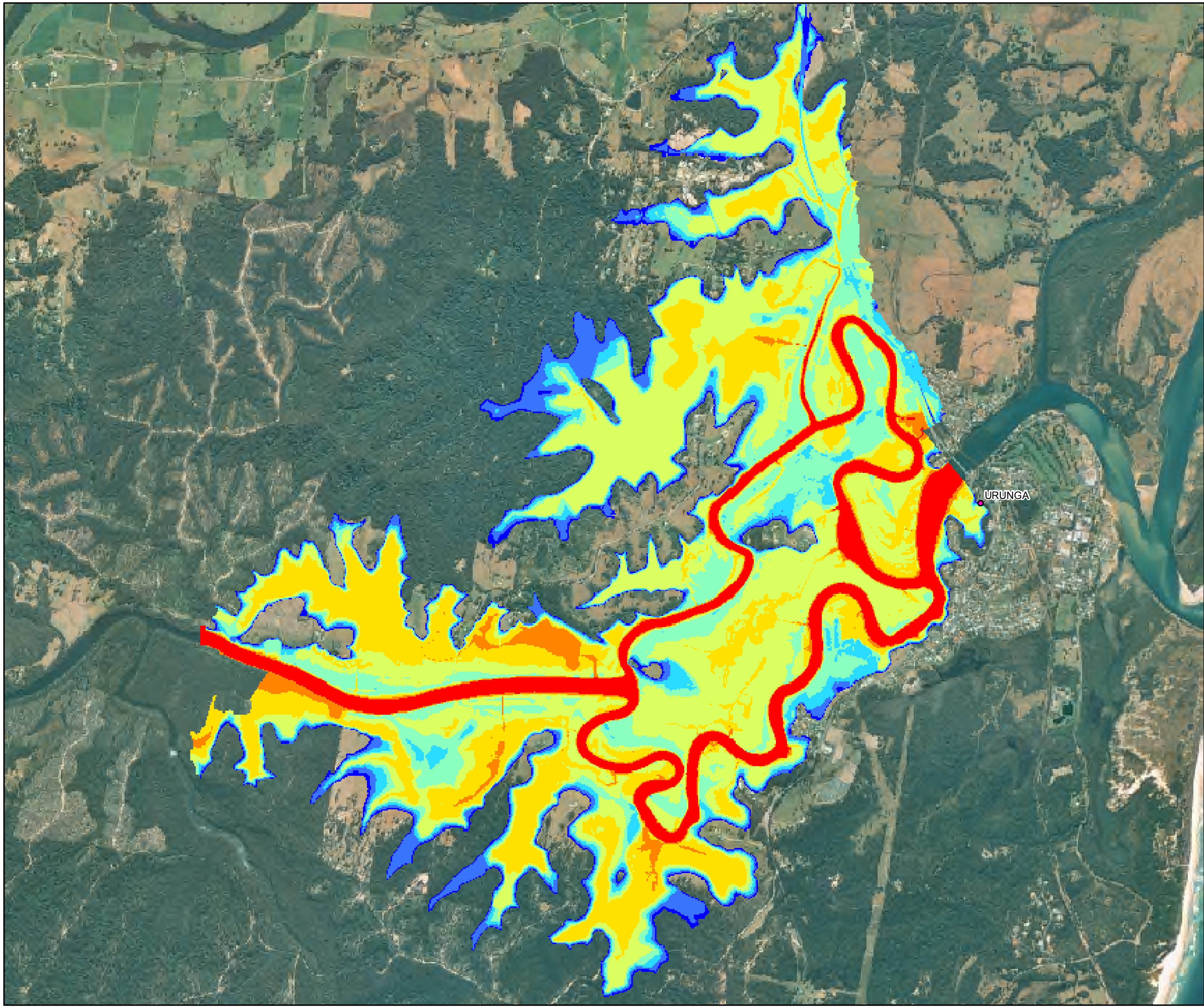
Figure A3-3
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Kalang River
Existing Conditions
2000 year ARI Flooding



Legend

Towns

Inundation

Depth (m)

- < 1
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- 6.0 - 7.0
- > 10.0

N

0 0.25 0.5 0.75 1 1.25
Kilometres

Projection: MGA Zone 56

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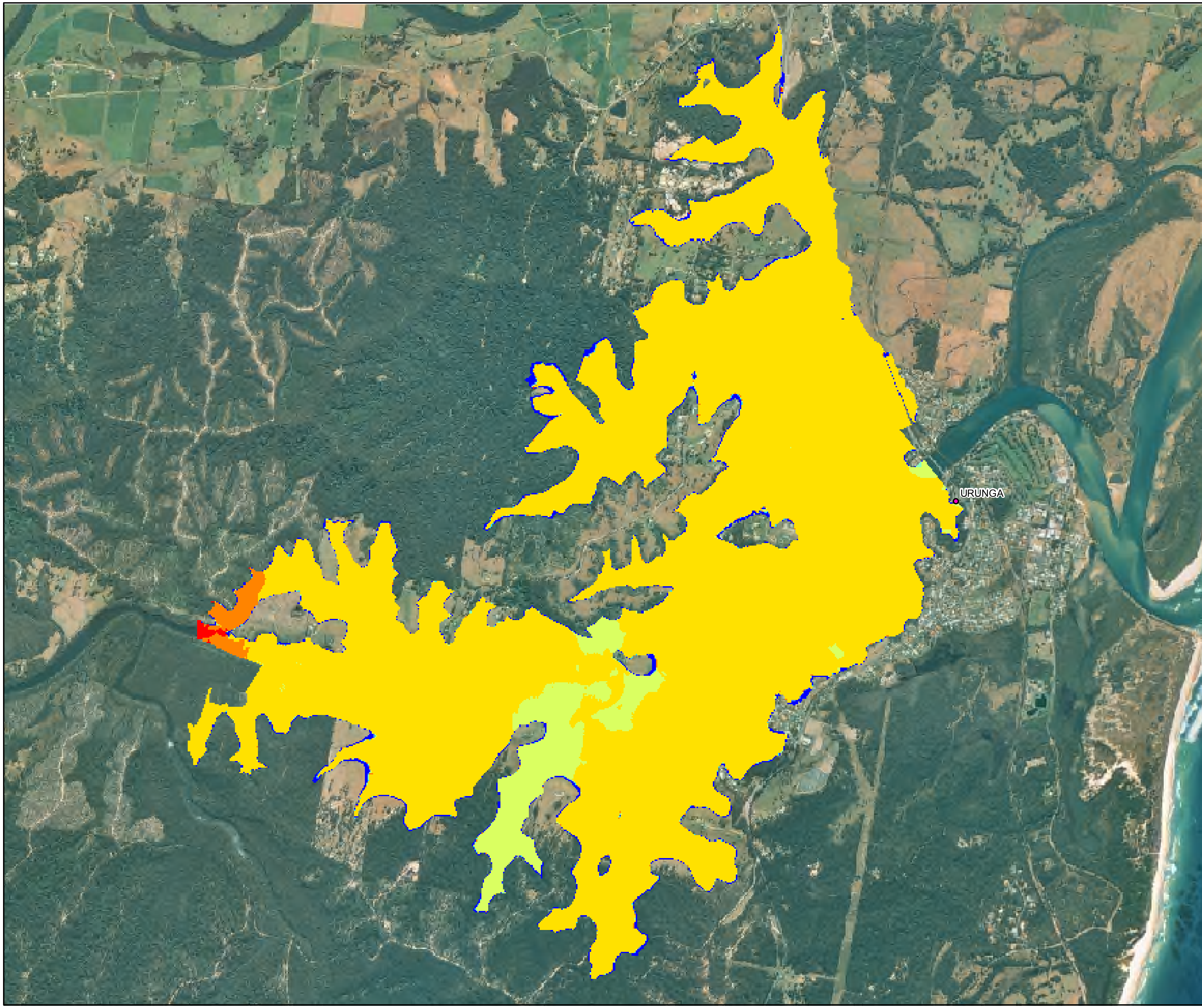

Figure A3-4
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Kalang River
Existing Conditions
100 year ARI
Flooding Comparision

Legend

• Towns

Afflux

Depth (m)

- < 0.5
- 0.50 - 0.52
- 0.52 - 0.54
- 0.54 - 0.56
- 0.56 - 0.58
- 0.58 - 0.60
- 0.60 - 0.70
- > 0.7

N

0 0.25 0.5 0.75 1 1.25
Kilometers

Projection: MGA Zone 56

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Appendix B Hydraulic results – developed conditions – existing climate

B.1 Nambucca River

Figure B1-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Developed Conditions
Existing Climate
10 year ARI
Change in Flood Level
Option 1

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
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Figure B1-2
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Developed Conditions
Existing Climate
100 year ARI
Change in Flood Level
Option 1

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200
Metres

Projection: MGA Zone 56

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Figure B1-3
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Developed Conditions
Existing Climate
10 year ARI
Change in Flood Level
Option 2

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ

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Figure B1-4
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Developed Conditions
Existing Climate
100 year ARI
Change in Flood Level
Option 2

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

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B.2 Warrell Creek

Figure B2-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Developed Conditions
Existing Climate
10 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.01m to -0.02m
- Change - Less than 0.01m
- Increase - 0.01m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 120 240 360 480 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ

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Figure B2-2
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Developed Conditions
Existing Climate
100 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.01m to -0.02m
- Change - Less than 0.01m
- Increase - 0.01m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 120 240 360 480 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

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B.3 Kalang River

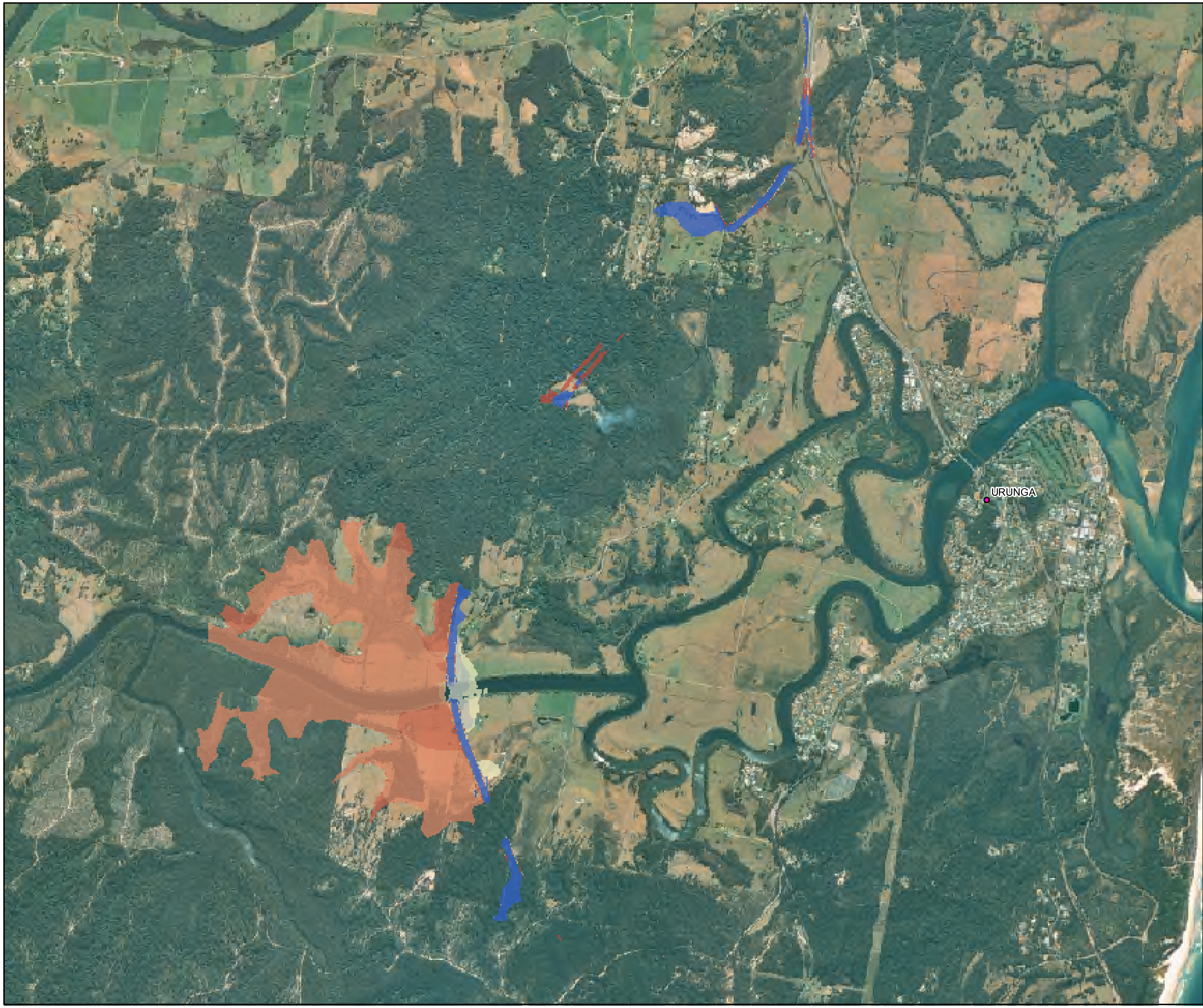

Figure B3-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Kalang River
Developed Conditions
Existing Climate
100 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 0.25 0.5 0.75 1 1.25
Kilometres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

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Appendix C Hydraulic Results – developed conditions – changed climate

C.1 Nambucca River

Figure C1-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Developed Conditions
Changed Climate
10 year ARI
Change in Flood Level
Option 1

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

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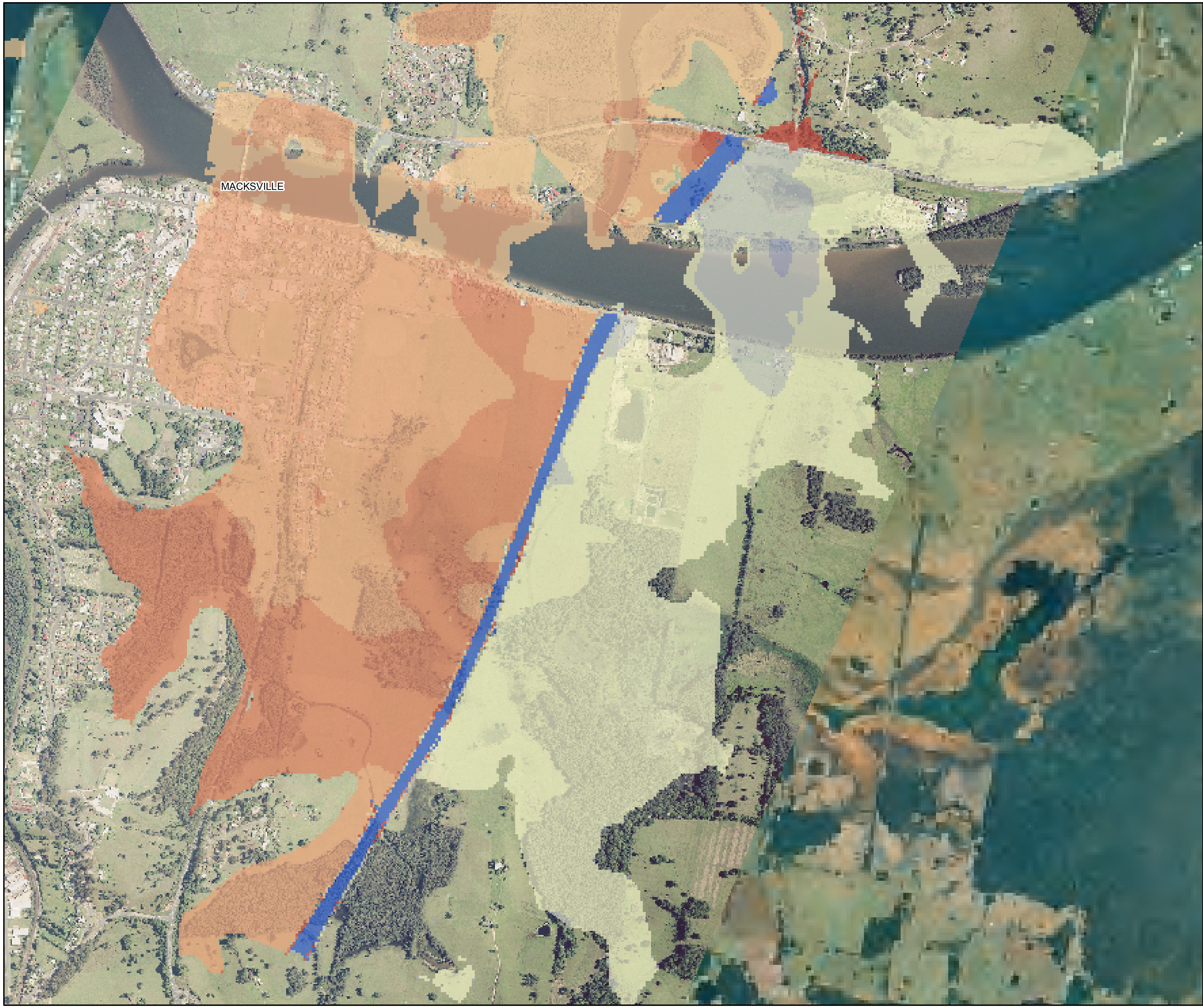

Figure C1-2
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment
Nambucca River Developed Conditions

100 year ARI
Change in Flood Level
Option 1

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ

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Figure C1-3
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Developed Conditions
Changed Climate
10 year ARI
Change in Flood Level
Option 2

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

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Figure C1-4
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment
Nambucca River
Developed Conditions
Changed Climate
100 year ARI
Change in Flood Level
Option 2

Legend

Change in Flood Level (m)
- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

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C.2 Warrell Creek

Figure C2-1 Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Developed Conditions
Changed Climate
10 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.01m to -0.02m
- Change - Less than 0.01m
- Increase - 0.01m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 120 240 360 480 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
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Figure C2-2
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Developed Condition
Change Climate
100 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.01m to -0.02m
- Change - Less than 0.01m
- Increase - 0.01m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 120 240 360 480 600
Metres

Projection: MGA Zone 56

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SKM

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C.3 Kalang River

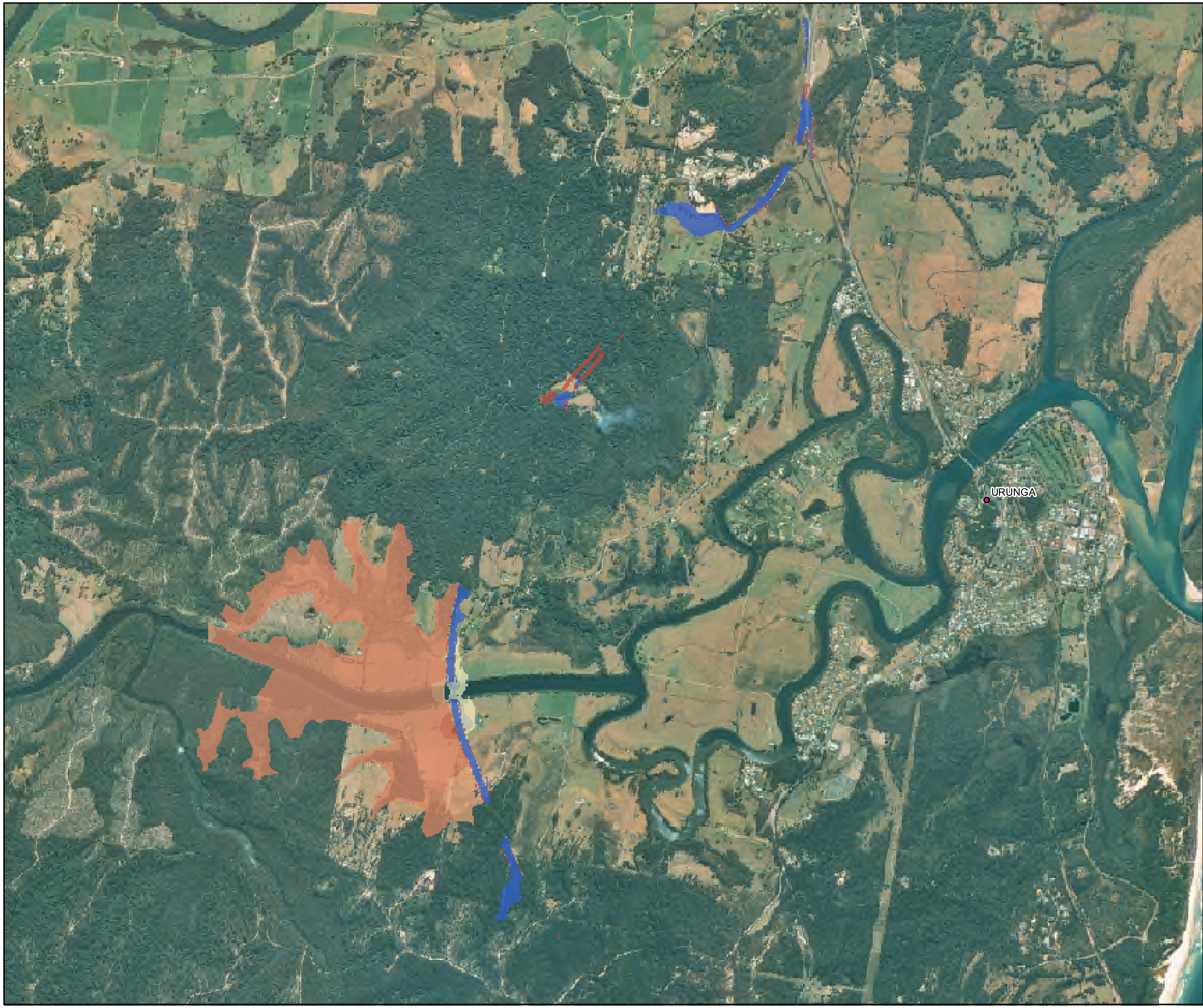

Figure C3-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Kalang River
Developed Conditions
Changed Climate
100 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 0.25 0.5 0.75 1 1.25
Kilometres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

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Appendix D Hydraulic results – impacts of climate change

D.1 Nambucca River

Figure D1-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Impact of Climate Change
10 year ARI
Change in Flood Level
Option 1

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ

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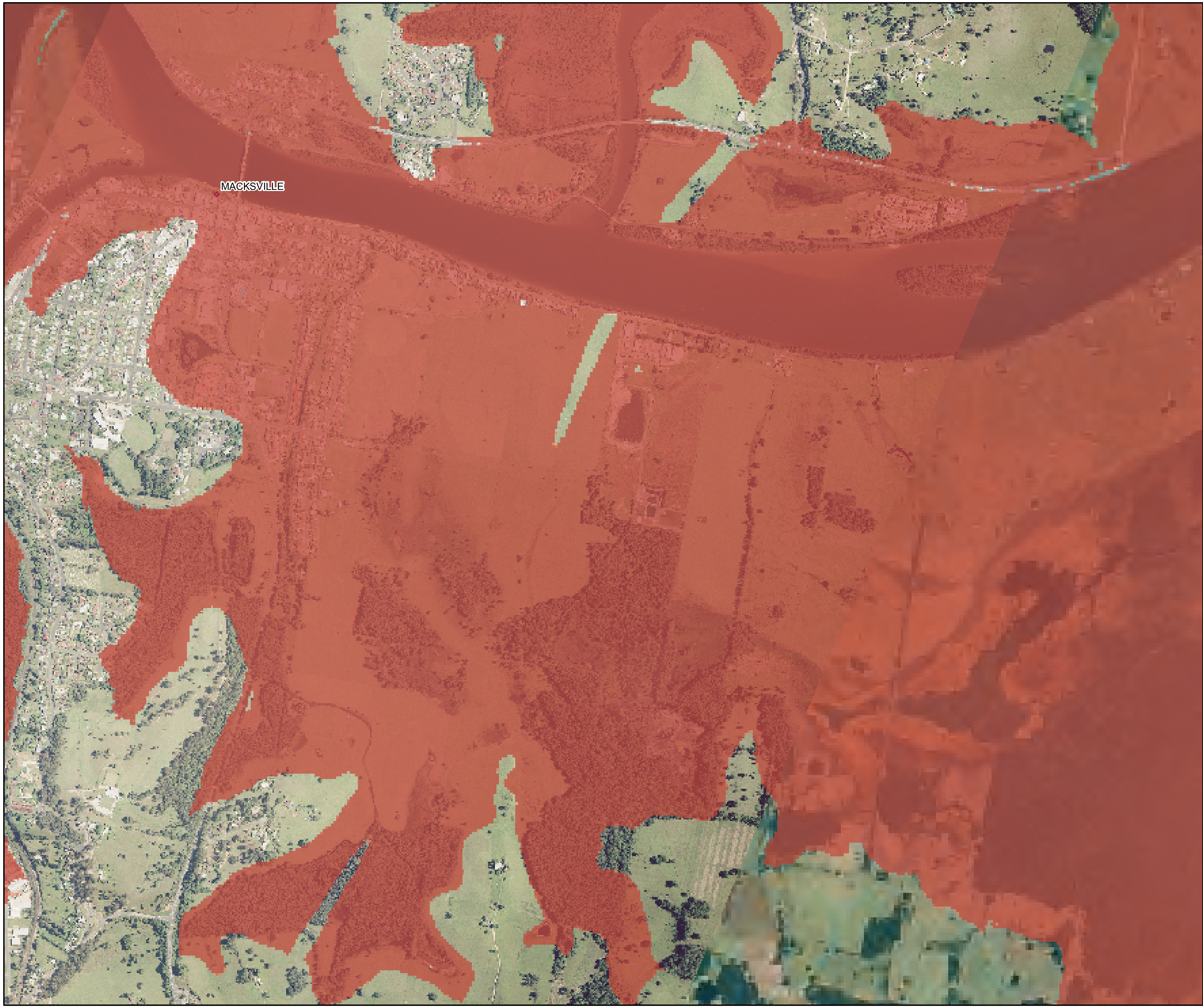

Figure D1-2
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Impact of Climate Change
100 year ARI
Change in Flood Level
Option 1

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ

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Figure D1-3
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Impact of Climate Change
10 year ARI
Change in Flood Level
Option 2

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ

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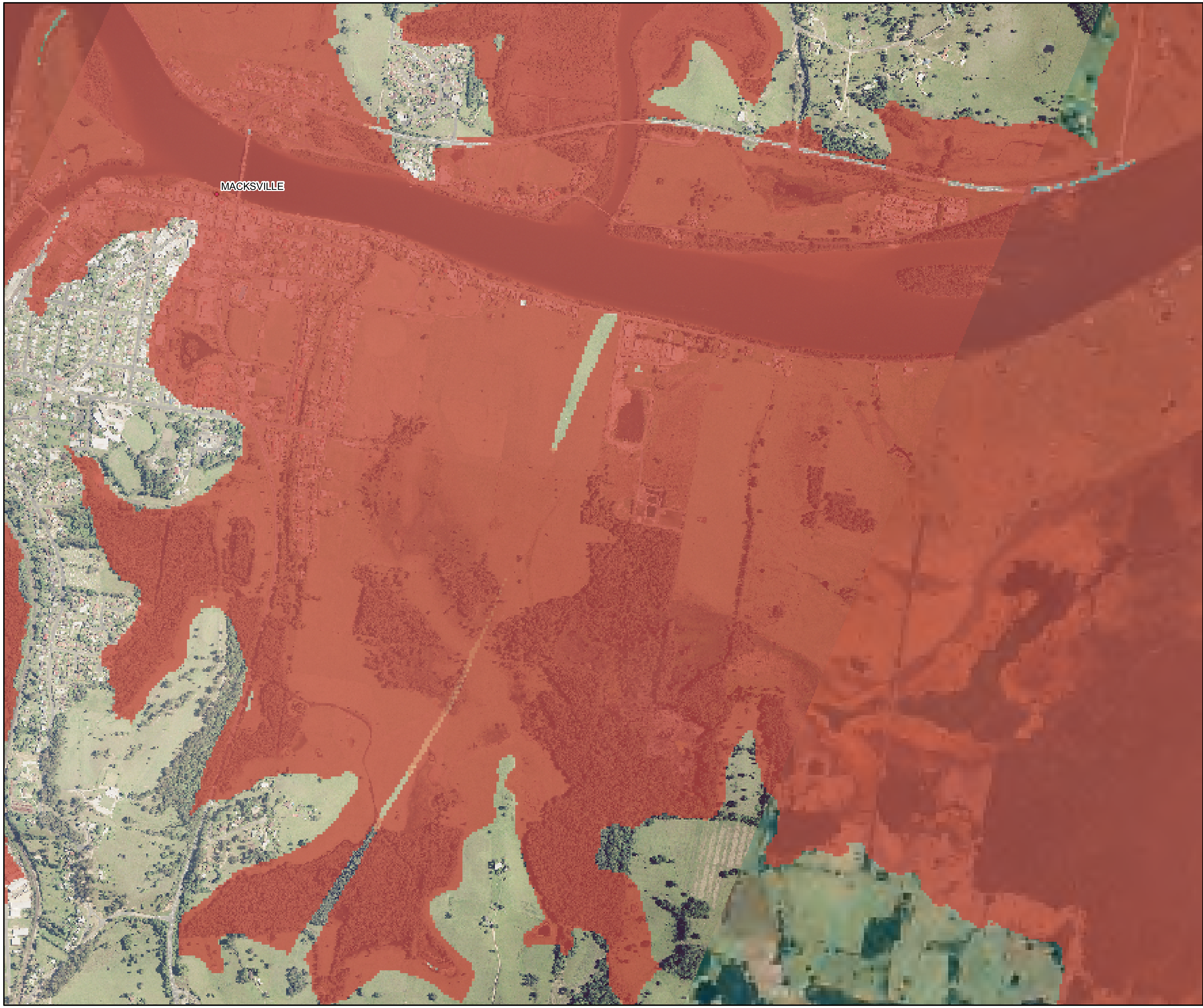

Figure D1-4
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Nambucca River
Impact of
Climate Change
100 year ARI
Change in Flood Level
Option 2

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 100 200 300 400 500 600
Metres

Projection: MGA Zone 56

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D.2 Warrell Creek

Figure D2-1 Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Impact of
Climate Change
10 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.01m to -0.02m
- Change - Less than 0.01m
- Increase - 0.01m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 120 240 360 480 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

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Figure D2-2 Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Warrell Creek
Impact of
Climate Change
100 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.01m to -0.02m
- Change - Less than 0.01m
- Increase - 0.01m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 120 240 360 480 600
Metres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

I:\ENVR\Projects\EN02286\33- Hydrology and Hydraulics\Spatial\Projects\Warrell_Creek_100y_AffluxC.mxd Produced: 12/02/2009

D.3 Kalang River

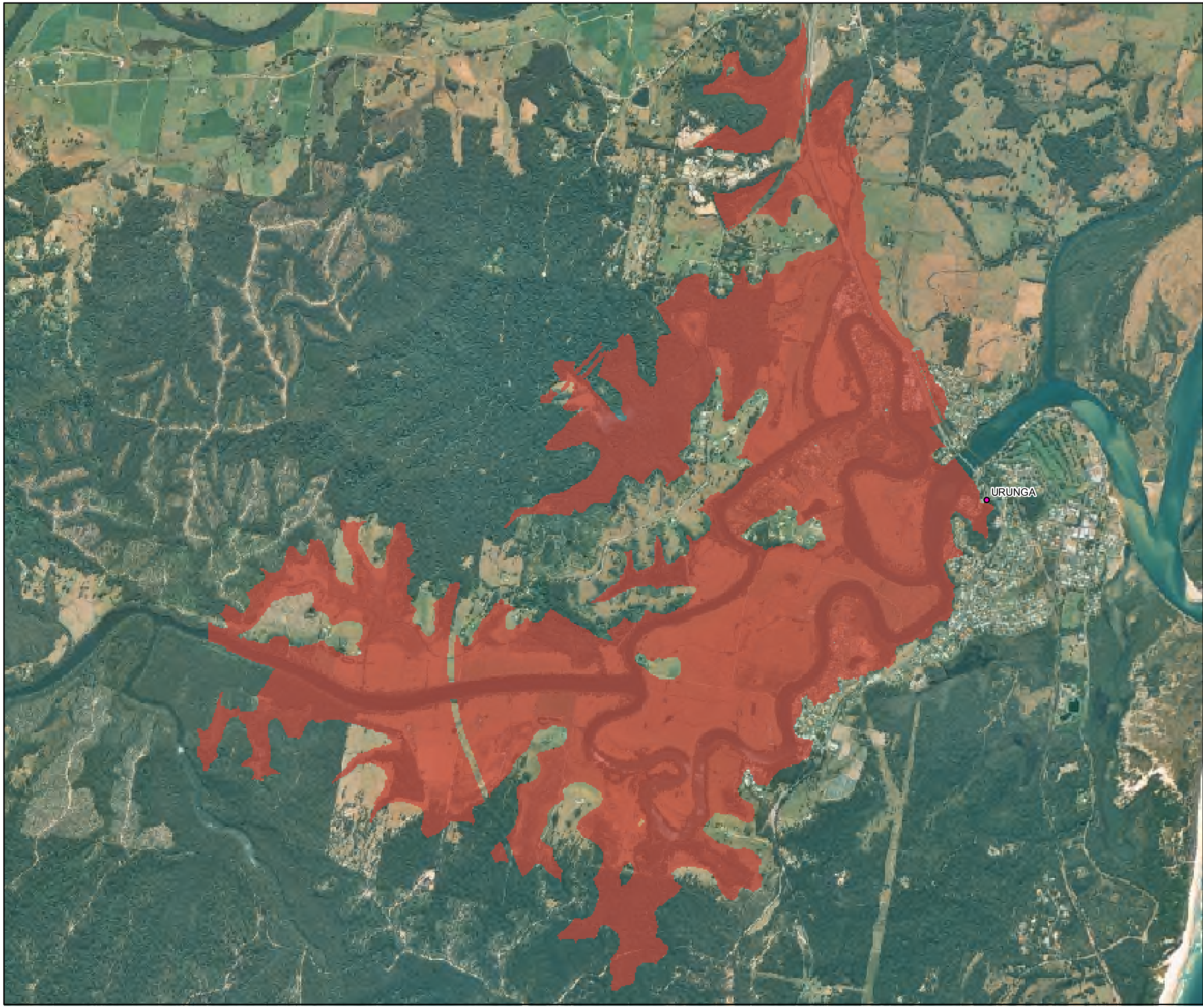

Figure D3-1
Pacific Highway Upgrade Project Warrell Creek to Urunga

Environmental Impact Assessment

Kalang River
Impact of Climate Change
100 year ARI
Change in Flood Level

Legend

Change in Flood Level (m)

- Decrease greater than 0.1m
- Decrease -0.08m to 0.1m
- Decrease -0.06m to -0.08m
- Decrease -0.04m to -0.06m
- Decrease -0.02m to -0.04m
- Decrease -0.015m to -0.02m
- Change - Less than 0.015m
- Increase - 0.015m to 0.02m
- Increase 0.02m to 0.04m
- Increase 0.04m to 0.06m
- Increase 0.06m to 0.08m
- Increase - greater than 0.08m

N

0 0.25 0.5 0.75 1 1.25
Kilometres

Projection: MGA Zone 56

SINCLAIR KNIGHT MERZ
SKM

I:\ENVR\Projects\EN02286\33- Hydrology and Hydraulics\Spatial\Projects\Kalang_100y_AffluxC.mxd Produced: 12/02/2009