Woolgoolga to Ballina Pacific Highway upgrade

Hydrological mitigation report Glenugie to Devils Pulpit

March 2017

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WOOLGOOLGA TO BALLINA
PACIFIC HIGHWAY UPGRADE

HYDROLOGICAL MITIGATION REPORT GLENUGIE TO DEVILS PULPIT

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

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Terms and definitions

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

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

TERM	EXPLANATION
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
mm	Millimetre
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 Clarence River regional floodplain crossed by the Woolgoolga to Ballina Pacific Highway upgrade. The following sections of the project are located within the Clarence regional floodplain and the floodplains of its significant tributaries:

- Glenugie to Tyndale. This section crosses the floodplains of Pheasants Creek, Coldstream River, Pillar Valley Creek, Chaffin Creek and Champions Creek.
- Tyndale to Maclean. This section crosses the floodplains of Shark Creek and the Clarence River South Arm.
- Maclean to Iluka Road. This section crosses the floodplain of the main Clarence River, James Creek, Serpentine Channel and the Clarence North Arm.
- Iluka Road to Devils Pulpit. This section crosses the floodplains of Tabbimoble Creek and Mororo Creek.

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

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

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

The Woolgoolga to Ballina upgrade team has used flood models developed for the environmental impact statement (EIS), which have been refined to include more detailed input data. The main Clarence River model was originally developed by the local authority in 2004 and subsequently refined for the purposes of the EIS, and subject to ongoing refinement and calibration after the EIS to improve its accuracy and reliability for use in detailed design. The model has been independently reviewed on numerous occasions and is considered to be a highly reliable tool for flood management planning within the catchment.

Due to the scale and complexity of the Clarence River catchment and the areas of the regional floodplain crossed by the project, the existing flood behaviour varies across the project area. In Glenugie to Tyndale and Iluka Road to Devils Pulpit the project is located in the upper to middle catchments of significant tributaries of the Clarence, and the critical flooding processes for floodplain interactions and potential impacts are those dominated by the local tributary catchments rather than the main regional floodplain. From Tyndale to Iluka Road the project passes through the main regional floodplain and the regional scale flood is the dominant process for project interactions and impacts.

In Glenugie to Tyndale and Iluka Road to Devils Pulpit 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 (about 1.5 to 3 m/s). Flooding occurs generally on agricultural or undeveloped land and at individual properties or small population centres.

From Tyndale to Iluka Road, critical flooding occurs for the 72 hour storm, and floodwaters rise and recede over weeks rather than days. Overland flow velocities tend to be in the low range (<1.5m/s). Flooding occurs on extensive areas of agricultural land, individual properties and small population centres as well as the larger population centres of Maclean and Harwood.

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

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

- The project will improve the current flood immunity of the highway. Through the Clarence regional floodplain various sections of the existing highway are prone to flooding at the 2 to the 15 year ARI event. The project will provide a flood immunity of between the 20 and the 100 year ARI to the upgraded highway.
- Within the area between Tyndale and Iluka Road, which are located within the regional floodplain, the project would result in minor changes in flood levels, velocities and durations, with the flood management objectives set by the Conditions of Approval generally achieved. However, there are some localised areas where the flood management objectives are not fully achieved. These are subject to further investigation and consultation.
- Within the Glenugie to Tyndale area of the project, the flood management objectives have not currently been achieved at nine cross drainage locations out of a total of 33, however, the impacts are generally related to localised increases in flood duration with impacts on flood levels and velocities generally meeting the objectives. These impacts are subject to further investigation and consultation.
- The flood management objectives have been achieved within the area between Iluka Road to Devils Pulpit of the project.

The flood impact assessment has included a flood damage assessment which identifies the number of properties that will experience an increase in flood level at the property, including an assessment of the change in above floor flood levels at affected properties. Out of about 760 properties, within the floodplains traversed by the project, only three properties would experience a potential increase in flood level exceeding the limit imposed by the flood management objectives. Investigations into these property impacts are ongoing.

The project will increase flood levels at the Maclean levee by about 15 millimetres. This is an improved outcome when compared with the EIS which predicted a flood level impact of about 30 millimetres at the levee. The improvement is due to refinements in the hydraulic design of the new bridge over the Clarence River at Harwood. While this outcome is an improvement on the EIS and within the limits set by the flood management objectives, the project team is carrying out further investigations and consulting with Clarence Valley Council on the potential impacts of this minor increase in flood level at the levee.

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

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

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

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

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

- upgrading the existing land drainage network to maintain connectivity of low flows and improve drainage time

- removing debris, blockages and vegetation to reinstate or improve flow paths
- upgrading or replacing flood-gated outlets to improve drainage back to the Clarence River

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

Cross drainage infrastructure including culverts and bridges has been optimised during the detailed design process to result in 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 flood management objectives, as far as possible for cane and agricultural lands as well as property and local road access. The additional infrastructure has been designed as floodplain relief structures. The infrastructure in the Glenugie to Tyndale and Iluka Road to Devils pulpit areas has changed marginally since the EIS, but significant increases in the infrastructure have been provided between Tyndale and Iluka Road, with an additional 1.7 kilometres of waterway area provided.

This report currently reflects the design at early December 2016 and as of that date there are some elements of the detailed design still being refined. Work is also ongoing on finalising the mitigation measures required to reduce or eliminate flooding impacts in areas where the flood management objectives are not fully achieved. The results provided with this report have resolved most but not all of these issues and further modelling work is being carried out to assess feasible and reasonable mitigation measures to resolve these issues. Discussions with local landowners and the community are also ongoing. Refer to Table 6.2 for a list of current departures from the flood management objectives.

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

1. INTRODUCTION

1.1 Background

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

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

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

1.2 Project description

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

Key features of the upgrade include:

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

Refer to Figure 1.1 for an overview of the project.

1.2.1 Adjacent Projects

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

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

Figure 1.1 General overview of Woolgoolga to Ballina Pacific Highway upgrade

1.3 Purpose of the report

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

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

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

1.4 Project approvals

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

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

Table 1.1 Minister's Conditions of Approval requirements

CONDITION OF APPROVAL REFERENCE	CONDITION OF APPROVAL	WHERE ADDRESSED
B31	The hydrological and flooding impacts resulting from the SSI are to be assessed during detailed design against the 'Design Objectives for Flood Management' described in Section 2.1 of the EIS Working Paper – Hydrology and Flooding. This shall include assessment against the 'Flood Management Objectives' and the 'Other Flood Impact Considerations' as well as the other requirements of this section of the EIS. The hydrology assessment shall include the refinement of or development of new flood models (where required) for the 14 catchments investigated during the EIS. These models shall be operated for the same design floods considered in the EIS, as well as the 2000 year ARI and the probable maximum flood (PMF) design events.	Section 5
B32	For the Corindi, Shark Creek and Farlows Flat areas, flooding and hydrological impacts resulting from existing highway infrastructure shall be assessed. As part of this assessment, flood models shall assess the impacts of recent highway upgrades in this area. Where the existing highway in these areas has resulted in adverse flooding and/or hydrological impacts, opportunities to reduce the quantum of these impacts shall be considered during the detailed design of the SSI, where feasible and reasonable.	Sections 4 and 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
D13	The Applicant shall prepare and implement a Hydrological Mitigation Report for properties where flooding and/or hydrological impacts are predicted to exceed the relevant flood management objective in the documents listed in condition A2 as a result of the SSI. The Report shall be prepared by a suitably qualified expert and be based on detailed surveys (e.g. floor levels) and associated assessment of potentially flood affected properties in the Corindi, Clarence and Richmond river floodplains. The Report shall:	This report

CONDITION OF APPROVAL REFERENCE	CONDITION OF APPROVAL	WHERE ADDRESSED
	(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 existing velocity is above 1.0m/s
	Grazing, forested and other rural lands	Below 1.0m/s where currently below this figure An increase of not more than 20% where existing velocity is above 1.0m/s
Flood direction	Residences	No change to the direction of watercourses or the direction of flood flows except for constriction in and expansion out of discrete openings (culverts and bridges) and construction diversions
	Cane farm land	
	Grazing, forested and other rural lands	

1.6 Independent hydrologist

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

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

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

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

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

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

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

1.7 Status of report

This report currently reflects the design at early December 2016 and as of that date there are some elements of the detailed design still being refined.

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

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

2. CONSULTATION

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

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

2.1 Consultation with government agencies

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

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

2.1.1 Environmental review group workshops

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

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

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

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

2.1.2 Additional agency consultation

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

2.2 Consultation activities

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

The purpose of the flooding consultation was to:

- provide the community with an opportunity to contribute to the process of managing potential impacts of the Woolgoolga to Ballina Pacific Highway upgrade

- provide the community with a update on the flood modelling process
- consult with landowners directly impacted in areas where the flood management objectives are not achieved.

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

2.2.1 Presentation

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

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

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

2.2.2 Stakeholder meetings

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

Table 2.1 Stakeholder meetings

Date	Stakeholder
20 July 2016	Clarence Valley Council
28 July 2016	Clarence Cane Growers and Harwood Sugar Mill
17 August 2016	Clarence Valley Council
23 August 2016	Shark Creek cane farmers, Clarence Cane Growers and Harwood Sugar Mill
24 August 2016	Clarence Valley Council
24 August 2016	State Emergency Services

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.

Three 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 group meetings

Date	Group	Location	Number of attendees
28 July 2016	Clarence River floodplain (north of Farlows Flat)	Harwood Community Hall, Harwood	More than 50
23 August 2016	Maclean interchange and Shark Creek	Maclean Civic Centre, Maclean	11
21 September 2016	Pillar Valley	Tucabia Hall, Tucabia	About 20

2.3 Consultation with affected landowners

The project team has been successful in minimising overall flooding impacts in the Clarence 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 meet all of the flood management objectives at all locations, as described in section 1.5.

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

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

2.4 Feedback

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

2.4.1 Agency feedback

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

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

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

2.4.2 Community and stakeholder feedback

Key areas of interest identified included:

During construction:

- road closures and accessibility during flooding events
- potential for construction activities to increase the impact of flooding
- maintenance of flooding and drainage infrastructure during construction

During operation:

- potential impact of the new bridge over the Clarence River at Harwood including overtopping of the Maclean levee
- potential increases in inundation on cane land
- maintenance of flooding and drainage infrastructure during operation including: mitigation measures proposed to manage potential debris build up; Shark Creek siltation; and predicted impacts to Lees and Crackers drains

Modelling validity and design:

- modelling process and accuracy of flood models' baseline assessments and inclusion of real data critical for ensuring accuracy of flood modelling
- flood modelling at Ferry Park
- design at Norleys and Gallagher's Lane
- Goodwood Street drainage
- flood gates and flood openings.

Consultation:

- support for the consultation process demonstrating the feedback received during the project's development had been incorporated into design
- consultation process for departures from the objectives.

2.5 Consultation by independent hydrologist

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

Table 2.3 Engagement activities involving WMAwater

Date	Stakeholder	Type of engagement
28 July 2016	Clarence Valley Council	Meeting
28 July 2016	Clarence Cane Growers and Harwood Sugar Mill	Presentation
23 August 2016	Shark Creek cane farmers, Clarence Cane Growers and Harwood Sugar Mill	Presentation
24 August 2016	State Emergency Services	Meeting
28 July 2016	Clarence River floodplain (north of Farlows Flat)	Flood focus group
23 August 2016	Maclean interchange and Shark Creek	Flood focus group
23 August	Property owner – Tyndale	Meeting
21 September 2016	Pillar Valley waterways	Flood focus group
22 September 2016	Property owner –Tyndale (follow up consultation #2)	Meeting
27 September 2016	Property owner – Glenugie Property owner – Glenugie	Video conference
15 November 2016	Property owner – Glenugie (follow up consultation #2) Property owner – Glenugie (follow up consultation #2)	Meeting
16 November 2016	Property owner – Tyndale	Meeting

Date	Stakeholder	Type of engagement
16 November 2016	Property owner – Tyndale (follow up consultation #3)	Meeting
8 February 2017	Property owner –Tyndale (follow up consultation #2)	Meeting
8 February 2017	Property owner – Glenugie (follow up consultation #3) Property owner –Glenugie (follow up consultation #3)	Meeting
8 February 2017	Property owner – Tucabia	Meeting

2.6 Adaptive management

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

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

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

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

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

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

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

- evidence of consultation with agencies.

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

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

2.7 Future consultation

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

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

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

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

3. STUDY AREA AND EXISTING FLOODING BEHAVIOUR

3.1 Catchment overview

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

- Tyndale to Maclean
- Maclean to Iluka Road, including the new bridge over the Clarence River at Harwood

Assessment of the flooding impacts of the permanent work in other local floodplain systems within the Clarence River system but outside of the regional floodplain has been carried out. These local catchments lie within the areas between Glenugie to Tyndale and Iluka Road to Devils Pulpit to the south and north of the Clarence River regional floodplain, and include:

- Glenugie to Tyndale local catchments:
  - Pheasants Creek
  - Coldstream River
  - Pillar Valley Creek
  - Chaffin Creek
  - Champions Creek
- Iluka Road to Devils Pulpit local catchments:
  - Tabbimoble Creek
  - Mororo Creek

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

3.1.1 Regional catchment

The Clarence River catchment is the largest on the east coast of NSW, with a catchment area of about 22,700km^2. The catchment extends from the Border ranges in the north; the Northern Tablelands (Stanthorpe to Glen Innes) in the west and from the Doughboy Ranges and the Dorrigo Plateau in the south. The river passes through a number of towns and small urban centres including Grafton, Lawrence, Maclean, Yamba, Harwood and Iluka. The river flows south, east and ultimately north-east to the Pacific Ocean at Yamba.

The upper catchment is generally forested land and the middle catchment is predominantly a mixture of cropping or pasture agricultural use.

The lower Clarence floodplain is predominantly rural residential properties with some small urban centres concentrated along the banks of the Clarence River including:

- Tyndale
- Maclean
- Harwood
- Chatsworth Island

The lower Clarence catchment land use is sugar cane which is grown intensively around Maclean, Harwood Island and Palmers Island. Shark Creek in the lower catchment can influence flooding of the area, however the Clarence River flows to Grafton are so great the flood behaviour of the lower floodplain tends to be dominated by flows from the upper catchment. The river is tidally influenced over a large section of the lower portion of the catchment with the estuary reaching more than 100 kilometres inland from the ocean.

Maclean is a small urban centre to the west of the upgrade and is located on the eastern bank of the Clarence River. Maclean is protected by the Maclean levee constructed in 1975.

Harwood is a small urban centre located on the northern bank of the Clarence River, next to the existing Pacific Highway, which will be duplicated and upgraded in this area. Harwood is positioned both east (downstream) and west (upstream) of the northern embankment of the existing and future case bridges over the Clarence River at Harwood.

3.1.2 Local catchments

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

3.1.2.1 Glenugie to Tyndale local catchments

The project traverses the lower Clarence River catchments of Pheasants Creek and the Coldstream River. Pillar Valley, Chaffin and Champions Creeks are tributaries of the Coldstream River crossing the alignment in this area. These tributaries generally flow south to north or east to west across the alignment towards the Clarence River. The terrain in this area is undulating and is largely forested with some areas of cleared pasture in the valleys.

3.1.2.2 Iluka Road to Devils Pulpit local catchments

The northern bank of the Clarence River North Arm and extends about 16 kilometres north along the alignment of the existing Pacific Highway. The local catchments in this area are Tabbimoble Creek and Mororo Creek.

Tabbimoble Creek is the larger of the two with a catchment area of about 35km^2 compared with Mororo Creek's catchment area of about 8km^2 hectares (incorporating the tributary named Garrets Gully). Tabbimoble Creek drains west to east across the alignment and ultimately joins the Esk River about six kilometres to the east of the existing highway.

Mororo Creek drains east to west across the alignment and discharges into the Back Channel sub-catchment of the Clarence River floodplain. The land use of the catchment is a mixture of rural/agricultural land and forest.

3.2 Existing flooding behaviour

This report covers from Pillar Valley Creek to Tabbimoble Overflow, including the Clarence River floodplain between Shark Creek to Clarence River North Arm. The lower floodplain areas of the Clarence are subject to frequent and extensive flood inundation. The existing flooding behaviour described in this section is based on the flood modelling analyses discussed in section 4.

3.2.1 Glenugie to Tyndale

As shown in Figure 3.1 the Woolgoolga to Ballina upgrade will traverse the lower Clarence River catchments of Pheasants Creek and the Coldstream River. Pillar Valley Creek, Chaffin Creek and Champions Creek are tributaries of the Coldstream River, which cross the alignment in this section. The terrain in the southern part of this section is undulating and ground cover is largely forested with some areas of cleared pasture in the valleys.

Pheasant Creek is a forested and partially confined minor waterway crossed by the project near its junction with Picaninny Creek. The catchment area of Pheasant Creek to this point is 4.74km^2. The land use in the catchment is mostly forest (Glenugie State Forest). The upper parts of Picaninny Creek (upstream of the existing Pacific Highway) have been cleared for agricultural purposes.

Further north, the Coldstream River runs in a general south to north direction. The main channel of the Coldstream River crosses the project west of Pillar Valley and has a catchment area at this location of 113km^2. The highest elevation in the catchment is about 300 metres and the upper reaches are steep with slopes of up to 25 percent. The slope reduces quickly to be generally less than five percent throughout the majority of the catchment.

The upper parts of the Coldstream River catchment are heavily forested and include Yuraygir National Park, Newfoundland State Forest and Glenugie State Forest. Some areas have been cleared for farming, with the greater proportion of farming land in the valleys and the lower part of the catchment. The lower part of the Coldstream River flows along the eastern side of a large basin within the Clarence River floodplain before joining the Clarence River South Arm.

Champions Creek is a tributary of Coldstream River and flows generally east to west from its eastern boundary to Somervale Road east of Tucabia. Further downstream, the creek turns north-west before joining with Coldstream River. The lower portion of the catchment has some clearing, but the majority of the catchment is dense forest. A large portion of the catchment is situated within Pine Brush State Forest.

This area of the upgrade is in an undeveloped area, with the proposed alignment located well away from the existing Pacific Highway. The existing Pacific Highway heads north towards Grafton and into the Clarence River regional floodplain before heading east and runs along the eastern bank of the Clarence River. The proposed alignment through this area is located on the edge of the regional floodplain. The regional flood levels tend to be higher than the local catchment flood levels along the alignment, particularly for the lower lying creek systems. However, the project has the potential to impact on local catchment flooding processes more than the regional flooding processes in this area.

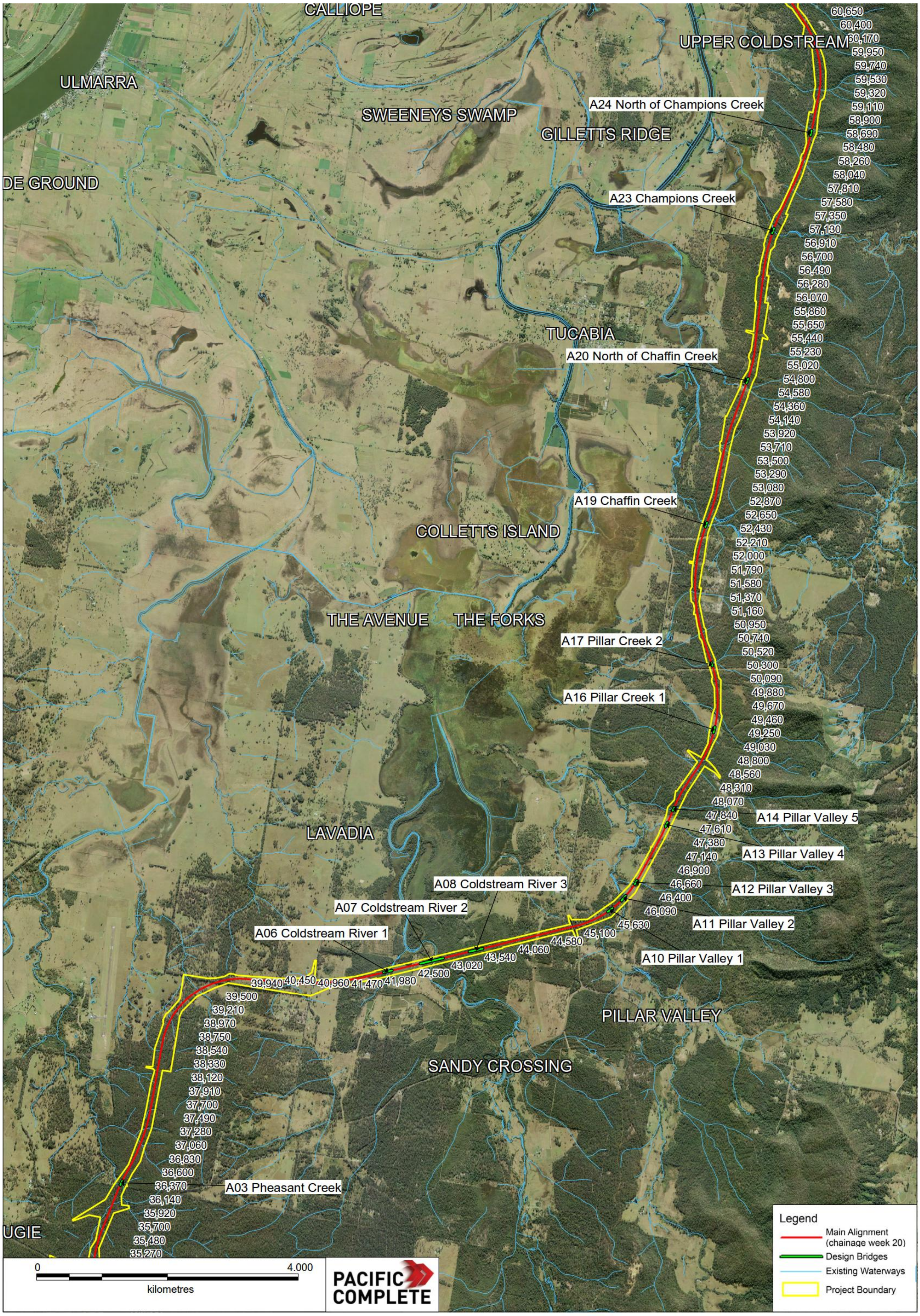

Figure 3.1 Overview of Glenugie to Tyndale

3.2.2 Tyndale to Maclean

As shown in Figure 3.2 the upgrade between Tyndale and Maclean is being built in an undeveloped area, with the alignment proposed about one to two kilometres east of the existing Pacific Highway which runs along the eastern bank of the Clarence River South Arm.

The existing Pacific Highway through the Clarence River floodplain has a varying flood immunity up to the 20 year Average Recurrence Interval (ARI), with some areas of the highway experiencing a flood immunity of less than a 5 year ARI event. Flooding in this area interacts with cane drain systems, flood gates, water/catchment basins and tributaries.

The highway crosses a number of cane drain networks at Tyndale. When flows break out of the Clarence River they spread east and start to inundate the flat and expansive floodplain and fill the network of cane drains. These cane drains then drain the water from the sugar cane fields back to the Clarence River via a series of flood-gated outlets. The largest cane drains that are crossed by the alignment are locally known as Crackers Drain and Lees Drain.

Breakouts from the Clarence River occur even in the 5 year ARI event when the existing Pacific Highway is overtopped south of Shark Creek. In events greater than a 5 year ARI event, large portions of the existing Pacific Highway in this section overtop along areas of both the Shark Creek and Chaselings Basin. These areas fill up during a regional flood event and remain inundated for typically more than a week after the main river flood peak has passed. The floodwaters then drain slowly from the flood-gated channels of the basin (including Crackers Drain, Lees Drain and Edwards Creek).

The alignment crosses the Shark Creek basin and Shark Creek channel. Shark Creek basin receives floodwater from the Clarence River when flows break out and move east into the Shark Creek basin. The Shark Creek basin also receives runoff from the local Shark Creek catchment on the east side of the alignment. Minor flooding occurs for the 5 year ARI event and widespread flooding is predicted for the larger events. Flooding in this area occurs when flood waters from the Clarence River overtops or spills into the floodplains. The Shark Creek basin and Chaselings Basin also fill with floodwaters from the Clarence River in events larger than a 5 year ARI.

North of Shark Creek, the upgraded highway runs parallel to the existing highway and through the Chaselings Basin. The Chaselings Basin receives water from the Clarence River when it breaks out at Ferry Park during events larger than the 5 year ARI. As the flood recedes some floodwaters leave the Chaselings Basin via Edwards Creek near Ferry Park.

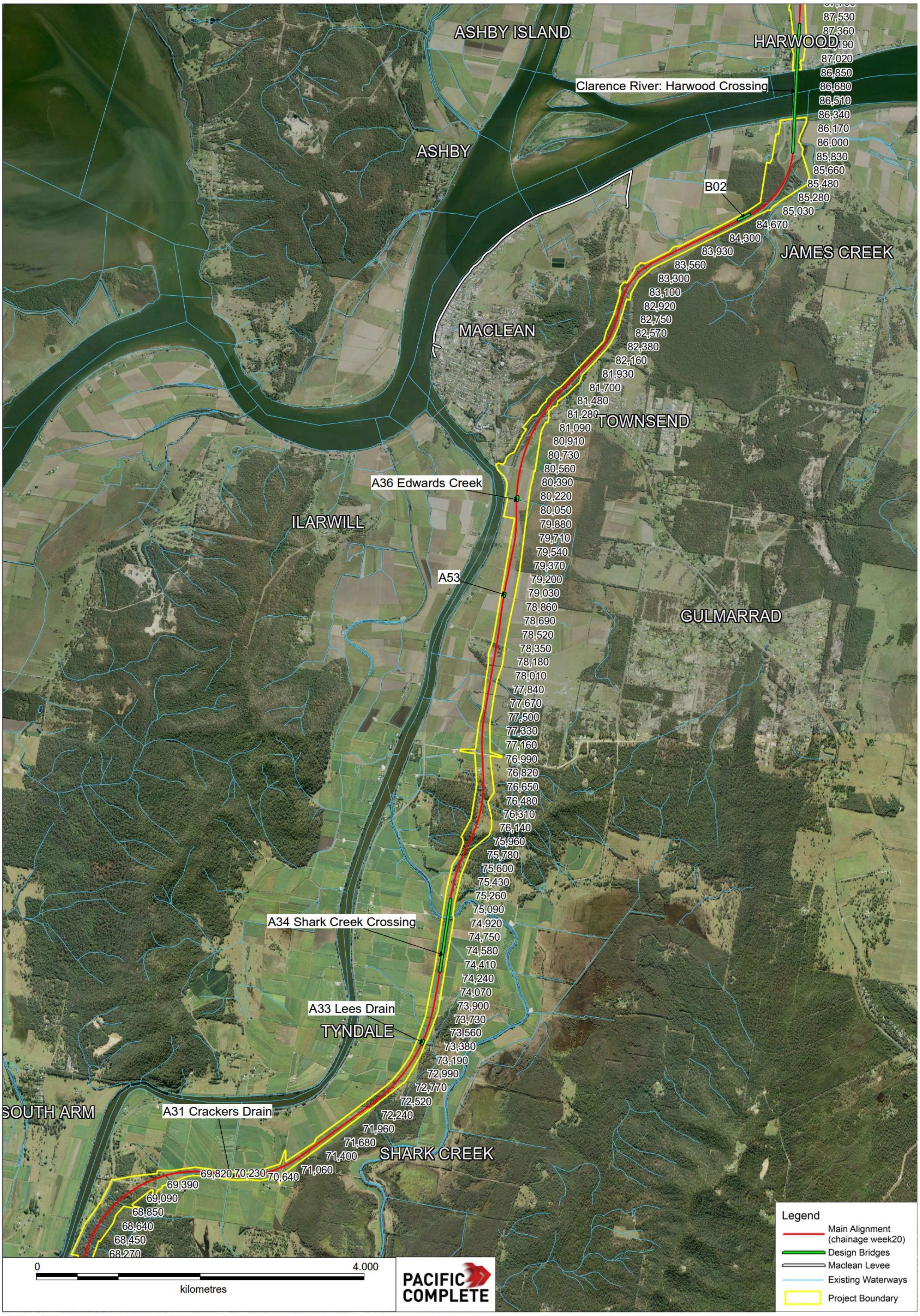

Figure 3.2 Overview of Tyndale to Maclean

3.2.3 Maclean to Iluka Road

A show in Figure 3.3, the project involves the upgrade and duplication of the existing Pacific Highway from Maclean to Iluka Road. The alignment traverses an area locally known as Farlows Flat.

This area experiences widespread flooding in all events in the vicinity of the alignment. The existing Pacific Highway through the Clarence River floodplain has a varying flood immunity up to the 20 year ARI event, with some areas of the highway experiencing a flood immunity of less than the 5 year ARI event.

Sugar cane farming occurs on the western side of the highway, where the existing highway has formed a barrier between the brackish tidal waters from the ocean and fresh water from the upstream catchment. The only existing cross drainage structure crossing the existing highway through the Farlows Flat area is a flood gated box culvert at the southern end of Farlows Flat.

The existing highway prevents brackish water from James Creek, which is tidally influenced, mixing with the fresh water on the western side of the alignment. Floodwaters that break out of the Clarence River at Yamba Road flow south towards a low swampy area at Farlows Flat.

In the Farlows Flat area the most recent highway works carried out in 2012 provides a flood immunity between 5 and 20 year ARI events (estimated in previous studies at about a 17 year ARI). The existing highway provides separation of brackish water and prevents water pushing west into Farlows Flat from James Creek during lower order events. There is only one flood gated culvert crossing through the existing highway that is operated to let water drain out of Farlows Flat and to the east into James Creek once the flood peak has passed.

Further north the alignment crosses the Clarence River at Harwood and continues through the flat floodplain areas of Harwood Island. The alignment then crosses Serpentine Creek and Chatsworth Island, continuing across the low lying floodplain and cane farmland with flows breaking out from Serpentine Channel and spreading north and south.

Flooding in this area, interacts with cane drain systems, flood gates, water/catchment basins and tributaries. The distribution of floodwaters from the Clarence River, Serpentine Channel and Clarence River North Arm, in conjunction with the flat terrain across the island and existing cane farm drain system produces complex flow behaviours.

Throughout Harwood and Chatsworth Islands, the highway crosses a number of cane drain networks which convey low flows throughout the floodplain and fill the network of cane drains. During high flows these cane drains also drain the water from the sugar cane fields back to the Clarence River via a series of flood-gated outlets.

The existing highway through Harwood and Chatsworth Islands has a flood immunity of less than a 5 year ARI event around Serpentine Creek. For large flood events that exceed a 20 year ARI, flow breaks out of the main channel of the Clarence River with the dominant flow direction from west to east across the floodplain of Harwood and Chatsworth Islands. The highway at Serpentine Creek is the lowest section of the highway and usually the first section to be overtopped in significant flood events. This has typically resulted in road closures of this section lasting several days.

The Clarence River North Arm and Chatsworth Road areas experience multi-directional flow between the river channel and floodplain. The new alignment travels alongside Mororo Bridge and crosses the Clarence River North Arm and Chatsworth Road. This area experiences multi-directional flow between the river channel and floodplain and is tidally influenced. For large flood events exceeding a 20 year ARI event, most of this area is inundated for more than 72 hours.

For flood events that exceed a 5 year ARI, flow breaks out of the main channel upstream and downstream of the Mororo Bridge and is generally conveyed from west to east, but at some stages of the flood hydrograph the flow direction reverses from east to west. Eddying of the flow occurs on the east side of the existing highway around localised high points on the floodplain. There is also a less dominant localised flow from north to south along and over the existing highway during the 20 year ARI event.

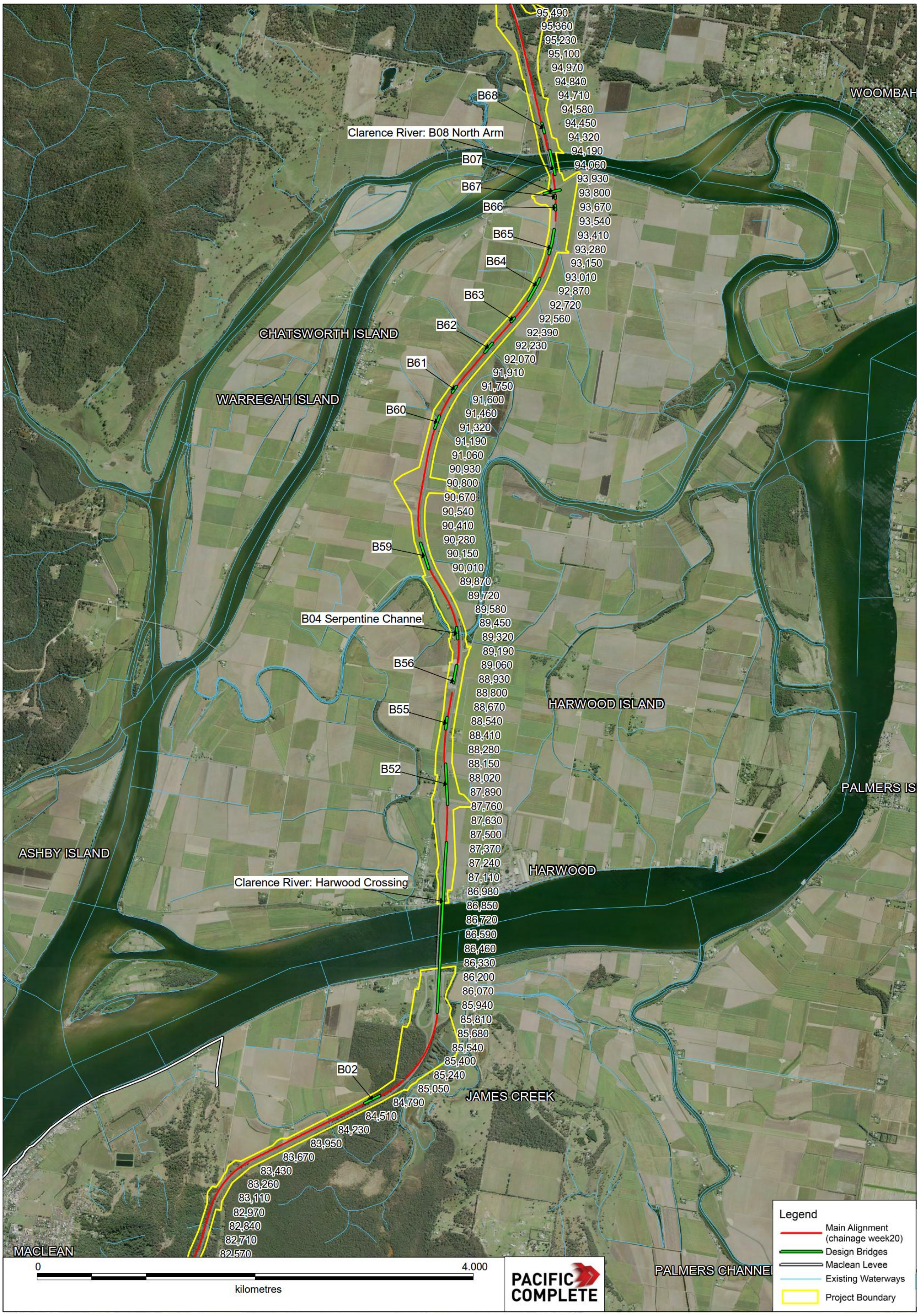

Figure 3.3 Overview of Maclean to Iluka Road

3.2.4 Iluka Road to Devils Pulpit

As shown in Figure 3.4, the upgrade travels between Iluka Road and Devils Pulpit beside the existing alignment, this area includes the local catchments of Mororo Creek and Tabbimoble Creek. Flooding in this area interacts with cane drain systems, flood gates, water/catchment basins and tributaries.

The project runs north to south through the Mororo Creek catchment of about 8km^2 (incorporating the tributary named Garrets Gully) and traverses several small and steep sub-catchments in the eastern half of the catchment in addition to a relatively wide and flatter main catchment on the Clarence River floodplain.

Tabbimoble Creek is the larger of the two local flooding sources with a catchment area of about 35km^2 and is crossed by the highway further north. Flows in this area are in a west-to-east direction via several main flow paths (including Tabbimoble Creek and Tabbimoble Overflow), in addition to a number of minor sub-catchment flow paths.

Existing bridges at the crossings of Tabbimoble Creek and Tabbimoble Overflow will be retained with an additional bridge built on the upstream (western) side.

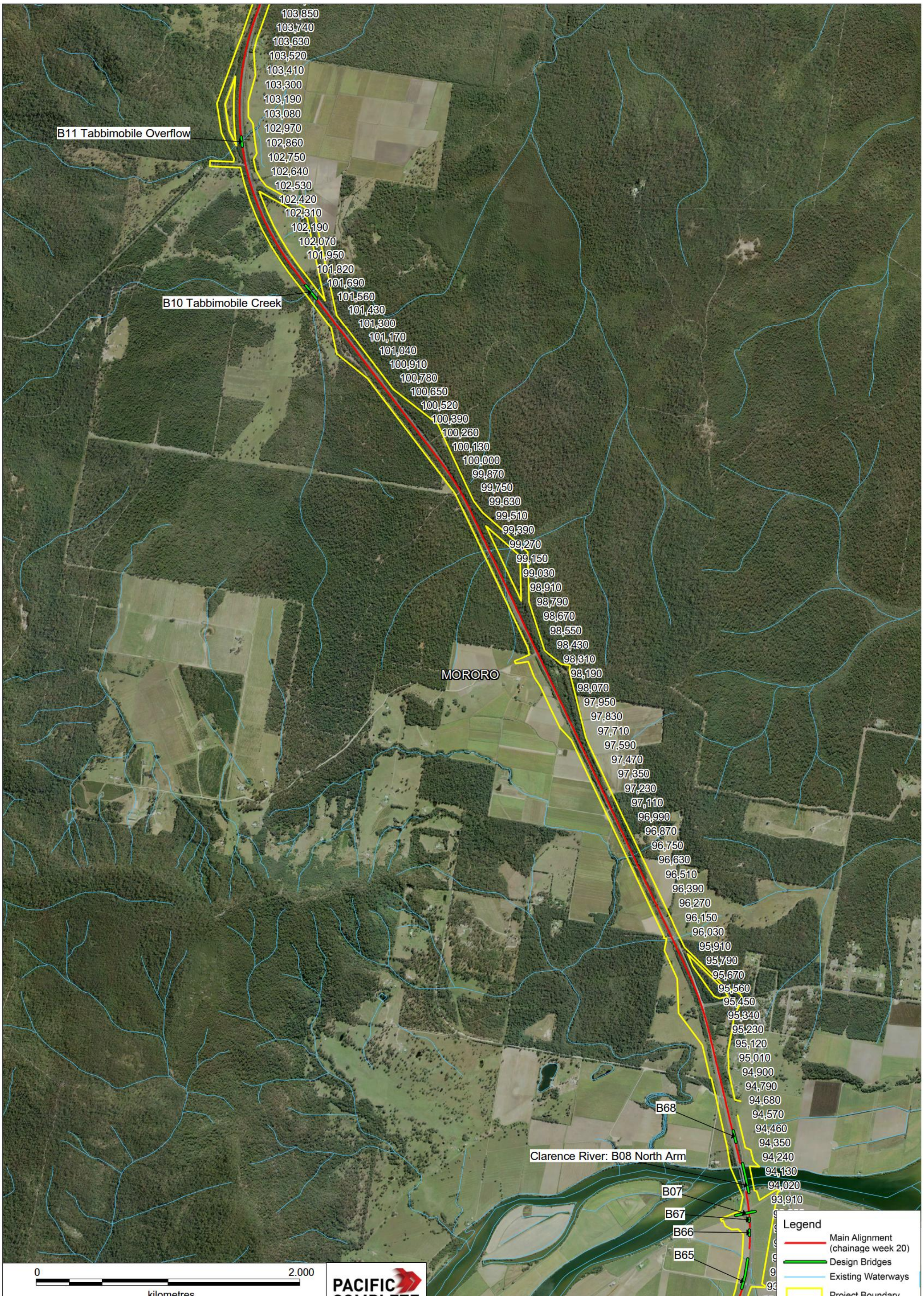

Figure 3.4 Overview of Iluka Road to Devils Pulpit

4. FLOOD MODELLING AND IMPACT ASSESSMENT METHODOLOGY

Flood modelling of the regional Clarence 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 model

The Clarence River regional model was originally developed for the then Clarence River County Council between 2000 and 2004 to provide flood planning information for the Lower Clarence River from Mountain View (about 10 kilometres upstream of Grafton) to Yamba. There have been multiple updates and calibration of the model since then commissioned by both Council and Roads and Maritime for use by the project before the detailed design phase.

The update to the flood model for the project involved the improved resolution of the 2D model for the project area by the refinement of the regional model 60 metre topographic grid to a 20 metre nested grid for the lower portion of the model. The lower portion of the model included the area of the Shark Creek Basin to the downstream boundary at the ocean. The refined grid was based on the aerial survey carried out by Roads and Maritime for the route selection phase of the project. The refined model was then re-calibrated to the 1980, 1996 and 2001 flood events.

The model was further updated following the January 2013 flood event. These latest updates to the Clarence River model included input of additional topographic and bathymetric survey information, refined bridge loss coefficients, re-calibration of the model to the January 2013 flood event and validation against the March 2001 flood event. The re-calibrated Clarence River flood model has been adopted as the basis for the hydraulic assessments for the detailed design phase of the project. The regional TUFLOW flood models have been developed over a number of design stages of the project, as summarised in Figure 4.1.

4.1.2 Local catchment models

The local catchment models in Pheasants Creek, Coldstream River, Pillar Valley Creek, Chaffin Creek and Champions Creek and Tabbimoble Creek and Mororo Creek 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 / WBNM 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.

Pre-EIS Flood Studies (Various, 1996-2010)

- Flood studies and model development prior to the EIS were undertaken to inform the development of a preferred route and assist the local councils with strategic floodplain management. See Appendix A of the EIS Hydrology Working Paper (SKM, November 2012).

EIS (Planning Alliance, 2012)

- Modelling undertaken to size structures and assess environmental impacts
- 20 year and 100 year ARI results presented in detail

Model update (Planning Alliance, 2013-2014)

- Prepared for use in design of Early Works and Detailed Design Stages
- Modelling updated for Clarence, Mid-Richmond and Lower Richmond flood models
- Models calibrated to recent flood events and verified against historical events

Preliminary Detailed Design (Pacific Complete, 2015-2016)

- Flood model impact predictions from previous stages checked with latest road model
- Waterway opening requirements adjusted to achieve flood management objectives
- Optioneering and refinement of design to detailed design level
- Validation of hydraulics and major structures

Detailed Design (Pacific Complete and Preferred Services Contractors, 2016-2017)

- Inclusion of detailed design from PSCs in the regional flood models at several design stages and testing of infrastructure performance against flood management objectives
- Flood impact mitigation options testing
- Independent verification of flood models and associated documentation, and workshops on performance of mitigation measures against flood management objectives
- Categorisation and definition of residual impacts and review by independent hydrologist
- Consultation with landowners on residual impacts

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 model

The model has 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. It should be noted that the +/-150 millimetre level of accuracy on flood level does not allow for precise estimates of levee overtopping at or around the overtopping threshold.

The regional model is a suitably developed and calibrated tool for defining existing and future conditions within the Clarence River regional floodplain. It has 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 model

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

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

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

4.2.2.2 Local catchment models

The local catchment hydraulic models are wholly 2D models (no 1D representation included) with grid resolutions of 10 metres adopted for the Glenugie to Tyndale model and five metres adopted for the Iluka Road to Devils Pulpit models. Existing cane drains and other land drainage features less than five to 10 metres wide were not included in the model. Therefore, the local catchment models may also overestimate flood extent and/or flood duration in localised areas where the minor drainage features are not represented.

4.2.3 Model extent

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

4.2.3.1 Regional model

The Clarence River hydraulic model covers a wide area roughly from Grafton to Yamba, including many of the 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 Clarence River. The Clarence River regional model has been used to assess flood impacts and inform bridge and cross drainage sizing for areas north of Crackers Drain (refer Figure 3.2). The first bridge opening is Crackers Drain and the last bridge opening is the last bridge before Iluka Road interchange, north of the Clarence River North Arm. The spatial extents of the regional and local catchment models are shown in Figure 4.2.

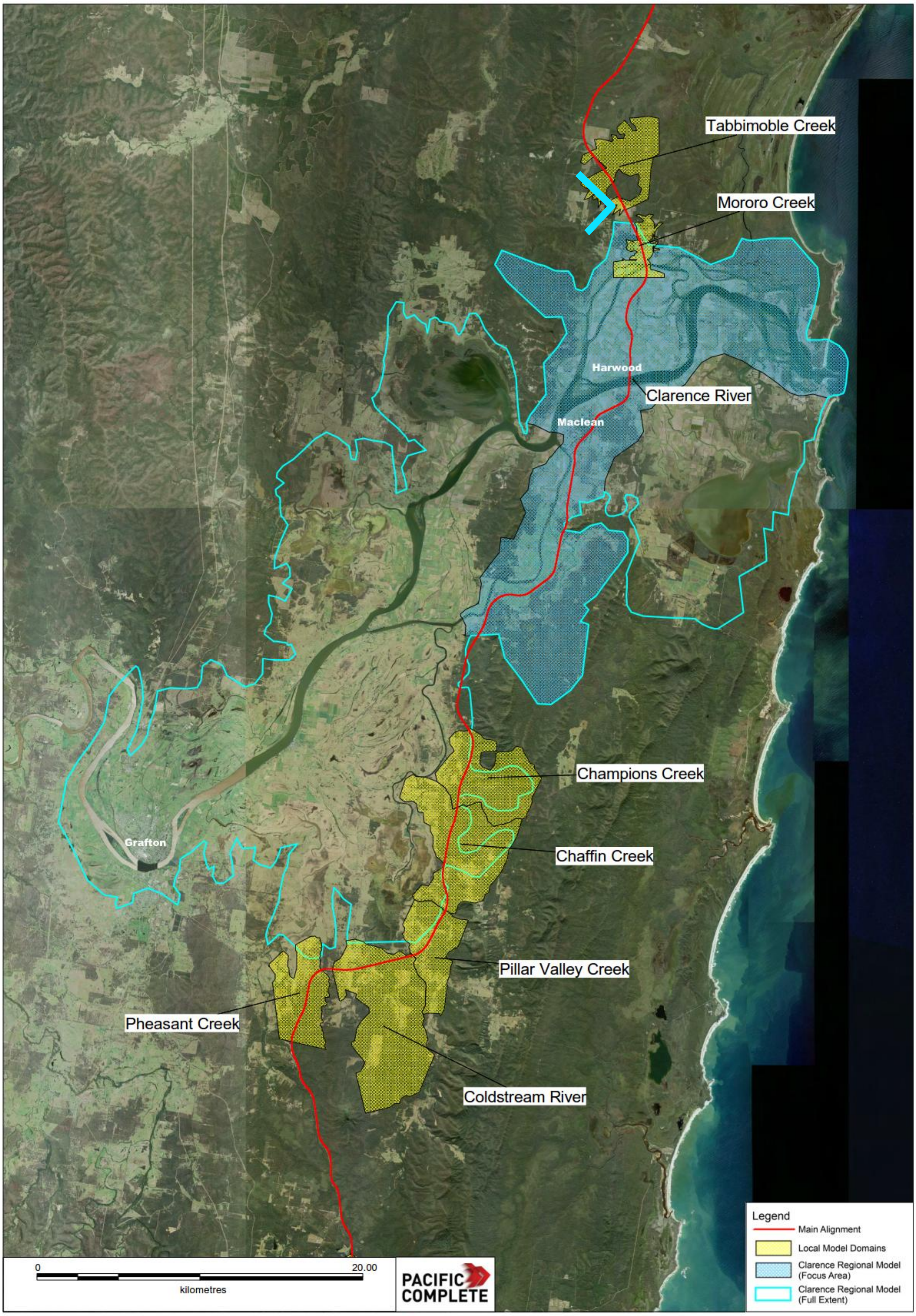

Figure 4.2 Overview of the extents of the Clarence River regional model and local catchment models

4.2.3.2 *Local catchment models*

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

- Glenugie to Tyndale hydraulic model extents:
  - Pheasants Creek– about 1.2 kilometres west, 1.5 kilometres east, 5 kilometres north and 1.2 kilometres south of the main Pheasants Creek crossing of the highway.
  - Coldstream River– about 2.8 kilometres west, 2.4 kilometres east, 1.3 kilometres north and 8 kilometres south of the main Coldstream River crossing of the highway.
  - Pillar Valley Creek– about 2 kilometres west, 1.5 kilometres east, 1.5 kilometres north and 5 kilometres south of the main Pillar Valley Creek crossing of the highway.
  - Chaffin Creek–about 2 kilometres west, 4 kilometres east, 4 kilometres north and 3 kilometres south of the main Chaffin Creek crossing of the highway.
  - Champions Creek– about 1.5 kilometres west, 4.5 kilometres east, 3 kilometres north and 2 kilometres south of the main Champions Creek crossing of the highway.
- Iluka Road to Devils Pulpit hydraulic model extents:
  - Tabbimoble Creek – about 2.2 kilometres west, 2.5 kilometres east, 3 kilometres north and 3 kilometres south of the main Tabbimoble Creek crossing of the highway.
  - Mororo Creek – about 2 kilometres west, 0.5 kilometres east, 1.2 kilometres north and 0.8 kilometres south of the main Tabbimoble Creek crossing 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 impact of the upgrade on flooding in the adjacent land for the local catchments.

4.2.4 Design events

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

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

4.2.5 Sensitivity analyses

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

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

4.3 Categorisation of flood impacts

Where the flood management objectives cannot be fully achieved 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 4.1 and 4.2
- 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 4.1 and 4.2.

Table 4.1 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 0.4m^2/s where currently below this value (i.e. remain in low hazard category)	N/A	N/A
Cane Farm Land	Velocities to remain below 1m/s where velocities are currently below 1 m/s Velocity increase to be below 20% where velocities exceed 1m/s	1.8*	Not used (velocities can increase up to the limit of 1.8m/s over unlimited area and still be classified as a low risk impact)
Grazing, Forested and Rural Areas	Velocities to remain below 1m/s where velocities are currently below 1 m/s Velocity increase to be below 20% where velocities exceed 1m/s	1.8*	Not used (velocities can increase up to the limit of 1.8m/s over unlimited area and still be classified as a low risk impact)

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

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

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

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

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

4.3.2 Flood duration impacts

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

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

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

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

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

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

4.3.2.1 Fringe, scattered and isolated duration impacts

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

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

Figure 4.3 provides a typical example of flood duration change reported around the edge of the Clarence River and Serpentine Channel in the Clarence 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.

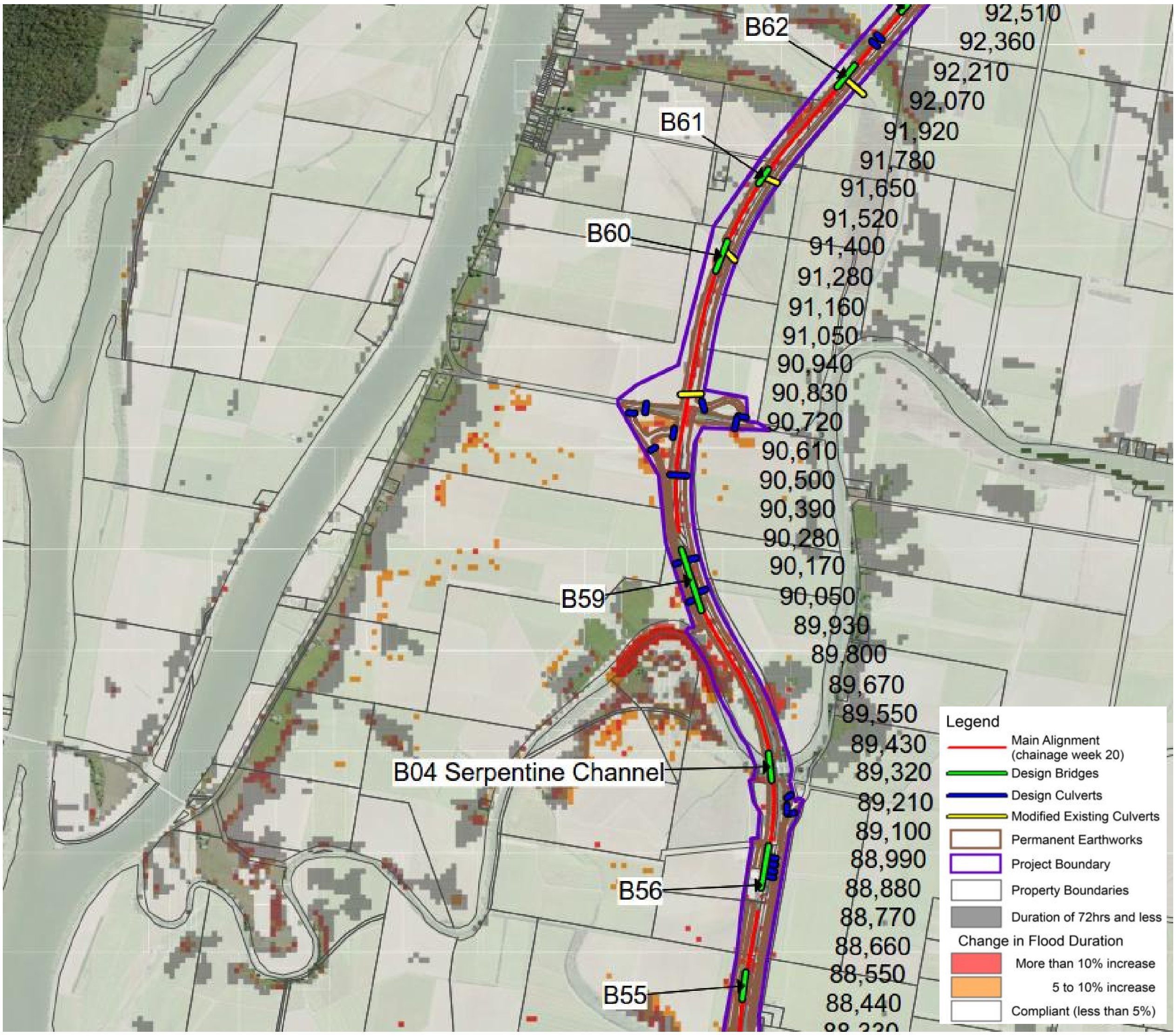

Figure 4.3 Example of fringe, scattered and isolated impacts

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

The assessment of duration is also limited by the model grid resolution and the level of detail represented. The purpose of the regional scale model is to represent the regional flood behaviour of the Clarence River floodplain. The models have been designed to include river tributaries and significant land drainage features that govern the distribution of flow across the floodplains. Small land drains are either coarsely represented or, in the case of drains or channels with widths less than a single grid cell, not represented at all.

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

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

Local catchment models have a higher grid resolution than the regional models (typically using grid resolutions of five 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 4.3 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 4.3 Flood duration impact on cane yield

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

Source: BSES Paper 'Managing Flood Damaged Cane'

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

4.4 Individual property assessment

4.4.1 Above floor level flooding assessment

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

Survey of floor levels and ground levels for the properties within the floodplain were available from the EIS. Further survey was collected for additional properties identified within the floodplain. For each property, the existing and proposed flood level was assessed from flood model results. Depth of flooding above the surveyed floor level was assessed at each property. All properties where there would be an increase in above floor level flood depths were identified. The magnitude of the afflux was then assessed in relation to flood management objectives (see section 1.5).

4.4.2 Individual property impacts

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

- flood level change

- velocity and direction change
- flood duration change.

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

5. FLOOD IMPACT ASSESSMENT

5.1 Overview of project outcomes relating to flooding

This section provides an overview of the key 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 Clarence regional floodplain various sections of the existing highway are prone to flooding between the two and 15 year ARI event. The project will provide a flood immunity of between the 20 and 100 year ARI.

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 cannot be removed by practical increases in the proposed drainage infrastructure. These are outlined in section 5.2. These residual effects may require work on individual properties or other mitigation measures to be agreed with the affected landowners.

Flood modelling of the Clarence River regional floodplain shows the project would result in minor changes in flood levels upstream of the proposed embankment and major bridges, including the crossings at Shark Creek, Clarence River at Harwood, Serpentine Creek and Clarence River North Arm at Mororo. 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 works, there are some minor decreases in flood level near Harwood and Chatsworth.

Under existing conditions, most of the land within the Clarence 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). There are some small localised areas within the regional floodplain between Maclean and Iluka Road where the flood duration is predicted to be affected by more than five percent. These are discussed further in section 5.2.3.

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

5.1.3 Urban centres

5.1.3.1 Maclean

Maclean is a small urban centre to the west of upgrade located on the eastern bank of the Clarence River. Maclean is protected by the Maclean levee constructed in the 1970s, which is about 3.5 kilometres long. Maclean experiences flooding when the levee is overtopped. There are no impacts to the township of Maclean in the 5 and 20 year ARI flood events as the Maclean levee is not overtopped. Figure C063 demonstrates in the 20 year ARI flood event there are small increases in flood level between five millimetres to 15 millimetres in the Clarence River main channel, with Maclean town behind the levee not impacted. Figure C64 shows the afflux for the 50 year ARI event is about 13 millimetres. The levee is overtopped under both existing and future conditions for the 50 year ARI event. The afflux in the residential area of Maclean immediately behind the levee is between 10 millimetres and 90 millimetres. Figure C065 shows that for the 100 year ARI flood event the levee is overtopped and a large part of Maclean is flooded, with afflux of between 10 millimetres and 15 millimetres in the main river channel and behind the levee. The project meets the flood management objectives for the 5, 20 and 100 year ARI events. Further analysis is being carried out and mitigation measures are under investigation for the impacts predicted for the 50 year ARI event.

5.1.3.2 Harwood

Harwood is a small urban centre located on the northern bank of the Clarence River, adjacent to the existing Pacific Highway, which will be duplicated and upgraded in this area. Harwood is positioned both east (downstream) and west (upstream) of the northern embankment of the existing and future bridges over the Clarence River. The new bridge crossing is significantly larger than the existing bridge crossing and spans the main Clarence River channel and some of the overbank area. The 1.5 kilometre bridge results in a minor increase in flood levels upstream due to the bridge piers in the waterway. The increase in flood level for the 20, 50 and 100 year ARI flood events are generally between 10 millimetres and 15 millimetres with a localised increase of up to 17 millimetres over 300 metres immediately upstream of the centre of the bridge in the 100 year ARI event. The changes to flood conditions in the Harwood area generally meet the flood management objectives for all assessment criteria for all reporting events.

5.1.4 Local catchment flooding impacts

5.1.4.1 Glenugie to Tyndale

Glenugie to Tyndale incorporates 33 cross drainage structures (comprised of 19 bridges and 14 culvert groups) to drain the local catchments of Pheasants Creek, Coldstream River, Pillar Valley Creek, Chaffin Creek and Champions Creek and their associated tributaries and overland flow paths. The flood management objectives have not been fully achieved at nine of these structures. The impacts are, however, generally related to localised increases in flood duration with impacts on flood levels and velocities generally meeting the objectives.

5.1.4.2 Iluka Road to Devils Pulpit

Iluka Road to Devils Pulpit incorporates 11 cross drainage structures (comprised of two bridges and nine culvert groups) to drain the local catchments of Tabbimoble Creek and Mororo Creek and their associated tributaries and overland flow paths. The flood management objectives are achieved at all locations for these local catchments.

5.2 Assessment of impacts against flood management objectives

Flood modelling was carried out for the 5, 20, 50 and 100 year ARI events to assess changes in the key flood parameters addressed by the flood management objectives, i.e. flood level, duration, velocity and flow direction. This section summarises the results for the future conditions based on the mitigation measures that have been tested and adopted. Some areas remain where the flood management objectives have not been achieved, as discussed in the following sections. Figures C001 to C062 included in Appendix C display the future flooding conditions in terms of flood level, depth, velocity, flow direction, flood duration and flood hazard across the Clarence River regional floodplain for the 5, 20, 50 and 100 year ARI flood events.

5.2.1 Flood level

Between Tyndale to Maclean the flood afflux maps show the flood impact objectives have been met for all four reporting events (5, 20, 50 and 100 year ARI events). Generally, the afflux is less than 25 millimetres with some pockets of 25 to 49 millimetres afflux.

Maclean to Iluka Road experiences widespread flooding in all events in the vicinity of the proposed highway. Table 5.1 provides the predicted existing and future flood levels at key locations in the Clarence River catchment and at key locations for proposed infrastructure. Figures C001 to C014 show the flood level difference (afflux) across the Clarence River floodplain. The mapping demonstrates only minor changes in flood level (afflux) occur due to the project. The majority of flood level impacts have not exceeded 50 millimetres and therefore meet the flood impact objectives for afflux (see section 1.5).

For Maclean to Iluka Road, the afflux maps show that the flood impact objectives have generally been met for the reporting events (5, 20, 50 and 100 year ARI events), with the exception of some localised areas. Where the afflux objective has been met, the flood level increase is between one and 49 millimetres, upstream of the highway. There is a minor decrease in flood levels downstream of the highway due to the upgrade. The change in flood level on the downstream side of the highway is in the range of minus one to 50 millimetres. This decrease in flood level is more apparent for the 5 and 20 year ARI events, while for the 50 and 100 year ARI events this change in flood level is less significant.

For the local catchments in between Glenugie and Tyndale, the afflux meets the objectives for the majority of the floodplain areas, with departures confined to the higher order events (50 year ARI and above) and mostly contained within or close to the project boundary. There are no afflux departures for the local catchments between Iluka Road and Devils Pulpit.

5.2.2 Flood velocity and direction

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

Figures C015 to C030 show the future conditions flood flow velocities and flow direction across the Clarence River floodplain. Figures C031 to C038 show the change in velocity as a percentage. Areas where the peak velocity is less than 1m/s have been overlain by a grey filter, demonstrating that much of the floodplain experiences velocities of less than 1m/s. Peak velocities in Table 5.2 show there is little to negligible change to the velocities for all reported events. Velocities in excess of 2m/s that occur in the main river along with slower moving flood flows in the floodplain of generally less than 1m/s remain unchanged for all reported events. Due to the large catchment and large flows, the proposed highway upgrade has little effect on the existing flow regime of the Clarence River. All flood impact 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.

For the local catchments between Glenugie and Tyndale, the velocity changes meet the objectives for the majority of the floodplain areas, with any departures confined to the higher order events (50 year ARI and above) and mostly contained within or close to the project boundary or through cross drainage structures where scour protection will be provided to withstand any localised velocity increases.

There are no velocity or flow direction departures for the local catchments between Glenugie and Tyndale and Iluka Road and Devils Pulpit.

5.2.3 Flood duration

Figures B029 to B036 demonstrate the total duration of flooding that occurs in the Clarence River catchment for the regional scale flood events. The mapping demonstrates the floodplain areas of the Clarence River experience long durations of flooding in excess of 72 hours for all events assessed. Under existing conditions for the critical storm duration of 72 hours (i.e. the storm duration that causes the worst case flooding in the regional catchment), most of the alignment between Maclean and Iluka Road is inundated for more than 72 hours for the 20, 50 and 100 year ARI events.

Figures C039 to C046 illustrate the change in flood duration across the Clarence River catchment in hours. Figures C047 to C054 show the percentage change in flood duration for the future conditions. Table 5.3 provides predicted existing and future conditions flood durations at key locations.

Between Tyndale and Maclean the flood duration objectives have been generally met for all four reporting events (5, 20, 50 and 100 year ARI events), however there are localised areas where the flood duration objectives have currently not been achieved.

Between Maclean and Iluka Road, the flood duration objectives have been generally met for most of the area for the 50 and 100 year ARI events, with the exception of some localised areas. Increases in flood duration are more significant in the 5 and 20 year ARI events, where the largest area of change in duration occurs around the Chatsworth Road south and north overpasses. In these areas the duration has increased by more than 72 hours. The duration impacts are most prominent in the 5 year ARI event, and may be overestimated due to the coarseness of the model grid and the lack of representation of drainage features (such as cane drains and swales) smaller than 20 metres wide which would convey flow back out to the river during lower flows and at the end of the storm event.

Figures 5.1 to 5.3 show the existing and future conditions flood level hydrographs at key infrastructure locations. While the overall mapping presented in Appendix C shows localised areas of the floodplain where duration has been impacted by the project, Figures 5.1 to 5.3 demonstrate the main flood hydrograph in the Clarence River is not affected by the project. The figures show that the downstream tidal boundary has an effect on the receding limb of the hydrographs at Harwood and Mororo Bridge.

Between Glenugie and Tyndale, the flood duration meets the objectives for the majority of the floodplain areas, with departures confined to the higher order events (50 year ARI and above) and mostly located either within or just outside the project boundary or along localised fringe areas of the floodplain.

There are no flood duration departures for the local catchments between Iluka Road and Devils Pulpit.

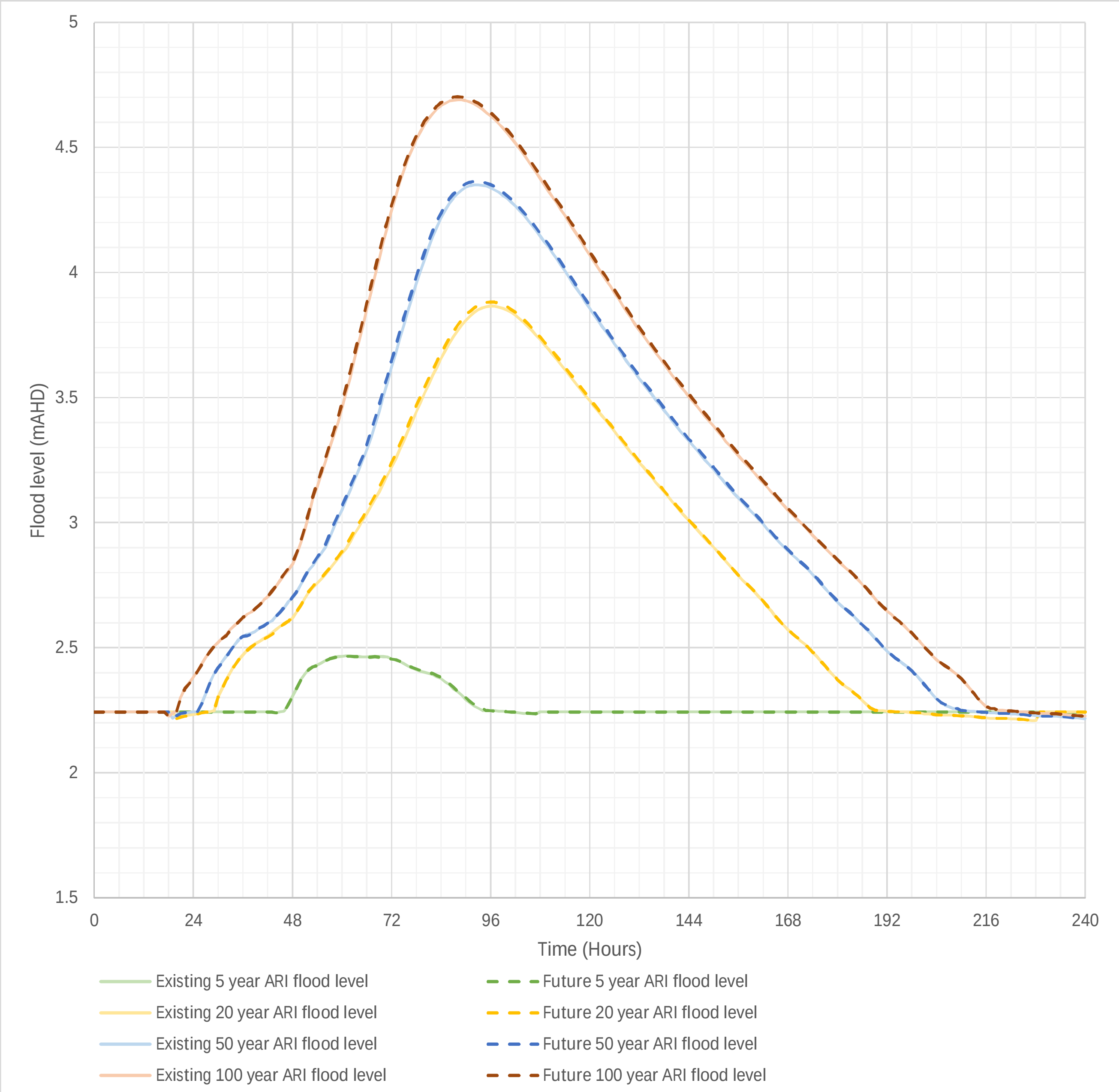

Figure 5.1 Flood level hydrographs at Shark Creek and Clarence River South Arm confluence

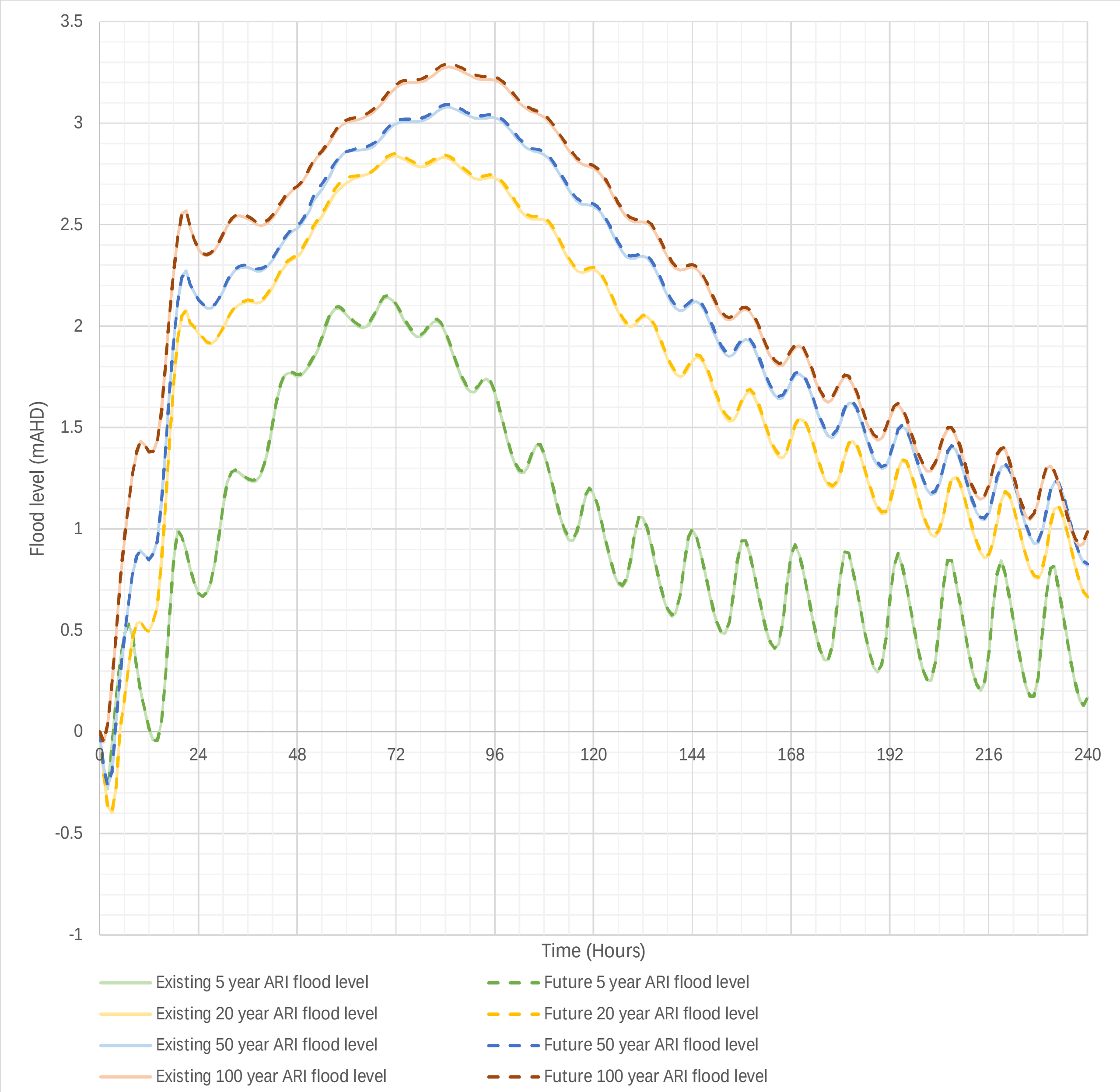

Figure 5.2 Flood level hydrographs at Harwood Bridge, Clarence River

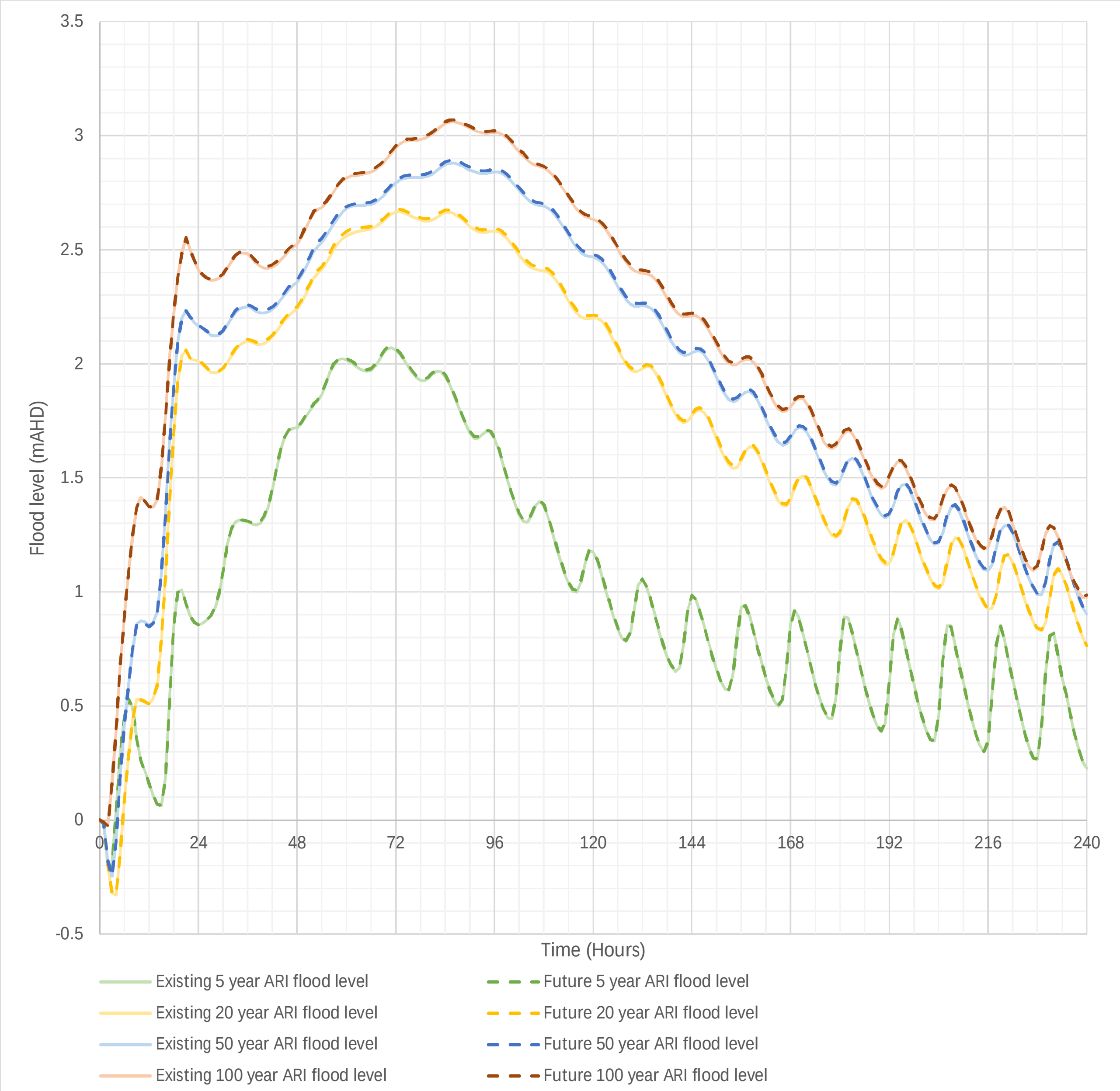

Figure 5.3 Flood level hydrographs at Mororo Bridge, Clarence River North Arm

Table 5.1 Existing and future conditions results – regional model flood levels at key locations

Location	05 year ARI			20 year ARI			50 year ARI			100 year ARI		
	Existing (m AHD)	Future (mAHD)	Afflux (mm)	Existing (m AHD)	Future (mAHD)	Afflux (mm)	Existing (m AHD)	Future (mAHD)	Afflux (mm)	Existing (m AHD)	Future (mAHD)	Afflux (mm)
Proposed Crackers Drain bridge (*A31Crackers-US)*	2.435	2.435	0	3.867	3.883	16	4.355	4.368	13	4.699	4.711	12
Proposed Shark Creek bridge location (H 1000.1)	2.415	2.415	0	3.867	3.88	13	4.352	4.366	14	4.694	4.707	13
Proposed Edwards Creek bridge (H A36-U)	N/A	N/A	N/A	3.706	3.717	11	4.076	4.087	11	4.376	4.399	23
Clarence River at Maclean Levee (H Maclean)	2.496	2.502	6	3.239	3.249	10	3.501	3.513	12	3.733	3.744	11
Farlows Flat near proposed bridge B02 (B02-D)	1.440	1.444	4	2.881	2.867	-14	3.136	3.137	1	3.350	3.360	10
Clarence River at Harwood Bridge (H RMS20_19)	2.141	2.150	9	2.836	2.848	12	3.076	3.090	14	3.275	3.291	16
Serpentine Creek Bridge (serp_74.2)	1.750	1.761	11	2.504	2.527	23	2.764	2.791	27	2.988	3.026	38
Clarence River at North Arm Bridge (B08-U)	2.070	2.077	7	2.668	2.677	9	2.882	2.893	11	3.064	3.070	6

Table 5.2 Existing and future conditions results – regional model flow velocities at key locations

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*	Existing (m/s)	Future (m/s)	Change in velocity (m/s)	Percentage change if >1m/s (%)*
Proposed Crackers Drain bridge (*SCCD_32)*	0.37	0.37	0.00	<1m/s	0.29	0.29	0.00	<1m/s	0.27	0.26	-0.01	<1m/s	0.23	0.22	-0.01	<1m/s
Proposed Shark Creek bridge location *(EX V 1000/ PROP V 10001)*	0.91	0.91	0.00	<1m/s	0.89	0.88	-0.01	<1m/s	0.90	0.88	-0.02	<1m/s	0.89	0.88	-0.01	<1m/s
Proposed Edwards Creek bridge	N/A	N/A	N/A	N/A	0.02	0.02	0.00	<1m/s	0.05	0.03	-0.01	<1m/s	0.07	0.05	-0.02	<1m/s
Clarence River at Maclean Levee	1.95	1.94	-0.01	-0.5%	2.49	2.49	0.00	0.0%	2.70	2.70	0.00	0.0%	2.91	2.91	0.00	0.0%
Farlows Flat near proposed bridge B02	0.00	0.00	0.00	<1m/s	0.06	0.18	0.12	<1m/s	0.08	0.22	0.14	<1m/s	0.10	0.16	0.06	<1m/s
Clarence River at Harwood Bridge	1.40	1.40	0.00	0.0%	1.63	1.63	0.00	0.0%	1.74	1.74	0.00	0.0%	1.83	1.83	0.00	0.0%
Serpentine Creek Bridge (V serp_75)	0.40	0.41	0.01	<1m/s	0.48	0.52	0.04	<1m/s	0.44	0.48	0.04	<1m/s	0.40	0.43	0.03	<1m/s
Clarence River at North Arm Bridge	0.87	0.87	0.00	<1m/s	1.06	1.06	0.00	0.0%	1.08	1.09	0.01	0.9%	1.08	1.12	0.04	3.7%

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

Table 5.3 Existing and future conditions results – regional model flood duration at key locations

Location	05 year ARI				20 year ARI				50 year ARI				100 year ARI			
	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)	Existing (hrs)	Future (hrs)	Duration change (hrs)	Percentage change (%)
Proposed Crackers Drain bridge	99	99	0.0	0.0%	125	120	-4.6	-3.6%	148	144	--4.5	-3.1%	165	160	-4.8	-2.9%
Proposed Shark Creek bridge location	213	216	3.7	1.7%	219	220	1.4	0.7%	220	222	2.2	1.0%	222	222	-0.1	-0.0%
Proposed Edwards Creek bridge	N/A	N/A	N/A	N/A	190	199	8.8	4.6%	195	203	8.3	4.2%	202	210	8.0	4.0%
Clarence River at Maclean Levee*	240	240	0.0	0.0%	240	240	0.0	0.0%	240	240	0.0	0.0%	240	240	0.0	0.0%
Farlows Flat near proposed bridge B02	149	149	0.4	0.3%	179	176	-2.3	-1.3%	184	183	-1.5	-0.8%	191	190	-0.9	-0.5%
Clarence River at Harwood Bridge*	240	240	0.0	0.0%	240	240	0.0	0.0%	240	240	0.0	0.0%	240	240	0.0	0.0%
Serpentine Creek Bridge	70	70	0.3	0.4%	85	82	-3.0	-3.5%	86	86	0.0	0.0%	86	86	0.0	0.0%
Clarence River at North Arm Bridge*	240	240	0.0	0.0%	240	240	0.0	0.0%	240	240	0.0	0.0%	240	240	0.0	0.0%

*these locations are in the Clarence River main channel so are always wet for the full model simulation

5.3 Individual property assessment

5.3.1 Above floor level flooding assessment

The flood management objective relating to flood level at residences allows up to 50 millimetre increase in flooding (afflux). Table 5.4 identifies the properties located in the floodplain and the number of properties affected by increases in above floor level flooding.

The table demonstrates that a very low number of properties will experience above floor level flooding increases of more than 50 millimetres. These results are based on the design at the time of writing this report and will be updated as required, if results change.

Table 5.4 Afflux impact at properties that are flooded above floor level

Afflux impact range (millimetres of above floor flooding)	Number of properties			
	5 year ARI	20 year ARI	50 year ARI	100 year ARI
Not flooded	703	620	536	240
Less than 25 millimetres	54	122	166	493
25 to 49 millimetres	1	16	55	23
50 to 249 millimetres	0	0	0	2
250 to 400 millimetres	0	0	1	0
More than 400 millimetres	0	0	0	0

5.3.2 Properties located behind Maclean Levee

In the EIS the Maclean levee was estimated to provide protection up to about the 36 year ARI flood event under existing conditions. In the proposed EIS case, a small increase in the Clarence River flood levels (in the order of 30 millimetres for events between 35 and 50 year ARI) resulted in increases in flood levels greater than 50 millimetres behind the levee for the 50 year ARI event, which does not meet the flood management objective for afflux. The flood immunity of the levee overtopping was assessed in the EIS to decrease from about 37 to 35.7 years ARI.

Flood modelling carried out for this phase of the project (detailed design) shows an afflux of 13 millimetres overtopping the levee during the 50 year event. This is consistent with and a slight improvement on the EIS flood modelling analysis. Therefore, the change in flood immunity for the future conditions is similar to the one year decrease stated in the EIS. This afflux impact in the main river of 13 millimetres is caused mainly by the new bridge over the Clarence River at Harwood Bridge, and is the lowest that can be practically achieved for a major crossing, reflecting a very efficient design for the piers located within the waterway. Figure 5.4 shows the main Clarence River hydrograph near the midpoint of the Maclean Levee. The figure shows that the flood behaviour of the Clarence River has remained unchanged at the levee, and the impacts due to the project, while not compliant with the flood management objectives for the 50 year ARI for predominantly undeveloped areas of land behind the levee, are minor when considering the size and magnitude of the flood events.

The predicted impact to flood levels in the township is still under investigation. The project team is working closely with Clarence Valley Council and State Emergency Service and further consultation will be carried out with the wider community, as appropriate, once the assessment is complete. Once finalised, the outcomes of this assessment will be published in an addendum to this report.

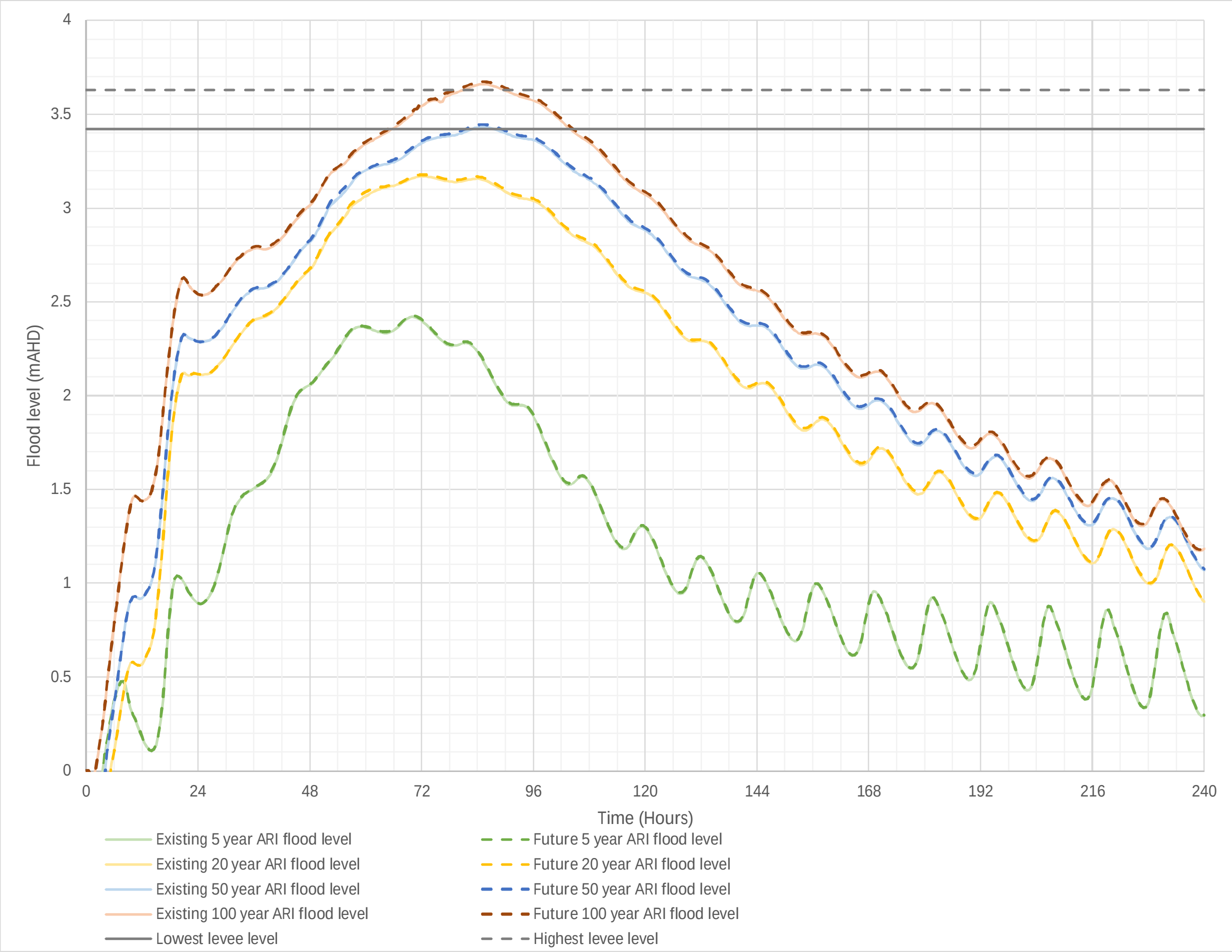

Figure 5.4 Flood level hydrographs for Clarence River at Maclean Levee

5.3.3 Individual property impacts

More than 160 configurations of bridge and flood relief culverts were modelled in the Clarence River floodplain and, while objectives have been met across the majority of the floodplain, there are some localised areas where it is not possible to fully achieve the objectives using reasonable and feasible bridge and flood relief culvert infrastructure.

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

Table 5.5 summarises the number of privately owned lots at which the flood management objectives are not fully achieved.

Table 5.5 Privately owned lots with predicted departures from the flood management objectives

Woolgoolga to Ballina project section	**Number of affected lots***		
	Afflux	**Duration**	**Velocity**
Glenugie to Tyndale	7	15	6
Tyndale to Maclean	0	6	0
Maclean to Iluka Road	5	11	0
Iluka Road to Devils Pulpit	0	0	0

**Note: number of affected lots does not include lots behind Maclean levee impacted in the 50 year ARI event (see section 5.3.3) as mitigation of these impacts is subject to further investigation and consultation with Clarence Valley Council*

There are relatively low numbers of lots in the Glenugie to Tyndale local catchments and throughout the Clarence River regional floodplain (Tyndale to Iluka Road) with 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 5.6.

Table 5.6 Habitable structures that have departures from the flood management objectives

Woolgoolga to Ballina project section	Number of affected habitable structures*		
	Afflux	Duration	Velocity
Glenugie to Tyndale	0	0	0
Tyndale to Maclean	0	3	0
Maclean to Iluka Road (excluding Maclean levee impacts)	0	0	0
Iluka Road to Devils Pulpit	0	0	0
**Note: number of affected lots does not include lots behind Maclean levee impacted in the 50 year ARI event (see section 5.3.3) as mitigation of these impacts is subject to further investigation and consultation with Clarence Valley Council*			

5.4 Utilities assessment

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

5.5 Access and infrastructure

In all locations the upgraded highway will provide more efficient and reliable flood evacuation routes since the flood immunity is being improved. Local access roads and property access have retained current or been provided higher flood immunity. The project will not adversely affect key flood access routes and will improve flood access and evacuation within the floodplain. Access out of the Clarence River regional floodplain and the surrounding local catchments is mainly by the existing Pacific Highway and a number of local access roads connecting to the highway.

5.5.1 Time of highway closure

The project will provide a flood immunity of 20 year ARI through the Clarence River floodplain which will reduce the frequency and time of closure of the highway during large floods.

As discussed in section 3.2, some areas of the existing highway between Glenugie to Iluka Road currently have a flood immunity of less than the 5 year ARI event. Historically these areas have experienced closures of several days to weeks as result of regional flooding. Supplementary hydrology assessments carried out for the submission / preferred infrastructure report (SPIR) identified the existing Pacific Highway was closed between Grafton and Iluka Road for a total of 91 hours (about four days) during the January 2013 flood event (estimated to be less than a 20 year ARI event). Additional time was required to inspect the road before it was reopened to traffic. The first part of the highway closed to traffic was Shark Creek and the last part of the highway to reopen was near Serpentine Creek.

Figure 5.5 shows during a 5 year ARI event, the lowest part of the highway, south of Shark Creek, would be inundated for 38 hours. During a 20 year ARI event, this part of the highway would be closed for 119 hours (about five days). The figure shows the lowest point of the upgraded highway between Lees Drain and Shark Creek would be flood free for these two events. For the higher order events (50 and 100 year ARI), the existing highway would be closed for up to seven days. This closure time is reduced significantly to about three days for the upgraded highway.

Figure 5.6 shows during a 5 year ARI event, the lowest part of the highway between Maclean and Iluka Road, south of Serpentine Creek, would be inundated for 49 hours. During a 20 year ARI event, this part of the existing highway would be closed for 151 hours (about six days) and up to seven days for the 50 and 100 year ARI events. The upgraded highway has been designed to provide 5 year ARI flood immunity for the southbound lane and at least a 20 year ARI flood immunity for the northbound lane. The figure demonstrates the future northbound lane will have shorter closure time of about two days for the 50 and 100 year ARI events at this location.

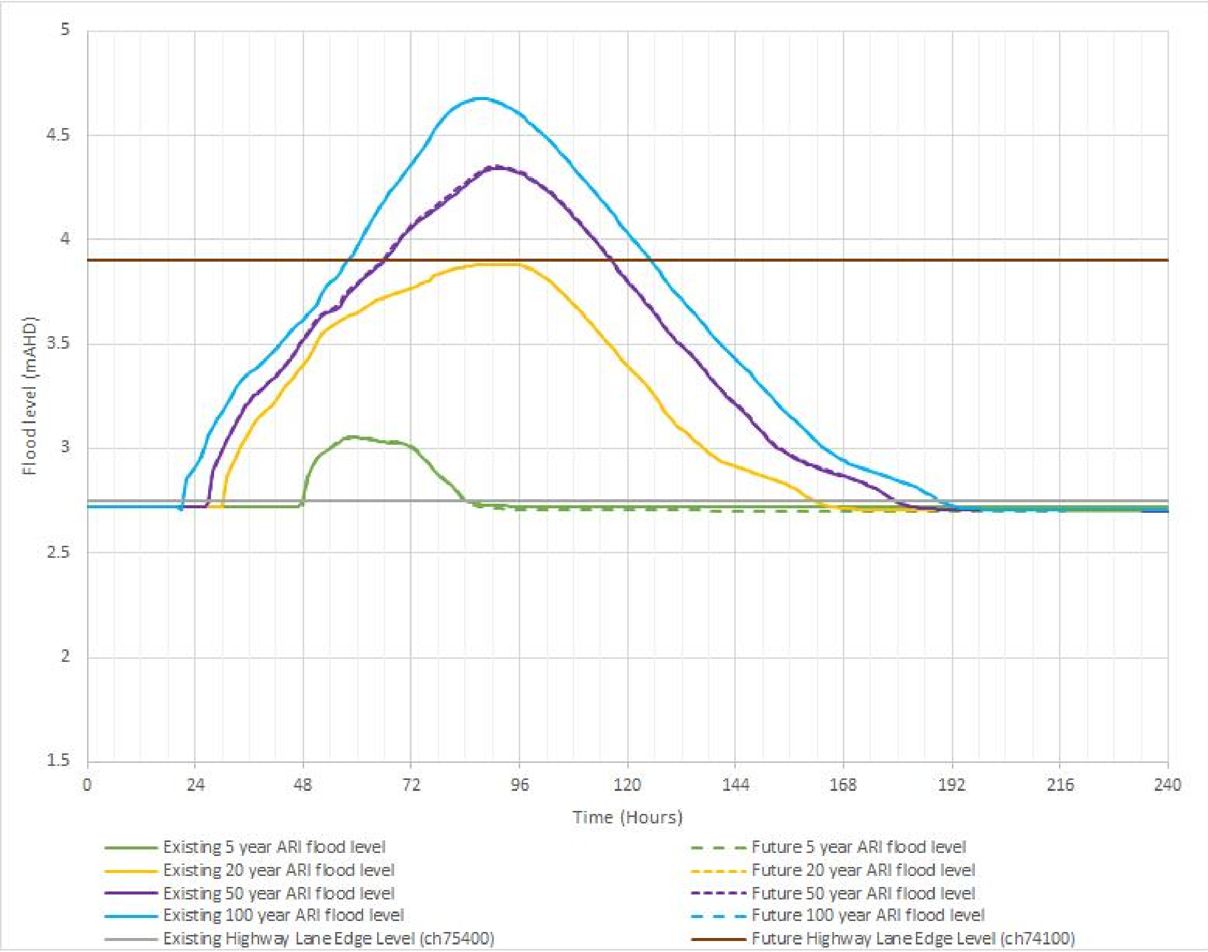

Figure 5.5 Inundation time for existing and future Pacific Highway - south of Shark Creek, Tyndale to Maclean

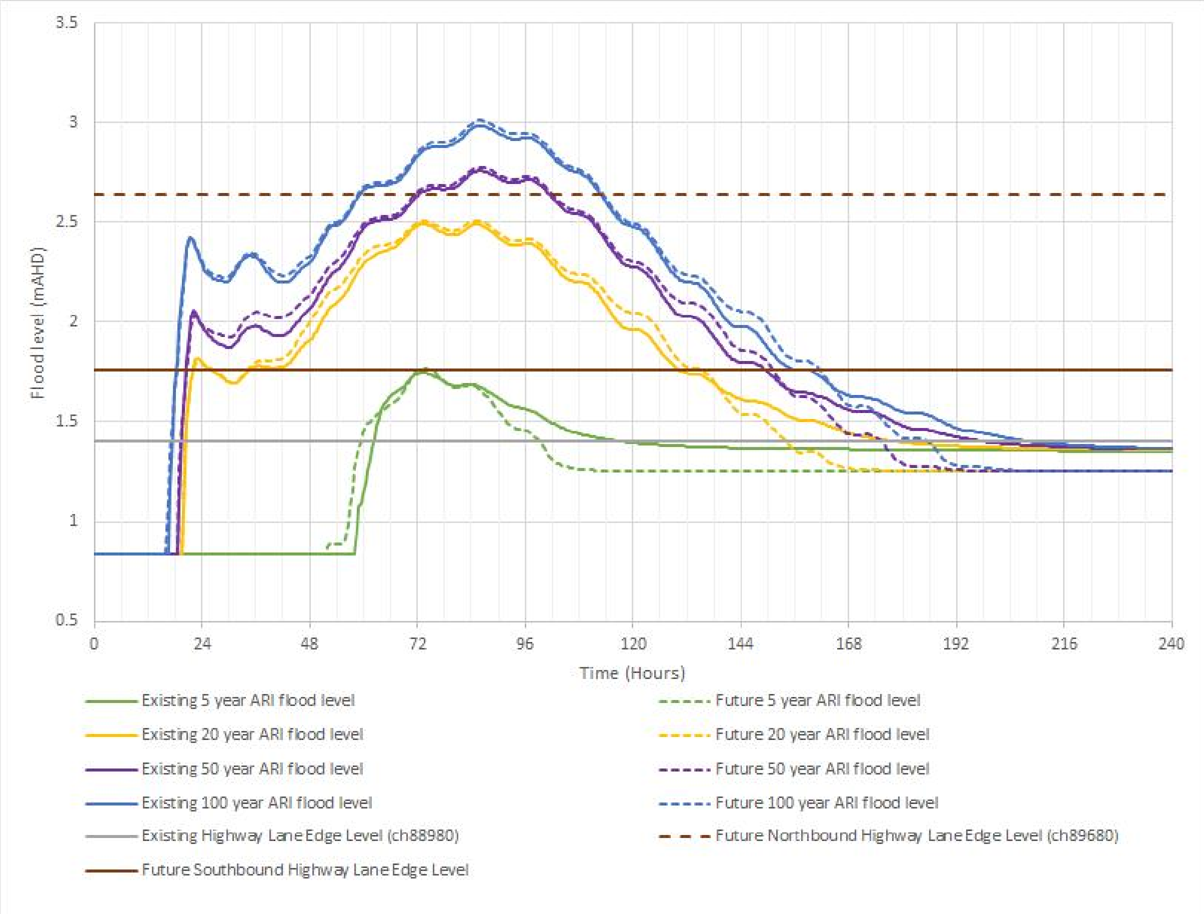

Figure 5.6 Inundation time for existing and future Pacific Highway - south of Serpentine Creek, Maclean to Iluka Road

5.5.2 Local access and property access assessment

Service roads connecting to the upgraded highway will be designed to retain or improve existing flood immunity. Local and property access is assessed as part of the individual property assessments and any associated departures or issues are included in the discussion in section 5.4.

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

5.6 Sensitivity analyses

5.6.1 Climate change

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

5.6.2 Future highway widening

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

6. MITIGATION MEASURES

6.1 General mitigation measures

6.1.1 Design refinements for flooding

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

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

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

Another key design refinement involved changing the flood immunity on the southbound lanes from north of Watts Lane to south of Carrols Lane. The benefits of this include:

- maintaining flow of traffic along the Pacific Highway during 20 year ARI events by contra flow on the northbound lanes. At present the Pacific Highway is closed to traffic during a 5 year ARI flood event
- keeping the southbound lane immunity at a 5 year ARI allows connection to local roads to be maintained during 5 year ARI flood events and fits within the design criteria
- improving local access road intersection immunity by increasing the flood immunity to the 5 year ARI flood event on local road connections, including improving local access during these flood events
- overall benefit to the Pacific Highway through improving flood immunity to the 5 year ARI flood event along the alignment
- creating cost efficiencies by reusing existing infrastructure.

6.1.2 Infrastructure option testing

Numerous design innovations and value engineering options were tested in the flood model.

A key objective of the project is to increase the reliability of the highway providing improved flood immunity, however, the degree of improved flood immunity needs to be balanced against affordability.

Review of the design on the southbound carriageway was carried out including:

- using the existing highway with lower embankments
- reducing bridging lengths

This approach:

- reduces capital costs by decreasing fill volumes and bridge length
- reduces land requirements and environmental impacts
- maintains the 1 in 20 ARI flood immunity on the northbound carriageway
- achieves the flood management objectives.

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. The configuration, design innovation and mitigation options tested and / or adopted are listed below:

- rationalise number of culverts locations, 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 landholders and nearby culvert banks adjusted

- modifications to bridge configurations by lowering the southern abutment to reduce fill requirements and use of alternate plank arrangement to minimise flooding impacts
- small local earthwork added to Roads and Maritime owned land to reduce flooding impacts on private property
- test of mitigation measures to size flood-gated outlet with bridge combination to eliminate duration impacts at Farlows Flat
- diversion channel and storage tested within the project boundary to eliminate impacts at Farlows Flat and Yamba Road
- lengthening of new bridge over the Clarence River at Harwood to reduce flooding impacts
- relocating Harwood Oval Link Road 20 metres south as requested by local stakeholders
- 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
- testing a combination of bridge locations and sizes, including combining original three-span openings design into one consolidated bridge
- modelling of multiple design scenarios for the 5 and 20 year ARI events to determine relative impacts versus optimum infrastructure for a range of pipe sizes, shapes and arrangements at sensitive locations
- testing of new drainage to direct overland flow back to the main river channel and Serpentine Creek to reduce 5 year ARI duration impacts
- converting large culvert banks to bridges near the Clarence North Arm to reduce requirement for ground treatment and improve construction timeline by reducing the requirement for settlement time
- multiple scenario tests of full/ part removal of existing roads and lanes to provide additional waterway area for flood relief and to minimise culverts
- testing of flipped intersection arrangement at the Chatsworth Road (north) / Fischers Lane overpass to reduce flood impacts at overpass locations in the floodplain.

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 lands 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 summarises the development of the design and changes to the total floodplain waterway opening width since the SPIR to the detailed design including the early work. Note the totals provided in the table are for flood relief structures only and do not include some minor cross drainage structures 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 due to a number of factors, including:

- providing improved access for landowners
- replacing banks of box culverts with bridges for improved constructability in soft soils
- improving mitigation of flood impacts on adjacent land.

Table 6.1 Comparison of waterway opening width at different design stages

DESIGN STAGE	GLENUGIE TO TYNDALE TOTAL WATERWAY OPENING WIDTH (M)	TYNDALE TO MACLEAN TOTAL WATERWAY OPENING WIDTH (M)	MACLEAN TO ILUKA ROAD TOTAL WATERWAY OPENING WIDTH (M)	ILUKA ROAD TO DEVILS PULPIT TOTAL WATERWAY OPENING WIDTH (M)
SPIR	2,265	595	4,881	308
Early works	No change from SPIR	1,078	6,400	246
Detailed design	2,165	1,072	6,065	259

6.2 Mitigation of impacts on private property

6.2.1 Land drainage improvements

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

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

Land drainage mitigation work has been designed for the southern approach of the new bridge over the Clarence River at Harwood within the project boundary. To minimise adverse flooding impacts to private land near Yamba Road and Farlows Flat, a small existing drainage path underneath the existing southern abutment of the Harwood Bridge has been upgraded and a new diversion channel constructed to facilitate the temporary storage of floodwater and flow path back to the river downstream of the bridge via a flood-gated outlet to James Creek once the flood peak has passed. The temporary storage takes advantage of the natural depression that exists inside the Yamba Road off-ramp loop, and will only store water when there is a significant flood event.

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

6.2.2 Schedule of departures and mitigation measures

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

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

ID	ITEM	CHAINAGE	DEPARTURES			LOTS AFFECTED	MITIGATION MEASURES / NEXT ACTIONS	CONSULTATION COMMENCED?	AGREEMENT REACHED?
			AFFLUX	VELOCITY	DURATION				
1	Cross drainage culvert CL-035880	35880 to 36010	50 and 100 year ARI events	5, 20, 50 and 100 year ARI events	5, 20, 50 and 100 year ARI events	State forest	Consult with environmental agencies on impacts and agree no mitigation required due to marginal nature of departure	Detailed consultation to be commenced	No
2	A06	42521 to 43053	20, 50 and 100 year ARI events	None	5, 20, 50 and 100 year ARI events	Lot 2 DP39766 Lot 60 DP1161185	Afflux departure relates to impact on Wants Lane access to properties rather than afflux on the properties. Wants Lane has <1 year ARI flood immunity under existing conditions so afflux impact does not significantly affect access. Continue to consult with landowners to assist in their understanding of the impacts.	Yes - several discussions held with landowners to date to explain details of impacts. Investigation of land drainage impacts to resolve duration impact is ongoing.	No
3	A08	43883	None	None	5, 20, 50 and 100 year ARI events	Lot 60 DP1161185	Marginal departure for flood duration on land that is subject to short duration flooding. Explain to landowner and agree no mitigation required due to marginal nature of departure	Yes	No
4	A19 / CC-052615	52424	100 year ARI event	5, 20, 50 and 100 year ARI events	5, 20, 50 and 100 year ARI events	Lot 13 DP1181706 Lot 14 DP1195225	Departures are marginal and/or localised to area adjacent to project boundary. Explain to landowner and agree no mitigation required due to marginal and highly localised nature of departures	Yes	No
5	A50	53760	5, 20, 50 and 100 year ARI events	50 and 100 year ARI events	100 year ARI event	Lot 108 DP751365 (Roads and Maritime owned land)	Departures are marginal and/or localised to area adjacent to project boundary. Consult with Roads and Maritime Property and agree no mitigation required due to marginal and highly localised nature of departures	Detailed consultation to be commenced	No
6	A23	57022	50 year ARI event	None	5, 20, 50 and 100 year ARI events	Lot 7000 DP1128077 Lot 7001 DP1128077	Discussions with landowner ongoing on impacts and potential mitigation measures. Impacts are on Somervale Road and access to property and not on buildings or structures.	Yes	No
7	A25	60863	None	5, 20, 50 and 100 year ARI events	5, 20, 50 and 100 year ARI events	Lot 11 DP1196658	Departures are marginal and/or localised to area adjacent to project boundary. Explain to landowner and agree no mitigation required due to marginal and highly localised nature of departures	Yes	No
8	Crackers Drain	69000 to 70700	None	None	5 year ARI event	Lot 14 DP805843 Lot 1 DP751389 Lot 696 DP1199716 Lot 310 DP1176209	On site verification of flood modelling results and investigation into land drainage improvements	Subject to further investigation	Subject to further investigation
9	Ponding east side of river and Omaras Lane	76000 to 78000	None	None	5, 20, 50 and 100 year ARI events	Lot 53 DP1014027 Lot 6 DP835402	On site verification of flood modelling results and investigation into reducing impact to RMS owned land only	Subject to further investigation	Subject to further investigation
10	Maclean Levee	82000 to 83500	50 year ARI	None	50 year ARI	TBC	Mitigation measures under investigation and consultation with Council progressing	Subject to further investigation	Subject to further investigation
11	Farlows Flat	84900 to 86300	None	None	5 year ARI event	Lot 6 DP1183272	Combination of land drainage improvements and cross drainage improvements under investigation to remove impact.	Yes - design solution identified	Subject to further investigation
12	James Creek	85100 to 86000	None	None	20 year ARI event	Lot 9 DP1183272	In consultation with landowner on marginal and/or localised nature of impacts and need for mitigation measures	Yes – mitigation measures proposed and subject to agreement	No
13	Harwood Oval	87100 to 87700	None	None	20, 50 and 100 year ARI events	Lot 92 DP665552	In consultation with landowner on marginal and/or localised nature of impacts and need for mitigation measures	Yes	No
14	Serpentine Creek	89000 to 91000	None	None	5, 20 and 50 year ARI events	Lot 11 DP1184890 Lot 13 DP1184890 Lot 22 DP1205802 Lot 6 DP247998 Lot 23 DP1148636	In consultation with landowners on marginal and/or localised nature of impacts and need for mitigation measures	All consulted with apart from Lot 11 DP1184890 – landowner unable to be contacted	No
15	Serpentine north 1	91010	5 year ARI	None	None	Lot 2 DP176717	On site verification of flood modelling results and investigation into land drainage improvements	Subject to further investigation	Subject to further investigation
16	Serpentine north 2	92590	100 year ARI	None	None	Lot 17 DP1184890	On site verification of flood modelling results and investigation into land drainage improvements	Subject to further investigation	Subject to further investigation
17	Crematorium	93860	5, 20 and 100 year ARI events	None	5, 20, 50 and 100 year ARI events	Lot 25 DP1195140 Lot 11 DP1118364 Lot 8 DP1013578	In consultation with landowners on marginal and/or localised nature of impacts and need for mitigation measures	Yes	No

6.3 Mitigation of impacts on access

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

The NSW State Emergency Service (SES) has been provided with information regarding the flood modelling process, the predictions of flood behaviour and the changed flood conditions around levee banks and the associated levee overtopping regimes.

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

6.4 Scour protection measures

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

6.5 Ongoing maintenance

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

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

7. CONCLUSIONS AND FURTHER WORK

7.1 Conclusions

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

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

The regional catchment and local catchment flood modelling has assessed over 160 configurations of bridge and flood relief culvert infrastructure across the Clarence 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 26 kilometres of road alignment located within one of Australia's largest and complex floodplains, a very low number of properties experience a departure from the flood management objectives. These departures have been the focus of detailed investigation and landholder consultation is ongoing in some cases and subject to review following the assessment of the final detailed design.

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

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

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

7.2 Further work

This report reflects the design at the December 2016 stage of the program and includes the road alignment, channel earthworks, cross drainage and bridge designs at various levels of design development. Generally, this point in the program reflects the substantial detailed design stage for infrastructure within the Clarence Regional floodplain between Tyndale and Iluka Road. The flood model will be updated once the final detailed design is complete.

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

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