Woolgoolga to Ballina Pacific Highway upgrade

Hydrological Mitigation Report Devils Pulpit to Ballina

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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.
ARR	Australian Rainfall and Runoff – a guide to flood estimation by Engineers Australia.
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. Week 20 chainage refers to the point in the design program when the chainage was frozen for reference purposes.
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.
CSIRO	Commonwealth Scientific and Industrial Research Organisation
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.
DPIE	NSW Department of Planning, Industry and Environment (formerly 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.

Term	Explanation
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
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 significant tributaries of the Richmond and Clarence Rivers:

- Devils Pulpit Upgrade to Trustums Hill. This section crosses the floodplains of Tabbimoble Floodway 1 and Oakey Creek. This section crosses tributaries of the Clarence and Richmond River catchments.
- 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 has addressed the outcomes to manage and mitigate potential impacts on landowners upstream and downstream of the project.

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

- the pre-construction and built flood conditions
- the modelling methodology used to define the flood conditions
- the flood impact mitigation works
- the role of the independent hydrologist appointed to the project to review and independently verify the flood modelling analyses carried out by the Woolgoolga to Ballina upgrade team, and the findings of the analyses.
- model updates and changes to the previous outcomes provided in the previous version of this report in April 2017.

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. These models were further refined and calibrated 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. The critical flooding processes for floodplain interactions and potential impacts are those dominated by the local tributary catchments rather than the main regional floodplains. 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.

In the sections 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 one to two days. Overland flow velocities tend to be in the medium range (approximately 1.5 to 3 m/s) and generally flooding occur 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), with flooding occurring 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 set the 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 key outcomes of the project relating to flooding include:

- improving the flood immunity of the highway. Through the Richmond River regional floodplain various sections of the former highway were prone to flooding from the 5 year ARI event. The upgraded highway provides a flood immunity of between the 20 and the 100 year ARI
- achieving the flood management objectives from Devils Pulpit Upgrade to Trustums Hill
- minor changes in flood levels, velocities and durations from Trustums Hill to Broadwater National Park, Broadwater National Park to Richmond River and Coolgardie Road to Ballina Bypass. With five localised areas where there are remaining departures. These have been subject to investigation and consultation with the impacted landowners
- two remaining departures at two cross drainage locations, with impacts related to localised increases in flood levels between Richmond River and Coolgardie Road. These have been subject to investigation and consultation with impacted landowners.

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. There are eight properties within the Richmond River regional floodplains traversed by the project, which experience new above floor flooding generally in the 50 year and 100 year ARI events; however the change in flood levels at these properties as a result of the project does not exceed the flood management objectives (less than 50 millimetre increase). There are no residential building flooding impacts in the local catchments as a result of the project.

The results at key points along the main rivers and waterways during a flood, demonstrate that the project has a negligible impact on overall flooding behaviour of the Richmond River. Since the April 2017 version of this report, some areas within the model have been refined with more recent survey (for example cane drain invert level surveys and minor cross drainage surveys on low flow paths). Where there are updates to the pre-construction case flood results (when compared to the April 2017 version of this report, these are in areas where the pre-construction case and built case flood models have been refined with more recent survey data.

Other design changes that were assessed in the flood model after the publication of the draft hydrological mitigation report in April 2017 mainly include minor drainage added to side roads and access tracks to retain existing low flow paths, and revised configuration of some access tracks for example underneath the Richmond River Bridge. These changes generally improved flooding compliance of the project overall, and had a particular benefit on duration impacts.

Access out of the Richmond River regional floodplain and the surrounding local catchments was mainly via the former Pacific Highway and a number of local access roads that connected to the highway. In all locations the upgraded highway provides more efficient and reliable flood evacuation routes since the flood immunity has been improved. 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 has instead improved 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 remain where design refinements were unable to resolve the departure. 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 has been carried out on departures. Consultation with these landowners started in July 2016 and has continued through construction and completion of the project. No further investigation or mitigation is proposed for the areas categorised as low risk impacts.

The project team has met with affected landowners (see Table 6.2) 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 most landowners have reached agreement on impacts and mitigation measures. Where agreement has not been reached, then the issue has been referred to the independent hydrologist and the outcomes have not required further mitigation under a feasible and reasonable assessment. In one instance, more refined modelling was carried out at the recommendation of the independent hydrologist.

Where additional flood mitigation infrastructure has not changed the flood outcome, local drainage improvements options for improved land drainage have been carried out in consultation with the local landowner and has included:

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

All of the above measures have been incorporated into the design and tested in the flood model as the consultation process has been carried out.

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. Increases in infrastructure have been provided between Trustums Hill and Broadwater National Park and Broadwater National Park and Richmond River, with an additional 290 metres of waterway opening width.

This report reflects the final design, including post issued for construction (IFC) design refinements tested and approved up to September 2021, including the final design of the new bridge over the Richmond River. Results provided with this report have resolved as many of the departures as practically possible with consultation activities on the departures and agreed mitigation measures finalised. Any additional drainage or flooding queries that arise following completion of this report will be addressed by Transport for NSW (TfNSW), as required.

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 former 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 has duplicated the former 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 includes 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
- a heavy vehicle checking station near Halfway Creek
- 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:

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

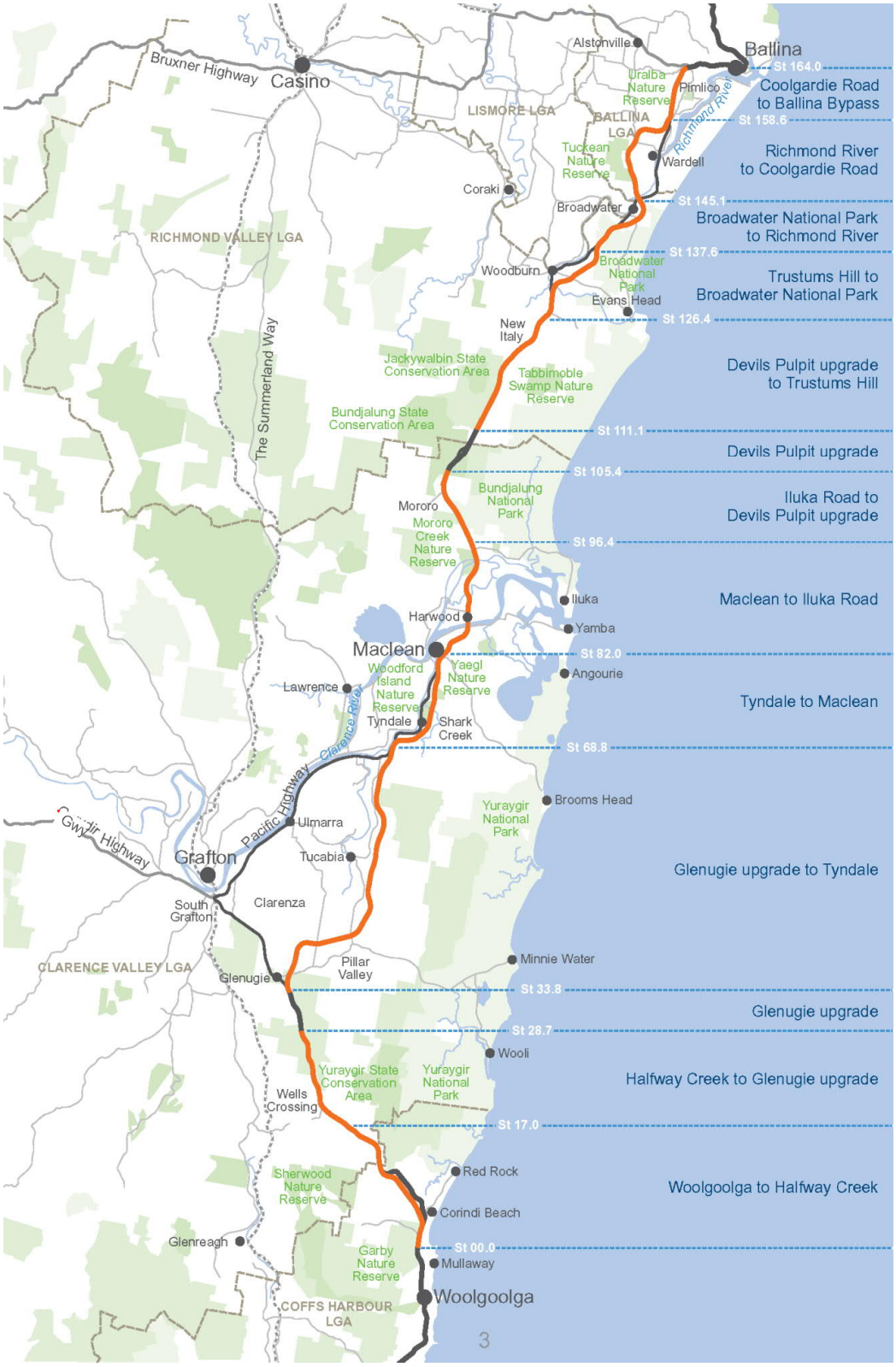

Figure 1.1 General overview of Woolgoolga to Ballina Pacific Highway upgrade

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 have been managed and mitigated on properties upstream and downstream of the project.

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

- the pre-construction 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 conditions of approval that relate to flooding and hydrological impacts 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 built 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
D13	The Applicant shall prepare and implement a Hydrological Mitigation Report for properties where flooding and/or hydrological impacts are	This report

Condition of Approval reference	Condition of Approval	Where addressed
	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:	
	(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
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 pre-construction 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 pre-construction 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, Industry and Environment (DPIE), 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 analyses 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 DPIE.

WMAwater have been involved as the independent hydrologist 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 regional 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 for the project. Independent verification of the flood models developed for the local catchments has been carried out by the detailed design consultants, unless a landowner issue was raised that triggered the independent hydrologist review process.

Where a landowner has contacted TfNSW with concerns of flooding and drainage impacts on their land, the project has, in some instances, referred the issue to the project's independent hydrologist for further investigation. If this process identified a departure it is included in Table 6.2, otherwise issues have confirmed to be categorised as low risk impacts or compliant with the flood management objectives. Where the independent hydrologist has determined reasonable mitigation measures, where required, these were agreed in consultation with the affected landowners.

WMAwater has also participated in the community consultation with local landowners and agencies. They have attended flood focus groups and stakeholder meetings throughout the project's development. 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 has continued through the construction and completion phases of the project, this has included attending flood focus groups and key stakeholder meetings.

1.7 Status of report

This report reflects the final project issued for construction (IFC) and post-IFC design refinements tested and approved up to September 2021, which includes the final design of the new bridge over the Richmond River. In line with Condition B43 (see Table 1.1) the final design of the bridge includes the removal and replacement of an embankment section with an extended bridge opening and total bridge opening span of 981 metres. The final issued for construction bridge design has been included in the flood impact assessment and the results presented in this report.

The key sections of the report updated from the previous revision (April 2017) to the current revision are presented in the table below.

Table 1.3 Sections updated in this revision

Section	Detail
Executive summary	Update to reflect final results of the flood modelling
2	An update to the consultation section summarising stakeholder consultation that has been carried out since the previous revision of this report
5.2	Update of flood assessment text and flood level hydrographs based on final results
5.3	An update to the individual property flooding assessment based on final results
5.6	Update to the climate change results for Mid-Richmond regional floodplain based on the final design
5.7	Update to the extreme flood event analysis for Mid-Richmond regional floodplain based on the final design
6.2	An update on the departures and mitigation measures based on final results
7	Conclusion updated to reflect final results of the flood modelling
Appendix A	Independent hydrologist final review letter
Appendix C	Update of built conditions flood maps for Mid-Richmond River regional floodplain updated
Appendix F	Update to climate change and extreme event mapping for Mid-Richmond regional floodplain based on the final design
Appendix G	Additional stakeholder consultation presentation slides added

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, Industry and Environment (DPIE)
- NSW Office of Environment and Heritage (OEH)
- Independent Woolgoolga to Ballina upgrade environmental representatives
- TfNSW.

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 has worked closely with our communities during the project's development and to minimise, manage and wherever possible mitigate impacts during construction and completion.

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 an 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 with follow up consultations with individual landowners continuing through to 2021.

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 G.

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 lists these stakeholder meetings.

Appendix G provides a copy of the presentation given to the Operations and Maintenance Review Group in May 2020.

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
11 September 2019	North Coast Floodplain Forum
20 May 2020	Operations and Maintenance Review Group - attended by TfNSW, Richmond Valley Council, Ballina Shire Council, NSW Department of Planning, Industry and Environment (Office of Environment, Energy and Science), NSW Police, NSW Ambulance, Fire & Rescue NSW, State Emergency Service, Rural Fire Service and Essential Energy

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.

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

2.3.1 Landowner meetings

Generally, consultation with affected landowners involved three meetings with the project team to discuss the predicted impacts at their property and how the project team will work to mitigate these impacts as far as is feasible and reasonable. Table 2.3 provides an overview of the consultation process with affected landowners identified in Table 6.2.

Table 2-3 Overview of affected landowner consultation process

Meeting number	Items for discussion	Details
1	Overview	Evolution of design from EIS and SPIR to current design
	Flood modelling	Flood management objectives. Flood modelling process. Design refinements.
	Property impact	Outlined overall impact in the catchment. Identified and explained technical non-conformance on property.
	Seek feedback	Landowner requested to identify how flooding impacts them – e.g. afflux, duration, velocity
	Site walkover	Requested permission to drive/walk the property and confirm: • land use (cane/ grazing etc)

		• flood relief infrastructure on property (drains, flood gates etc)
	Next steps	Pacific Complete to take feedback on board and investigate options
2	Follow up on enquiries	Close out actions from previous meeting including provision of any additional information requested.
	Outline steps taken, as required	Steps taken may have included: • carried out an inspection of the localised drainage infrastructure on the stakeholder's property • carried out further localised flood modelling including the drainage infrastructure on the property • investigated options for further reducing the potential impact at the property.
	Proposed mitigation measures, as required	Discuss outcomes of at property drainage inspection. Provide landowner with proposed mitigation measures.
	Seek feedback	Request landowner feedback on proposed mitigation measures.
	Next steps	If mitigation work at property is required –a property adjustment plan based on mitigation measures discussed and agreed was developed. If no mitigation work at property required – correspondence was issued to close out the consultation process.
3	Mitigation work	Present property adjustment plan developed. Confirm landowner acceptance of mitigation measures. Request property owner authorisation of work.
	Next steps	Schedule work with property owner. Carry out mitigation work. Inspect work and confirm with property owner acceptance of work.

Consultation with affected landowners (three) about the departures identified in this report has concluded. Table 6.2 provides a schedule of the departures, flood mitigation measures and flood mitigation / consultation actions.

This report reflects the final design including post-IFC design refinements that have been tested and approved up to September 2021. The results provided in this report have resolved as many of the departures as feasibly and reasonably possible and has included mitigations measures and recommendations from the independent hydrologist, where applicable.

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 has continued 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 project's 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.

Consultation has been ongoing throughout the design, construction and completion of the project. As required, flooding or drainage concerns raised by landowners have been reviewed with additional studies carried out to confirm compliance with flood management objectives and review outcomes communicated to the landowner.

Any further queries or concerns raised by landowners during the final stages of completion will continue to be investigation and consulted on, with involvement of the independent hydrologist as required. If these investigations identify further departures requiring mitigation and/or acceptance by affected landowners, then these will be documented in an addenda to this report.

2.5 Consultation by independent hydrologist

Table 2.4 shows when and how WMAwater has engaged with stakeholders as the project's independent hydrologist.

Table 2-4 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

Date	Stakeholder	Type of engagement
16 November 2016	State Emergency Services	Presentation
16 November 2016	Property owner – Woodburn	Meeting
17 November 2016	Property owner – Woodburn	Meeting
2017 to 2018	Property owners - Woodburn	Meetings
2018 to 2019	Property owners – Broadwater, Woodburn	Meetings
2018 to 2019	Property owner – New Italy, Woodburn, Broadwater	Meetings
2019 to 2020	Property owners – New Italy, Woodburn, Broadwater	Meetings
2020 to 2021	Property owners – Woodburn, Broadwater	Meetings

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 project has been designed to ensure wherever reasonable and feasible the flood management objectives are met. Areas where these objectives have not been achieved are outlined section 6 of this report. A schedule of mitigation measures is 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. Adaptive management allowed design refinements to optimise or reduce potential flooding impacts. Refinements were carried out in line with the principles and objectives outlined in this report. Minor changes to the design, either from flood optimisation or engineering reasons, were reviewed by the project team for potential flooding impacts.

A design change, which resulted in a better or improved outcome was able to be adopted with no further action. If a proposed design change worsened an outcome, Pacific Complete consulted with relevant stakeholders and the independent hydrologist, as required to determine an appropriate way forward. Changes to flood relief structures or design options included consideration of:

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

3. STUDY AREA AND EXISTING FLOODING BEHAVIOUR

3.1 Catchment overview

During 2016 to 2021 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 and Clarence River systems 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. Figure 4.2 presents the locations of local catchment flood model extents.

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 about 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 traverses 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 about 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 traverses 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 upgraded 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 about 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 former Pacific Highway through Woodburn to Broadwater National Park – see Figure 3.2. The upgraded highway is in a greenfield area from the start of this section at the Tuckombil Canal crossing to about 500 metres south east of the former 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 former Pacific Highway through the Richmond River floodplain had a variable level of flood immunity up to the 20 year ARI event. The portion of the former Pacific Highway that ran 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.

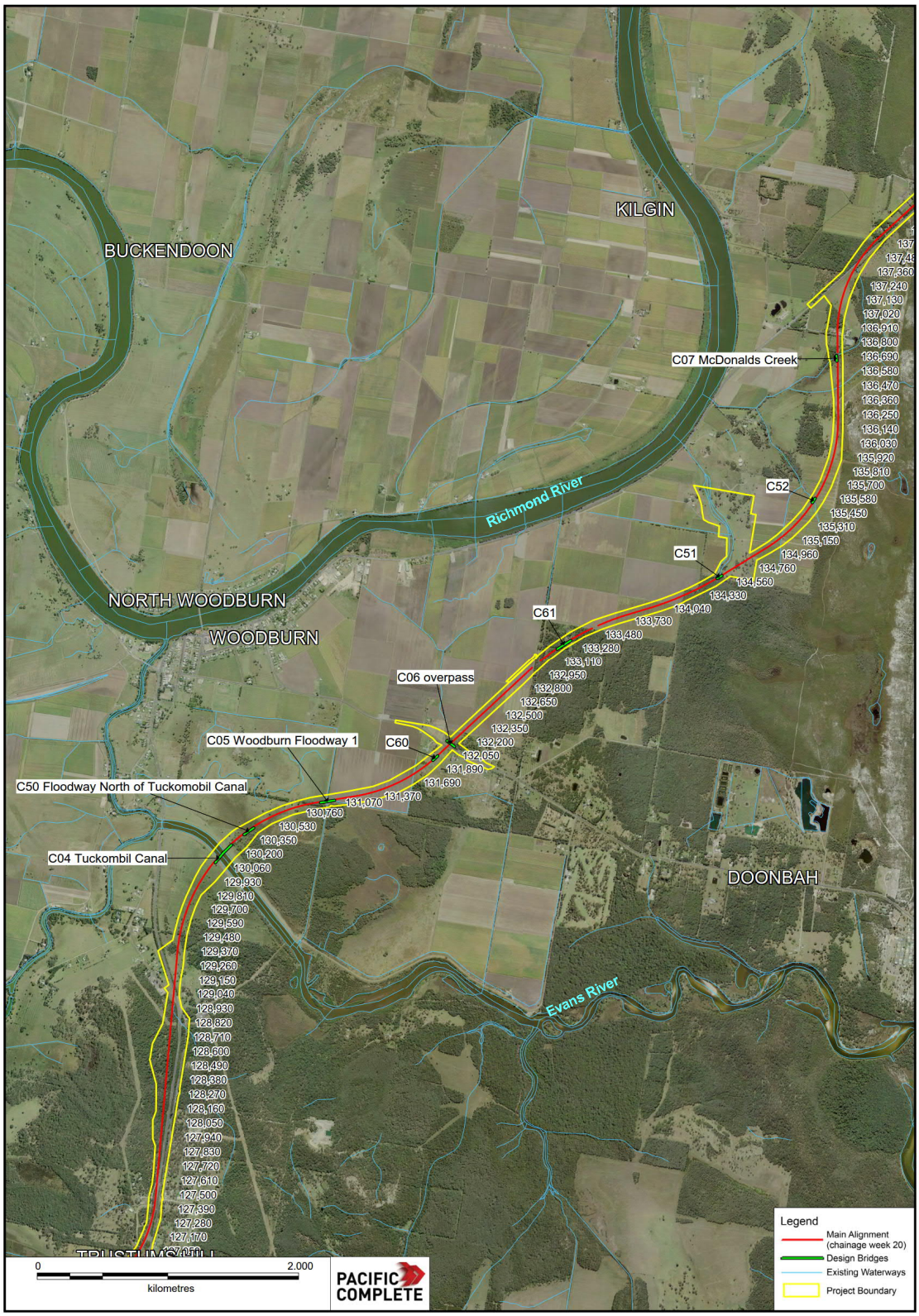

Figure 3.2 Trustums Hill to Broadwater National Park

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 upgraded highway then runs along the outer extent of the floodplain to the south and west of the former Pacific Highway as it passes through Broadwater. The upgraded 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.

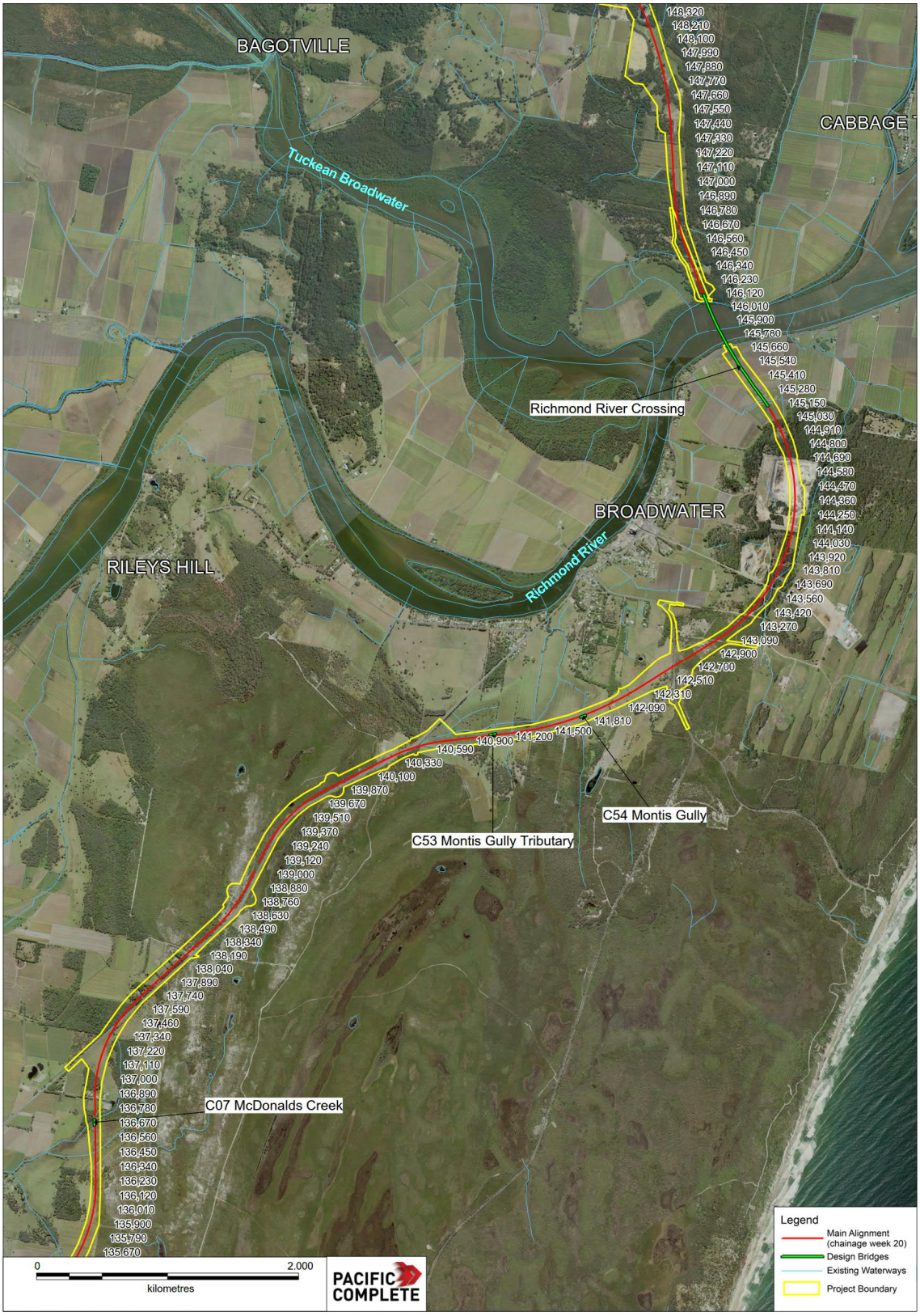

Figure 3.3 Overview of Broadwater National Park to Richmond River

3.2.4 Richmond River to Coolgardie Road

This section begins 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 former 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 upgraded 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 this section. 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.

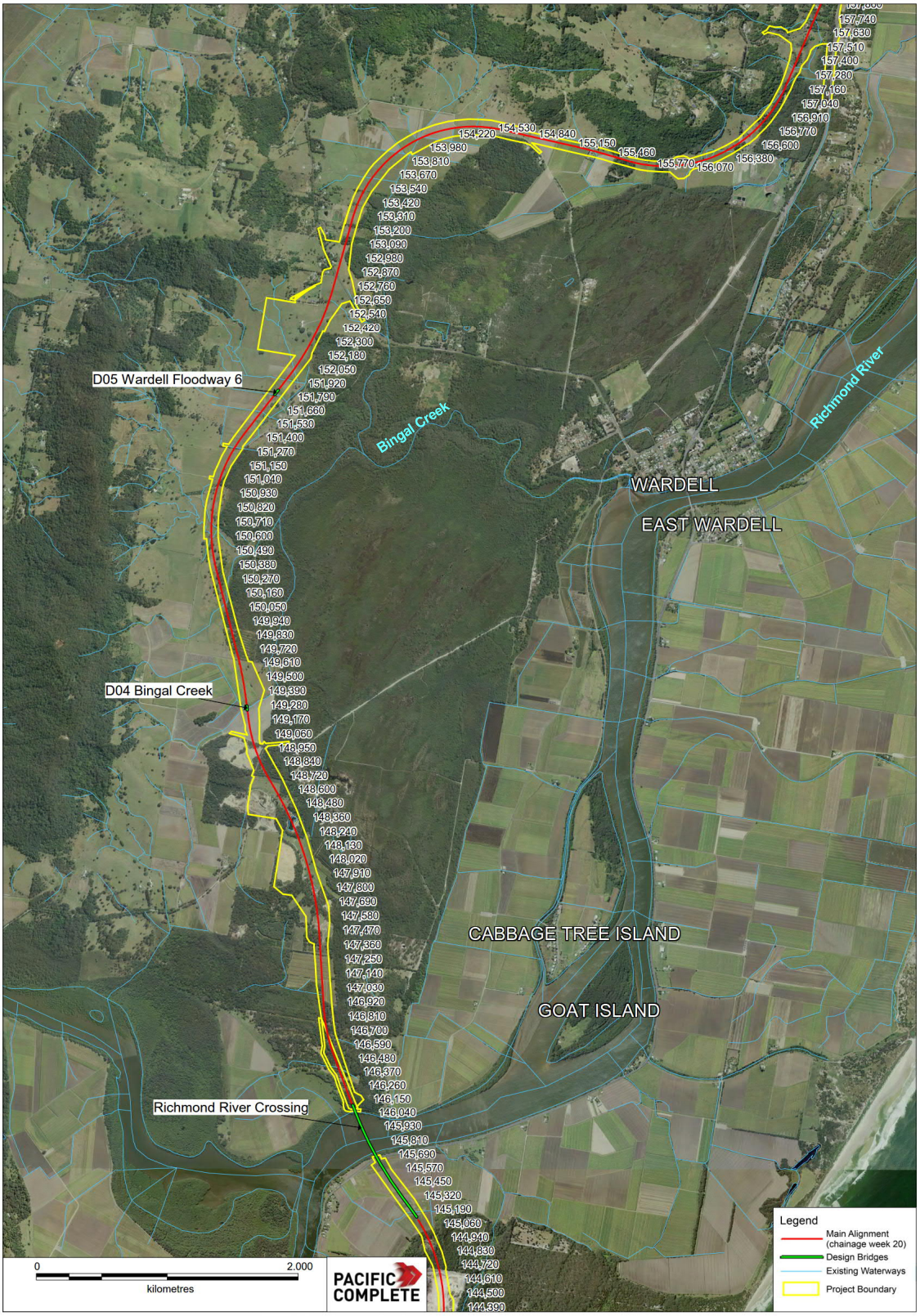

Figure 3.4 Richmond River to Coolgardie Road

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 at the Pimlico to Teven work – see Figure 3.5. The highway upgrade for this section follows the former 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 former Pacific Highway was 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 TfNSW 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 TfNSW 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 pre-construction 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. A local catchment rain on grid model was developed by Pacific Complete for the new bridge over the Richmond River area to model the local drainage system in a better resolution and to test the infrastructure in the area (at the recommendation of the independent hydrologist). The smaller scale local model confirmed compliance with the flood management objectives.

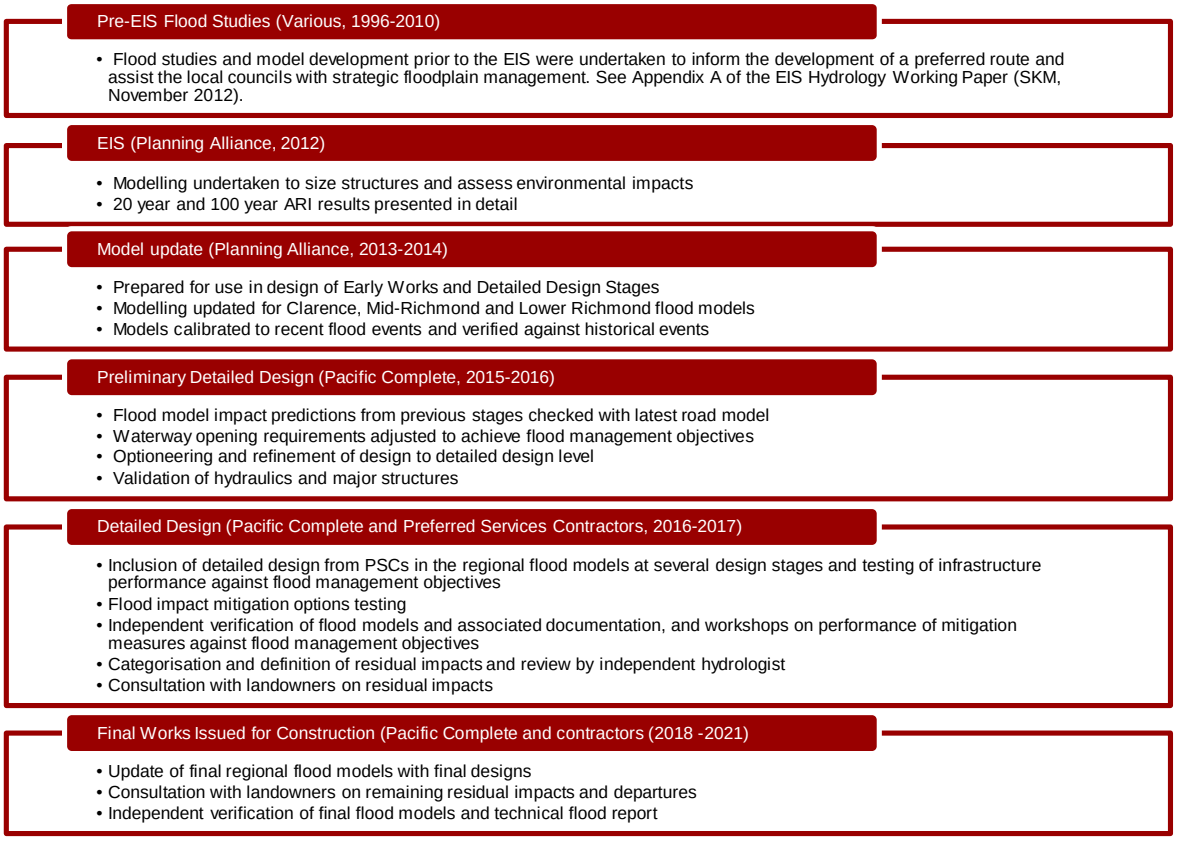

Figure 4.1 Staging of regional flood model development

4.2 Overview of flood assessment 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. For the purposes of a comparative assessment in this report, flood level results are documented to a finer resolution (3 decimal places) than the expected accuracy of the model to demonstrate compliance with flood management objectives.

The regional models are suitably developed and calibrated tools for defining pre-construction and built 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. There are some isolated areas along the Richmond River channel where gaps in the flood mapping occur between the model grid and the 1d connection. These areas are located in the main river and away from the project. This does not affect the results of the flood modelling assessment.

The hydraulic model generally 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. At locations where the cane drains were identified as important in the regional flood behaviour, the model has been updated to include representation of these local features.

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 underestimate the flood extent and overestimate 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 have represented 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 underestimate flood extent and overestimate 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 new bridge over the Richmond River Bridge at Broadwater. The regional model includes the final design of the new bridge over the Richmond River (CH145800). 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.
- Richmond River to Coolgardie Road 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.

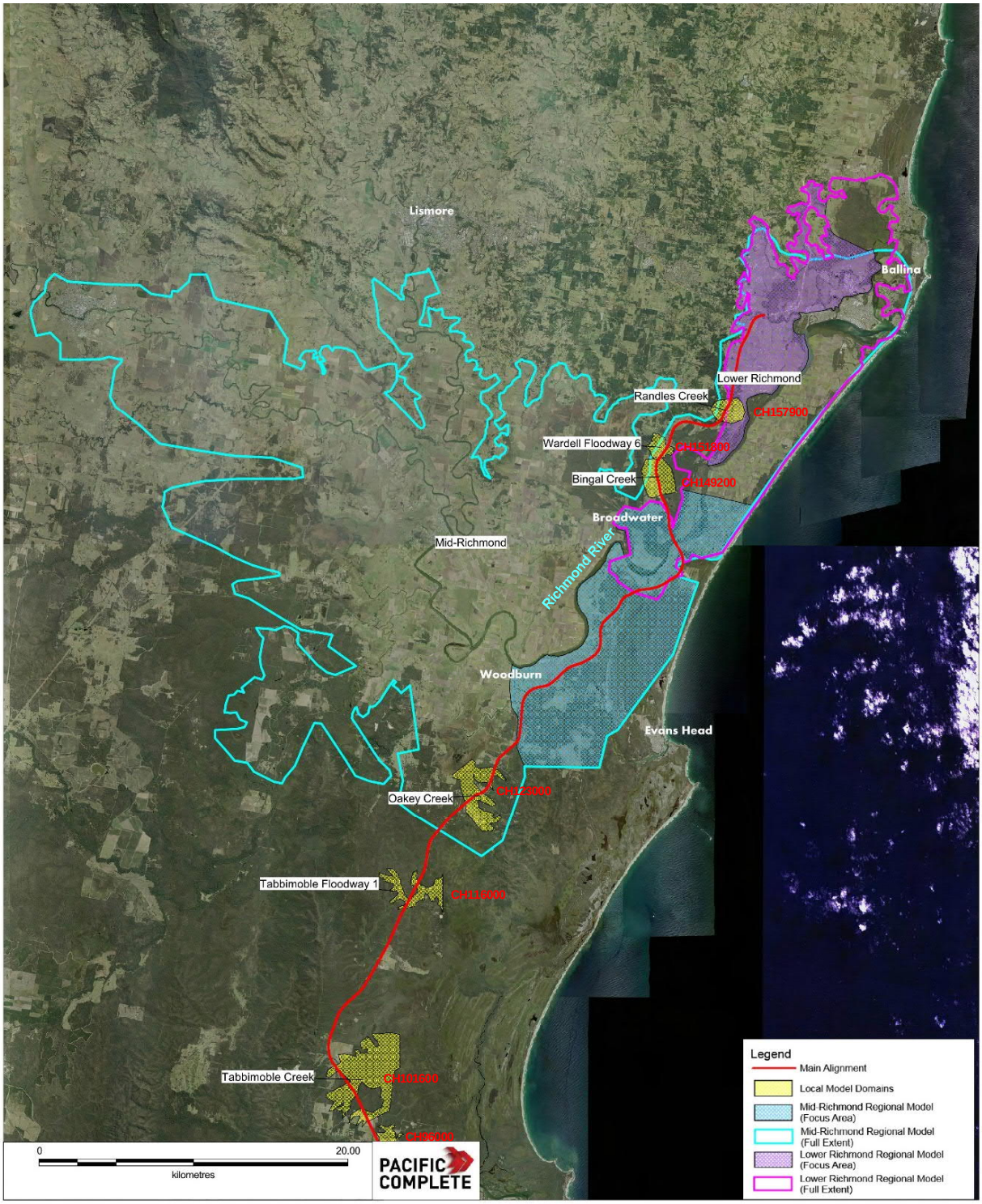

Figure 4.2 Overview of the extents of the Richmond River regional models and local catchment models

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 (regional catchments only)

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 former 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 investigated to assess 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. Results are presented in Section 5.6.
- **Extreme event** – the interaction of the estimated PMF with the highway upgrade was tested to see if the built highway had any impact on the flood behaviour of the PMF. Results are presented in Section 5.7.
- **Future widening** – the impact of future widening of the upgraded highway, particularly lengthening of bridges and cross drainage culverts in the direction of flow. This sensitivity test was not able to be assessed without a concept design for the future widening works. These future widening works would be subject to a separate environmental assessment process based on a developed concept design, therefore this sensitivity test is no longer deemed necessary for the purposes of the project and will not be considered further.

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 1m/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 1m/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 two metres and above for local models 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 percent increase) and orange and red areas represent non-compliant > five percent and > 10 percent increases in flood duration respectively.

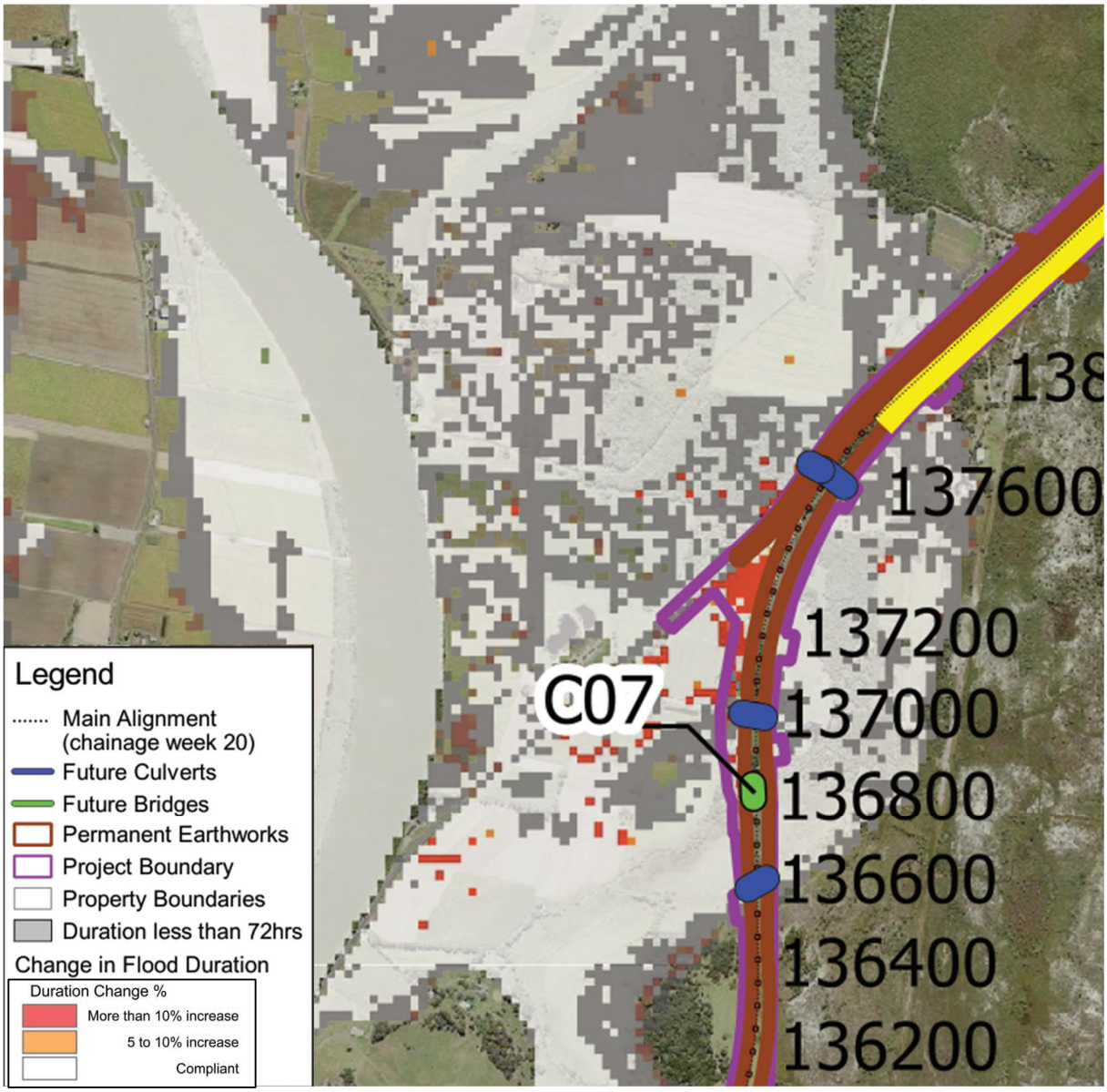

Figure 4.3 Example of fringe, scattered and isolated impacts

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 pre-construction 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. 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 is unlikely 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 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 (most frequent 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 built 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 built 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. This is applicable for regional catchment and local catchment models, where there is surrounding 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 pre-construction conditions and the change in the depth of above floor flooding as a result of work 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 pre-construction case and built case flood levels were assessed from flood modelling 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 former 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 work that could not be removed by practical increases in drainage infrastructure. These are outlined in section 5.2. Residual effects which required work on individual properties or other mitigation measures were 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 built embankment and major bridges, including the crossings at Tuckombil Canal and the new bridge over the Richmond River. Increases in peak flood levels upstream of the project are considered minor and generally meet the limits set by the flood management objectives in the CoA. Downstream of the work, 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 pre-construction 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 scattered and isolated areas with low risk impacts throughout the floodplain. Consultation on low risk impacts is not required for this categorisation of impact. Refer to section 4.3, which describes the categorisation of impacts as low risk or departures.

There are some small areas within the regional floodplain of the Richmond River (both Mid and Lower catchments) where the flood management objectives have not been met for flood level change and duration change. These remaining departures are discussed further in section 6.2.

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 upgraded 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 C008 in Appendix C). The afflux for the 100 year ARI event is generally between 25 and 35 millimetres (see Figure C0010). 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 new bridge over the Richmond River. This bridge crossing spans the majority of the floodplain (with a 981 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 C012 to C014 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 Trustums 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 been achieved. There are no remaining departures.

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 been achieved at two of these structures, with the impacts generally related to localised increases in flood level. Table 6-2 provides further details on the remaining departures.

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 built 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 built flooding conditions in terms of flood level, depth, velocity, flow direction, flood duration and flood hazard across the Mid and Lower Richmond River regional floodplains for the 5, 20, 50 and 100 year ARI flood events.

There are a limited number of locations where isolated cells or groups of cells located a significant distance from the upgraded highway show increased flood impacts. As these locations are not in the vicinity of the upgrade or considered to be impacted by the work, these areas are considered to be result of localised numerical instability or model noise and as such will not be presented further in this section.

5.2.1 Flood level and afflux

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 section 1.5. Tables 5.1 and 5.4 provide the predicted pre-construction and built conditions flood levels at key locations in the Mid-Richmond and Lower Richmond catchments and at key river locations in the Richmond River. The locations in these tables represent points along the main rivers and waterways during a flood and not in the floodplain, demonstrating that the project has a negligible impact on overall flooding behaviour of the Richmond River. Where there are updates to the pre-construction case flood results (when compared to the April 2017 version of this report), these are in areas where the pre-construction case and built case flood models have been refined with more recent survey data (for example cane drain invert level survey and minor cross drainage surveys on low flow paths).

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 (up to 150 millimetres) occurs in an area of mixed agricultural and forested land to the north of the new bridge over the Richmond River in the 50 year ARI event at CH147400 (Figure C013).

Between Trustums Hill and Broadwater National Park there is a minor decrease in flood levels downstream of the highway. The change in flood level on the downstream side of the highway has decreased in the range of one to 50 millimetres. This decrease in flood level is more apparent for the 50 and 100 year ARI events, while for the 5 and 20 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). An area of higher afflux (more than 150 millimetres) occurs in an area of mixed agricultural and forested land to the south west of the Whytes Lane overpass (CH160000) in the 20, 50 and 100 year ARI events (Figures E007 to E009).

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 has decreased in the range of one to 25 millimetres with localised decrease of up to 75 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 rarer events (100 year ARI) and mostly contained within or close to the project boundary or within TfNSW 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 modelled events.

Figures C031 to C038 and E018 to E021 show the change in velocity across the Mid and Lower Richmond River floodplains 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 modelled 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 modelled events. Due to the large catchment and large flows, the built highway 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 built 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 pre-construction and built conditions at key locations in the Mid-Richmond River catchment and at key locations for upgraded 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 three localised areas where the flood duration objectives are not been met (CH134600, CH137000 and CH145000). Table 6-2 provides further details on these remaining departures.

Figures 5.1 to 5.6 show the pre-construction and built 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, Figures 5.1 to 5.4 demonstrate that the main flood hydrograph in the Mid-Richmond River is not affected by the project. Figures 5.5 to 5.6 show that the overall shape and timing of flooding in the floodplain areas is not significantly affected by the project. The very small differences in hydrograph shape are the minor (allowable) changes in duration and flood level that are below the flood management objectives. The figures show that the downstream tidal boundary has an effect on the hydrographs at the crossing of the new bridge over the Richmond River.

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

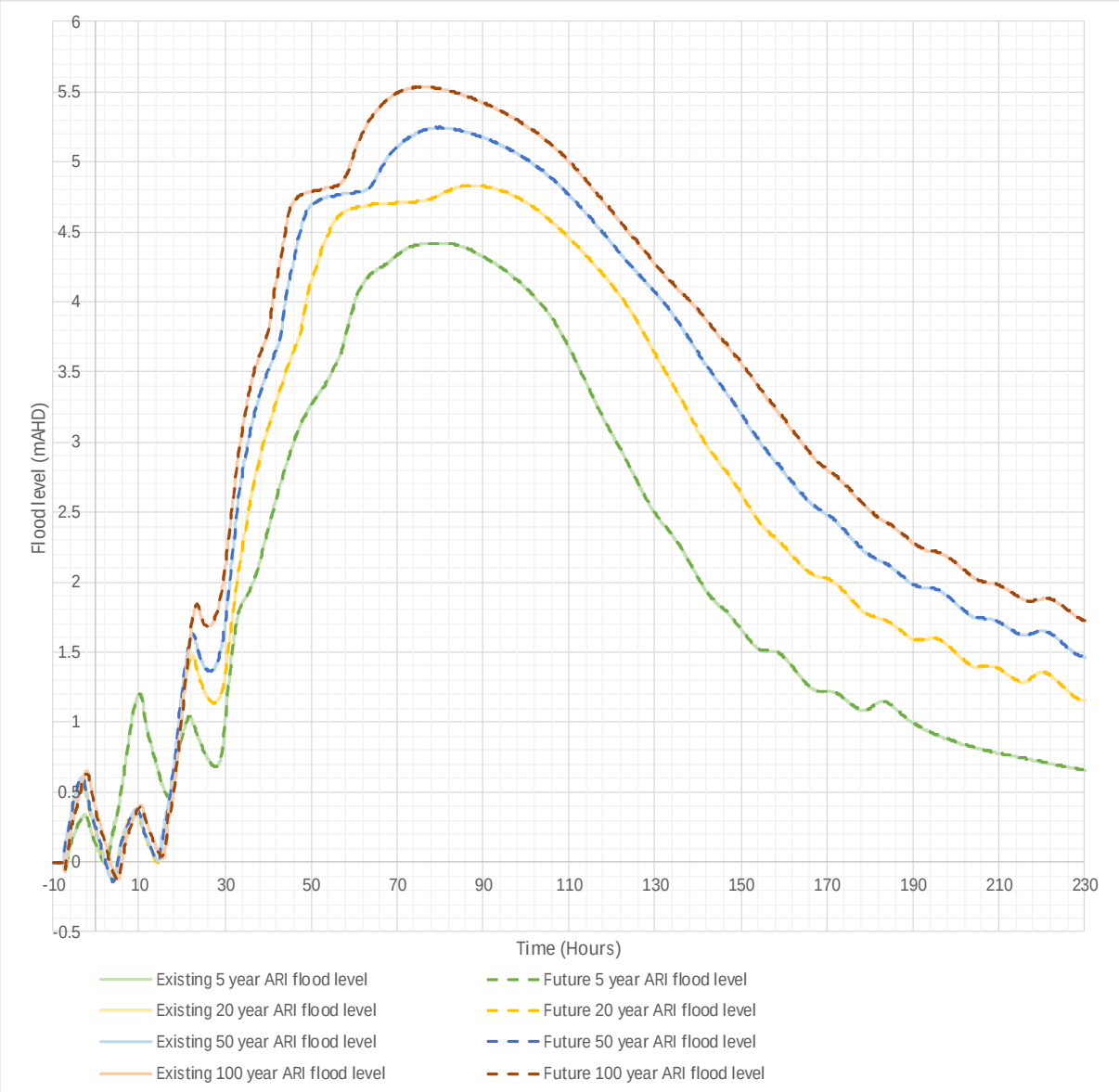

Figure 5.1 Flood level hydrographs at Richmond River at Bungawalbin Junction (CH130400)

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

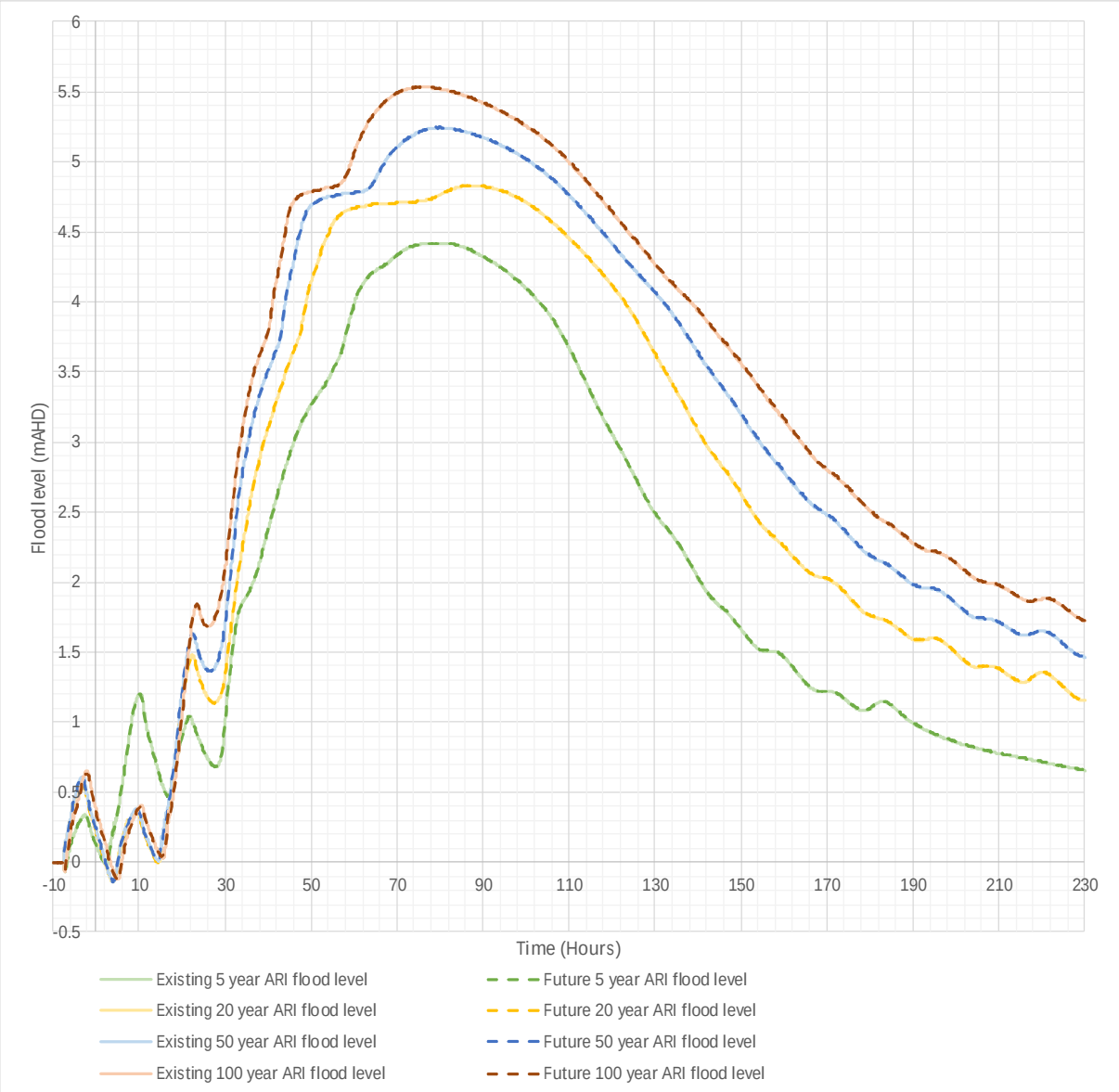

Figure 5.2 Flood level hydrographs at Richmond River upstream of Court St Bridge, Woodburn (CH131000) (Hydrograph location is at bridge crossing of main Richmond River channel at Woodburn – see Figure 3.2)

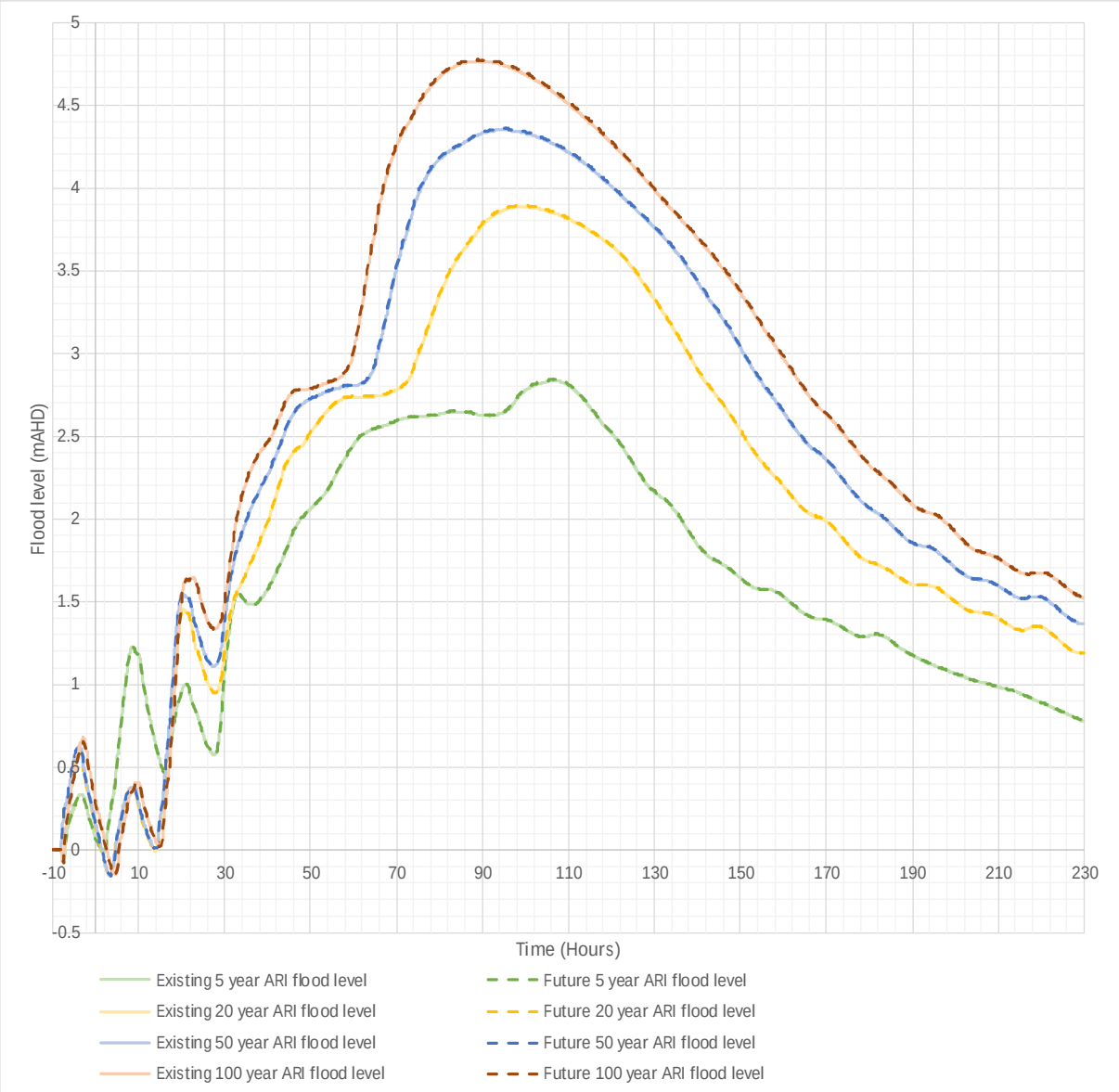

Figure 5.3 Flood level hydrographs at Tuckombil Canal downstream of former Pacific Highway Bridge (CH130200)

(Hydrograph location is downstream of former highway crossing of Tuckombil Canal – see Figure 3.2)

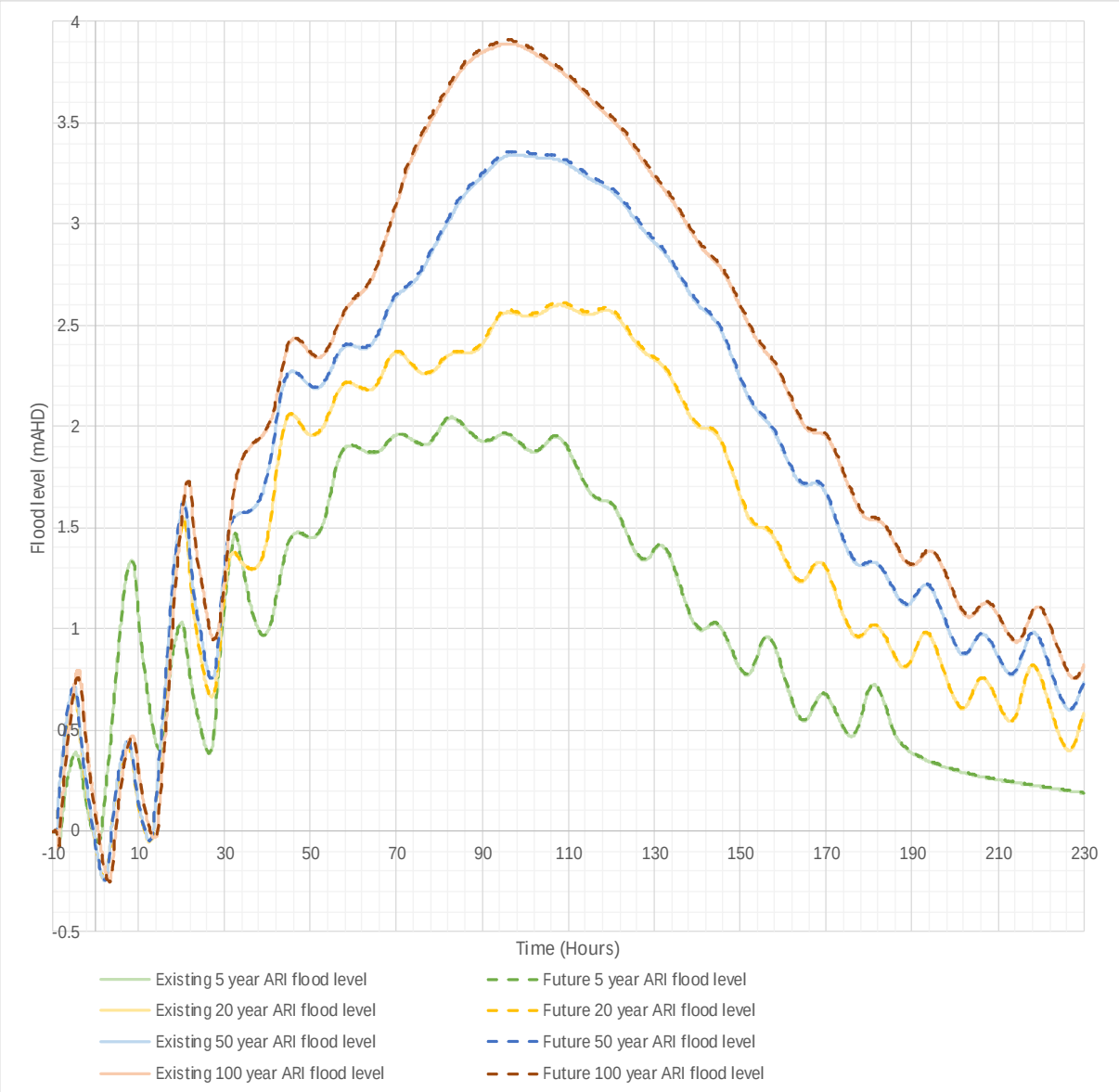

Figure 5.4 Flood level hydrographs at Richmond River upstream of new Pacific Highway Bridge (CH145800) (Hydrograph location is upstream of new highway crossing of Richmond River – see Figure 3.3)

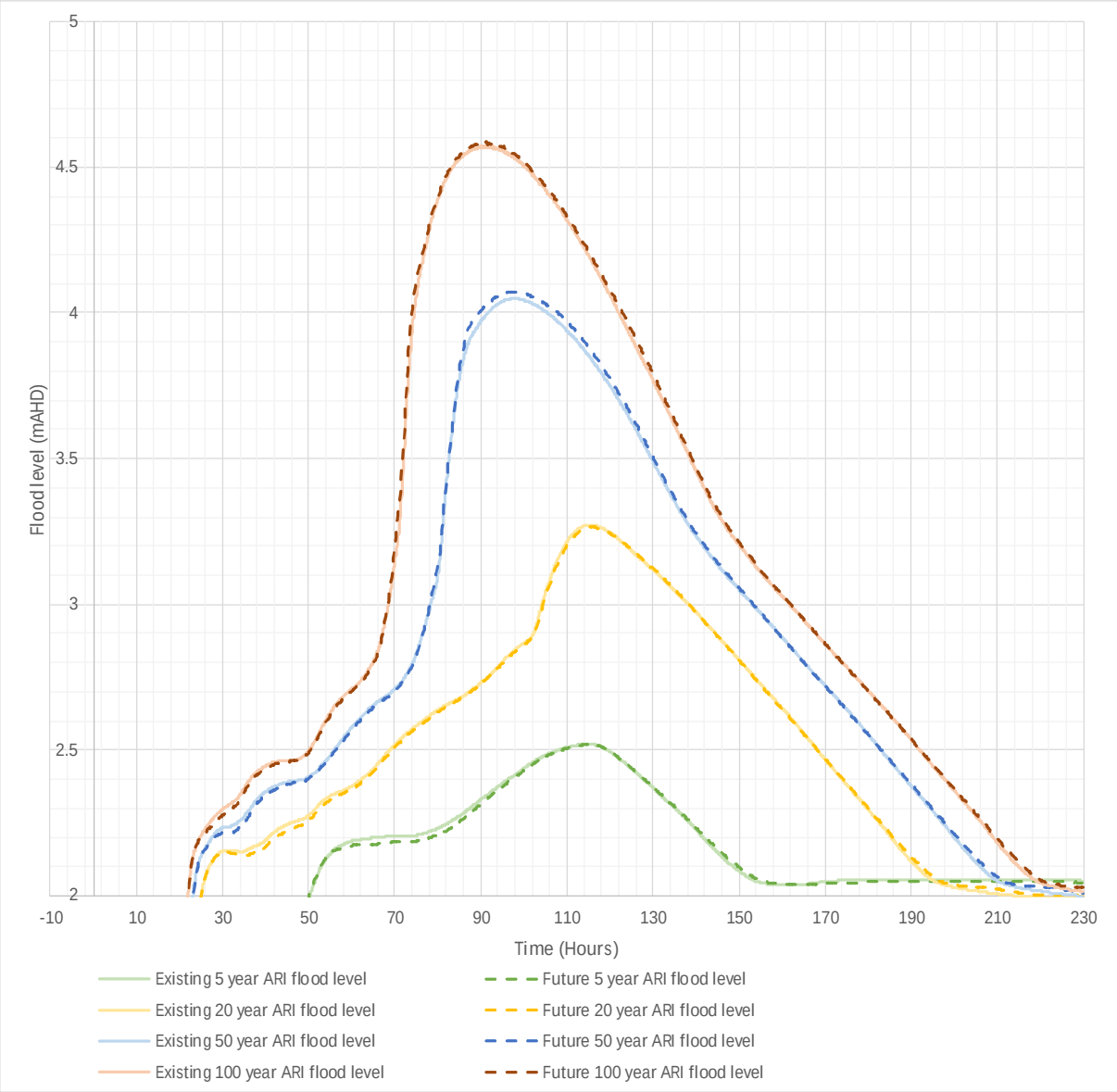

Figure 5.5 Flood level hydrographs at floodplain location CH133000 on the Northbound side of highway (Hydrograph location is in the floodplain adjacent to the new highway at CH133000 – see Figure 3.2)

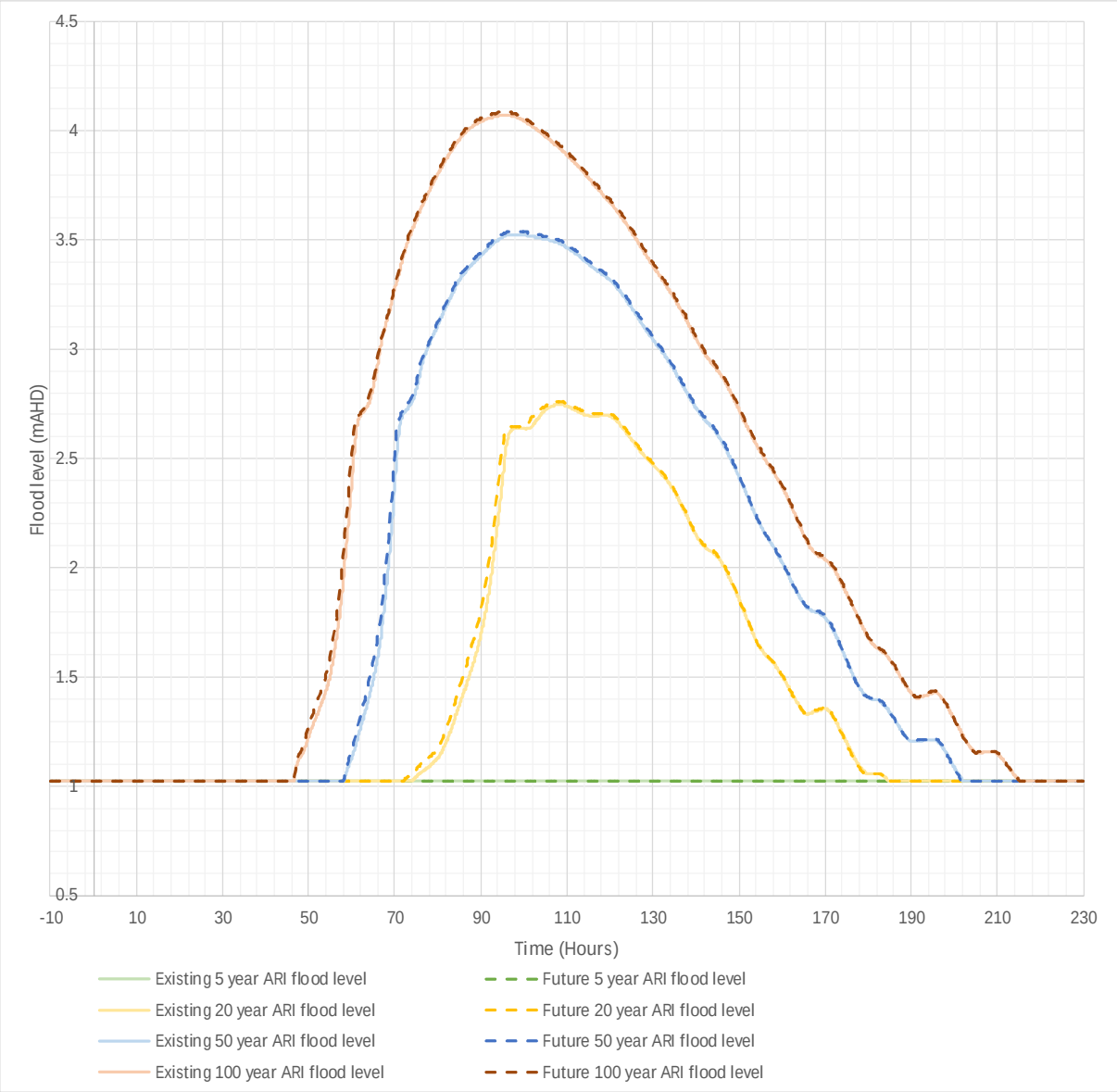

Figure 5.6 Flood level hydrographs at floodplain location CH142000 (Northbound side of highway)

(Hydrograph location is in the floodplain adjacent to the new highway at CH142000 – 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 built 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 pre-construction and built conditions at key locations in the Lower Richmond River catchment and at key locations for upgraded and new infrastructure.

Between Coolgardie Road and Ballina Bypass the flood management objectives for duration have been generally met for all four modelled events (5, 20, 50 and 100 year ARI events). There are some areas of scattered and isolated changes generally along the fringe areas which are classified as low risk impacts and not departures.

Figures 5.7 to 5.11 show the pre-construction and built conditions flood level hydrographs at key infrastructure locations. While the overall mapping presented in Appendix E shows localised areas of the floodplain where low risk duration impacts have occurred due to the project, Figures 5.7 to 5.9 demonstrate that the main flood hydrograph in the Lower Richmond River and the surrounding local catchment tributaries are not affected by the project. Figures 5.10 and 5.11 show that the overall shape and timing of flooding in the floodplain areas is not significantly affected by the project. The very small differences in hydrograph shape are the minor (allowable) changes in duration and flood level that are below the flood management objectives. The figures show that the downstream tidal boundary has an effect on the hydrographs at all plotted locations.

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

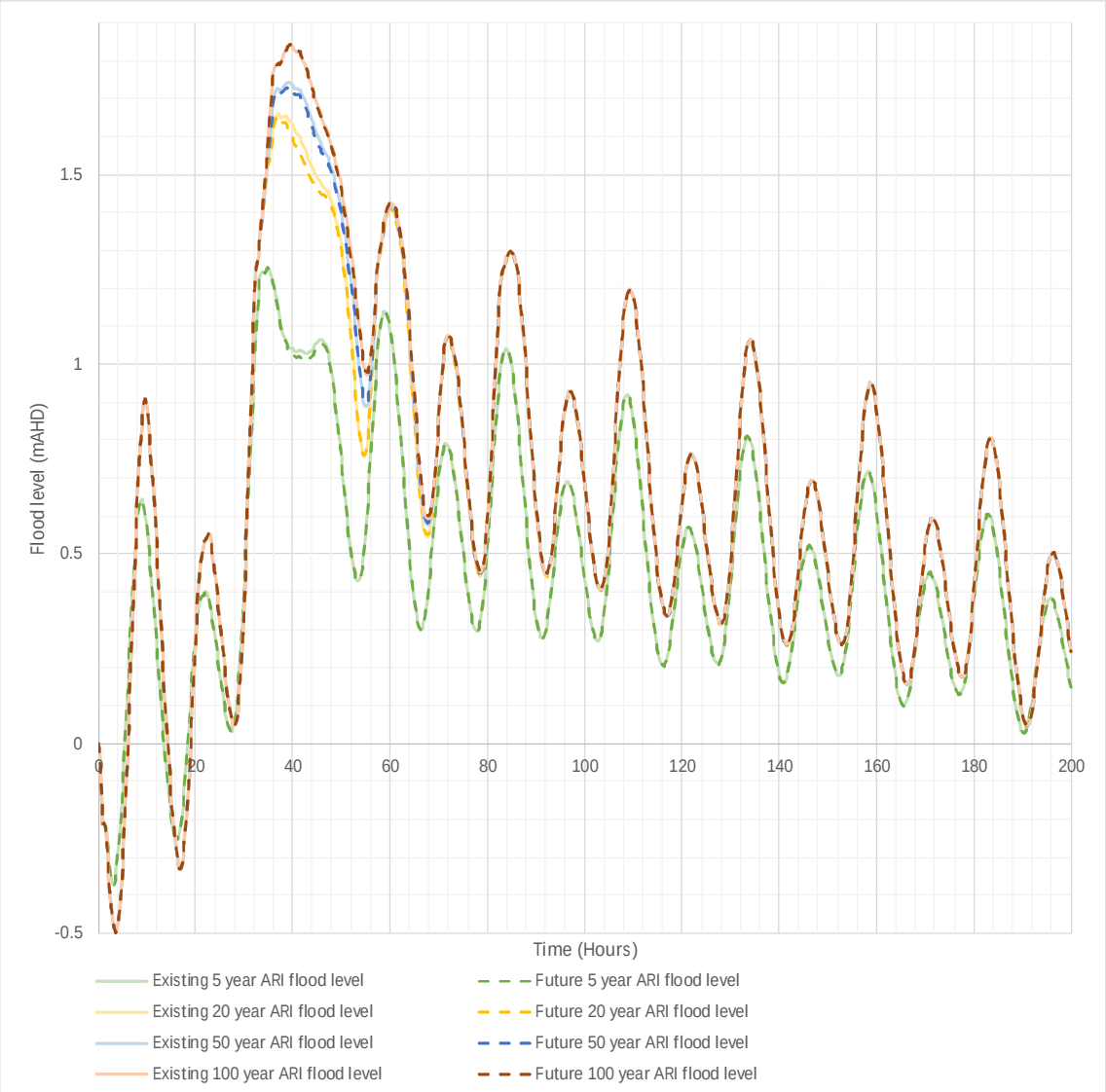

Figure 5.7 Flood level hydrographs at Duck Creek upstream of upgraded Pacific Highway bridge for hydrological scenario B

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

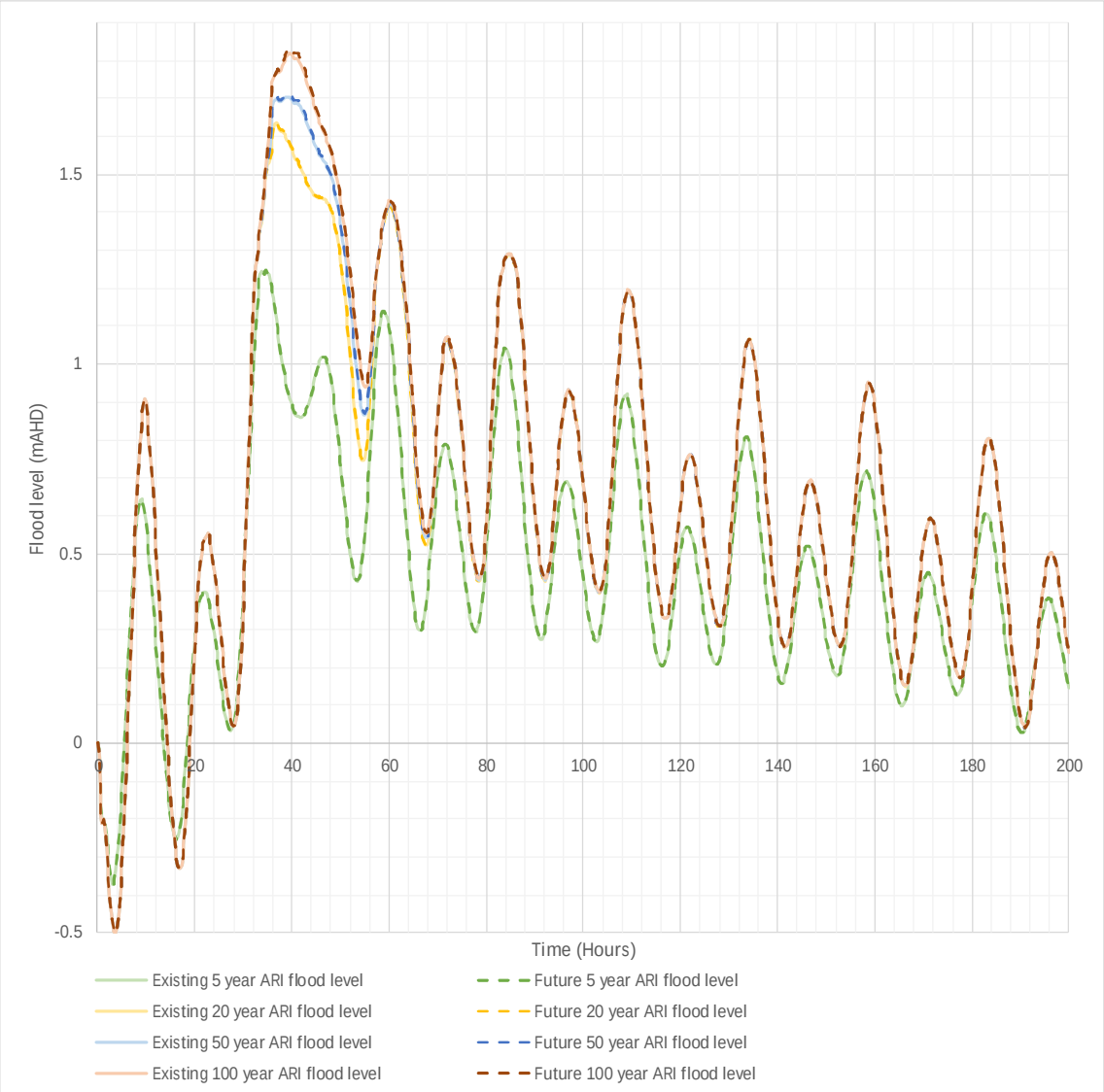

Figure 5.8 Flood level hydrographs at Emigrant Creek upstream of upgraded Pacific Highway bridge for hydrological scenario B

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

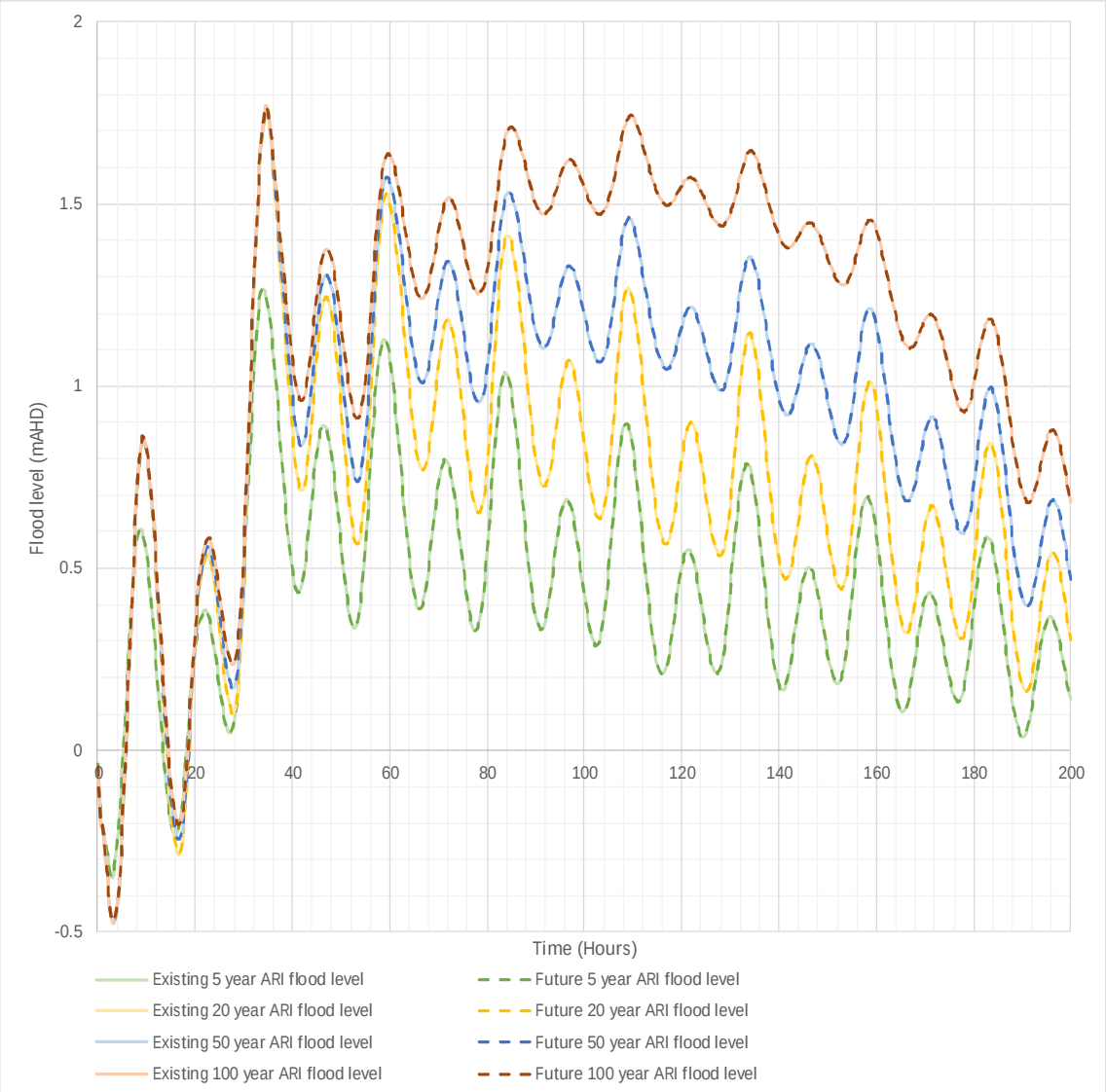

Figure 5.9 Flood level hydrographs at Richmond River at Burns Point for hydrological scenario A

(Hydrograph location is downstream of creek crossings at Teven Junction near West Ballina – see figure 3.5)

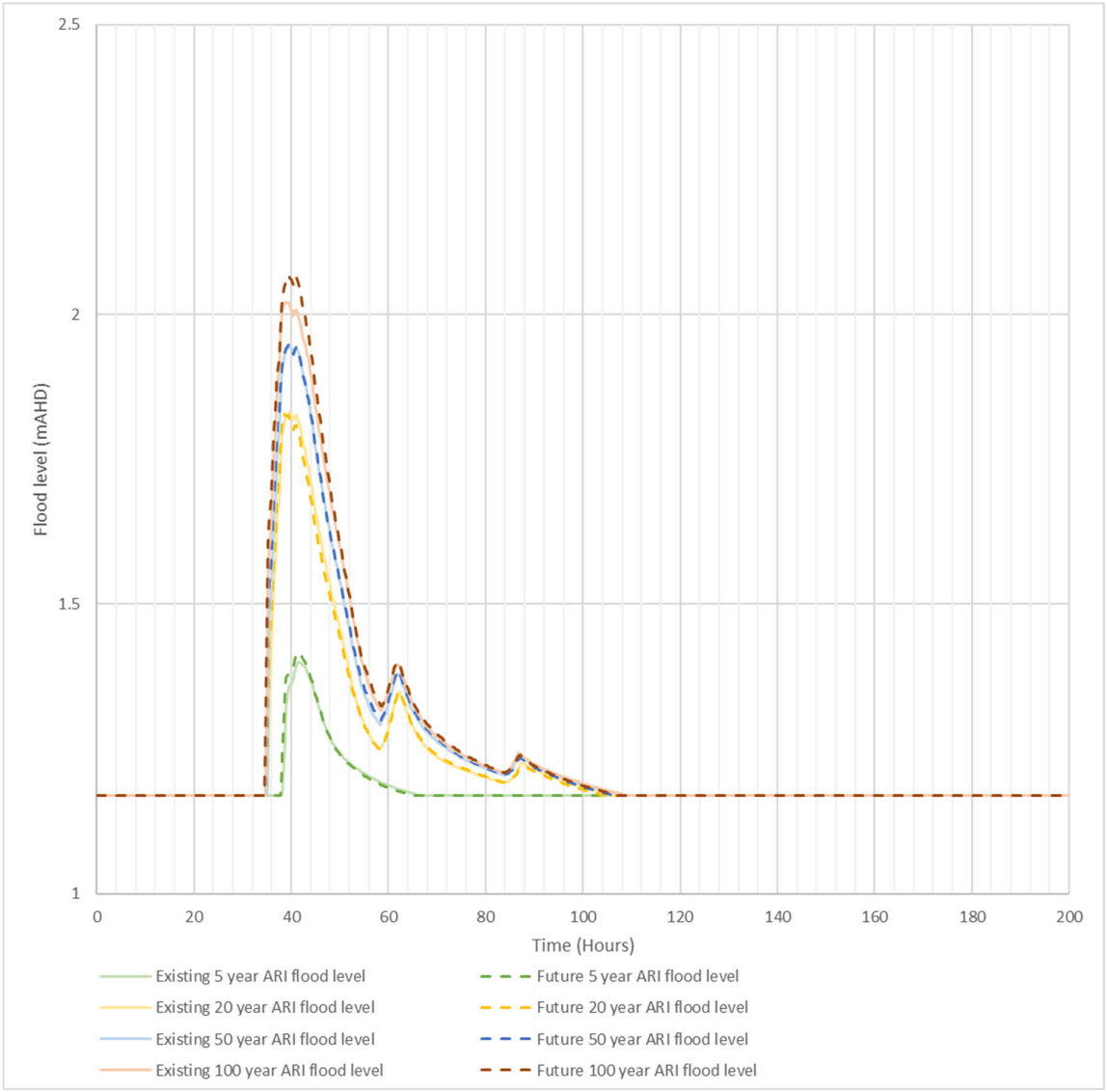

Figure 5.10 Flood level hydrographs at floodplain location CH160500 (Western side) – hydrological scenario B (Hydrograph location is in the floodplain adjacent to the new highway at CH160500 – see Figure 3.5)

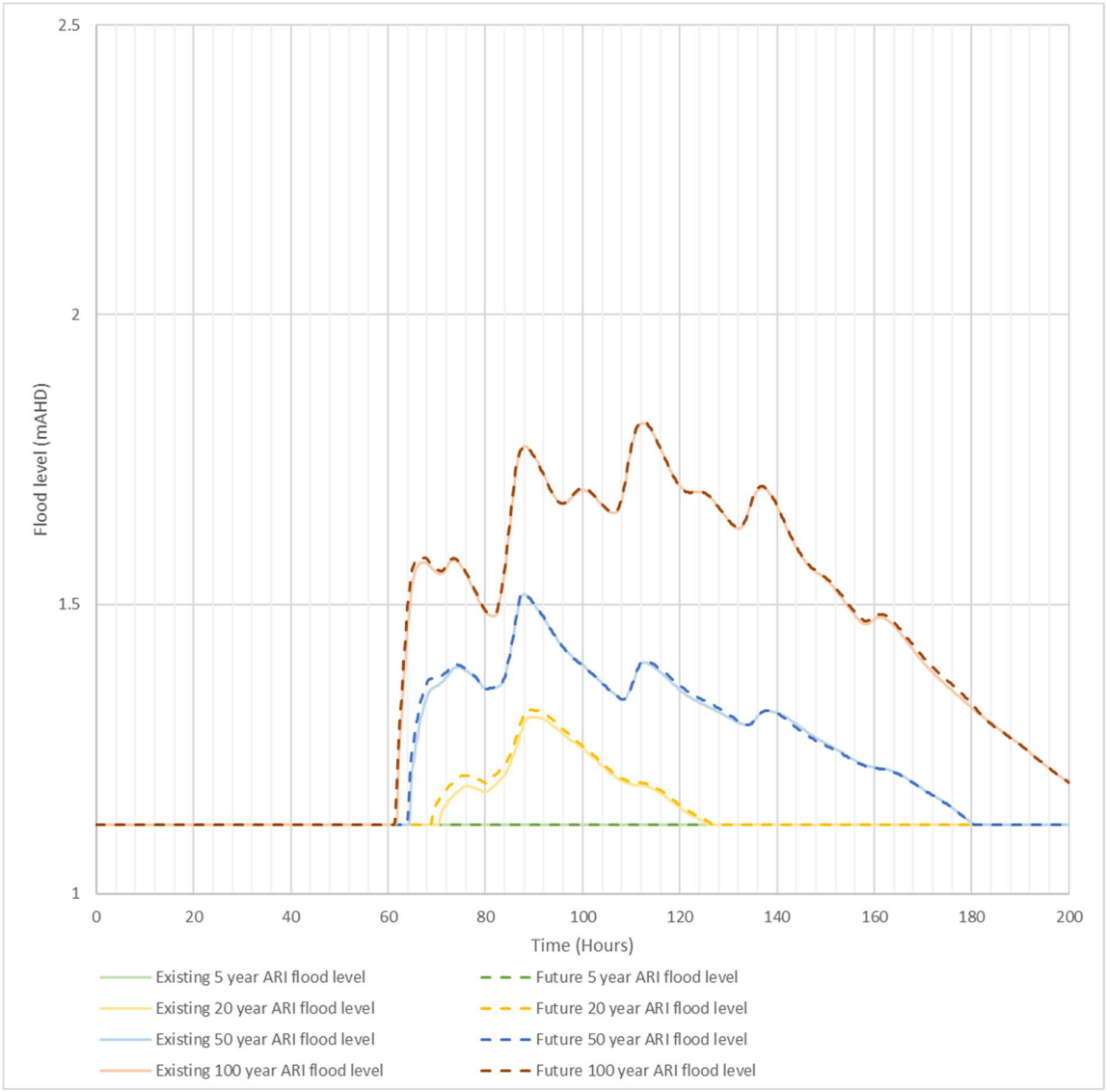

Figure 5.11 Flood level hydrographs at floodplain location CH160500 (Eastern side) – hydrological scenario A (Hydrograph location is in the floodplain adjacent to the new highway at CH160500 – see Figure 3.5)

Table 5-1 Pre-construction and built conditions results – flood levels at key river locations, Mid-Richmond River

Location	05 year ARI			20 year ARI			50 year ARI			100 year ARI		
	Pre-construction	Built	Afflux (mm)	Pre-construction	Built	Afflux (mm)	Pre-construction	Built	Afflux (mm)	Pre-construction	Built	Afflux (mm)
Coraki - (Confluence with Wilsons River) (CH133800)	5.391	5.392	1	5.983	5.983	0	6.184	6.184	0	6.351	6.352	1
Bungawalbin Junction (CH130400)	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) (CH131000)	3.340	3.341	1	3.847	3.853	6	4.289	4.298	9	4.736	4.746	10
Tuckombil Canal (Former Pacific Highway Bridge) (CH130200)	2.833	2.839	6	3.885	3.892	7	4.348	4.355	7	4.764	4.774	10
Broadwater (U/S of new Broadwater Bridge) (CH142800)	2.154	2.157	3	2.723	2.735	12	3.471	3.486	15	4.019	4.034	15
Bagotville (D/S of existing Bagotville Rd Bridge) (CH148000)	2.062	2.066	4	2.722	2.735	13	3.560	3.575	15	4.123	4.137	14
Upgraded Tuckombil Canal (U/S of C04) (CH130200)	2.491	2.499	8	3.423	3.434	11	4.065	4.074	9	4.576	4.584	8
Upgraded Woodburn Floodway (U/S of C05) (CH131100)	0.897	0.934	37	3.272	3.264	-8	4.057	4.078	21	4.577	4.605	28
New Richmond River Bridge (U/S of Portion F) (CH145800)	2.045	2.049	4	2.601	2.615	14	3.343	3.359	16	3.893	3.909	16

Table 5-2 Pre-construction and built conditions results – flow velocity at key river locations, Mid-Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*
Coraki - (Confluence with Wilsons River) (CH133800)	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 (CH130400)	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	2.03	-0.01	-0.1%
Woodburn - (U/S of Court St Bridge) (CH131000)	1.25	1.24	0.01	-0.1%	1.35	1.35	0.00	-0.1%	1.35	1.35	0.00	-0.1%	1.35	1.35	0.00	-0.2%
Tuckombil Canal (Former Pacific Highway Bridge) (CH130200)	1.48	1.47	0.01	-0.3%	1.87	1.86	-0.01	-0.3%	2.07	2.07	0.00	-0.2%	2.19	2.17	-0.02	-0.9%
Broadwater (U/S of new Broadwater Bridge) (CH142800)	1.33	1.32	0.01	-0.2%	1.46	1.46	0.00	0.1%	1.63	1.63	0.00	-0.2%	1.78	1.78	0.00	0.0%
Bagotville (D/S of Bagotville Rd Bridge) (CH148000)	0.48	0.48	0.00	<1m/s	0.77	0.77	0.00	<1m/s	0.94	0.94	0.00	<1m/s	1.09	1.09	0.00	-0.0%
Upgraded Tuckombil Canal (U/S of C04) (CH130200)	1.25	1.27	0.02	1.7%	1.74	1.74	0.00	-0.3%	1.98	1.97	-0.01	-0.3%	2.11	2.09	-0.02	-1.0%
Upgraded Woodburn Floodway (U/S of C05) (CH131100)	0.04	0.01	-0.03	<1m/s	0.17	0.27	0.10	<1m/s	0.32	0.57	0.24	<1m/s	0.41	0.62	0.21	<1m/s
New Richmond River Bridge (U/S of Portion F) (CH145800)	1.12	1.12	0.00	-0.3%	1.27	1.27	0.00	-0.1%	1.47	1.47	0.00	-0.1%	1.66	1.65	-0.01	-0.3%

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

Table 5-3 Pre-construction and built conditions results – flood duration at key river locations, Mid-Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)
Coraki - (Confluence with Wilsons River) * (CH133800)	>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 (CH130400) *	>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) (CH131000) *	>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 (former Pacific Highway Bridge) (CH130200) *	>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 new Broadwater Bridge) (CH142800) *	>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) (CH148000) *	>230	>230	0.0	0.0%	>230	>230	0.0	0.0%	>230	>230	0.0	0.0%	>230	>230	0.0	0.0%
Upgraded Tuckombil Canal (U/S of C04) (CH130200) *	>230	>230	0.0	0.0%	>230	>230	0.0	0.0%	>230	>230	0.0	0.0%	>230	>230	0.0	0.0%
Upgraded Woodburn Floodway (U/S of C05) (CH131100)	72.4	71.8	-0.5	-0.7%	123.8	144.5	20.7	16.7%	161.9	161.9	0.0	0.0%	169.7	169.6	-0.1	-0.1%
New Richmond River Bridge (U/S of Portion F) (CH145800) *	>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 of 230 hours

Table 5-4 Pre-construction and built conditions results – flood levels at key river locations, Lower Richmond River

Location	05 year ARI			20 year ARI			50 year ARI			100 year ARI		
	Pre-construction	Built	Afflux (mm)	Pre-construction	Built	Afflux (mm)	Pre-construction	Built	Afflux (mm)	Pre-construction	Built	Afflux (mm)
Regional Flood Event – Scenario A												
Richmond River upstream of Pimlico Island (CH157400)	1.397	1.397	0	1.902	1.902	0	2.263	2.264	1	2.745	2.745	0
Duck Creek upstream of Pacific Highway Bridge (CH164400)	1.235	1.235	0	1.513	1.510	-3	1.600	1.587	-13	1.754	1.754	0
Emigrant Creek upstream of Pacific Highway Bridge (CH164800)	1.234	1.234	0	1.506	1.505	-1	1.580	1.580	0	1.747	1.749	2
Richmond River at Burns Point (confluence with Emigrant Creek) (CH166400)	1.264	1.264	0	1.769	1.769	0	1.770	1.770	0	1.768	1.769	1
North of Whytes Lane Overpass on Northbound/Western side (CH160200)	N/A	N/A	N/A	1.666	1.657	-9	1.753	1.740	-13	1.844	1.835	-9
Local Flood Event – Scenario B												
Richmond River upstream of Pimlico Island (CH157400)	1.450	1.451	1	1.939	1.939	0	1.948	1.948	0	1.963	1.963	0
Duck Creek upstream of Pacific Highway Bridge (CH164400)	1.254	1.254	0	1.661	1.652	-9	1.742	1.728	-14	1.839	1.841	2
Emigrant Creek upstream of Pacific Highway Bridge (CH164800)	1.248	1.248	0	1.638	1.638	0	1.703	1.710	7	1.819	1.832	13
Richmond River at Burns Point (confluence with Emigrant Creek) (CH166400)	1.286	1.286	0	1.794	1.795	1	1.797	1.798	1	1.802	1.802	0
North of Whytes Lane Overpass on Northbound/Western side (CH160200)	1.401	1.417	18	1.832	1.829	-3	1.948	1.949	1	2.021	2.068	47

Table 5-5 Pre-construction and built conditions results – flow velocity at key river locations, Lower Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Pre-construction (m/s)	Built (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*
Regional Flood Event – Scenario A																
Richmond River upstream of Pimlico Island (CH157400)	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 (CH164400)	0.80	0.81	0.01	<1m/s	0.84	0.81	-0.03	<1m/s	0.77	0.75	-0.02	<1m/s	0.71	0.73	0.02	<1m/s
Emigrant Creek upstream of Pacific Highway Bridge (CH164800)	0.97	0.97	0.00	<1m/s	1.43	1.46	0.03	1.9%	1.44	1.46	0.02	1.0%	1.39	1.39	0.00	0.0%
Richmond River at Burns Point (confluence with Emigrant Creek) (CH166400)	1.22	1.22	0.00	0.0%	1.60	1.60	0.00	0.0%	1.93	1.93	0.00	0.0%	2.20	2.20	0.00	0.0%
North of Whytes Lane Overpass on Northbound/Western side (CH160200)	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	0.04	-0.01	<1m/s
Local Flood Event – Scenario B																
Richmond River upstream of Pimlico Island (CH157400)	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 (CH164400)	0.90	0.91	0.01	<1m/s	0.82	0.83	0.01	<1m/s	0.82	0.91	0.09	<1m/s	0.84	1.00	0.16	<1m/s
Emigrant Creek upstream of Pacific Highway Bridge (CH164800)	1.16	1.16	0.00	-0.3%	1.67	1.67	0.00	0.0%	1.82	1.82	0.00	0.0%	1.92	1.94	0.02	1.1%
Richmond River at Burns Point (confluence with Emigrant Creek) (CH166400)	1.21	1.21	0.00	0.0%	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)	0.03	0.03	0.00	<1m/s	0.07	0.10	0.03	<1m/s	0.10	0.10	0.00	<1m/s	0.14	0.11	-0.03	<1m/s

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

Table 5-6 Pre-construction and built conditions results – flood duration at key river locations, Lower Richmond River

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)	Pre-construction (hrs)	Built (hrs)	Duration change (hrs)	Percentage change (%)
Regional Flood Event – Scenario A																
Richmond River upstream of Pimlico Island * (CH157400)	>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 (CH164400) *	>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 (CH164800) *	>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) (CH166400) *	>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)	N/A	N/A	N/A	N/A	63.75	63.50	-0.3	-0.4%	120.75	120.25	-0.5	-0.4%	159.50	159.75	0.3	0.2%
Local Flood Event – Scenario B																
Richmond River upstream of Pimlico Island * (CH157400)	>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 (CH164400) *	>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 (CH164800) *	>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) (CH166400) *	>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)	14.50	14.25	-0.3	-1.7%	40.25	40.00	-0.3	-0.6%	48.50	48.50	0.0	0.0%	50.75	50.75	0.0	0.0%

*these locations are in the main channels so are always wet for the full model simulation of 200 hours

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.

Table 5-7 Afflux at properties that are flooded above floor level in the Mid-Richmond floodplain

Afflux 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	321
25 to 49 millimetres	0	1	0	29
50 to 249 millimetres	0	0	0	0
250 to 400 millimetres	0	0	0	0
More than 400 millimetres	0	0	0	0

Table 5.8 identifies the number of new properties that experience above floor flooding in built conditions.

Table 5.8 Number of properties that are flooded above floor level in the Mid-Richmond floodplain

Model scenario	Number of properties			
	5 year ARI	20 year ARI	50 year ARI	100 year ARI
Pre-construction conditions	6	86	212	348
Built conditions	6	87	216	350
Change	0	1	4	2

5.3.1.2 Lower Richmond floodplain

Table 5-9 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 50 millimetres.

Table 5-9 Afflux at properties that are flooded above floor level in the Lower Richmond floodplain

Afflux range (millimetres of above floor flooding)	**Number of properties**			
	5 year ARI	**20 year ARI**	**50 year ARI**	**100 year ARI**
Not flooded	4229	4103	4085	4032
Less than 25 millimetres	15	141	159	208
25 to 49 millimetres	0	0	0	4
50 to 249 millimetres	0	0	0	0
250 to 400 millimetres	0	0	0	0
More than 400 millimetres	0	0	0	0

Table 5.10 identifies the number of new properties that experience above floor flooding in built conditions.

Table 5.10 Number of properties that are flooded above floor level in the Lower Richmond floodplain

Model scenario	**Number of properties**			
	5 year ARI	**20 year ARI**	**50 year ARI**	**100 year ARI**
Pre-construction conditions	15	141	156	208
Built conditions	15	141	159	212
Change	0	0	3	4

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 feasible and reasonable 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 worked with individual stakeholders to address instances where we have been unable to achieve all of the flood management objectives.

Table 5-11 summarises the number of privately owned lots at which the flood management objectives are not achieved. This includes eight lots owned by TfNSW and three lots owned by others.

Table 5-11 Privately owned lots that have departures from the flood management objectives

Woolgoolga to Ballina project section	Number of privately owned lots with flooding departures		
	Afflux	Duration	Velocity
Devils Pulpit Upgrade to Trustums Hill	0	0	0
Trustums Hill to Broadwater National Park	2	2	0
Broadwater National Park to Richmond River	0	0	0
Richmond River to Coolgardie Road	6	0	0
Coolgardie Road to Ballina Bypass	1	0	0
Note: number of affected lots includes TfNSW owned land			

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 5-12.

Table 5-12 Habitable structures that have departures from the flood management objectives

Woolgoolga to Ballina project section	Number of habitable structures with flooding departures		
	Afflux	Duration	Velocity
Devils Pulpit Upgrade to Trustums Hill	0	0	0
Trustums 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
Note: number of affected habitable structures includes TfNSW owned properties			

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 has provided 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 has improved flood access and evacuation within the floodplain. Access out of the Richmond River regional floodplain and the surrounding local catchments was mainly by the former Pacific Highway and a number of local access roads connecting to the highway.

5.5.1 Time of highway closure

The project has provided 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 former highway through the Richmond regional floodplain has a flood immunity of less than the 20 year ARI event. The portion of former 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 former 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 5.12 shows during a 5 year ARI event, the lowest part of the former highway between Woodburn and Broadwater would be inundated for about 30 hours. During a 20 year ARI event, this part of the former highway would be closed for about 90 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 former highway would be closed for up to five days. This closure time is reduced significantly to about three days for the upgraded highway.

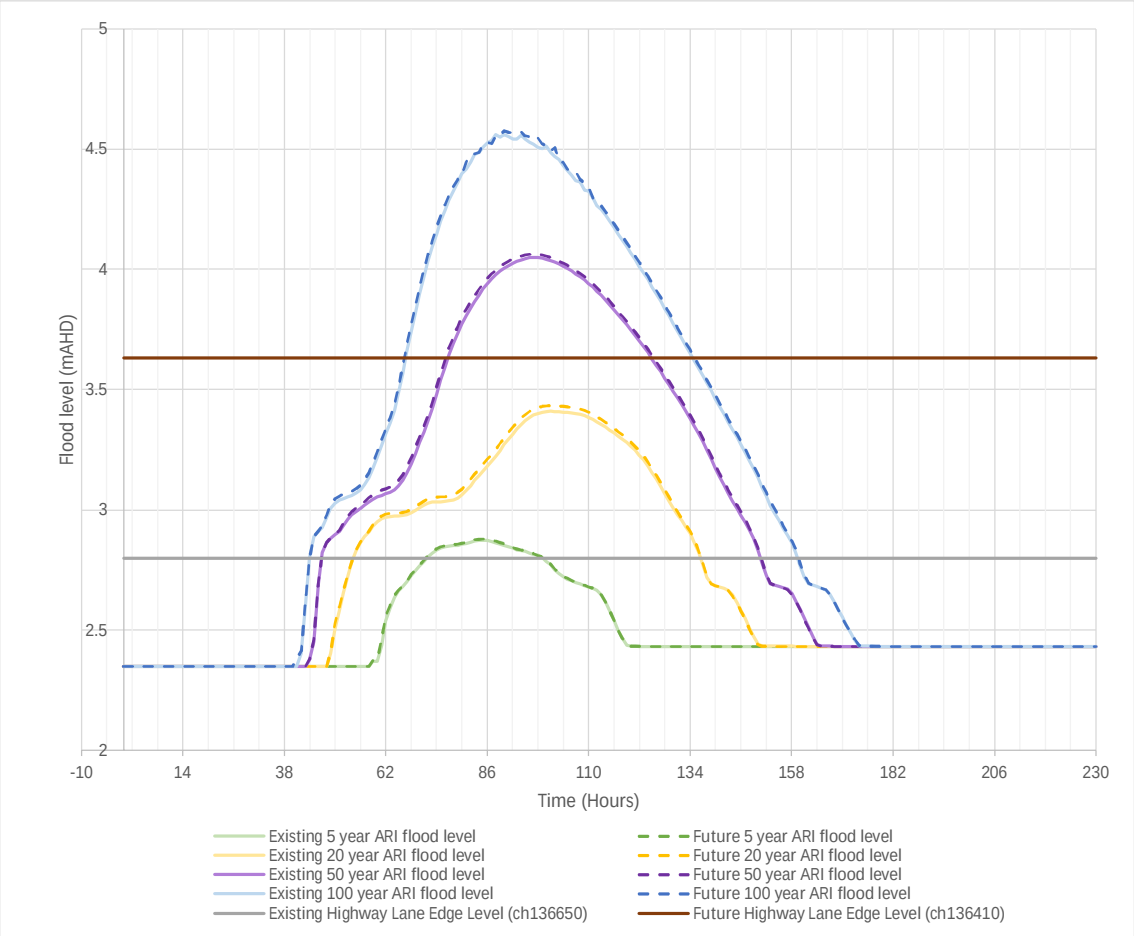

Figure 5.12 Inundation time for former and upgraded Pacific Highway - at lowest point of former highway and lowest point of upgraded highway between Woodburn and Broadwater

5.5.2 Local access and property access assessment

Service roads connecting to the upgraded highway have been designed to retain or improve pre-construction flood immunity. Local and property access has been 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 pre-construction conditions for all modelled events. Due to the large catchment and large flows, the highway upgrade has little effect on the pre-construction case 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 Climate change sensitivity analysis

Future climate change projections have the potential to change the flood behaviour of catchments assessed as a part of this project and could result in an increase in rainfall intensities and sea levels. This section addresses the potential for this change in flood behaviour to impact on the project.

5.6.1 Climate change projections

For the assessment of climate change, the projected changes in climate behaviour were assessed for the mid-point in the project design life of 100 years. It was assumed that the project would be open to traffic in 2020 and this makes the projected 2070 climate change conditions the central point (2020 to 2120) in the design life.

Climate change projections were assessed using CSIRO and NSW Government advice (current at the time of the assessment) and then reviewed for consistency with the EIS and other projects within the Pacific Highway Program. Based on this assessment and consistency review approach, the following climate change projections were adopted. These projections were adopted so that a consistent comparison against the EIS climate change impacts could be carried out:

- sea level increase of +0.6m
- 10 percent increase in flow, similar to 10 percent increase in rainfall as prescribed by the guidelines representing assumed future conditions for 2070 – the halfway point of the project design life (note that the 10 percent factor was applied to flows rather than rainfall because the original rainfall-runoff models were not made available).

It is noted that the guidance on allowances for climate change have since been superseded by ARR2019 during the course of this project. A check against the ARR2019 guidance (interim climate change factors from the ARR Datahub) found that the chosen projections above would be close to Representative Concentration Pathway for climate change (RCP) 4.5 for the year 2090.

5.6.2 Results

5.6.2.1 Mid-Richmond River catchment

The results for the climate change assessment for the 100 year and 20 year ARI events are presented in Table 5-13. The results demonstrate that the climate change peak flood levels are up to 0.38 metre higher than present day flood levels in the 100 year ARI event. The climate change flood extent is generally less than 100 metres wider in lateral extent than the present day climate conditions flood extent across the model domain. For the 20 year ARI built condition with climate change, the results are up to 0.46 metre higher than present day levels.

Figures F001 to F004 are provided in Appendix F and show the flood level difference (afflux) for the climate change assessment. The assessment shows that even though flood levels have increased across the floodplain, the impact range is very similar to the predictions for the present day climate conditions (refer Appendix C).

Table 5-13 100 year and 20 year ARI climate change peak flood levels for the Mid-Richmond catchment

Location	Pre-construction conditions				Built conditions			
	100y ARI + climate change (mAHD)	100y ARI (mAHD)	20y ARI + climate change (mAHD)	20y ARI (mAHD)	100y ARI + climate change (mAHD)	100y ARI (mAHD)	20y ARI + climate change (mAHD)	20y ARI (mAHD)
Coraki - (U/S of Coraki Rd Bridge) (CH133700)	6.60	6.51	6.22	6.14	6.60	6.51	6.22	6.14
Bungawalbin Junction (CH130400)	5.69	5.53	5.01	4.83	5.69	5.54	5.01	4.83
Woodburn - (U/S of Court St Bridge) (CH131000)	5.06	4.74	4.04	3.85	5.07	4.75	4.05	3.85
Tuckombil Canal (Former Pacific Highway Bridge) (CH130200)	5.05	4.76	4.08	3.89	5.06	4.77	4.09	3.89
Broadwater (U/S of new Broadwater Bridge) (CH142800)	4.38	4.02	3.13	2.72	4.39	4.03	3.14	2.74
Bagotville (D/S of Bagotville Rd Bridge) (CH148000)	4.49	4.12	3.18	2.72	4.50	4.14	3.20	2.74
Upgraded Tuckombil Canal (U/S of C04) (CH130200)	4.91	4.58	3.70	3.42	4.95	4.58	3.70	3.43
Upgraded Woodburn Floodway (U/S of C05) (CH131100)	4.92	4.58	3.73	3.27	4.92	4.61	3.74	3.26
New Richmond River Bridge (U/S of Portion F) (CH145800)	4.24	3.89	3.02	2.60	4.26	3.91	3.03	2.62

5.6.2.2 Lower Richmond River catchment

The results for the climate change assessment for the 100 year and 20 year ARI events are presented in Table 5-14 below. The results demonstrate that the climate change peak flood levels are up to 0.46 metre higher than present day climate flood levels for the 100 year ARI event. The climate change flood extent is generally less than 100 metres greater than the present day climate flood extent across the model domain. For the 20 year post- upgrade condition with climate change, the results are up to 0.44 metre higher than present day conditions.

Flood level change (afflux) figures for the climate change assessment are provided in Appendix F for the Lower Richmond catchment. The assessment shows that even though flood levels have increased across the floodplain, the impact range is very similar in most areas to the predictions for the present day provided in Appendix E, except for one isolated area on the western side of the highway between CH162500 and 164000 that is affected for the 100 year ARI climate change scenario (refer to figure F006).

In this localised area, the predicted impact would exceed the flood management objectives for the 100 year ARI event for the project if climate change projections were realised to a maximum of 90 millimetres afflux. There are three dwellings located within the affected area with one predicted to be impacted above floor level to a depth of 51 millimetres. The remaining two dwellings have floor levels located above the 100 year ARI with climate change flood level.

Table 5-14 100 year and 20 year ARI climate change peak flood levels for the Lower Richmond catchment

Location	Pre-construction condition				Built conditions			
	100y ARI + climate change (mAHD)	100y ARI (mAHD)	20y ARI + climate change (mAHD)	20y ARI (mAHD)	100y ARI + climate change (mAHD)	100y ARI (mAHD)	20y ARI + climate change (mAHD)	20y ARI (mAHD)
Richmond River upstream of Pimlico Island (CH157400)	3.06	2.75	2.37	1.94	3.06	2.75	2.36	1.94
Duck Creek upstream of Pacific Highway Bridge (CH164400)	2.24	1.84	2.04	1.66	2.24	1.84	2.04	1.65
Emigrant Creek upstream of Pacific Highway Bridge (CH164800)	2.24	1.82	2.04	1.64	2.24	1.83	2.04	1.64
Richmond River at Burns Point (confluence with Emigrant Creek) (CH166400)	2.26	1.80	2.24	1.79	2.26	1.80	2.24	1.80
North of Whytes Lane Overpass on Northbound/Western side (CH160200)	2.28	2.02	2.05	1.83	2.31	2.07	2.00	1.83

5.6.2.3 Local catchments

A sensitivity analysis was also undertaken for the 100 year ARI event for the local catchments outside of the Mid-Richmond and Lower Richmond regional floodplains. A 10 to 15 percent increase to the design rainfall intensity was modelled. Results show that hydraulic impacts under climate change conditions are in a similar range to those for the present day design conditions, with some localised increases in affected areas.

5.7 Extreme event sensitivity analysis

The Probable Maximum Flood (PMF) is an estimate of the upper limit of flood magnitude or largest flood that can occur in a specific catchment. The Probable Maximum Flood (PMF) event is based on Probable Maximum Precipitation (PMP) rainfall estimates combined with a downstream ocean level of a 500 year ARI storm surge. This section documents the interaction of the estimated PMF for the Richmond regional catchment.

5.7.1 Results

5.7.1.1 Mid Richmond River catchment

Figures F007 to F008 in Appendix F demonstrate the pre-construction case PMF flood depth and extent. The results at key reporting locations are included in Table 5-15. The results indicate that the PMF peak flood levels are up to 3.7 metres higher than the 100 year ARI peak flood levels. The flood extent for the PMF is significantly wider than the 100 year ARI flood extent for most of the model domain and particularly though Broadwater National Park where the PMF flood is up to 500 millimetres more extensive than the 100 year ARI flood extent.

Table 5-15 Mid Richmond River PMF and 100 year ARI peak flood levels

Location	Pre-construction conditions		
	PMF (mAHD)	100y ARI (mAHD)	Difference (m)
Coraki - (U/S of existing Coraki Rd Bridge) (CH137700)	8.60	6.51	2.09
Bungawalbin Junction (CH130400)	8.44	5.53	2.91
Woodburn - (U/S of Court St Bridge) (CH131000)	8.31	4.74	3.57
Tuckombil Canal (Former Pacific Highway Bridge) (CH130200)	8.27	4.76	3.51
Broadwater (U/S of new Broadwater Bridge) (CH142800)	7.70	4.02	3.68
Bagotville (D/S of Bagotville Rd Bridge) (CH148000)	7.77	4.12	3.65
Upgraded Tuckombil Canal (U/S of C04) (CH130200)	8.26	4.58	3.68
Upgraded Woodburn Floodway (U/S of C05) (CH131100)	8.25	4.58	3.67
New Richmond River Bridge (U/S of Portion F) (CH145800)	7.48	3.89	3.59

5.7.1.2 Lower Richmond River catchment

Figure F009 in Appendix F demonstrates the pre-construction case PMF flood depth and extent. The results at key reporting locations are included in Table 5-16.

The results indicate that the PMF flood extent is significantly greater than the 100 year ARI flood extent. Near the project the PMF extends beyond the 100 year ARI near Pimlico Island and on the western side of the project the PMF extends further to the west up to the end of the project in the north. It can be seen that the PMF through the area is up to 1.7 metres higher than the 100 year ARI peak flood level.

Table 5-16 Lower Richmond River PMF and 100 year ARI peak flood levels

Location	**Pre-construction conditions**		
	PMF (mAHD)	**100y ARI (mAHD)**	**Difference (m)**
Richmond River upstream of Pimlico Island (CH157400)	4.46	2.75	1.71
Duck Creek upstream of Pacific Highway Bridge (CH164400)	3.21	1.84	1.37
Emigrant Creek upstream of Pacific Highway Bridge (CH164800)	3.21	1.84	1.37
Richmond River at Burns Point (confluence with Emigrant Creek) (CH166400)	3.18	1.80	1.38
North of Whytes Lane Overpass on Northbound/Western side (CH160200)	3.18	1.82	1.36

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.

The design changed below were assessed in the flood model, after the publication of the draft hydrological mitigation report in April 2017 included:

- additional minor drainage added to side roads and access tracks to retain existing low flow paths
- raised property access track near Lang Hill
- revised configuration for the access track for work on the new bridge over the Richmond River bridge

If the design refinements investigated did not have any adverse impacts to the flooding outcomes as identified in this report, no further action was taken in regards to consultation or approvals. The work proceeded as proposed subject to consideration of other project approval requirements. The project team also consulted with DPIE to determine whether any further approvals were required.

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 TfNSW 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 Oxleyan Pygmy Perch (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 built works 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.

At the issued for construction design stage, none of the above mitigation measures have been required as the flood impacts have been compliant over most of the regional floodplain. Table 6.2 outlines where flooding departures have been identified and agreed with landowners.

6.2.2 Schedule of departures and mitigation measures

Table 6.2 provides the schedule of departures from the flood management objectives and associated mitigation measures.

The project team has worked with landowners and the independent hydrologist to resolve departures through the design process; however a small number of departures remain that were not able to be mitigated by design refinements.

Drainage and flooding concerns raised by landowners have been reviewed by the independent hydrologist. The independent hydrologist review did not result in any additional departures.

In one instance, more refined flood modelling was carried out as a result of the independent hydrologist's review to confirm the impacts and compliance status.

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	Consultation undertaken?	Status
			Afflux	Velocity	Duration				
1	Cross drainage culverts: CL-135210, CL135160	135000 (mid Richmond River regional catchment)	20 year ARI event	None	None	Lot 104 DP755624 (TfNSW owned land) Lot 6 DP755624 (TfNSW owned land)	The project team has consulted with TfNSW Services. TfNSW have accepted the departures as outlined. Please note TfNSW have confirmed they will accept technical departures and will ensure any future use of the property encompasses the detail/restrictions pertaining to the technical departures.	Yes - finalised	Agreement reached
2	Cross drainage culvert: CL-136820	137000 (mid Richmond River regional catchment)	None	None	5, 20, 50 and 100 year ARI events	Lot 133 DP839607 (TfNSW owned land)	The project team has consulted with TfNSW. TfNSW have accepted the departures as outlined. Please note TfNSW have confirmed they will accept technical departures and will ensure any future use of the property encompasses the detail/restrictions pertaining to the technical departures.	Yes - finalised	Agreement reached
3	Cross drainage culvert: CL-147213	147200 (mid Richmond River regional catchment)	50 year ARI event	None	None	Lot 13 DP1212613 Lot 6 DP843369 (TfNSW owned land)	For the private property, the landowner has been consulted and has indicated verbal acceptance of the impacts. For the TfNSW owned land, the project team has consulted with TfNSW. TfNSW have accepted the departures as outlined. Please note TfNSW have confirmed they will accept technical departures and will ensure any future use of the property encompasses the detail/restrictions pertaining to the technical departures.	Yes - finalised Yes - finalised	Agreement reached Agreement reached
4	Bridge D04	149240 (local catchment model)	100 year ARI event	None	None	Lot 2 DP1192234 Lot 3 DP 1192234	Landowner has been consulted and has indicated verbal acceptance of the impacts.	Yes - finalised	Agreement reached
5	Bridge D10	157870 (local catchment model)	5, 20, 50 and 100 year ARI events	None	None	Lot 1 DP1074389 (TfNSW owned land) Lot 2 DP1072389 (TfNSW owned land)	The project team has consulted with TfNSW. TfNSW have accepted the departures as outlined. Please note TfNSW have confirmed they will accept technical departures and will ensure any future use of the property encompasses the detail/restrictions pertaining to the technical departures.	Yes - finalised	Agreement reached
6	Cross drainage culvert: CL-159883	159700 (lower Richmond Regional model)	20, 50 and 100 year ARI events	None	None	Lot 5 DP223267 (TfNSW owned land)	The project team has consulted with TfNSW. TfNSW have accepted the departures as outlined. Please note TfNSW have confirmed they will accept technical departures and will ensure any future use of the property encompasses the detail/restrictions pertaining to the technical departures.	Yes - finalised	Agreement reached
7	Raised access track for landowner	134600 (Mid Richmond Regional model)	None	None	50 year ARI event	Lot 6 DP755624 (TfNSW owned land)	The project team has consulted with TfNSW. TfNSW have accepted the departures as outlined. Please note TfNSW have confirmed they will accept technical departures and will ensure any future use of the property encompasses the detail/restrictions pertaining to the technical departures.	Yes - finalised	Agreement reached

6.3 Mitigation of impacts on access

In all locations the upgrade has provided 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 with 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) and local Council have been provided with information regarding the flood modelling process, the predictions of flood behaviour and the changed floodplain conditions.

Local Council has been provided the detailed design flood model and will be provided the final flood model.

SES will be provided with outputs of the final updated flood model, incorporating the final design, as requested.

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 TfNSW owned land. TfNSW are responsible for maintenance of any drainage and flood mitigation work on TfNSW owned land. Following commissioning of the project, TfNSW have adopted 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 has been 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 POST-PROJECT COMPLETION

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; and the impact mitigation measures incorporated into the design.

The upgrade has provided 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, only two private landowners experience a departure from the flood management objectives on their property. These departures have been the focus of detailed investigation and landholder consultation. Agreements have been reached for all departures and no further assessment is proposed.

More detailed modelling and investigations have been carried out in areas of low risk impacts to confirm compliance with the flood management objectives.

This report has covered the flood behaviour and impacts, departures and consultation with affected landowners up to September 2021 and demonstrates an improvement to departures through design refinements, inclusion of mitigation measures and additional detail into the flood model from the April 2017version of this report. Consultation and investigation of appropriate at property mitigation with affected landowners has been undertaken with no further action proposed.

Positive outcomes for the flood modelling process have been achieved through consultation with DPIE, OEH, 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 Post-project completion

This report reflects the final issued for construction design as of September 2021 including post-IFC design refinements which have been tested in the flood model and approved.

The results provided with this report have resolved as many of the departures as practically possible, with consultation activities on departures completed. Any additional drainage or flooding queries that arise following completion of the project will be addressed by TfNSW, as required.

Appendix A

Independent hydrologist review letter

Appendix B

Pre-construction (existing) conditions flood maps for Mid-Richmond River regional floodplain

Appendix C

Built (future) conditions flood maps for Mid-Richmond River regional floodplain

Appendix D

Pre-construction (existing) conditions flood maps for Lower Richmond River regional floodplain – composite results

Appendix E

Built (future) conditions flood maps for Lower Richmond River regional floodplain – composite results

Appendix F

Climate change and extreme event flood maps for Mid-Richmond and Lower Richmond regional floodplains

Appendix G

Flood impact consultation information