Woolgoolga to Ballina Pacific Highway upgrade

Hydrological mitigation report Devils Pulpit to Ballina

April 2017

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WOOLGOOLGA TO BALLINA PACIFIC HIGHWAY UPGRADE

HYDROLOGICAL MITIGATION REPORT DEVILS PULPIT TO BALLINA

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This document is a controlled document prepared in accordance with AS /NZS ISO 9001:2008 Quality Management Systems Requirements, and is regularly reviewed and updated. Audits confirming the effective implementation of the procedures / activities described herein provide verifiable evidence that Pacific Complete conforms to specified requirements.

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Terms and definitions

The terms, abbreviations and definitions below are used in this report.

TERM	EXPLANATION
Afflux	Increase in flood level as a result of an obstruction to flow. Calculated by the flood level difference. Usually measured in millimetres.
AHD	Australian Height Datum. This is the standard elevation reference used for mapping purposes throughout Australia. Elevation is in metres.
ARI	Average Recurrence Interval. 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 reaching a height as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years.
Catchment	The catchment at a particular point is the area of land that drains to that point.
Cell	Can refer to: Culvert design: Single opening. Hydraulic modelling: Element in a two-dimensional hydraulic model representing a specific geographic area on the floodplain.
Chainage	Distance along the alignment from a fixed starting point
CoA	EIS Conditions of Approval, NSW DP&E, 2014. The Planning Minister's conditions of approval for the project.
Critical storm duration	The storm duration that produces the highest value of a particular flooding parameter (i.e. flood level, velocity or duration) in a subject catchment. Typically, this is taken as the storm duration that causes the highest flood levels in the catchment.
Design flood	A hypothetical flood representing a specific likelihood of occurrence.
Downstream	Moving or situated in the direction that a river flows; further from the source of the river.
DPE	NSW Department of Planning and Environment
EIS	Environmental Impact Statement
Flood	Relatively high water level that overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences, including tsunami.
Flood depth	The height of the flood described as a depth of water above a particular location (e.g. 2 metres above a floor, yard or road), usually measured in metres.
Flood hazard	The hazard due to flooding that has the potential to cause damage to the community. Flood hazard is typically represented numerically as the product of flood depth and flood velocity (i.e. depth x velocity).
Flood immunity	The level at which land is protected from a flood event. The flood event for which the land will remain dry.
Flood level	The level of the flood related to a standard level such as Australian Height Datum mAHD (e.g. the flood level was 5.6 m AHD)
Floor level survey	A survey to obtain the current floor heights of buildings and structures
Flood mitigation	Permanent or temporary measures taken in advance of a flood to reduce its impacts
Floodplain	Land adjacent to a river or creek that is periodically inundated due to floods, including all land that is susceptible to inundation by the probable maximum flood (PMF) event.
Habitable structure	A living or working area within a structure, such as a lounge room, dining room, rumpus room, kitchen, or bedroom. Does not include utility rooms like garages.
Historical flood	A flood that has occurred in the recent or distant past.
Hydraulics	The study of the dynamics of flow in order to predict water levels and velocities in time and space

TERM	EXPLANATION
Hydrograph	A graph showing how a river or creek's discharge changes with time.
Hydrology	The study of how rainfall is converted to runoff in a catchment in order to determine flow quantities
km^2	Square kilometre
Levee	An embankment or wall that regulates water levels (including flooding). e.g. earth-fill embankment, concrete blockwork
m	Metre
m/s	Metres per second
Multi-cell	Multiple number of individual openings within a culvert structure.
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.
PMF	Probable Maximum Flood, an extreme flood deemed to be the maximum flood likely to occur.
Runoff	The amount of rainfall that ends up as stream flow
Scour	Scour is the removal of particles of soil or rock around a structure. Scouring usually occurs when the velocity of the flowing water increases resulting in sediment transport
SES	NSW State Emergency Service
Soffit	Underside of a bridge or highest internal point within a culvert.
SPIR	Submissions / Preferred Infrastructure Report
SSI	State Significant Infrastructure (otherwise referred to as 'the project' in this report).
TUFLOW	1 and 2 dimensional flood analysis software package used to model complex flood behaviour.
Upstream	Moving or situated in the opposite direction from that in which a river flows; nearer to the source of that river
Velocity	The speed of floodwaters, usually in metres per second

EXECUTIVE SUMMARY

This document forms the hydrological mitigation report for the portion of the Richmond River regional floodplain that is crossed by the Woolgoolga to Ballina (W2B) Pacific Highway upgrade. The following sections of the project are located within the Richmond regional floodplain and the floodplains of its significant tributaries:

- Devils Pulpit Upgrade to Trustums Hill. This section crosses the floodplains of Tabbimoble Floodway 1 and Oakey Creek.
- Trustums Hill to Broadwater National Park. This section crosses the floodplain of the Mid-Richmond River.
- Broadwater National Park to Richmond River. This section crosses the floodplain of the Mid-Richmond River.
- Richmond River to Coolgardie Road. This section crosses the floodplains of Bingal Creek, Wardell Floodway 6 and Randles Creek.
- Coolgardie Road to Ballina Bypass. This section crosses the floodplain of the Lower Richmond River.

The purpose of the hydrological mitigation report is to address the requirements of the Minister's Conditions of Approval D13 for the project (Application No. SSI-4963). The report documents the outcomes of the project relating to flooding and outlines how the project team will address the outcomes to manage and mitigate potential impacts on landowners upstream and downstream of the project.

The report considers flood impacts to property, access and infrastructure and documents:

- the existing and proposed flood conditions
- the modelling methodology used to define the flood conditions
- the proposed flood impact mitigation works
- any further mitigation works still under investigation in areas where residual flooding impacts are predicted to occur
- the role of the independent hydrologist appointed to the project to review and independently verify the flood modelling analyses being carried out by the Woolgoolga to Ballina upgrade team, and the findings of the analyses.

The Woolgoolga to Ballina upgrade team has used flood models developed for the environmental impact statement (EIS), which have been refined to include more detailed input data. The Lower and Mid-Richmond River models were originally developed by the local authorities up to 2008 and 2010 and subsequently refined for the purposes of the EIS, and subject to ongoing refinement and calibration after the EIS to improve their accuracy and reliability for use in detailed design. The models have been independently reviewed on numerous occasions and are considered to be highly reliable tools for flood management planning within the catchment.

Due to the scale and complexity of the Richmond River catchment and the areas of the regional floodplain crossed by the project, the existing flood behaviour varies across the project area. From Devils Pulpit Upgrade to Trustums Hill and from Richmond River to Coolgardie Road the project is located in the upper to middle catchments of significant tributaries of the Clarence and Richmond Rivers, and the critical flooding processes for floodplain interactions and potential impacts are those dominated by the local tributary catchments rather than the main regional floodplain. From Trustums Hill to Broadwater National Park, Broadwater National Park to Richmond River and Coolgardie Road to Ballina Bypass the project passes through the main regional floodplains and the regional scale flood is the dominant process for project interactions and impacts.

From Devils Pulpit Upgrade to Trustums Hill and from Richmond River to Coolgardie Road the critical flooding generally occurs for storm events of 12 hours duration or less, and floodwaters rise and recede over 1 to 2 days. Overland flow velocities tend to be in the medium range (approximately 1.5 to 3 m/s). Flooding occurs generally on agricultural or undeveloped land and at individual properties or small population centres.

From Trustums Hill to Broadwater National Park, Broadwater National Park to Richmond River and Coolgardie Road to Ballina Bypass, the critical flooding occurs for the 72 hour storm, and floodwaters rise and recede over weeks rather than days. Overland flow velocities tend to be in the low range (<1.5m/s). Flooding occurs on extensive areas of agricultural land, individual properties and small population centres, as well as the larger population centres of Woodburn, Broadwater and Wardell.

The Conditions of Approval have imposed flood management objectives on the project which allow only marginal changes in flood behaviour in the adjacent land. In sensitive areas (such as urban areas and cane growing land), the project must not increase flood levels by more than 50 millimetres or flood durations by more than five percent. Significant changes in flood velocity and flow direction are also prohibited by the flood management objectives.

The following summarises the key outcomes of the project relating to flooding:

- The project will improve the current flood immunity of the highway. Through the Richmond regional floodplain various sections of the existing highway are prone to flooding at the 5 to the 20 year ARI event. The project will provide a flood immunity of between the 20 and the 100 year ARI to the upgraded highway.
- From Trustums Hill to Broadwater National Park, Broadwater National Park to Richmond River and Coolgardie Road to Ballina Bypass, where the project is located within the regional floodplains, the project would result in minor changes in flood levels, velocities and durations, with the flood management objectives set by the Conditions of Approval generally achieved. However, there are some localised areas where the flood management objectives are not fully achieved. These are subject to further investigation and consultation.
- From Devils Pulpit Upgrade to Trustums Hill the project has achieved the flood management objectives.
- From Richmond River to Coolgardie Road the flood management objectives have not currently been achieved at two cross drainage locations out of a total of 45, however, the impacts are generally related to localised increases in flood level. These impacts are subject to further investigation and consultation.

The flood impact assessment has identified the number of properties that will experience an increase in flood level at the property, including an assessment of the change in above floor flood levels at affected properties. Out of about 5,095 properties within the floodplains traversed by the project, a very low number of properties would experience a potential increase in flood level that exceeds the limit imposed by the flood management objectives, with no properties experiencing increases in above floor flood level. Investigations into these property impacts are ongoing.

Access out of the Richmond River regional floodplain and the surrounding local catchments is mainly via the existing Pacific Highway and a number of local access roads that connect to the highway. In all locations the future upgraded highway will provide more efficient and reliable flood evacuation routes since the flood immunity is being improved by the upgrade works. Local access roads and property access have been provided an equivalent or higher flood immunity. As such, the upgrade will not adversely affect key flood access routes, and will instead improve flood access and evacuation.

The project team has consulted with the community, government agencies, key stakeholders and landowners on flooding issues since project inception. The purpose of this consultation was to enable the incorporation of local knowledge, capitalise on local expertise, provide consistency with plans held by other local authorities and emergency service providers and promote stakeholder and community understanding of the project outcomes relating to flooding.

The project has generally achieved the flood management objectives; however, some localised and/or marginal departures from the objectives occur. The project has categorised the impacts into ‘low risk impacts’ and ‘departures’ from the flood management objectives, with the former constituting nominal exceedances of the flood impact objectives that are confined to non-sensitive areas and/or are within the bounds of model uncertainty. In line with the Conditions of Approval consultation with individual stakeholders is being carried out on departures to further investigate the predicted impacts and to identify potential options for localised mitigation. Consultation with these landowners started in July 2016. No further investigation or mitigation is proposed for the areas categorised as low risk impacts.

The project team has met with a number of the affected landowners to discuss the predicted impacts at their property. At these meetings the project team discussed the predicted impacts and reasonable and feasible mitigation measures. Discussions with landowners are ongoing.

Where additional flood mitigation infrastructure does not change the flood outcome local drainage improvements may be required on private land. In these areas, options for improved land drainage in consultation with the local landowner may include:

- upgrading the existing land drainage network to maintain connectivity of low flows and improve drainage time
- removing debris, blockages and vegetation to reinstate or improve flow paths
- upgrading or replacing flood-gated outlets to improve drainage back to the Richmond River

Such measures have already been incorporated into the design in some areas and are under investigation in other areas.

Cross drainage infrastructure including culverts and bridges has been optimised during the detailed design process to result in the optimum waterway openings along the alignment. The cross drainage recommended in the EIS has been carried through the various design processes, with additional cross drainage infrastructure provided to achieve the flood management objectives as far as possible for cane land and agricultural land as well as property and local road access. The additional infrastructure has been designed as floodplain relief structures. The infrastructure from Devils Pulpit Upgrade to Trustums Hill, Richmond River to Coolgardie Road and Coolgardie Road to Ballina Bypass has changed marginally since the EIS, but significant increases in the infrastructure have been provided from Trustums Hill to Broadwater National Park and from Broadwater National Park to Richmond River, with an additional 290 metres of waterway area provided.

This report currently reflects the design at April 2017 and as of that date there are some elements of the detailed design that are still being refined. Work is also ongoing on finalising the mitigation measures required to reduce or eliminate flooding impacts in areas where the flood management objectives are not fully achieved. The results provided with this report have resolved most but not all of these issues and further modelling work is being undertaken to assess feasible and reasonable mitigation measures to resolve these issues. Discussions with local landowners and the community are also ongoing. Refer to Table 6.2 for a list of current departures from the flood management objectives.

Addenda to this report will be issued as the design of all infrastructure relevant to flood behaviour and impacts progresses to final detailed design.

1. INTRODUCTION

1.1 Background

The Pacific Highway upgrade is one of the largest road infrastructure projects in NSW. It connects Sydney and Brisbane, and is a major contributor to Australia's economic activity. The road is a vital piece of the nation's infrastructure and is a key link in the National Land Transport Network. The Australian and NSW governments have been jointly upgrading the Pacific Highway since 1996.

An upgraded Pacific Highway must continue to service the needs of the travelling public and achieve transport efficiencies, while also ensuring ecological sustainability and meeting the needs of the coastal communities that live along the highway. Upgrading new sections and carrying out safety improvements to the existing highway have brought major improvements to road conditions. These improvements support regional development and provide:

- safer travel
- reduced travel times with improved transport efficiency
- more consistent and reliable travel
- improved amenity for local communities.

1.2 Project description

The 155 kilometre upgrade between Woolgoolga to Ballina (referred to as the 'project' in this report) is the last highway link between Hexham and the Queensland border to be upgraded to four lanes. The project will duplicate the existing highway to two lanes in each direction from about six kilometres north of Woolgoolga (north of Coffs Harbour) to about six kilometres south of Ballina. The project bypasses the towns of Grafton, Ulmarra, Woodburn, Broadwater and Wardell. The project will include building new lanes and realigning the road.

Key features of the upgrade include:

- duplicating 155 kilometres of the Pacific Highway to a motorway standard (Class M) or arterial road (Class A), with two lanes in each direction and room to add a third lane if required in the future
- split-level (grade-separated) interchanges at Range Road, Glenugie, Tyndale, Maclean, Yamba/Harwood, Woombah (Iluka Road), Woodburn, Broadwater and Wardell
- bypasses of South Grafton, Ulmarra, Woodburn, Broadwater and Wardell
- more than 100 bridges including major crossings of the Clarence and Richmond rivers
- bridges and underpasses to maintain access to local roads that cross the highway
- access roads to maintain connections to existing local roads and properties
- structures designed to safely encourage animals over and under the upgraded highway where it crosses key animal habitat or wildlife corridors
- rest areas conveniently located at intervals to assist with reducing driver fatigue
- heavy vehicle checking stations near Halfway Creek and north of the Richmond River
- emergency stopping facilities and U-turn bays
- relocation of utilities and provision of roadside furniture, fencing (including wildlife exclusion fencing) and lighting.

Refer to Figure 1.1 for an overview of the project.

1.2.1 Adjacent Projects

Hydrology and flooding assessments for adjacent Pacific Highway upgrade projects are not included as part of the hydrology modelling for the Woolgoolga to Ballina upgrade as they have been addressed under their own approvals. Adjacent projects include:

- Pimilico to Teven stage two upgrade
- Devils Pulpit Pacific Highway upgrade
- Glenugie Pacific Highway upgrade

Figure 1.1 General overview of Woolgoolga to Ballina Pacific Highway upgrade

1.3 Purpose of the report

The purpose of the hydrological mitigation report is to address the requirements of the Minister's Conditions of Approval (CoA) D13 for the Woolgoolga to Ballina Pacific Highway upgrade (Application No. SSI-4963). The report documents the predicted flooding effect of the upgrade and outlines how potential impacts will be managed and mitigated on properties upstream and downstream of the project.

The report considers flood impacts to property, access and infrastructure and documents:

- the existing and predicted flood conditions
- the modelling methodology used to define flood conditions
- assessment of compliance against flood objectives.

1.4 Project approvals

The Pacific Highway Woolgoolga to Ballina Project (the project) was approved as State Significant Infrastructure (SSI) under Part 5.1 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) (SSI-4963) on 24 June 2014, and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (012/6394) on 14 August 2014.

The CoA include a number of conditions of approval that relate to flooding and hydrological impacts. These are outlined in Table 1.1.

Table 1.1 Minister's Conditions of Approval requirements

CONDITION OF APPROVAL REFERENCE	CONDITION OF APPROVAL	WHERE ADDRESSED
B31	The hydrological and flooding impacts resulting from the SSI are to be assessed during detailed design against the 'Design Objectives for Flood Management' described in Section 2.1 of the EIS Working Paper – Hydrology and Flooding. This shall include assessment against the 'Flood Management Objectives' and the 'Other Flood Impact Considerations' as well as the other requirements of this section of the EIS. The hydrology assessment shall include the refinement of or development of new flood models (where required) for the 14 catchments investigated during the EIS. These models shall be operated for the same design floods considered in the EIS, as well as the 2000 year ARI and the probable maximum flood (PMF) design events.	Section 5
B33	Where the objectives and considerations referred to in condition B31 cannot be complied with, the Applicant shall: (a) achieve compliance through modified embankment or drainage design. This might include new or duplicated drainage structures designed to minimise afflux and other impacts to waterways that traverse the road alignment, to the greatest extent practicable; or (b) achieve an acceptable level of mitigation of impacts through alternative design measures (e.g. raised access tracks) in consultation with the affected land-owner; or (c) reach agreement with affected landowners on impacts to property.	Section 6
B43	The Applicant shall investigate the removal of the proposed embankment at station 145.2 and its replacement with an extension to the Richmond River bridge. The investigation shall consider issues around hydrology and flooding (including meeting the flooding objectives for bridges), constructability, cost, funding arrangements and visual impacts. The investigation shall include consideration of other relevant environmental impacts (noise, heritage, biodiversity, traffic etc) and consider any alternative options. A copy of the investigation shall be submitted to the Secretary prior to the commencement of any bridge approach or embankment works in the vicinity.	Section 1.7

CONDITION OF APPROVAL REFERENCE	CONDITION OF APPROVAL	WHERE ADDRESSED
D13	The Applicant shall prepare and implement a Hydrological Mitigation Report for properties where flooding and/or hydrological impacts are predicted to exceed the relevant flood management objective in the documents listed in condition A2 as a result of the SSI. The Report shall be prepared by a suitably qualified expert and be based on detailed surveys (e.g. floor levels) and associated assessment of potentially flood affected properties in the Corindi, Clarence and Richmond river floodplains. The Report shall:	This report
	(a) Identify properties in those areas likely to have an increased/exacerbated impact and detail the predicted impact; The types of impacts to be considered include all those examined in the EIS including but not limited to changes in flood levels and velocities, alteration to drainage, reduction in flood evacuation access or capability, impacts on infrastructure, impacts on stock and agriculture, and impacts to the environment;	Section 5
	(b) identify mitigation measures to be implemented to address these impacts;	Section 6
	(c) identify measures to be implemented to minimise scour and dissipate energy at locations where flood velocities are predicted to increase as a result of the SSI and cause localised soil erosion and/or pasture damage;	Sections 5.2.2 and 6.4
	(d) be developed in consultation with the relevant council, NSW State Emergency Service and directly-affected landowners;	Sections 6.2 and 6.3
	(e) identify operational and maintenance responsibilities for items (a) to (c) inclusive; and	Section 6.5
	(f) refer to the assessments described in conditions B31 and B32.	Section 5.2
	(g) The report may be submitted in stages to suit the staged construction of the SSI. Construction shall not commence within those areas likely to have altered flood conditions until such time as works identified in the hydrological mitigation report have been completed, unless otherwise agreed by the Secretary.	Noted
D14	Based on the mitigation measures identified in condition D13, the Applicant shall prepare and implement a final schedule of feasible and reasonable flood mitigation measures proposed at each directly-affected property in consultation with the landowner. The schedule shall be provided to the relevant landowner(s) prior to the implementation/construction of the mitigation works, unless otherwise agreed by the Secretary. A copy of each schedule of flood mitigation measures shall be provided to the Department of Planning and Environment and the relevant council prior to the implementation/construction of the mitigation measures on the property.	Table 6.2
D15	The Applicant shall employ a suitably qualified and experienced independent hydrological expert, whose appointment has been endorsed by the Secretary, to deal with all hydrological matters and assist landowners in negotiating feasible and reasonable mitigation measures.	Sections 1.6 and 2.5

CONDITION OF APPROVAL REFERENCE	CONDITION OF APPROVAL	WHERE ADDRESSED
D16	The Applicant shall provide feasible and reasonable assistance to the relevant council and/or NSW State Emergency Service, to prepare any new or necessary update(s) to the relevant plans and documents in relation to flooding, to reflect changes in flooding levels, flows and characteristics as a result of the SSI.	Section 6.3

1.5 Flood management objectives

The changes to flood conditions due to the project are required to be assessed against the flood management objectives set by the CoA. Condition B31 of the CoA requires the project to achieve the flood management objectives set by the EIS. Flood management objectives have been set for:

- flood level
- flood duration
- flood velocity
- flood direction.

The flood management objectives are applicable to the 5, 20, 50 and 100 year Average Recurrence Interval (ARI) events. Table 1.2 outlines the project flood management objectives.

Table 1.2 Flood management objectives

Parameter	Location	Flood management objectives
Flood level	Residences	Up to 50 millimetre increase
	Cane farm land	Up to 50 millimetre increase
	Grazing, forested and other rural lands	Generally up to 250 millimetres with localised increase of up to 400 millimetres for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares)
Flood duration	Residences	No more than 5% increase
	Cane farm land	No more than 5% increase
	Grazing, forested and other rural lands	No more than 10% increase
Flood Velocity	Residences	Velocity x depth to remain in the zone of low hazard for children below 0.4m^2/s.
	Cane farm land	Below 1.0m/s where currently below this figure An increase of not more than 20% where existing velocity is above 1.0m/s
	Grazing, forested and other rural lands	Below 1.0m/s where currently below this figure An increase of not more than 20% where existing velocity is above 1.0m/s
Flood direction	Residences	No change to the direction of watercourses or the direction of flood flows except for constriction in and expansion out of discrete openings (culverts and bridges) and construction diversions
	Cane farm land	
	Grazing, forested and other rural lands	

1.6 Independent hydrologist

Condition D15 requires the project team to employ a suitably qualified independent hydrologic expert, whose appointment has been endorsed by the Secretary of the Department of Planning and Environment (DPE), to deal with all hydrological matters and assist landowners in negotiating feasible and reasonable mitigation measures.

Flood management specialist consultants WMAwater have been engaged to carry out the independent hydrologist role. The role involves critical review of the flood modelling and analysis carried out by the Woolgoolga to Ballina upgrade team as well as meetings with affected stakeholders and landowners to address concerns about flooding and drainage aspects of the project. The appointment of WMAwater to this role has been approved by DPE.

WMAwater have been involved as the independent verifier for previous stages of the project and have an in-depth knowledge of the regional flood models and local community concerns about flooding. WMAwater previously reviewed the flood models at the EIS and SPIR design stages and concluded the modelling approach used in the EIS assessment was appropriate and the regional models were extensively calibrated against available historical flood events, which provided confidence in their reliability.

WMAwater have reviewed the Woolgoolga to Ballina flood models and reports throughout the design process. This has included review of:

- modelling inputs
- modelling methodology for bridges and culverts
- assessments of compliance with the flood management objectives
- reports relating to flood modelling and impact assessment, including this report

Please refer to Appendix A for confirmation of WMAwater's review of the flood modelling and assessments carried out to date. Independent verification of the flood models developed for the local catchments has been carried out by separate independent consultants.

WMAwater has also participated in the community consultation with local landowners and agencies. During the detailed design stage, WMAwater attended weekly meetings with the project team to keep up to date with the status of design development and flood modelling. WMAwater's role is ongoing and will continue through the construction and completion phases of the project.

1.7 Design status for Richmond River Bridge

The proposed new Richmond River Bridge north of Broadwater will be delivered under a design and construct contract that has yet to be awarded. Tenderers for the project have been provided with a reference design for the bridge that includes the removal of the embankment section at station 145.2 and replacement with an extension of the bridge, in accordance with Condition B43 (see Table 1.1). Once the contract has been awarded the project team will work with the successful tenderer to ensure that the detailed design of the bridge is developed in accordance with the CoA and the flood management objectives.

1.8 Status of report

This report currently reflects the design at April 2017 and as of that date there are some elements of the detailed design still being refined. For the Richmond River Bridge the detailed design has yet to be commenced, as discussed above in section 1.7.

Work is also ongoing to finalise the mitigation measures required to reduce or eliminate flooding impacts in areas where the flood management objectives are not fully achieved. The results provided within this report have resolved most but not all of these issues and further modelling work is being carried out to assess feasible and reasonable mitigation measures to resolve these issues. Discussions with local landowners and the community are also ongoing.

Addenda to the report will be issued as required to record agreements on impacts and mitigation measures with the landowners as the project proceeds to construction.

2. CONSULTATION

The project team has consulted with the community, government agencies, key stakeholders and landowners during development of the hydrological mitigation report. The purpose of this consultation was to:

- incorporate local knowledge and expertise
- provide consistency with plans held by other local authorities and emergency service providers
- promote stakeholder and community understanding of the modelling outcomes.

2.1 Consultation with government agencies

Consultation with key agency stakeholders has been ongoing since project inception. The Environmental Review Group (ERG) was formed in 2015. The purpose of this group is to actively engage government agencies in the project as it is delivered and seek feedback on environmental matters. Invitations to participate in the group were extended to representatives from:

- NSW Department of Primary Industries and Fisheries (DPI)
- NSW Environmental Protection Agency (EPA)
- NSW Department of Planning and Environment (DPE)
- independent Woolgoolga to Ballina upgrade environmental representatives
- Roads and Maritime.

2.1.1 Environmental review group workshops

A number of presentations have been developed and delivered to the ERG. The initial presentation delivered on 24 February 2016 included:

- flood modelling history and background
- drainage, including cross drainage hydrology and hydraulic designs
- flooding including proposed approach
- detailed design progress and delivery timeframes.

Ongoing presentations since March 2016 have provided updates on the flood modelling progress and included:

- flood modelling status
- progression from SPIR to current and associated design refinements
- flooding objectives
- process for completing assessments and consulting on impacts
- summary of outcomes of flood modelling to date
- summary of non-conformances for permanent and temporary works
- explanation of the independent verification process
- process for completing assessments and ongoing consultation.

2.1.2 Additional agency consultation

Further consultation has been carried out with agency representatives from the EPA in October 2016 on specifics relating to the flood modelling and departures. The consultation focussed on proposed solutions as part of minor drainage design amendments to provide individual property solutions to departures. Feedback from the EPA has been incorporated into design solutions and provided to individual property owners, where applicable.

2.2 Consultation activities

The project team aims to work closely with our communities during the project's development and to minimise, manage and wherever possible mitigate impacts during construction.

The purpose of the flooding consultation was to:

- provide the community with an opportunity to contribute to the process of managing potential impacts of the Woolgoolga to Ballina Pacific Highway upgrade
- provide the community with a update on the flood modelling process
- consult with landowners directly impacted in areas where the flood management objectives are not achieved.

Consultation on the outcomes of the flood modelling started in July 2016 and is ongoing.

2.2.1 Presentation

A presentation was developed and provided at key stakeholder meetings and at the flood focus groups. This presentation included:

- evolution of design from EIS and SPIR to current design
- flood management objectives and flood modelling methodology
- identified impacts in the catchment
- design refinements incorporated to mitigate flooding impacts identified
- introduction to the project's independent hydrologist
- identified and explained departures and outlined consultation process proposed with landowners.

The presentation was tailored for the different areas. An example of the type of presentation delivered can be found in Appendix F.

2.2.2 Stakeholder meetings

A number of stakeholder meetings were carried out. These meetings included the flooding presentation followed by the opportunity to ask questions. Meetings were attended by key project team personnel as well as the project's independent hydrologist. A summary of the key issues raised at these meetings is provided in section 2.4.2. Table 2.1 list these stakeholder meetings.

Table 2.1 Stakeholder meetings

Date	Stakeholder
27 July 2016	Richmond Valley Council
27 July 2016	Ballina Shire Council
01 August 2016	Richmond River Cane Growers Association & Broadwater Sugar Mill
20 September 2016	Richmond River Cane Growers Association – Board of Directors
16 November 2016	State Emergency Services
8 March 2017	Rous County Council

2.2.3 Reforming the flood focus groups

Flood focus groups were formed as part of the environmental assessment phase in 2012. The opportunity to participate in the 2016 flood focus groups was open to all interested parties. The following activities were carried out to advertise the reformation of the groups:

- email campaign to registered stakeholders
- phone calls to 2012 flood focus group members
- advertisements in local newspapers.

Two flood focus groups were carried out with the wider community. The flood focus groups ran from 5.30pm – 7.30pm and included a presentation, followed by the opportunity to ask questions. The project team was also available after the presentation to answer questions. Table 2.2 outlines the location and number of attendees at each meeting.

Table 2.2 Flood focus groups

Date	Group	Location	Number of attendees
16 August 2016	Mid and Lower Richmond River floodplains	Broadwater Community Hall, Broadwater	30
20 September 2016	Pimlico	Wardell Hall, Wardell	15

2.3 Consultation with affected landowners

The project team has been successful in minimising overall flooding impacts in the Richmond regional and local floodplains. Flooding impacts, however, are influenced by factors such as catchment characteristics / conditions and nature of the flood event, and it has not been possible to fully achieve the flood management objectives at all locations, as described in section 1.5.

In accordance with CoA B33, where the project team has been unable to achieve the flooding objectives we are consulting with individual stakeholders to discuss the predicted impacts and identify potential options for localised mitigation.

Consultation started with landowners in July 2016. The project team has met with a number of the affected landowners and discussions are ongoing.

2.4 Feedback

Feedback about the predicted flooding impacts was invited from key stakeholders and the community.

2.4.1 Agency feedback

In general, feedback from agencies has been positive during the development of the flooding assessment. Additional items requested include:

- ongoing involvement in the development of site specific and at property mitigation
- further investigations into potential impacts to ecological communities as a result of predicted flooding impacts.

The project team will continue to work with key environmental agencies and groups throughout the project's development.

2.4.2 Community and stakeholder feedback

Key areas of interest identified were as follows:

During operation:

- impact from flooding events upstream
- impact of 72 hour storm in flat areas around Woodburn
- Tuckombil Canal weir influence on local flood behaviour (not part of this project)
- maintenance of flooding and drainage infrastructure during construction and operation
- potential impacts of the new Richmond River bridge
- support for the consultation process and for demonstrating incorporation of feedback received during the projects development
- potential increases in inundation on cane land
- baseline assessments and inclusion of real and recent data critical to for ensuring accuracy of flood modelling
- mitigation measures proposed to manage potential debris build up

- flood gates and flood openings
- Richmond River siltation
- accuracy of flood models.

During construction:

- road closures and accessibility during flooding events
- potential for construction activities to increase impacts of flooding modelling process
- consultation process for departures from the objectives.

2.5 Consultation by independent hydrologist

Table 2.3 shows when and how WMAwater has engaged with stakeholders as the project's independent hydrologist.

Table 2.3 Engagement activities involving WMAwater

Date	Stakeholder	Type of engagement
27 July 2016	Richmond Valley Council	Meeting
01 August 2016	NSW Sugar & Richmond River Cane Growers	Presentation
16 August 2016	Richmond River floodplain (upper and lower)	Flood Focus Group
23 August 2016	Property owner – Pimlico Property owner – Pimlico Property owner – Wardell	Meeting Meeting Meeting
20 September 2016	Richmond River Cane Growers – Board of directors	Meeting
20 September 2016	Pimlico	Flood Focus Group
16 November 2016	State Emergency Services	Presentation
16 November 2016	Property owner – Woodburn	Meeting
17 November 2016	Property owner – Woodburn	Meeting

2.6 Adaptive management

This report has been prepared to address the specific requirements of the Ministers Conditions of Approval as they relate to flooding. The detailed design of the project has been developed as outlined in this report to ensure wherever reasonable and feasible it meets the flood management objectives outlined in the project EIS. There are a number of areas where these objectives have not been fully achieved, as outlined in the report. Mitigation measures continue to be identified for these locations and a schedule of mitigation measures in included in Table 6.2.

The project team is committed to reducing potential flooding impacts from the project on the receiving land-uses and stakeholders. The design as developed may undergo further refinements in order to optimise or reduce potential flooding impacts. These design refinements will be undertaken in accordance with the principles and objectives outlined in this report. Should there be a minor change to the design, either from flood optimisation or engineering reasons, the project team will review the potential flooding impacts on this change against the outcomes provided in this report.

If the design change results in a better or improved outcome at the specific location then it may be adopted with no further action. Should the design change result in a worse outcome at the specific location then Pacific Complete would consult further with relevant stakeholders and the independent hydrologist to determine an appropriate way forward. This may include further consultation with stakeholders and implementation of additional mitigation measures.

Any decision on changes to flood relief structures or design options would include the following considerations:

- affordability
- technical and constructability investigations
- total life costs
- potential flooding impacts or benefits
- consultation with relevant stakeholders, including independent experts

If the proposed design changes developed are identified as having a poorer flooding outcome to that identified in this report, the project team would prepare an addendum to the hydrological mitigation report that outlined the following:

- identify proposed design refinements
- identify catchment areas impacted
- identify individual landowner or infrastructure potentially impacted by changes
- summary of assessment against project flood management objectives
- outline of proposed mitigation measures
- evidence of consultation with agencies.

This report would be provided to the relevant stakeholders for approval as required.

If the proposed design refinements investigated do not have any adverse impacts to the flooding outcomes as identified in this report, no further action will be taken in regards to consultation or approvals. The works can proceed as proposed subject to consideration of other project approval requirements. The project team would also consult with DPE to determine whether any further approvals are required.

2.7 Future consultation

There are a number of departures identified in this report. Table 6.2 provides a schedule of the current status of departures and flood mitigation measures / consultation actions, including:

- property ID
- nature of departures
- status of landowner consultation
- status of agreement.

Consultation with affected landowners is ongoing and this schedule will be progressively updated. The project team propose to regularly update the schedule and provide to the DPE. It is important to note the project team is involving the independent hydrologist during this consultation process to assist and provide advice as required.

If there is an area of dispute between the project team and landowners about the nature of mitigation measures offered, the project team will seek advice and input from the independent hydrologist on whether the measures being offered are considered reasonable and feasible given the potential impacts. If the issue is not be able to be resolved after this consultation, the project team will provide this information to the DPE to confirm all efforts have been exhausted. The schedule status will remain pending as the project team will provide opportunity for landowners to re-engage in the consultation process at a later date.

3. STUDY AREA AND EXISTING FLOODING BEHAVIOUR

3.1 Catchment overview

During 2016 the project team carried out further flood modelling of the regional floodplains of the Clarence and Richmond rivers as part of the detailed design process. The regional flood modelling included assessment of predicted flooding impacts related to permanent and temporary work. The following sections interact with the Richmond River regional floodplain:

- Trustums Hill to Broadwater National Park in the Mid-Richmond floodplain
- Broadwater National Park to Richmond River, including the new bridge over the Richmond River north of Broadwater, in the Mid-Richmond floodplain
- Coolgardie Road to Ballina Bypass in the Lower Richmond floodplain

Assessment of the flooding impacts of the permanent works in other local floodplain systems within the Richmond River system but outside of the regional floodplains has been carried out. These local catchments lie within the areas between Devils Pulpit Upgrade to Trustums Hill and Richmond River to Coolgardie Road, and include:

- Devils Pulpit Upgrade to Trustums Hill local catchments:
  - Tabbimoble Floodway 1
  - Oakey Creek
- Richmond River to Coolgardie Road local catchments:
  - Bingal Creek
  - Wardell Floodway 6
  - Randles Creek

This report addresses both regional and local catchment flood impact assessment outcomes and mitigation measures.

3.1.1 Regional catchment

The Richmond River catchment in the Northern Rivers region of NSW is one of the largest in coastal NSW with a catchment area of about 6,900km^2. The catchment extends from the Border ranges in the north and the Richmond ranges in the west and south. The river flows in a south, east and ultimately north easterly direction to reach its outlet to the Pacific Ocean at Ballina. The upper catchment is generally forested land with the Mid to Lower catchment area predominantly a mixture of cropping or pasture agricultural land. The river is tidally influenced into its mid-catchment with the tidal influence extending occurring over 100 kilometres upriver from its outlet.

The Mid-Richmond River refers to the expansive river and floodplain area located upstream of Broadwater. This area of the catchment has a number of major tributaries which influence flooding in the catchment, including the Wilson River and Bungawalbin Creek. The smaller Evans River catchment is also connected to the Mid-Richmond floodplain via the man-made Tuckombil canal which connects to the river at Woodburn and was constructed with the intent of improving the drainage and flooding in the area. This canal allows flows into the Evans River and catchment which outlets to the ocean approximately 20 kilometres away.

The Lower Richmond River refers to the lower 30 kilometres of the river and floodplain with flooding in this area of the catchment also influenced by a number of smaller catchments to the north west, including Maguires Creek, Duck Creek and Emigrant Creek.

The Richmond River and its tributaries pass through a number of towns and urban centres including Casino, Lismore, Coraki, Woodburn, Broadwater, Wardell and Ballina.

3.1.2 Local catchments

The project has also assessed the flooding impacts in local floodplain systems within the Richmond River system.

3.1.2.1 Devils Pulpit Upgrade to Trustums Hill local catchments

The Devils Pulpit Upgrade to Trustums Hill section of the project will traverse the Clarence / Richmond River tributary catchments of Tabbimoble Floodway 1, Oakey Creek and other minor tributaries.

The Tabbimoble Floodway 1 local catchment extends to about 12km^2. The catchment drains to the south-east, eventually discharging into the Clarence River after approximately 25 kilometres. Most of the vegetation present in this area consists of dense forest with localised rural residential areas. Flooding from the main Clarence River does not influence flood behaviour in the Tabbimoble Floodway 1 catchment.

The Oakey Creek local catchment extends to about 15km^2. It extends over Oakey Creek and Norton's Gully catchments, which are tributaries of the Richmond River. Most of the sub-catchments are covered by dense forest vegetation, with patches of grazing and rural residential areas. Runoff from Oakey Creek and Norton's Gully flows to the north-west, discharging into the Richmond River floodplain. Flooding from the Richmond River can interact with and impact flood behaviour in Oakey Creek and Norton's Gully.

3.1.2.2 Richmond River to Coolgardie Road local catchments

The Richmond River to Coolgardie Road section of the project will traverse the Richmond River tributary catchments of Bingal Creek, Wardell Floodway 6, Randles Creek and other minor tributaries.

In this section the new highway alignment is generally located in low lying areas subject to local catchment floodplain processes and surface sheet flow. Some cane growing land exists within the local catchments but the land is predominantly forested and grazing areas. The top of the catchments are quite undulating with relatively steep slopes away from the low lying areas adjacent to the proposed highway. None of the local catchments in this section are influenced by flooding in the main Richmond River.

The catchment areas to the new highway crossings of the local creeks are as follows: Bingal Creek – 1km^2; Wardell Floodway 6 – 1.3km^2; Randles Creek – 2.6km^2.

3.2 Existing flooding behaviour

This report covers the area from Tabbimoble Floodway 1 to the Lower Richmond River at Ballina, including the Mid-Richmond River floodplain between Tuckombil Canal to the Richmond River bridge; and the lower Richmond River floodplain including Duck Creek and Emigrant Creek. The mid and lower floodplain areas of the Richmond River are subject to frequent and extensive flood inundation. The total catchment area of the river is about 6,900km^2. The existing flooding behaviour described in this section is based on the flood modelling analyses discussed in section 4.

3.2.1 Devils Pulpit Upgrade to Trustums Hill

This section of the project traverses the local catchment systems of Tabbimoble Floodway 1 and Oakey Creek – see Figure 3.1. The Tabbimoble Floodway 1 catchment upstream of the project is entirely within the Double Duke State Forest. The waterway flows alongside the southern boundary of Tabbimoble Swamp Nature Reserve and then into Bundjalung National Park. Runoff from Tabbimoble Floodway 1 flows towards the south-east, eventually discharging into the Clarence River after approximately 25 kilometres. Regional flooding from the Clarence River does not affect the Tabbimoble catchment since the local catchment elevation is much higher than the low-lying regional floodplain.

There are a number of other small local catchments crossed by the alignment in this section between Tabbimoble Floodway 1 and Oakey Creek. Most of the vegetation present in this area consists of dense forest with localised rural residential areas.

Oakey Creek and Norton's Gully catchments are located in the northern part of this area and are tributaries of Evans River which flows into the Richmond River. Most of the catchments are covered by dense forest vegetation, with patches of grazing and rural residential areas. The floodplain generally has gentle slopes, while the hill slopes along the catchment's eastern and south-eastern boundaries are steep. Runoff from Oakey Creek and Norton's Gully flow to the north-west, discharging into the Richmond River floodplain. Flooding from the Richmond River can interact with and impact flood behaviour in Oakey Creek and Norton's Gully.

Figure 3.1 Overview of Devils Pulpit Upgrade to Trustums Hill

3.2.2 Trustums Hill to Broadwater National Park

This section of the project runs in a north easterly direction from Trustums Hill across the Richmond River floodplain to the south of the existing Pacific Highway through Woodburn to Broadwater National Park – see Figure 3.2. The highway is in a greenfield area from the start of this section at the Tuckombil Canal crossing to approximately 500 metres south east of the existing Pacific Highway crossing, and progressing in a north easterly direction across the floodplain and across Evans Head Road.

The southern end of the section crosses a number of other small local catchments as far as the Woodburn interchange. Most of the vegetation present in this area consists of dense forest with localised rural residential areas.

Flooding from the regional catchment in this area occurs when floodwaters break out from the southern bank of the Richmond River causing widespread inundation of the flat and expansive floodplain. Floodwaters are drained from the floodplain areas via the network of cane drains. Floodwaters can take several days to drain away in this area.

The existing Pacific Highway through the Richmond River floodplain has a variable level of flood immunity up to the 20 year ARI event. The portion of the existing Pacific Highway that runs along the south eastern floodplain of the Richmond River connecting the urban centres of Woodburn and Broadwater is estimated to have a flood immunity of between the 5 and 10 year ARI events.

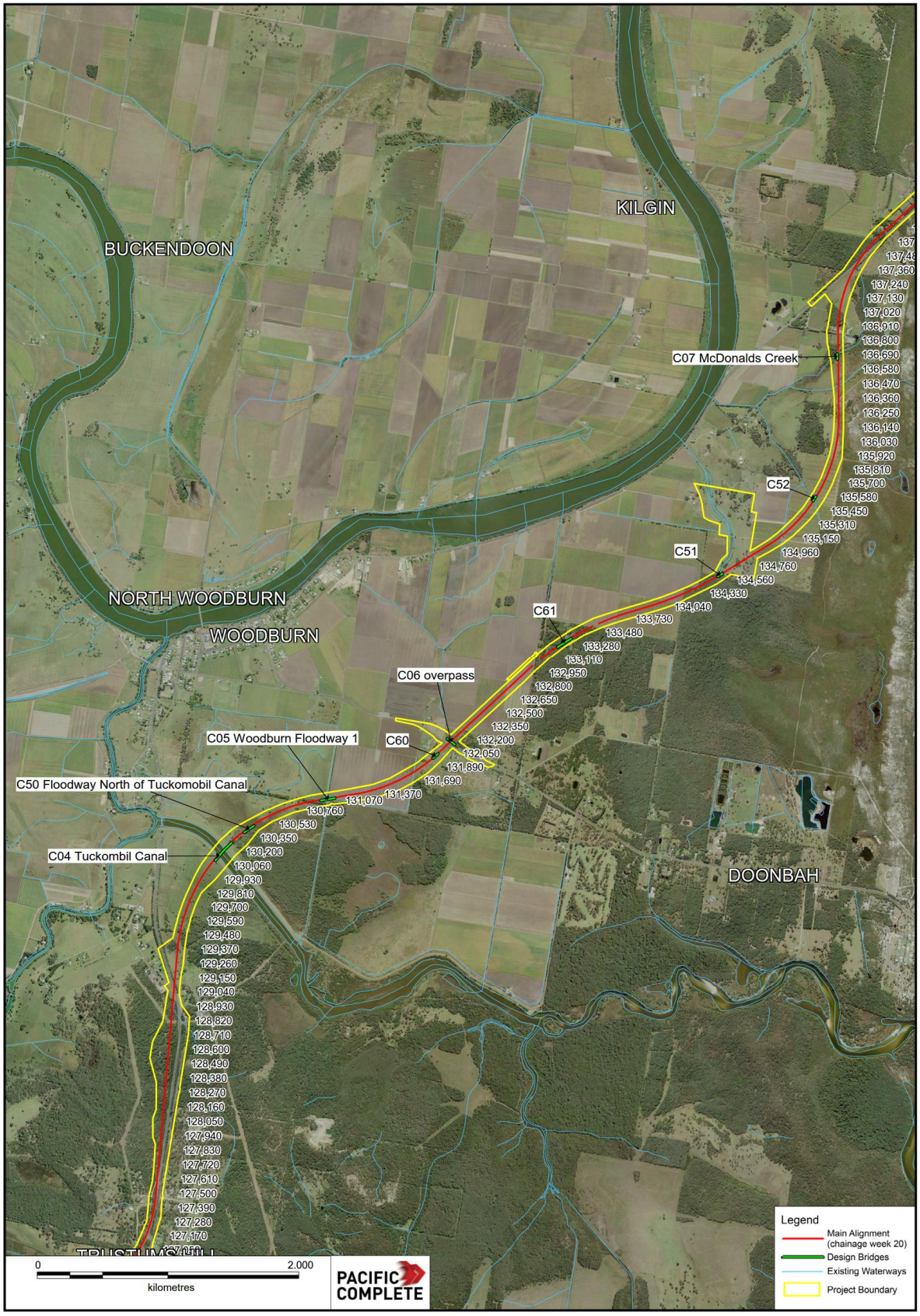

Figure 3.2 Trustums Hill to Broadwater National Park

3.2.3 Broadwater National Park to Richmond River

This section of the project begins in Broadwater National Park above the floodplain and runs in a north easterly direction – see Figure 3.3. The future highway then runs along the outer extent of the floodplain to the south and west of the existing Pacific Highway as it passes through Broadwater. The future highway then crosses the Richmond River to the north of Broadwater before connecting with higher ground on the northern bank of the Richmond that is above the floodplain.

Regional catchment flooding in this area generally occurs in events that exceed the 5 year ARI when floodwaters from the Richmond River break out of the southern river bank inundating the floodplain. The floodwaters are drained from the floodplain areas via a network of cane drains and can take several days to drain away.

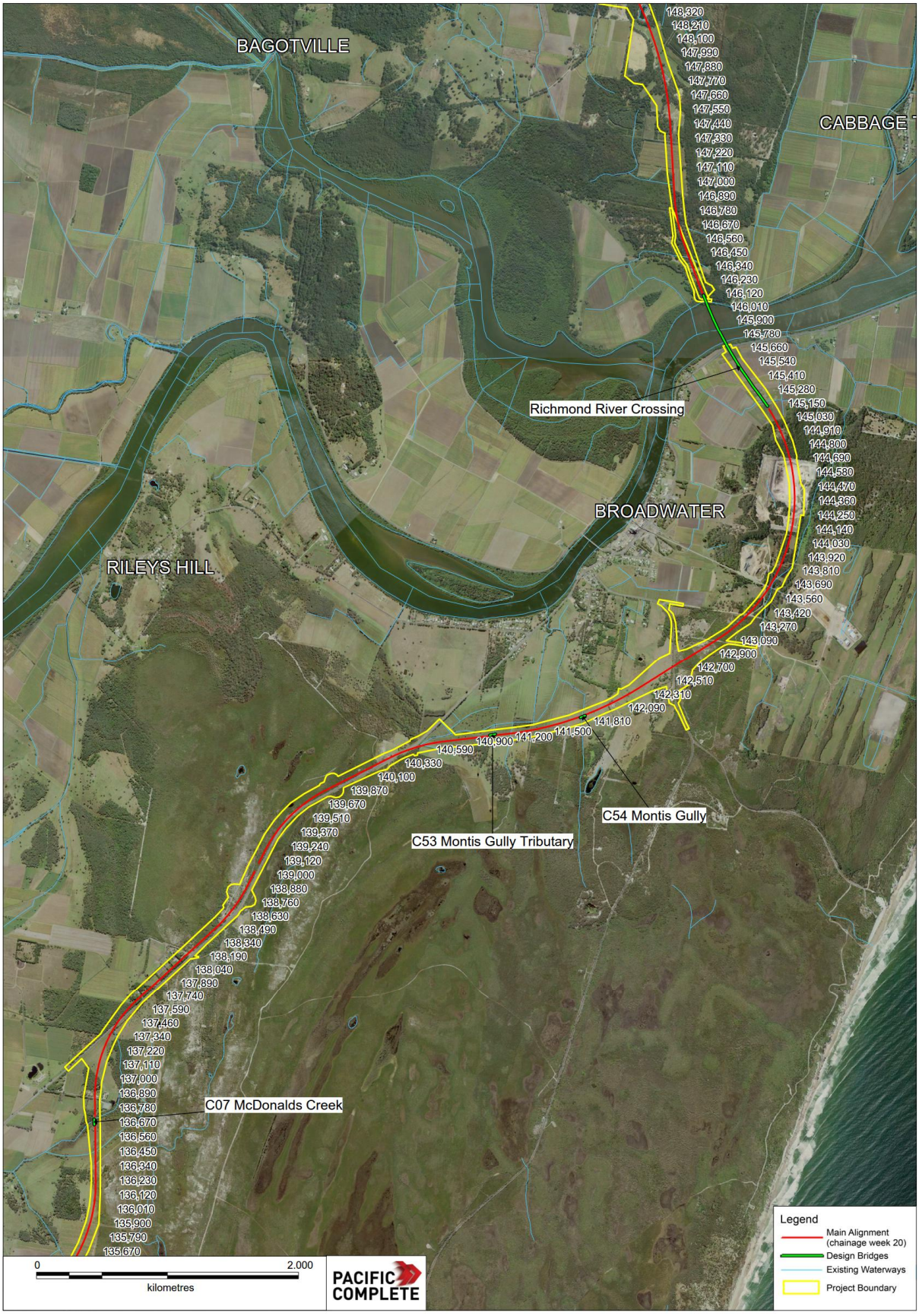

Figure 3.3 Overview of Broadwater National Park to Richmond River

3.2.4 Richmond River to Coolgardie Road

This section commences on the southern side of Richmond River and is located between the Mid-Richmond and the Lower Richmond River floodplains – see Figure 3.4. It includes the local catchments of Bingal Creek, Wardell Floodway 6 and Randles Creek.

The highway through this section is located in low lying areas subject to local catchment flows and surface sheet flow. Some areas have been cultivated for cane growing but generally areas adjacent to the major waterways are forested and grazing land. The top of the catchments are quite undulating with maximum elevations reaching 90 metres Australian Height Datum (AHD) with relatively steep slopes away from the low lying areas adjacent to the proposed highway.

Bingal Creek is located north of Broadwater. The catchment consists of cane farmland to the west of the alignment and cattle/grazing to the east. Bingal Creek flows east towards the coast.

Further north along this section is Wardell Floodway 6. The flooding behaviour of the Wardell area is relatively complex. A smaller region of cane land exists to the west of Wardell, with some drainage diversion being required along the project to combine cane drains through culvert structures. The Wardell Floodway 6 generally flows in an easterly direction.

Randles Creek is a tributary of the Lower Richmond River and is located at the northern end of Section 10. It is a minor waterway which becomes Saltwater Creek immediately downstream of the project crossing. The adjacent land generally comprises forested valley floors and flats, and alluvial floodplain. The waterway is well-vegetated with good stands of native trees and shrubs growing along the edges and vicinity, which contributes to river health and the stability of banks. This stream will likely engage with the regional floodplain in relatively small flow events.

This section traverses through the environmentally-sensitive Ballina Koala population, which is a critical consideration in the design and construction of the road with the inclusion of multiple fauna crossings.

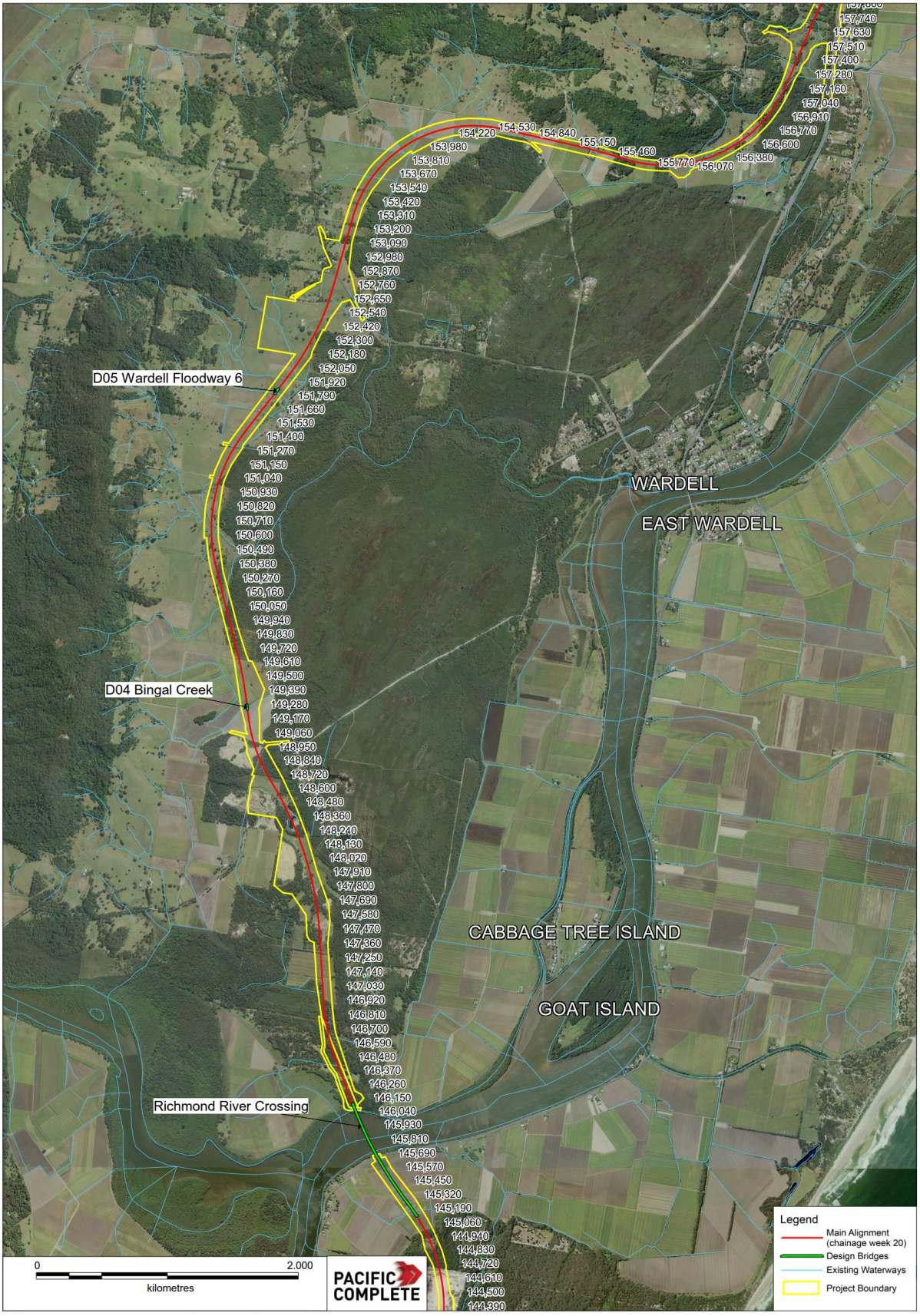

Figure 3.4 Richmond River to Coolgardie Road

3.2.5 Coolgardie Road to Ballina Bypass

This section runs in a northerly direction from Coolgardie Road to the end of the project where it ties into the Ballina Bypass works at the Pimlico to Teven works – see Figure 3.5. The highway upgrade for this section follows the existing highway route along the western edge of the Richmond River floodplain.

Flooding along this section occurs due to floodwaters breaking out from the Richmond River and inundating the low-lying flood-plain to the east of the highway. Flooding can also occur as a result of local catchment flooding in this area.

North of Broadwater the existing Pacific Highway is estimated to overtop during a 5 year ARI event between Broadwater and the intersection with Boundary Creek Road with the section from Wardell to the Ballina Bypass tie-in having a 20 year flood immunity.

Figure 3.5 Overview of Coolgardie Road to Ballina Bypass

4. FLOOD MODELLING AND IMPACT ASSESSMENT METHODOLOGY

Flood modelling of the regional Richmond River catchment was carried out using the TUFLOW software program. TUFLOW is a combined one -dimensional (1D) and two-dimensional (2D) hydraulic modelling software package used to model complex rivers and their floodplains. TUFLOW is able to handle complex flow behaviours including:

- shallow and wide flooding experienced on the floodplain
- deep and fast moving flow experienced in river channels.

4.1 Overview of flood model history

4.1.1 Regional models

The Richmond River catchment has historically been split into upper, mid and lower sections for the purposes of flood studies and investigations. This project has used the hydraulic models previously developed for the mid and lower portions of the catchment. Refer to Figure 4.1 for an overview of the history of the development of the regional flood models.

4.1.1.1 Mid-Richmond River regional flood model

The Mid-Richmond River regional flood model was developed for Richmond River County Council and Richmond Valley Council between 1999 and 2010 to provide flood planning information for the Mid-Richmond floodplain. There have been multiple updates and calibrations of the model since then, commissioned by both Council and Roads and Maritime for at various design stages of the project.

A key update to the model for the project involved improving the resolution of the 2D model in the project area by refinement of the 60 metre grid to a 20 metre nested grid on the left bank floodplain of the Richmond River between Woodburn and Broadwater. The refined grid was based on the aerial survey carried out by NSW Department of Lands and Property Information in 2010. The model update included the addition of a number of features from the aerial survey to represent significant riverbank, levee and road embankments. The refined model was then re-calibrated to the 2009 flood event and verified against the 1974 event. The refined and re-calibrated model has been adopted as the basis for the hydraulic assessments of the project for the area between Trustums Hill and Richmond River.

4.1.1.2 Lower Richmond River regional flood model

The Lower Richmond River regional flood model was originally developed for Ballina Shire Council over a number of stages between 1996 and 2008 in order to provide flood planning information for Ballina and surrounding areas. There have been multiple updates and calibrations of the model since then, commissioned by both Council and Roads and Maritime at various design stages of the project.

A key update to the flood model for the project involved updating the model topography from a number of aerial survey sources captured in 2010, and refining the 40 metre grid to a 10 metre nested grid within the project corridor. Another key update involved the revision of the existing conditions model to represent the 2013 floodplain conditions with the Ballina Bypass works in place. The improvements also included development of 1D channel representations of Richmond River and North Creek. The upstream boundary condition for the model was updated from a flood level hydrograph to a flood flow hydrograph. The updated model has been adopted as the basis for the hydraulic assessments of the project for the area between Coolgardie Road and Ballina Bypass.

4.1.2 Local catchment models

The local catchment models in the Devils Pulpit Upgrade to Trustums Hill section (Tabbimoble Floodway 1, Oakey Creek and other local systems) and in the Richmond River to Coolgardie Road section (Bingal Creek, Wardell Floodway 6, Randles Creek and other local systems) were originally developed for the EIS and further refined by the project team during the development of the detailed design.. The models were developed using a combination of XP-RAFTS software for hydrology and TUFLOW for hydraulics. These models were also updated and refined for the local catchments, with input of additional topographic and catchment information and further model development to provide a set of local catchment flood models suitable for use in detailed design.

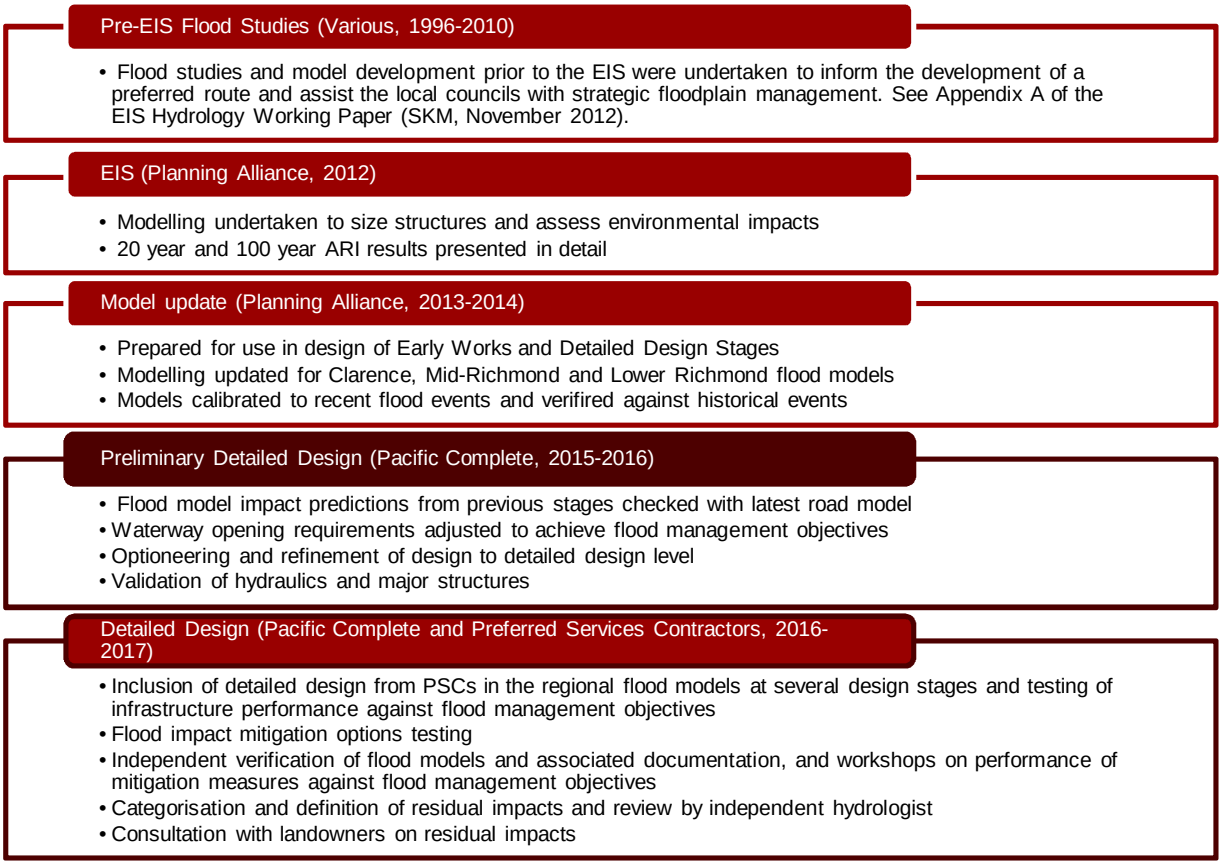

Figure 4.1 Staging of regional flood model development

4.2 Flood modelling methodology

4.2.1 Model validity

4.2.1.1 Regional models

The regional models have been calibrated against historical flood events with an expected accuracy of +/- 150 millimetres for flood levels and +/- 10 millimetres for changes in flood levels, which is consistent with industry standards.

The regional models are suitably developed and calibrated tools for defining existing and future conditions within the Richmond River regional floodplain. They have been reviewed by the independent hydrologist at various stages throughout the model development as outlined in Figure 4.1.

4.2.1.2 Local catchment models

The local catchment models were developed in line with industry standards. Generally, no calibration data exists for the local catchments and calibration is not possible for these models. In the absence of calibration, the models were subjected to sensitivity analyses of key input parameters to determine the predictive range of the models and conservative values were adopted for the key parameters as necessary to allow for model uncertainty.

4.2.2 Model representation

4.2.2.1 Regional models

Major river channels and floodplains in which flow patterns are complex and multi-directional are modelled in 2D. Smaller rivers and creeks in the model area are generally represented as 1D hydraulic networks as the flow patterns in these systems are relatively simple and in one direction from upstream to downstream. The networks are made up of a series of channel cross sections linked together over short channel lengths. The 1D sub-model is dynamically linked to the 2D sub-model representing the floodplain adjacent to the river and creek channels, freely transferring water between the sub-models via 1D-2D boundaries as floodwaters spill between the channels

and floodplains. This is an industry standard approach to simulating flow behaviour in complex floodplains containing numerous creek channels of varying size.

The hydraulic model does not include a representation of all minor drainage systems in the floodplain, such as cane drains and other small land drainage channels, as these channels tend to have widths less than the model grid resolution (10-20 metres) and do not affect the regional flood behaviour.

The level of detail in the models is appropriate for assessing regional flood behaviour and the impacts of the highway on this behaviour, however, it should be noted the models may overestimate the flood extent and/or flood duration in local areas where the minor drainage features are not represented.

4.2.2.2 Local catchment models

The local catchment hydraulic models are wholly 2D models (no 1D representations included) with grid resolutions of three to five metres adopted for the catchments within the Devils Pulpit Upgrade to Trustums Hill section and two to three metres adopted for the catchments within the Richmond River to Coolgardie Road section. The grid resolutions for the local catchment models will represent existing cane drains and other land drainage features to some extent, but not where these features are less than the grid resolution. Therefore, the local catchment models may also overestimate flood extent and/or flood duration in localised areas where the minor drainage features are not represented.

4.2.3 Model extent

The spatial extents of the regional and local catchment models are shown in Figure 4.2.

4.2.3.1 Regional models

The Mid-Richmond River hydraulic model covers the area from Casino to Ballina, including many large local creek catchment systems. Outside of these local catchments the regional model has been used to assess the impacts of the upgrade on regional flood events governed by the Richmond River.

The Mid-Richmond River regional model has been used to assess flood impacts and inform bridge and cross drainage sizing for areas of the Trustums Hill to Broadwater National Park section north of chainage 129000 inclusive of Tuckombil Canal Bridge (chainage 130125) and the Richmond River Bridge at Broadwater. To the south of the Mid-Richmond River model area, the Oakey Creek local model overlaps the south of the Mid-Richmond River model. This local model does not have significant hydraulic interactions with the regional floodplain and is used to inform flood impacts and bridge sizing for the alignment in this local catchment area.

The Lower Richmond River hydraulic model covers the area from north of Broadwater to Ballina, including a number of local creek catchment systems. Outside of these local catchments the regional model has been used to assess the impacts of the upgrade on regional flood events governed by the Richmond River.

The Lower Richmond River regional model has been used to assess flood impacts and inform cross drainage sizing for areas north of chainage 159000. There are no bridge openings in this section of the W2B upgrade but the bridge crossings from the Pimlico to Teven highway upgrade works at Duck and Emigrant Creek are included in the model at the northern connection with the Ballina Bypass.

To the south west of the Lower Richmond River model area, a number of local models have been developed, including Bingal Creek and Randles Creek, representing the local catchment flows of the Richmond River tributaries. These local models do not have significant hydraulic interactions with the regional floodplain and have been used to inform flood impacts and bridge sizing for the alignment in the local catchment areas.

The spatial extents of the regional and local catchment models are shown in Figure 4.2.

4.2.3.2 Local catchment models

The hydraulic model extents for the local catchment models are as follows (see also Figure 4.2):

- Devils Pulpit Upgrade to Trustums Hill hydraulic model extents:
  - Tabbimoble Floodway 1 – covers about 12km^2 and extends about 700 metres upstream and one kilometre downstream of the highway.
  - Oakey Creek – covers about 15km^2 and extends about 700 metres upstream and 500 metres downstream of the highway.
- Section 10 hydraulic model extents:

- Bingal Creek – covers about 2.5km^2 and extends about 800 metres upstream and one kilometre downstream of the highway.
- Wardell Floodway 6 – covers about 3km^2 and extends about 500 metres upstream and 300 metres downstream of the highway.
- Randles Creek – covers about 3km^2 and extends about 500 metres upstream and 500 metres downstream of the highway.

The local catchment models have been used to size cross drainage structures (bridges and culverts) in these areas and to test the impacts of the highway on flooding in the adjacent land for the local catchments.

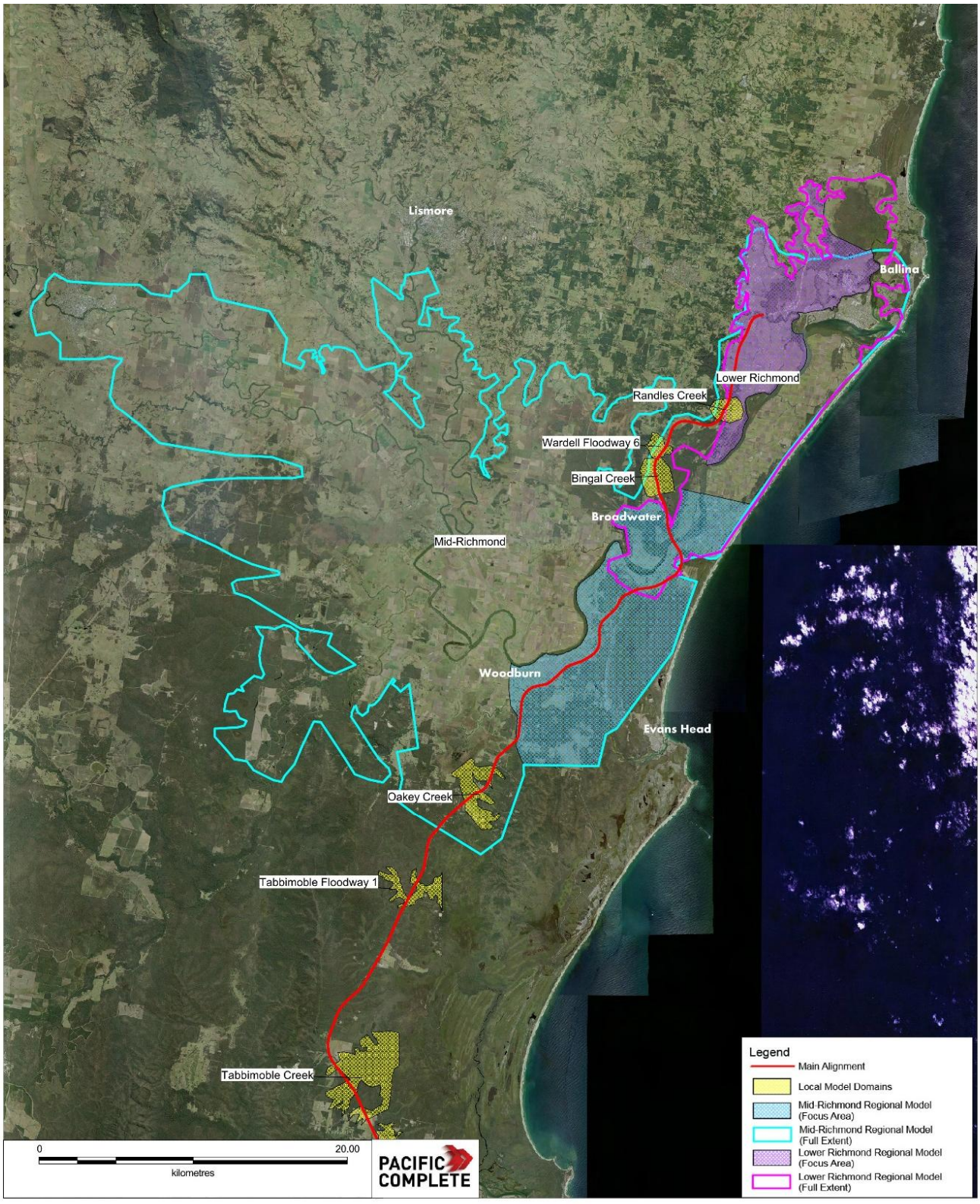

Figure 4.2 Overview of the extents of the Richmond River regional models and local catchment models

4.2.4 Design events and scenarios

4.2.4.1 Design events

The regional and local catchment flood models were run for the following design flood events:

- 5 year ARI
- 20 year ARI
- 50 year ARI
- 100 year ARI
- 2,000 year ARI event
- probable maximum flood (PMF) event

4.2.4.2 Lower Richmond hydrological scenarios

For the Lower Richmond model area, there are two critical hydrological scenarios for different areas of the project depending on the location of interest in the catchment. For areas on the eastern side of the highway closer to the Richmond River, the regional catchment event (i.e. the 72 hour storm which produces worst case flooding in the wider regional catchment), known as 'hydrological scenario A', is the critical event. For areas to the west of the existing highway, the local catchment event (i.e. the shorter duration storm which produces worst case flooding in the local catchments west of the highway), known as 'hydrological scenario B', is the critical event. Both the local and regional scenarios have been assessed in the Lower Richmond modelling and the inputs to these scenarios are provided in Table 4.1. For the purposes of mapping results from the two scenarios, a composite result taking the maximum value from each scenario has been adopted.

Table 4.1 Lower Richmond hydrological scenarios

Scenario	Description
A	Regional Richmond River event: 100 year ARI Richmond River flow, 100 year ARI 72 hour rainfall, 10 year ARI storm tide
B	Local catchment event: 10 year ARI Richmond River flow, 100 year ARI 12 hour rainfall, 10 year ARI storm tide

4.2.5 Sensitivity analyses

The following sensitivity analyses were carried out using the flood models to test the impacts of potential future scenarios on flooding behaviour and to check that these potential future impacts are similar to those predicted for the present day design scenario:

- climate change – the impact of the highway upgrade on flood behaviour was tested under climate change conditions, including increased rainfall intensity and sea level rise.
- future widening – the impact of future widening of the upgraded highway, particularly lengthening of bridges and cross drainage culverts in the direction of flow.

4.3 Categorisation of impacts

Where the flood management objectives cannot be fully met through provision of reasonable cross drainage structures and other mitigation measures, the impacts have been categorised. The categorisation considers the dominant land use and the potential effects of the highway on the use of this land. The categorisation has been applied to land covered by both the regional and local catchment models.

4.3.1 Impact categories

The intent of the categorisation of impacts is to allow the project to focus reporting and consultation with agencies, the community and affected landholders on flooding impacts which represent a clear departure from the objectives.

Areas of impact that do not meet the flood management objectives have been categorised as either:

- Minor or localised impacts that either nominally exceed the flood impact objectives and/or are confined to non-sensitive areas and/or are within the bounds of model uncertainty. These are termed 'low risk impacts' and are not subject to further investigation or mitigation.
- More significant impacts that clearly exceed the impact limits and are located in sensitive areas. These are considered to be departures from the flood management objectives and are subject to consultation with affected landowners and potential mitigation where feasible.

The categories are further defined as follows:

- Low risk impacts: minor and/or localised impacts that do not meet the flood management objectives for flood velocity and duration. To fall into this category the impact should meet the criteria provided in Tables 4.2 and 4.3.
- Departures: any impact that does not meet the flood management objective for flood level change (afflux); and any velocity and duration impacts exceeding the criteria provided in Tables 4.2 and 4.3.

Table 4.2 Criteria adopted for low risk impact category for flood velocity

Land use type	Velocity limit from Flood Management Objectives (%)	Absolute flood velocity limit (m/s)	Impact area limit (ha)
Houses and Urban Areas	Velocity x depth to remain below 0.4 m^2/s where currently below this value (i.e. remain in low hazard category)	N/A	N/A
Cane Farm Land	Velocities to remain below 1m/s where velocities are currently below 1 m/s Velocity increase to be below 20% where velocities exceed 1m/s	1.8*	Not used (velocities can increase up to the limit of 1.8m/s over unlimited area and still be classified as a low risk impact)
Grazing, Forested and Rural Areas	Velocities to remain below 1m/s where velocities are currently below 1 m/s Velocity increase to be below 20% where velocities exceed 1m/s	1.8*	Not used (velocities can increase up to the limit of 1.8m/s over unlimited area and still be classified as a low risk impact)

Notes:
**Based on velocity threshold above which erosion of land with moderate to good vegetation cover could occur*

Table 4.3 Criteria adopted for low risk impact category for flood duration

Land use type	Duration increase limit from Flood Management Objectives (%)	Total duration change limit (hrs)	Total duration limit (hrs)	Impact area limit (ha)
Houses and Urban Areas	5%	1*	N/A	Not used
Cane Farm Land	5%	1*	72**	0.5^
Grazing, Forested and Rural Areas	10%	1*	N/A	5#

Notes:
**Proposed threshold for flood fringe areas that flood for short periods of time*
***Based on threshold of submergence time that causes damage to cane*
^Proposed threshold for highly localised areas of impact on sensitive land
#Proposed threshold for localised areas of impact on non-sensitive land (and consistent with flood management objective definition of 'small areas' for this land use type - see Table 1.2, row 3).

The next section provides a discussion on flood duration impacts to support the impact categorisation and to demonstrate apparent duration impacts at floodplain fringes or in scattered areas are generally minor and/or due to the coarseness of topographic data representation in flood models.

4.3.2 Flood duration impacts

The flood management objectives set limits on the increase in flood duration in terms of percentage change:

- no more than five percent increase in the flood duration for houses, urban areas and cane farm land
- no more than 10 percent increase in the flood duration for grazing, forested and other rural lands.

These objectives do not differentiate between the following levels of impact:

- Increases in flood duration in areas that experience short duration or shallow depth flooding, or increases that occur on the outer extent of the floodplain where most of the floodplain has seen little or no change in flood duration. Such increases are likely to have insignificant impacts on the affected land.
- Increases in flood duration in areas that experience long duration and high depth flooding for days at a time, with the increases extending across multiple sub-catchments or extensive hydraulically connected flood storage areas. Such increases are likely to have significant impacts on the affected land as they have the potential to affect access and agricultural production.

The flood management objectives for flood level impact acknowledge impacts in areas that experience short duration/ local catchment flooding are less significant, and allow a higher level of impact over small areas up to five hectares in grazing, forested and rural areas.

This section provides a detailed explanation for the categorisation of low risk impacts relating to flood duration, which represent the majority of the impacts in this category.

4.3.2.1 Fringe, scattered and isolated duration impacts

The flood models used for the project, including those used for regional and local catchment assessments, generally adopt a 2D modelling approach for the floodplains. This involves representing the floodplain topography on an interpolated grid. To achieve manageable run times the models need to adopt a relatively coarse grid resolution of five metres and above or 20 metres and above in the case of the regional models. This modelling approach tends to result in numerous fringe, scattered and isolated duration impacts in the following cases which may or may not be real impacts:

- on the fringe of the floodplain where flooding is of shallow depth, of short duration (for example hours rather than days) and over small areas
- In areas where the flood model grid is too coarse to represent small or localised drainage features and pathways that allows the flooded area to drain after the peak of an event. In such cases the models may retain floodwater in low areas where in reality these can drain out through features that are not represented accurately in the models (for example local cane drains).

Figure 4.3 provides a typical example of flood duration change reported in the Mid-Richmond regional flood model. In the figure, the white areas represent a compliant flood duration impact (< 5% increase) and orange and red areas represent non-compliant > five percent and > 10 percent increases in flood duration respectively.

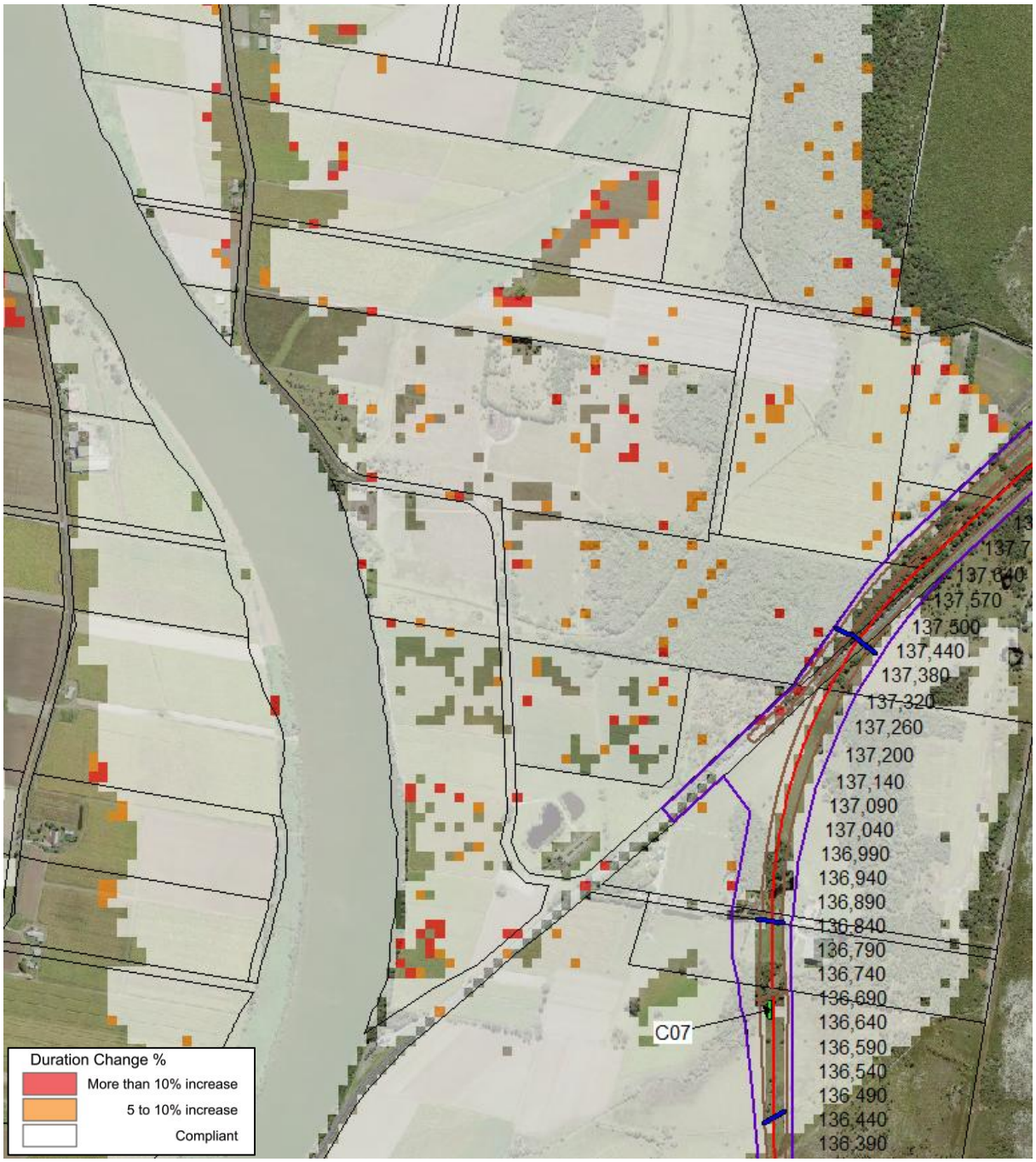

Figure 4.3 Example of fringe, scattered and isolated impacts

This example demonstrates the overall impact on the floodplain meets the flood management objectives for flood duration but there are fringe, scattered and isolated impacts exceeding the objectives. These generally occur on the fringes of the flood extent in areas of shallow depth that are wet in the model for short periods of time.

In this example, the critical duration is the 72 hour event, which produces flood durations generally in excess of 72 hours for the wider floodplain under existing conditions. Durations of less than 72 hours occur along the fringe of the floodplain and at isolated high points/ features in the local topography. At these locations, the depth and duration of flooding can vary significantly from one flood model grid cell to the next. In the future with the Woolgoolga to Ballina upgrade in place, any minor increase in flood level can result in high impacts on the flood duration in these fringe areas or high points, even when the flood level and velocity objectives are met.

The assessment of duration is also limited by the model grid resolution and the level of detail represented. The purpose of the regional scale model is to represent the regional flood behaviour of the Richmond River floodplain.

The models have been designed to include river tributaries and significant land drainage features that govern the distribution of flow across the floodplains. Small land drains are either coarsely represented or, in the case of drains or channels with widths less than a single grid cell, not represented at all.

Coarse representation of minor drainage features does not affect the accuracy of model predictions of peak flood levels and velocities, but may affect the connectivity back to the main river and the ability to accurately represent the drainage of flat areas on the floodplain, and thus overestimate the impact on flood duration. This is exacerbated by the proposed works where local land drainage and other features draining these areas are intercepted by the project earthworks. However, in reality the detailed design preserves these local features via localised channel and cross drainage works which are not necessarily represented well by the flood model grid resolution.

In the regional flood models the areas of fringe, scattered and isolated flood duration impacts are most noticeable for the 5 year event (lowest event modelled), as the floodplain experiences shallow depth disconnected flooding patterns for which the minor land drainage features have more of a significant influence than in other events.

Local catchment models have a higher grid resolution than the regional models (typically using grid resolutions of two to 10 metres rather than 20 to 60 metres), however, they still do not represent all minor land drainage features in the local catchment floodplains. As such similar fringe, scattered and isolated results are obtained.

4.3.2.2 Categorisation of flood duration impacts on cane land

The flood management objectives for the project set the most stringent impact criteria for houses/ urban areas and for cane farm land use. Impacts on houses/ urban areas are generally subject to strict application of the objectives given the sensitivity of these land uses. However, for cane land, the acceptability of flood duration impacts can be assessed against published research relating to flooding impacts on cane crops - refer to the Bureau of Sugar Experiment Stations (BSES) paper 'Managing Flood Damaged Cane'. This paper identifies four days as the time of submergence that will cause damage to cane. Table 4.4 relates cane yield loss to time of submergence based on information provided in the paper (note that the paper does not provide a yield loss estimate for a four day submergence time).

Table 4.4 Flood duration impact on cane yield

Duration of submergence	Percentage yield loss (%)
5 days (120 hours)	15-20%
10 days (240 hours)	30-60%
15 days (360 hours)	37-100%

Source: BSES Paper 'Managing Flood Damaged Cane'

Based on this information, flood duration impacts resulting in total flood durations of up to three days (72 hours) on cane land in future conditions (with the upgrade in place) are assessed as low risk impacts rather than departures. This low risk impact category would apply regardless of the percentage change in flood duration. Therefore, if the flood duration impact on an area of cane land exceeds 10 percent but the total flood duration for that area remains below three days, this is assessed as a low risk impact rather than a departure. The justification for this is a total flood duration of three days under future conditions remains well below the time of submergence that causes damage to cane and loss of yield, and therefore three days is considered to be a conservative threshold for flood duration impacts on cane land.

4.4 Individual property assessment

4.4.1 Above floor level flooding assessment

Above floor level flooding refers to the depth of flooding above floor level in a building. The assessment of above floor level flooding allows for the identification of properties where flooding enters the building on the property, the depth of above floor flooding under existing conditions and the change in the depth of above floor flooding as a result of works in the floodplain.

Survey of floor levels and ground levels for the properties within the floodplain were available from the EIS. Further survey was collected for additional properties identified within the floodplain. For each property, the

existing and proposed flood level was assessed from flood model results. Depth of flooding above the surveyed floor level was assessed at each property. All properties where there would be an increase in above floor level flood depths were identified. The magnitude of the afflux was then assessed in relation to flood management objectives (see section 1.5).

4.4.2 Individual property impacts

Flood impacts at individual properties were assessed on a lot by lot basis against the flood management objectives outlined in section 1.5. This was first assessed through a review of the project flood impact maps against the flood management objectives for:

- flood level change
- velocity and direction change
- flood duration change.

The duration impact assessment described in section 4.3.2 was applied to flood maps to identify areas not meeting flood management objectives. Floor level assessment results were reviewed (section 4.4.1) and a detailed assessment including identification of habitable structures, using aerial photographs and cadastral information, was carried out. This was then verified by site visits and discussions with landowners.

5. FLOOD IMPACT ASSESSMENT

5.1 Overview of project outcomes relating to flooding

This section provides an overview of the outcomes of the project relating to flooding. A more detailed discussion of the flooding impacts is provided in sections 5.2 to 5.6.

5.1.1 Highway flood immunity

The project will improve the current flood immunity of the highway. Through the Richmond regional floodplain various sections of the existing highway are prone to flooding at the 5 year ARI event. The project will provide a flood immunity of between the 20 and the 100 year ARI to the upgraded highway.

5.1.2 Regional flooding impacts

Raised embankments have the potential to cause additional obstruction to the flow and drainage paths which may result in changes to flood behaviour and flow distributions around the upgraded highway, causing increased flood levels and flood durations on adjacent land. These impacts can be mitigated through appropriate design of the new cross drainage infrastructure to provide sufficient additional waterway opening to offset the effect of the flow obstruction caused by the raised highway embankments. The bridge and cross drainage design has been optimised along the project alignment and there are some minor residual effects of the project works that cannot be removed by practical increases in the proposed drainage infrastructure. These are outlined in section 5.2. These residual effects may require works on individual properties or other mitigation measures to be agreed with the affected landowners.

Flood modelling of the Richmond River regional floodplain shows that the project would result in minor changes to flood levels upstream of the proposed embankment and major bridges, including the crossings at Tuckombil Canal and the Richmond River Bridge. Increases in peak flood levels upstream of the project works are considered minor and generally meet the limits set by the flood management objectives in the CoA. Downstream of the works, there are some minor decreases in flood level in the area between Broadwater National Park and Richmond River. Refer to Figures C003 to C014 in Appendix C for the Mid-Richmond model results; and Figures E002 to E009 in Appendix E for the Lower Richmond model results representing a composite of maximum results from hydrological scenario A and B (see section 4.2.4.2).

Under existing conditions, most of the land within the Richmond River regional floodplain is flooded for more than 72 hours for the 20, 50 and 100 year ARI events. For the 5 year ARI event areas around the fringe of the floodplain are flooded for a range of durations from less than six hours up to 72 hours. The project is not expected to result in major changes to the flood duration and overall the change in duration across the regional floodplain is minor and meets the limits set by the flood management objectives (less than five percent increase). Refer to Figures C047 to C054 and E026 to E029. There are some small localised areas within the regional floodplain between Trustums Hill and Richmond River where the flood duration is increased by more than five percent. These are discussed further in section 5.2.3.

The flood modelling demonstrates there would be no noticeable impact on the flow velocity or direction in the regional floodplain areas since velocities and flow directions are dominated by the slow moving and expansive floodwaters from the large Richmond River catchment upstream of the highway.

5.1.3 Urban centres

5.1.3.1 Woodburn

Woodburn is a large urban centre located to the north of the Trustums Hill to Broadwater National Park section between the proposed highway and the Richmond River. The town is located on the river overbank and experiences flooding in all modelled events. For the 20 year ARI flood event the project will result in increases in flood level (afflux) within Woodburn of between 5 and 25 millimetres (see Figure C004 in Appendix C). The afflux for the 100 year ARI event is generally between 25 and 35 millimetres (see Figure C006). The flood management objectives are met for all criteria and for all modelled events in the Woodburn urban area (see Appendix C).

5.1.3.2 Broadwater

The township of Broadwater is located directly upstream of the proposed new Richmond River Bridge. The future bridge crossing spans the majority of the floodplain (with a 972 metre bridge opening – refer to section 1.7) and results in a minor increase in flood levels upstream due to the presence of the bridge piers in the waterway. The increases in flood level are generally between 15 and 25 millimetres in the 20 to 100 year ARI events (see Figures

C003 to C006 in Appendix C). The flood management objectives are met for all criteria and for all modelled events in the Broadwater area (see Appendix C).

5.1.4 Local catchment flooding impacts

5.1.4.1 Devils Pulpit Upgrade to Trustrums Hill

The Devils Pulpit Upgrade to Trustums Hill section incorporates 39 cross drainage structures (comprised of three bridges and 36 culvert groups) to drain the local catchments of Tabbimoble Floodway 1, Oakey Creek and their associated tributaries and overland flow paths. The flood management objectives have not currently been achieved at two of these structures, with the impacts generally related to localised increases in flood level and duration.

5.1.4.2 Richmond River to Coolgardie Road

The Richmond River to Coolgardie Road section incorporates 45 cross drainage structures (comprised of 10 bridges and 35 culvert groups) to drain the local catchments of Bingal Creek, Wardell Floodway 6, Randles Creek and their associated tributaries and overland flow paths. The flood management objectives have not currently been achieved at two of these structures, with the impacts generally related to localised increases in flood level.

5.2 Assessment of impacts against flood management objectives

Flood modelling was carried out for the 5, 20, 50 and 100 year ARI events to assess changes in the key flood parameters addressed by the flood management objectives, i.e. flood level, duration, velocity and flow direction. This section summarises the results for the future conditions based on the mitigation measures that have been tested and adopted. Some areas remain where the flood management objectives have not been achieved, as discussed in the following sections. The figures included in Appendices C and E display the future flooding conditions in terms of flood level, depth, velocity, flow direction, flood duration and flood hazard across the Richmond River regional floodplain for the 5, 20, 50 and 100 year ARI flood events.

5.2.1 Flood level

Tables 5.1 and 5.4 provide the predicted existing and future conditions flood levels at key locations in the Mid-Richmond and Lower Richmond catchments and at key locations for future infrastructure. Figures C003 to C014 show the flood level difference (afflux) across the Mid-Richmond River floodplain and Figures E002 to E009 show the afflux across the Lower Richmond floodplain. The mapping demonstrates that only minor afflux occurs due to the project. The majority of flood level impacts have not exceeded 50 millimetres and therefore meet the flood management objectives for afflux provided in section1.5.

From Trustums Hill to Richmond River the maps show that the afflux is less than 25 millimetres with some localised areas of 25 to 49 millimetres afflux. An area of higher afflux occurs in an area of mixed agricultural and forested land to the north of the Richmond River Bridge in the 50 year ARI event.

Between Broadwater National Park and Richmond River there is a minor decrease in flood levels downstream of the highway. The change in flood level on the downstream side of the highway is in the range of minus one to -50 millimetres. This decrease in flood level is more apparent for the 5 and 20 year ARI events, while for the 50 and 100 year ARI events the change in flood level is less significant.

Between Coolgardie Road and Ballina Bypass the composite afflux maps show that the flood management objectives have generally been met for the modelled events for both hydrological scenarios A and B (refer to section 4.2.4.2 for the description of these scenarios).

Where the afflux objective has been met, the flood level increase is between one and 49 millimetres. It can also be seen that there is a minor decrease in flood levels at some locations in the vicinity of the highway due to the upgrade. The change in flood level is in the range of minus one to -25 millimetres.

There are no afflux departures for the local catchments between Devils Pulpit Upgrade and Trustums Hill. For the local catchments between Richmond River and Coolgardie Road, the afflux meets the objectives for the majority of the floodplain areas, with any departures confined to the higher order events (100 year ARI) and mostly contained within or close to the project boundary or within Roads & Maritime owned land.

5.2.2 Velocity and flood direction

The regional flood model results show that peak velocities in excess of 2m/s occur in the major channels, with slower moving flood flows in the floodplain. The existing floodplain velocities are generally less than 1m/s for all reported events.

Figures C031 to C038 and E018 to E021 show the change in velocity across the Richmond River floodplain as a percentage. Peak velocities in Tables 5.2 and 5.5 demonstrate that there is little to negligible change to the velocities for all reported events. Velocities in excess of 1m/s that occur in the main river along with slower moving flood flows in the floodplain of generally less than 1m/s remain unchanged for all reported events. Due to the large catchment and large flows, the proposed highway upgrade has little effect on the existing flow regime of the Richmond River. All flood management objectives for velocity and flow direction have been met.

Localised velocity increases through bridges and culverts have been addressed by the design of appropriate scour and erosion protection methods.

There are no velocity or flow direction departures for the local catchments between Devils Pulpit Upgrade and Trustums Hill and between Richmond River and Coolgardie Road.

5.2.3 Flood duration – Mid-Richmond

Figures C047 to C054 show the change in flood duration as a percentage in the Mid-Richmond floodplain for the future conditions. Increases in flood duration have the potential to adversely affect the productivity of cane growing land. Table 5.3 provides flood durations under both existing and future conditions at key locations in the Mid-Richmond River catchment and at key locations for future infrastructure.

Between Trustums Hill and Richmond River the flood management objectives for duration have generally been met for most of the area for all four modelled events (5, 20, 50 and 100 year ARI events), however, there are localised areas where the flood duration objectives are not fully met. The duration impacts are most prominent in the 5 year ARI event.

Figures 5.1 to 5.4 show the existing and future conditions flood level hydrographs at key infrastructure locations. While the overall mapping presented in Appendix C shows localised areas of the floodplain where duration has been impacted by the project, the figures demonstrate that the main flood hydrograph in the Mid-Richmond River is not affected by the project. The figures show that the downstream tidal boundary has an effect on the hydrographs at the future Richmond River bridge crossing.

The flood duration objectives are fully met for the local catchments between Devils Pulpit Upgrade and Trustums HIll.

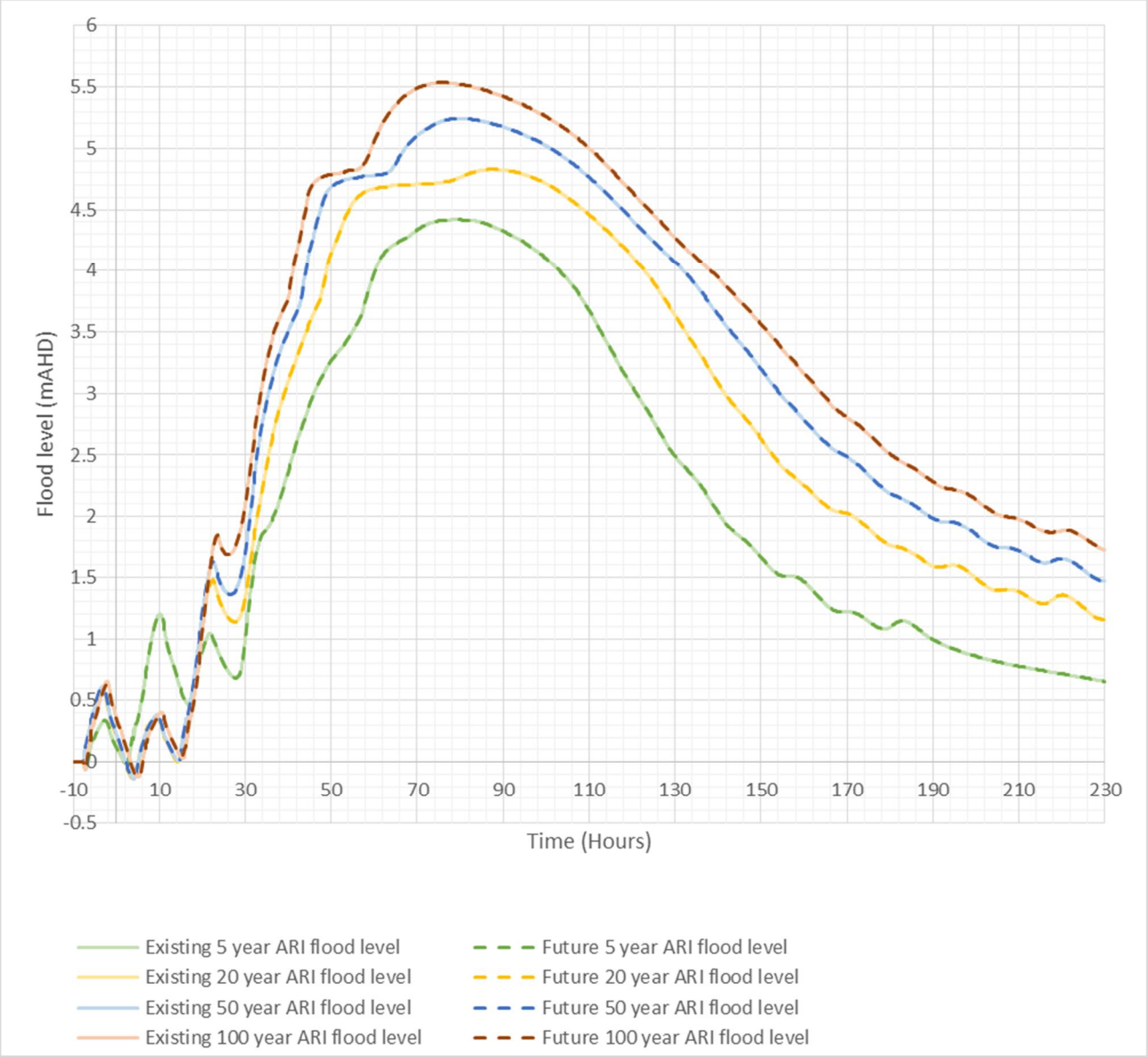

Figure 5.1 Flood level hydrographs at Richmond River at Bungawalbin Junction

(Hydrograph location is at confluence of Richmond River and Bungawalbin Creek between Coraki and the project area)

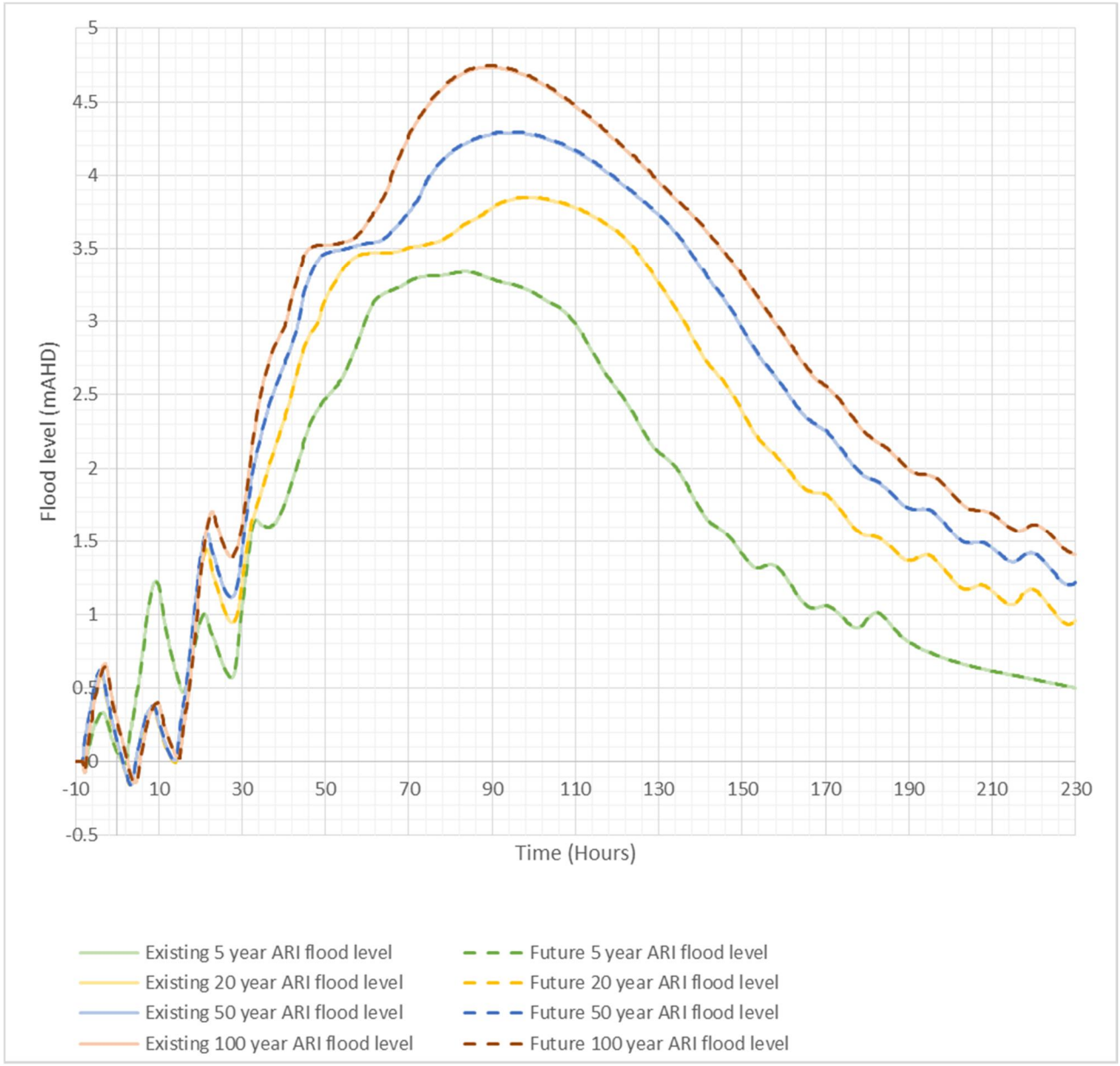

Figure 5.2 Flood level hydrographs at Richmond River upstream of Court St Bridge, Woodburn

(Hydrograph location is at bridge crossing of main Richmond River channel at Woodburn – see Figure 3.2)

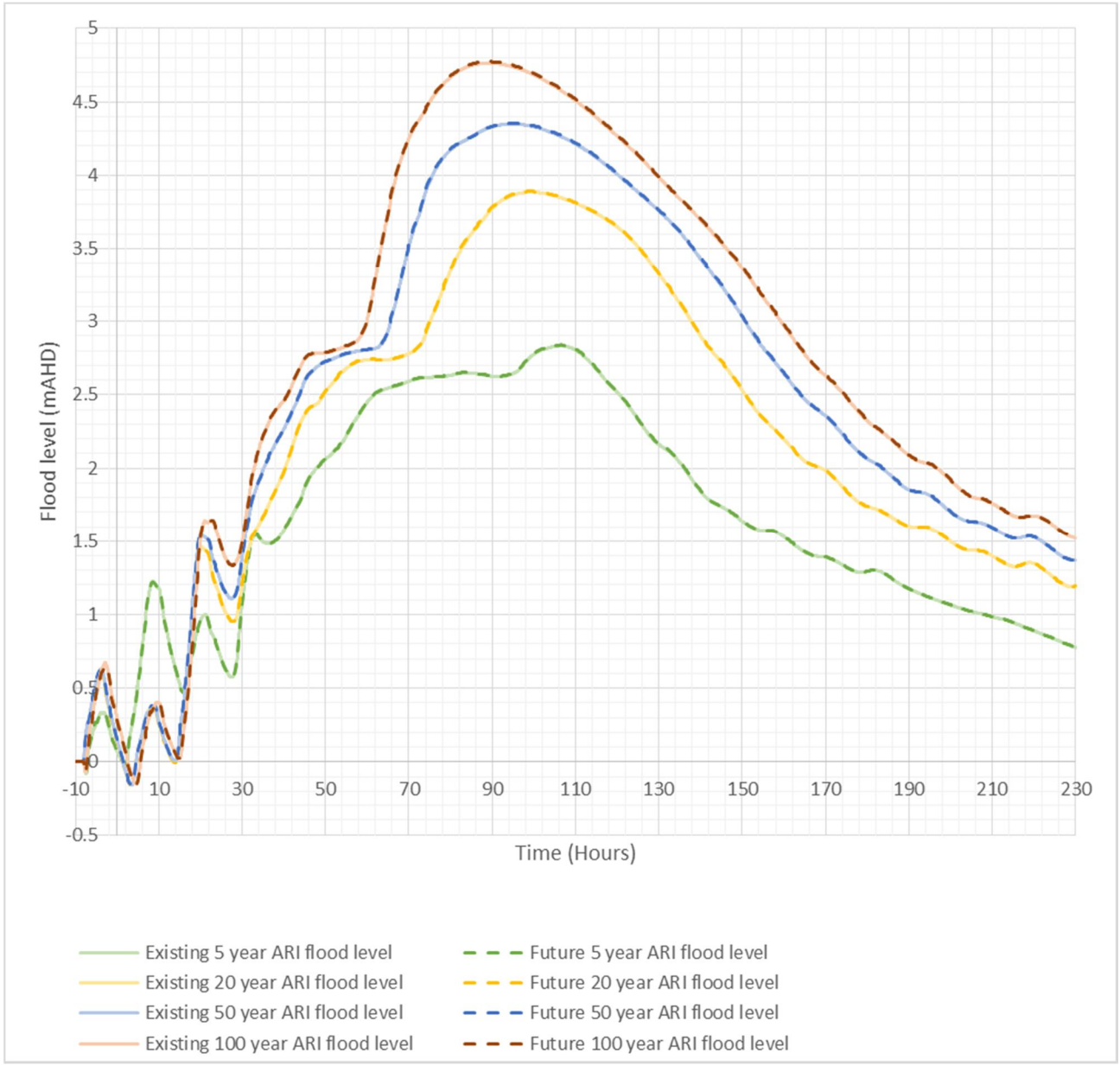

Figure 5.3 Flood level hydrographs at Tuckombil Canal downstream of Existing Pacific Highway Bridge (Hydrograph location is downstream of existing highway crossing of Tuckombil Canal – see Figure 3.1)

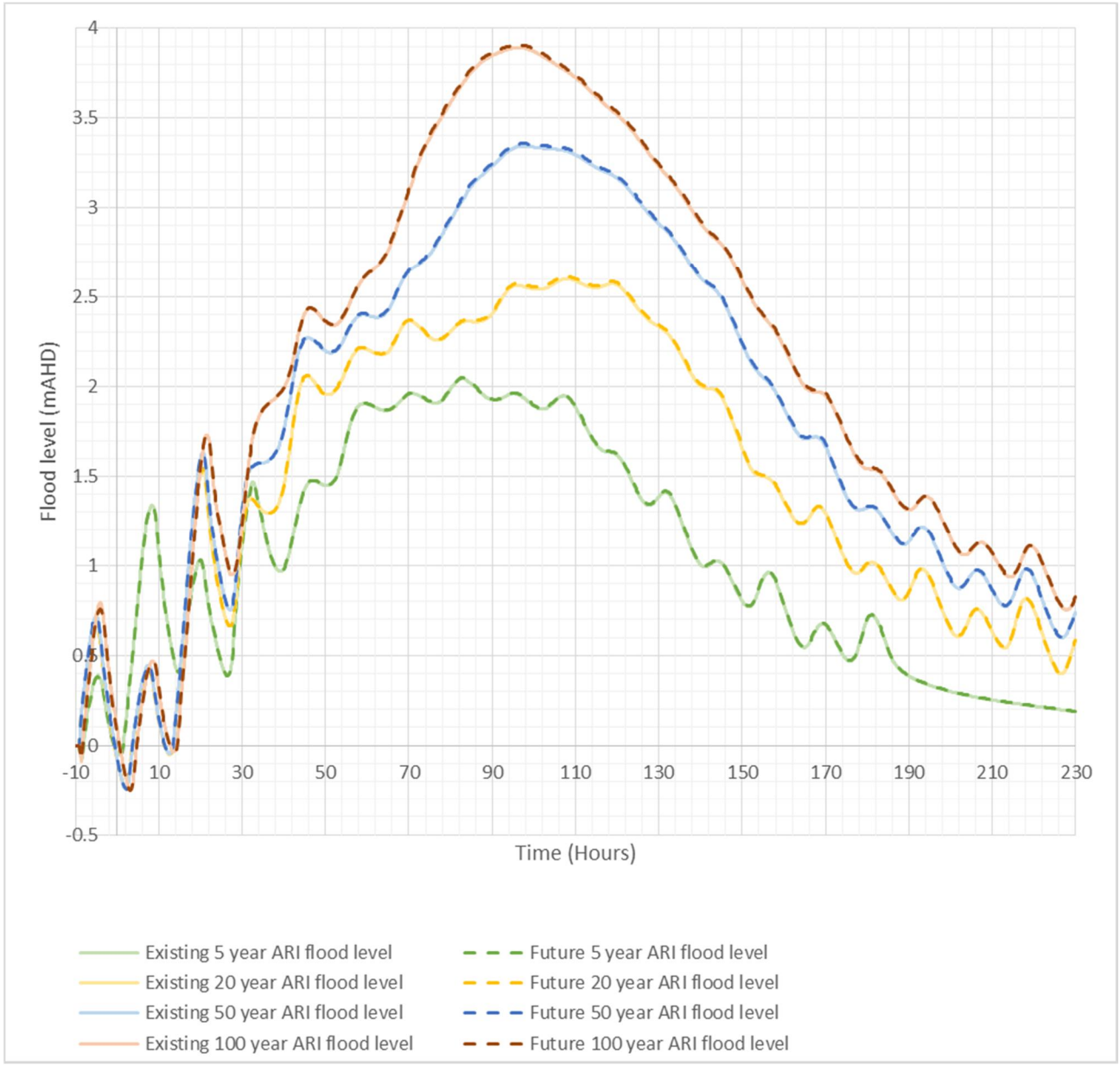

Figure 5.4 Flood level hydrographs at Richmond River upstream of new Pacific Highway Bridge (Hydrograph location is upstream of new highway crossing of Richmond River – see Figure 3.3)

5.2.4 Flood duration – Lower Richmond

Figures E026 to E029 show the percentage change in flood duration in the Lower Richmond floodplain for the future conditions. Increases in flood duration have the potential to adversely affect the productivity of cane growing land. Table 5.6 provides flood durations under both existing and future conditions at key locations in the Lower Richmond River catchment and at key locations for future infrastructure.

Between Coolgardie Road and Ballina Bypass the flood management objectives for duration have been generally met for most of the area for all four modelled events (5, 20, 50 and 100 year ARI events), however there are some localised areas where the flood duration has increased more than the allowable limit. Increases to flood duration are more significant in the 5 and 20 year ARI events in this section.

Figures 5.5 to 5.7 show the existing and future conditions flood level hydrographs at key infrastructure locations. While the overall mapping presented in Appendix E shows localised areas of the floodplain where duration has been impacted by the project, the figures demonstrate that the main flood hydrograph in the Lower Richmond River and the surrounding local catchment tributaries are not affected by the project. The figures show that the downstream tidal boundary has an effect on the hydrographs at all plotted locations.

The flood duration objectives are fully met for the local catchments between Richmond River and Coolgardie Road.

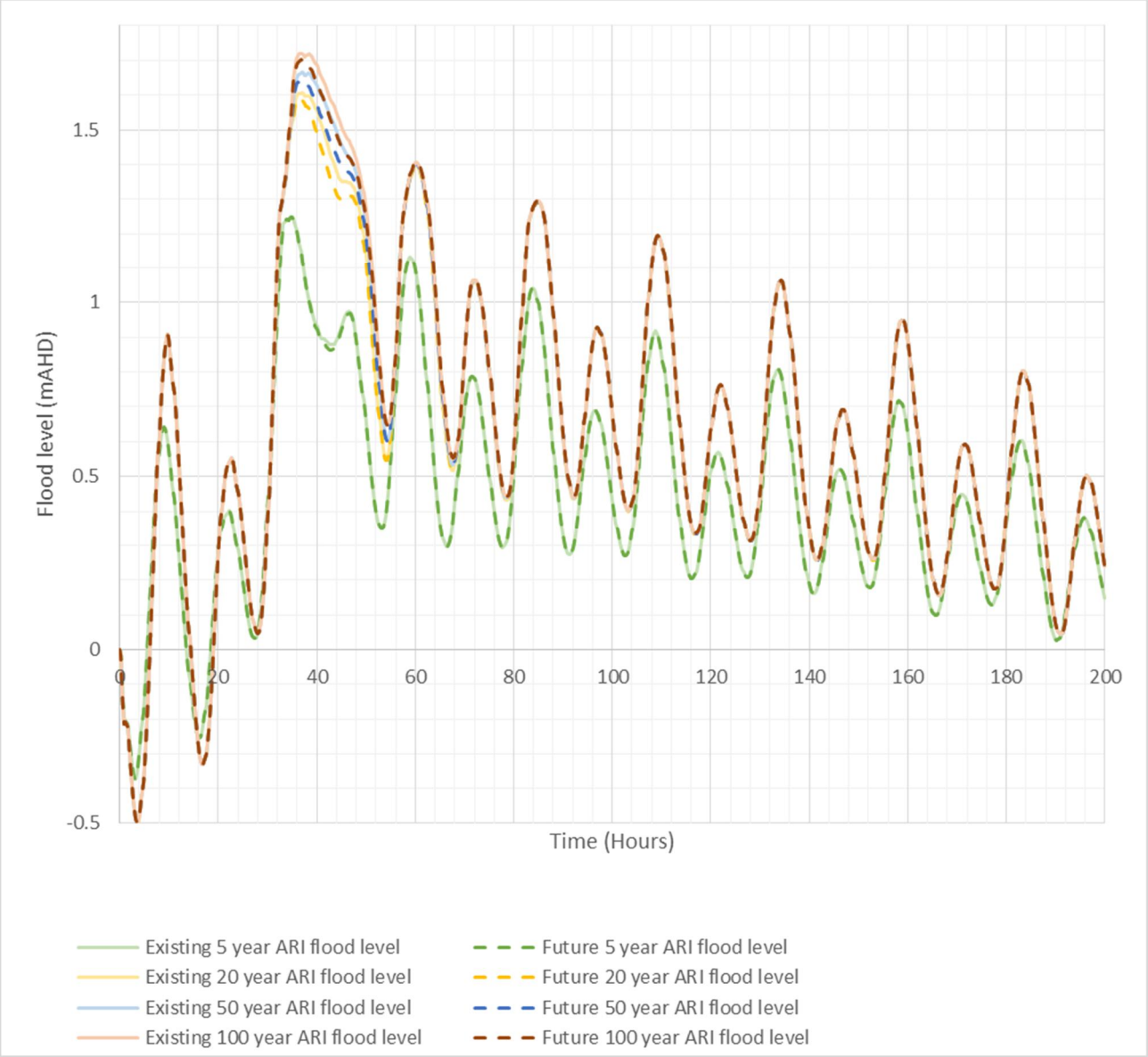

Figure 5.5 Flood level hydrographs at Duck Creek upstream of future Pacific Highway bridge for hydrological scenario B

(Hydrograph location is upstream of creek crossings at Teven Junction – see Figure 3.5)

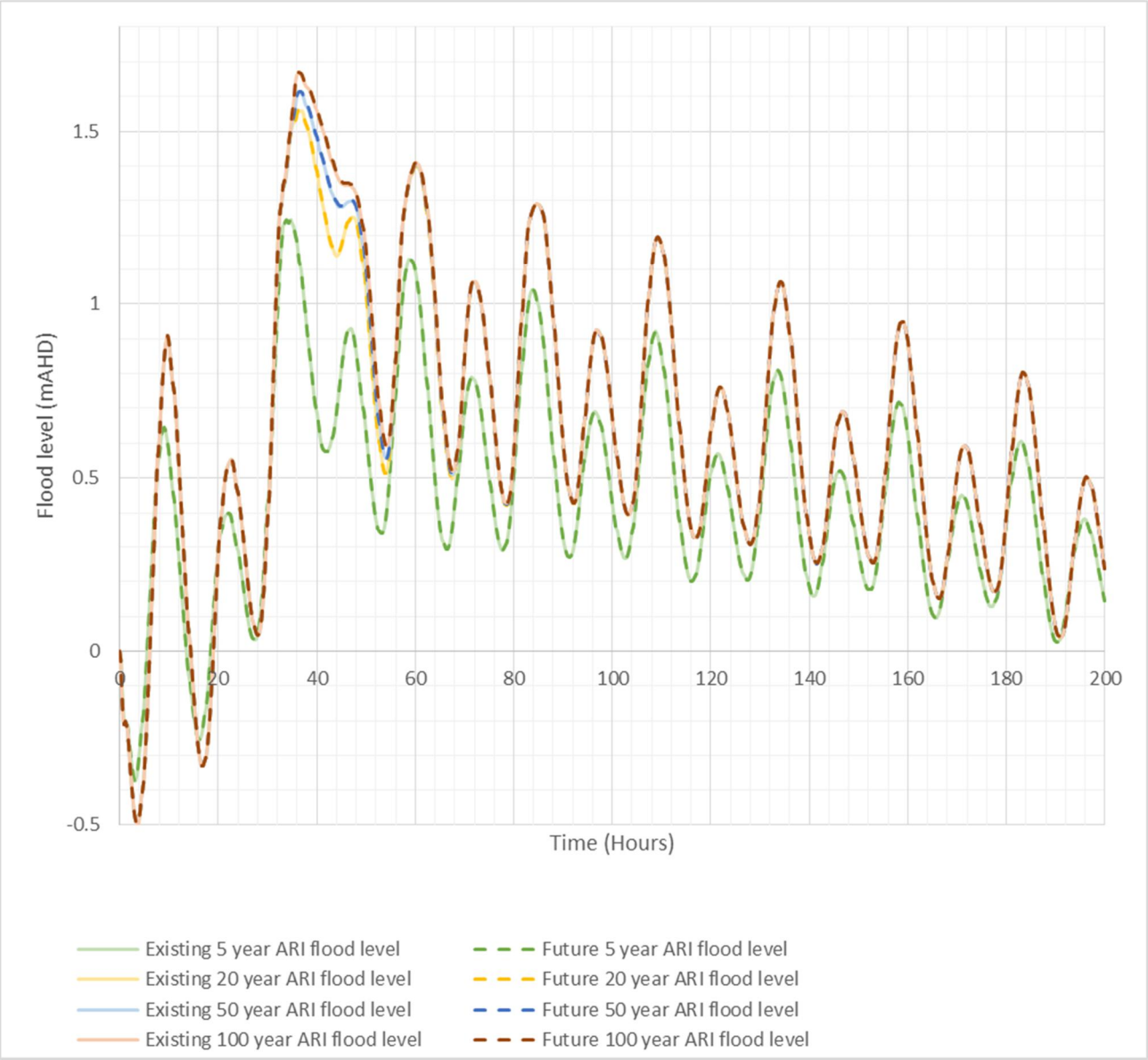

Figure 5.6 Flood level hydrographs at Emigrant Creek upstream of future Pacific Highway bridge for hydrological scenario B

(Hydrograph location is upstream of creek crossings at Teven Junction – see Figure 3.5)

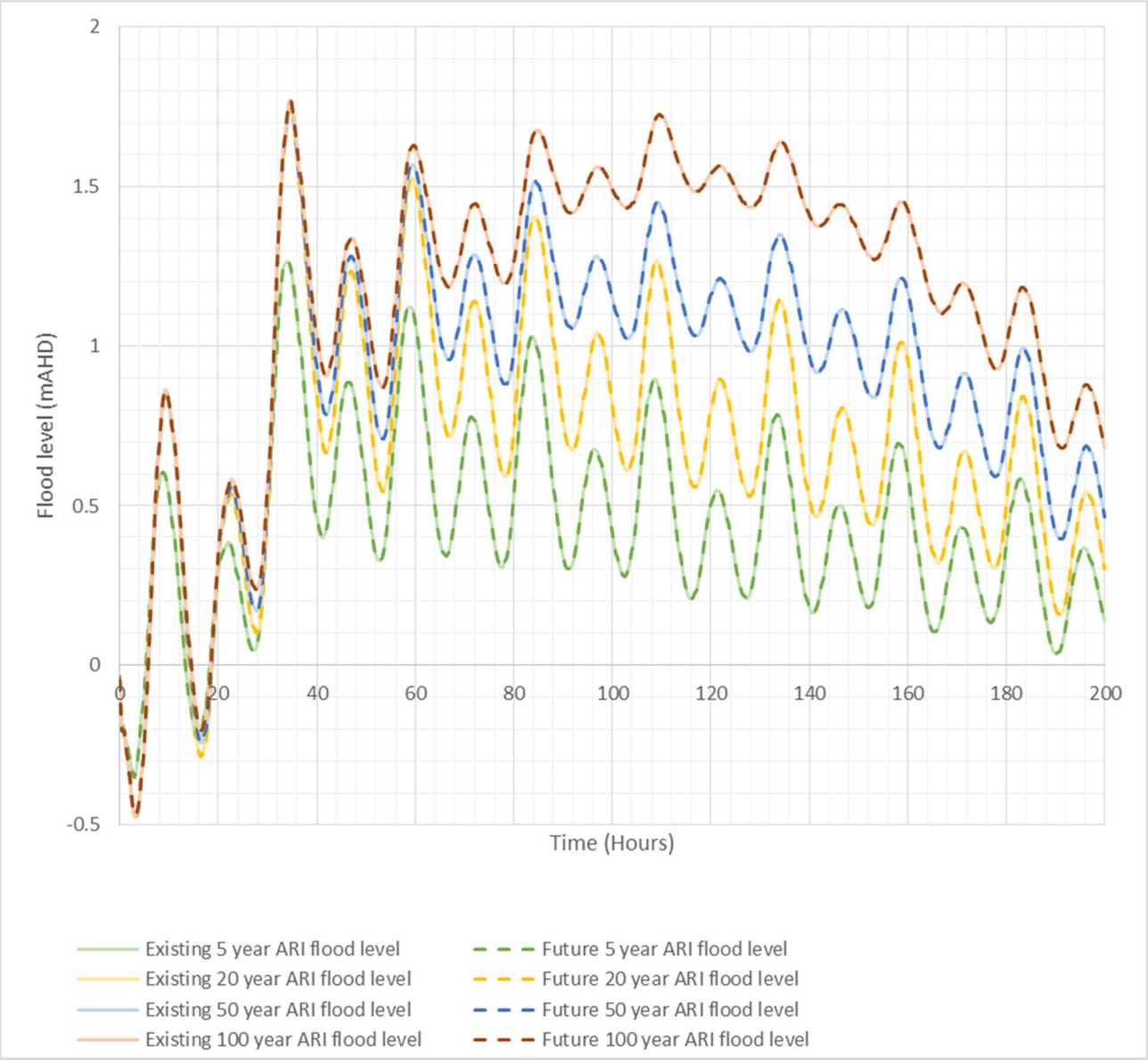

Figure 5.7 Flood level hydrographs at Richmond River at Burns Point for hydrological scenario A (Hydrograph location is downstream of creek crossings at Teven Junction near West Ballina)

Table 5.1 Existing and future conditions results – flood levels at key locations, Mid-Richmond River

Location	05 year ARI			20 year ARI			50 year ARI			100 year ARI		
	Existing	Future	Afflux (mm)	Existing	Future	Afflux (mm)	Existing	Future	Afflux (mm)	Existing	Future	Afflux (mm)
Coraki - (Confluence with Wilsons River) *rr_63.42*	5.391	5.392	1	5.983	5.983	0	6.184	6.184	0	6.351	6.352	1
Bungawalbin Junction *rr_55.20*	4.419	4.420	1	4.828	4.829	1	5.244	5.245	1	5.534	5.536	2
Woodburn - (U/S of Court St Bridge) *rr_42.82br*	3.340	3.341	1	3.847	3.851	4	4.289	4.297	8	4.736	4.746	10
Tuckombil Canal (Existing Pacific Highway Bridge)) *er_0.03br*	2.833	2.839	6	3.885	3.890	5	4.348	4.355	7	4.764	4.773	9
Broadwater (U/S of Broadwater Bridge) *rr_26.75*	2.154	2.157	3	2.723	2.734	11	3.471	3.484	13	4.019	4.033	14
Bagotville (D/S of Bagotville Rd Bridge) *br_4.20*	2.062	2.065	3	2.722	2.734	12	3.560	3.573	13	4.123	4.136	13
Tuckombil Canal (U/S of C04) *er_0.26*	2.491	2.499	8	3.423	3.432	9	4.065	4.075	10	4.576	4.584	8
Woodburn Floodway (U/S of C05)	0.897	0.934	37	3.272	3.276	4	4.057	4.080	23	4.577	4.606	28
Richmond River Bridge (U/S of Portion F) *rr_24.79*	2.045	2.049	4	2.601	2.614	13	3.343	3.358	15	3.893	3.908	15

Table 5.2 Existing and future conditions results – flow velocity at key locations, Mid-Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*
Coraki - (Confluence with Wilsons River) *rr_63.42*	1.00	1.00	0.00	0.0%	1.11	1.11	0.00	0.0%	1.19	1.19	0.00	0.0%	1.25	1.25	0.00	0.0%
Bungawalbin Junction *rr_55.20*	1.59	1.59	0.00	0.0%	1.86	1.86	0.00	0.0%	1.94	1.94	0.00	-0.1%	2.04	2.04	0.00	0.0%
Woodburn - (U/S of Court St Bridge) *rr_42.82br*	1.25	1.24	0.00	-0.1%	1.35	1.35	0.00	-0.1%	1.35	1.35	0.00	-0.2%	1.35	1.35	-0.01	-0.4%
Tuckombil Canal (Existing Pacific Highway Bridge)) *er_0.03br*	1.48	1.47	0.00	-0.3%	1.87	1.86	0.00	-0.3%	2.07	2.06	-0.01	-0.3%	2.19	2.16	-0.02	-1.1%
Broadwater (U/S of Broadwater Bridge) *rr_26.75*	1.33	1.32	0.00	-0.2%	1.46	1.46	0.00	0.1%	1.63	1.63	0.00	-0.2%	1.78	1.78	-0.01	-0.3%
Bagotville (D/S of Bagotville Rd Bridge) *br_4.20*	0.48	0.48	0.00	<1m/s	0.80	0.82	0.02	<1m/s	0.94	0.94	0.00	<1m/s	1.09	1.09	0.00	-0.3%
Tuckombil Canal (U/S of C04) *er_0.26*	1.25	1.26	0.01	1.0%	1.73	1.72	0.00	-0.2%	1.95	1.95	0.00	0.1%	2.05	2.06	0.01	0.3%
Woodburn Floodway (U/S of C05)	0.04	0.01	-0.02	<1m/s	0.17	0.27	0.10	<1m/s	0.32	0.57	0.25	<1m/s	0.41	0.62	0.22	<1m/s
Richmond River Bridge (U/S of Portion F) *rr_24.79*	1.12	1.12	0.00	-0.2%	1.27	1.27	0.00	-0.1%	1.47	1.47	0.00	-0.2%	1.66	1.65	-0.01	-0.4%

*if the velocity remains below 1m/s then the flood impact criteria for velocity is already met

Table 5.3 Existing and future conditions results – flood duration at key locations, Mid-Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)
Coraki - (Confluence with Wilsons River) * *rr_63.42*	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%
Bungawalbin Junction *rr_55.20* *	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%
Woodburn - (U/S of Court St Bridge)* *rr_42.82br*	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%
Tuckombil Canal (Existing Pacific Highway Bridge) * *er_0.03br*	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%
Broadwater (U/S of Broadwater Bridge)* *rr_26.75*	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%
Bagotville (D/S of Bagotville Rd Bridge)* *br_4.20*	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%
Tuckombil Canal (U/S of C04)* *er_0.26*	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%
Woodburn Floodway (U/S of C05)	72.4	71.8	-0.6	-0.8%	123.8	125.2	1.4	1.1%	153.5	155.0	1.4	0.9%	162.0	163.0	1.0	0.6%
Richmond River Bridge (U/S of Portion F) * *rr_24.79*	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%	230	230	0.0	0.0%

*these locations are in the main channels so are always wet for the full model simulation

Table 5.4 Existing and future conditions results – flood levels at key locations, Lower Richmond River

Location	05 year ARI			20 year ARI			50 year ARI			100 year ARI		
	Existing	Future	Afflux (mm)	Existing	Future	Afflux (mm)	Existing	Future	Afflux (mm)	Existing	Future	Afflux (mm)
Regional Flood Event – Scenario A												
Richmond River upstream of Pimlico island rr_14.01	1.397	1.397	0	1.902	1.902	0	2.253	2.253	0	2.735	2.735	0
Duck Creek upstream of Pacific Highway Bridge DC0100	1.233	1.233	0	1.502	1.492	-10	1.588	1.553	-35	1.709	1.707	-2
Emigrant Creek upstream of Pacific Highway Bridge ec_05.71	1.233	1.233	0	1.472	1.471	-1	1.529	1.529	0	1.707	1.706	-1
Richmond River at Burns Point (confluence with Emigrant Creek) rr_6.39	1.265	1.265	0	1.769	1.769	0	1.772	1.772	0	1.770	1.770	0
North of Whytes Lane Overpass on Northbound/Western side (CH160200) H_Interchange	N/A	N/A	N/A	1.642	1.631	-11	1.726	1.709	-17	1.808	1.795	-13
Local Flood Event – Scenario B												
Richmond River upstream of Pimlico island rr_14.01	1.452	1.452	0	1.939	1.939	0	1.948	1.948	0	1.963	1.963	0
Duck Creek upstream of Pacific Highway Bridge DC0100	1.266	1.268	2	1.641	1.602	-39	1.708	1.668	-40	1.762	1.728	-34
Emigrant Creek upstream of Pacific Highway Bridge ec_05.71	1.247	1.247	0	1.559	1.561	2	1.614	1.615	1	1.670	1.671	1
Richmond River at Burns Point (confluence with Emigrant Creek) rr_6.39	1.293	1.293	0	1.794	1.795	1	1.797	1.798	1	1.803	1.804	1
North of Whytes Lane Overpass on Northbound/Western side (CH160200) H_Interchange	1.386	1.406	20	1.808	1.803	-5	1.919	1.916	-3	1.994	2.019	25

Table 5.5 Existing and future conditions results – flow velocity at key locations, Lower Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*
Regional Flood Event – Scenario A																
Richmond River upstream of Pimlico island rr_14.01	1.14	1.14	0.00	0.0%	1.37	1.37	0.00	0.0%	1.54	1.54	0.00	0.0%	1.68	1.68	0.00	0.0%
Duck Creek upstream of Pacific Highway Bridge DC0100	0.93	0.94	0.01	<1m/s	1.03	1.00	-0.03	<1m/s	0.93	0.89	-0.04	<1m/s	0.89	0.86	-0.03	<1m/s
Emigrant Creek upstream of Pacific Highway Bridge ec_05.71	0.43	0.43	0.00	<1m/s	1.06	1.09	0.02	2.4%	1.07	1.10	0.03	2.9%	1.02	1.05	0.03	2.8%
Richmond River at Burns Point (confluence with Emigrant Creek) rr_6.39	1.22	1.22	0.00	0.0%	1.60	1.60	0.00	0.0%	1.92	1.92	0.00	0.0%	2.19	2.19	0.00	0.0%
North of Whytes Lane Overpass on Northbound/Western side (CH160200) H_Interchange	N/A	N/A	N/A	N/A	0.03	0.03	0.00	<1m/s	0.04	0.04	0.00	<1m/s	0.05	0.05	0.00	<1m/s
Local Flood Event – Scenario B																
Richmond River upstream of Pimlico island rr_14.01	1.14	1.14	0.00	0.0%	1.26	1.26	0.00	0.0%	1.26	1.26	0.00	0.0%	1.26	1.26	0.00	0.0%
Duck Creek upstream of Pacific Highway Bridge DC0100	1.02	1.04	0.02	1.8%	1.00	0.97	-0.03	<1m/s	0.97	0.95	-0.02	<1m/s	0.93	0.93	0.00	<1m/s
Emigrant Creek upstream of Pacific Highway Bridge ec_05.71	0.66	0.66	0.00	<1m/s	1.28	1.31	0.03	2.5%	1.41	1.44	0.04	2.6%	1.48	1.51	0.03	2.2%
Richmond River at Burns Point (confluence with Emigrant Creek) rr_6.39	1.21	1.22	0.00	0.1%	1.42	1.42	0.00	0.0%	1.42	1.42	0.00	0.0%	1.42	1.42	0.00	0.0%
North of Whytes Lane Overpass on Northbound/Western side (CH160200) H_Interchange	0.03	0.04	0.01	<1m/s	0.07	0.10	0.02	<1m/s	0.11	0.13	0.02	<1m/s	0.14	0.14	0.00	<1m/s

*if the velocity remains below 1m/s then the flood impact criteria for velocity is already met

Table 5.6 Existing and future conditions results – flood duration at key locations, Lower Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)
Regional Flood Event – Scenario A																
Richmond River upstream of Pimlico island* * rr_14.01	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
Duck Creek upstream of Pacific Highway Bridge * DC0100	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
Emigrant Creek upstream of Pacific Highway Bridge * ec_05.71	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
Richmond River at Burns Point (confluence with Emigrant Creek) * rr_6.39	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
North of Whytes Lane Overpass on Northbound/Western side (CH160200) H_Interchange	N/A	N/A	N/A	N/A	12.25	11.75	-0.5	-4.1%	119.75	119.75	0.0	0.0%	159.25	159.5	0.3	0.2%
Local Flood Event – Scenario B																
Richmond River upstream of Pimlico island* * rr_14.01	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
Duck Creek upstream of Pacific Highway Bridge * DC0100	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
Emigrant Creek upstream of Pacific Highway Bridge * ec_05.71	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
Richmond River at Burns Point (confluence with Emigrant Creek) * rr_6.39	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%	200	200	0.0	0.0%
North of Whytes Lane Overpass on Northbound/Western side (CH160200) H_Interchange	13.75	13.75	0.0	0.0%	36.25	35.75	-0.5	-1.4%	38.5	39.25	0.8	1.9%	42.25	42.5	0.3	0.6%

*these locations are in the main channels so are always wet for the full model simulation

5.3 Individual property assessment

5.3.1 Above floor level flooding assessment

5.3.1.1 Mid-Richmond floodplain

The flood management objective relating to flood level at residences allows up to 50 millimetre increase in flooding (afflux). Table 5.7 identifies the properties located in the Mid-Richmond floodplain and the number of properties affected by increases in above floor level flooding.

The table shows that no properties will experience above floor level flooding increases of more than 50 millimetres. These results are based on the design at the time of writing this report and will be updated as required, if results change.

Table 5.7 Afflux impact at properties that are flooded above floor level in the Mid-Richmond floodplain

Impact range (millimetres of above floor flooding)	Number of properties			
	5 year ARI	20 year ARI	50 year ARI	100 year ARI
Not flooded	845	764	635	501
Less than 25 millimetres	6	86	216	323
25 to 49 millimetres	0	1	0	27
50 to 249 millimetres	0	0	0	0
250 to 400 millimetres	0	0	0	0
More than 400 millimetres	0	0	0	0

5.3.1.2 Lower Richmond floodplain

Table 5.8 identifies the properties located in the Lower Richmond floodplain and the number of properties affected by increases in above floor level flooding. No properties were identified to have increased above floor level flooding by more than 25 millimetres. These results are based on the design at the time of writing this report and will be updated as required, if results change.

Table 5.8 Afflux impact at properties that are flooded above floor level in the Lower Richmond floodplain

Impact range (millimetres of above floor flooding)	Number of properties			
	5 year ARI	20 year ARI	50 year ARI	100 year ARI
Not flooded	4,233	4,108	4,099	4,061
Less than 25 millimetres	11	136	145	183
25 to 49 millimetres	0	0	0	0
50 to 249 millimetres	0	0	0	0
250 to 400 millimetres	0	0	0	0
More than 400 millimetres	0	0	0	0

5.3.2 Individual property impacts

More than 200 configurations of bridge and flood relief culverts were modelled in the Richmond River floodplain and, while objectives have been met across the majority of the floodplain, there are some localised areas where it is not possible to fully achieve the objectives using reasonable and feasible bridge and flood relief culvert infrastructure.

Waterway openings have been optimised along the alignment and in most cases further adjustment to the waterway openings did not improve the impacts to a significant degree. In line with CoA B33, the project team has been working with individual stakeholders to address instances where we have been unable to achieve all of the flood management objectives.

Table 5.9 summarises the number of privately owned lots at which the flood management objectives are not fully achieved.

Table 5.9 Privately owned lots that have departures from the flood management objectives

Project section	Number of privately owned lots with flooding departures		
	Afflux	Duration	Velocity
Devils Pulpit Upgrade to Trustrums Hill	0	0	0
Trustrums Hill to Broadwater National Park	1	0	0
Broadwater National Park to Richmond RIver	1	1	0
Richmond River to Coolgardie Road	3	0	0
Coolgardie Road to Ballina Bypass	0	0	0

There is a relatively low number of lots throughout the Richmond River regional floodplain and local catchments that experience departures from the flood management objectives. These departures are not predicted to have significant impacts on the use or productivity of the land.

The number of habitable structures subject to flooding departures has also been assessed and is presented in Table 5.10.

Table 5.10 Habitable structures that have departures from the flood management objectives

Project section	Number of habitable structures with flooding departures		
	Afflux	Duration	Velocity
Devils Pulpit Upgrade to Trustrums Hill	0	0	0
Trustrums Hill to Broadwater National Park	0	0	0
Broadwater National Park to Richmond RIver	0	0	0
Richmond River to Coolgardie Road	0	0	0
Coolgardie Road to Ballina Bypass	0	0	0

5.4 Utilities assessment

Flooding impacts on existing utilities and new utilities have been assessed. The utilities design has taken into account flood risk and new or modified utilities are generally located away from flood prone areas. Where utilities could not be located out of flood prone areas they have been designed to be resilient to flooding.

5.5 Access and infrastructure

In all locations the upgraded highway will provide more efficient and reliable flood evacuation routes since the flood immunity is being improved. Local access roads and property access have retained current or been provided higher flood immunity. The project will not adversely affect key flood access routes and will

improve flood access and evacuation within the floodplain. Access out of the Richmond River regional floodplain and the surrounding local catchments is mainly by the existing Pacific Highway and a number of local access roads connecting to the highway.

5.5.1 Time of highway closure

The project will provide a flood immunity of 100 year ARI through most of the Richmond River floodplain, with localised sections of 20 year ARI immunity, which will reduce the frequency and time of closure of the highway during large floods.

As discussed in section 3.2, some areas of the existing highway through the Richmond regional floodplain currently have a flood immunity of less than the 20 year ARI event. The portion of existing Pacific Highway that runs along the south eastern floodplain of the Richmond River connecting the urban centres of Woodburn and Broadwater is estimated to have a flood immunity of between a 5 and 10 year ARI event, and less than 5 year ARI flood immunity in localised sections. North of Broadwater the existing Pacific Highway is estimated to overtop during a 5 year ARI event between Broadwater and the intersection with Boundary Creek Road. Road closures of several days to weeks could be experienced as result of regional flooding. Additional time is also usually required to inspect the road before it can be reopened to traffic.

Figure 5.5 shows during a 5 year ARI event, the lowest part of the highway between Woodburn and Broadwater would be inundated for about 25 hours. During a 20 year ARI event, this part of the highway would be closed for about 85 hours (over three days). The figure shows that the lowest point of the upgraded highway would be flood free for these two events. For the higher order events (50 and 100 year ARI), the existing highway would be closed for up to five days. This closure time is reduced significantly to about three days for the upgraded highway.

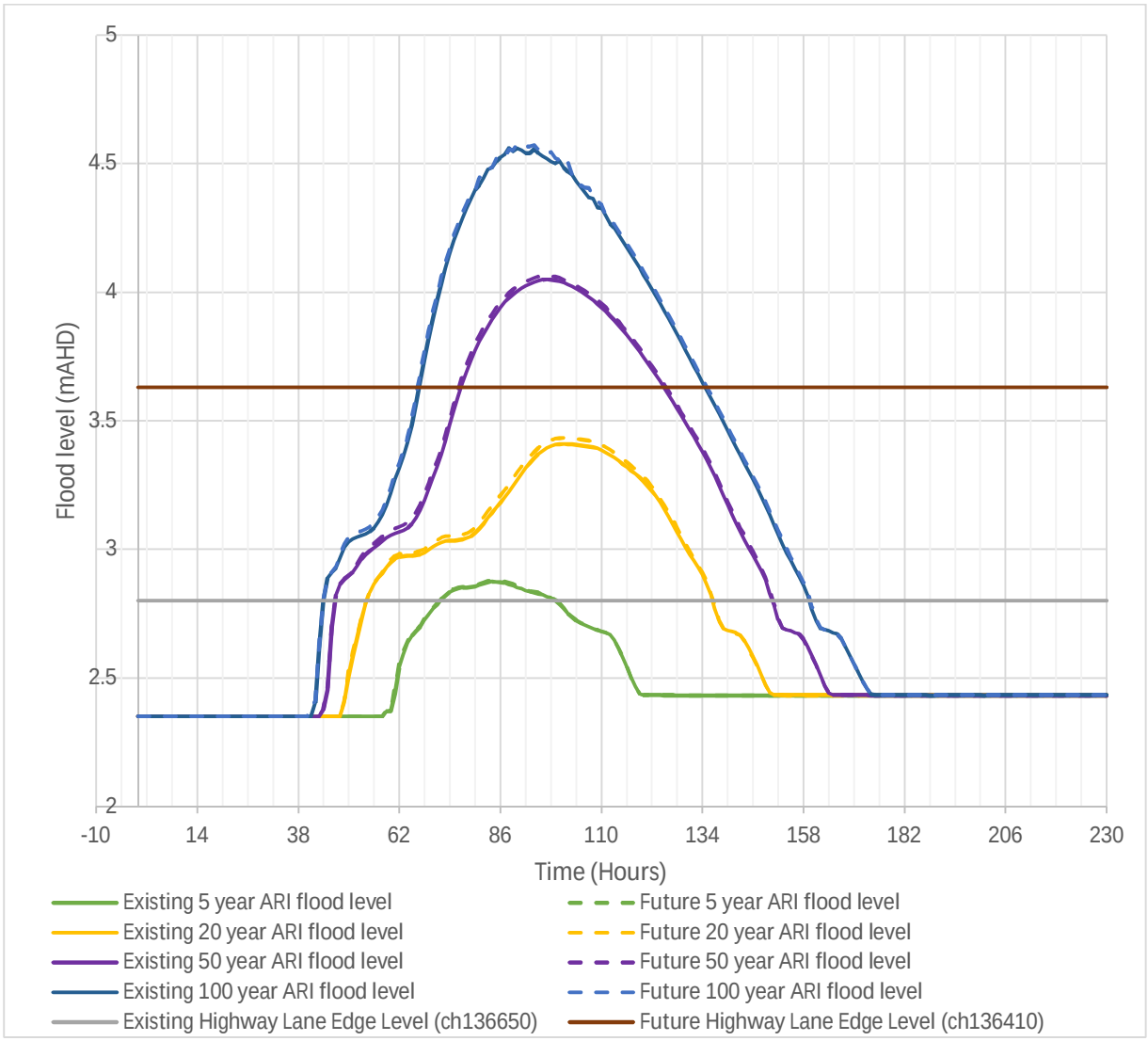

Figure 5.8 Inundation time for existing and future Pacific Highway - at lowest point of existing highway between Woodburn and Broadwater

5.5.2 Local access and property access assessment

Service roads connecting to the upgraded highway will be designed to retain or improve existing flood immunity. Local and property access is assessed as part of the individual property assessments and any associated departures or issues are included in the discussion in section 5.3.

5.5.3 Flood hazard

Flood hazard is the hazard due to flooding that has the potential to cause damage to the community. Flood hazard is typically represented numerically as the product of flood depth and flood velocity (i.e. depth x velocity). The following flood hazard categories have been adopted for this project:

- low flood hazard is < 0.4 m^2/s
- significant flood hazard is in the range 0.4 to 0.6 m^2/s
- extreme flood hazard is > 0.6 m^2/s

The majority of the regional floodplain experiences low hazard flooding with areas of higher hazard generally isolated to the main channels. Some isolated areas of higher hazard occur close to the main

channels in the more extreme 50 and 100 year ARI events. Figures C055 to C062 and E018 to E021 demonstrate that the flood hazard categories in the regional floodplain with the upgrade in place are generally unchanged from existing conditions for all reported events. Due to the large catchment and large flows, the highway upgrade has little effect on the existing flow regime of the Richmond River. Since the velocities remain unchanged and there are minor differences in flood level, the flood hazard due to the project remains unchanged. Similar results are seen in the local catchments, with only localised changes in flood hazard occurring in areas where velocity changes occur.

5.6 Sensitivity analyses

5.6.1 Climate change

The EIS considered the projects potential impacts under future climate scenarios. In accordance with the project's Conditions of Approval, further investigation into climate change is currently being carried out and the outcomes of this assessment will be included in an addendum to this report.

5.6.2 Future highway widening

The project team is carrying out an assessment of the impact of future widening of the upgraded highway, particularly lengthening of bridges and cross drainage culverts in the direction of flow. The outcomes of this assessment will be included in an addendum to this report.

6. MITIGATION MEASURES

6.1 General mitigation measures

6.1.1 Design refinements for flooding

The detailed design process is an opportunity to incorporate innovation, and wherever possible, reduce impacts. During detailed design additional studies were carried out to ensure all constraints and opportunities were considered. A number of design refinements have been incorporated to further reduce flooding impacts.

A key design refinement was replacing culverts with bridges. The benefits of this include:

- providing additional and larger flood openings in the road to accommodate flood flows
- strategic placement of openings at primary flow locations providing structures less susceptible to weather damage
- enabling a reduced recovery period after weather events
- providing better access and reducing maintenance required
- offering increased certainty of design performance and design life.

6.1.2 Infrastructure option testing

Numerous design innovations and value engineering options were tested in the flood model. Mitigation option testing was also carried out to remove or reduce the remaining areas of flood impact, and to test options for improved cross drainage configurations suggested by local landowners. Overall, the Richmond River flood modelling assessed over 200 configurations of bridge and flood relief culvert infrastructure across the Richmond floodplain in an attempt to achieve the flood management objectives using economically feasible infrastructure. Various configurations, design innovations and mitigation options that were tested/adopted are listed below:

- bridge length increased at Tuckombil Canal to allow local road access under the bridge and set abutments back from the canal embankments
- rationalise number of culverts and position, with consideration of landowner requirements and access track requirements for farm machinery and stock movement
- modification of bridge opening (lengthening and shortening) configurations as requested by local landholder and nearby culvert banks adjusted accordingly
- modifications to bridge configurations to reduce fill requirements and use of alternate plank arrangement to minimise flooding impacts
- small local earthworks added to Roads and Maritime owned land to reduce flooding impacts on private land
- diversion channel design scenarios tested within the project boundary and within adjacent cane drain network to reduce duration impacts between Trustums Hill and Broadwater National Park
- multi-cell box culverts converted to bridge option due to design considerations such as constructability, timeframe and soft soil between Trustums Hill and Broadwater National Park
- option to lower alignment with agreement from local stakeholders to reduced bridge clearances for the Tuckombil Canal; required road flood immunity of 20 year ARI maintained but reduced embankment height led to a reduction in flood impacts in 50 and 100 year ARI events
- conversion of multiple culverts to bridge option to meet Oxleyan Pygmy Perch (OPP) (endangered fish species) requirements for fish passage between Trustums Hill and Richmond River
- option to combined Broadwater viaduct (at chainage 145110) with the Richmond River Bridge to provide a single bridge opening at this location to meet condition B43 as set out in the CoA
- test of multiple design options to vertical alignment of access ramps in front of bridge openings to minimise flood impacts upstream of ramps within the floodplain

- modelling of multiple design scenarios for 5 year ARI and 20 year ARI to determine relative impacts for optimum infrastructure configurations for a range of pipe sizes, shapes and arrangements at sensitive locations.

6.1.3 Optimised bridge and cross drainage infrastructure

Cross drainage infrastructure including culverts and bridges have been improved during the detailed design process to result in optimal waterway openings along the alignment. The cross drainage recommended in the EIS and SPIR has been carried through the various design processes. Additional cross drainage infrastructure has been included in the design to achieve the flood management objectives as far as possible for cane land and agricultural land, as well as property and local road access. The additional infrastructure has been designed as floodplain relief structures (part of cross drainage structures) with associated scour protection.

Table 6.1 below summarises the development of the design and changes to the total floodplain waterway opening width since the SPIR stage. Note that the totals provided in the table are for flood relief structures only, and do not include some minor cross drainage structures that have been provided to maintain cane drain connectivity across the highway, or to connect small local drainage catchments. The overall waterway opening width has increased from the SPIR stage due to a number of factors, including:

- improved outcomes for OPP fish passage requirements
- provision of improved access for landowners
- replacement of banks of box culverts with bridges for improved constructability in soft soils and improved mitigation of flood impacts on adjacent land.

Table 6.1 Comparison of waterway opening width (m)

DESIGN STAGE	DEVILS PULPIT UPGRADE TO TRUSTUMS HILL TOTAL WATERWAY WIDTH (M)	TRUSTUMS HILL TO BROADWATER NATIONAL PARK TOTAL WATERWAY WIDTH (M)	BROADWATER NATIONAL PARK TO RICHMOND RIVER TOTAL WATERWAY WIDTH (M)	RICHMOND RIVER TO BALLINA BYPASS TOTAL WATERWAY WIDTH (M)
SPIR	176	435	890	314
Detailed Design	187	601	1,016	338

6.2 Mitigation of impacts on private property

6.2.1 Land drainage improvements

In addition to the general mitigation measures outlined in the previous section, in some cases local drainage improvements may be required on private land where additional flood mitigation infrastructure provided through the proposed work does not change the flood outcome. In these areas, options for improved land drainage in consultation with the local landowner may include:

- upgrading the existing land drainage network to maintain connectivity of low flows and improve drainage time
- removing debris, blockages and vegetation to reinstate or improve flow paths
- upgrading or replacing flood-gated outlets to improve drainage back to the Richmond River.

Other land drainage improvements are required to be discussed with landowners and then tested and investigated hydraulically before being progressed. Investigations into land drainage improvement work on private land are ongoing in areas where flooding departures have been identified.

6.2.2 Schedule of departures and mitigation measures

Table 6.2 provides a current schedule of departures from the flood management objectives on private land and associated mitigation measures. The departures and mitigation measures are subject to ongoing consultation and investigation.

Table 6.2 Schedule of departures from flood management objectives on private land and associated mitigation measures

ID	ITEM	CHAINAGE	DEPARTURES			LOTS AFFECTED	MITIGATION MEASURES / NEXT ACTIONS	CONSULTATION COMMENCED?	AGREEMENT REACHED?
			AFFLUX	VELOCITY	DURATION				
1	Cross drainage culverts: CL-135210, CL135160	135000	20 year ARI event	None	None	Lot 104 DP755624 (Roads and Maritime owned land) Lot 6 DP755624 (Roads and Maritime owned land)	Consult with Roads and Maritime Property	Yes	Acceptance in principle, subject to further consultation
2	Cross drainage culvert: CL-136820	137000	None	None	5, 20, 50 and 100 year ARI events	Lot 133 DP839607 (Roads and Maritime owned land)	Consult with Roads and Maritime Property	Yes	Acceptance in principle, subject to further consultation
3	Cross drainage culvert: CL-147213	147200	50 year ARI event	None	None	Lot 232 DP755691 Lot 6 DP843369 (Roads and Maritime owned land)	Mitigation not possible as impact is due to loss of floodplain storage. Discussed with landowner who has accepted the impact in principle – further consultation required to explain the details of the impact	Yes	No
4	Bridge D04	149240	100 year ARI event	None	None	Lot 2 DP1192234, Lot 268 DP727428	Additional cross drainage options have been tested but impact is subject to change due to ongoing quarrying activities on the land that are changing the landform. Latest landform to be modelled and departure to be reviewed against new modelling results.	Subject to further investigation	Subject to further investigation
5	Bridge D10	157870	5, 20, 50 and 100 year ARI events	None	None	Lot 1 DP1074389 (Roads and Maritime owned land) Lot 2 DP1072389 (Roads and Maritime owned land)	Options to remove departure have been tested which concluded that only feasible mitigation is channel diversion which would have adverse impacts on local ecology. Proposal is to accept departure for flooding to avoid ecological disturbance. Further consultation with RMS Property is required.	Yes	Acceptance in principle, subject to further consultation

6.3 Mitigation of impacts on access

In all locations the upgrade will provide more efficient and reliable flood evacuation routes since the flood immunity is being improved by the upgrade. Local access roads and property access have been provided a higher flood immunity. Therefore the project will improve flood access and evacuation along the upgraded highway and connecting local roads.

The NSW State Emergency Service (SES) has been provided with information regarding the flood modelling process, the predictions of flood behaviour and the changed floodplain conditions.

SES will be provided with the results from the final updated flood model, incorporating the final design, and the flood modelling team will facilitate the SES processes in updating their flood datasets and parts of their emergency response plans that rely on this data.

6.4 Scour protection measures

Industry standard scour protection measures have been provided at cross drainage structures to avoid scouring and erosion of land through and adjacent to the structures. This typically takes the form of rock protection at culvert inlets and outlets and around bridge abutments and piers. Detailed design of the scour protection measures has been carried out using the results from the regional and local catchment flood models.

6.5 Ongoing maintenance

The majority of the project's drainage and flooding infrastructure is on Roads and Maritime owned land. Roads and Maritime will be responsible for maintenance of any drainage and flood mitigation work on Roads and Maritime owned land. Following commissioning of the project, Roads and Maritime will adopt the maintenance diaries developed by the project team of the design packages for cross drainage, bridges and flood mitigation work. These maintenance regimes will ensure the drainage and flood mitigation work will function as intended during flood events and will be repaired / reinstated as required following large events.

Work carried out on local roads for construction will be maintained by the contractor for the duration of construction. Once construction is complete, the maintenance of the roads will become the responsibility of the local Council. Flood mitigation work would be carried out on private property, as required, after which the responsibility of maintaining this work would be passed to the landowner.

7. CONCLUSIONS AND FURTHER WORK

7.1 Conclusions

This report has described the flood modelling and impact assessment process carried out between Devils Pulpit Upgrade and Ballina Bypass of the Woolgoolga to Ballina Pacific Highway upgrade; the outcomes of the impact assessment process; the impact mitigation measures already incorporated into the design; and those still under investigation.

The upgrade will provide a higher standard of flood immunity to the local community along key access and evacuation routes.

The regional catchment and local catchment flood modelling has assessed over 200 configurations of bridge and flood relief culvert infrastructure across the Richmond River floodplain, taking into account feedback from landholders, design developments and improvements to deliver a design that achieves the flood management objectives for the project over the majority of the floodplain.

Where practical flood mitigation measures have not been able to achieve the flood management objectives, the residual flood impacts have been identified as low risk impacts or departures from the objectives. Generally these departures are marginal exceedances of the impact limits or constitute scattered and isolated effects along the fringes of the floodplain that do not affect the function of the land. Of about 49 kilometres of road alignment located within one of Australia's largest and complex floodplains, a very low number of properties experience a departure from the flood management objectives. These departures have been the focus of detailed investigation and landholder consultation is ongoing in some cases and subject to review following the assessment of the final detailed design.

Positive outcomes for the flood modelling process have been achieved through consultation with DPE, Council, SES, landowners and residents including:

- minimising adverse environmental and property impacts as far as practicable
- improving access for emergency management and evacuation
- no adverse impact to existing infrastructure
- equitable community outcomes including:
  - engaging affected landowners and residents in a fair and consistent manner
  - open and honest communication and consultation with government agencies, affected landowners and residents.

The mitigation measures proposed in this report are considered adequate to manage the flooding impacts of the Woolgoolga to Ballina upgrade and to meet the conditions of approval.

7.2 Further work

This report reflects the design at the April 2017 stage of the program and includes the road alignment, channel earthworks, cross drainage and bridge designs at various levels of design development. Generally, this point in the program reflects the substantial detailed design stage for infrastructure within the Richmond regional floodplain between Devils Pulpit Upgrade and Ballina Bypass. The flood model will be updated once the final detailed design is complete.

Assessment of any changes to the design at the issued for construction stage and beyond will continue to be reported and addenda to this document released as required.

Testing of flood impact mitigation measures will also continue to be subject to review by the independent hydrologist WMAwater, in parallel with further consultation with affected landowners.