UPGRADING THE PACIFIC HIGHWAY

Woolgoolga to Ballina Planning Alliance

UPGRADING THE PACIFIC HIGHWAY

Woolgoolga to Ballina Upgrade

Working Paper - Hydrology and Flooding

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Contents

Glossary of terms and abbreviations

afflux	Rise in flood level as a result of an obstruction to flow.
annual exceedance probability (AEP)	The chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 cubic metres per second has an AEP of five per cent, it means that there is a five per cent chance (ie a 1 in 20 chance) of a peak discharge of 500 cubic metres per second (or larger) occurring in any one year (see also average recurrence interval).
average annual flood damages	The long-term average annual cost of damages as a result of flooding for a given property.
Australian Height Datum (AHD)	National survey datum corresponding about to mean sea level.
average recurrence interval (ARI)	The long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20 year ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. (see also annual exceedance probability)
cell	*Culvert design:* Single opening. *Hydraulic modelling:* Element in a two-dimensional hydraulic model representing a specific geographic area on the floodplain.
catchment	The catchment at a particular point is the area of land that drains to that point.

design flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 100 year ARI or one per cent AEP flood).
ephemeral	Flowing only in response to recent and local precipitation; does not experience permanent flow.
flood	Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.
flood behaviour	The pattern / characteristics / nature of a flood.
flood damage	The financial and social costs of flooding.
flood depth	The height or elevation of floodwaters above ground level.
flood impact	The increase (or in some cases decrease) in flood levels or flood depths as a result of the project.
flood level	The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".
floodplain	Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.
floodplain management	The coordinated management of activities that occur on the floodplain.
flood prone land	Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (ie the entire floodplain).
flood storage	Floodplain area that is important for the temporary storage of floodwaters during a flood.

floodway	A flow path (sometimes artificial) that carries significant volumes of floodwaters during a flood.
historical flood	A flood that has actually occurred.
hydraulic	The term given to the study of water flow in rivers, estuaries and coastal systems.
hydrograph	A graph showing how a river or creek's discharge changes with time.
hydrology	The term given to the study of the rainfall-runoff process in catchments.
mAHD	Metres above Australian Height Datum (see Australian Height Datum).
multicell	Multiple number of individual openings within a culvert structure.
m/s	Metres per second (a common measure of speed / velocity).
m^3/s	Cubic metres per second (a common measure of flow).
peak flood level, depth, flow or velocity	The maximum flood level, depth, flow or velocity that occurs during a flood event at any given point.
probable maximum flood (PMF)	An extreme flood deemed to be the maximum flood likely to occur.
probability	A statistical measure of the likely frequency or occurrence of flooding.
RCP	Reinforced concrete pipe
RCBC	Reinforced concrete box culvert

runoff	The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.
Soffit	Underside of a bridge.
stage	See flood level.
stage hydrograph	A graph of water level over time.
velocity	The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, ie the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi-2D computer flood model is quoted as the depth and width averaged velocity, ie the average velocity across the whole river or creek section.
water level	See flood level.

Executive summary

Introduction

A detailed hydrology and flooding study was carried out as part of the Pacific Highway upgrade from Woolgoolga to Ballina.

The objective of the study was to assess the flooding impacts to or from the project to inform the environmental impact statement (EIS) and to meet the Director-General's Environmental Impact Assessment Requirements (EARs) for the project.

The following hydrologic and hydraulic assessments were undertaken as part of this study:

- Design objectives and criteria for flooding, in consideration of legislation and previous development project design were developed.
- Community and stakeholders were consulted and outcomes reviewed.
- Flood models used for previous stages of the project were reviewed. Where necessary, these were replaced or improved to meet the needs of the EIS.
- A range of design flood events were modelled and historical flooding reviewed to define the existing case flooding behaviour.
- Flood model results were analysed to identify required locations of structures and incorporated in the design to achieve the flood objectives.
- Potential flood impacts during construction were assessed against the design objectives for flood management.
- Potential flood impacts during operation were assessed against the design objectives for flood management.
- Geomorphological impacts due to waterway diversions and other significant modifications to natural flow paths were assessed.
- Impacts to farm dams, including acquisition and removal of catchment area were assessed.
- Climate change impacts, including sea level rise and increased rainfall intensity and design capacity of proposed and existing stormwater drainage structures were assessed.

Study area

The project is located in the Northern Rivers catchment areas, which includes three water catchment areas: Coffs Harbour waterways, Clarence River and Richmond River. The Coffs Harbour waterways catchment is around 508 square kilometres including the Corindi River catchment and coincides with the southern part of the project. The Clarence River catchment, which coincides with the central part of the project, is a large catchment covering around 22,000 square kilometres. The Richmond River catchment covers an area of around 7,000 square kilometres and coincides with the northern part of the project.

The hydrology and flooding study and flood models focus on watercourses and associated floodplains that the project would cross. The project crosses 17 waterways including two large river systems – the Clarence River and the Richmond River.

Assessment methodology

The development of the project concept design has been guided by specific flood immunity criteria and flood impact objectives. Hydrological and hydraulic modelling techniques have been used to identify the project design requirements to meet these criteria and objectives, including the requirements for road embankment levels and waterway openings (such as bridge and culvert structures).

The project has been designed to achieve the following minimum flood immunity levels:

- All highway carriageways above the 20 year average recurrence interval (ARI) flood levels for the crossings of the Clarence and Richmond rivers and their floodplains
- All carriageways above the 100 year ARI flood levels for the remainder of the corridor.

As it is not possible to achieve zero impact in all areas of the floodplain, flood management objectives were developed to be used in the assessments. The objectives aim to provide tolerances for changes in flooding behaviour (flood height, flood durations, flood flows, directions and velocities) that are realistically achievable. Tolerances were established for change in flooding behaviour for three types of land uses for land outside the project boundary:

- Houses, commercial premises and urban areas
- Cane farm land
- Grazing area, forested lands and other rural areas.

The flood management objectives are shown in Table 1. The project has been designed to achieve these objectives where feasible and cost-effective. As well as the flood impact objectives listed above, there were a number of other elements of flood behaviour that were assessed to determine the flood impacts of the project including:

- Floodwater rate of rise and warning time
- Flood evacuation and flood access
- Bed and bank stability impacts
- Flood hazard impacts

The bed and bank stability impacts were assessed as part of a geomorphological assessment of each waterway to be crossed by the project with a bridge.

Table 1 Flood management objectives for different land-uses

Parameter	Objectives		
	Houses and urban areas	**Cane farm land**	**Grazing land, forest land and other rural areas**
Flood level (height)	Less than 50 mm increase for any assessed flood event (up to the 100 year ARI event).	Less than 50 mm increase for any assessed flood event (up to the 100 year ARI event).	Generally less than 250 mm increase with localised increases of up to 400 mm for any assessed flood event acceptable over small areas (up to the 100 year ARI event).
Flood duration	No more than a 5% increase.	No more than a 5% increase.	No more than a 10% increase.
Flood velocity	Velocity-depth to remain in the zone of low hazard for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011) where current velocity-depth are currently low hazard.	Velocities to remain below 1.0 m/s where currently below this figure. An increase of not more than 20 per cent where existing velocity is above 0.3 m/s.	Velocities to remain below 1.0 m/s where currently below this figure. An increase of not more than 20 per cent where existing velocity is above 1 m/s.
Flood direction	No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges).		

The flood impacts attributable to the project were undertaken by quantifying the flooding behaviour of the base case (usually the existing case) and comparing that with the flooding behaviour of the case with the project constructed.

The flood behaviour of all mapped watercourses and associated floodplains crossed by the project were simulated with hydrological and hydraulic models. Over 15 different models were used.

The flood models are typically two-dimensional flood models, which are well suited to simulating road embankments and associated waterway structures (eg bridges and culverts). The models were generally based on those currently used by local government authorities for flood risk management in the Clarence River, Richmond River and the Ballina areas, with modifications made to meet the specific needs of this assessment.

Flood events assessed

The 100 year ARI flood is a highly important flood event as it is typically used for setting floor levels and fill levels in residential and commercial areas. Hence, the assessment of the 100 year ARI flood provides an assessment of the impact of the project on the future development potential of affected land. For this reason, it is critical that this study includes an assessment of this flood for all watercourses crossed by the project. The 100 year ARI flood is also used to benchmark the flood management objectives to direct culvert and bridge design along the project.

In addition to the 100 year ARI event, each major watercourse was assessed with a frequent flood event (two year ARI for local catchments or five year ARI for the major floodplains), the 20 year ARI event, and a rare event equivalent to approximately the 200 year ARI. The impacts associated with flood events in between these events or smaller than the two or five year ARI event can be generally estimated by interpolation or extrapolation of these results.

The exceptions to the relationship described above are on the Clarence and Richmond river floodplains. Here, the floodplain flows are quite complex with considerable interaction between floodplain flowpaths over a range of flood events.

Furthermore, the flood impacts on the lower Clarence River floodplain are complicated by the small difference between the 20 year ARI flood levels and the 50 year ARI levels. This difference is smaller than the crossfall height of the road embankment (ie the level difference between the low outer edge and the high middle edge of the road). Hence, in a 50 year ARI flood event, the road embankment would not be overtopped and all flows would pass through the culverts and bridges. For these reasons, an additional 50 year ARI flood event was assessed for the Clarence River floodplain and the Mid Richmond River floodplain.

For the Lower Richmond River floodplain (ie Duck Creek and Ballina area), the difference between the 20 year ARI and the 100 year ARI flood levels is very small. For most parts of this section, the crossfall height of the road embankment is larger than this difference. This means that although the flood immunity of the road is only 20 year ARI in this section, the road embankment would not be overtopped in the 100 year ARI flood event. Hence, for the Lower Richmond River, the 50 year ARI event was not assessed as there would be a generally linear increase in the impacts between these two flood events.

The flood events that have been determined to meet the aims of assessing a range of events are shown in Table 2 Table for each flood investigation area.

Table 2 Modelled watercourses and the flood events assessed in the modelling study

Flood investigation area	Event assessed					
	2 year ARI	5 year ARI	20 year ARI	50 year ARI	100 year ARI	~200 year ARI
Corindi River	✓		✓		✓	✓
Halfway Creek	✓		✓		✓	✓
Pheasant Creek	✓		✓		✓	✓
Coldstream River	✓		✓		✓	✓
Pillar Valley Creek	✓		✓		✓	✓
Chaffin Creek and nearby creeks	✓		✓		✓	✓
Champions Creek and vicinity	✓		✓		✓	✓
Clarence River (Glenugie to Tyndale)		✓	✓	✓	✓	✓
Clarence River (Tyndale to Maclean)		✓	✓	✓	✓	✓
Clarence River (Maclean to Iluka Road)		✓	✓	✓	✓	✓
Mororo Creek	✓		✓		✓	✓
Tabbimoble Creek	✓		✓		✓	✓

Flood investigation area	Event assessed					
	2 year ARI	5 year ARI	20 year ARI	50 year ARI	100 year ARI	~200 year ARI
Tabbimoble Floodway No. 1	✓		✓		✓	✓
Oakey Creek	✓		✓		✓	✓
Mid Richmond River		✓	✓	✓	✓	✓
Lower Richmond River		✓	✓		✓	✓

Community consultation

A number of community consultation and engagement activities including advertisements, community updates, community information centre open days and community liaison group meetings had been conducted prior to 2010. The route selection and concept design included consideration of the issues raised at these meetings.

A planning focus meeting was held for the project in August 2011, identifying the project to government agencies. This meeting formed part of the development of the Director-General's environmental assessment requirements for the environmental impact statement. Hydrology issues that were raised by government agencies were addressed in subsequent assessments.

Four meetings are planned to take place during 2011 and 2012 to engage and address community concerns and display results of the environmental assessments.

Existing flood behaviour

Flooding on the large Clarence and Richmond river floodplains can extend over a number of weeks. This can result in damage to buildings and roads, loss or stranding of livestock, loss of crops and blockage of access.

Flooding also occurs in upper catchment waterways where fast flows and rapid rise and fall of creek levels can occur. In some areas, the short duration flooding of these upper waterways is influenced by long duration flood inundation of the larger floodplains (Clarence and Richmond rivers).

The level of the existing highway is below the 20 year ARI flood event level in many locations. This means that the highway can be inundated by flood waters during a 20 year ARI flood event.

Flood model simulations were carried out for all 15 flood models for a range of flood events to define the flood behaviour of the base case. This included mapping of flood levels, depths, velocities (magnitude and direction), times of inundation and rates of rise and fall.

A survey of house floor levels was carried out for this project and combined with floor level data from other sources. This data in conjunction with flood levels for a range of flood events enabled an estimate of the long-term average annual flood damage to be derived for each impacted house on the floodplain.

Over 500 properties have been identified as being subject to over-floor flood inundation in the impacted parts of Chatsworth, Harwood and Maclean and surrounding areas.

Over 300 properties have been identified as being subject to over-floor flood inundation along the Mid Richmond River and in the impacted areas of Coraki, Woodburn and Broadwater.

The township of Ballina and surrounding area is also particularly prone to flooding with many properties experiencing flooding along Maguires Creek, Duck Creek, Emigrant Creek and the Lower Richmond River.

Construction impacts to flood behaviour

The following activities may result in hydrology and flooding impacts during the construction phase of the project:

- Placement of temporary construction facilities: Approximately 49 potential sites for temporary construction facilities are located on the floodplains or below the 20 year ARI flood level
- Early construction of road embankments at soft soil sites: The project would require construction of sections of embankment in advance of the road construction to accelerate the settlement of soft soils at nine sites. The impacts associated with these fill areas has been quantified using the flood models. The resulting impacts are within the flood impact objectives
- Construction of temporary connections to the existing highway: All but four of the potential temporary connection locations are outside of floodplain areas. The four temporary connection locations, while located on floodplain areas, would not result in any additional flooding impacts relative to the predicted impacts of the completed project (ie operational impacts)
- Impact on cane drains: The main area where this has been identified as a potential issue is within the Shark Creek basin. This issue would be further investigated and addressed during detailed design in conjunction with the verification of temporary construction site locations.

Operational impacts to flood behaviour

The main potential hydrology and flooding issue associated with project operation is a change in flood behaviour as a result of placing embankments and new infrastructure on floodplains and across waterways.

Potential operational impacts were reduced in the concept design stage by incorporating structural crossings designed with the aim of meeting the project flood impact objectives to the greatest extent practicable and in consideration of other environmental needs.

The project would result in impacts to flood levels, flood inundation periods, and the timing of flood water rise and fall. However, all of the flooding impacts of the project would meet the flood management objectives.

Due to the relatively steep flood gradients of the smaller creek floodplains, the impacts to flood levels would dissipate quickly to below 50 millimetres within a few hundred metres upstream of the project boundary. The steeper gradient of the floodplain also limits the lateral width of the floodplain, so that the flood extent resulting from the project is not much larger than that under existing conditions.

The risk to people, stock and property relating to evacuation or emergency access would not be increased by the project in all areas with the exception of the landowner on Byrons Lane in the Clarence River catchment, some areas in the Oakey Creek catchment and Woodburn in the Richmond River catchment. The increased risks in the Oakey Creek and Richmond River catchments are associated with an increase in the rate of flood level rise which could reduce evacuation time for residents. In the case of the landowner on Byrons Lane, the project will make boat access to the highway difficult during times of flooding, thereby reducing flood access.

Overall, the project results in a substantial improvement in the flood immunity of the Pacific Highway. This would improve flood access and the ability to evacuate during a flood event. It would also reduce the frequency and duration of highway closures due to flooding.

Operational impacts to hydrology

There would not be any discernible change to the hydrology of downstream waterbodies, such as wetlands or the Solitary Islands Marine Park, due to the increase in impervious areas resulting from the project. The fractional increases in impervious areas due to the project are less than two per cent and generally less than one per cent.

Ten farm dams are expected to experience some loss of catchment area as a result of the project, which would reduce the overall volume of rainfall-runoff captured by the dam.

Climate change

Climate change is predicted to result in changes to sea levels, storm surge magnitudes and rainfall intensities. The effects of these predicted changes on the project and the expected impacts of the project were assessed. These assessments included consideration of the project life and the timeframes of the climate change predicted changes.

In consideration of the influence of climate change on the flood immunity and flood impacts of the project, the following conclusions can be made:

- The long-term variability of the frequency of large river flood events indicates that a 10 per cent increase in rainfall intensities would have only a minor impact on embankment flood immunity compared to the impact of natural variability in flood frequencies.
- The consequences of rainfall intensities increases for this project are not catastrophic. The proposed road embankment is designed to withstand flood inundation. Overtopping of the road embankment would not constitute a failure of the embankment, but rather a disruption to highway traffic.
- The project provides sufficient drainage capacity at most waterway crossings to accommodate a 10 per cent increase in rainfall intensity and a 0.6m rise in sea levels such that flood level impact objectives would still be met.
- Additionally, the project contains sufficient flexibility to accommodate modification of existing embankment heights and waterway openings (culverts and bridges) to manage further increases in rainfall intensity if required in the future.

Mitigation and management: pre-construction measures

This working paper provides details of measures to be carried out in the pre-construction phase including upgrading of flood models, changes to be made to the design during detailed design, on-going consultation, and geomorphological assessments.

Mitigation and management: construction measures

This working paper provides details of measures to mitigate flood impacts due to ancillary facilities temporary cane drainage changes, border fencing, maintenance of highway cross-drainage during construction and instream pier construction. Construction on or near waterways will need to be managed at the detailed design stage in accordance with the NOW guidelines which consider instream works, outlet structures, riparian corridors, watercourse crossings and Vegetation Management Plans.

Mitigation and management: operational measures

The project design has been developed so that the potential impacts on flooding are reduced to a level that meets the flood impact objectives. Specific measures to be carried out during the operational phase of the project have been identified including maintenance of waterway structures to minimise the effect of debris blockage. As well, to provide an adaptive response to possible changes to the climate, should the need for raising the road embankment levels, this would be carried out during periodic pavement rehabilitation works.

1. Introduction

1.1. The project

NSW Roads and Maritime Services (RMS) is seeking project approval for the Woolgoolga to Ballina Pacific Highway upgrade project (the project) which is located on the NSW North Coast. The approval is sought under Part 5.1 of the Environmental Planning and Assessment Act 1979 (EP&A Act).

The project would upgrade around 155 kilometres of highway, forming a major part of the overall Pacific Highway Upgrade Program. The project would provide a four-lane divided carriageway from around five kilometres north of Woolgoolga to around six kilometres south of Ballina. Figure 1-1 shows the regional location of the project.

The project has been divided into eleven sections between tie-ins with the existing Pacific Highway to aid description, and the impact assessment for the project is described for each of these sections (refer to Table 1-1).

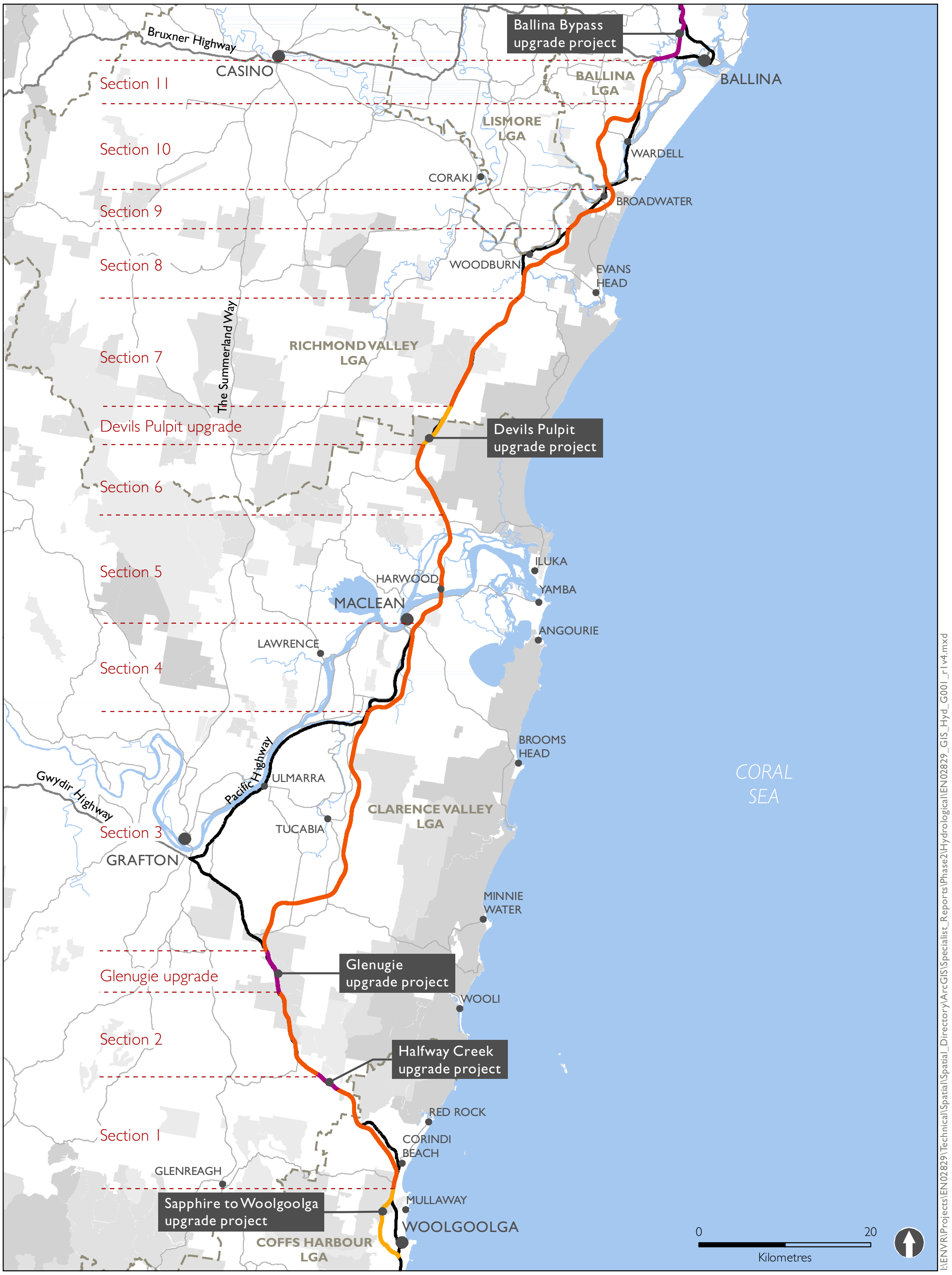
Table 1-1 Project sections and lengths

Project section	Location	Station		Length (kilometres)
		Start	Finish	
1	Woolgoolga to Halfway Creek	0	17.0	17.0
2	Halfway Creek to Glenugie upgrade	17.0	28.7	11.7
3	Glenugie upgrade to Tyndale	33.8	68.8	35.0
4	Tyndale to Maclean	68.8	82.0	13.2
5	Maclean to Iluka Road, Mororo	82.0	96.4	14.4
6	Iluka Road to Devil's Pulpit upgrade	96.4	105.6	9.2
7	Devil's Pulpit upgrade to Trustums Hill	111.1	126.4	15.3
8	Trustums Hill to Broadwater National Park	126.4	137.6	11.2
9	Broadwater National Park to Richmond River	137.6	145.1	7.5
10	Richmond River to Coolgardie Road	145.1	158.6	13.5
11	Coolgardie Road to Ballina bypass	158.6	164.0	5.4

While the project is for a four-lane motorway standard upgrade, the construction and opening of the project would be staged. Staging could include some sections being constructed and opened initially as a four-lane arterial standard upgrade.

The project does not include the Pacific Highway upgrades at Glenugie and Devils Pulpit, which are located between Woolgoolga and Ballina, as Glenugie is now complete and Devils Pulpit is under construction. Together with the Glenugie and Devils Pulpit upgrades, the project would complete a total of 164 kilometres of upgraded highway between Woolgoolga and Ballina.

Figure 1-1 Project overview



The project

Upgrade completed to dual carriageway

Upgrade under construction

Existing Pacific Highway

The key features of the project include:

- Around 155 kilometres of motorway standard highway, comprising a four-lane divided carriageway (two lanes in each direction) that can be upgraded to a six-lane divided carriageway in the future, if required
- Bypasses of Grafton, South Grafton, Ulmarra, Woodburn, Broadwater and Wardell
- Ten interchanges to provide access to and from the upgraded highway at:
- Range Road (Corindi)
- Glenugie (Eight Mile Lane)
- Tyndale (Sheey's Lane)
- Maclean (Goodwood Street)
- Yamba Road (Harwood)
- Watts Lane (Harwood)
- Iluka Road (Woombah)
- Woodburn (Trustums Hill Road)
- Broadwater (Evans Head Road)
- Wardell (Coolgardie Road)
- About 40 bridge crossings of waterways or floodplains, including bridges over the Clarence and Richmond rivers
- About 55 overbridge and underpass structures to maintain access along local roads crossed by the project
- Viaducts located where the project would cross low-lying or flood-prone areas
- Service roads and access roads to maintain connections to existing local roads and properties
- Structures to help wildlife cross above or below the project including crossings for tree-dwelling mammals, dedicated culverts under the highway and over-land fauna bridges
- Rest areas located at around 50 kilometre intervals for both northbound and southbound traffic. These are located at:
- Tucabia (north and southbound)
- North of Mororo Road (southbound)
- South of Old Bagotville Road (north and southbound)
- Heavy vehicle weigh station located near Halfway Creek.

In addition to these key features, the project would include construction sedimentation basins, operational water quality basins and construction facilities such as compounds and batching plants.

Construction would be staged from 2013 onwards following project approval, depending on the availability of funding. Construction of the project would generally comprise the conventional techniques employed on most major highway projects, modified for specific environmental or engineering constraints. RMS seeks approval for construction working hours for all day (8am–5pm) on Saturdays and between 6am and 7pm on weekdays.

An indicative outline of construction activities may include:

- Establishment of the construction site and ancillary facilities
- Enabling works, including adjustments to utilities, property adjustments, works to existing drainage and provision of construction access roads
- Clearing and grubbing of vegetation, stripping of topsoil and stockpiling for re-use
- Construction of road cuttings and embankments
- Treating areas of soft soil to stabilise the underlying soil sub-layers
- Installing drainage and bridging structures
- Laying of pavement materials
- Installing pavement markings, signposting, street lighting and progressive landscaping.

The project would not be built in one phase. The project would be delivered in stages as further funding becomes available and to best manage construction and material resources. Stages would be identified that prioritise and target upgrades and works that would best deliver safety and traffic efficiency improvements, and best deliver value for money outcomes.

This working paper assesses the potential impacts of the full motorway standard upgrade for construction and operation. Where there are relevant differences between the full motorway standard upgrade and the initial upgrade to arterial standard, those impacts are also assessed. Impacts are generally identified through the eleven project sections identified above.

Further information on the description of the project and the assessment of other environmental aspects can be found in the main volume of the environmental impact statement.

1.2. Study objectives and scope

1.2.1. Objectives

The objective of the hydrology and flooding study is to assess the flooding impacts to or from the project to inform the environmental impact statement and meet the Director-General’s environmental assessment requirements for the project.

The specific flooding and hydrology objectives for the project and applied to the assessment of the concept design are:

- Flood immunity level of 20 year average recurrence interval (ARI) flood level as a minimum, with 100 year ARI flood level immunity if feasible
- Minimal potential changes to and impact on the hydraulic systems of the Clarence and Richmond river floodplains and smaller river and creek systems
- Minimal potential impact to properties, dwellings and existing road infrastructure and drainage systems
- Limited impacts to flood depths and flood durations on dwellings and urban areas, cane farm land and other agricultural land for any assessed flood event (ie less than or equal to 100 year ARI event).

Further detail on flood immunity and flood management objectives are discussed in Section 2.1.

1.2.2. Purpose of working paper

The hydrology and flooding working paper covers a suite of assessments on hydrological and hydraulic processes affected by the project to meet the Director-General's environmental assessment requirements. The assessment includes:

- Developing design objectives and criteria for flooding, in consideration of legislation and previous development project design
- Consulting with community and stakeholders and reviewing outcomes of previous development project consultation
- Reviewing existing flood models for the study area, including flood assessments and modelling undertaken during the previous development projects
- Reviewing the existing environment and flooding behaviour of the study area through modelling for a range of design flood events and historical flooding
- Analysing flood model results to identify required locations of structures and direct design to achieve flood objectives
- Assessing potential flood impacts during construction, including temporary connections and impacts on cane drainage networks
- Assessing potential flood impacts during operation, including:
- Potential changes to flooding behaviour (levels, velocities, direction and duration)
- The impact of changes to flooding behaviour on infrastructure, property and business operations (including agricultural land and stock movement to flood refuges and evacuation routes)

- The impact of changes to flooding behaviour on hazard and emergency service within the affected area
- The impact of changes to flooding behaviour on future development potential of access affected land
- Consideration of Probable Maximum Flood (PMF) impacts and increased cost of annual flood damages
- Assessing geomorphological impacts because of diversions and other significant modifications to natural flow paths
- Assessing impacts to farm dams, including acquisition and removal of catchment area
- Assessing climate change impacts, including sea level rise, increased rainfall intensity and design capacity of proposed and existing stormwater drainage structures
- Developing mitigation and management measures for flood impacts during construction and operation.

1.2.3. Environmental assessment requirements

Roads and Maritime Services of NSW (RMS) is seeking approval for the project under Part 5.1 of the NSW *Environmental Planning and Assessment Act 1979* (the Act).

The EARs stipulate minimum requirements for the study. The requirements relevant to hydrology and flooding are presented in Table 1-2.

Table 1-2 Director-General's environmental assessment requirements

Reference	Requirements	Where addressed in report
Soils, sediments and water	The EIS must address:	
	• impacts on surface water flows, quality and quantity, with particular reference to any likely impacts on surrounding water bodies, wetlands and their habitats, including potential indirect impacts on the Solitary Island Marine Park by works in the Arrawarra Creek and Corindi River Catchments;	Section 6.22
	• flooding impacts and characteristics, to and from the project, with an assessment of the potential changes to flooding behaviour (levels, velocities and direction) and impacts on bed and bank stability, through flood modelling, including:	Sections 6.2 to 6.17

Reference	Requirements	Where addressed in report
	• hydraulic modelling for a range of flood events,	Chapters 5 and 6
	• description, justification and assessment of design objectives (including bridge, culvert and embankment design),	Section 2.2 Section 2.3 Sections 6.2 to 6.17
	• an assessment of afflux and flood duration (inundation period) on land, infrastructure, property and business operations (including agricultural land and stock movement to flood refuges and evacuation routes), hazard and emergency service within the affected area, and future development potential of access affected land, and	Chapters 5 and 6
	• consideration of the effects of sea level rise, changes to rainfall frequency and/or intensity as a result of climate change, including an assessment of the capacity of proposed (and existing) stormwater drainage structures;	Chapter 7

1.3. Definitions

1.3.1. Study area

The study area for the hydrology and flooding study is generally considered the area that may be directly or indirectly affected by the project.

The hydrology and flooding study and flood models focus on watercourses and associated floodplains that the project would cross. These include numerous creeks and two large river systems – the Clarence River and the Richmond River.

The flood study area is the extent of land potentially impacted in the 100 year ARI flood for creek catchments and the 20 year ARI flood for the Clarence and Richmond rivers.

The separate flood investigation areas assessed in detail by this study are:

- Corindi River (including Blackadder Creek and Cassons Creek) and floodplain
- Halfway Creek and floodplain
- Pheasant Creek
- Coldstream River and floodplain

- Pillar Valley Creek and floodplain
- Chaffin Creek (including unnamed creeks near Mitchell Road and Bostock Road)
- Champions Creek and floodplain
- Clarence River (and floodplain areas including Shark Creek and Chatsworth / Harwood Islands)
- Mororo Creek and floodplain
- Tabbimoble Creek and floodplain
- Tabbimoble Floodway No. 1 and floodplain
- Oakey Creek and floodplain
- The Mid Richmond River (including Tuckombil Canal and McDonalds Creek) and floodplain areas. For the purposes of this assessment, the Mid Richmond River is defined as the extent of catchment upstream from Broadwater
- The Lower Richmond River (including Duck Creek and Emigrant Creek) and floodplain areas, (including Ballina). For the purposes of this assessment, the Lower Richmond River is defined the extent of catchment downstream from Broadwater.

Figure 1-2 through Figure 1-6 present the mapped extents of these watercourses. These flood map areas represent the extent of flood impacted area from the project, in line with the Director-General's environmental assessment requirements. They do not cover the full extent of flooded area investigated.

The impacted community areas assessed in this study on the Clarence and Richmond river floodplains are also shown in Figure 1-2 through Figure 1-6. These include communities between Tyndale and Maclean, communities on and surrounding Chatsworth and Harwood islands, and the communities of Woodburn, Broadwater, Ballina and surrounding areas.

The definition of the existing flooding behaviour of each of the floodplains is in Sections 4.2 through to 4.15. This description of the 'baseline' conditions form the basis of the impact assessment presented in subsequent chapters.

1.3.2. Terminology

This working paper uses terminology that is specific to the project or to hydrology and flooding. This section provides definitions for specific terminology used within the working paper.

Project boundary

The project boundary is defined by the permanent boundary needed to construct the project and maintain the project in operation. The width of the corridor varies along its length, depending on factors such as the locations of interchanges and sediment basins. The boundary is typically about 150 metres wide but is wider where features such as interchanges are proposed.

Station

Station refers to the measurement in kilometres from the start of the project (around five kilometres north of Woolgoolga) to the termination of the project (around six kilometres south of Ballina).

Culvert structure

A drain, usually circular or boxed (rectangular), that allows water to pass under an embankment (eg highway). Culvert structures many either be single cell (one opening) or multicell (multiple openings).

Flood event

The term “flood event” can refer to either:

- A historical flood event, being an actual event which has occurred for which flood levels and rainfall data may have been gauged, or
- A design flood event, which is generated based on a design storm of a specific duration (critical duration) that creates the greatest volume of rainfall-runoff for a given probability of occurrence.

Historical flood events are usually referred to using the month and year of the event. Historical flood events may be compared with a design event of a similar size to indicate the likelihood of that specific event occurring.

Design flood events are generally referenced to a probability using either the terms Average Recurrence Interval (ARI) or Annual Exceedance Probability (AEP).

The ARI refers to the long-term average number of years between the occurrence of a flood as big as (or larger than) the selected event. For example, floods with a discharge as great as (or greater than) the 20 year ARI design flood will occur with widely varying periods between these events but the average period would be 20 years.

The AEP relates to the chance of a flood of a given size (or larger) occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 cubic metres per second has an AEP of five per cent, it means that there is a five per cent chance (ie a one in 20 chance) of a peak discharge of 500 cubic metres per second (or larger) occurring in any one year.

These terms are statistically related but not equivalent. The two terms converge as the probability of the event becomes rarer. For example, a five year ARI event has an AEP of 18.1 per cent (compared to “one in five” or 20 per cent), while a 100 year ARI event has an AEP of 0.995 per cent (compared to “one in 100” or one per cent).

This working paper adopts the ARI terminology. However, it is recognised that AEP is the more appropriate terminology for large events (greater than 10 year ARI). This is due to a difference in the statistical analyses used to estimate the magnitude of rare events compared with that used for frequent events.

Average annual flood damages

This term describes the long-term average annual cost of damages as a result of flooding for a given property. To calculate this long-term average, flood damages are calculated for a number of floods with varying annual probabilities. The damages for each flood are then appropriately weighted to the annual probability. Hence, a 100 year ARI flood has an annual probability of approximately one per cent. Hence, the damages associated with that flood are weighted by using one per cent of the damages. This process is repeated for the full range of flood events to create a long-term annual damage total.

One-dimensional and two-dimensional hydraulic modelling

One-dimensional hydraulic modelling represents flow in one dimension (ie the direction of flow). These types of models are typically used where the primary direction of the flow is known and/or when detail is required to represent the channel characteristics. One-dimensional modelling of flooding in a waterway uses a series of cross-sectional profiles along a reach of interest. The movement of water between cross-sections is calculated at each profile based on hydraulic parameters, such as slope, roughness and hydraulic gradient with the resulting flood levels reported at each cross-section.

Two-dimensional modelling is typically used where the direction of flow is variable and/or complex. In particular, two-dimensional models are often used where flow is not confined to a waterway and the direction and velocity is influenced by the features of the floodplain, such as crops, dense vegetation, buildings and urban areas. Two-dimensional modelling simulates flooding across the floodplain and waterway using a mesh of cells (usually a grid) with attributed ground level data. The movement of water between cells is calculated at each cell based on hydraulic parameters, such as slope, roughness and hydraulic gradient. Because all model parameters are linked to the grid cell representing a specific parcel of land, all model results, including flood levels and velocities, can be easily converted into spatial layers and mapped.

One-dimensional and two-dimensional models are often linked to enable better resolution of flooding within a channel while also representing spatial variation in flooding across the floodplain.

Both one-dimensional and two-dimensional hydraulic models simulate flood levels, depths and velocities. Both modelling types require hydrological inputs to estimate how rainfall is converted to runoff (inflow). These are generated from hydrological (rainfall-runoff) models.

Hydrological rainfall-runoff modelling

Hydrological models are computer-based models which simulate the processes of rainfall over a catchment becoming runoff in a flood event. These models represent the catchments as a network of inter-connected sub-catchments, each defined by parameters such as area, slope, vegetation type and soil infiltration characteristics.

Inputs to these models are typically rainfall distributions of flood-producing rainfall events such as a 100 year ARI flood. These rainfall patterns vary with intensity over the duration of the rainfall event and the total rainfall depth is derived from statistical analyses of regional rainfall records.

Figure 1-2 The project alignment - Arrawarra to Glenugie

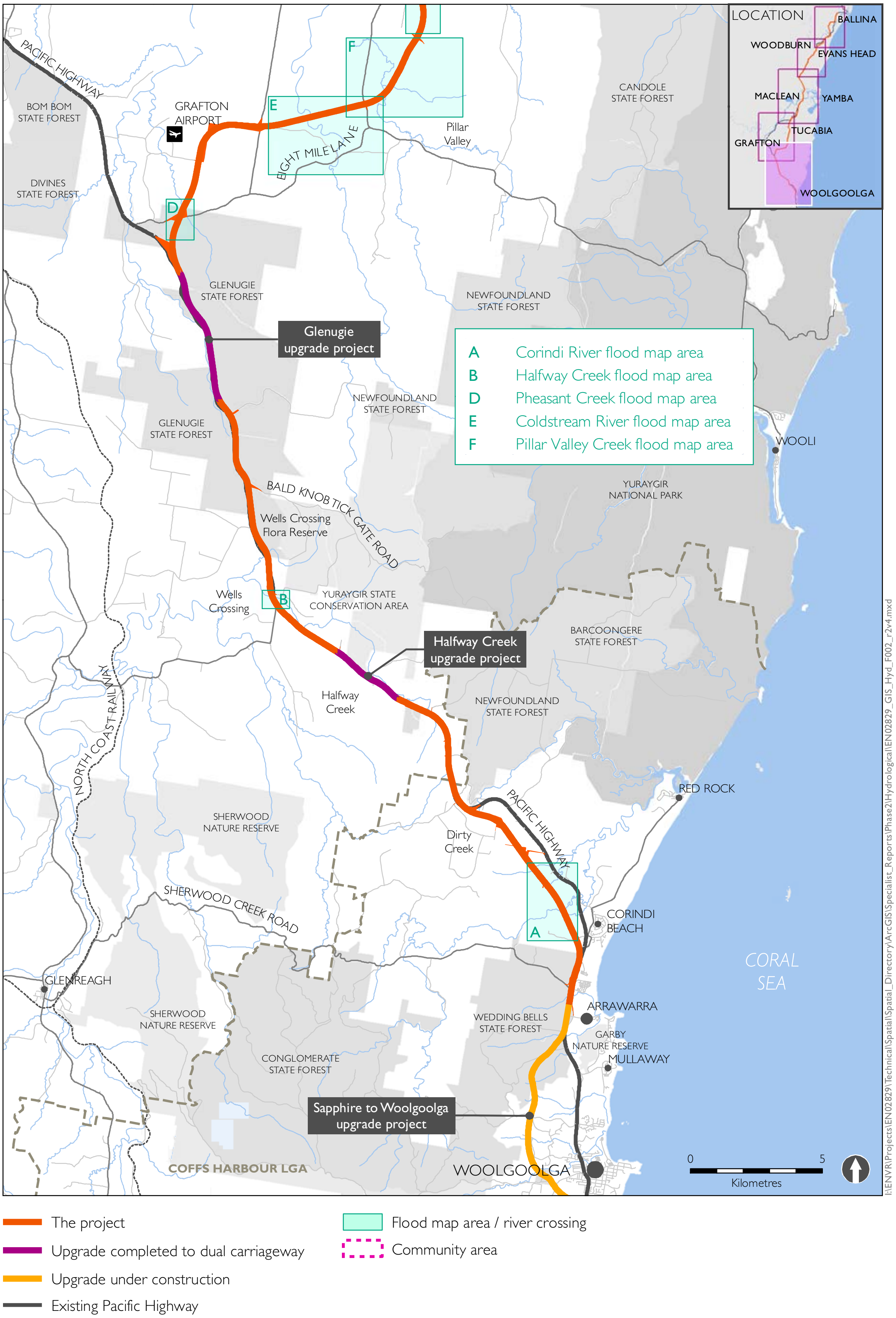
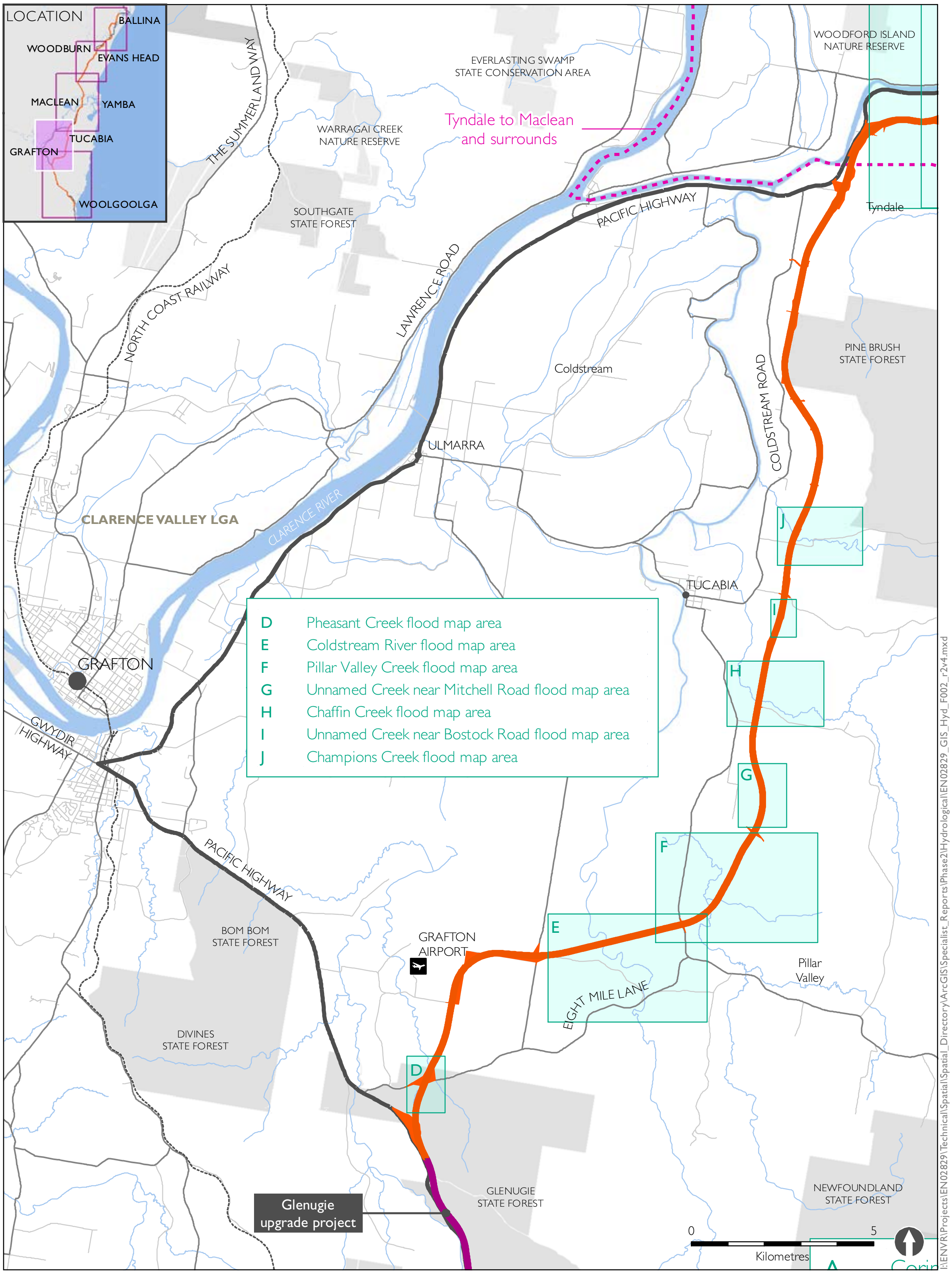


Figure 1-3 The project alignment - Glenugie to Tyndale



The project
Upgrade completed to dual carriageway
Upgrade under construction
Existing Pacific Highway
Flood map area / river crossing
Community area

Figure 1-4 The project alignment - Tyndale to Devils Pulpit

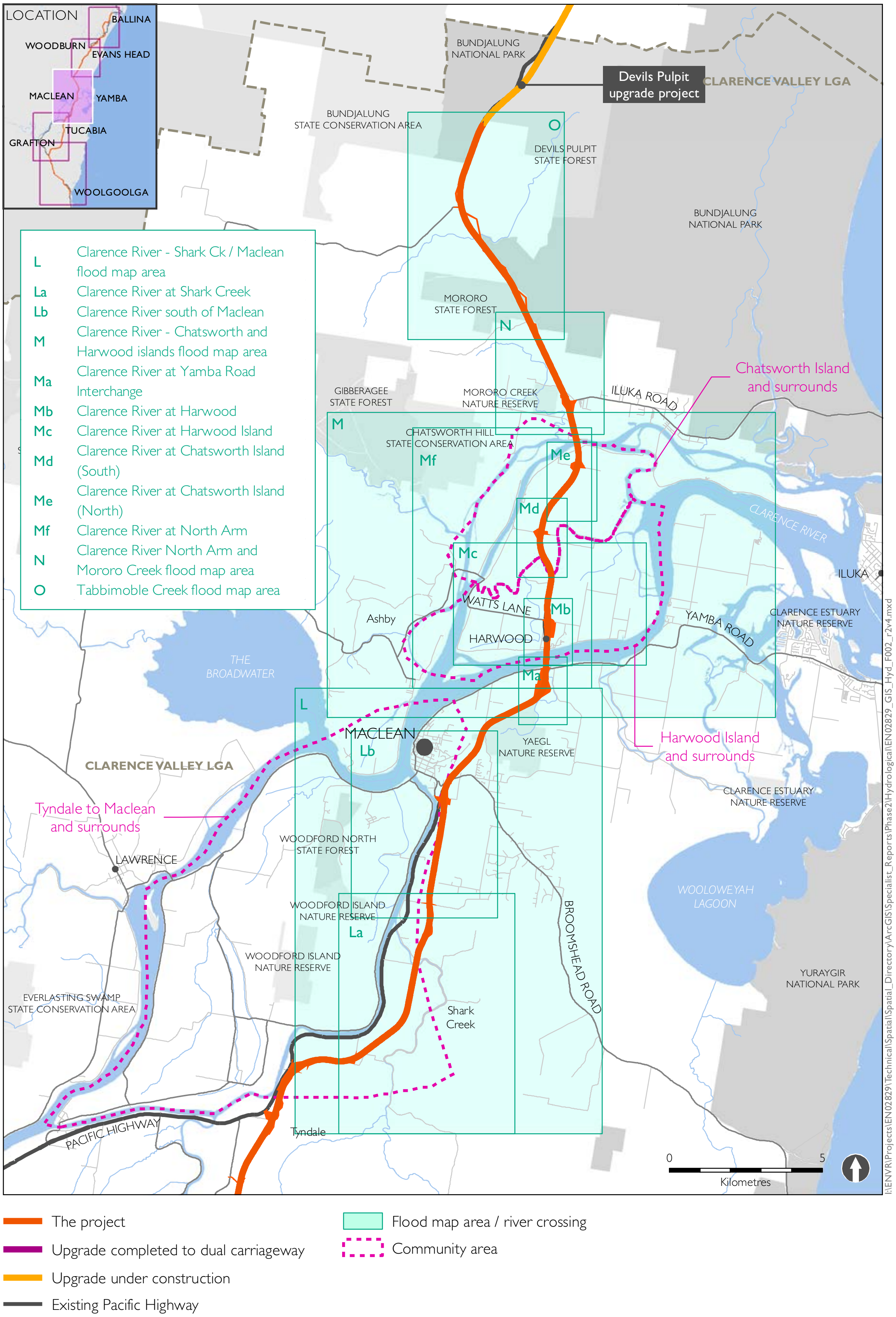


Figure 1-5 The project alignment - Devils Pulpit to Woodburn

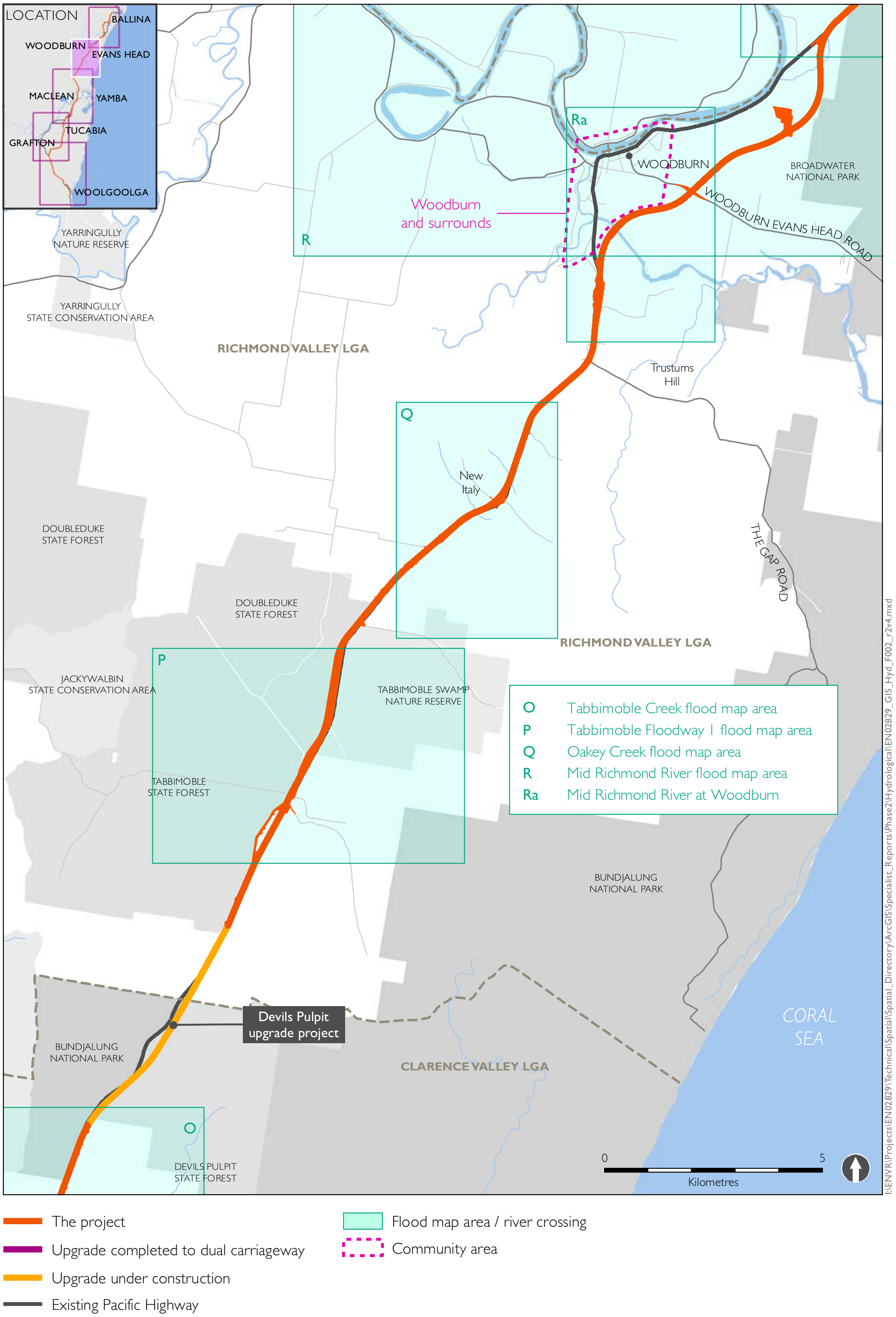
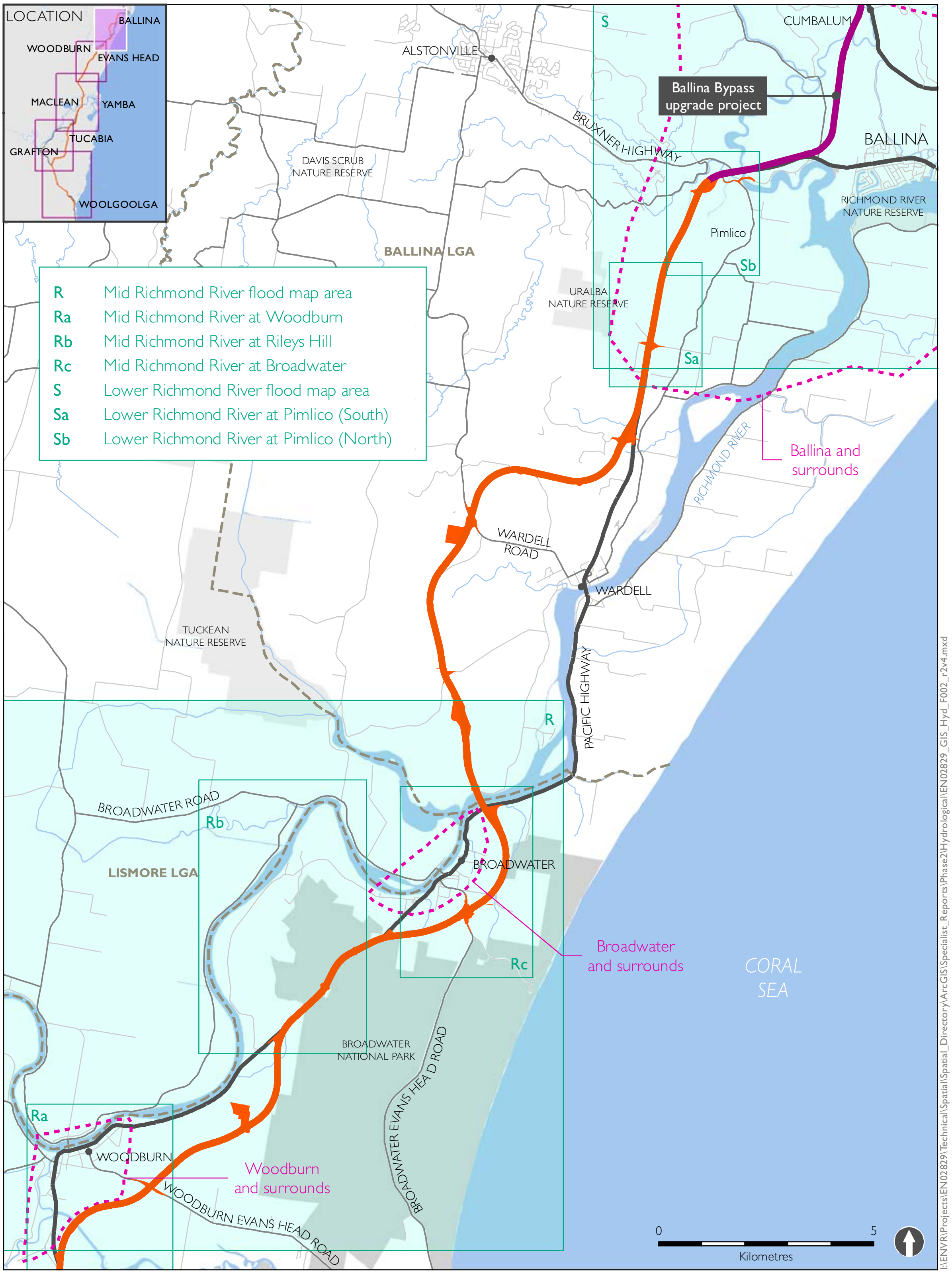


Figure 1-6 The project alignment - Woodburn to Ballina



The project
Upgrade completed to dual carriageway
Upgrade under construction
Existing Pacific Highway
Flood map area / river crossing
Community area

2. Assessment methodology

2.1. Design objectives for flood management

2.1.1. Design objectives and mitigation measures

The development the concept design of the project included assessing the flood impacts and changing the design until the design objectives for flood management were met. This is an iterative modelling process to meet (where practicable) the management objectives, with the final design based on the modelling results.

The design of embankments, bridges and culverts are justified as they achieve the flood immunity criteria and (all or in part) flood management objectives set for the project. In some cases, due to the need to provide access or fauna connectivity, bridge or culvert structures may be oversized from the hydrological need.

In some locations, the design objectives for flood management would not be met. Recommendations are made in Chapter 8 regarding mitigation measures to ensure these design objectives for flood management would be met.

2.1.2. Road flood immunity design objectives

Roadway flood immunity is defined for this project as the edge of pavement being at or above the designated flood level. Therefore, all lanes would be free from flood inundation in the designated flood event.

The minimum level of flood immunity for M class roadways for this project is 20 year ARI and the target immunity, if feasible, is 100 year ARI. All M class roads of the project, apart from those crossing the Richmond and Clarence river floodplains, would have 100 year ARI flood immunity.

Based on cost considerations, the design flood immunity adopted for the M class roads crossing the Richmond and Clarence river floodplains is the 20 year ARI. By way of comparison, it should be noted that the level of the existing highway across these floodplains is generally well below the proposed immunity levels. The project would, therefore, provide a better flood immunity level than currently exists.

To clarify this design objective, if a section of the project designated M class is affected by both long duration major river (Richmond River or Clarence River) flooding as well as flooding from a local catchment (eg tributary creek of these larger rivers), then the project would have all four lanes above the 20 year ARI long duration major river flood levels and above the 100 year ARI local catchment flood levels (designed to whichever is the higher).

The justification for this design objective is associated with the overall objective of RMS to achieve, where feasible and reasonable, 100 year ARI flood immunity for the Pacific Highway. This is on the basis that setting the objective at this level would provide significantly reduced road closures due to flooding, safer travel for Pacific Highway users, reduced road damage due to flood inundation and improved access for local residents during flood events.

It is recognised that the cost associated with constructing the sections of the project on the extensive and large Clarence and Richmond river floodplains to 100 year ARI flood immunity would be very high. Hence, RMS in consultation with community and local councils determined that the lower 20 year ARI immunity would be acceptable on these long floodplain crossings.

Flood immunity for the service road network that would accompany the M class stage will be at a similar level to the existing local road network in the vicinity.

2.1.3. Flood management objectives

Bridges and culverts within the length of floodplain crossings would minimise the changes to existing flood patterns (flood height, flood durations, flood flows, directions and velocities). However, it is not possible to achieve zero impact in all areas of the floodplains. Localised changes to flood patterns would occur where the project crosses the floodplains, such as constriction and expansion of flood flows through proposed culverts resulting in afflux.

Therefore, realistically achievable changes to flood patterns are determined with consideration of the risks and impacts of those changes, as described in the following section.

Flood management objectives apply outside the project boundary.

Flood level impact objectives

- **Houses, commercial premises and urban areas:** Less than 50 millimetres increase in flood height for any assessed flood event (less than and equal to the 100 year ARI event). *Justification:* This criterion is consistent with many other Pacific Highway upgrade projects. Assessments of changes to long-term flood damages for houses and commercial premises indicate that an increase of 50 millimetres in flood depths over a range of flood events would result in only a minor increase (in the order of a few percent) to the long-term flood damages
- **Cane farm land:** Less than 50 millimetres increase in flood height for any assessed flood event (less than and equal to 100 year ARI event)
  Justification: This flood level impact criterion generally recognises that an increase of 50 millimetres in flood depth for sugar cane would not result in damage to a crop
- **Grazing area, forested lands, other rural areas:** Generally less than an increase of 250 millimetres, with localised increases of up to 400 millimetres for short duration / local catchment flooding acceptable over small areas (nominally less than five hectares) up to the 100 year ARI event.
  Justification: This criterion is appropriate as these lands can accommodate higher flood levels for short periods of time (a few hours) without any significant increase in land damage or decreased use of the land. Furthermore, the crossing of the project through these land uses is generally located on steeper floodplains where the increase in flood level does not extend very far upstream.

Flood inundation duration impact objectives

- **Houses, commercial premises and urban areas:** No more than five per cent increase in the flood duration.
  Justification: This ensures minimal impact to residents that may be isolated within houses, or may have evacuated and wish to return within a reasonably similar timeframe as is currently possible
  - **Cane farm land:** No more than five per cent increase in the flood duration.
    Justification: In recognition of cane industry concerns about the duration of flood inundation, the five per cent increase in the flood duration was adopted to minimise the risk of the project causing boiling of the cane, which can occur when floodwaters inundate a crop during hot and sunny weather. This objective has been discussed in consultation with cane farm growers at the Flood Focus Group meetings as detailed further in Section 2.2.8
  - **Grazing area, forested lands, other rural areas:** No more than ten per cent increase in the flood duration.
    Justification: This objective has been developed in recognition that vegetation on grazing and forested land is better able to cope with inundation than cane.

Flood velocity and direction impact objectives

- **Houses, commercial premises and urban areas:** Velocity-depth products to remain in the zone of low hazard for children (ie less than 0.4 metres squared per second based on Australian Rainfall and Runoff, Project 10, 2011) where the velocity-depth products are currently low hazard. This objective is justified in terms of maintaining safe flooding conditions during flood events
- **Cane farm land:** Velocities to remain below one metre per second where currently below this figure based on erosion on bare soils. An increase of not more than 20 per cent where existing velocity is above one metre per second. This objective is justified in terms of minimising the erosion of soil on cane farms based on accepted velocity limits for erosion
- **Grazing area, forested lands, other rural areas:** Velocities to remain below one metre per second where currently below this figure. An increase of not more than 20 per cent where existing velocity is above one metre per second. This objective is justified in terms of minimising the erosion of soil on agricultural lands based on accepted velocity limits for erosion
- No changes to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

2.1.4. Other flood impact considerations

The consideration of the flood management objectives discussed above forms the basis of the project design of waterway openings. However, there are other flood impacts associated with the project that are assessed. These are discussed below.

Floodwater rate of rise and warning time

- **Houses, commercial premises and urban areas:** Rates of floodwater rise and warning times should be similar to those of the base case
- **Cane farm land:** no consideration
- **Grazing area, forested lands, other rural areas:** Rates of floodwater rise and warning times should be similar to those of the base case.

Flood evacuation and flood access

- **Houses, commercial premises and urban areas:** Time available to evacuate should be similar to that for the base case. Evacuation routes should not be impassable due to flood water inundation for any longer or any sooner than the base case
- **Cane farm land:** no consideration
- **Grazing area, forested lands, other rural areas:** Time available to move stock to higher ground should be similar to that for the base case. Stock access to higher ground should not be impeded by the project or the flood impacts attributable to the project.

Bed and bank stability impacts

- Consideration of areas where the velocities would be above scouring threshold values and where the potential for scouring would be increased by the project.

Flood hazard impacts

A full consideration of hazard parameters, based on *Floodplain Development Manual* (NSW Government, 2005), includes:

- Depths of flooding
- Velocities of flooding
- Velocity-depth products
- The duration of flooding
- The rate of rise of floodwaters

- Evacuation issues
- Effective warning time
- Effective flood access
- The size of flood assessed
- Flood readiness of the communities / residents on the floodplain.

This assessment considers changes to all of the above categories except the last two listed above. Given that the project would not change the size of the flood nor the level flood readiness of the community, the individual assessments of the other hazard categories are used to assess the cumulative changes to flood hazard.

2.1.5. Flood events assessed

The 100 year ARI flood is a highly important flood event as it is typically used for setting floor levels and fill levels in residential and commercial areas. Hence, the assessment of the 100 year ARI flood provides an assessment of the impact of the project on the future development potential of affected land. For this reason, it is critical that this study includes an assessment of this flood for all watercourses crossed by the project. The 100 year ARI flood is also used to benchmark the flood management objectives to direct culvert and bridge design along the project.

In addition to the 100 year ARI event, each major watercourse was assessed with a frequent flood event (two year ARI for local catchments or five year ARI for the major floodplains), the 20 year ARI event, and a rare event equivalent to approximately the 200 year ARI.[1] The impacts associated with flood events in between these events or smaller than the two or five year ARI event can be generally estimated by interpolation or extrapolation of these results.

The exceptions to the relationship described above are on the Clarence and Richmond river floodplains. Here, the floodplain flows are quite complex with considerable interaction between floodplain flowpaths over a range of flood events.

Furthermore, the flood impacts on the lower Clarence River floodplain are complicated by the small difference between the 20 year ARI flood levels and the 50 year ARI levels. This difference is smaller than the crossfall height of the road embankment (ie the level difference between the low outer edge and the high middle edge of the road). This concept is represented in Figure 2-1 for the Clarence River at Chatsworth and Harwood islands and also in Figure 2-2 for the Richmond River near Woodburn.

Hence, in a 50 year ARI flood event, the road embankment would not be overtopped and all flows would pass through the culverts and bridges.

For these reasons, an additional 50 year ARI flood event was assessed for the Clarence River floodplain and the Mid Richmond River floodplain.

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[1] Hydrology for the 100 year ARI climate change scenario (10% increase in rainfall) was found to be equivalent to approximately the 200 year ARI event (± 3.5%).

For the Lower Richmond River floodplain (ie Duck Creek and Ballina area), the difference between the 20 year ARI and the 100 year ARI flood levels is very small. For most parts of this section, the crossfall height of the road embankment is larger than this difference. This concept is represented in Figure 2-3 for the Lower Richmond River east of Duck Creek.

This means that although the flood immunity of the road is only 20 year ARI in this section, the road embankment would not be overtopped in the 100 year ARI flood event. Hence, for the Lower Richmond River, the 50 year ARI event was not assessed as there would be a generally linear increase in the impacts between these two flood events. This approach is also consistent with the Ballina Bypass flood assessments.

The flood events that have been determined to meet the aims of assessing a range of events are shown in Table 2-1 for each flood investigation area.

Table 2-1 Flood events assessed for each flood investigation area

Flood investigation area	Event assessed					
	2 year ARI	5 year ARI	20 year ARI	50 year ARI	100 year ARI	~200 year ARI
Corindi River	✓		✓		✓	✓
Halfway Creek	✓		✓		✓	✓
Pheasant Creek	✓		✓		✓	✓
Coldstream River	✓		✓		✓	✓
Pillar Valley Creek	✓		✓		✓	✓
Chaffin Creek and nearby creeks	✓		✓		✓	✓
Champions Creek and nearby creeks	✓		✓		✓	✓
Clarence River (Glenugie to Tyndale)		✓	✓	✓	✓	✓
Clarence River: (Tyndale to Maclean)		✓	✓	✓	✓	✓
Clarence River (Maclean to Iluka Road)		✓	✓	✓	✓	✓
Mororo Creek	✓		✓		✓	✓
Tabbimoble Creek	✓		✓		✓	✓
Tabbimoble Floodway No. 1	✓		✓		✓	✓
Oakey Creek	✓		✓		✓	✓
Mid Richmond River		✓	✓	✓	✓	✓
Lower Richmond River		✓	✓		✓	✓

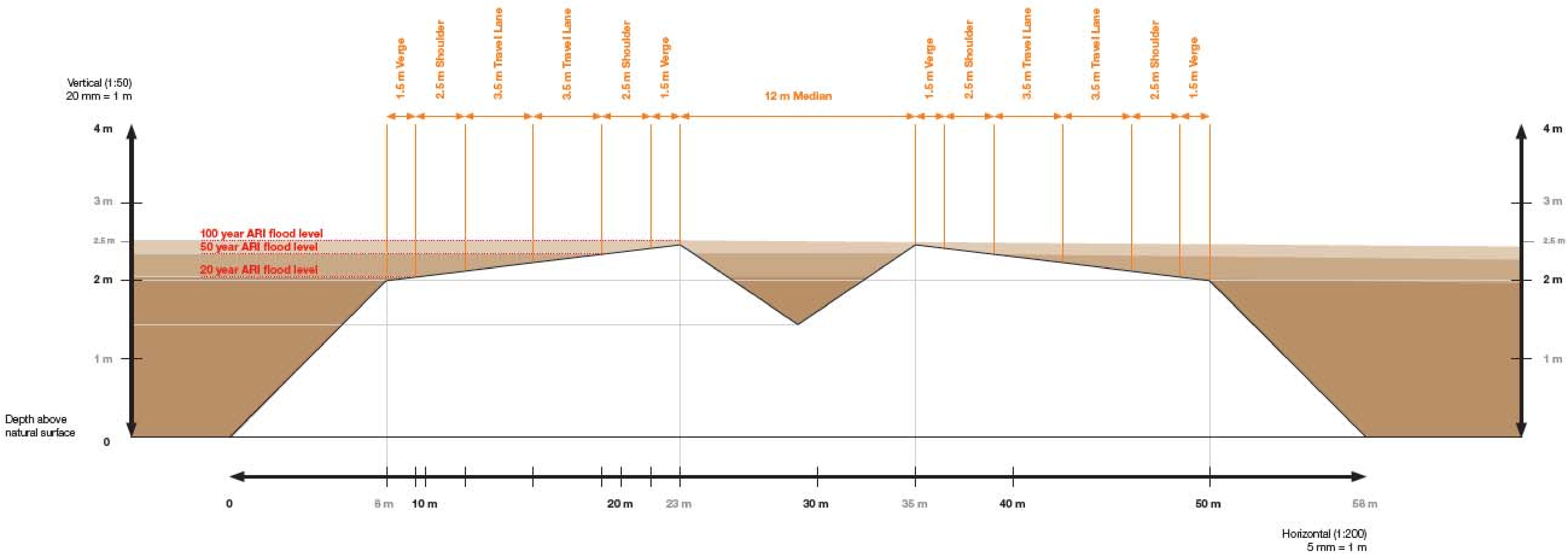

Figure 2-1 Clarence River flood levels at Chatsworth and Harwood islands – Section 5

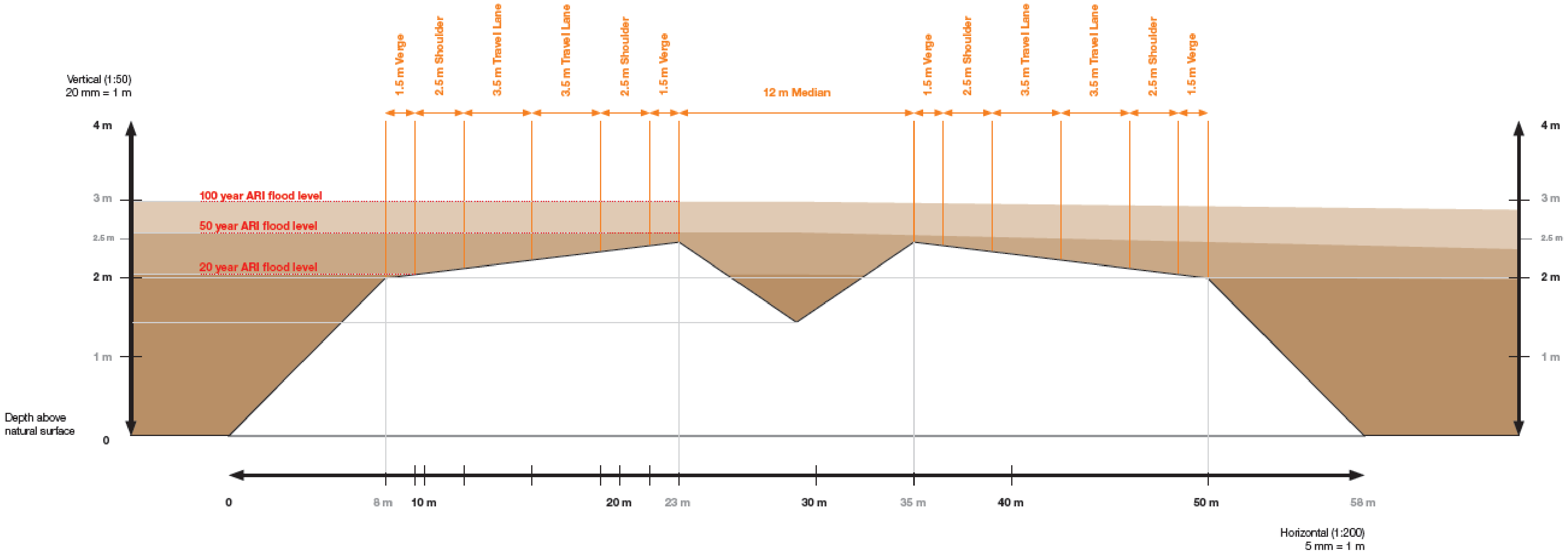

Figure 2-2 Richmond River flood levels south-east of Woodburn – Section 8

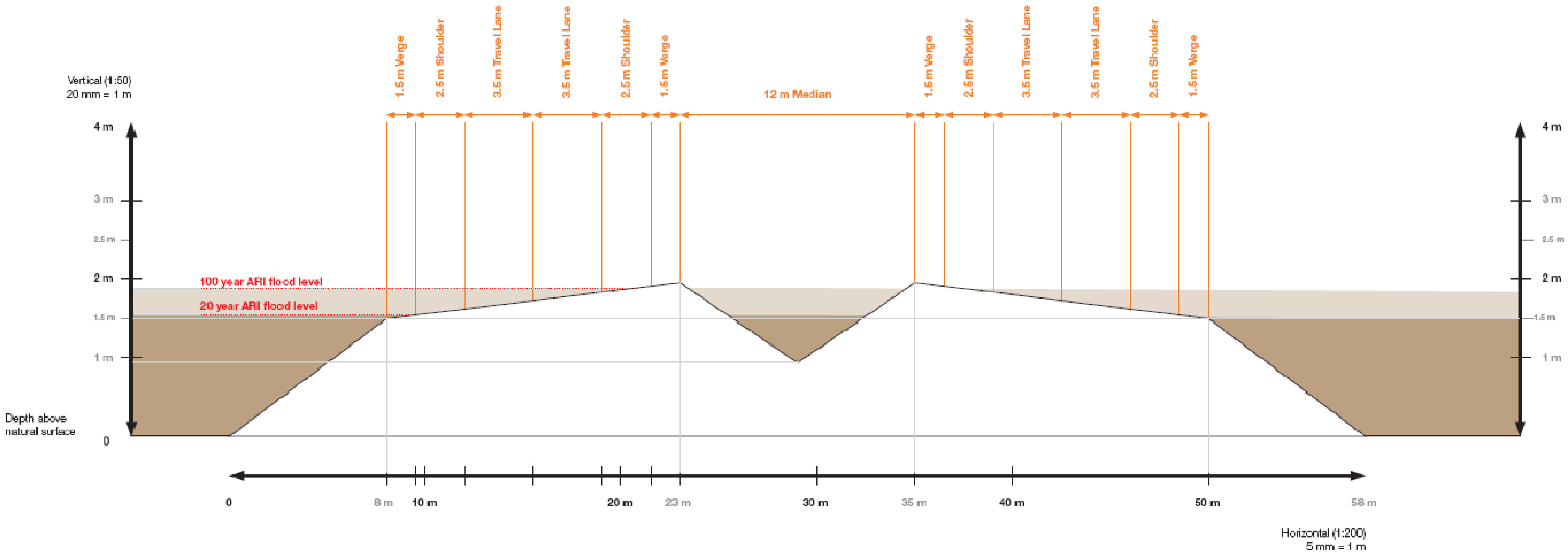

Figure 2-3 Lower Richmond River flood levels south-west of Duck Creek Bridge – Section 11

2.1.6. Floodplain management policy

Floodplain management in New South Wales is carried out under the NSW Government's Flood Prone Land Policy which is presented in the *Floodplain Development Manual* (NSW Government, 2005). This policy provides a strategic approach to floodplain management. As well, the policy *"promotes the use of a merit approach which balances social, economic, environmental and flood risk parameters to determine whether particular development or use of the floodplain is appropriate and sustainable"*.

The management of flood prone land is, primarily, the responsibility of local government. Technical support and funding is provided by the New South Wales government through OEH (Office of Environment and Heritage).

There are well-established floodplain management processes underway for the Clarence River, Richmond River and the Ballina area. While the smaller creek systems crossed by the project are also managed by the relevant councils, there have not been individual floodplain risk management studies for these creeks.

The flood models used in this study have been based on the adopted flood models used for flood risk management on these floodplains by the relevant local government authority for each of the Clarence River, Richmond River and the Ballina areas. However, the Clarence River flood model and the Ballina area flood model have been modified to specifically suit the needs of this impact assessment.

The New South Wales Office of Water has published a series of guidelines relating to management of construction works for a controlled activity within waterways or on waterfront land. These guidelines include:

- Controlled activity exemptions
- Instream works
- Laying pipes and cables in watercourses
- Outlet structures
- Riparian corridors
- Vegetation Management Plans
- Watercourse crossings.

The project would be designed to be constructed in accordance with these guidelines at the detailed design phase.

2.2. Flood assessment methods

2.2.1. Design process

The project crosses many waterways (rivers, creeks, gullies, agricultural drains). Flows would be conveyed through the project via bridges or culverts at each waterway. The project would also include significant lengths of road embankment across floodplains. Flood flows would be conveyed through the project via culverts and bridges across these floodplain sections.

Descriptions of the main waterways and floodplains are in Chapter 4 of this working paper and crossing structures (ie bridges and culverts) are described in Chapter 6. They are also described in the Transport Working Paper and corresponding chapters of the Environmental Impact Statement.

The flood management objectives defined in this assessment direct the design of road embankment, bridge and culvert design. The design objectives for hydrology and flooding therefore encapsulate the flood management objectives detailed in Section 2.1. The road embankment is designed to meet the stated flood immunity and flood management objectives defined in Section 2.1.2. Bridges and culvert sizes are also designed to ensure immunity is obtained as per the requirements in Section 2.1.2, and to meet the flood management objectives detailed in Section 2.1.3.

The design becomes an iterative process to achieve a design that will meet all stated flood management objectives; ie, that which would, at minimum, reduce impacts to a level that is tolerable for the land use conditions of any given impacted area.

The iterative process of assessing and refining bridge and culvert design to meet the stated flood management objectives also considers other aspects such as engineering design, cost, constructability, and environmental design considerations (eg the interaction of cross road drainage with fauna crossings).

Culverts sizes are based on either limiting upstream afflux or limiting exit velocities. All bridges in the concept design would have the soffit (underside of bridge structure) at least 300 millimetres above the 100 year ARI flood level. This would allow for debris passage during large flood events. Hence, the hydraulic losses for all bridges include losses for horizontal constriction and pier losses but do not include losses for vertical constriction of the flow.

The design process up to construction is ongoing. Subsequent phases of the project may involve further revision of these sizes or further assessment of options between bridges and culverts. These potential design changes would not affect the overall outcomes of this hydrology and flooding study.

Minor waterway crossing design

Minor waterways were deemed to be those waterways crossed by the project with catchments nominally smaller than four square kilometres (at the location of project crossing). An assessment of these minor waterways outside the extents of major creeks, rivers and floodplains was undertaken to determine design peak catchment discharges and to adequately size transverse culverts to carry floodwaters underneath the project.

Catchment areas of the minor waterways were measured and a hydrological assessment was undertaken to determine design peak discharges for the 100 year ARI storm event. The assessment uses the hydrologic model XP-RAFTS and the probabilistic Rational Method[2] recommended for use in eastern New South Wales by Institute of Engineers (2001).

Hydraulic modelling and sizing of proposed transverse culvert structures for ensures the two following design objectives are met:

- The increase in the 100 year ARI flood level upstream of the highway would meet the flood management objectives
- The proposed highway would be immune from flooding for the 100 year ARI event.

Transverse culverts would be a minimum of 450 millimetres in diameter. Pipe culverts less than or equal to 600 millimetres in diameter or box culverts less than or equal to 600 millimetres high were designed with a 50 per cent blockage factor.

Details and locations of all culverts (around 700) are not in this report, due to the large number of minor waterway crossing structures. However, all design structures for minor waterway crossings would meet the two design objectives. There would be detailed assessment of these crossings as part the project detailed design.

2.2.2. Flood impact assessment

The flood impacts attributable to the project are undertaken by quantifying the flooding behaviour of the base case (usually the existing case) and comparing that with the flooding behaviour of the case with the project constructed. This is a common method of assessing flood impacts associated with changes on floodplains (eg infrastructure development). This method allows the identification and isolation of only those changes to flood behaviour that are attributable to the project.

In all areas, except the lower Richmond River floodplain (ie Duck Creek and Ballina area), the base case is the existing case. However, on the Ballina floodplain, the base case is the floodplain as it was in 1998. This choice of base case allows consistency with all of the flood assessments carried out for the Ballina Bypass.

The flood models used to define the flood behaviour of the flood investigation areas is discussed below in Section 2.2.3.

The changes to the flooding behaviour derived from the flood modelling are used to define the impacted areas of the flood investigation areas. These areas are then overlaid on aerial photography and property information to identify the impacts to houses, commercial premises, farm infrastructure, cropping areas, grazing and forested areas, likely evacuation routes and flood refuges. As well, plots of flood level rise and fall over the duration of the flood events assessed are produced to consider changes attributable to the project.

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[2] A simple, commonly-used rainfall-runoff model.

This allows identification of the magnitude of the predicted impacts for a range of flooding parameters. On the basis of these identified impacts, the project is assessed against the flood management objectives listed in Section 2.1.

For watercourses smaller than those assessed with flood models, the assessments involved determining the size of culverts required to convey flows safely under the road embankment without unacceptable impacts (as identified in the flood objectives) on the surrounding environment. Peak flows are estimated using either the probabilistic Rational Method or other hydrological rainfall-runoff models.

As discussed in Section 1.1, staging of the project would result in some sections being initially construction to a class A standard before being upgrading to class M. In these sections, the class M upgrade is considered to have a higher impact than Class A, due to an extension in the culvert length, which must then also cross service roads. Consequently, full class M design is adopted for the operational impact assessment flood modelling to assess the greatest flood impact of the project.

2.2.3. Flood modelling to define impacts

The flood impact assessments for the project are undertaken using hydrological and hydraulic models which are individually considered appropriate for the size and type of each watercourse and catchment crossed. These models are detailed further in Section 2.2.5. In instances where a previous model was not considered appropriate for the current application, either these models were modified or a new approach was adopted.

For the crossings of rivers, major (named) creeks and floodplains, dynamic flood modelling defines the existing flood behaviour and the potential impacts on this flood behaviour resulting from the project. Generally, models for previous development projects were used, as described in Section 2.2.4. Exceptions to this are:

- Due to the limited upstream extent of the existing Corindi River model, a TUFLOW model was created to with greater upstream extent to better represent flow distributions between Corindi River, Blackadder Creek and Cassons Creek
- Due to the limited extent of the HEC-RAS model developed previously for Halfway Creek, a TUFLOW model was developed to better define the flooding behaviour and impacts of the project in this area
- The previous flood assessment of the Mid Richmond River used a SOBEK flood model. The current assessment uses a larger TUFLOW flood model developed by Richmond Valley Council and Richmond River County Council. This flood model uses more current and accurate terrain data, calibrates the January 2008 flood event, and is more extensive than the previous SOBEK model. Discussions between RMS and Richmond Valley Council determined that the TUFLOW model formed a better basis for the assessment of the flood impacts, and the model has subsequently been adopted in this study.

The flood models are typically two-dimensional flood models, which are well suited to simulating road embankments and associated waterway structures (eg bridges and culverts). More detail on two-dimensional and one-dimensional hydraulic modelling is provided in Section 1.3.2.

2.2.4. Flood assessments undertaken for previous development projects

All of the major watercourses crossed by the project were assessed as part of previous flood assessments undertaken as part of the route selection and concept design development phases.

A number of different flood modelling programs were used to simulate flood behaviour on the watercourses crossed in these previous projects. The hydrological models (rainfall inputs to calculate runoff) and hydraulic models (runoff inputs to calculate levels, velocities, etc) for each watercourse are presented in Table 2-2.

Table 2-2 Flood models used for flood investigation areas (previous studies)

Watercourse	Hydrological model	Hydraulic model
Corindi River (including Blackadder Creek and Cassons Creek)	XP-RAFTS	TUFLOW[1]
Halfway Creek	XP-RAFTS	HEC-RAS[2]
Pheasant Creek	WBNM[4]	TUFLOW[1]
Coldstream River	WBNM[4]	TUFLOW[1]
Pillar Valley Creek	WBNM[4]	TUFLOW[1]
Chaffin Creek	WBNM[4]	TUFLOW[1]
Champions Creek	WBNM[4]	TUFLOW[1]
Clarence River (and floodplain areas, Shark Creek and Chatsworth / Harwood islands)	Cordery-Webb and FFA[5]	TUFLOW[1]
Mororo Creek	XP-RAFTS	MIKE-FLOOD[1]
Tabbimoble Creek	XP-RAFTS	MIKE-FLOOD[1]
Tabbimoble Floodway 1	XP-RAFTS	MIKE-FLOOD[1]
Oakey Creek	XP-RAFTS	MIKE-FLOOD[1]
Richmond River south (including Tuckombil Canal and McDonalds Creek)	WBNM[4]	SOBEK[3]
Richmond River and its surrounding tributaries	XP-RAFTS	MIKE-11[2]
Richmond River south (including Tuckombil Canal and McDonalds Creek)	XP-RAFTS	TUFLOW[1]
Richmond River north (including Duck Creek and Emigrant Creek)	XP-RAFTS and FFA[5]	TUFLOW[1]

1. Two-dimensional / one-dimensional dynamically linked model
2. One-dimensional model
3. Two-dimensional model
4. Watershed Boundary Network Model
5. Flood Frequency Analysis

Other Richmond River flood studies

Numerous flood studies have been carried out on the Richmond River floodplain over the last 25 years. These flood studies collectively include areas of the Richmond River upstream of Casino and Lismore extending down to the lower reaches of the river and estuary around Ballina. These studies and their relevance for the project are summarised in Table 2-3.

Table 2-3 Previous Richmond River flood studies

Flood study	Relevance to project
Mid Richmond Flood Study (WBM 1999)	First attempt to model the whole Richmond River floodplain.
Woodburn to Ballina Preferred Route / Concept Design Hydrology / Hydraulics Report (RTA, 2007)	Used to size bridges and culverts. Limited area modelled, not whole floodplain. Model used for route selection and early concept design but has been superseded by the current assessment as it was not considered adequate for EIS
Richmond River Flood Mapping Study (BMT WBM, 2010)	Model developed in that study has been used as basis for this assessment.
Ballina Floodplain Management Study (WBM, 1996)	Hydrological models developed have been used as part of the current study. Used for early Ballina Bypass assessments in the late 1990s.
Ballina Bypass Pacific Highway upgrade (WBM, 2002-2009)	Forms the basis of the 2D flood model developed for the Ballina Bypass flood assessments. Used for the project near the Ballina area (Section 4.15).

Further detail on these studies is summarised in Appendix A.

2.2.5. Flood assessments undertaken for the current EIS study

Table 2-4 summarises the use of flood models in this study for each catchment, including any revision of previous modelling.

Table 2-4 Flood models used in current impact assessment modelling

Watercourse	Hydrological model	Hydraulic model	Additional comments
Corindi River (including Blackadder Creek and Cassons Creek)	XP-RAFTS	TUFLOW[1]	Revised with higher resolution and updated terrain data which supersedes previous model. Not calibrated – no known flood records in the catchment.
Halfway Creek	XP-RAFTS	TUFLOW[1]	Uses 2 m grid based on 1 m contour data. Extends 1.4 km upstream to 600 m downstream of the project. Not calibrated – no known flood records in the catchment.

Watercourse	Hydrological model	Hydraulic model	Additional comments
Pheasant Creek	WBNM[3]	TUFLOW[1]	Previous development project model. Not calibrated – no known flood records in the catchment. Peak flows verified against flow estimation methods.
Coldstream River	WBNM[3]	TUFLOW[1]	Previous development project model. Not calibrated – no known flood records in the catchment. Peak flows verified against flow estimation methods.
Pillar Valley Creek	WBNM[3]	TUFLOW[1]	Previous development project model. Not calibrated – no known flood records in the catchment. Peak flows verified against flow estimation methods.
Chaffin Creek	WBNM[3]	TUFLOW[1]	Previous development project model. Not calibrated – no known flood records in the catchment. Peak flows verified against flow estimation methods.
Champions Creek	WBNM[3]	TUFLOW[1]	Previous development project model. Not calibrated – no known flood records in the catchment. Peak flows verified against flow estimation methods.
Clarence River (and floodplain areas, Shark Creek and Chatsworth / Harwood Islands)	Cordery-Webb and FFA[4]	TUFLOW[1]	Detailed model of entire floodplain. Based on local government flood study with several stages of refinement and calibration. More detail provided in Section 4.9.1.
Mororo Creek	XP-RAFTS	MIKE-FLOOD[1]	Previous development project model. Not calibrated – no known flood records in the catchment.
Tabbimoble Creek	XP-RAFTS	MIKE-FLOOD[1]	Previous development project model. Not calibrated – no known flood records in the catchment.
Tabbimoble Floodway 1	XP-RAFTS	MIKE-FLOOD[1]	Previous development project model. Not calibrated – no known flood records in the catchment.
Oakey Creek	XP-RAFTS	MIKE-FLOOD[1]	Previous development project model. Not calibrated – no known flood records in the catchment.
Mid Richmond River	XP-RAFTS	TUFLOW[1]	Adopted from Richmond River Flood Mapping Study. Differs from model used for route selection phase of the project. More detail on this model and reasons for selection provided in Appendix A.
Lower Richmond River	XP-RAFTS	TUFLOW[1]	Ballina Bypass Pacific Highway upgrade flood model. Two durations modelled: 72 hr event used for assessing flooding in Richmond River and 12 hr event used for local catchment flooding. Further detail is provided in Section 4.15.

1. Two-dimensional / one-dimensional dynamically linked model
2. One-dimensional model
3. Watershed Boundary Network Model
4. Flood Frequency Analysis

Richmond River flood model details

Further flood modelling of the Richmond River floodplain was required as part of the current study. Waterway sizes (bridges and culverts) were re-assessed with revised impact objectives and improved flood models.

The decision was made to use the more recent Richmond River County Council two-dimensional/one-dimensional flood model instead of the two-dimensional flood model developed as part of the previous route selection phase. The reasons for this decision were:

- The Richmond River County Council model included a re-calibration of the hydrological model
- The Richmond River County Council model is based on more accurate terrain data
- The Richmond River County Council hydraulic model was calibrated to the recent January 2008 and May 2009 flood events. Furthermore, the calibration and verification of the model was extensive (four flood events with over 250 recorded flood levels used)
- The Richmond River County Council model has been adopted by Richmond Valley Council as the basis for development control across the floodplain. Hence, any changes to 100 year ARI flood levels resulting from the project could be easily incorporated into Council's planning instruments
- The Richmond River County Council model was seen to have a longer life which would assist in the progress of the project over coming years.

As mentioned above, the calibration and verification of the Richmond River County Council flood model was based on assessing four flood events. The four flood events chosen represented a range of flood durations. There was also a range of available flood records, against which the flood model was calibrated and verified. The flood events and data used to calibrate and verify the flood model are summarised below:

- May 2009 (46 points and 10 gauges)
- January 2008 (78 points and 10 gauges)
- March 1974 (66 points and 8 gauges)
- February 1954 (61 points).

The model calibration and verification process was an important phase in developing a flood model that adequately represented the flooding behaviour and complex flooding mechanisms of the Richmond River floodplain.

2.2.6. Independent review of flood modelling

In response to community and stakeholder concerns regarding the risk of flooding along the project, the RMS commissioned a review of the flood modelling undertaken for the project. This assessment was undertaken independently of the Environmental Assessment. Details of the independent review are documented in *Woolgoolga to Ballina Pacific Highway Upgrade – Independent review of flood modelling* (WMA, 2012).

The independent review was undertaken on all watercourse models used in the flood assessment – consisting of a hydrological and a hydraulic model for each of the 14 watercourses assessed. The independent review drew the following conclusions:

- The modelling approach used in the assessment is appropriate and suitable for the application with only minimal changes being required for delivery of current assessment
- Regional floodplain models were extensively calibrated against available historical flood levels with good reproduction of these events. The calibration of these models provides confidence in the reliability of predicted flood levels and results
- Some aspects of the modelling approach required modification to improve the reliability of the assessment at either the concept design or detailed design phase.

Recommendations made in the independent review were discussed with the Alliance. Most of the findings of the review have now been addressed in the flood assessment. Further modifications are still required as part of the detailed design phase.

Table 2-5 provides a summary of the findings of the review and how these have been addressed by the Alliance. Appendix B further provides a summary of the form loss validation assessment which was undertaken in response to the review.

Table 2-5 Independent review findings and response

Watercourse (models)	General comments	Findings requiring attention	Response to independent review
All Watercourses/Models	Modelling approach appropriate Developed models suitable for purpose subject to minor corrections where applicable	This phase Need to validate form losses of critical structures against alternative methods	HEC-RAS models developed for four example waterway crossings: • Champions Creek (example of small creek) • Clarence River (critical crossing) • Tuckombil Canal (critical crossing) • Richmond River (critical crossing). • The results of these HEC-RAS checks on the afflux are discussed in Appendix B. The assessments indicate that the HEC-RAS model results validate the flood model assessments.
		To consider impact of blockages on drainage structure performance	Assumptions regarding blockage of culverts under the proposed upgrade have been incorporated into sensitivity analyses. These are discussed in Chapter 6 of the working paper.
		To revise sub-catchment delineation where necessary for post development scenarios	The effect of this issue was assessed on the Corindi River floodplain (as an example of a smaller river/creek system) and the Richmond River (example of a larger river system). In both cases, the changes to sub-

Watercourse (models)	General comments	Findings requiring attention	Response to independent review
			catchment delineation to create sub-catchments either side of the route results in changes less than 2mm on these floodplains. Hence, this issue is not seen as critical to the derivation of flood impacts or flood behaviour. This is mainly due to the way that the flood modelling software spreads the flow evenly over all inundated areas at the peak of the flood event. At this time, the distribution of inundated portions of the local sub-catchments approximate the distribution of local inflows. Furthermore, these local sub-catchment inflows represent only a very small fraction of the total floodplain flow at the peak of the flood.
Corindi River (XP-RAFTS + TUFLOW)	Proposed drainage structures/waterway crossings implemented properly	This phase Afflux >250mm found at small areas outside of project boundary though no assets affected, larger waterway crossings not justified	No response required – impacts for this section discussed in Chapter 6 of working paper with reference to flood management objectives.
		Prior to detailed design Model terrain could be extended for modelling extreme events, ie PMF	Agree

Watercourse (models)	General comments	Findings requiring attention	Response to independent review
Halfway Creek (XP-RAFTS + TUFLOW)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	<u>This phase</u> Local catchment runoff excluded though contribution to flow is minimal	Agree this assumption is reasonable as the local catchment area is less than 10% of the total catchment contributing to that point.
		<u>Prior to detailed design</u> Model terrain could be extended for modelling extreme events, ie PMF	Agree
Pheasant Creek (WBNM + TUFLOW)	Afflux criteria met	<u>This phase</u> Proposed works (Ch 39400-40000) for unnamed creek floodplain north of Pheasant Ck not included in the model Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary Omission of form losses for major waterway structures proposed	The sizing of the culverts for the un-named creek north of Pheasant Creek was carried out using alternative methods and not the TUFLOW flood model due to the small size of the catchment. This issue was fixed in the latest flood modelling that is reported in the working paper. This issue was fixed in the latest flood modelling that is reported in the working paper.
Coldstream River	Proposed drainage structures/waterway	<u>This phase</u>	

Watercourse (models)	General comments	Findings requiring attention	Response to independent review
(WBNM + TUFLOW)	crossings implemented properly	Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary Afflux >250mm found at small areas outside of project boundary though no assets affected, larger waterway crossings not justified Omission of form losses for major waterway structures proposed	This issue was fixed in the latest flood modelling that is reported in the working paper. No response required – impacts for this section discussed in Chapter 6 of working paper with reference to flood management objectives. This issue was fixed in the latest flood modelling that is reported in the working paper.
Pillar Valley Creek (WBNM + TUFLOW)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	<u>This phase</u> Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary Omission of form losses for major waterway structures proposed	This issue was fixed in the latest flood modelling that is reported in the working paper. This issue was fixed in the latest flood modelling that is reported in the working paper.
Chaffin Creek (WBNM + TUFLOW)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	<u>This phase</u> Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary Omission of form losses for major waterway	This issue was fixed in the latest flood modelling that is reported in the working paper. This issue was fixed in the latest flood

Watercourse (models)	General comments	Findings requiring attention	Response to independent review
		structures proposed	modelling that is reported in the working paper.
Champions Creek (WBNM + TUFLOW)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	This phase Direct rainfall option implemented incorrectly though impact changes are restricted to sub-catchments downstream of project boundary Omission of form losses for major waterway structures proposed	This issue has been fixed in the latest flood modelling that is reported in the working paper. This issue has been fixed in the latest flood modelling that is reported in the working paper.
Clarence River (Cordery-Webb, UH, FFA + TUFLOW)	Model calibration and validation performed Proposed drainage structures/waterway crossings implemented properly	This phase Hydraulic model running at moderately high Courant numbers A few abnormalities found in the model 2D elevations (Zpts) Missing a 2D-2D connection for linking model domains Afflux up to 100mm found at isolated locations, may have been addressed by later design changes	Timestep reduced to produce lower Courant numbers. This issue has been fixed in the latest flood modelling that is reported in the working paper. This issue has been fixed in the latest flood modelling that is reported in the working paper. This issue has been fixed in the latest flood modelling that is reported in the working paper.

Watercourse (models)	General comments	Findings requiring attention	Response to independent review
		Prior to detailed design Hydrosurvey data used to develop the model terrain could be updated Cross-sections for Serpentine Channel not based on actual surveyed data	 Agree Agree
Mororo Creek (XP-RAFTS + MIKE-FLOOD)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	Nil	No response required
Tabbimoble Creek (XP-RAFTS + MIKE-FLOOD)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	Nil	No response required
Tabbimoble Floodway 1 (XP-RAFTS + MIKE-FLOOD)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	Nil	No response required

Watercourse (models)	General comments	Findings requiring attention	Response to independent review
Oakey Creek (XP-RAFTS + MIKE-FLOOD)	Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	Nil	No response required
Richmond River south (WBNM + TUFLOW)	Model calibration and validation performed Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	<u>This phase</u> Form loss adopted for proposed bridge structures relatively low and needs to be validated Specification error for bridge/channel along Rocky Mouth Ck	This issue has been addressed. Details of the assessment are provided in Appendix B. This issue has been fixed in the latest flood modelling that is reported in the working paper.
Richmond River north (XP-RAFTS, FFA + TUFLOW)	Model calibration and validation performed Proposed drainage structures/waterway crossings implemented properly Afflux criteria met	<u>This phase</u> Hydraulic model run time could be extended further Schematisation error for waterway upstream of Emigrant Ck	This issue has been fixed in the latest flood modelling that is reported in the working paper. This issue has been fixed in the latest flood modelling that is reported in the working paper.

2.2.7. Flood damages impact assessment

The assessment includes a flood damage impact for residences in areas expected to experience flood impacts within the Clarence and Richmond river floodplains. This includes the regions of Harwood, Chatsworth, Coraki, Woodburn, Broadwater and Ballina as well as outlying residential areas.

Survey data for these populations is collated from councils or survey undertaken. Collected data includes floor levels, building type and floor area (for commercial properties). Building type classifications includes:

- Commercial property
- Small (floor area less than 186 square metres)
- Medium (floor area 186-650 square metres)
- Large (floor area greater than 650 square metres)
- Residential property
- Fully detached
  - Single storey
  - Double storey
- High set
  - Multi unit
  - Single storey
  - Double store

In instances where the building type is unknown, property classification is based on other data (eg description, property type, number of floors and number of units).

Residential damage curves were applied (Maroochy Shire Council 2006) which estimate internal and structural damages based on the depth of flooding above floor level and external damages based on depth of flooding above ground level for each building type.

Commercial damage curves were applied (based on ANUFLOOD data provided in NR&W (2002) Guidelines) which estimate damages based on depth of flooding above floor level for small, medium and large commercial properties. Estimation of damages for large commercial properties is proportional to floor area.

Residential and commercial damage curves use March 2011 dollars as a relative change from existing conditions. Therefore, inflation does not affect the flood damage impact assessment.

Estimates of average annual damages per property are estimated by integrating the relationship between the probability of a flood in any given year and the costs incurred by that flood. Assessed floods range from the probable maximum flood (PMF) (ie highest possible cost of damages with nominally zero per cent probability) to the flood with probability at which flood damages cease to occur (for this assessment, assumed to be 10 year ARI event). The integral (area under the curve) represents the statistical average annual damages for that property. The difference in area between the curve generated for the existing and operating cases of the project represent the increase (or decrease) in flood damages, or impact to flood damages. This concept is represented in Figure 2-4.

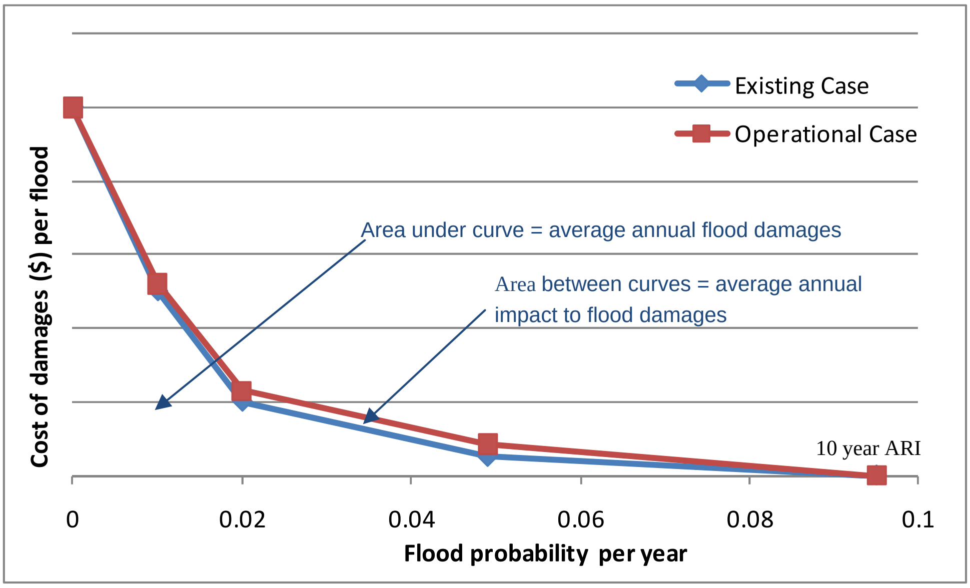

Figure 2-4 Flood damages assessment

Using a conservative assumption for flood levels in the PMF, the 20, 50 and 100 year ARI floods on the Clarence River and 20 and 100 year ARI flood on the Richmond River were sufficient to provide a reasonable assessment of flood damages for these areas.

The floor level survey data across the Clarence and Richmond river floodplains is not comprehensive. The survey tasks were concentrated around townships and areas experiencing a negative impact from the project. In order to better control the quality of the assessment and results, only houses experiencing a rise in flood level as a result of the project are included.

This means that the increase in annual flood damages documented as a result of the project represents the aggregate increase of only those houses with increased flood levels. It does not consider houses experiencing a decrease in flood levels (and corresponding reduction in flood damages) or houses which do not experience any impacts. This approach provides the most conservative understanding of the change to flood damages as a result of the project.

This means the average increase in flood damages across all areas experiencing either a rise or fall in flood levels would be less than that documented here. In some areas, where many residences would experience a reduction in flood levels (eg Ballina), the overall impact to annual flood damages is positive (ie flood damages are decreased as a result of the project). However, this gives a false impression of impact for those houses which would experience a rise in average annual damages from floods in those areas.

2.2.8. Flood impact assessment of cane land

Flood management objectives for cane farm land are provided in Section 2.1.3 and have been used to direct design of the project. Flood level and inundation impacts have been assessed against these objectives with respect to cane land along the length of the project. Where these objectives would not be met under the current design, measures have been provided to either reduce or mitigate these impacts.

A brief overview of flooding impact relevant for cane land on the Clarence and Richmond River floodplains is provided below.

Potential flooding impacts on cane land

Cane crops can be damaged by flood events, with the extent of damage determined by the time of year, flood height, duration of inundation, velocity of flood water and the debris load. Fully operational drainage systems are paramount in successfully removing the floodwater from the cane paddocks.

A flooding event in summer has a greater effect on cane survival than a flood in late autumn or winter. The cane crop is most vulnerable to inundation as its lower height allows silt to fill the throat of the cane stalk and destroy the growing point.

The cane is most affected by flood inundation in hot conditions as the cane scalds during inundation and will be destroyed after periods as short as two days. These crops will then need replanting during the following season.

The most expensive year in a cane paddock harvest history is the plant year. Hence, any increase in the number of plant years required due to increased frequency of lost crops would make the paddock less profitable.

The duration of inundation and the season is also critical for mature cane crops, as it causes plant death and lowered sugar content. This is of particular concern in the low lying floodplain areas such as Shark Creek.

The velocity of the flood water is an issue for more mature cane crops as the higher velocity causes the crops to dislodge and become covered by silt and debris. A crop in this condition is likely to begin ‘shoot and root’ development at the nodes resulting in lowered sugar content. Flood debris and lodged cane result in a slowing of the harvesting operations and subsequently dramatically increases the harvesting costs. Debris, silt and un-burnt leaf material also slow the crushing process, which increases production costs.

Flooding events that deposit silt debris in the cane fields will decrease the efficiency of the harvesting operation. There are also flow-on effects where the crushing operation is slowed and the wear rate of the mill equipment is increased. As a result, the repairs and maintenance costs and the rate in which the milling equipment needs to be replaced are increased.

The processing industry needs additional cane to be presented for crushing and is actively promoting cane production to local land holders. Therefore, any event or activity that lowers the quantity of cane presented to the mill would reduce the profitability and viability of the milling operation.

Justification of flood management objectives for cane land

The flood management objectives for cane lands were developed with consideration of the vulnerabilities discussed above. Over a number of years, many discussions were held with cane farmers in the study area to discuss these flood management objectives. Specifically, the increase on flood depths of less than 50 millimetres was discussed and there was general consensus that this increase would be generally acceptable.

More importantly, the increase to the time of inundation was discussed with cane farmers. It was recognised that no increase in the time of flood inundation would completely minimise the risk of crop damage. However, this could only be achieved by removing all of the floodplain embankments and constructing bridges across the floodplains. The project crosses 50 kilometres of floodplain with cane land (23 kilometres on the Clarence River floodplain and 27 kilometres on the Richmond River floodplain). The costs associated with this length of bridge would make the project unviable. Furthermore, there would still be some very small increases in flood depths and inundation times due to the effect of bridge piers.

The flood management objectives of five per cent increase in the time of flood inundation has been developed on the following:

- Consistency with other highway upgrades across floodplains with cane such as the Ballina Bypass project.
- Recognition that a balance between project costs and impacts to cane crop health following flood events needs to be established.

In summary, the significance of the flooding to cane growers has been recognised in the development of the concept design. Specific considerations in this regard include the following:

- The nature of the flood event (especially duration, height and velocity) has been a key consideration in the flood modelling, and special attention has been paid to this in developing the waterway opening requirements.
- The inclusion of bridges and culverts across the floodplain has been based on replicating the existing flood patterns as closely as possible.
- The need to ensure that the drainage system remains functional during construction and operation of the project is highlighted in the Concept Design Report. Further consideration will need to be given to this in the detailed design phase.

2.2.9. Farm dams impact assessment

The project would cross the catchments of several farm dams in or adjacent to the project.

Dams directly impacted within the project would be acquired by the project as part of the land acquisition process.

Dams indirectly impacted, due to a reduction in overall catchment area as a result of the project redirecting overland flow (typically within road cutting sections) were identified through 2010 aerial imagery. Corresponding catchments for each dam were determined from terrain data for the area, with impacted area defined where the catchment would intercept the project.

In some instances, the project would intercept the dam catchment without being considered to indirectly affect the dam. This may occur where:

- Culverts or bridge structures would maintain current flow paths across the project.
- The existing highway already redirects flow from the natural catchment of the dam and therefore the project would not result in any further substantial reduction in catchment area.

The farm dam assessment identifies the location and number of dams directly impacted, and the proportion of affected catchment area of dams indirectly impacted.

2.2.10. Geomorphological assessment of waterways

At each watercourse crossed by the project there is potential for the project to impact on the stability of the bad and banks. This potential impact is the result of concentrating flood flows through discrete openings in the embankments across floodplains.

To assess these impacts, a geomorphological assessment of the watercourses crossed by the project was carried out. The main focus of the assessment was on those watercourses to be crossed by bridges as the bed and banks would be largely unaltered by the project crossing (apart from the construction of piers which is also addressed).

Those watercourses to be crossed by culverts would include replacement of a length of watercourse (in the order of 50 metres) with a culvert designed to convey floodwaters through the project embankment. In these locations, a detailed assessment of each crossing would be carried out during detailed design as it requires a design process based on the exit velocity of the culvert which is determined by the final design of the culvert.

For those watercourses to be crossed by bridges, the geomorphological assessment involved the following elements:

- A site visit of each watercourse or reliance upon photography of the watercourse crossing.
- An assessment of the existing watercourse geomorphology as it relates to the setting within its floodplain, the condition of the bank vegetation and the type of watercourse.
- An assessment of the predicted changes to bed and bank velocities for a range of flood events including common flood events (either two year ARI or five year ARI) and rarer flood events (20 and 100 year ARI flood events). These velocity assessments were based on the two-dimensional flood model assessments carried out for the concept design and flood impact assessment.
- The changes to predicted bed and bank velocities were assessed to determine the potential for increasing the risk of channel form change. These assessments included

consideration of the capacity for increased flood velocities given the condition of vegetation coverage on the banks as guided by scour thresholds listed in Table 2-6.

Table 2-6 Typical bank scour velocities (DNRW, 2007)

Bank Condition	Typical bank scour velocity (m/s)[1]
Non vegetated banks	0.5 – 1.5 (depending on soil type / erodibility)
Poorly vegetated banks (sparse groundcover)	1.0 – 1.5 (depending on soil erodibility)
Well vegetated (grassed banks, thick shrub and tree cover, healthy coverage of fibrous-rooted herb layer)	2.0 – 3.0 (erosion-resistant soils)

1. Average jetting velocity impacting on a channel bank.

2.2.11. Geomorphological assessment of diversions

A geomorphological assessment is required in locations where the project would modify the existing waterway.

To avoid crossing Picaninny Creek at its junction with Pheasant Creek, the specific location of Picaninny Creek would be diverted along the western edge of the project. The concept design would include the requirements of such a diversion and ensure that its specification meets guidelines set out for waterway design and watercourse diversions.

In conjunction with the concept design, there is a geomorphological assessment for this location. It considers the existing geomorphology with respect to several parameters with a diversion design consistent with guideline criteria, as set out in *Watercourse Diversions – Central Queensland Mining Industry* (DERM, 2011). These criteria include:

- The channel capacity must be at least equivalent to the natural stream capacity in that vicinity
- The length of the channel should be nearly the equivalent length of the watercourse it replaces or some form of stable energy dissipater must be incorporated
- The diversion channel must exhibit features similar to the natural existing watercourse such as meanders, terraces, benches, etc
- Assessment of the stability and erosion characteristics of the diversion design
- The capacity of the floodplain to deal with out of channel flows
- Potential hydraulic and geomorphic impacts of the diversion channel on the adjoining natural reaches of the watercourse both upstream and downstream of the diversion.

The selected diversion route modelling uses the one-dimensional model HEC RAS (4.0) to confirm that the proposed alignment and profile design and features provided a stable bed and grade to manage creek flows. Further detail on the model inputs and outputs are included in Appendix C.1

Peak discharges would be used to develop the channel geometry design, which aims to provide flow velocities, stream power and shear stresses within set parameters. Hydrological modelling assesses the size of events experienced in this reach of Picaninny Creek. For the purposes of this conceptual assessment and design, some events are estimates. For the purposes of the diversion capacity, the containment of flow in a five year ARI event has been specified. These events are summarised in Table 2-7 below.

Table 2-7 Peak discharges through Picaninny Creek

ARI event	Peak flow (m^3/s)	Derived
2	10	Estimate
5	28	Model
100	42	Model

The diversion design has been based on the *Technical Guidelines for Waterway Management (*2007, DSE*)* and associated concepts and criteria. These criteria include velocity, shear stress, stream power, bed grade, channel width and channel depth. Further detail is provided in Appendix C.2. It should be noted that many of these criteria have been developed for Central Queensland systems, and as such have not been used prescriptively.

3. Consultation

3.1. Previous consultation (pre 2010)

3.1.1. Woolgoolga to Wells Crossing

The previous development project of Woolgoolga to Wells Crossing upgrade included engagement of property owners, the local community and stakeholders. This included two community information sessions, advertising, five community updates, focus groups and a community liaison group.

During the route options display, 79 submissions were received from residents in the Corindi area. Through these submissions, a preferred route option and variant were developed with consideration of the key issues identified by the community and stakeholders.

Issues relating to flooding were raised and discussed at community liaison group meetings and the value management workshop. These concerns were part of the multi-criteria assessment during route selection and further project development.

3.1.2. Wells Crossing to Iluka Road

The Wells Crossing to Iluka Road upgrade travels through extensive floodplains with large areas developed for cane farming and other farming uses. A hydrology and flooding focus group was formed during the previous development project to gain valuable information relating to the existing flooding regime and to review issues associated with upgrading the highway. Impacts on the sugarcane industry and housing, maintaining access across floodplains and waterway scouring, were noted as issues of particular importance to the community. Design objectives, the study process and findings of the flood analysis were also discussed during focus group meetings.

In evaluating the route options and selecting the preferred route, RMS held a three day value management workshop. The invited participants included representatives of local residents, businesses, Aboriginal groups and other non government organisations.

In addition, there were eight community updates, three meetings at each of the four community liaison groups, community meetings and provision of a free-call information line and project email address.

The participation of community members, particularly affected land owners, has continued since the announcement of the preferred route, through individual discussions, sharing of local knowledge and conditions. This is directly influencing the engineering design of the route to achieve the best possible outcome for the regional community.

3.1.3. Iluka Road to Woodburn

Community and stakeholder involvement during the previous development project of the Iluka Road to Woodburn upgrade included six community updates, five community information sessions, face to face meetings between the community and the study team, and advertisements.

Flooding and drainage were raised as key issues and were investigated through hydrological assessment.

The preferred concept design report, concept design report and Devils Pulpit project information were available on the internet and a project information line that allowed members of the community to speak with the project team was also made available. Written submissions and comments on the project were also encouraged.

3.1.4. Woodburn to Ballina

Advertisements, five community updates, community information centre open day and 12 community liaison group meetings were part of the community and stakeholder involvement during the previous development project for this section of the upgrade. Additionally, several focus groups were consulted, including a flooding focus group and sugar industry focus group.

The project traverses the large Richmond River floodplain, intersecting with the Emigrant Creek floodplain. The sugar industry focus group raised concerns regarding inundation times and siltation. Discussions in the flooding focus group further explained the process and design objectives for the study and the complexity of the area with construction of roadway in one area affecting other areas.

Information provided by the flooding focus group included photographs of recent flooding and observations of flooding patterns. The impact on inundation times and increase to peak flood levels were noted as important issues. Structure sizes, mitigation requirements, the accuracy of the modelling and the afflux associated with different route options were also discussed.

The route selection and concept design included consideration of the issues raised.

3.2. Current consultation (post 2010)

A planning focus meeting was held for the project in August 2011, identifying the project to government agencies. This meeting formed part of the development of the Director-General's environmental assessment requirements for the environmental impact statement. Hydrology issues that were raised by government agencies include:

- Concern about flooding on the Richmond River floodplain
- Flood impacts on agriculture and property (dwellings)
- Flood immunity of the highway including connectivity to other roads
- Effect of change to hydrology on agricultural land (eg on Coldstream River floodplain), existing hydrological regime should be maintained

These issues have been addressed in this assessment.

Project flood focus groups are currently being undertaken with community members. The intent of these focus groups is to provide local communities an opportunity to contribute during the development of the project with respect to flood related concerns, such as evacuation and drainage.

Meetings held or planned during 2011 and 2012 include:

- Meeting 1 – Overview and update of community concerns and issues and the way forward. Undertaken in mid November 2011
- Meeting 2 – Feedback on the independent assessment and addressing any issues. Undertaken in mid February 2012
- Meeting 3 – Presentation of responses to independent assessment and other matters raised in meetings 1 and 2. Undertaken in early August 2012
- Meeting 4 – Environmental assessment display and stakeholder meetings. To be undertaken during the public exhibition period
- Meeting 5 - Only required if there are changes that come out of the submissions.

Each meeting was delivered at two locations to address issues across both major catchments: Wardell for the Richmond River and Harwood for the Clarence River. Community members have raised a range of concerns through this forum to date.

The main issues raised for the Richmond River floodplain include:

- Proposed bridges and culverts in section crossing Tuckombil Canal / Evans River floodplain
- Proposed culverts under upgrade near Lumleys Lane (drainage of catchments west to east)
- Proposed culverts under upgrade at Wardell interchange and Saltwater Creek / Randles Creek
- Maintenance of culverts, management of debris, wire rope safety fence blockage
- Concerns regarding flood modelling: scenarios, afflux limits (the maximum effect the upgrade will have on flood levels), catchments included, etc
- Access during flood events (people, SES, stock etc)
- Assessment of sea level rise and increased rainfall intensity due to climate change.

The main issues raised for the Clarence River floodplain include:

- Changes to flooding behaviour in Shark Creek area
- Impacts to cane drainage network at Shark Creek area
- Coldstream River bridges / culverts
- Increases to flood levels in Maclean (overtopping of levee)
- Maintenance of culverts, management of debris
- Assessment of more frequent, smaller floods
- Concerns regarding flood modelling (data used etc)
- Access during flood events (people, SES, stock etc).

A full summary of minutes for Meetings 1, 2 and 3 at Wardell and Harwood are included in Appendix D.

As well there were concerns raised by residents in the vicinity of the Corindi River regarding the impacts of the project with regard to the recent upgrade of the existing Pacific Highway further downstream from the project.

4. Existing environment

4.1. Regional context

The study area, as defined in Section 1.3, includes numerous creeks and two large river systems (Clarence and Richmond rivers) and their floodplains. Locations are provided in Figure 1-2.

Catchments of watercourses crossed by the project range from small unnamed tributaries of less than two square kilometres to the major Clarence and Richmond river systems of around 20,000 square kilometres and 7000 square kilometres respectively.

This chapter includes a description of the existing flooding characteristics of these watercourses. The definition of the existing flooding behaviour forms the basis of the impact assessment presented in subsequent chapters.

The study area is characterised by relatively steep catchments (five to 15 per cent) with some steeper catchments characterised by slopes of up to 25 per cent. Floodplain slopes are generally in the order of 0.5 to one per cent gradient.

Several of the catchments, such as Corindi River and Halfway, Pheasant, Champions, Tabbimoble and Oakey creeks are predominantly forested, intercepting numerous state forests and national parks, including:

- Conglomerate State Forest
- Wedding Bells State Forest
- Glenugie State Forest
- Yuraygir National Park
- Newfoundland State Forest
- Double Duke State Forest.

Most catchments include cleared areas used for agriculture, grazing and rural residential land uses. These areas are typically in lower areas of the catchment and closer to the existing highway. The potential impact of the project on cane drainage networks, residential evacuation routes and flood damages is discussed in subsequent chapters.

4.2. Corindi River

4.2.1. Catchment description

The project crosses the Corindi River in Section 1, one kilometre to the north-west of Corindi Beach, and around eight kilometres upstream of its outlet to the Pacific Ocean at Red Rock. The project passes through a cleared, rural area 800 metres to the west of the existing highway. The catchment to this point is 81.2 square kilometres.

The catchment contains relatively steep terrain with slopes in most parts in the order of five per cent to 15 per cent. Slopes on the floodplain in the vicinity of the project are less than one per cent.

The land use of the catchment is predominantly forest (Conglomerate State Forest and Wedding Bells State Forest), with the flatter sections of the valley floor in addition to hilltops along the northern boundary of the river cleared for agriculture and rural residential land use.

In the cleared rural area adjacent to the route, a small shed has been indentified within 100m of the Corindi River. The shed is situated at the back of a property on the western side of the existing highway, located approximately 1.3 kilometres west of the Corindi River highway crossing. No other buildings have been located on the Corindi River floodplain.

Blackadder Gully, Cassons Creek, and Redbank Creek are tributaries of the Corindi River, located in the lower section of the floodplain.

4.2.2. Existing flooding behaviour

Existing flooding behaviour is assessed through hydrological and hydraulic flood modelling. The type of models used in this catchment are summarised in Table 2-4. The peak flood levels[3] for the 100 year ARI flood event for Corindi River in the vicinity of the project are presented in Figure 4-1.

The peak flood levels in the vicinity of the project are around 10.2 metres Australian Height Datum (AHD) to 12.4 metres AHD. The peak 100 year ARI flow is 750 cubic metres per second in the Corindi River at the project site, including flows in Cassons Creek and Blackadder Gully.

Figure 4-2 shows the existing peak flood depths[4] for the 100 year ARI flood event for Corindi River floodplain in the vicinity of the project.

Peak flood velocities on the floodplain in this flood event are typically 1.0 to 1.5 metres per second and are considered moderately high. Flood velocities are high (exceeding two metres per second) in the main channels and flow paths in the valley. Existing peak velocities are presented in Figure 4-3.

The main flow paths on the floodplain, which cross the project, consist of the main Corindi River channel, in addition to an extensive floodway 350 metres wide to the north of the main channel. A

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[3] **Flood level:** the height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as "stage".

[4] **Flood depth:** the height or elevation of floodwaters above ground level.

smaller floodway which includes Cassons Creek is located along the northern portion of the floodplain.

Cassons Creek and Blackadder Gully and their floodplains form major overland flow paths for flood flows breaking out of the Corindi River during large flood events. The break-out flow from the river flows north-east to these creeks results in a strong flood gradient in that direction along the project route. Hence, flood levels along the route vary considerably due to this complex flow pattern. The flood levels in the Corindi River are much higher than the flood levels further north along the route due to this pattern.

4.2.3. Geomorphic characteristics

A high level and preliminary geomorphic assessment has been conducted for this waterway based on aerial photography, soil maps and a site inspection.

Corindi River

Corindi River may be classified as a meandering, unconfined but stable waterway vegetated banks. This alluvial stream is situated within public and private lands. The land comprises both alluvial floodplain, and forested floodplains. The alluvial floodplain is utilised for productive farming and cropping enterprises. The river has the potential to actively meander and is unconfined within the floodplain.

Corindi River has well-vegetated banks. To instigate considerable erosion or a change in channel form, the following would need to occur:

- Bank velocities of two to three metres per second
- Bank slumping due to floodplain saturation
- Flood events greater than five year ARI (localised channel erosion and slumping)
- Flood events greater than 20 year ARI (bank erosion causing channel change is possible).

Plate 4-1 shows Corindi River, 620 metres east of the project crossing.

Plate 4-1 Corindi River

Blackadder Gully

Blackadder Gully is a minor alluvial tributary of Corindi River, appearing to be a disconnected meandering anabranch through pasturelands. The waterway is largely void of over-storey vegetation, with introduced pasture grasses growing down to the edge of the water.

The land comprises both alluvial floodplain, and forested floodplains and the creek is unconfined within the floodplain and has the potential to actively meander.

Plate 4-2 shows Blackadder Gully, about 800 metres east of the project. The project crosses the Corindi River floodplain upstream of the gully formation, close to where the gully was once connected to Corindi River.

To instigate a change in channel form or for considerable erosion to occur on these waterways, the following events would need to occur:

- Major flooding of the order five year ARI or greater
- Bank slumping due to floodplain saturation.

Plate 4-2 Blackadder Gully looking upstream

Cassons Creek

Cassons Creek is a minor waterway that crosses the project about one kilometre north of Corindi River. The adjacent land generally comprises forested valley floors and flats, and alluvial flood plain. The waterway has unconfined banks and is well vegetated with good stands of native trees and shrubs growing along the edges and vicinity. This riparian vegetation contributes to river health and the stability of banks. The stream is likely to engage with the floodplain in relatively small flow events.

To instigate a change in channel form or for considerable erosion to occur on these waterways, flooding of the order two year ARI or greater would need to occur.

Cassons Creek, 560 metres north-east of the project crossing, is shown in Plate 4-3.

Plate 4-3 Cassons Creek looking downstream

Redbank Creek

Redbank Creek is a minor gully, forming a tributary of Cassons Creek.

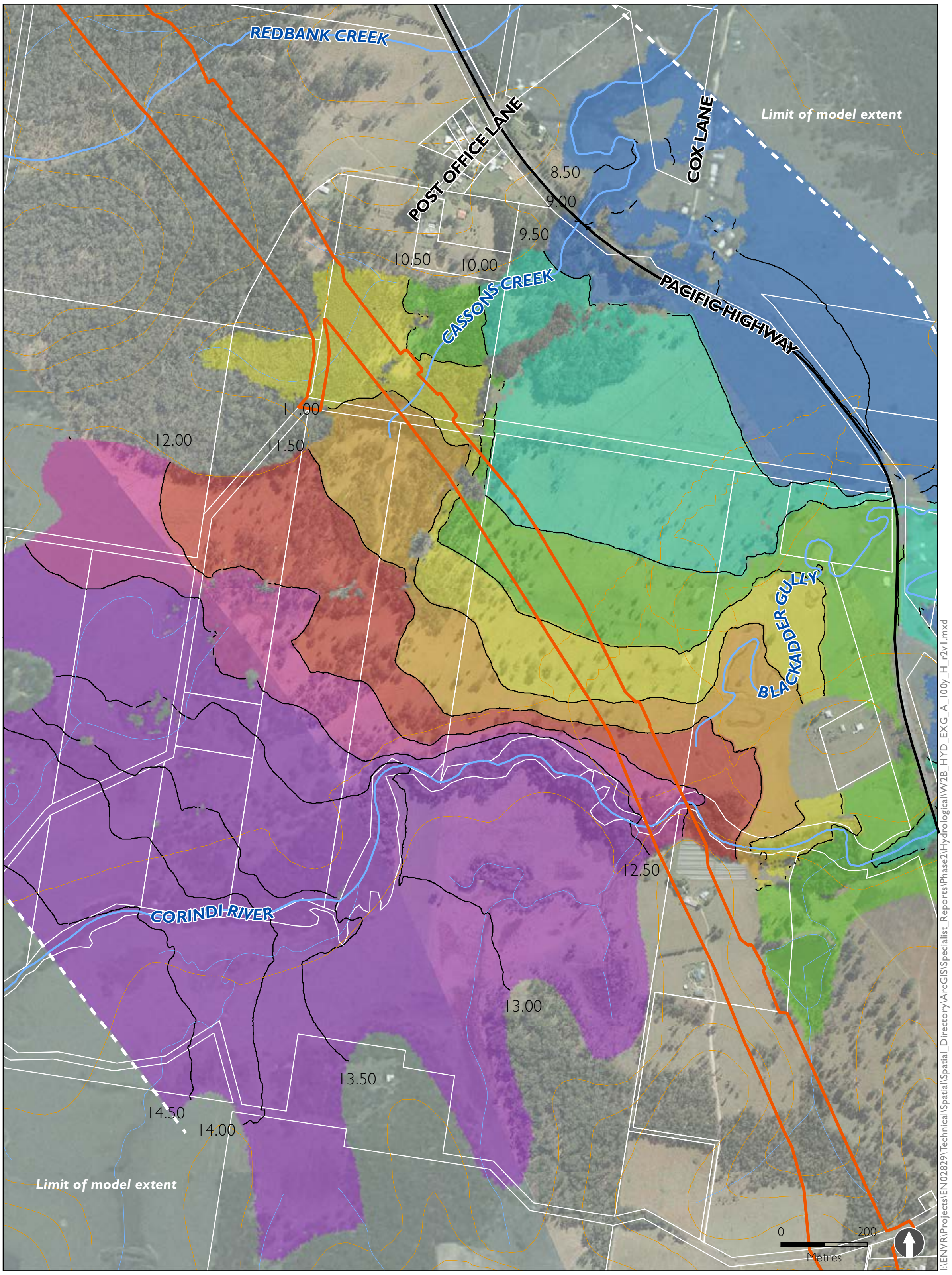
The gully has poorly-vegetated and very unstable and eroded banks at the location of assessment (at the existing Pacific Highway crossing). Significant scour along its deep and narrow channel is evident and has eroded out at least 500 millimetres in depth beneath the existing concrete culvert apron.

To instigate a change in channel form on this waterway, flooding of the order two year ARI or greater would need to occur. Given the evidence of significant scour downstream of the existing Pacific Highway, it is likely that smaller events may also contribute to bed and bank erosion.

Plate 4-4 shows Redbank Creek looking downstream, about 750 metres downstream from the project crossing.

Plate 4-4 Redbank Creek looking downstream

Figure 4-1 Peak 100 year ARI flood levels: Corindi River



The project

Existing Pacific Highway

5m ground level contours (indicative)

Flood levels - m (AHD)

9.50 10.00 10.50 11.00 11.50 12.00 12.50

Figure 4-2 Peak 100 year ARI flood depths: Corindi River

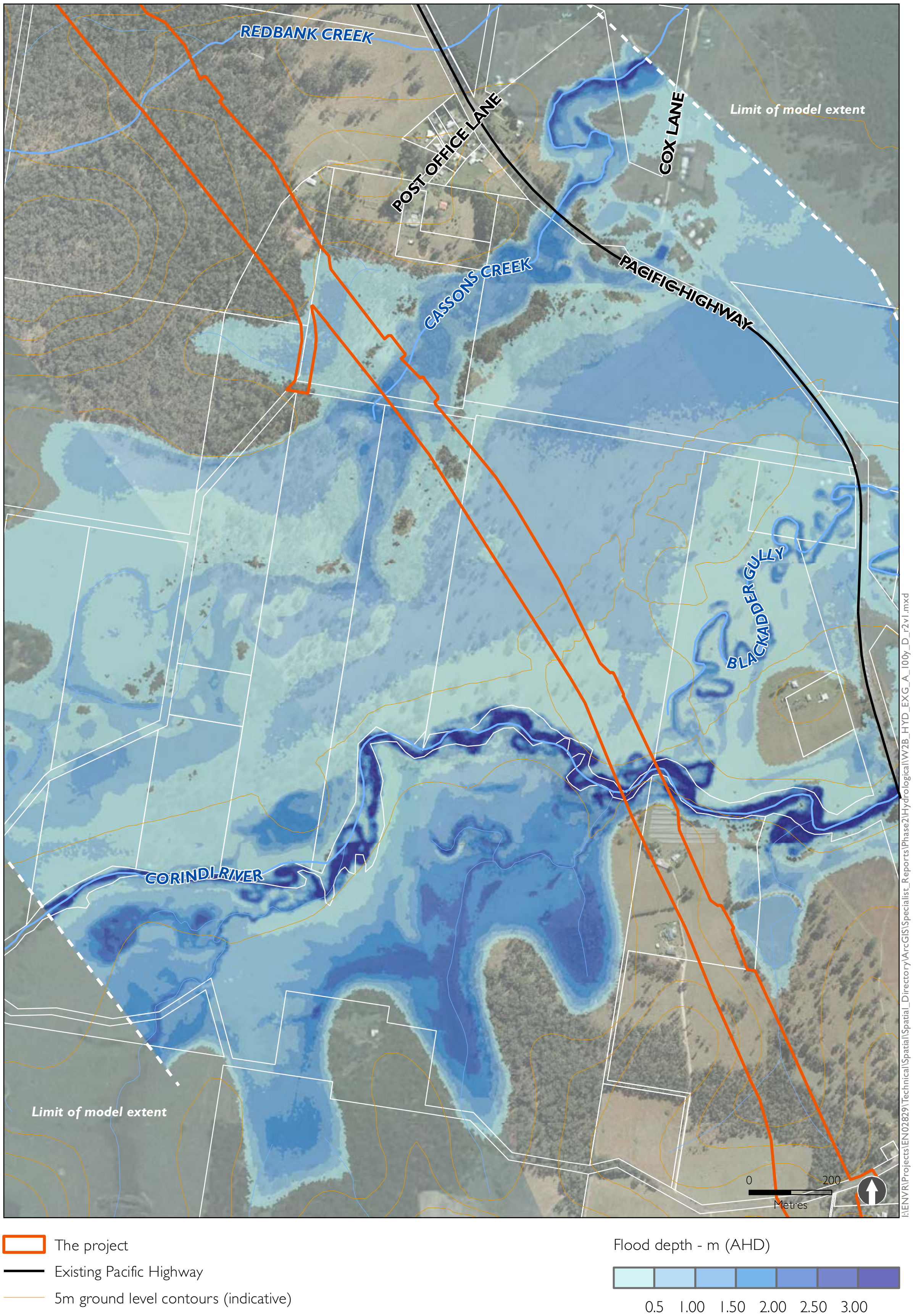
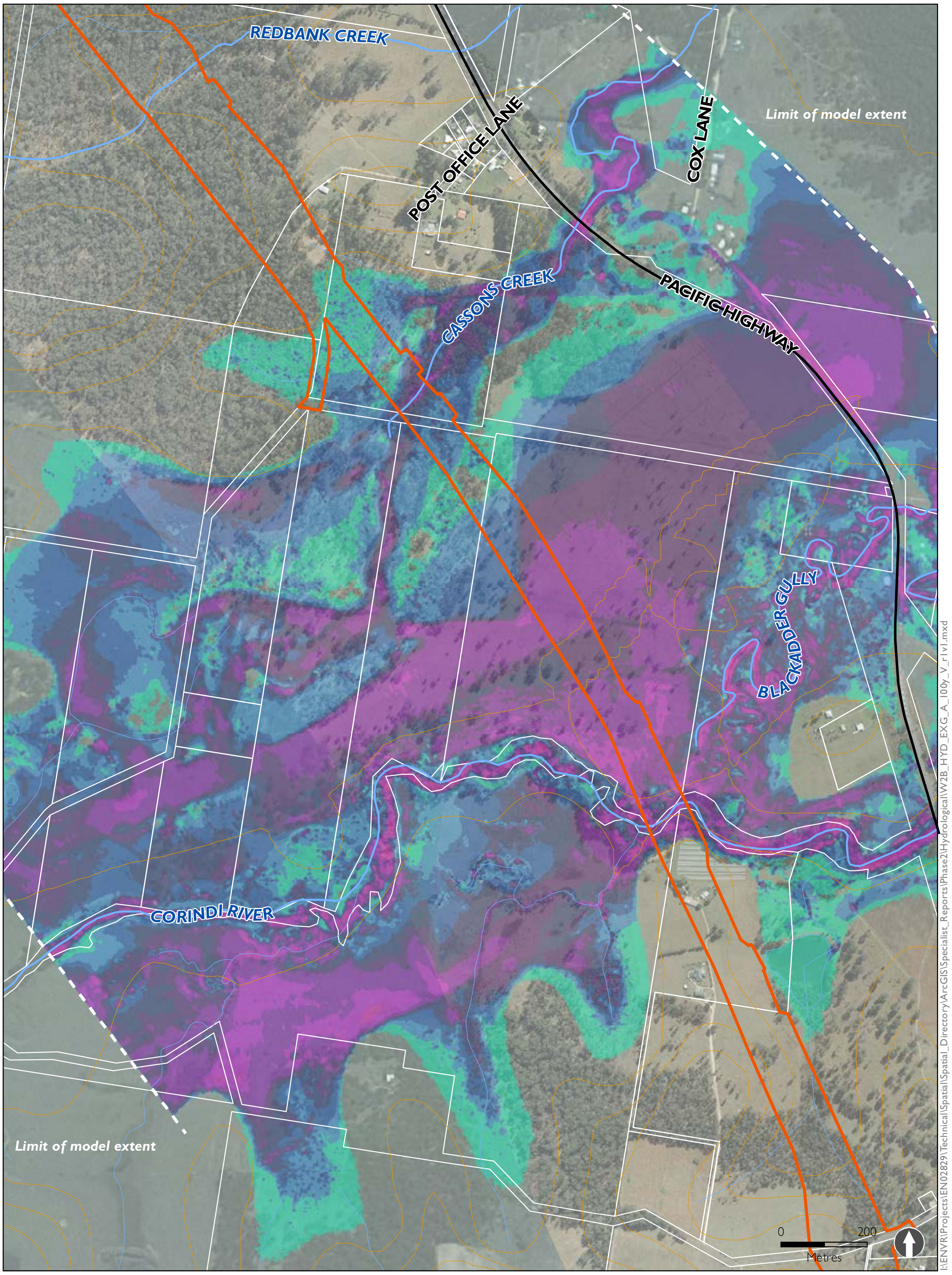


Figure 4-3 Peak 100 year ARI flood velocities: Corindi River



The project
Existing Pacific Highway
5m ground level contours (indicative)

Flood velocity - m/s

0.2 0.4 0.6 0.8 1.0 1.5 2.0

4.3. Halfway Creek

4.3.1. Catchment description

The project crosses Halfway Creek in Section 2, very close to the existing highway crossing, immediately to the south of the Luthers Road intersection. The catchment to this point is 23.3 square kilometres. Although the project only crosses Halfway Creek at one point, the creek also travels in alongside the project for around four kilometres.

The catchment contains relatively steep terrain with slopes in most parts in the order of five per cent to 15 per cent. Slopes on the floodplain in the vicinity of the project are in the order of 0.5 per cent to one per cent.

The existing highway crosses Halfway Creek at two points: the main waterway via a bridge, and a secondary channel immediately south of the bridge via a concrete box multicell culvert of four openings each measuring 3.0 metres wide by 2.4 metres high. The two channels converge just downstream of the crossing.

The land use of the catchment is predominantly forest, with some rural areas located close to the existing highway. No buildings have been identified within the Halfway Creek floodplain.

4.3.2. Existing flooding behaviour

Existing flooding behaviour has been assessed through hydrological and hydraulic flood modelling. The type of models used in this catchment are summarised in Table 2-4. The peak flood levels for the 100 year ARI flood event for Halfway Creek in the vicinity of the project are presented in Figure 4-4. The peak flood levels in the vicinity of the project are in the order of 57.0 metres AHD (downstream of the project) to 60.6metres AHD (upstream of the project).

The large drop in flood level across the bridge over Halfway Creek is due to the turbulence caused by floodwaters reaching the underside of the bridge deck. While the upstream flood level is above the soffit of the bridge, the 100 year ARI flood does not overtop the bridge deck.

Peak flood depths for the 100 year ARI flood event in this area are presented in Figure 4-5.

The peak 100 year ARI flow in Halfway Creek at the project site is 329 cubic metres per second. Peak flood velocities in this flood event are moderate, typically 0.5 to 1.5 metres per second, with localised high velocities greater than three metres per second due to local channel hydraulic controls and the existing bridge and culvert structures.

The main flow paths on the floodplain consist of the main Corindi River channel, in addition to an extensive floodway 350 metres wide to the north of the main channel. A smaller floodway which includes Cassons Creek is located along the northern portion of the floodplain.

4.3.3. Geomorphic characteristics

A high level and preliminary geomorphic assessment has been conducted for this waterway based on aerial photography, soil maps and a site inspection.

Halfway Creek

Halfway Creek is relatively stable, due to the likely existence of rock bars and valley margins. The adjacent land generally comprises forested valley floors and flats, and alluvial flood plain. Halfway Creek tends to have deeper channels and higher banks due to geologically confining features such as bedrock and less erodible banks.

Halfway Creek has well-vegetated banks and it is unlikely bed deepening will occur in this waterway. To instigate considerable erosion or a change in channel form, the following would need to occur:

- Bank velocities of two to three metres per second
- Flood events greater than two year ARI (localised bank erosion)
- Flood events greater than five year ARI (localised erosion instabilities)
- Flood events greater than 20 year ARI (bank erosion causing channel change is possible).

Plate 4-5 shows Halfway Creek within 100 metres of the proposed project crossing.

Plate 4-5 Halfway Creek looking upstream

Figure 4-4 Peak 100 year ARI flood levels: Halfway Creek

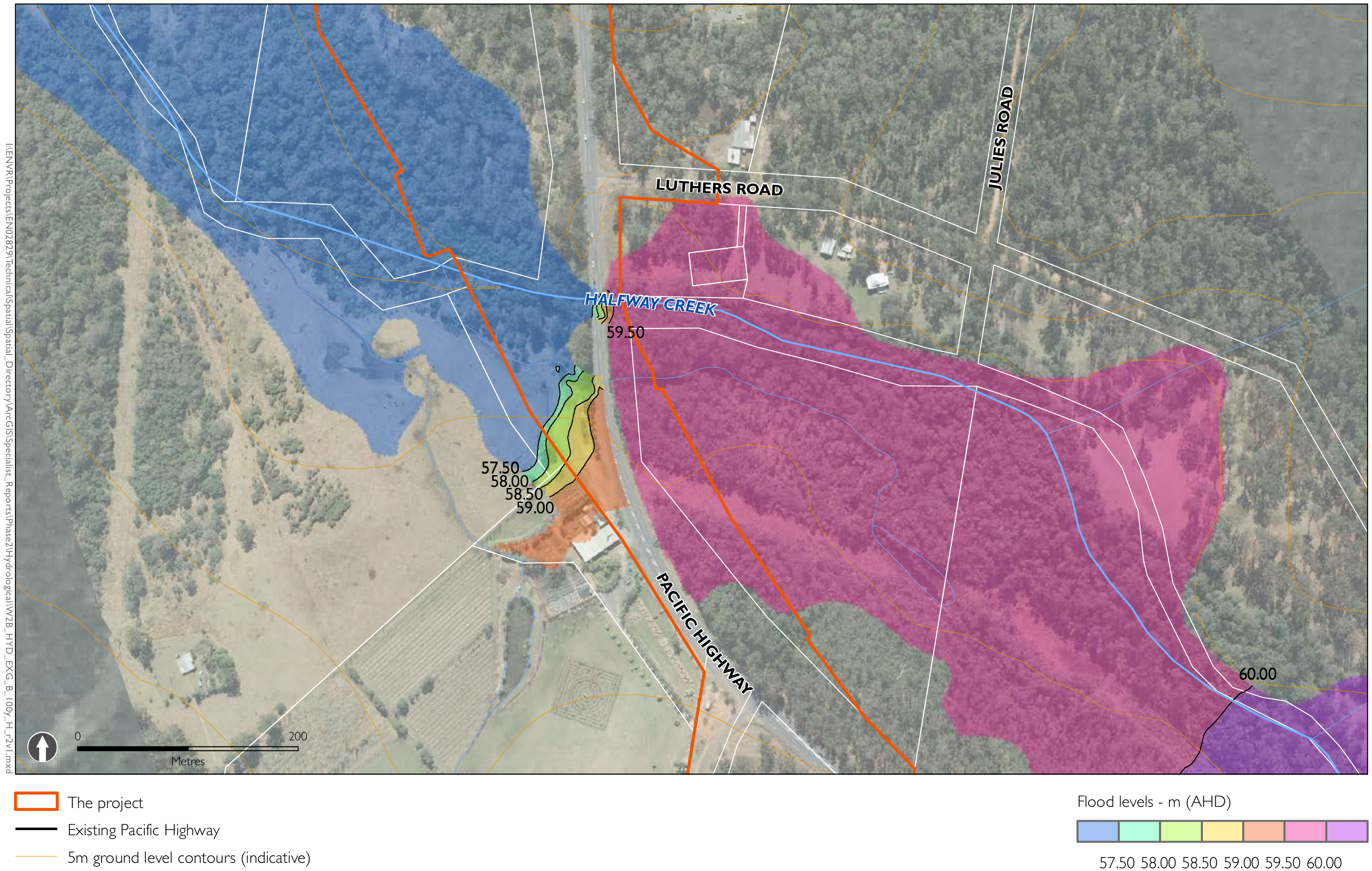
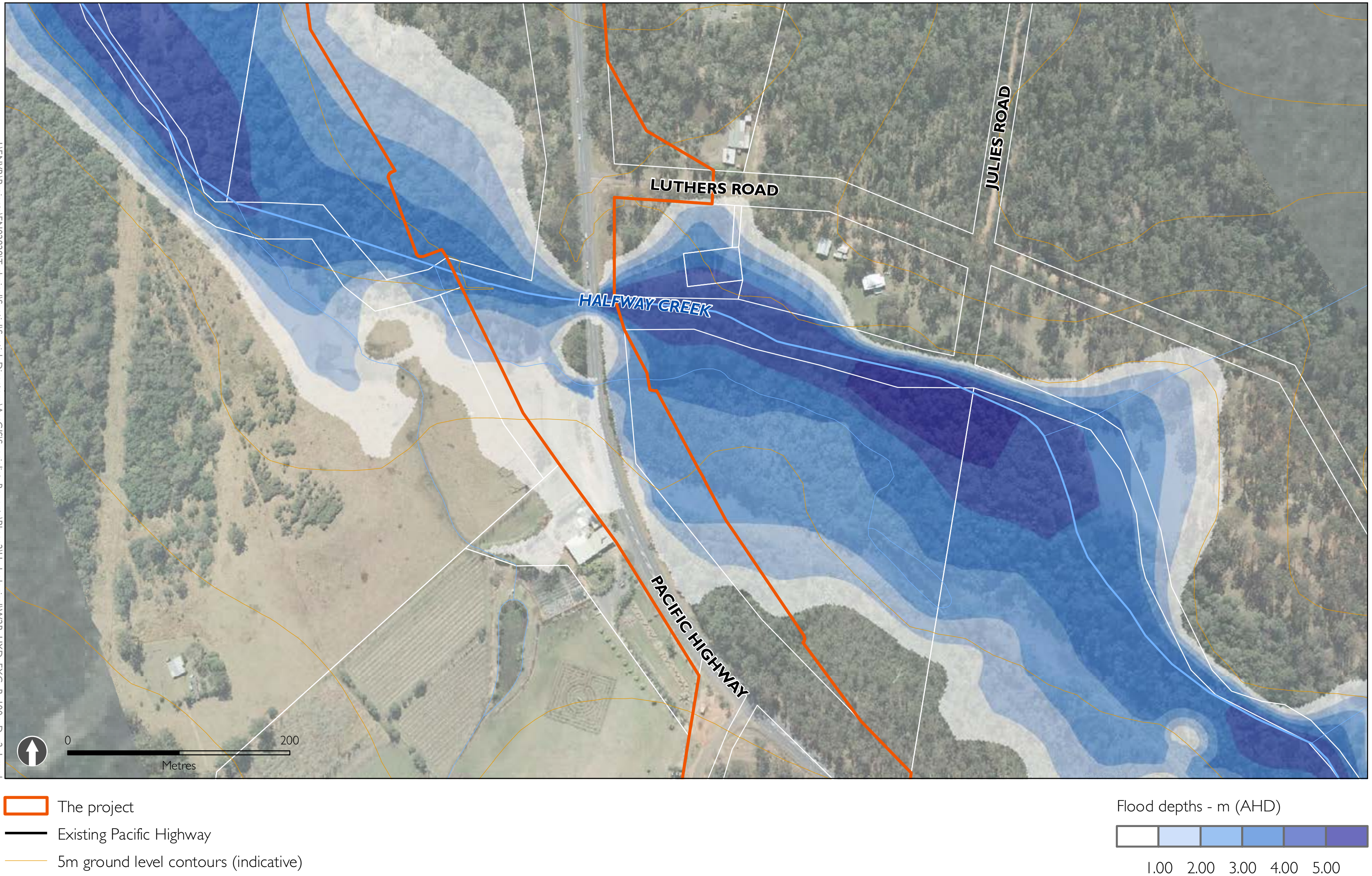


Figure 4-5 Peak 100 year ARI flood depths: Halfway Creek



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4.4. Pheasant Creek

4.4.1. Catchment description

Pheasant Creek is crossed by Section 3 of the project near its junction with Picaninny Creek. The catchment area of Pheasant Creek to this point is 4.74 square kilometres. The catchment area of Picaninny Creek to the project is about 1.96 square kilometres. Both catchments contain relatively steep terrain with slopes in most parts ranging from five to 10 per cent.

The land use in the catchments is mostly forest (Glenugie State Forest). The upper parts of Picaninny Creek (upstream of the existing Pacific Highway) have been cleared for agricultural purposes. No buildings have been identified within the Pheasant Creek floodplain.

4.4.2. Existing flooding behaviour

Existing flooding behaviour has been assessed through hydrological and hydraulic flood modelling. The type of models used in this catchment are summarised in Table 2-4. The peak flood levels for the 100 year ARI flood event for Pheasant Creek in the vicinity of the project is presented in Figure 4-6. Pheasant Creek peak flood levels in the vicinity of the project are about 20 metres AHD. Peak flood depths for the 100 year ARI flood event for Pheasant Creek are presented in Figure 4-7.

Eight Mile Lane crosses both Picaninny and Pheasant creeks in this area. The 100 year ARI flood event results in significant overtopping of Eight Mile Lane. Hence, the existing Eight Mile Lane crossing of Pheasant Creek result in only minor disturbances to the natural flood gradient.

The 100 year ARI flow is 67 cubic metres per second in Pheasant Creek and 39 cubic metres per second in Picaninny Creek. Peak flood velocities in this flood event are relatively high at 1.2 metres per second due to the somewhat steep floodplain terrain (slopes of about 0.5 per cent).

4.4.3. Geomorphic characteristics

A high level and preliminary geomorphic assessment has been conducted for this waterway based on aerial photography, soil maps and a site inspection.

Pheasant Creek

Pheasant Creek may be classed as a forested and partially confined minor waterway. This creek is situated within public and private lands and the adjacent land generally comprises forested valley floors and flats, and alluvial flood plain.

This waterway has well-vegetated banks with good stands of native trees and shrubs growing along the edges and vicinity, which contributes to river health and the stability of banks.

It is likely that Pheasant Creek will engage with the floodplain in relatively small flow events. To instigate considerable erosion or a change in channel form, the following would need to occur:

- Bank slumping due to floodplain saturation may occur in all flood events
- For flood events greater than two year ARI, localised channel erosion and slumping may occur
- For events greater than 20 year ARI bank erosion causing channel change is possible.

Plate 4-6 shows Pheasant Creek within 500 metres of the project crossing.

Plate 4-6 Pheasant Creek looking downstream

Picaninny Creek

Picaninny Creek is a small tributary in the Pheasant Creek catchment. The creek presently intersects 8 Mile lane, which is a main interchange point east of Grafton (at station 35.9).

The creek is a small meandering ephemeral creek, which sits within a narrow floodplain within the Glenugie State Forest. As the creek is ephemeral[5], the bed and banks are heavily vegetated with an estimated 50 to 90 per cent of tree cover on its banks.

[5] Does not experience permanent flow.

The existing creek has two distinct gradients: about -0.85 per cent for the initial 400 metres and then steepening to around -1.15 per cent as it approaches the confluence with Pheasant Creek.

Plate 4-7 shows Picaninny Creek within 500 metres of the project crossing.

Plate 4-7 Picaninny Creek looking downstream

Figure 4-6 Peak 100 year ARI flood levels: Pheasant Creek

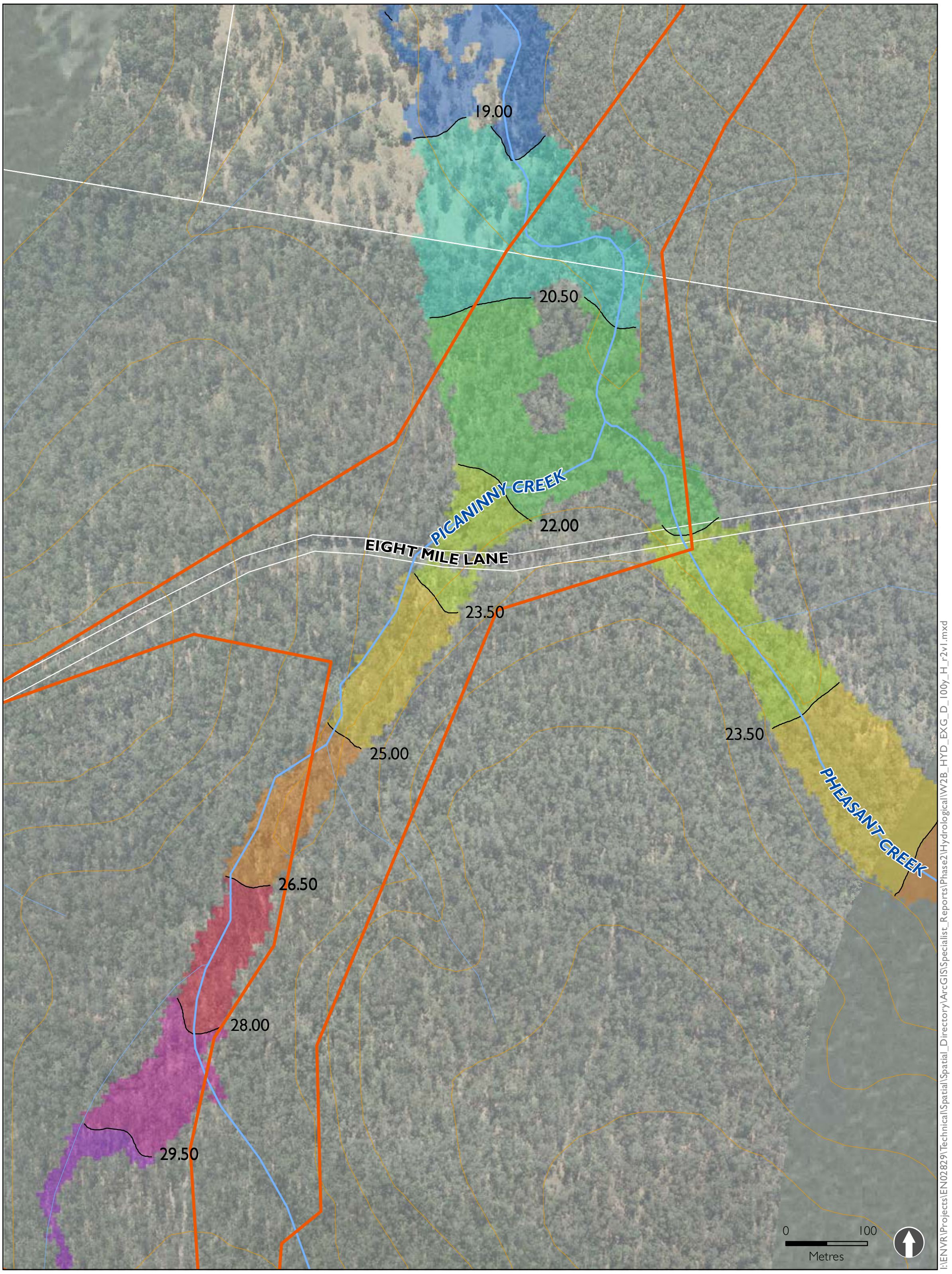
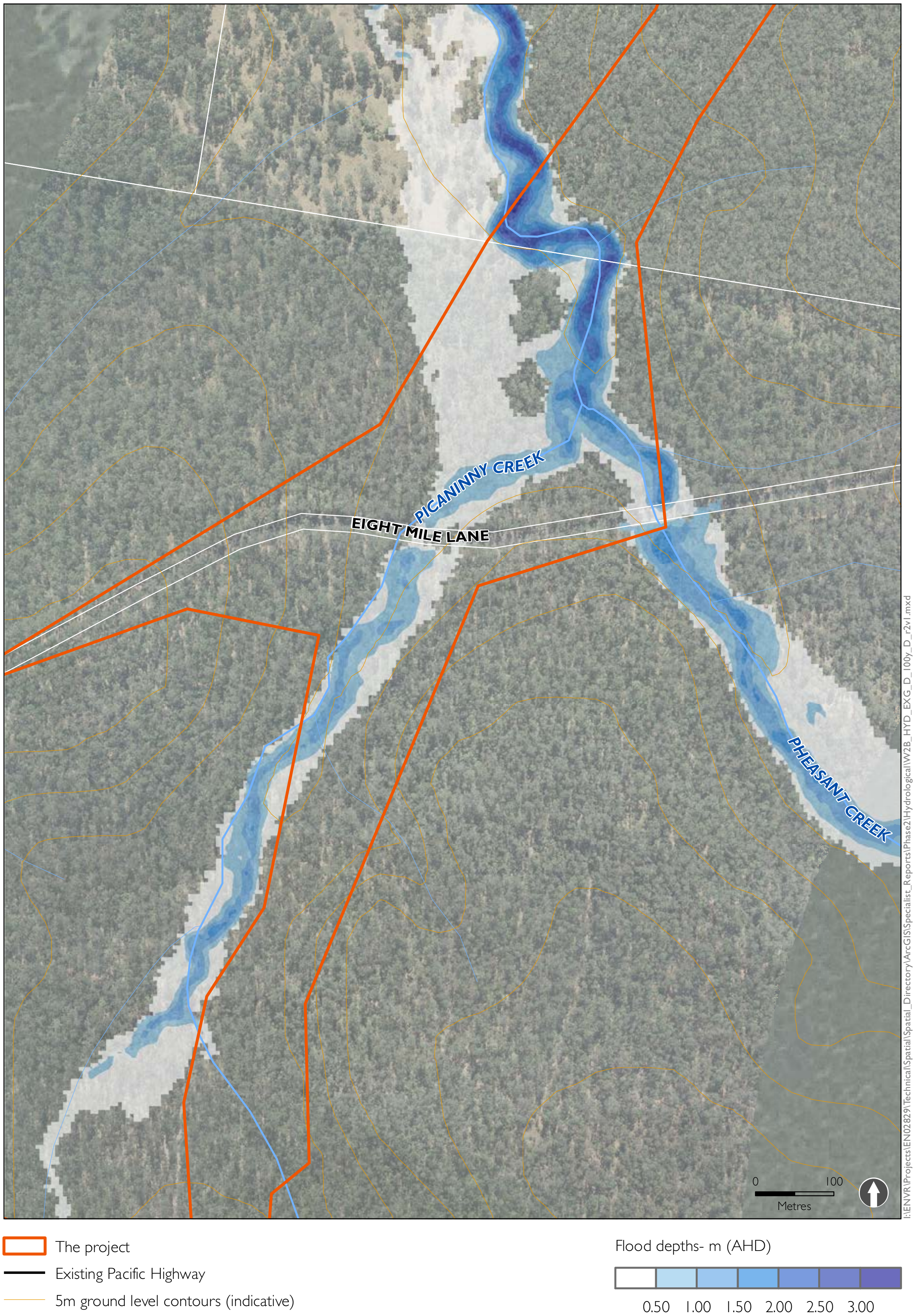


Figure 4-7 Peak 100 year ARI flood depths: Pheasant Creek



4.5. Coldstream River

4.5.1. Catchment description

The Coldstream River runs in a general south to north direction. The main channel of the Coldstream River crosses Section 3 of the project west of Pillar Valley at about station 43.4 and has a catchment area to this location of 113 square kilometres. An unnamed tributary of the Coldstream River crosses the project to the west of the main channel at station 42.7 and has a catchment area of 8.5 square kilometres to the project.

The highest elevation in the catchment is about 300 metres and the upper reaches are steep with slopes of up to 25 per cent. The slope reduces quickly to be generally less than five per cent throughout the majority of the catchment.

The upper parts of the catchment are heavily forested and include Yuraygir National Park, Newfoundland State Forest and Glenugie State Forest. Some areas have been cleared for farming, with the greater proportion of farming land in the valleys and the lower part of the catchment. No buildings have been identified within the Coldstream River floodplain.

The lower part of the Coldstream River flows along the eastern side of a large basin within the Clarence River floodplain before joining the Clarence River South Arm.

4.5.2. Existing flooding behaviour

Existing flooding behaviour has been assessed through hydrological and hydraulic flood modelling. The type of models used in this catchment are summarised in Table 2-4. The 100 year ARI peak flood levels for the proposed Coldstream River crossing are presented in Figure 4-8. The peak flood levels in the vicinity of the project range from 2.8 metres AHD to 3.0 metres AHD.

Figure 4-9 shows the peak flood depths for the Coldstream River in a 100 year ARI flood event.

The peak 100 year ARI flow rate across the entire floodplain at the project location is about 1100 cubic metres per second. The Coldstream River contributes about 1020 cubic metres per second and the tributary to the west 80 cubic metres per second. The average peak velocity across the floodplain is 0.6 metres per second. Existing peak velocities are presented in Figure 4-10.

4.5.3. Geomorphic characteristics

A high level and preliminary geomorphic assessment has been conducted for this waterway based on aerial photography, soil maps and a site inspection.

Coldstream River

The Coldstream River is a meandering medium alluvial waterway with stable banks. The land comprises both alluvial floodplain, and forested floodplains. The alluvial floodplain is utilised for productive farming and cropping enterprises. The river is well vegetated with good cover of native trees and shrubs.

The Coldstream River has the potential to actively meander and is unconfined within the floodplain. To instigate considerable erosion or a change in channel form, the following would need to occur:

- Major flooding of the order five year ARI or greater
- Bank slumping due to floodplain saturation.

Plate 4-8 shows this creek, within 300 metres of the project crossing.

Plate 4-8 Coldstream River

Coldstream River tributary

One of Coldstream River's tributaries also crosses the project, around 700 metres west of the main channel crossing. Plate 4-9 shows this creek, about 400 metres away from the project crossing.

This Coldstream River tributary may be classed as a forested and partially confined minor waterway. The creek is situated within public and private lands and adjacent land generally comprises forested valley floors and flats, and alluvial flood plain.

This tributary has poorly-vegetated banks and will engage with the floodplain in relatively small flow events. To instigate considerable erosion or a change in channel form, the following would need to occur:

- Bank slumping due to floodplain saturation
- Flood events greater than two year ARI (localised channel erosion and slumping)
- Flood events greater than 20 year ARI (bank erosion causing channel change).

Plate 4-9 shows this creek, within 300 metres of the project crossing.

Plate 4-9 A tributary of Coldstream River, looking downstream

Figure 4-8 Peak 100 year ARI flood levels: Coldstream River

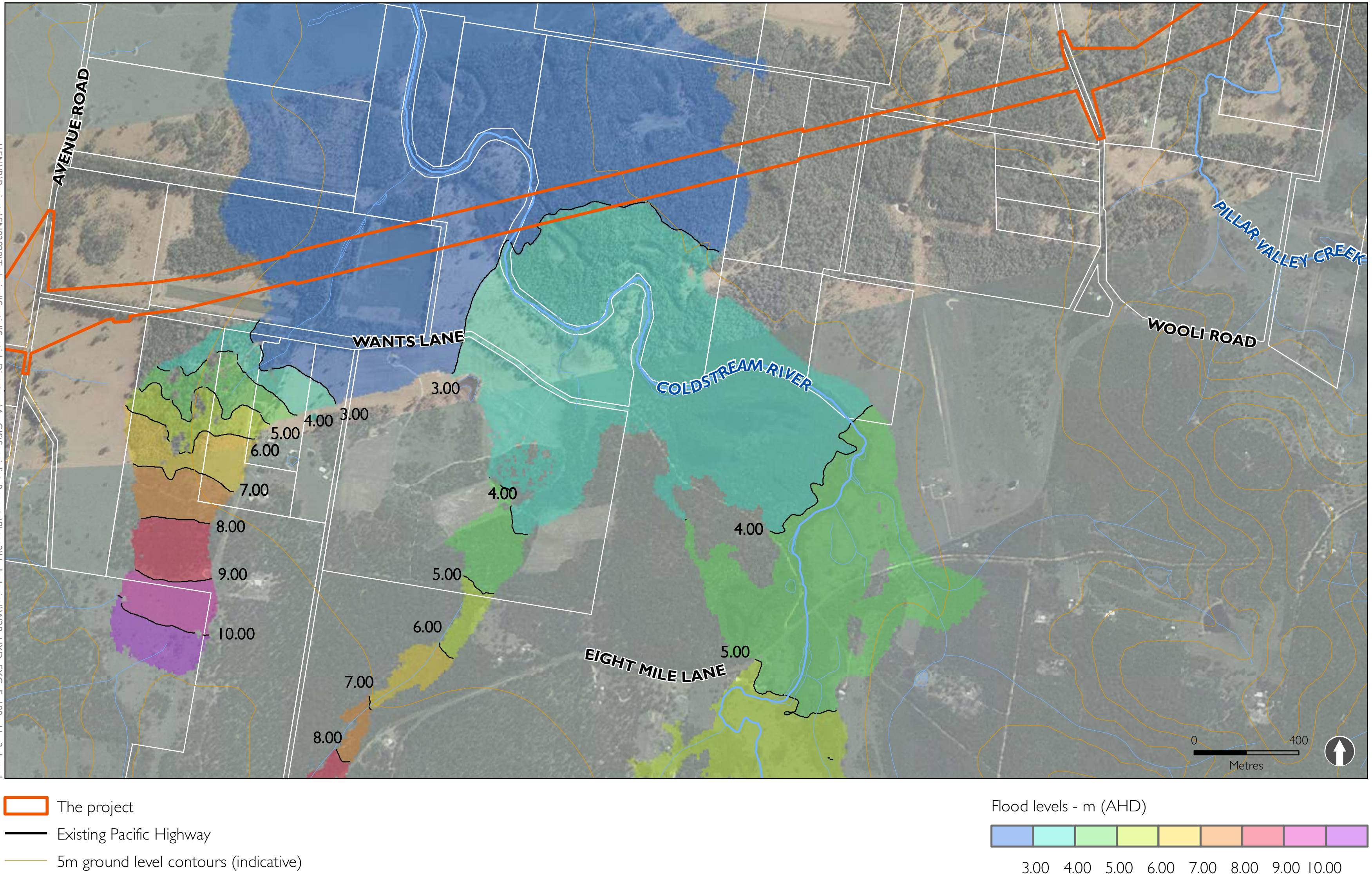


Figure 4-9 Peak 100 year ARI flood depths: Coldstream River

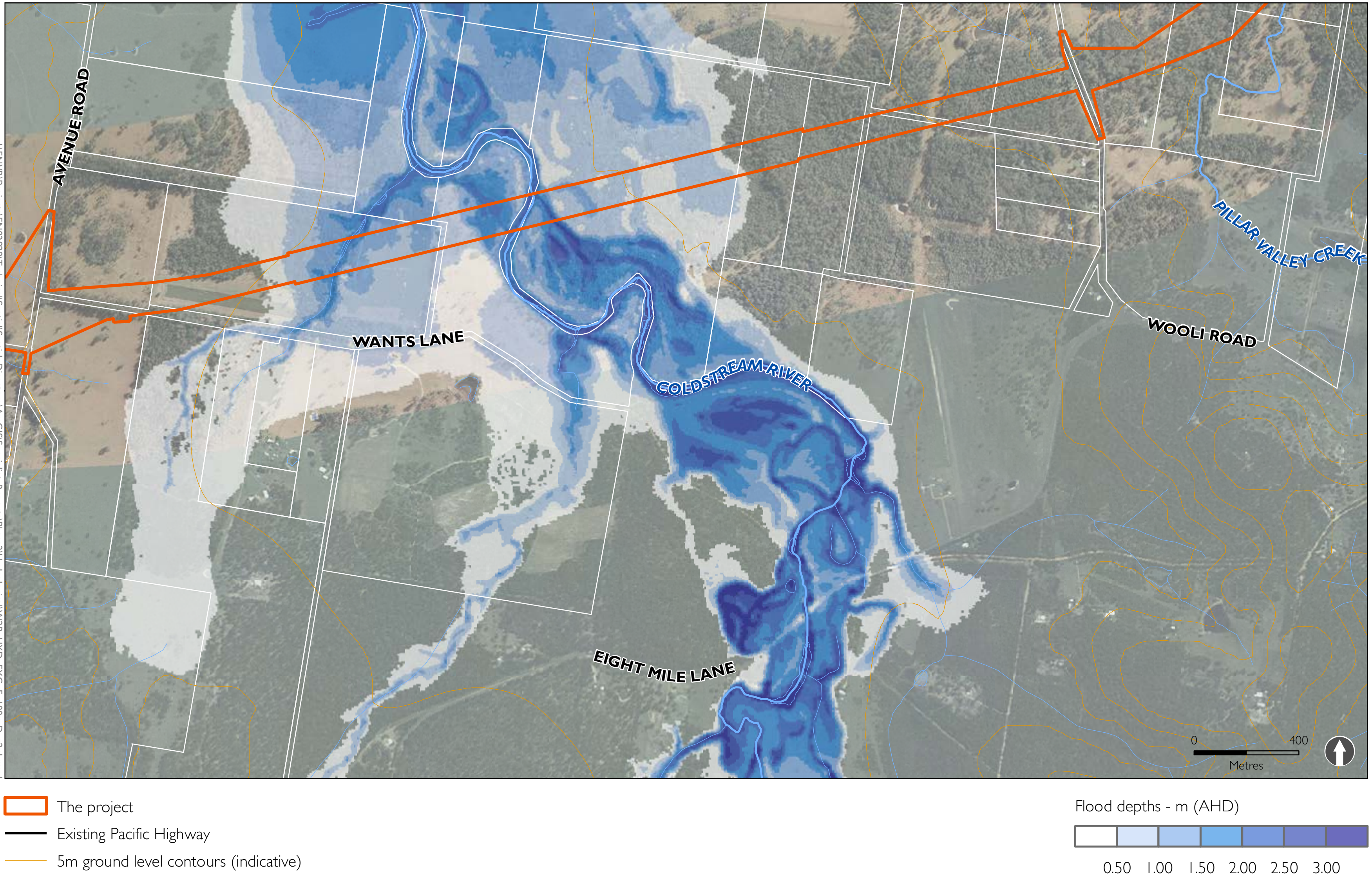


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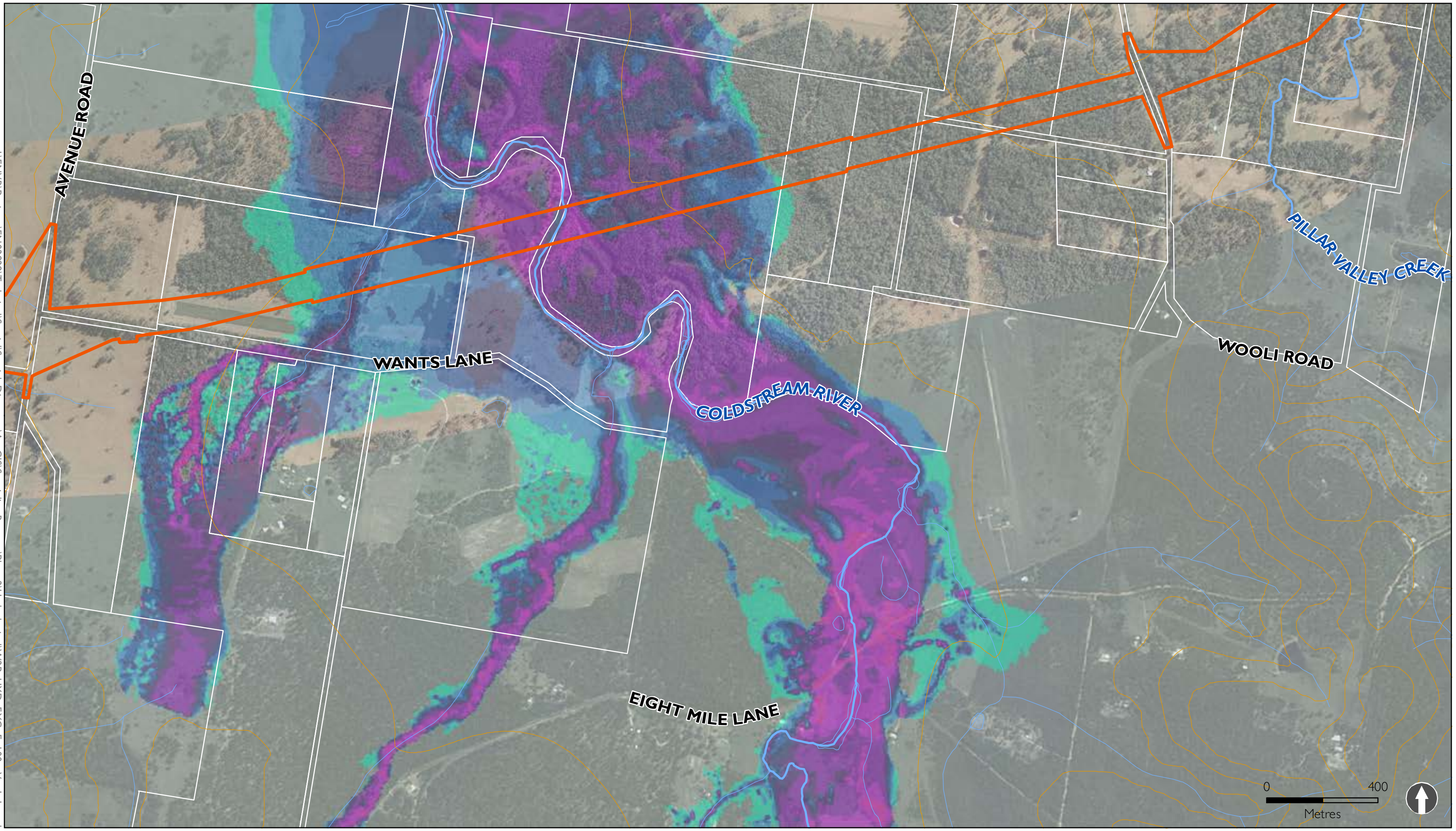
Figure 4-10 Peak 100 year ARI flood velocities: Coldstream River



The project
Existing Pacific Highway
5m ground level contours (indicative)

Flood velocity - m/s

0.2 0.4 0.6 0.8 1.0 1.5 2.0

4.6. Pillar Valley Creek

4.6.1. Catchment description

The Pillar Valley Creek crosses Section 3 of the project at about station 46.5 and has a catchment area to this location of 51 square kilometres. The project also crosses Black Snake Creek and two other unnamed tributaries of Pillar Valley Creek to the north of the main channel. The combined tributary catchment area at the crossings is 7.5 square kilometres.

At two kilometres upstream from the crossing, the creek divides into two catchments of similar size. The majority of the catchment has moderate slopes of two to five per cent with relatively flat floodplains adjacent to the main channel. The ridges at the upper regions of the catchment are quite steep with slopes up to 25 per cent.

The floodplain areas are mostly cleared land used for grazing. The steep hills forming the valley are mostly covered with dense forest. No buildings have been identified within the Pillar Valley Creek floodplain.

4.6.2. Existing flooding behaviour

Existing flooding behaviour has been assessed through hydrological and hydraulic flood modelling. The type of models used in this catchment are summarised in Table 2-4. Peak flood levels for the 100 year ARI flood event for Pillar Valley Creek in the vicinity of the project are presented in Figure 4-11. The peak flood levels at the project crossing of Pillar Valley Creek for this event are around 8.7 metres AHD.

Figure 4-12 shows peak flood depths in the Pillar Valley Creek area for the 100 year ARI flood event.

Estimated peak flood flows in Pillar Valley Creek are 488 cubic metres per second for the 100 year ARI flood event. The tributary shown has a peak 100 year ARI flow rate of 60 cubic metres per second.

The project also runs diagonally across the floodplain further north encompassing the two unnamed tributaries at stations 47.8 and 47.9. The peak flood level for the 100 year ARI event ranges from 8.7 metres AHD to 9.6 metres AHD. The peak flow across this floodplain is 67 cubic metres per second.

4.6.3. Geomorphic characteristics

A high level and preliminary geomorphic assessment has been conducted for this waterway based on aerial photography, soil maps and a site inspection.

Pillar Valley Creek

Pillar Valley Creek is an unconfined, meandering alluvial creek with stable bed and banks situated within public and private lands. The land comprises both alluvial and forested floodplains. The alluvial floodplain is utilised for productive farming and cropping enterprises. Alluvial creeks have the potential to actively meander, and are unconfined within the floodplain.

The forested waterway is well vegetated with good cover of native trees and shrubs. To instigate considerable erosion or a change in channel form, the following would need to occur:

- Bank slumping due to floodplain saturation
- Flood events greater than five year ARI (localised channel erosion and slumping)
- Flood events greater than 20 year ARI (bank erosion causing channel change).

Plate 4-10 shows Pillar Valley Creek, about 2.6 kilometres downstream from the project crossing.

Plate 4-10 Pillar Valley Creek looking downstream

Black Snake Creek

Black Snake Creek is a tributary of Pillar Valley Creek which crosses the project about 300 metres north-east of the main channel, along the project corridor. The waterway is a minor creek with forested, stable banks.

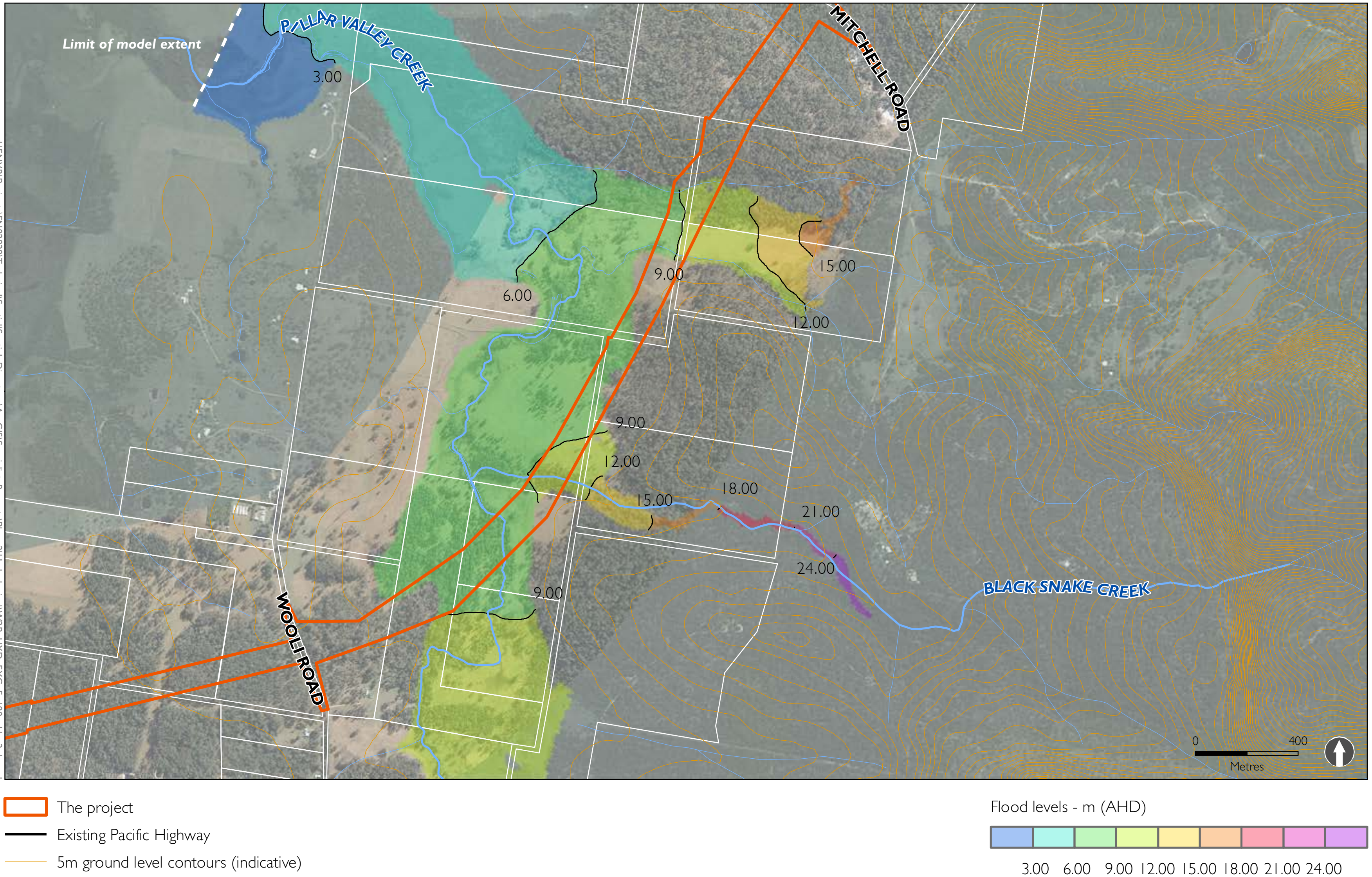
To instigate a change in channel form or for considerable erosion to occur, this creek would need to experience flooding of the order two year ARI or greater.

Unnamed creeks near Mitchell Road

There are small waterways which are upper tributaries of the Coldstream River that cross the project around two kilometres north of Pillar Valley.

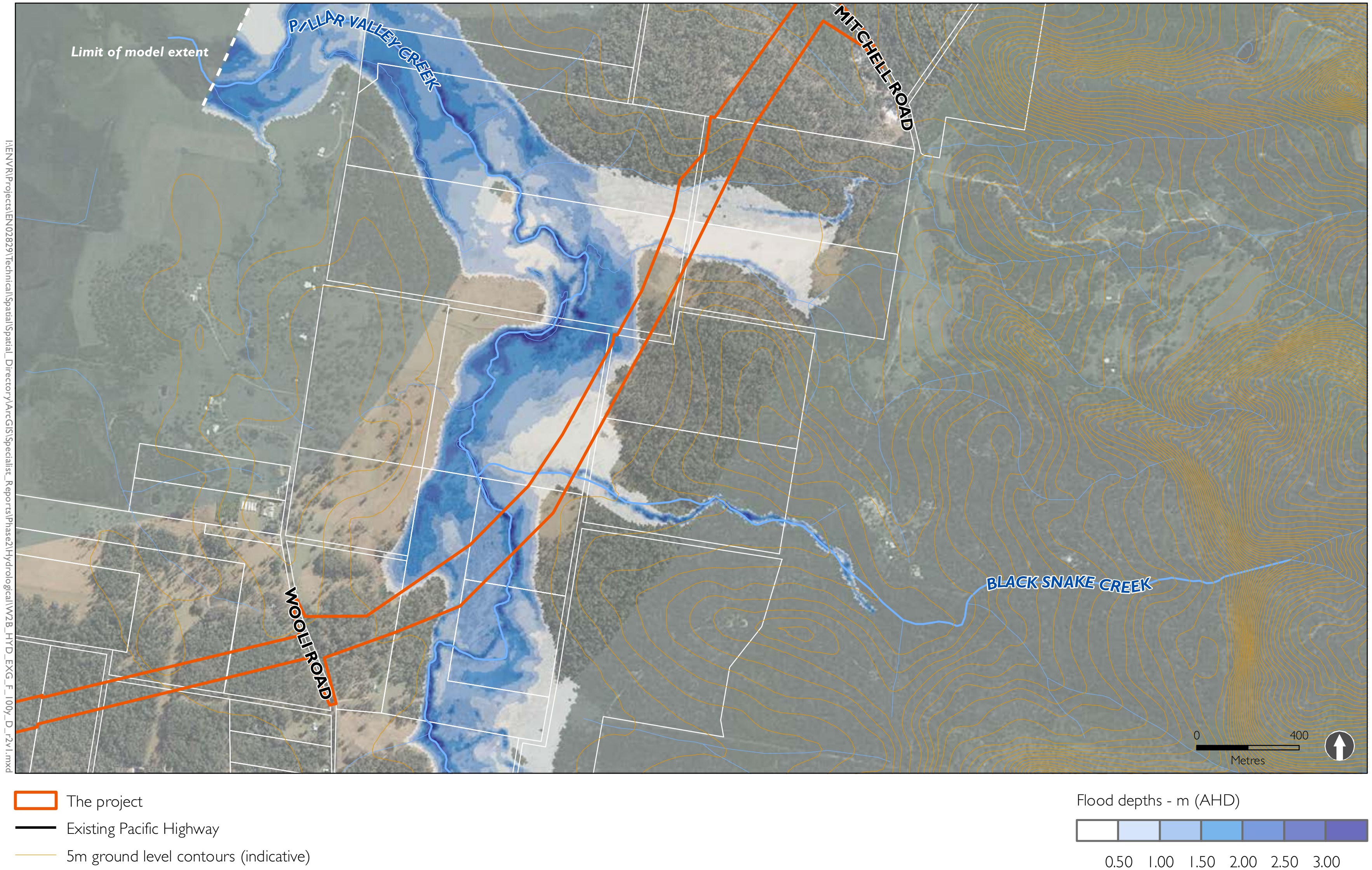
These waterways are classed as minor unconfined depressions which act as drainage lines through agricultural lands. They have well-vegetated banks, likely with a high weed component. These depressions are shallow, ephemeral, and often consisting of unconnected pools of water.

Figure 4-11 Peak 100 year ARI flood levels: Pillar Valley Creek



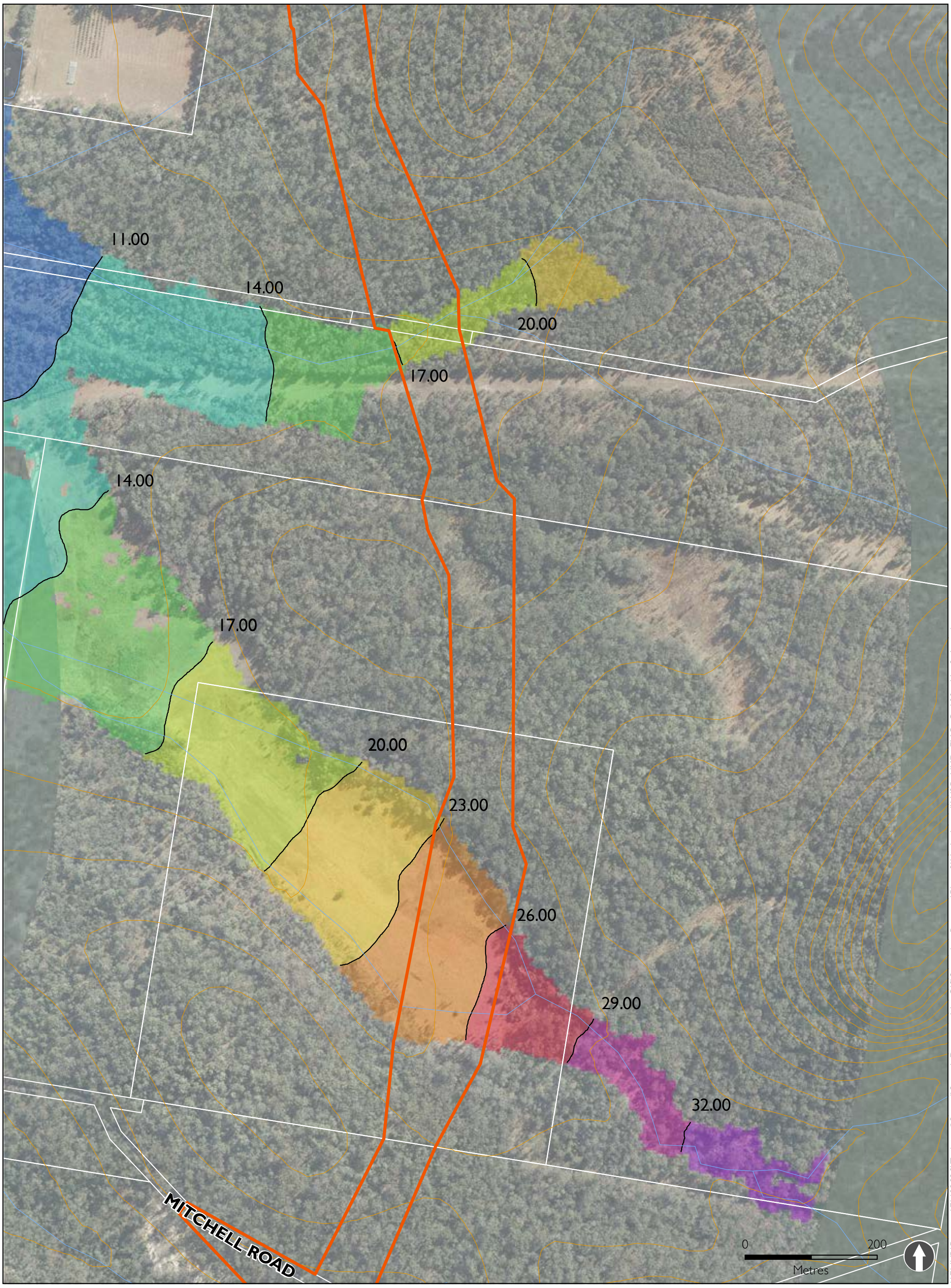
I:\ENVR\Projects\EN02829\Technical\Spatial\Spatial_Directory\ArcGIS\Specialist_Reports\Phase2\Hydrological\W2B_HYD_EXG_F_100y_H_r2v1.mxd

Figure 4-12 Peak 100 year ARI flood depths: Pillar Valley Creek



I:\ENVR\Projects\EN02829\Technical\Spatial\Spatial_Directory\ArcGIS\Specialist_Reports\Phase2\Hydrological\W2B_HYD_EXG_F_100y_D_r2v1.mxd

Figure 4-13 Peak 100 year ARI flood levels: unnamed creek near Mitchell Road



The project

Existing Pacific Highway

5m ground level contours (indicative)

Flood levels - m (AHD)

11.00 14.00 17.00 20.00 23.00 26.00 29.00 32.00

Figure 4-14 Peak 100 year ARI flood depths: unnamed creek near Mitchell Road

4.7. Chaffin Creek and nearby creeks

4.7.1. Catchment description

Chaffin Creek flows east to west within Section 3 of the project and is crossed perpendicular to flow to the project at station 52.6 (Bostock Road west of Tucabia). The area of the catchment to the crossing is 48 square kilometres.

Two unnamed creeks to the south of Chaffin Creek and near Mitchell Road, at stations 49.6 and 50.4 have catchment areas of 1.2 square kilometres and 1.6 square kilometres respectively upstream of the project. Two tributaries of Chaffin Creek located to the north of the Chaffin Creek crossing at stations 54.8 and 55.1, near Bostock Road, have a combined catchment area of 4.5 square kilometres upstream of the project.

The majority of the catchment has moderate slopes between two and five per cent, while the large floodplain through the centre of the catchment has slopes of less than 0.5 per cent. The land use of the Chaffin Creek catchment is mostly cleared farmland with some areas of medium to dense forest. One property, consisting of a house and several sheds, exists on Firth-Heinz Road within 60 metres of the creek. No other buildings have been identified within the Chaffin Creek floodplain.

A portion of the upper reaches are located within the Candole State Forest.

4.7.2. Existing flooding behaviour

Existing flooding behaviour has been assessed through hydrological and hydraulic flood modelling. The type of models used in this catchment are summarised in Table 2-4. Peak flood levels and depths for the 100 year ARI flood event for Chaffin Creek and nearby creeks are presented in Figure 4-13 to Figure 4-18. The peak 100 year ARI flood levels where the project crosses Chaffin Creek range from 4.8 metres AHD to 5.1 metres AHD. Peak flood flow in the 100 year ARI event in Chaffin Creek is 409 cubic metres per second. Average peak velocities across the Chaffin Creek floodplain are one metre per second.

The unnamed creeks to the south have peak 100 year ARI flood flow rates of 27 cubic metres per second near station 49.6 and 13 cubic metres per second near station 50.4. The creek at station 49.6 has a peak flood range for the same event of 25.1 to 25.7 metres AHD and near station 50.4 the peak flood level is 18 metres AHD.

The peak 100 year ARI flow rates in the northern tributaries are 45 cubic metres per second near station 54.8 and 30 cubic metres per second near station 55.1. Peak flood levels range from 4.7 metres AHD to 5.2 metres AHD near station 54.8 and 6.0 metres AHD to 7.0 metres AHD near station 55.1.

4.7.3. Geomorphic characteristics

A high level and preliminary geomorphic assessment has been conducted for this waterway based on aerial photography and soil maps.

Chaffin Creek

Chaffin Creek may be defined as a partially confined and stable creek due to the presence of bedrock. The adjacent land generally comprises forested valley floors and flats, and alluvial flood plain. It is likely that geological features such as bedrock and less erodible banks confine the deeper channels and higher banks Chaffin Creek.

Due to geologically confining features it is unlikely bed deepening will occur on these streams. The forested waterway is well vegetated with good cover of native trees and shrubs. To instigate considerable erosion or a change in channel form, the following would need to occur:

- Flood events of two year ARI or greater (localised bank erosion)
- Flood events greater than 20 year ARI (bank erosion and channel change).

Plate 4-11 shows Chaffin Creek within 300 metres of the project crossing.

Plate 4-11 Chaffin Creek

Unnamed creeks near Bostock Road

The project crosses two small tributaries of Chaffin Creek near Bostock Road, about 2.5 kilometres north of the Chaffin Creek crossing. These creeks have been assessed as minor gullies with forested, unconfined channels. Erosion tends to be prevalent due to their deeper and narrower channels, which have resulted from bed and bank erosion.

To instigate a change in channel form or for considerable erosion to occur on these waterways, flooding in the order of two year ARI event or greater would need to occur.

Figure 4-15 Peak 100 year ARI flood levels: Chaffin Creek

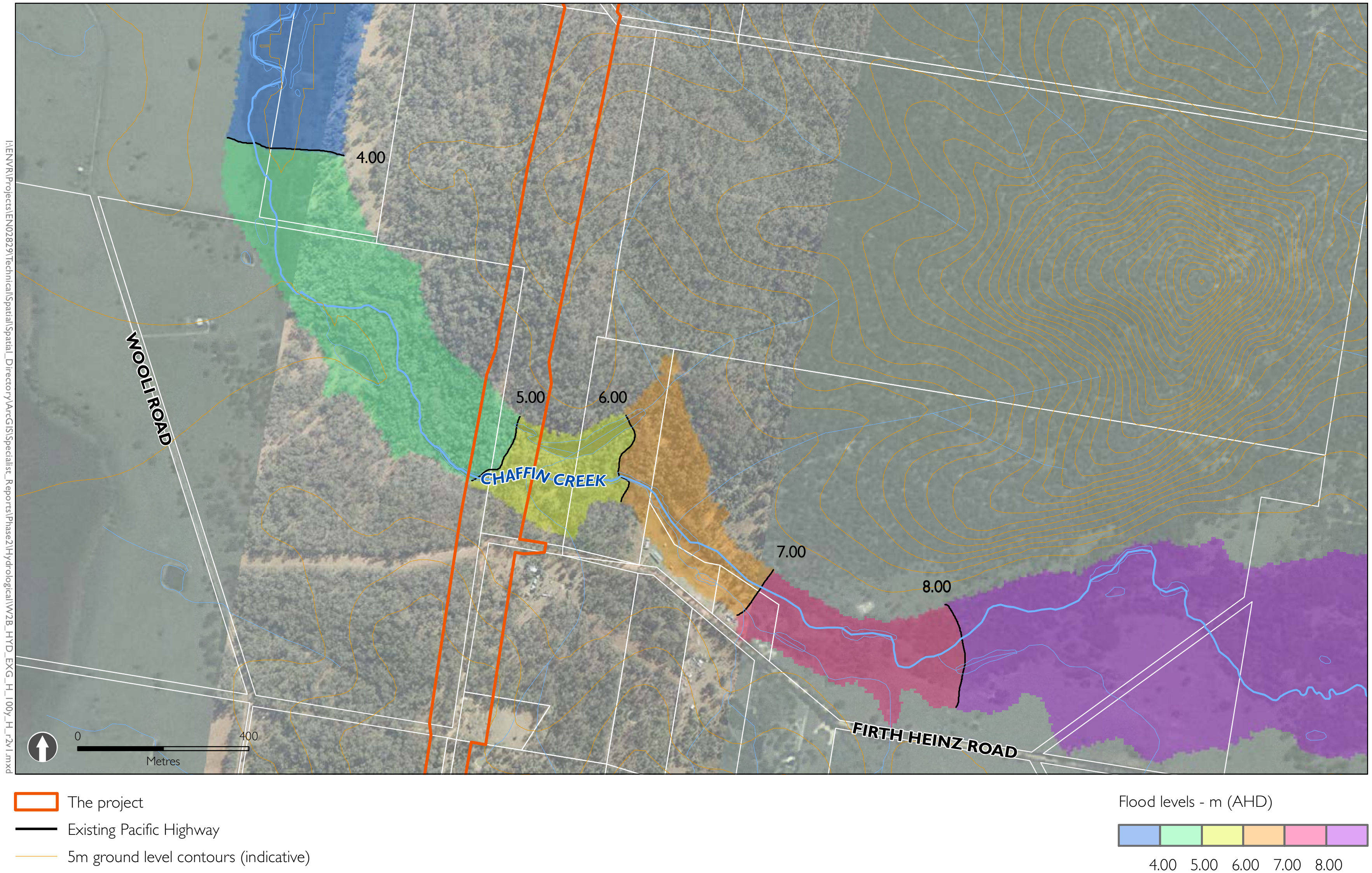


Figure 4-16 Peak 100 year ARI flood depths: Chaffin Creek

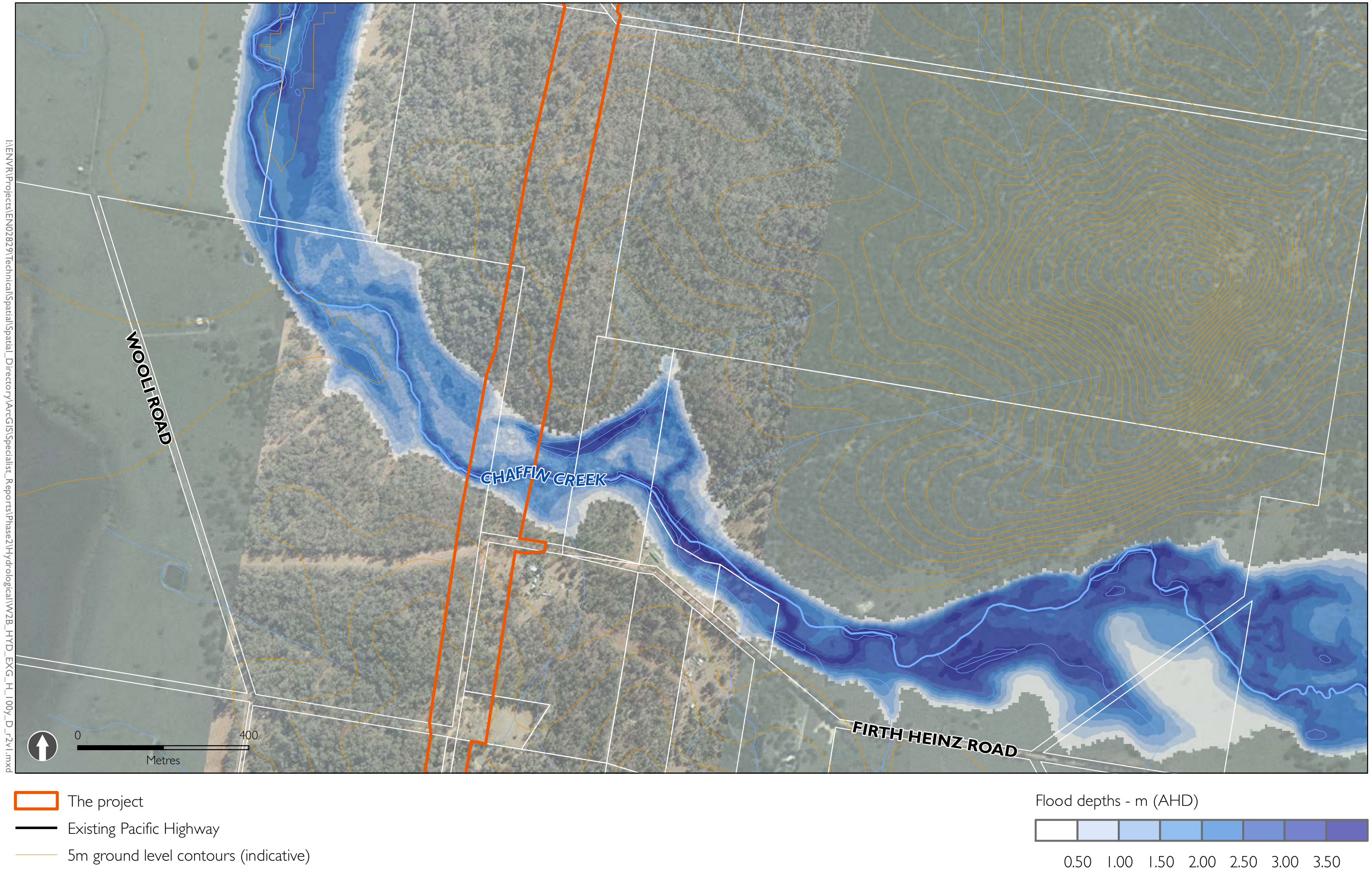
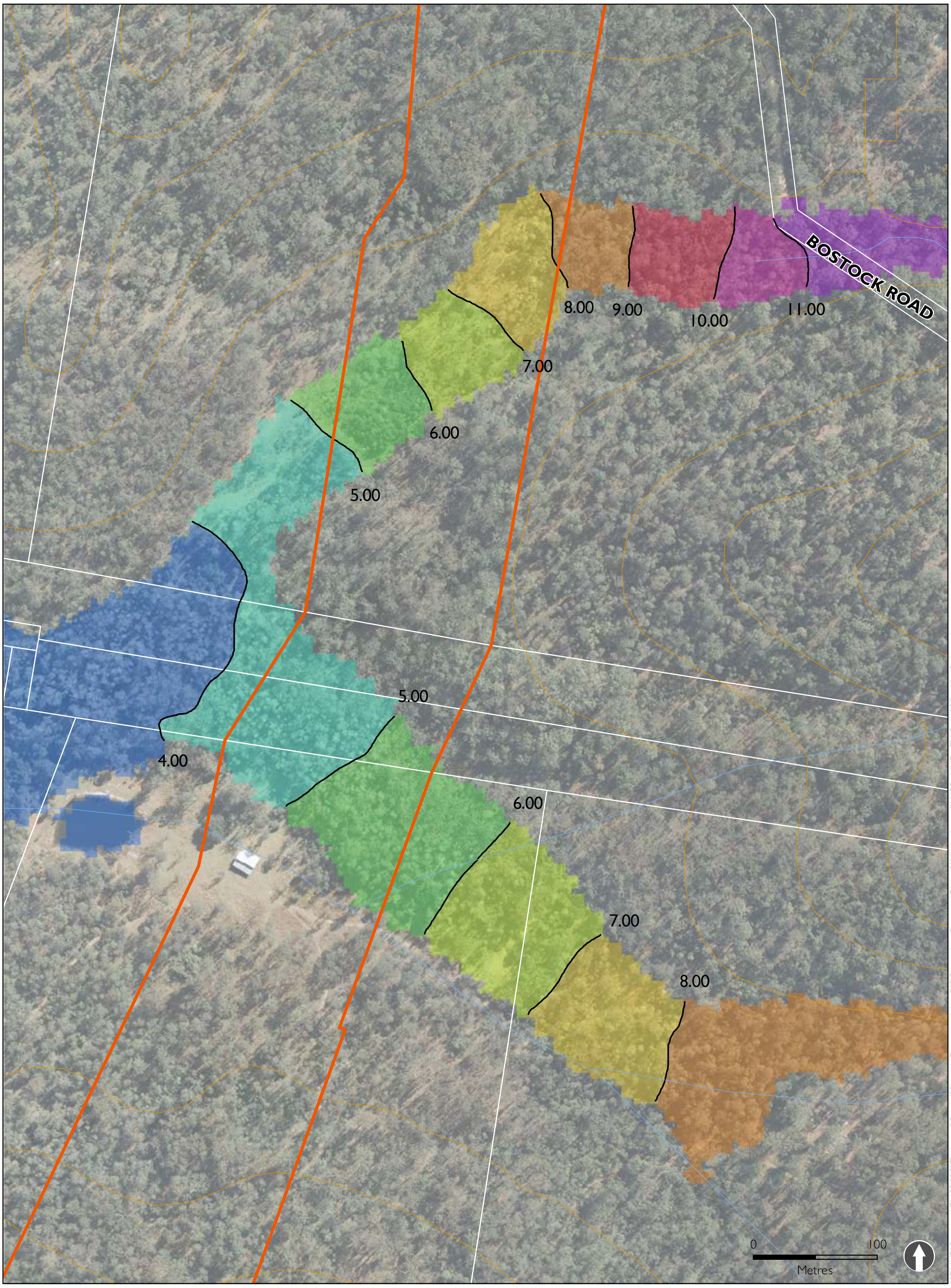


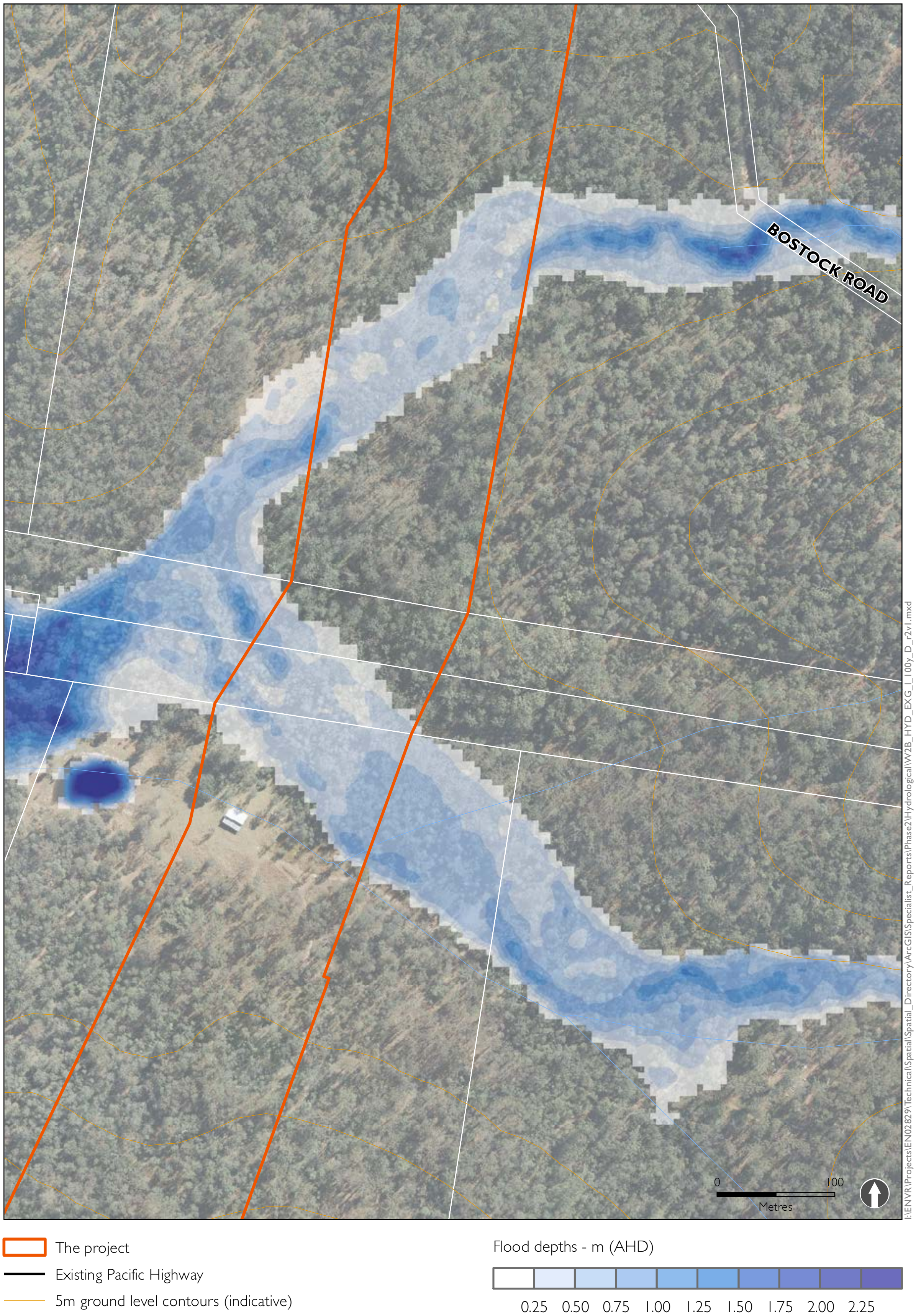
Figure 4-17 Peak 100 year ARI flood levels: unnamed creek near Bostock Road



The project
Existing Pacific Highway
5m ground level contours (indicative)

Flood depths - m (AHD)
4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00

Figure 4-18 Peak 100 year ARI flood depths: unnamed creek near Bostock Road



4.8. Champions Creek and nearby creeks

4.8.1. Catchment description

The contributing Champions Creek catchment area to the project is 16.5 square kilometres. Champions Creek flows generally east to west from its eastern boundary to the project where it crosses at station 57.1. Champions Creek is located within Section 3 of the project at Somervale Road east of Tucabia. Further downstream, the creek turns north-west before joining with Coldstream River.

The majority of the catchment has moderate slopes of two to five per cent with steep ridges along the eastern and northern boundaries. Immediately upstream of the project a significant constriction in the catchment results in a steep sided, narrow floodplain. The floodplain remains relatively constricted at the project location before widening out onto the Champions Creek floodplain. No buildings have been identified within the Champions Creek floodplain; however, immediately upstream of the project flooding may affect access to a neighbouring property.

The lower portion of the catchment has some clearing, but the majority of the catchment is dense forest. A large portion of the catchment is situated within Pine Brush State Forest.

A small, unnamed creek to the north of Champions Creek at station 58.8 has a catchment area of 1.3 square kilometres to the project. This catchment is steep, densely forested and has a narrow floodplain at the project location.

4.8.2. Existing flooding behaviour

Existing flooding behaviour has been assessed through hydrological and hydraulic flood modelling. The type of models used in this catchment are summarised in Table 2-4. The peak Champions Creek flood levels and depths for the 100 year ARI flood event in the vicinity of the project are presented in Figure 4-19 and Figure 4-20. The 100 year ARI flood levels are relatively high in the upper part of the catchment due to the pinch point in the valley around 750 metres upstream of the project. As the floodplain widens, the flood levels decrease.

The 100 year ARI peak Champions Creek flood levels near the project are around 3.2 metres AHD and flood flows are 161 cubic metres per second.

The 100 year ARI peak flood levels on the unnamed creek to the north range from 18.7 metres AHD to 19.2 metres AHD and flood flows are 24 cubic metres per second.

4.8.3. Geomorphic characteristics

A high level and preliminary geomorphic assessment has been conducted for this waterway based on aerial photography, soil maps and a site inspection.

Champions Creek

Champions Creek is a partially confined, forested waterway. The waterway is relatively stable and likely to be stabilised by bedrock. The adjacent land generally comprises forested valley floors and flats, and alluvial flood plain. These waterways tend to have deeper channels and higher banks, and tend to be confined due to geological features such as bedrock and less erodible banks.

Champions Creek has poorly-vegetated banks but it is unlikely bed deepening will occur. Localised bank erosion may occur in events of the order two year ARI or greater. Changes to the channel may occur during flood events of greater than 20 year ARI.

Plate 4-12 shows Champions Creek within 300 metres of the project crossing.

Plate 4-12 Champions Creek

Figure 4-19 Peak 100 year ARI flood levels: Champions Creek

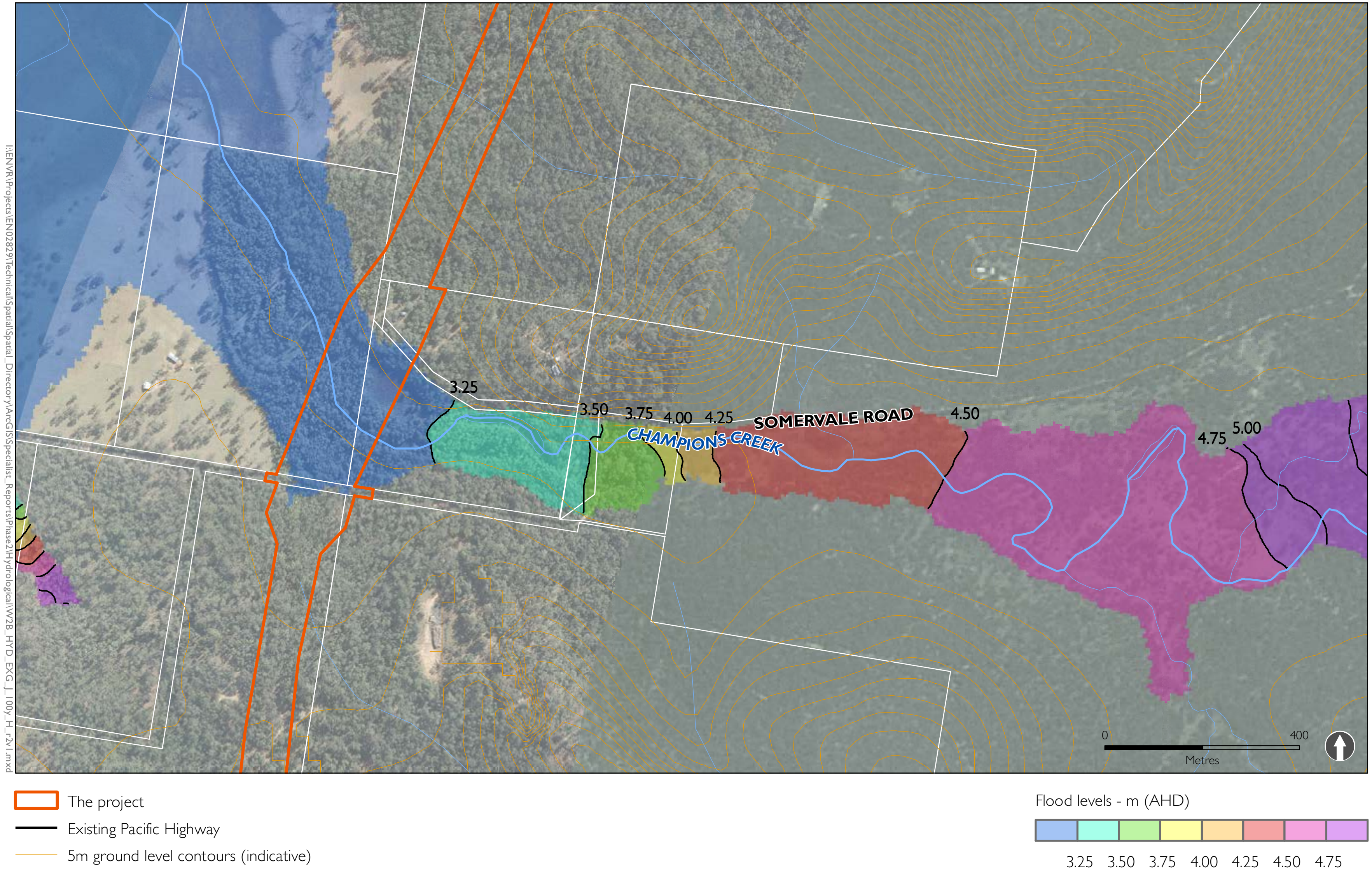
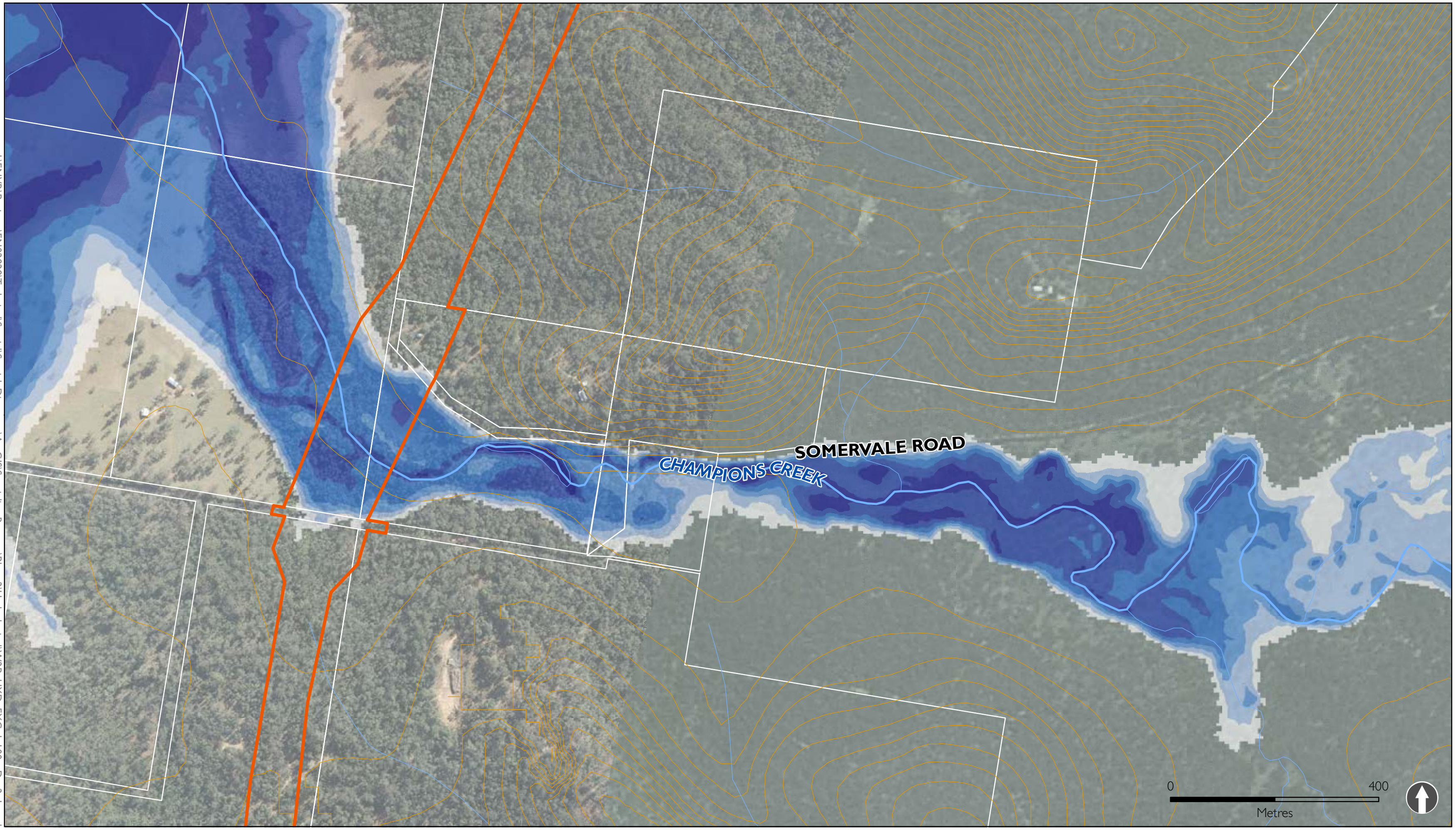


Figure 4-20 Peak 100 year ARI flood depths: Champions Creek



The project

Existing Pacific Highway

5m ground level contours (indicative)

Flood depths - m (AHD)

0.50 1.00 1.50 2.00 2.50