NSW Roads and Maritime Services

WOOLGOOLGA TO BALLINA | PACIFIC HIGHWAY UPGRADE

ENVIRONMENTAL IMPACT STATEMENT

MAIN VOLUME 1A

Chapter 8 – Hydrology and flooding

Chapter summary

This chapter presents a summary of a detailed study of potential issues relating to flooding and hydrology.

The project is located in the Northern Rivers catchment area. It would cross the Clarence River and the Richmond River and their floodplains. These are both large coastal rivers with major tributaries and substantial floodplains. The project would also cross several smaller watercourses and their floodplains.

The area contained within the project boundary, and surrounding it, is subject to frequent and extensive flooding. This can be caused by one or a combination of: rainfall in the upper catchment, rainfall in the local catchment, and large ocean tides. Flooding is generally concentrated on and around the coastal floodplains and inundation in these areas can extend over a number of weeks. This can result in damage to buildings and roads, loss or stranding of livestock, loss of crops and blocked access.

The project incorporates numerous waterway openings and crossing structures (such as bridges and culverts) to convey flows safely under the road embankment without unacceptable flooding impacts on the surrounding environment. The locations and dimensions of these structures have been designed with the aim of meeting the project flood impact objectives to the greatest extent practicable and in consideration of other environmental needs, including the need for fauna crossing points along the upgraded highway.

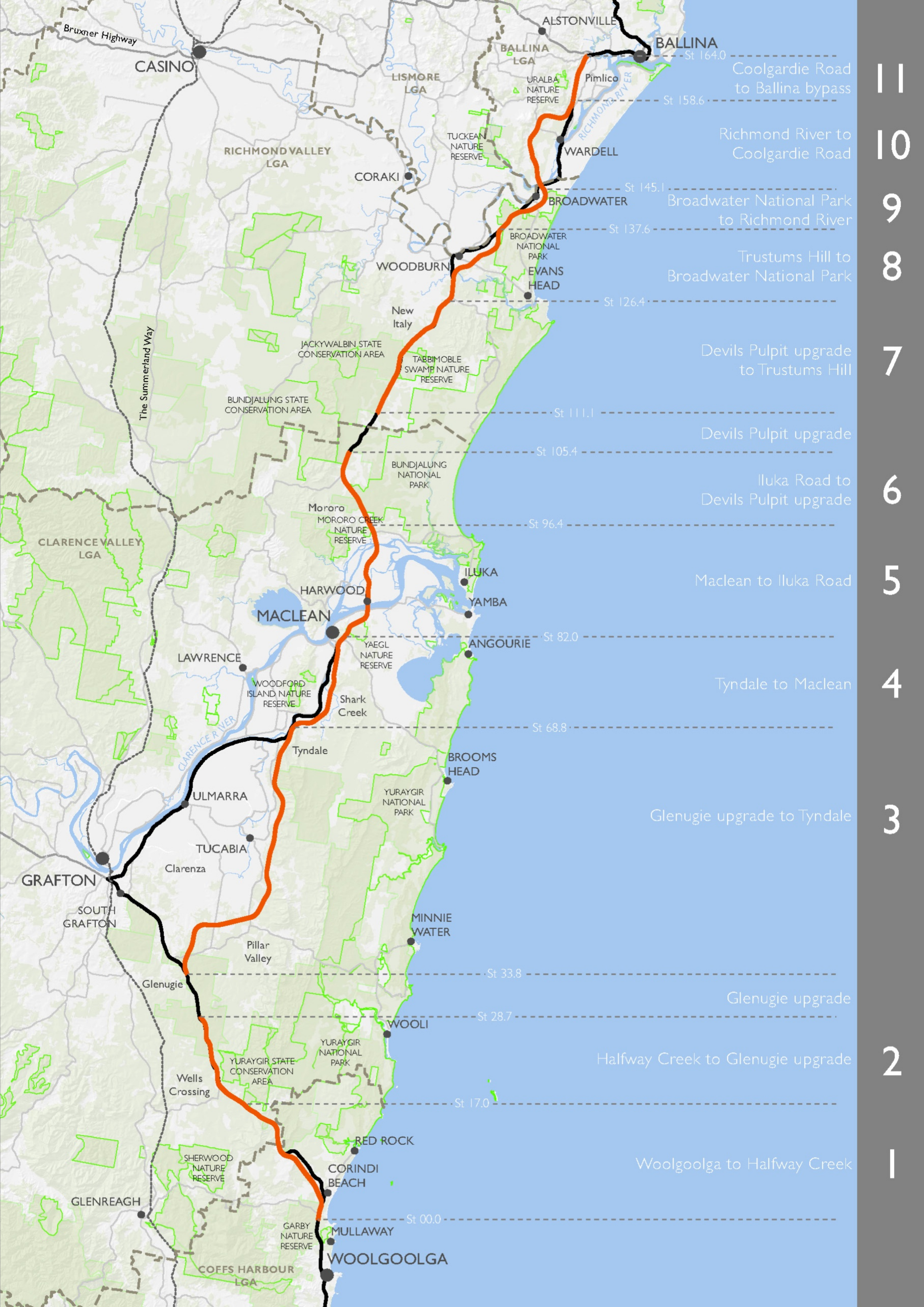
This assessment finds that the project's flood impact objectives would be achieved in all areas potentially impacted by the project during its operation. The project would have minor impacts on flood levels, flood inundation periods, and the timing of floodwater rise and fall, as well as some minor localised impacts. The project would not, however, have any significant adverse impacts on property access or the use or productivity of agricultural land.

Minor increases in flood levels and inundation periods in some areas would result in a small reduction in the amount of land available for future development.

Significantly, the project would result in a substantial improvement in the flood immunity of the Pacific Highway, which is currently flood-prone in several places. This would improve the ability of people to evacuate when flooding occurs. It would also reduce the frequency and duration of highway closures due to flooding.

RMS 12.604A

ISBN 978-1-922041-80-7



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Tyndale to Maclean
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Glenugie upgrade to Tyndale
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EVANS HEAD
New Italy
JACKYWALBIN STATE CONSERVATION AREA
TABBIMOBLE SWAMP NATURE RESERVE
The Summerland Way
BUNDJALUNG STATE CONSERVATION AREA
BUNDJALUNG NATIONAL PARK
Mororo
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CLARENCE VALLEY LGA
ILUKA
HARWOOD
YAMBA
MACLEAN
ANGOURIE
YAEGL NATURE RESERVE
LAWRENCE
WOODFORD ISLAND NATURE RESERVE
Shark Creek
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ULMARRA
YURAYGIR NATIONAL PARK
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SOUTH GRAFTON
MINNIE WATER
Pillar Valley
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COFFS HARBOUR LGA

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8 Hydrology and flooding

This chapter presents a summary of a detailed study of potential issues relating to flooding and hydrology (hydrology pertains to the movement, distribution, and quality of water). The full details and results of this study are presented in the Working paper – Hydrology and flooding (SKM, 2012). This study was independently peer reviewed (WMA, 2012). The study addressed the Director General's environmental assessment requirements, which are provided below.

Director General's requirements	Where addressed
The EIS must address	
• impacts on surface water flows, quality and quantity, with particular reference to any likely impacts on surrounding water bodies, wetlands and their habitats, including potential indirect impacts on the Solitary Island Marine Park by works in the Arrawarra Creek and Corindi River Catchments;	Section 8.4.19 Section 9.2.2 (Chapter 9) Section 9.3 (Chapter 9)
• flooding impacts and characteristics, to and from the project, with an assessment of the potential changes to flooding behaviour (levels, velocities and direction) and impacts on bed and bank stability, through flood modelling, including: • hydraulic modelling for a range of flood events, • description, justification and assessment of design objectives (including bridge, culvert and embankment design), • an assessment of afflux and flood duration (inundation period) on land, infrastructure, property and business operations (including agricultural land and stock movement to flood refuges and evacuation routes), hazard and emergency service within the affected area, and future development potential of access affected land, and • consideration of the effects of sea level rise, changes to rainfall frequency and/or intensity as a result of climate change, including an assessment of the capacity of proposed (and existing) stormwater drainage structures;	Section 8.3 and 8.4 Section 8.5
• waterways to be modified as a result of the project, including ecological, hydrological and geomorphic impacts (as relevant), including temporary crossings, and measures to rehabilitate the waterways to preconstruction conditions or better, including fish passage requirements consistent with Policy and Guidelines for Fish Friendly Waterway Crossings (Department of Primary Industries, 2004);	Section 8.4.19 Section 8.4.20 Section 8.6 Section 10.3 (Chapter 10) Section 10.3 (Chapter 10)

8.1 Assessment methodology

8.1.1 Study objectives

The key objectives of the hydrology and flooding assessment were to:

- Inform the development of the project concept design, including the requirements for:
  - Road embankment levels (so carriageways would achieve the desired level of flood immunity)
  - Bridges and culverts (to convey flows safely under the road embankment without unacceptable hydrology and flooding impacts on the environment and land uses)
  - Additional drainage and water management structures (to manage the surface runoff generated from the impervious surfaces of the new highway carriageways)
- Identify any resultant potential impacts on hydrology and flooding associated with the proposed concept design for the project
- Identify any further management measures that would be required to manage resultant impacts.

8.1.2 Design criteria and objectives for flooding

The development of the concept design for the project has been guided by specific flood immunity criteria and flood impact objectives. Hydrological and hydraulic modelling techniques have been used to identify the project design requirements to meet these criteria and objectives, including the requirements for road embankment levels, waterway openings (such as bridge and drainage structures) and surface runoff management. This is an iterative modelling process to meet (where practicable) the management objectives, with the final design based on the flood modelling results.

The design of embankments, bridges and culverts in the concept design are justified as they achieve the flood immunity criteria and (all or in part) the flood management objectives set for the project.

In some cases, due to the need to provide property access or fauna connectivity, bridge or culvert structures may be oversized from the hydrological need. This is assessed in Section 8.4 for each floodplain crossed by the project.

Design criteria

There are sections of the project that would be affected by long duration flooding of the Clarence or Richmond rivers, and short duration local catchment flooding (ie flooding of tributaries of these larger rivers). The design criteria for flood immunity mean that these sections would be above the 20 year annual recurrence interval (ARI) flood level for the Clarence and Richmond rivers, and above the 100 year ARI local catchment flood level (whichever is the higher). Figure 8-1 shows the proposed flood immunity levels across the upgraded highway.

Other elements of the project that would help the highway to achieve flood immunity requirements include:

- Road embankment and carriageways: These have been designed to withstand flood inundation
- Embankments and batters: Embankment levels and associated batter widths can be increased to address the effects of climate change, as required
- Bridges: The design flood immunity of all bridges on the Clarence and Richmond river floodplains is greater than the 100 year ARI design immunity level of the carriageways. Specifically, the soffit level (underside) of these would be 300 millimetres above the 100 year ARI flood immunity level to allow debris to pass under the bridges to minimise the effects of debris blockage.

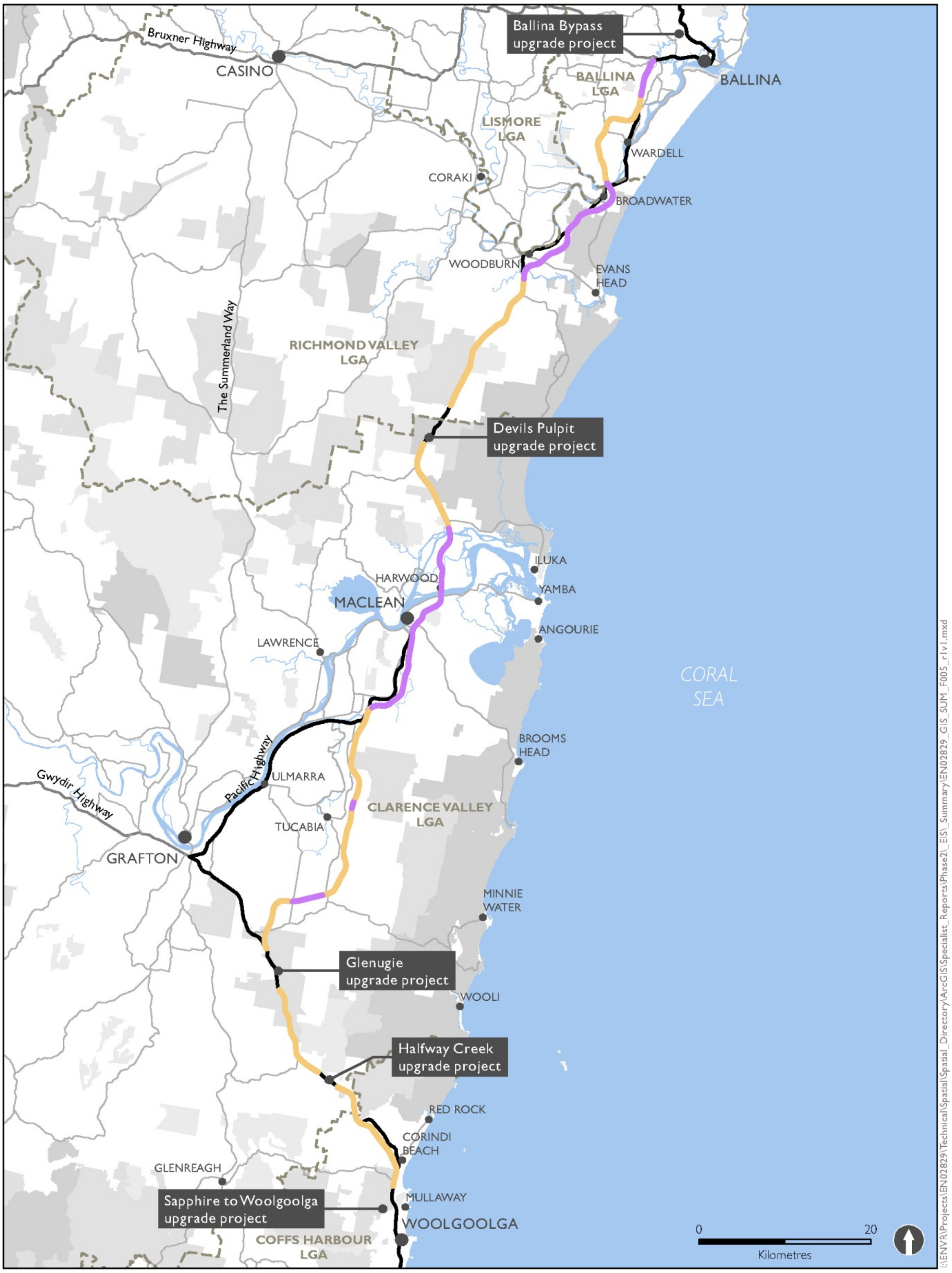

Figure 8-1: Proposed flood immunity levels across the upgraded highway

KEY TERM – Average Recurrence Interval (ARI)

Used to describe the frequency or probability of a given flood occurring (eg a 100 year ARI flood refers to a flood as high as or larger than a flood which recurs, about every 100 years)

Flood impact objectives

While the project would incorporate bridges and culverts over floodplain crossings to minimise impacts on existing flood patterns (including flood heights, durations, flow velocities and flow directions), it is not possible to achieve zero impact in all areas of the floodplains.

The flood impact objectives therefore aim to minimise the potential risks to land use, property and people. These objectives are listed in Table 8-1. The project has been designed to achieve these objectives where feasible and cost-effective. Further information on the derivation of and justification for these objectives is provided in the Working paper – Hydrology and flooding.

Table 8-1: Flood impact objectives

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

As well as the flood impact objectives listed above, the following elements of flood behaviour were also assessed to determine the flooding related impacts of the project:

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

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

8.1.3 Study scope and methodology

The hydrology and flooding impact assessment involved:

- Reviewing the results of previous studies carried out for the route selection and concept design development phases of the project
- Undertaking additional hydrological and hydraulic modelling to provide further information on flood behaviour
- Identifying residual flooding impacts of the project with particular focus on rate of rise and warning time of floods, flood evacuation and access, waterway bed and bank stability and flood hazards
- Identifying any potential measures to mitigate residual impacts
- Identifying the potential impacts on the project from climate change
- Assessing potential ancillary facility locations.

Model types

Hydrological and hydraulic models were used to simulate flows and flood behaviour for all mapped watercourses and associated floodplains crossed by the project (refer to Section 8.2). Over 15 different models were used, with the model type depending upon the size and characteristics of the waterway being examined.

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

Estimates of rainfall intensities for the study area were derived using standard techniques outlined in Australian Rainfall and Runoff (Institution of Engineers Australia, 1987).

Flood events assessed

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

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

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

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

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

The flood events that have been determined to meet the aims of assessing a range of events are shown in Table 8-2 for each flood investigation area.

Table 8-2: Modelled watercourses and the flood events assessed in the modelling study

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

Independent review of flood modelling

As part of the hydrology study for the project and in response to community and stakeholder concerns of the risk of flooding along the project, RMS commissioned WMA Water to undertake an independent review of the flood modelling for the project.

This assessment was undertaken independently of the environmental impact statement. Details of the review are documented in Woolgoolga to Ballina Pacific Highway Upgrade – Independent review of flood modelling (WMA, 2012).

The report presents detailed findings from a review of the hydrologic and hydraulic models used for the flooding investigations, with a particular focus on the modelling of the major cross-drainage structures and waterway crossings for the highway upgrade.

Many of the findings of the review have now been addressed in the flood assessment. More details on the findings of the independent review and how these have been addressed are provided in the Working Paper - Hydrology and flooding.

The report, 'Woolgoolga to Ballina Pacific Highway Upgrade – independent review of flood modelling', is available on the project website at www.rms.nsw.gov.au/pacific.

Flood Focus Groups

During the display of the refined concept design in October 2011, a number of community members stated that flooding is a major concern. As a result of this feedback, RMS established flood focus groups for the Richmond and Clarence river floodplains. The aim of these groups was to create a forum for discussion and exchange of information on flooding events between the project team and the community.

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

- The Clarence group had 31 members and the Richmond group had 28 members. The groups met in November 2011, February 2012 and August 2012
- Meeting 1 – Overview and update of community concerns and issues and the way forward. Undertaken in mid November 2011
- Meeting 2 – Feedback on the independent assessment and addressing any issues. Undertaken in mid February 2012
- Meeting 3 – Presentation of responses to independent assessment and other matters raised in meetings 1 and 2. Undertaken in early August 2012.

The main issues raised for the Richmond River floodplain include:

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

The main issues raised for the Clarence River floodplain include:

- Changes to flooding behaviour in the Shark Creek area
- Impacts to the cane drainage network at Shark Creek area
- Coldstream River bridges / culverts
- Increases to flood levels in Maclean (overtopping of levee)

- Maintenance of culverts, management of debris
- Assessment of more frequent, smaller floods
- Concerns regarding flood modelling (data used etc)
- Access during flood events (people, SES, stock etc).

A further meeting is scheduled to occur during the display of the EIS, where the findings of the hydrology assessment would be discussed.

8.1.4 Terminology

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

Flood event

The term "flood event" can refer to either:

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

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

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

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

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

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

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

Average annual flood damages

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

Photo 1: Eight Mile Lane, Glenugie

One-dimensional and two-dimensional hydraulic modelling

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

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

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

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

Hydrological rainfall-runoff modelling

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

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

KEY TERM – Afflux

Afflux is an increase in water level resulting from changes to flow paths and/or flood storage areas.

Photo 2: View of the Richmond River from the Wardell bridge

8.2 Existing environment

8.2.1 General catchment description

The project is located in the Northern Rivers catchment area, which includes three broad water catchments:

- Coffs Harbour waterways
- Clarence River
- Richmond River.

The Coffs Harbour waterways catchment, which coincides with the southern part of the project, is a small catchment of around 508 square kilometres. It has 13 sub-catchments, all of which originate in steep topography and flatten out towards the coast. The catchment includes the Corindi River and its floodplain, as well as the short coastal catchment of Arrawarra Creek.

The Clarence River catchment, which coincides with the central part of the project, is a large catchment covering around 22,000 square kilometres, extending from tableland areas in the west to the ocean at Yamba. It has 56 sub-catchments and has a large coastal floodplain incorporating the towns of Grafton, Maclean and Yamba. A characteristic of the catchment, particularly around the coastal floodplain, is the occurrence of swamps, wetlands and backwaters.

The Richmond River catchment covers an area of around 7000 square kilometres and coincides with the northern part of the project. It has 23 sub-catchments and incorporates the towns of Woodburn, Broadwater, Wardell and Ballina. It has a large coastal floodplain stretching from Evans Head to Byron Bay.

8.2.2 Watercourses crossed by the project

The project would cross the Clarence and the Richmond rivers. These are both large coastal rivers with major tributaries and substantial floodplains.

The Clarence River is one of the largest rivers on the east coast of Australia. It is around 250 kilometres long and has a tidal limit extending about 90 kilometres inland. Peak flows in the Clarence River during large flood events are in the order of 20,000 cubic metres per second and the total inflow volume is more than 4000 gigalitres (eight times the volume of Sydney Harbour).

The Richmond River is around 170 kilometres long and has a tidal limit extending around 90 kilometres from the ocean. Peak flows in the Richmond River during flood events are in the order of 10,000 cubic metres per second.

The project would also cross several smaller watercourses and their floodplains, including the Corindi River, Halfway Creek, Pheasant Creek, Coldstream River, Pillar Valley Creek, Chaffin Creek, Champions Creek, Tabbimoble Creek, Oakey Creek and Duck Creek.

The watercourses crossed by the project are listed in Table 8-3.

Table 8-3: Watercourses crossed by the project

Broad water catchment	Watercourses crossed by the project	Project section
Coffs Harbour waterways	Corindi River	1
	Halfway Creek	2
	Pheasant Creek	3
Clarence River	Coldstream River	3
	Pillar Valley Creek	3
	Chaffin Creek and nearby unnamed creeks near Mitchell and Bostock roads	3
	Champions Creek and nearby unnamed creek to the north of Champions Creek	3

Broad water catchment	Watercourses crossed by the project	Project section
	Clarence River	3, 4 and 5
	Shark Creek	4
	Mororo Creek	6
	Tabbimoble Creek	6
	Tabbimoble Floodway No. 1	7
Richmond River	Oakey Creek	7
	Tuckombil Canal	8
	Richmond River	8 and 9
	Duck Creek	11

8.2.3 Catchment sizes and characteristics

The catchment sizes of watercourses crossed by the project range from less than two square kilometres for small unnamed tributaries to around 20,000 square kilometres for the Clarence River system and 7000 square kilometres for the Richmond river system. The study area is characterised by relatively steep catchments (generally, five to 15 per cent, but some steeper catchments have slopes of up to 25 per cent). Floodplain slopes are generally in the order of 0.5 to one per cent gradient. Some catchments, such as Corindi River and Halfway, Pheasant, Champions, Tabbimoble and Oakey creeks are predominantly forested, and flow through State forests and national parks. Most catchments include cleared areas used for agriculture, grazing and rural residential land uses. These cleared areas are typically in lower parts of the catchment and closer to the existing highway.

8.2.4 Flooding

The area contained within the project boundary, and surrounding it, is subject to frequent and extensive flooding. This flooding can be caused by one or a combination of:

- Rainfall in the upper catchment
- Rainfall in the local catchment
- Large ocean tides.

Flooding is generally concentrated on and around the coastal floodplains and inundation in these areas can extend over a number of weeks. This can result in damage to buildings and roads, loss or stranding of livestock, loss of crops and blocked access. Flooding also occurs in some upper catchment waterways where fast flows and rapid changes to creek levels can eventuate.

In some areas, local authorities have constructed levees, flood gates and other features to manage the effects of flooding. Levees provide some protection from Clarence River flooding for Grafton, South Grafton, Ulmarra and Maclean, but other towns such as Cowper, Brushgrove, Tucabia and Harwood are not protected.

The number of properties in the impacted parts of Chatsworth, Harwood and Maclean and surrounding areas that are inundated in the current 20, 50 and 100 year ARI flood events is shown in Table 8-4, Table 8-5 and Table 8-6.

Table 8-4: Flooded properties in the impacted parts of Chatsworth Island and surrounds during different flood events

Flood event	Flood level (depth above floor level)	Commercial properties	Fully detached			Multi-unit	
			Single storey	High-set	Double storey	Single storey	Double storey
20 year	0.5 m +	0	0	5	0	0	0
	0-0.5 m	0	0	1	3	0	0
50 year	0.5 m +	0	0	6	1	0	0
	0-0.5 m	4	9	0	3	0	0
100 year	0.5 m +	0	0	6	2	0	0
	0-0.5 m	7	12	0	4	0	0

Table 8-5: Flooded properties in the impacted parts of Harwood Island and surrounds during different flood events

Flood event	Flood level (depth above floor level)	Commercial properties	Fully detached			Multi-unit	
			Single storey	High-set	Double storey	Single storey	Double storey
20 year	0.5 m +	2	2	32	8	0	0
	0-0.5 m	6	3	2	2	1	0
50 year	0.5 m +	4	3	33	10	0	0
	0-0.5 m	6	11	2	0	1	0
100 year	0.5 m +	8	4	34	10	1	0
	0-0.5 m	8	23	1	0	0	0

Table 8-6: Flooded properties in the impacted parts of Maclean, Ashby, Gulmarrad, Woodford Island and Shark Creek during different flood events

Flood event	Flood level (depth above floor level)	Commercial properties	Fully detached			Multi-unit	
			Single storey	High-set	Double storey	Single storey	Double storey
20 year	0.5 m +	2	3	23	13	0	0
	0-0.5 m	4	6	1	2	0	0
50 year	0.5 m +	54	134	24	17	1	1
	0-0.5 m	22	110	0	3	0	0
100 year	0.5 m +	66	162	24	17	1	1
	0-0.5 m	12	102	0	4	0	0

In the Richmond River catchment, Tuckombil Canal was constructed to relieve flooding in the Richmond Valley by directing flows from the Richmond River to flood storage areas east of Woodburn, which then flow to the ocean via the Evans River. There is a natural constriction of the Richmond River near Broadwater caused by the Blackwall Range to the north and remnant coastal sand dunes to the south. The Tuckean Swamp is located to the west of Wardell and provides significant flood storage upstream of the constriction. The Bagotville Barrage, constructed upstream of the Tuckean Swamp in the 1970s, acts as a tide gate to limit tidal influences on the Tuckean Swamp.

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

Many properties experience flooding along the mid Richmond River, and impacts would be experienced in the townships of Woodburn and Broadwater. The number of properties that are inundated in the 20 and 100 year ARI flood events is shown in Table 8-7 and Table 8-8.

Table 8-7: Flooded properties in the impacted parts of Woodburn and surrounds during different flood events

Flood event	Flood level (depth above floor level)	Commercial properties	Fully detached			Multi-unit	
			Single storey	High-set	Double storey	Single storey	Double storey
20 year	0.5 m +	1	1	0	14	0	0
	0-0.5 m	13	2	0	2	0	0
50 year	0.5 m +	14	2	0	17	0	0
	0-0.5 m	13	10	0	1	0	0
100 year	0.5 m +	28	11	0	18	0	0
	0-0.5 m	2	30	0	2	0	0

Table 8-8: Flooded properties in the impacted parts of Broadwater and surrounds during different flood events

Flood event	Flood level (depth above floor level)	Commercial properties	Fully detached			Multi-unit	
			Single storey	High-set	Double storey	Single storey	Double storey
20 year	0.5 m +	0	1	0	0	0	0
	0-0.5 m	5	1	0	9	0	0
50 year	0.5 m +	9	4	0	23	0	0
	0-0.5 m	6	21	0	8	0	0
100 year	0.5 m +	16	29	0	31	0	0
	0-0.5 m	0	27	0	1	0	0

The township of Ballina and the surrounding area is also particularly flood-prone with many properties experiencing flooding along Maguires Creek, Duck Creek, Emigrant Creek and the lower Richmond River. Impacts would be experienced in the township of Ballina as well as surrounding areas. The number of properties that are inundated in the 20 and 100 year ARI flood events is shown in Table 8-9.

Table 8-9: Flooded properties in the impacted parts of Ballina and surrounds during different flood events

Flood event	Flood level (depth above floor level)	Commercial properties	Fully detached			Multi-unit	
			Single storey	High-set	Double storey	Single storey	Double storey
20 year	0.5 m +	2	0	7	1	0	0
	0-0.5 m	50	73	14	26	1	3
100 year	0.5 m +	4	7	22	6	0	0
	0-0.5 m	68	187	39	49	5	14

8.2.5 Flood immunity of the existing highway

The flood immunity of the existing highway between Woolgoolga to Ballina is shown in Figure 8-2. In many locations, the existing highway has a flood immunity of below the 20 year ARI flood event.

Clarence River

An assessment was undertaken to determine the flood immunity of the existing Pacific Highway within the Clarence River floodplain. The following flood immunities have been estimated for the length of existing highway from Grafton to Tyndale:

- The highway would be overtopped at Tyndale upstream of the Coldstream Road intersection in a seven year ARI flood event
- The section of highway north of Ulmarra would overtop in an eight year ARI flood event
- The remainder of the highway along this section would overtop in a 15 year ARI flood event.

The following flood immunities have been estimated for the length of the existing highway from Tyndale to Maclean:

- The area south of the Shark Creek bridge would be cut off during a three to four year ARI flood event
- The Ferry Park area would be overtopped during a 10 year ARI flood event
- The highway would overtop near Causleys Lane in Gulmarrad during a six year ARI flood event.

The flood immunity for the length of existing highway from Maclean to Iluka Road was also estimated. Nominally, this section of highway would overtop north of Serpentine Channel during a five year ARI flood event. However, a section on Chatsworth Island may also overtop during a three to four year ARI flood event. The section of highway north of Maclean at Farlows Flat has been recently raised to provide a flood immunity of 14 year ARI. Previously, it was the most flood prone section of the highway in the project, with a flood immunity of around four year ARI.

Photo 3: View of the Clarence River at Harwood looking east

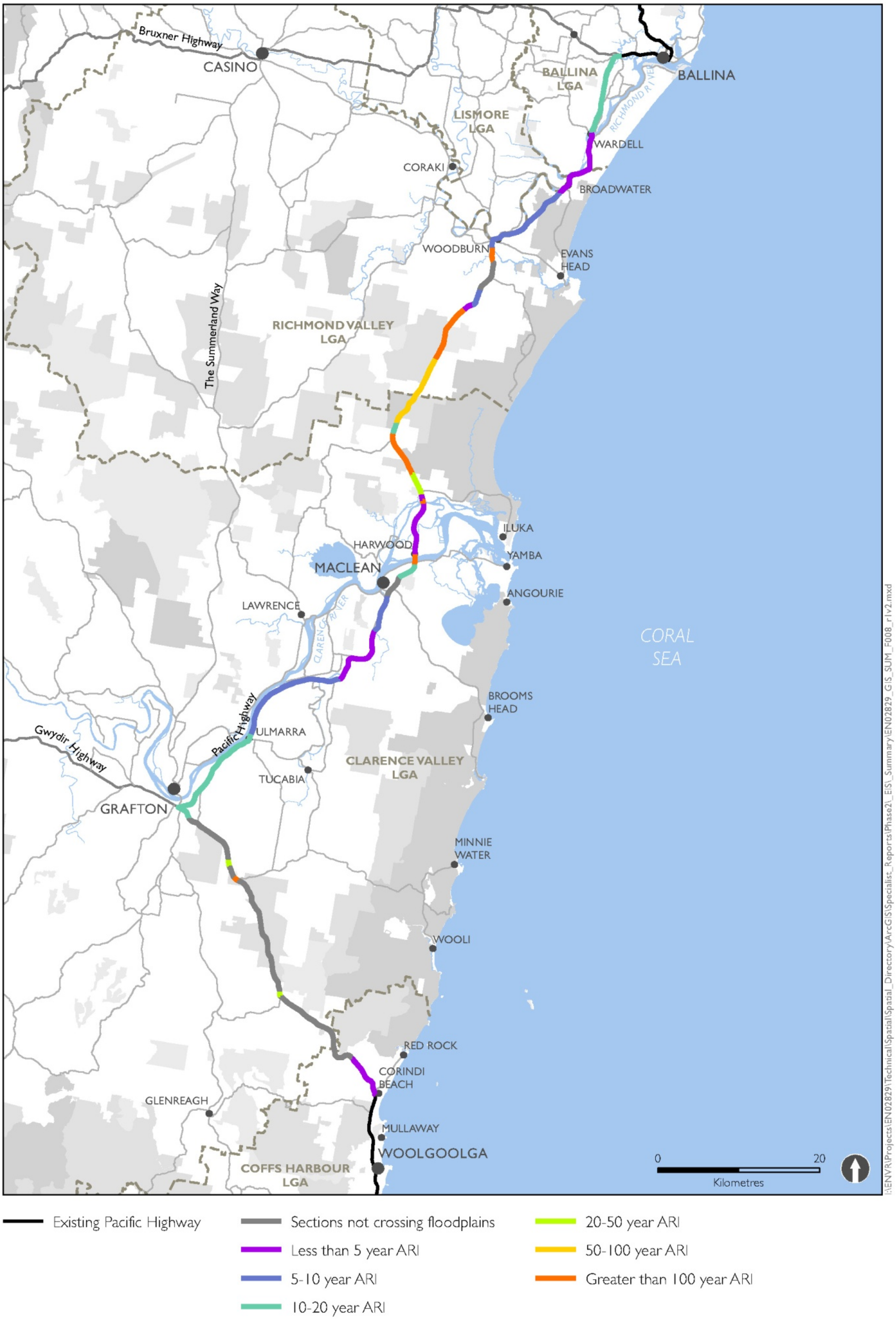

Figure 8-2: Flood immunity of the existing Pacific Highway

Richmond River

An assessment was undertaken to determine the flood immunity of the existing Pacific Highway within the Richmond River floodplain. The following flood immunities were estimated for this length of the highway:

- From Woodburn to Broadwater, the immunity of this section is between a five and a 10 year ARI flood event. From the model results, it is estimated that the road will be overtopped during an eight year ARI flood event
- From Broadwater to Wardell, the most flood prone area is between Broadwater and the intersection with Boundary Creek Road, where the highway overtops during a 5 year ARI flood event. Through Broadwater, the highway would overtop during an event with an ARI of slightly less than 20 years
- From Wardell to the Ballina bypass tie-in, the existing highway would not overtop in a 20 year ARI flood event.

Photo 4: Existing Pacific Highway crossing of the Richmond River

8.2.6 Climate change

The study area may be affected by climate change due to the enhanced greenhouse effect and consequent global warming. The CSIRO report Climate Change in the Northern Rivers Catchment (CSIRO, 2007) provides projections for climate change of relevance to the project study area. These projections suggest that there will be an increase in the frequency of intense storms causing flooding. Additionally, by 2030, average temperatures could increase by between 0.2 and 1.8 degrees Celsius.

While the ultimate effects of climate change are uncertain, there are two anticipated outcomes of global warming that are likely to impact hydrology and flooding in the study area:

- A rise in sea levels
- An increase in rainfall intensity.

These climate change factors have been considered in the assessment of hydrology and flooding issues associated with the project.

8.3 Assessment of construction impacts

The following construction activities may result in hydrology and flooding impacts:

- Ancillary facilities
- Early construction of road embankments at soft soil treatment sites
- Construction of temporary connections to the existing highway
- Construction sites and haul roads, which may cross a number of cane drains.

These activities are discussed below.

8.3.1 Ancillary facilities

Ninety potential sites for ancillary facilities have been identified for the project, including sites outside of the project boundary.

Forty-one of these sites are located outside floodplain areas and are unlikely to have any impact on hydrology or flooding, or be affected by flooding.

However, 49 of these sites are located either on floodplains or below the level of the 20 year ARI flood and could therefore be affected by flooding and have hydrology and flooding impacts on upstream areas. These sites would need to be built up on embankments to provide sufficient flood immunity. Of these sites:

- Fifteen are located or partially located in areas of low velocity backwater and would result in only a minor loss of flood storage and have negligible impacts on flooding within the respective catchments
- Ten are located along the project in areas of floodplain that experience low velocity flows and conveyance. Given their position along the project, these sites would have hydrology and flooding impacts that are consistent with the operational impacts of the project and would not require additional impact mitigation
- Twenty-four may result in moderate or significant flood impacts.

Table 8-10 presents the potential hydrology and flooding impacts of these ancillary facilities. Further investigations are occurring concurrently with the display of this EIS, with results identified in the project submissions report.

Table 8-10: Hydrology and flooding impacts of potential ancillary facilities

Project section	Site No.	Predicted impact
3	2	Use of the site would completely block the waterway of a small catchment. Would cause substantial flood impacts without sufficient drainage through site.
3	5	Site immediately adjacent to main channel of the small unnamed creek near Mitchell Road, and currently partially blocking a future bridge, and therefore a main flow path. Site likely to experience flooding, particularly during large events.
4	2	Site is located on Shark Creek floodplain. Use of the site would have limited impact on regional flooding but considerable impact on drainage as the site is currently blocking cane drains. Would incur some loss of flood storage.
4	6	Site immediately adjacent to the Clarence River South Arm channel. In an area of potentially high flood conveyance and likely to incur flood impacts during a 20 year ARI flood event.

Project section	Site No.	Predicted impact
4	7a	Site is in an area of relatively low velocity backwater flooding. However, due to the proximity to a low point in the Shark Creek embankment, it experiences higher conveyance and drainage of the Shark Creek catchment during flooding than surrounding areas. Therefore, use of the site may have some impacts on drainage and duration of inundation of the Shark Creek catchment during large floods.
4	7b	Site is in an area of relatively low velocity backwater flooding. However, due to proximity to a low point in the Shark Creek embankment, it experiences higher conveyance and drainage of the Shark Creek catchment during flooding than surrounding areas. Therefore, use of the site may have some impacts on drainage and duration of inundation of the Shark Creek catchment during large floods.
5	2a	Site is adjacent to the southern bank of the main Clarence River channel in an area of high conveyance and moderate flow velocities during 20 year ARI (and larger) flood events. Use of the site may have some flood impacts during large events.
5	2b	Site would block the southern end of the Clarence River bridge crossing adjacent to the main channel. It is in an area of high conveyance and moderate flow velocities during 20 year ARI (and larger) flood events. Use of the site is likely to have considerable flood impacts if a large flood event was to occur during construction.
5	2d	Site is adjacent to the southern bank of the main Clarence River channel in an area of high conveyance and moderate flow velocities during 20 year ARI (and larger) flood events. Use of the site would block southern end of the Clarence River bridge crossing. Likely to incur considerable flood impacts during large events.
5	3a	Site is adjacent to the northern bank of the main Clarence River channel in an area of high conveyance and moderate flow velocities during 20 year ARI (and larger) flood events. Use of the site would be partially buffered by the existing highway, but would be obstructing the northern end of the current Harwood Bridge and bridge upgrade. Use of the site would likely have substantial flood impacts during large events.
5	4a	Use of the site would completely obstruct 16-cell culvert on Chatsworth Island (corresponding culverts for Section 5 – site 4b). Use of the site would likely have moderate flood impacts during large events.
5	4b	Use of the site would completely obstruct 16-cell culvert on Chatsworth Island (corresponding culverts for Section 5 – site 4a). Use of the site would likely have moderate flood impacts during large events.
5	3b	Site would completely obstruct a floodplain bridge at station 87.3, immediately north of the Harwood Bridge. Would experience unacceptable and substantial upstream impacts during large events.
5	5c	Site area is small but its use would completely obstruct a small bridge on Chatsworth Island and would have significant upstream impacts during large flood events.
5	6	Site is located on a breakout channel during large floods in Mororo Creek catchment. Use of the site would have substantial impacts on cane land to the north of the site.
6	3a	Outer regions of site are located in Tabbimoble Creek floodplain. Use of the site would completely obstruct culverts across the project. Its use would have substantial flood impact without mitigation.
6	3b	Site is partially located in the Tabbimoble Creek floodplain. Use of the site would completely obstruct the existing floodplain bridge. Its use would incur substantial flood impacts upstream.
8	1	Site is located in the lower Richmond River floodplain. Use of the site would cause some loss of flood storage and would create a minor obstruction to Tuckombil Canal floodplain flow.
8	2a	Site is located in lower Richmond River floodplain. Use of this location would block culverts across the project. It would also have substantial upstream flood impacts.

Project section	Site No.	Predicted impact
8	2b	Site is located in the lower Richmond River floodplain. Use of this location would block culverts across the project and have substantial upstream flood impacts.
8	2c	Site is located in the lower Richmond River floodplain. Use of this location would partially block culverts across the project.
9	1	Site is located in the lower Richmond River floodplain. Use of the site would cause some removal of flood storage and minor flood impacts.
10	1a	Site is currently located on the floodplain immediately adjacent to the Richmond River channel. Use of the site would block the southern underpass of the bridge over the Richmond River, and would create a major obstruction to flows during flood events which exceed the capacity of the river.
11	2	Site is currently located in front of a major drainage section of the highway, consisting of several large multi-cell culverts. Use of this location is considered to be unable to accommodate a construction site without unacceptable flood impacts.

8.3.2 Early construction of road embankments at soft soil treatment sites

At ten sites, embankments would be constructed at the start of road construction to accelerate the settlement of soft soils (refer to Table 8-11 and shown in Figure 6-2 to Figure 6-42 in Chapter 6 (Description of the project- construction)). These sites are referred to as 'soft soil sites' and are located on the Clarence River and Richmond River floodplains.

Table 8-11: Soft soil embankment sites

Reference	Station	Location	Catchment
Section 4			
SS-01	72.9 – 75.0	South of Shark Creek	Clarence River
SS-02	77.1 - 77.5	North of McIntyres Lane	Clarence River
SS-03	78.4 - 80.9	North and south of Edwards Creek	Clarence River
Section 5			
SS-04	84.9 - 86.0	Clarence River crossing (south)	Clarence River
SS-05	87.2 - 87.7	Clarence River crossing (north)	Clarence River
SS-06	89.1 - 89.7	North and south of Serpentine Channel	Clarence River
SS-07	92.4 - 93.3	South of Carrols Lane	Clarence River
Section 8			
SS-08	129.7 - 130.8	North and south of Tuckombil Canal	Richmond River
Section 9			
SS-09	145.0 – 145.5	South of Richmond River Bridge, Broadwater	Richmond River
Section 11			
SS-10	159.9 - 163.9	North of Whytes Lane and south of Duck Creek	Richmond River

To accelerate settlement of these soft soils, the initial height of these embankments may be higher than the final design embankment height for the project, depending on the soil settlement method selected. Once the soft soils are adequately settled, the excess fill would be removed to reduce the embankment heights to the final project design level. For the purposes of this assessment, it has been assumed that the initial height of the embankments at these sites may be above the 100 year ARI flood levels until adequate settlement has been achieved.

The flood impacts associated with these embankments have the potential to be greater than those of the completed project as the embankments would be temporarily higher than the design levels of the project.

To mitigate impacts, the flow of water through local waterways and agricultural drains crossed by the embankments would be maintained through temporary culverts, which would be sized during detailed design. For the purposes of the flood impact assessment, it was conservatively assumed that the temporary drainage culverts would not convey floodwaters. The potential flooding impacts associated with the soft soil sites on the Clarence River and Richmond River floodplains are described below.

Clarence River soft soil sites

The soft soil sites on the Clarence River floodplain would be in two general locations:

- Shark Creek to Maclean interchange (SS-01 to SS-03)
- Just south of the Clarence River and Chatsworth and Harwood islands (SS-04 to SS-07).

The soft soil sites on the Shark Creek floodplain and in the Chaselings basin area would cross a number of major cane drains. It is important that these drains remain operational throughout the construction period. The project would include temporary drainage culverts that would convey local runoff to the Clarence River.

One of the most important flood elements on the Chaselings basin area is the Goodwood Street underpass. When the Clarence River floods, floodwaters break the riverbanks near Ferry Park and cross Cameron Street. Floodwaters then pass under the existing Pacific Highway via the Goodwood Street underpass and fill the large Chaselings basin area. In the early stages of a Clarence River flood, this is the first (and for some time only) flow path into the Chaselings basin area.

The construction of the embankments would include a gap to allow traffic to pass on Goodwood Street. Hence, the existing flood regime on the Clarence River floodplain would be maintained, with floodwaters from the rising Clarence River passing through the current Goodwood Street underpass and then through the gap in the embankment and into the Chaselings basin area.

Within the Chatsworth and Harwood islands section, the embankments would partially block the floodplain. However, this blockage would only represent 33 per cent of the flow width across the Chatsworth and Harwood islands floodplain. A gap of 180 metres would be included in embankment SS-07 on Chatsworth Island to allow a flow path through the embankment to reduce the impact it would otherwise have on the surrounding flood levels.

The soft soil treatment embankments would result in minor changes to the flooding patterns and rates of floodwater rise and fall on the Clarence River floodplain. Specific changes would be as follows:

- Flow from the back-flooding of the Shark Creek basin (once the river bank is overtopped) would pass south along embankment SS-01 prior to flowing into the broader Shark Creek basin. However, flooding velocities would be low on this floodplain due to the relatively slow rate of floodwater rise
- The rate of floodwater rise would increase on the western side of SS-03. In addition, the duration of land inundation (with levels of around 2.5 metres Australian Height Datum (AHD)) would increase by 10 to 15 hours (on top of an existing inundation time of around 90 hours). While this exceeds one of the flood impact objectives (ie limiting increases in inundation time to five per cent) the increase in inundation time would occur at the commencement of flooding (due to an increase in the rate of floodwater rise) and would not increase the risk of cane ’scalding’ (over-heating of flood-inundated cane)
- General flooding patterns and flow distribution on Chatsworth and Harwood islands would undergo minor changes as Clarence River floodplain flows would pass around embankments SS-04, SS-05, SS-06 and SS-07. Rates of floodwater rise and fall would not be significantly affected.

Therefore, the predicted impacts of the soft soil treatment embankments on the Clarence River floodplain and sugarcane areas would meet the stated impact objectives for cane areas and residential areas, even without culverts across local drainage waterways. The impacts actually experienced would be reduced with the proposed culverts in place.

KEY TERM – Australian Height Datum (AHD)

The standard reference level used to express the relative height of various features. A height given in metres AHD is essentially the height above sea level.

Richmond River soft soil sites

The soft soil sites on the Richmond River floodplain would be in three general locations:

- South and north of Tuckombil Canal, on both sides of the canal levee but not within the canal (SS-08)
- South of the Duck Creek crossing near Ballina, from five kilometres south of the crossing to 500 metres south of Duck Creek crossing (SS-09)
- South of the Richmond River crossing near Broadwater (SS-10).

The predicted impacts of the soft soil sites in the vicinity of Tuckombil Canal would be very minor. This is due to the relatively small section of the floodplain that would be blocked by the embankments – 1500 metres of the total 4500 metres, or 33 per cent. The area that would be blocked also has lower flow rates than the remainder of the floodplain.

The predicted impacts of the soft soil site south of the Richmond River crossing near Broadwater would not result in any additional flooding impacts over and above the predicted impacts of the completed project.

The embankments near Duck Creek would result in a minor increase in flood levels, as follows:

- Flood levels to the west of the embankments would increase up to 25 millimetres in the 100 year ARI flood event
- Flood levels to the east of the embankments would increase by a maximum of 15 millimetres, with the majority of the floodplain being impacted by less than 10 millimetres
- Flood levels within the Emigrant Creek floodplain would increase by less than 50 millimetres, except for a small (less than one hectare) area within a densely vegetated, tight meander of Emigrant Creek
- Flood levels within a small area of the Ballina bypass project boundary would increase by more than 50 millimetres.

There would be negligible impacts on the time of inundation of cane land as a result of the soft soil embankments; the embankments would meet the flood impact objectives for this area during construction.

Therefore, the predicted impacts of the soft soil treatment embankments on the Richmond River floodplain and sugarcane areas would meet the stated impact objectives for cane areas and residential areas.

8.3.3 Construction of temporary connections to the existing highway

RMS is proposing to stage the delivery of the project based on consideration of funding. Each stage would involve upgrading a combination of one or more project sections, with some sections of highway being upgraded in advance of others.

The construction of earlier delivery stages may require construction of a temporary connection to the existing Pacific Highway, where adjoining sections may not yet be upgraded. These temporary connections would be located within the project boundary and would not require acquisition of additional land.

Each potential temporary connection location has been examined to determine if it would result in any impacts on flood behaviour and to identify any impact mitigation required for the period in which the temporary connection would operate. It was found that:

- All but four of the potential temporary connection locations are outside of floodplain areas and would not result in any significant flooding impacts
- The four temporary connection locations, while located on floodplain areas, would not result in any additional flooding impacts over and above the predicted impacts of the completed project.

8.3.4 Construction sites and haul roads – impacts on cane drains

The construction sites and haul roads may cross a number of cane drains. It is critical that the capacity of cane drains is not reduced as this could result in significant delays to the drainage of cane lands, which could result in extended inundation and potential loss of crops. The main area where this has been identified as a potential issue is within the Shark Creek basin.

This issue would be further investigated and addressed during detailed design in conjunction with the verification of temporary construction site locations. The design would need to verify that the conveyance characteristics of the cane drains are maintained through the provision of waterway crossings under any construction sites and haul roads. Temporary drainage would be oversized to prevent blockages.

Photo 5: Northern end of project at proposed tie-in with Ballina bypass upgrade

8.4 Assessment of operational impacts

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

There would also be a minor increase in the rate and volume of stormwater runoff from the catchment due to the increase in impervious surface area (due to the replacement of natural areas with highway infrastructure). As the increase in impervious surface area would be less than one percent of the overall catchment area, this impact is considered to be immaterial and has not been quantitatively assessed.

The following sections detail:

- How the potential hydrology and flooding impacts of the project have been addressed in the design of the project
- The remaining impacts of the project, based on the current concept design
- The implications of future climate change.

8.4.1 Reduction of potential operational impacts through the design process

The project incorporates numerous waterway openings and crossing structures (such as bridges and culverts) to convey flows safely under the road embankment without unacceptable flooding impacts on the surrounding environment. The locations and dimensions of these structures have been designed with the aim of meeting the project flood impact objectives to the greatest extent practicable and in consideration of other environmental needs, including the need for fauna crossing points along the upgraded highway. Where the project is close to the existing Pacific Highway alignment (eg from Maclean to Woodburn), the bridges and culverts would be similar to and (in some locations) larger than the existing structures. The bridge structures and waterway openings are listed in Chapter 5 (Description of the project - operation).

The project also incorporates a system of drainage structures, grassed swales and water quality detention basins to manage surface runoff generated from the impervious surfaces of the new carriageways. The design of the drainage system would prevent potential impacts on receiving waters, including scour and erosion. The drainage structures incorporated within the project would include existing drainage structures, which would be modified to accommodate any increased paved surface area. Appropriate protection would be provided upstream of, through and downstream of waterway structures to prevent adverse impacts on the bed and bank stability of watercourses.

8.4.2 Residual operational impacts of the project

The flood impact objectives would be achieved in all areas potentially impacted by the project during its operation. The project would have minor impacts on flood levels, flood inundation periods, and the timing of floodwater rise and fall, as well as some minor localised flooding impacts. The project would not, however, have any significant adverse impacts on property access or the use or productivity of agricultural land from changes to flooding behaviour.

Minor increases in flood levels and inundation periods in some areas would result in a small reduction in the amount of land available for future development. Or, if used, would require that the land be built up to provide appropriate flood immunity immediately upstream of the highway. The small decrease in future land use potential due to flooding is assessed to be minor, when compared against the increase in development potential as a result of the project.

In addition, the project would result in a substantial improvement in the flood immunity of the Pacific Highway, which is currently flood-prone in several places. This would improve the ability of people to evacuate when flooding occurs. It would also reduce the frequency and duration of highway closures due to flooding.

The impacts of the project on flooding are discussed in the following sections for each of the watercourses and associated floodplain areas crossed by the project.

8.4.3 Corindi River

Flood management objectives

Land use within the flatter sections of the catchment consists mostly of agricultural and rural residential use. There are some forested areas on the higher ground and vegetation along the Corindi River. There are no residences but there is a shed about 100 metres from the Corindi River upstream of the project. The flood management objectives for this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to a 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 ha) up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses
- No more than 10 per cent increase in the flood duration on grazing, forested and other rural lands
- Velocities to remain below one metre per second near houses and below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on Australian Rainfall and Runoff, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

Upstream of the Corindi River crossing, the project would cause peak 100 year ARI levels within the creek to increase by up to 150 millimetres (and 125 millimetres in the 20 year ARI flood event).

In a small area less than 15 metres upstream of the project along the floodplain between the Corindi River and Cassons Creek, flood levels increase by more than 400 millimetres. Impacts are up to 430 millimetres in the 100 year ARI flood event (and 350 millimetres in the 20 year ARI flood event) and reduce to less than 250 millimetres within 150 metres upstream of the project. These impacts do not meet the flood management objectives for this catchment.

Downstream of Corindi River floodplain bridge, peak levels are increased due to the concentration of flow through this structure in the new embankment.

The areas adversely impacted by flooding are mostly used for grazing. Due to the relatively steep gradient of the Corindi River floodplain, areas that have flood levels increased by more than 250 millimetres are confined to within 80 metres of the project boundary in all assessed flood events.

The constriction caused by the embankment at Cassons Creek would result in a peak 100 year ARI flood level increase of up to 170 millimetres upstream of the project boundary (and 110 millimetres in the 20 year ARI flood event). This area is a mixture of wooded and cleared grazing land. About 350 metres upstream of the project on Cassons Creek, flooding impacts would be as low as 50 millimetres in the 100 year ARI flood event (and 25 millimetres in the 20 year ARI flood event).

A shed is located on the floodplain upstream of the project and the predicted impact at this shed is about 20 millimetres in the 20 year and 100 year ARI flood event. No other buildings would be impacted by the project.

Downstream of the project, levels in the Corindi River would decrease in all assessed ARI flood events.

The increased levels on agricultural and forested land described above are unlikely to affect farming operations, as stock and machinery are unlikely to be within the floodway at the peak of the flood.

The steeper gradient of the floodplain also limits the lateral width of the floodplain, so that the flood extent resulting from the project is not much larger than that under existing conditions.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

The duration of increased flood levels on agricultural land would be relatively short (around a few hours) due to the relatively short duration of flood events in the Corindi River and Cassons Creek. Impacts to agricultural operations due to increased inundation periods would therefore be negligible. No residences would be affected by increased flood inundation periods.

Flood velocity and direction impacts

Velocities at the project boundary, downstream of the 85 metre bridge over Corindi River, are up to 1.6 metres per second in the 100 year ARI flood event, which is an increase of about five per cent from the current situation. These impacts dissipate downstream to close to zero per cent within about 100 metres of the project boundary.

Velocities downstream of the 280 metre floodplain bridge would be around 1.4 metres per second in the 100 year ARI flood event, which is an increase of 20 per cent compared to the existing scenario. The area downstream of the bridge is open grassland, and is not expected to experience increased scour as a result of the greater velocities.

Velocities downstream of the 56 metre bridge over Cassons Creek are up to 1.5 metres per second in the 100 year ARI flood event, which is an increase of 20 per cent compared to the existing scenario. These increased velocities are contained within Cassons Creek, and decrease to less than one metre per second within 125 metres of the project boundary.

The potential for scour at these locations as a result of the project would need to be confirmed at the detailed design phase through a geomorphologic assessment with suitable mitigation measures identified and incorporated into the final design (eg rock armouring or increasing the bridge span). This issue has been further discussed below with respect to bed and bank stability.

The proposed location of culverts and bridges would minimise changes in flow direction and flood behaviour. Minimal areas that are currently flood free would be inundated as a result of the project. Some constriction and expansion of flow into and out of waterway structures would also occur.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have similar rate of floodwater rise as the existing situation. North of Corindi River there is a small reduction in the warning time of around 10 minutes, which is less than the five per cent of the overall time of inundation.

There are no houses or commercial premises impacted by the project in this area. Hence, the flood warning time for residents would be unaffected.

Flood level plots for the catchment are in Working paper – Hydrology.

Flood evacuation and flood access impacts

Due to the similar rate of floodwater rise as the existing case, there would not be any change to the potential for evacuation in this area.

There is a potential for stock access in times of flood to be affected as the project would separate flooded land from higher ground at station 4.6. This potential would need to be confirmed with affected land owners at the detailed design phase.

Flood hazard impacts

Agricultural land immediately upstream of the project would experience a faster rise of flood level. However, this would not increase the level of flood hazard for people, stock or property.

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

The project would increase velocities on the right bank and bed of Corindi River by about 10 per cent for two year ARI flood events through to 100 year ARI flood events. Similar increases are predicted on the left bank in common flood events. These changes are unlikely to result in changes to bed form of the channel.

It is predicted that peak velocities on the left bank of Corindi River would increase by about 50 per cent in rarer 20 year and 100 year ARI flood events. While this is a large percentage increase, it is on a low base velocity of about 0.8 metres per second increasing to about 1.2 metres per second. It is likely that the well vegetated channel banks could accommodate these increases in peak velocity without increased risk of erosion.

For Cassons Creek, the project would not result in any changes to the peak bed and bank velocities in the common flood events (two year ARI). For the 20 year and 100 year ARI flood events, peak velocities on the bed and banks would increase by about 20 per cent due to the project. While this is a moderate percentage increase, it is on a low base velocity of between 0.5 metres per second to about 1.2 metres per second.

The rate of recession in Cassons Creek would also be increased by around 25 per cent. Increased rate of recession has the potential to increase the risk of erosion through bank slumping. It is likely that the well vegetated channel banks could accommodate both the increases in peak velocity and rate of recession without increased risk of erosion. However, this would need to be confirmed at the detailed design phase through a detailed geomorphological assessment.

The concept design includes bridge piers located on or near the bed and banks of both Corindi River and Cassons Creek. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

Redbank Creek is a small watercourse north of Cassons Creek. At the current Pacific Highway crossing, there is clear evidence of bed and bank scour. As such, this waterway may have increased risk of erosion as a result of the project. This waterway would require a geomorphological assessment at the detailed design phase to identify and mitigate project impacts.

8.4.4 Halfway Creek

Flood management objectives

Land use within the catchment is mostly forest, with some cleared agricultural areas, mostly downstream (west) of the existing highway. There would be no residences outside of the project boundary that would be within the flood extent for this catchment. The flood management objectives of relevance to this catchment are:

- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than ten per cent increase in the flood duration on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The enhanced hydraulic capacity of the proposed highway bridges over Halfway Creek would reduce peak 100 year ARI levels upstream by an average of 120 millimetres (and 450 millimetres in the 20 year ARI flood event).

A small area of agricultural land to the west of the proposed bridge over Halfway Creek would experience increased peak 100 year ARI levels up to 350 millimetres (and 150 millimetres in the 20 year ARI flood event) due to the altered flow regime as a result of the project. All other areas would experience a decrease in flood levels as a result of the project – the enhanced hydraulic capacity of the proposed highway bridge over Halfway Creek would reduce flood levels upstream by an average of 120 millimetres.

No residences would experience flood level impacts in this floodplain.

Increased flood levels between the highway and local access road would result from the increased upstream bridge capacity and downstream bridge constriction. These are within the project boundary.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

The period of inundation would reduce across all areas outside of the project boundary where a reduction in peak flood level would occur. Again, the area of permanent planting would benefit from a shorter period of inundation.

The small area to the west of the service road bridge that would experience increased flood levels would also experience a minor increase in inundation duration. This would have negligible impact on agricultural activities at this location.

No residences would be affected by increased flood inundation periods.

Flood velocity and direction impacts

The constriction and expansion patterns for the Halfway Creek catchment would be very similar to existing due to the proposed embankment and structures being in a similar location to existing.

Downstream of the culverts, velocities decrease by 44 per cent in the 100 year ARI flood event. Velocities are less than one metre per second upstream of the culverts.

Downstream of the highway bridge, velocities increase by up to 60 per cent, with velocities up to two metres per second in the 100 year ARI flood event. This is a result of the increased flow through the bridge over Halfway Creek and constriction of flow through the service road bridge.

Velocities decrease to less than one metre per second within 100 metres of the project boundary. This change is not expected to have an impact on people, stock or property.

The potential for scour at these locations as a result of the project would need to be confirmed at the detailed design phase through a geomorphologic assessment.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

There are no houses or commercial premises impacted by the project in this area.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

As this section of the project would be a duplication of the existing highway, no known evacuation routes would be severed by the project. As such, there is not expected to be any impact to flood evacuation in this area. Ability to evacuate is likely to be enhanced by the increase in flood immunity of the road. The level of flood immunity provided by the proposed service road (ie Eggins Drive) to Corindi would be further reviewed in consultation with Coffs Harbour City Council.

Flood hazard impacts

Agricultural land immediately upstream of the project would experience a faster rise of flood level. However, this would not increase the level of flood hazard for people, stock or property.

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

The project would decrease velocities on the right bank and bed of Halfway Creek beneath the project crossing for two year ARI flood events through to 100 year ARI flood events due to the removal of the existing highway bridge.

It is predicted that peak velocities on the left bank of Halfway Creek at the project crossing would increase by about 150 per cent in a two year ARI flood event and about 20 per cent in 20 year and 100 year ARI flood events. While this is a large percentage increase for the two year ARI flood event, it is on a very low base velocity of between 0.3 metres per second increasing to about 0.8 metres per second.

However, as a result of the constriction of flow through the service road bridge around 30 metres downstream of the bridge over Halfway Creek, velocities increase by up to 60 per cent from around 2.0 to around 3.0 metres per second. These velocity changes are likely to change erosion potential in this channel.

The concept design includes bridge piers located on or near the bed and banks of Halfway Creek. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.5 Pheasant Creek

Flood management objectives

Land use within the area surrounding the project is mostly forest, with some of the downstream (northern) areas cleared for agricultural use. There are no houses or cane farm land within the flood extent that would be influenced by the project. The flood management objectives for this catchment are:

- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than ten per cent increase in the flood duration on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

Downstream of the project, impact to peak 100 year ARI flood levels in Pheasant Creek would be 20 to 25 millimetres for a distance of about 250 metres (and 60 millimetres in the 20 year ARI flood event for around 300 metres). This decreases to zero millimetres in the 100 year ARI within 350 metres (and to less than five millimetres for the 20 year ARI flood). Upstream of the Eight Mile Lane crossing over Pheasant Creek, peak 100 and 20 year ARI flood levels would increase by about 25 millimetres due to the project.

No residences would experience flood level impacts in this floodplain.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

Increases in the period of inundation would be negligible in all areas and would not impact on land use, people or property.

Flood velocity and direction impacts

Velocities upstream and downstream of the 55 metre bridge over Pheasant Creek in the 100 year ARI flood event are greater than one metre per second, but within the 20 per cent increase flood management objective. This change is not expected to have an impact on people, stock or property.

Velocity in the Picaninny Creek diversion channel would be much higher than currently exists at this location due to the altered flow path. Flow directions would also be affected. However, these changes would be contained within the project boundary, and would be clear with the constructed diversion channel signifying a defined flow path.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have a similar rate of floodwater rise as the existing case.

There are no houses or commercial premises impacted by the project in this area. Hence, the flood warning time for residents would be unaffected.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

There are no known evacuation routes that would be severed by the project.

Due to the similar rate of floodwater rise as the existing case, there would not be any change to the potential for evacuation in this area.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

The project would decrease velocities on the bed and banks of Pheasant Creek for two year ARI flood events through to 100 year ARI flood events due to the diversion of Picanniny Creek catchment to downstream of the bridge crossing. Hence, the bed and bank stability of Pheasant Creek is unlikely to be impacted by the project.

The concept design includes bridge piers located on or near the bed and banks of Pheasant Creek. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.6 Coldstream River

Flood management objectives

Within the area that would be affected by the project, land use is split relatively evenly between forest and farming (predominantly grazing). There are no houses within the 100 year ARI flood extent. However, a small cluster of houses have primary access via Wants Lane, which crosses the western tributary of the Coldstream River about 370 metres upstream of the project. The flood management objectives of relevance to this catchment are:

- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 ha) up to the 100 year ARI flood event
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

Peak 100 year ARI flood levels upstream of the project would be increased by up to 300 millimetres between the 300 metre and 160 metre bridges (and 260 millimetres in the 20 year ARI flood event). Impacts in the 100 year ARI flood upstream of the 160 metre bridge reduce to less than 250 millimetres within about 200 metres upstream of the project (and less than five millimetres in the 20 year ARI flood).

An area of around 5.6 hectares would experience impacts greater than 250 millimetres but less than 400 millimetres. These impacts do not meet the flood management objectives for this catchment.

Near the Wooli Road/Lloyds Road intersection, three kilometres (river length) upstream of the project, impacts to flood levels for both the 100 year and 20 year ARI flood levels would reduce to 10 millimetres. The area of increase outside of the project boundary is forested and is unlikely to suffer a reduction in productivity as a result of increased flood levels.

Downstream of the project in between Coldstream River 2 bridge and the Coldstream River 3 bridge, peak 20 and 100 year ARI flood levels would be decreased by over 300 millimetres due to the embankment impeding flow through this area (in 200, 100 and 20 year ARI flood events).

The floodplain of the western tributary would experience peak 100 year ARI flood level increases generally around 190 millimetres to 210 millimetres (and around 125 millimetres to 140 millimetres in the 20 year ARI flood event). Levels between Coldstream River 1 bridge and the Coldstream River 2 bridge, would be up to 240 millimetres higher than the existing 100 year ARI levels (and 175 millimetres in the 20 year ARI flood event).

Of particular note, levels along Wants Lane would be increased by up to 200 millimetres during the 100 year ARI flood event as a result of the project (and 130 millimetres in the 20 year ARI flood event).

Downstream of each of the three bridges, peak flood levels would increase slightly (less than 55 millimetres at the 120 metre long and 300 metre long bridges, and up to 190 millimetres at the 160 metre long bridge in the 100 and 20yr ARI flood events) due to the concentration of flows through the bridges as a result of the project.

No residences would experience flood level impacts in this floodplain.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

The period of inundation throughout the floodplain is increased slightly as a result of the constriction of the project embankment. This is unlikely to be of concern throughout the forested and agricultural areas impacted by the project.

Along Wants Lane, flood depths would reach a level that prohibits normal vehicle accessibility slightly earlier, and would stay above this level slightly longer.

Flood velocity and direction impacts

Downstream of the Coldstream River 1 bridge, velocities would be around 1.1 metres per second in the 100 year ARI flood event, representing a 120 per cent increase from existing conditions. This impact is highly localised, with velocities decreasing to less than one metre per second within 50 metres of the project boundary.

Velocities upstream and downstream of the Coldstream River 2 bridge are up to 1.5 metres per second in the 100 year ARI flood event; however, the increase in velocity from existing conditions is within the 20 per cent flood management objective.

Velocities downstream of the Coldstream River 3 bridge would be around 1.25 metres per second, about an 80 per cent increase from existing conditions. This increase reduces to the 20 percent flood management objective within 300 metres of the project boundary.

The potential for scour at these locations as a result of the project would need to be confirmed at the detailed design phase through a geomorphologic assessment.

There would be little change to flood velocity and direction as a result of the project beyond the highlighted effects of constriction and expansion. Velocity changes are not expected to have impact on people, stock or property.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have similar rate of floodwater rise as the existing case immediately upstream of the project boundary at the Coldstream River and western tributary bridges and also along Wants Lane. There is a reduction in warning time of 15 to 20 minutes at the bridge over the unnamed creek to the east of the Coldstream River.

There are some houses which have primary access via Wants Lane. As Wants Lane experiences similar rates of rise as the existing case, the flood warning time for these residents would not be affected.

The area around the bridge over the unnamed creek to the east of the Coldstream River is predominantly forested and there are no residences nearby. As a result, there would be no impact of reduced warning time on residents.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

Several residences have primary access via Wants Lane, which is inundated along a length of about 1500 metres in the 100 year ARI flood. Due to the similar rate of floodwater rise as the existing case along this road, there would not be any change to the potential for evacuation in this area.

It is assumed that the two Wants Lane bridges become non-trafficable (ie more than 0.3 metres over the bridge) when floodwaters reach 2.5 metres AHD. Flood levels on the two Wants Lane bridges indicate that the time at which the roads become cut by floodwaters does not change. The duration that the bridges are non-trafficable (ie flood levels above 2.5 metres AHD) does not increase.

There is a reduction in warning time at the main bridge over Coldstream River. There is potential for nearby grazing land in the area to experience a small reduction in warning time which may impact on the ability to evacuate stock.

Peak flood depths would be higher along Wants Lane due to the project. It is not anticipated that access would be attempted during the peak of a 100 year ARI flood event. As discussed above, the trafficability of the road bridges would not be adversely affected. Hence, the project is unlikely to increase the flood hazard of these properties.

The project would impact on the potential for stock movement and evacuation to higher ground at station 43.1 at the eastern edge of a proposed 300 metre bridge across the Coldstream River and floodplain. At this location, the landholder owns land on both sides of the project boundary. In times of flood and especially as floodwaters rise, there is a need to move stock from the northern side of the proposed road to the southern side where there is better access to flood-free land. An access track has been included in the design under this bridge at a level of 2.1 metres AHD to increase the time available for cattle movement from the north to the south of the bridge.

At the Wooli Road/Lloyds Road junction, there would be less than 25 millimetres increase in peak flood depths. Hence, there would be little or no change to the ability to use this road for access during flood events.

Flood hazard impacts

Agricultural land immediately upstream of the project would experience a faster rise of flood level. However, this would not increase the level of flood hazard for people, stock or property. As discussed, the trafficability of the two Wants Lane road bridges upstream would also not be adversely affected by the project during large flood events. As a result, the project is unlikely to increase the flood hazard of surrounding properties.

Therefore, it is considered that the overall level of flood hazard would not be increased by the project.

Bed and bank stability impacts

The project would increase velocities on the bed and banks by about 10 per cent for two year ARI flood events. For the 20 year ARI and 100 year ARI flood events, the project would result in a redistribution of flow on the floodplain which would result in increases of 30 per cent to 50 per cent for the banks of the western tributary. While this is a large percentage increase, it is on a low base velocity of about 0.7 metres per second increasing to about 1.1 metres per second.

However, the vegetation coverage on the banks in this watercourse is poor. This would indicate that the project could result in an increased risk of bank erosion during rare flood events. As previously discussed, velocities also increase by up to 120 per cent from existing conditions downstream of the bridge at this location. Velocities decrease to less than one metre per second within 50 metres of the project boundary.

The rate of recession would also be increased by around 55 per cent at the project crossing and around 40 per cent at Wants Lane upstream. An increased in the rate of flood recession has the potential to increase the risk of erosion through bank slumping.

The project would not increase velocities on the bed and banks for two year ARI flood events. For the 20 year ARI and 100 year ARI flood events, the project would result in increases of about 10 per cent for the bed and banks of the Coldstream River. It is likely that the well vegetated channel banks could accommodate these increases in peak velocity without increased risk of erosion.

The concept design includes bridge piers located on or near the bed and banks of both the Coldstream River and its western tributary. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.7 Pillar Valley Creek

Flood management objectives

Floodplain areas within the catchment consist largely of grazing land and forested area. There are no houses within the 100 year ARI flood extent that would be affected by the project. The flood management objectives for this catchment are:

- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event

- No more than 10 per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The maximum impact during the 100 year ARI flood event upstream of the project boundary at the Pillar Valley Creek anabranch would be 220 millimetres increase (and 170 millimetres in the 20 year ARI flood event). This anabranch shares a floodplain with Pillar Valley Creek. Closer to Pillar Valley Creek, the maximum impact would be 160 millimetres increase (and 120 millimetres in the 20 year ARI flood event).

Impacts on flood levels at Black Snake Creek would be less than 10 millimetres increase in all assessed ARI flood events. This impact would be highly localised, dissipating to negligible within 15 metres of the project boundary.

Impacts outside the project boundary at the tributaries north of Black Snake Creek (combined floodplain of two tributaries) would be less than 10 millimetres increase in flood level. These impacts dissipate to zero impact within 30 metres of the project boundary in all assessed ARI flood events.

Peak flood levels increase downstream of the project boundary by less than 30 millimetres at the two unnamed creeks north of Mitchell Road. No impact occurs upstream of the first unnamed creek north of Mitchell Road. Upstream of the second creek north of Mitchell Road, a localised impact of up to 220 millimetres occurs in the 100 year ARI flood event (and 160 millimetres in the 20 year ARI flood event). This decreases to less than five millimetres within 45 metres upstream of the project boundary.

No residences would experience flood level impacts in this floodplain.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

While there would be some increase in the period of inundation upstream of the project, this would be less than the 10 per cent flood management objective for grazing, forested and other rural areas.

Flood velocity and direction impacts

The proposed location of culverts and bridges would minimise changes in flow direction and flood behaviour. Some constriction and expansion of flow into and out of waterway structures would occur. The extent of inundation downstream of the northern-most tributary is reduced as a result of proposed embankments and culvert configuration. No areas outside of the project boundary that are currently flood free would be inundated as a result of the project.

Velocities upstream and downstream of all structures that are greater than one metre per second in the 100 year ARI flood event are all within the 20 per cent flood management objective. There would be little change to flood velocity and direction as a result of the project beyond the highlighted effects of constriction and expansion.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have similar rate of floodwater rise as the existing case. There is an increase in warning time at some locations downstream of the project boundary.

There are no houses or commercial premises impacted by the project in this area.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

There are no known evacuation routes that would be severed by the project.

Due to the similar rate of floodwater rise as the existing case, there would not be any change to the potential for evacuation in this area.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access), would not be increased by the project.

Agricultural land immediately upstream of the project would experience a faster rise of flood level. However, this would not increase the level of flood hazard for people, stock or property.

Bed and bank stability impacts

For the southern tributary (station 46.07), the project would increase velocities on the bed and banks by less than 10 per cent for two year ARI flood events. These changes are unlikely to result in changes to bed form of the channel erosion. For the 20 year ARI and 100 year ARI flood events, the project would result in a redistribution of flow on this tributary floodplain which would result in decreases in bed and bank velocities.

At the Pillar Valley Creek crossing (station 46.34), the project would result in increases of about 10 to 20 per cent for the bed and bank velocities for all flood events. It is likely that the well vegetated channel banks could accommodate these increases in peak velocity without increased risk of erosion as the resulting velocities would be well below two metres per second threshold for scour on well vegetated banks.

The toe of the northern abutment of the bridge over Pillar Valley Creek would be close to the right bank of Pillar Valley Creek. The exact location of this abutment would need to be considered in detailed design to minimise impacts to the bank formation.

At the Black Snake Creek crossing (station 46.67), the project would result in increases of less than 10 per cent for the bed and bank velocities for all flood events. These increases to velocities are about two to four metres per second due to the relatively steep nature of the floodplain. However, it is likely that the well vegetated and forested channel banks could accommodate these minor increases in peak velocity without increased risk of erosion.

For the northern tributary of Pillar Valley Creek (station 47.66), the project would result in increases of less than 10 per cent for the bed and banks for all flood events.

The rate of recession in this creek would also be increased by around 35 per cent. Increased rate of recession has the potential to increase the risk of erosion through bank slumping. It is likely that the well vegetated and forested channel banks could accommodate these minor increases in peak velocity and increases in rate of recession without increased risk of erosion. However, this would need to be confirmed at the detailed design phase through a detailed geomorphological assessment.

The concept design includes bridge piers located on or near the bed and banks of Pillar Valley Creek and its tributaries. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.8 Chaffin Creek and nearby unnamed creeks

Flood management objectives

The land use of the Chaffin Creek catchment is mostly cleared farmland with some areas of medium to dense forest. The project would traverse mostly forested areas, cutting across small cleared areas. There are two houses on the edge of the 100 year ARI flood extent. The flood management objectives of relevance to this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The maximum flood level increase outside of the project boundary caused by the project in a 100 year ARI flood event on Chaffin Creek would be less than 290 millimetres (and less than 200 millimetres in a 20 year ARI flood event). Impacts would reduce to an increase of 250 millimetres within 15 metres upstream of the project boundary and to an increase of 50 millimetres within 500 metres upstream of the project boundary for a 100 year ARI flood event.

Two sheds are inundated at a property about 500 metres upstream of the project boundary. Impacts experienced at these sheds are about 50 millimetres for the 100 year ARI flood level. The house is not inundated during a 20 year ARI flood and unlikely to be inundated during a 100 year ARI flood, but this would need to be confirmed with survey. This house, if inundated, would experience an increase of 50 millimetres in a 100 year ARI flood event. No other residences would experience flood level impacts in this floodplain.

Unnamed Creek 3 near Bostock Road would experience an impact of less than 20 millimetres increase upstream of the project for all assessed ARI flood events and less than 60 millimetres downstream. At the nearby Unnamed Creek 4 near Bostock Road, the project would have less than five millimetres impact on peak 20 and 100 year ARI flood levels upstream of the project boundary and less than 40 millimetres impact downstream of the project boundary for 100, 20 and five year ARI flood events. In the 200 year ARI flood event, the impact is less than 75 millimetres.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

While there would be some increase in the period of inundation at the houses upstream of the Chaffin Creek crossing, this would be less than the five per cent objective.

The period of inundation would not increase by more than 10 per cent on grazing, forested and other rural lands.

Flood velocity and direction impacts

Velocities upstream and downstream of all structures that are greater than one metre per second in the 100 year ARI flood event are all within the 20 per cent flood management objective.

Flow velocities near the house and sheds upstream of the Chaffin Creek crossing do not vary greatly from the existing scenario and are less than one metre per second.

There would be no changes to the direction or behaviour of flooding other that associated with constriction and expansion near structures.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have similar rate of floodwater rise as the existing case immediately upstream and downstream of the project boundary the unnamed creek near Mitchell Road, Chaffin Creek and the unnamed creek near Bostock Road. As a result, there would be no impact of reduced warning time on residents or for stock evacuation.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

Primary access for the residence upstream of the project is Firth Heinz Road to the south of Chaffin Creek. This road would pass over the project and join Wooli Road to the west via an overpass. As this access would not be cut by the project and would not experience flood impacts as a result of the project, there would be no change to the potential for evacuation of this area.

A property north of and adjacent to Mitchell Road is currently used as a refuge for stock during regional (Clarence River) flooding. This property is cut by the project with the majority of land to the west of the project. Regardless of whether stock is currently mobilised to the Mitchell Hill refuge via truck or overland, access to the property would be maintained via the Mitchell Road underpass. As this access would not be cut by the project and access would not otherwise experience flood impacts as a result of the project, there would be no change to the potential for flood evacuation of the Clarence River floodplain to the Mitchell Hill flood refuge. However, impacts to flood evacuation and stock refuge at this property would need to be further considered and confirmed at the detailed design phase.

Flood levels would rise more rapidly on Chaffin Creek, particularly adjacent to the upstream boundary of the project property where peak flood level increases are greatest. However, this would not affect the ability of stock or people to evacuate the area safely, and would not affect the operations of the farm to any greater extent than existing conditions.

The houses upstream of Chaffin Creek crossing that would have flood waters adjacent to them at the front of the buildings during the 100 year ARI flood event would still have dry access at the rear of the house as per current conditions.

Flood hazard impacts

Agricultural land immediately upstream of the project would experience a faster rise of flood level.

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

The project would increase velocities on the right bank and bed of Chaffin Creek by about 10 per cent for two year ARI flood events through to 100 year ARI flood events. Similar increases are predicted on the left bank in common flood events. These changes are unlikely to result in changes to bed form of the channel erosion. The creek bed form is relatively stable due to the presence of bedrock.

It is predicted that peak velocities on the left bank of Chaffin Creek would increase by about 50 per cent in 20 year and 100 year ARI flood events. While this is a large percentage increase, it is on a low base velocity of about 1.1 metres per second increasing to about 1.6 metres per second. It is likely that the well vegetated channel banks could accommodate these increases in peak velocity without increased risk of erosion as the resulting velocities would be well below the threshold of two metres per second for scour on well vegetated banks. At the property boundary downstream of the structure, velocities increase by less than 20 per cent increase in the 100 year ARI flood event.

The rate of recession in Chaffin Creek would also be increased by around 25 per cent. Increased rate of recession has the potential to increase the risk of erosion through bank slumping. However, due to the presence of bedrock and well vegetated banks, bank slumping and subsequent increased risk of erosion is unlikely as a result of an increase in the rate of flood recession.

The concept design includes bridge piers located on or near the bed and banks of Chaffin Creek. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.9 Champions Creek and nearby unnamed creek

Flood management objectives

The majority of the area that would be impacted by the project is dense forest, with some clearing at the upper extent of the impact. There are no houses within the 100 year ARI flood extent within that would be affected by the project. The flood management objectives of relevance to this catchment are:

- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The maximum flood level increase in the 100 year ARI flood event at Champions Creek would be 370 millimetres in the 100 year ARI flood event (with up to 280 millimetres impact in the 20 year ARI flood event). This would dissipate to less than 250 millimetres impact within 120 metres upstream of the project boundary, and to 150 millimetres impact within 250 metres. The area where Somervale Road crosses Champions Creek, around 460 metres upstream of the project boundary, would experience impacts of about 90 millimetres in the 100 year ARI flood event (and 70 millimetres impact in the 20 year ARI flood event).

A property access track extending along the northern bank of the creek floodplain would experience impacts. This impact is discussed further below in regard to flood access issues. No houses would otherwise experience flood level impacts from the project.

A small area downstream of the project boundary would experience a peak 100 year ARI water level increase of less than 50 millimetres due to the concentration of flow at the culvert outlet.

The impact outside of the project at the unnamed creek north of Champions Creek would be less than five millimetres increase upstream in all ARI flood events, and less than 20 millimetres downstream.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

During local flooding, increases in flood inundation duration are only experienced above 2.1 metres AHD immediately upstream of the project boundary. Flood inundation duration is extended by 10 minutes at around 2.3 metres AHD (from about 150 to 160 minutes in inundation duration) up to 20 minutes at 2.5 metres AHD (from about 80 to 100 minutes in inundation duration). However, the duration of inundation is relatively short and there is no inundation of residences at this location.

Little impact is experienced at less than 2.1 metres AHD at this location, and no flood inundation duration impacts are experienced further upstream at the Somervale Road bridge or downstream of the project.

No flood inundation duration impacts are experienced during regional (Clarence River) flood events.

Any increase in the period of inundation on grazing, forested and other rural lands resulting from the project would not affect the productivity of the land.

Flood velocity and direction impacts

For the 80 metre bridge over Champions Creek, velocities at the project boundary upstream and downstream of this bridge are below one metre per second in the 100 year ARI flood event. At the 50 metre bridge, velocities downstream are reduced compared to the existing scenario.

There would be no changes to the direction or behaviour of flooding other than that associated with contraction and expansion adjacent to waterway structures.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have similar rate of floodwater rise as the existing case downstream of the project boundary and at the Somervale Road bridge across Champions Creek. There would be a slight reduction in warning time of less than 10 minutes immediately upstream of the project when local flooding reaches about 2.5 metres AHD. A reduction in warning time of up to 10 minutes may therefore be experienced at the driveway access to the property north of the creek.

There would be no impacts to rate of rise or warning time during regional back-up flooding from the Clarence River as a result of the project.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

The primary access for residences upstream of the project is Somervale Road which crosses Champions Creek upstream of the project. Residents rely upon crossing Somervale Road in local flood events prior to extended periods of inundation in subsequent Clarence River flood events.

The impacts of the project would reduce the time available for access to and from these residences. This reduction in time would affect the ability to prepare for any subsequent loss of flood access in long duration Clarence River flood events.

During local flooding immediately upstream of the project boundary there are increases to the time of inundation above 2.3 metres AHD. As a result, there may be implications for where flooding crosses the road easement on the northern bank of Champions Creek depending on the elevation of the road itself. It is estimated that the road in this area would be around 2.3 metres AHD, correlating with the road being cut for a further 10 minutes during an overall inundation period of around 2.5 hours.

Either lengthening of the project bridge over Champions Creek to reduce impacts or raising Somervale Road and the private access track would mitigate this impact.

During regional flooding, where access is likely to be cut for several days (under existing conditions), there would be no flood evacuation or access impacts experienced as a result of the project.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Agricultural land immediately upstream of the project would experience a faster rise of flood level. However, this would not increase the level of flood hazard for people, stock or property.

Bed and bank stability impacts

At the location of the bridge, the project would increase velocities on the bed and banks of Champions Creek by about 70 per cent for two year ARI flood events and up to 120 per cent for the 20 year ARI and 100 year ARI flood events. Velocities decrease to less than one metre per second in all events at the project boundary downstream.

These increases in velocity would result in an increased potential for bank erosion as the resulting velocities are between 1.0 and 1.5 metres per second and the banks have poor vegetation coverage.

The rate of recession in Champions Creek would also be increased by around 25 per cent. Increased rate of recession has the potential to increase the risk of erosion through bank slumping; however, bank slumping is considered to be unlikely in this creek due to the presence of bedrock.

The concept design includes bridge piers located on or near the bed and banks of Champions Creek. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

The increases in bed and bank velocities predicted at the tributary north of Champions Creek (station 58.64) are less than 10 per cent and unlikely to result in changes to bed form of the channel erosion.

8.4.10 Clarence River (Glenugie to Tyndale)

Flood management objectives

Land use within the catchment along the project route is predominantly forest, with some rural and agricultural areas. There are a few houses that are within the 100 year ARI flood extent. The flood management objectives of relevance to this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The loss of flood storage due to the construction of the embankments for the project has been assessed in the Clarence River flood model. There would be no discernible change (more than 10 millimetres increase) to flood levels due to this filling.

Flood inundation duration impacts

There would be no impact to flood inundation durations in these local catchments during Clarence River regional flooding as a result of the project.

Flood velocity and direction impacts

During Clarence River regional flooding, there would be no impacts to flood velocity in these local catchments greater than 0.1 metres per second increase as a result of the project.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

There would be no impact to the rate of floodwater rise during Clarence River regional flooding as a result of the project.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

This section of the project does not follow the existing highway route. As such there is potential for the project to impact on evacuation and access routes (for people and stock during flood events).

Two properties immediately south-east of the confluence of Coldstream River and the Clarence River South Arm are currently used as a refuge for stock during Clarence River regional flooding. These properties would be cut by the project with more than two-thirds of land on the west of the project. Access to the properties would be maintained via a new road and overpass which would connect to Coldstream Road to the west. As this access would not be cut by the project and the properties would not otherwise experience flood impacts as a result of the project, there would be no change to the potential for flood evacuation of the Clarence River floodplain to the Tyndale flood refuge.

Flood evacuation and flood access impacts at the creek catchments along this catchment as a result of regional flooding are discussed in Sections 8.4.5 to 8.4.9.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

Bed and bank stability impacts would be dominated by the much faster moving local floods through the local catchments. These impacts are discussed in the crossings of the Clarence River tributaries in section 8.4.5(Pheasant Creek) to section 8.4.9 (Champions Creek).

8.4.11 Clarence River (Tyndale to Maclean)

Flood management objectives

Land use within this portion of the Clarence River catchment consists of residential, forested, cane farm land, and other agricultural and rural uses. The flood management objectives of relevance to this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- Less than 50 millimetres increase in flood heights on cane farm land for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses and cane land
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain and below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The waterway openings and the predicted impacts of the project on peak flood levels for the 20 year ARI flood events are presented Figure 8-4. Flood level impact maps for the 50 year and 100 year ARI flood events are in Working paper – Hydrology and flooding.

The impact of the project on peak flood levels would be less than 15 millimetres increase for the 100 year flood. The 20 year and 200 year ARI flood events experience impacts up to 15 and 10 millimetres respectively.

During a five year flood, impacts of 15 millimetres are experienced along the project boundary in Shark Creek. Larger impacts of up to 40 millimetres would be experienced between McIntyres Lane and Townsend during a five year ARI flood event. Houses in the south of Townsend would experience increases in flood levels of up to 35 millimetres.

No house on the floodplain was shown to have an increase in peak flood levels of more than 50 millimetres.

Flood impacts to property

The increase in flood levels results in an increase of about 0.6 per cent in the sum total of average annual flood damages for residences in the impacted area between Tyndale and Maclean. A histogram showing the distribution of increased flood levels as a result of the project is presented in Figure 8-3. There are no properties which experience greater than 50 millimetres increase in flood levels. Increases of less than 50 millimetres would meet the flood management objectives for the area.

The existing mean of average annual flood damages for residences in this area is about $3,500.

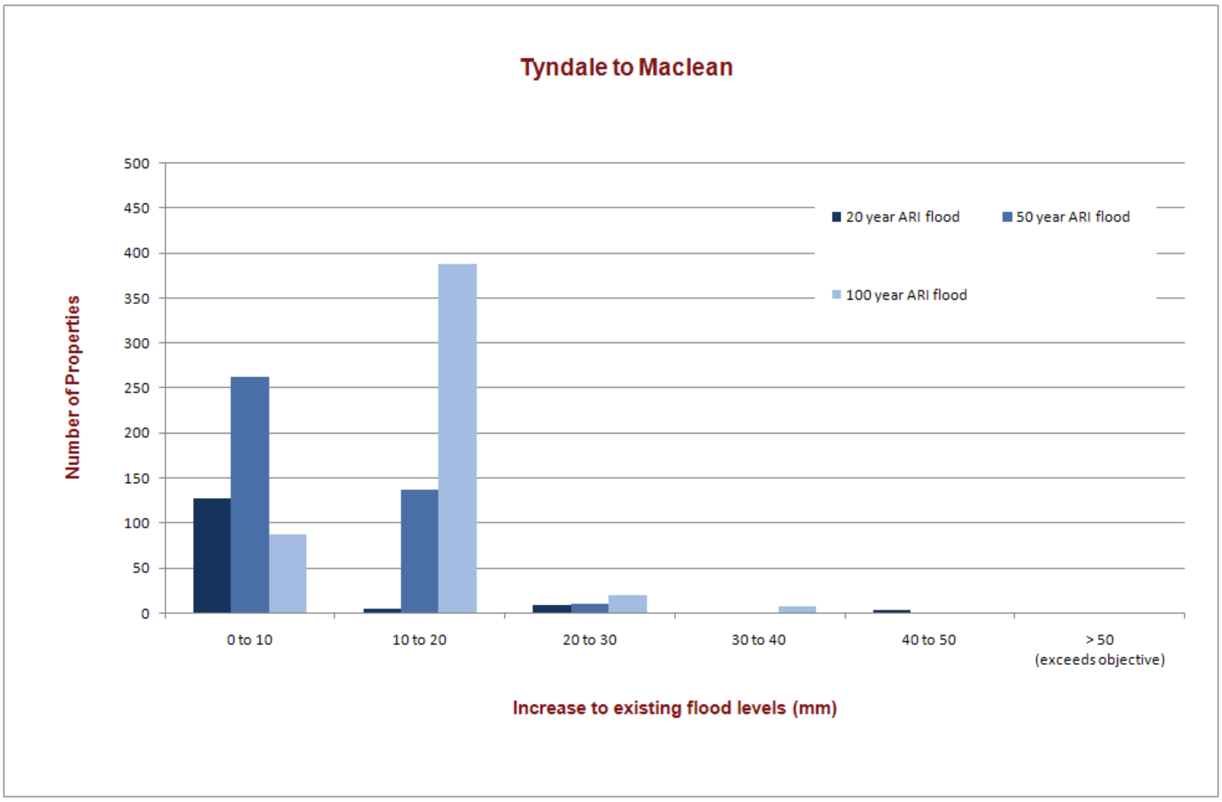

Figure 8-3: Distribution of impact on existing flood levels between Tyndale and Maclean (including Ashby, Gulmarrad, Woodford Island, South Arm, Shark Creek and Brushgrove)

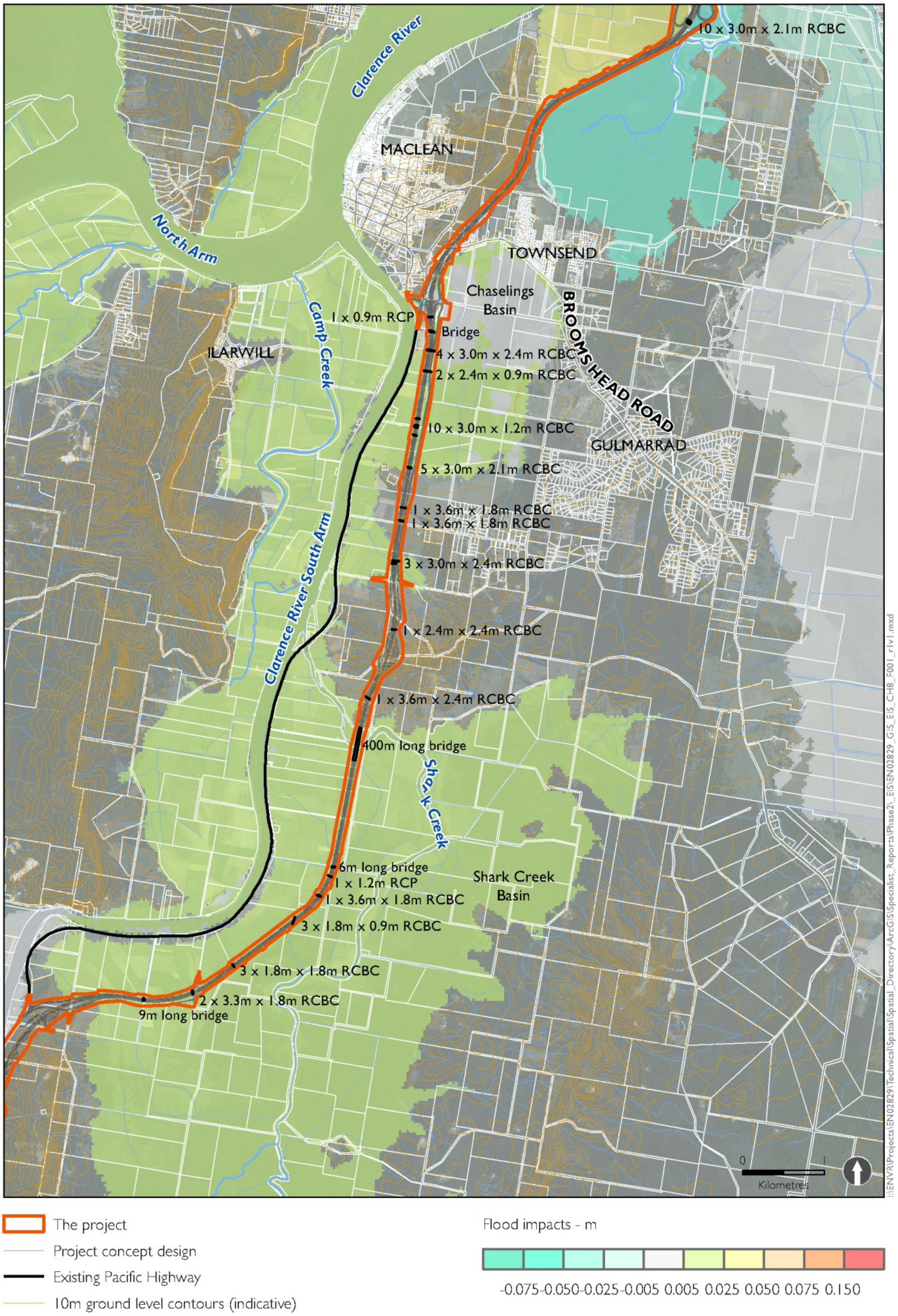

Figure 8-4: Flood impacts 20 year ARI flood event: Clarence River at Shark Creek / Maclean

Photo 5: Flood level indicator on main street of Maclean town

Flood inundation duration impacts

Land below 2.2 metres AHD would not experience any change in flood inundation duration. Above 2.2 metres AHD, there are some areas that would experience an increase in the total duration of flood inundation. The maximum impact experienced would be around an eight per cent increase at 3.0 metres AHD. As the vast majority of land in this area is below 2.0 metres AHD, sugar cane is not expected to be subjected to any increase in the duration of inundation.

It is possible there may still be isolated pockets of sugar cane land above 2.2 metres AHD which could experience some increase in inundation duration. However, increase in inundation period at the start of the flood is less potentially damaging to cane crops than that at the end of the flood event, as it is less likely that there would be sufficient sunshine to heat the water to a level that would damage crops. The nearest elevated land (around 2.6 metres AHD) to where impacts have been modelled would experience less than the objective of no more than five per cent increase in duration of flood inundation.

There is negligible change to the recession of the flood.

Flood velocity and direction impacts

The most important elements of the proposed cross-drainage are the openings to replace the existing Goodwood Street underpass. Cameron Street along the riverbank where the Clarence River first breaks its banks would be left unchanged. Hence, the time at which floods first enter the Chaselings Basin would not change, nor would the frequency of flooding of the basin. The replacement openings have been sized to convey a similar rate, velocity and direction of inflow into the basin, resulting in a similar rate of floodwater rise and peak levels.

The very long duration of the event means that flood velocities are low throughout the floodplain (less than one metre per second).

As for the structures to the south of the Goodwood Street underpass, the proposed location of culverts and bridges would minimise changes in flow direction and flood behaviour. Some constriction and expansion of flow into and out of waterway structures would occur.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

Along the western boundary of the project above 2.2 metres AHD, flood levels rise earlier in the project case compared to the existing case. However, as the land in this area is used only for cane farming (and further, the vast majority of land is below 2.0 metres AHD), no residential or commercial premises would experience impacts to the rate of flood rise and warning time. Likewise, no grazing or forested land would be affected.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

This section of the project does not follow the existing highway route. As such there is potential for the project to impact on evacuation and access routes (for people and stock during flood events). The majority of the route in this section passes through sugar cane land. The local roads that provide access to the existing highway during floods are Byrons Lane and Shark Creek Road and would cross the project (Byrons Lane passes over and Shark Creek Road passes under the project). Hence, it is unlikely that access during floods would be affected in this area.

However, there is a landholder adjacent to the project on the eastern side that would have reduced flood access during times of flooding. This owners of this property on Byrons Lane use a small boat to gain access to the existing highway when floodwaters rise sufficiently high to make car access along Byrons Lane not possible. The project would make it very difficult if not impossible to access the existing highway by boat.

Although floodwaters would rise earlier than under existing conditions in the Shark Creek Basin, the size of the catchment means that there is sufficient warning of a flood approach, and the rate of flood level rise is slow enough, to have negligible effect on the ability of stock to evacuate the area safely. There would also be negligible effect on the operations of farming.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

Shark Creek is the only watercourse crossed by the project in this section with natural bed and banks and was therefore the only waterway assessed in terms of bed and bank stability. Shark Creek is unique for crossings of this project in that the peak flood velocities occur during increasing flood levels of a flood event as Clarence River floodwaters flow backwards into the large floodplain storage areas of Shark Creek. As such, the discussion below discusses the changes to the velocities at the peak of the flood as well as the changes to peak backflow velocities.

The project would increase velocities at the peak of the flood from about 0.2 metres per second to 0.5 metres per second. These are low velocities and likely to be lower than the velocities experienced on a daily basis from tidal inflows and outflows. Hence, the changes to the velocities at the peak of the flood are unlikely to result in any change to the form of the creek bed and bank.

The maximum back-flow velocity of 1.7 metres per second in Shark Creek during flood events would not change as a result of the project. Further, the distribution of the velocities would also remain unchanged. Hence, it is unlikely that the project would result in any change to the bed and bank form of Shark Creek.

The concept design includes bridge piers located on the banks of Shark Creek. However, the concept design includes 32 metre bridge spans which would be sufficient to avoid piers in the permanent water part of Shark Creek. The piers on the banks would have the potential to result in localised erosion of the bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

The project would cross cane drains in three locations via short bridges. These cane drains are maintained by Clarence Valley Council as flood mitigation assets. As the bridges would clear span the cane drains, there would be limited impacts. The common flows in these drains would not be impeded or changed in any way. Flood flows would be similar with very low velocities (less than 0.4 metres per second).

8.4.12 Clarence River (Maclean to Iluka Road)

Flood management objectives

Land use within this portion of the Clarence River catchment consists of residential, forested, cane farm land, and other agricultural and rural uses. The flood management objectives for this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- Less than 50 millimetres increase in flood heights on cane farm land for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses and cane land
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The waterway openings and the predicted impacts of the project on peak flood levels for the 20 year ARI flood events are presented in Figure 8-5. Flood level impact maps for the 50 year and 100 year ARI flood events are in Working paper – Hydrology and flooding.

The concept design generally results in higher flood levels compared to existing conditions to the west of the project and lower flood levels to the east of the project. Increases in peak flood levels are less than 50 millimetres in all areas outside of the project boundary except for an area of 0.6 hectares to the north-west of the interchange at Harwood. This area experiences a maximum impact of 65 millimetres increase at the western edge of the project boundary in the 50 year ARI flood event. This would not affect residences but would affect cane land adjacent to the highway. As such, these impacts do not meet the flood management objectives for this catchment.

An extension of 30 metres of culverts to the south of the interchange would be sufficient to reduce these impacts to 50 millimetres at the project boundary. The design of drainage structures across Chatsworth Island would be further reviewed during detailed design to enable the most appropriate and cost-effective structures to be installed.

The five year ARI flood event indicates the project has the potential to alter flood behaviour and increase flood levels by about 200 millimetres over a 420 hectare area on Chatsworth Island. This potential change to flood behaviour could occur because the existing highway is only slightly overtopped in this event and acts as an impediment to flow from the east. As the bank of the Clarence River at Chatsworth village is not breached in a five year ARI flood event, the affected area is inundated from back-up flooding from the eastern parts of Chatsworth Island. The increased culvert capacity in the Class M version of the project would provide passage for flow in these smaller flood events, resulting in the increase in flood levels of up to 250 millimetres on sugar cane land. This effect would be mitigated by constructing the project service road to the same level as the existing highway for a length of about 750 metres to serve as a low level levee and maintain the existing flooding behaviour in these smaller events only.

South of the Yamba Road interchange, a multicell culvert about 30 metres long at station 85.4 also has the potential to provide passage for flow in these smaller flood events, resulting in the increases in flood levels on the sugar cane land at James Creek west of the project. This effect would be mitigated by constructing the on ramp to the interchange at about 1.0 metres AHD to serve as a low level levee and maintain the existing flooding behaviour in these smaller events only.

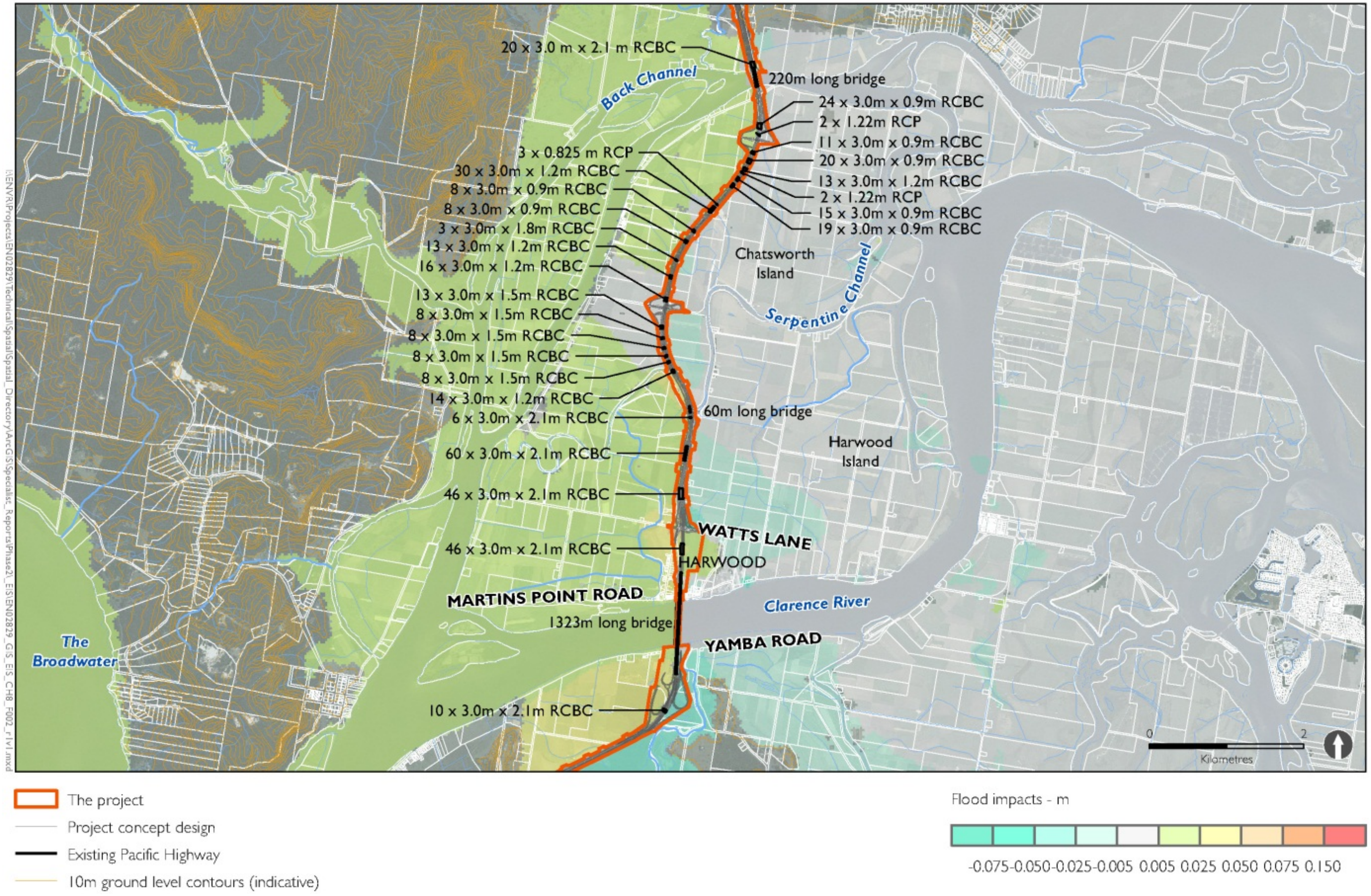

Figure 8-5 Flood impacts 20 year ARI flood event: Clarence River at Chatsworth and Harwood islands

Flood impacts to property

The increase in flood levels to the west of the project results in a three per cent increase in the sum total of average annual flood damages for residences on Chatsworth Island. The average annual flood damages west of the project near Harwood would increase by 1.8 per cent. Residences and businesses to the east of the project were not included in this study, but would experience a reduction in the average annual flood damages. This is a result of 50 and 100 year ARI flood levels mostly reducing in this area and 20 year ARI flood levels either reducing or experiencing a negligible (less than two millimetres) increase.

The existing mean of average annual flood damages for impacted residences in this area is about $3,500 for Harwood Island and about $1,900 for Chatsworth Island. This is likely a reflection of Harwood Island experiencing greater flooding than Chatsworth Island in the more frequent 20 year ARI flood events. The more frequent a flood event occurs, the greater weighting the damages incurred by that flood have on the average annual flood damage for a property.

Histograms showing the distribution of increased flood levels for Chatsworth and Harwood islands and surrounding areas as a result of the project are presented in Figure 8-6 and Figure 8-7. There are no properties which experience greater than 50 millimetres increase in flood levels. Increases of less than 50 millimetres would meet the flood management objectives for the area.

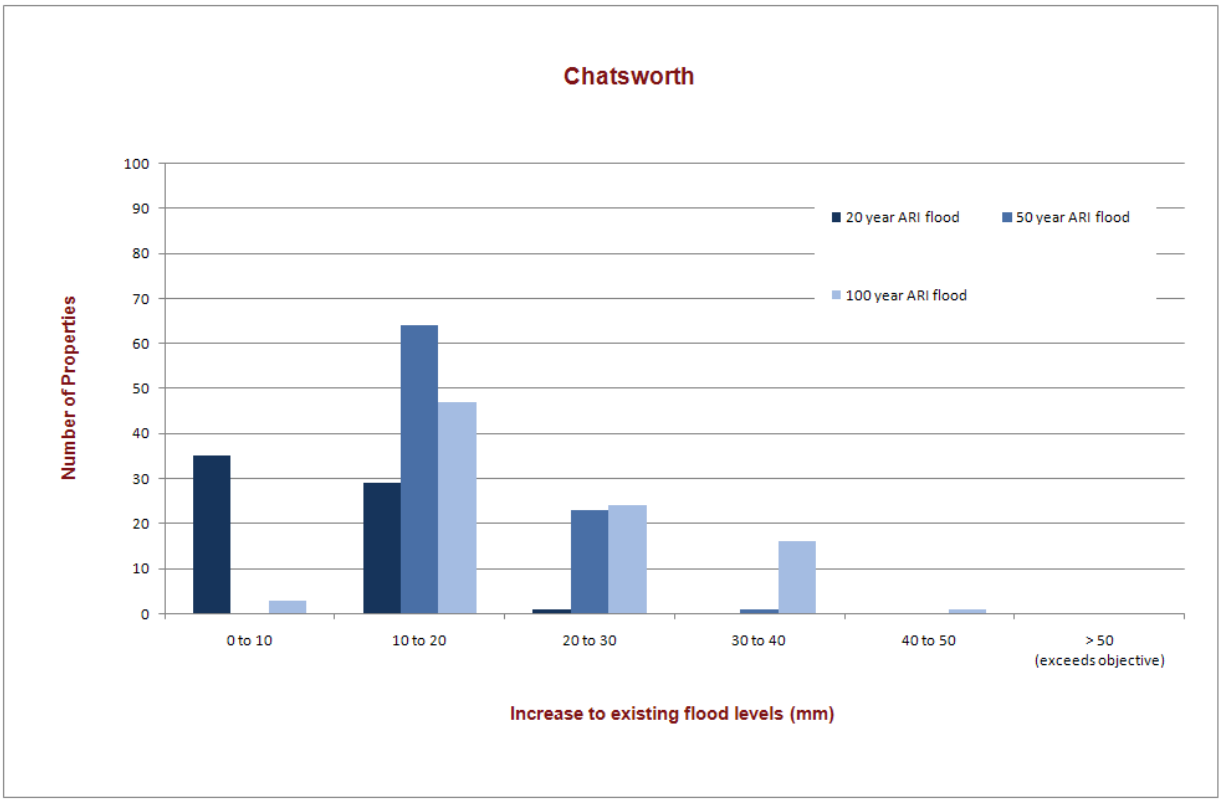

Figure 8-6: Distribution of impact on existing flood levels on Chatsworth Island and surrounding areas

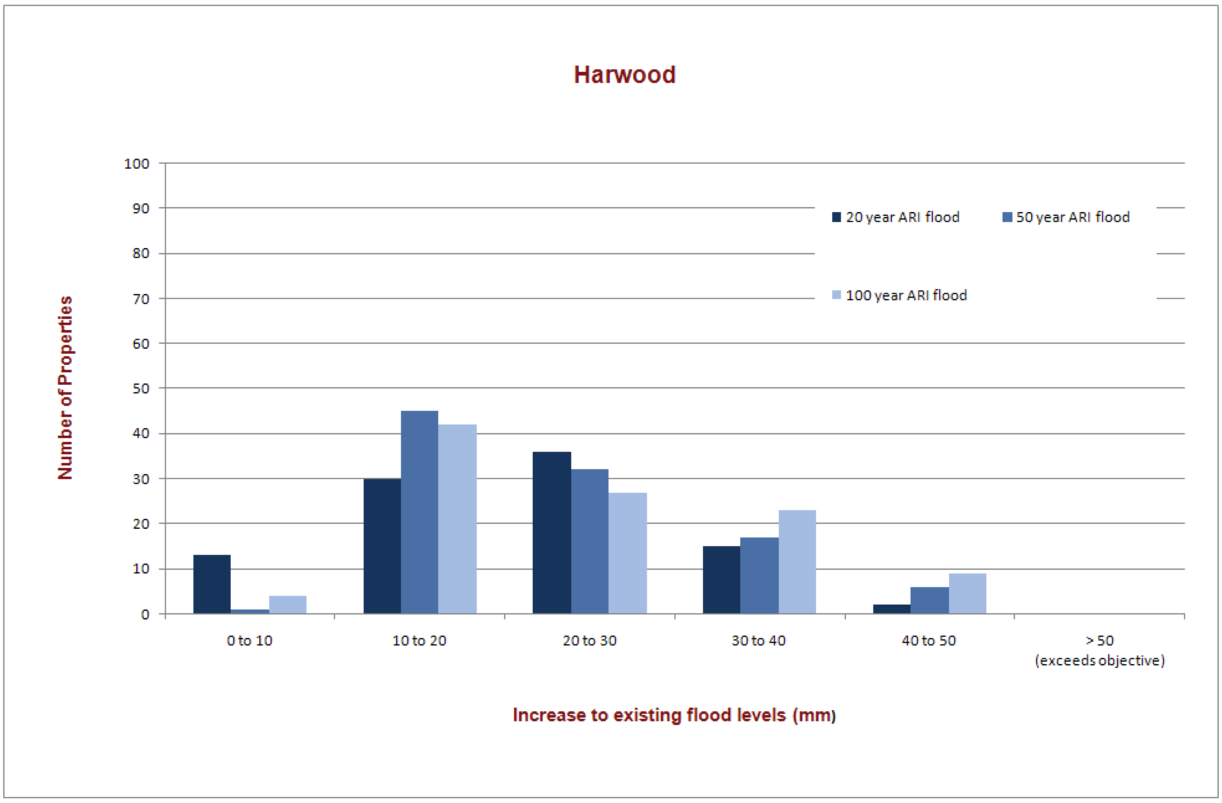

Figure 8-7: Distribution of impact on existing flood levels on Harwood Island and surrounding areas

Flood inundation duration impacts

The project would have little impact on flood inundation times and rates of floodwater rise and recession for most of Chatsworth and Harwood islands. The only areas that would experience any increase in inundation time are low-lying areas south-west of the Yamba Road interchange and along the western boundary of the project between Serpentine Channel and Chatsworth Road. These impacts amount to around three per cent and five per cent increase in inundation duration respectively.

Flood velocity and direction impacts

The upstream velocities would be related to flood debris impact on bridge piers. The changes to the upstream velocities are minimal.

Velocities are less than one metre per second upstream and downstream of all structures in the 100 year ARI flood event, and across the entire Chatsworth and Harwood islands.

Flow distribution throughout this part of the river system would not be greatly impacted by the project, with the majority of flow conveyed by the Clarence River Main Arm and North Arm.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

At the northern bank of the Clarence River Main Arm, the project would have a similar rate of rise as the existing case.

At the upstream edge of the project boundary south of the Yamba Road interchange, the rate of rise is slightly faster than the existing case. There is a reduction in warning time for land below 1.5 metres AHD of up to five hours. As the land use around and immediately upstream of this location is agricultural, it would not to have any impact on flood warning time for residents.

Immediately downstream of the project at Harwood, there would be around an increase in 80 millimetres in the initial storm surge peak between the existing case and the project case. As a result, land within this elevation range (between around 2.15 to 2.25 metres AHD at the project boundary) would experience flooding about 10 hours earlier (with around 20 hours warning time). As most houses have habitable floor levels well above the height of this initial storm surge peak, it is unlikely that any houses would flood earlier than they would under the project case. It may, however, reduce the time for residents in a small number of high-set houses with ground levels within this 80-millimetre-range to protect items stored underneath their houses.

On Chatsworth Island, between the Serpentine Channel and Chatsworth Road, there would also be a decrease in flood warning time of up to 10 hours for land below 1.5 metres AHD. As the land use around this location (and below 1.5 metres AHD) is agricultural, this is not expected to have any impact on flood warning time for residents. Above 1.8 metres AHD, there is little change in flood warning time.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

There would also be a decrease in evacuation time available in low-lying areas south-west of the Yamba Road interchange and between Serpentine Channel and Chatsworth Road. However, these low-lying areas are agricultural and as such no impacts would be experienced by residents.

The increased immunity of the highway would in most cases provide greater ability to evacuate during large flood events. Meetings with the State Emergency Services in the Clarence River area indicated that there would need to be changes to the emergency plans to accommodate the changes in highway access locations and the improved flood immunity of the highway.

The clearance under the Harwood Bridge during the peak of a 100 year ARI flood event would be in the order of 12 metres. Hence, this bridge is unlikely to cause any impediment to boat movements during flood events associated with disaster management or evacuations.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

For the main arm crossing of the Clarence River, the project would increase velocities on the bed and banks by less than 10 per cent for all floods. These changes are unlikely to result in changes to bed form of the channel erosion due to the generally stable nature of the bed and banks and the relatively low velocities predicted.

For the north arm crossing of the Clarence River, the project would increase velocities on the bed and banks by about 10 to 20 per cent for all floods. These changes are unlikely to result in changes to bed form of the channel erosion due to the generally stable nature of the bed and banks and the relatively low velocities predicted.

For the crossing of Serpentine Channel, the modelling predicts that the project would not increase velocities for the five year ARI flood events. For the 20 year and 100 year ARI flood events, the project would increase velocities by about 20 per cent from 0.9 metres per second to 1.1 metres per second. These changes are unlikely to result in changes to bed form of the channel erosion due to the generally stable nature of the bed and banks and the relatively low velocities predicted. Velocities would reduce to less than one metre per second at the project boundary upstream and downstream of this crossing.

The concept design includes bridge piers located on or near the bed and banks of both the Clarence River (main arm and north arm) and Serpentine Channel. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.13 Mororo Creek

Flood management objectives

Land use within the catchment is a mixture of rural, agricultural and forest. There are no houses within the of 100 year ARI flood extent that would be affected by the project. The flood management objectives for this catchment are:

- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

Downstream of the culvert at station 96.21, impacts of up to 80 millimetres would be experienced during the 100 year ARI flood event. This area is sugar cane land and the area with impacts above the flood management objective of more than 50 millimetres for this land use would be about 0.6 hectares. While these impacts exceed the flood management objective for this land use, this would occur in a short duration flood event with shallow depths of flooding (less than 0.3 metres). The flood management objectives for sugar cane lands were developed with a focus on long duration flood events on large floodplains. In these types of flood events, increased flood depths and durations of inundation can reduce sugar cane crop health. In short duration flood events, it is highly unlikely that small increases in flood depths on shallow base depths would result in any damage to sugar cane crop health.

No residences would be subject to flood level impacts in this area.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

While there would be some minor increase in the period of inundation downstream of the culverts at station 96.1 and 96.2, this would not impact on the productivity of the land at that location.

Where peak flood levels are reduced, a reduction in inundation duration would also occur.

Flood velocity and direction impacts

The overall location of culverts would not change, resulting in negligible changes in velocity and flow direction. Velocities are less than one metre per second upstream and downstream of all structures in the 100 year ARI flood event.

No areas that are currently flood free would be inundated as a result of the project.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have a similar rate of rise as the existing case for most locations.

Upstream and downstream of the culverts near station 97.0 there would be a reduction in warning time of around 12 minutes and six minutes respectively. As the land use around and immediately upstream of this location is agricultural, this would not have any impact on flood warning time for residents.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

As this section of the project would be a duplication of the existing highway, no known evacuation routes would be severed by the project. As such, there is not expected to be any impact to the potential for evacuation in this area. The increased immunity of the highway would, in most cases, provide greater ability to evacuate during large flood events.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access)would not be increased by the project.

Bed and bank stability impacts

The project does not include any bridges in this section. All watercourses are proposed to be crossed by extension or augmentation of existing culvert crossings. Appropriate scour protection would be provided upstream of, through and downstream of culvert structures.

8.4.14 Tabbimoble Creek

Flood management objectives

Land use within the catchment is a mixture of rural, agricultural and forest. A few houses near the intersection of Tullymorgan-Jackybulbin Road and the Pacific Highway are within the 100 year ARI flood extent. The flood management objectives for this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The area upstream of the project boundary is expected to experience increases typically less than 50 millimetres during all modelled flood events. Some slightly larger impacts are observed downstream of the project at the northern end of this section, with up to 275 millimetres impact experienced in the 100 year event (slightly less in other assessed events). This decreases to less than 50 millimetres impact within 190 metres of the project boundary.

Upstream of the project at the southern end of this section, up to 70 millimetres impact is expected during 20 and 100 year ARI flood events as a result of altered culvert arrangements. Larger impacts of up to 90 millimetres are expected during a 200 year ARI flood event. Flood level impacts during a two year ARI flood event are around 25 millimetres. All impacts decrease to less than 10 millimetres impact within 200 metres of the project boundary.

Impacts to the north of the Tullymorgan-Jackybulbin Road / Pacific Highway intersection result from the additional carriageway being spatially separated from the existing motorway. Water levels are increased in the 20, 100 and 200 year ARI flood events by up to 100 millimetres. Level increases of up to 125 millimetres are observed during a two year ARI flood event.

One residence and one shed near the Tullymorgan-Jackybulbin Road / Pacific Highway intersection are impacted by the 100 year ARI flood event. Flood level increases would be less than 10 millimetres for both residence and shed during all assessed flood events.

The above impacts and those on other agricultural or rural land are within the flood management objectives.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

While there would be some increase in the period of inundation at the houses near the Tullymorgan-Jackybulbin Road / Pacific Highway, this would be less than the flood management objective (no more than a five per cent).

Any increase in the period of inundation on grazing, forested and other rural lands resulting from the project would not affect the productivity of the land.

Flood velocity and direction impacts

A slight change to the direction of flow would occur where the second carriageway deviates from the route of the existing carriageway to the north of the Tullymorgan-Jackybulbin Road / Pacific Highway intersection. These changes are within flood management objectives.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

In the Tabbimoble Creek catchment, the project would have a similar rate of rise as the existing case for most locations.

The project in this area duplicates the existing highway and bridges over Tabbimoble Creek and adjacent tributary. As a result, there would not be any impact to the flood warning time at these locations.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

As this section of the project would be a duplication of the existing highway, no known evacuation routes would be severed by the project. Therefore, there is not expected to be any impact to the potential for evacuation in this area. The increased immunity of the highway would in most cases provide greater ability to evacuate during large flood events.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access)would not be increased by the project.

Bed and bank stability impacts

The project would increase velocities on the right bank and bed of Tabbimoble Creek by about 10 per cent for two year ARI flood events through to 100 year ARI flood events. Similar increases are predicted on the left bank in common flood events. These changes are unlikely to result in changes to bed form of the channel erosion. The creek is relatively stable.

It is predicted that peak velocities on the left bank of Tabbimoble Creek would increase by about 50 per cent in 20 year and 100 year ARI flood events. While this is a large percentage increase, it is on a low base velocity of about 0.8 metres per second increasing to about 1.2 metres per second. It is likely that the well vegetated channel banks could accommodate these increases in peak velocity without increased risk of erosion as the resulting velocities would be well below the threshold of two metres per second for scour on well vegetated banks. Velocities would reduce to less than one metre per second at the project boundary upstream and downstream of this crossing.

For the creek crossing at station 102.85, north of Tabbimoble Creek, the project would duplicate the existing bridge and result in similar velocities to the existing case with risk of bank erosion unlikely.

The concept design includes bridge piers located on or near the bed and banks of Tabbimoble Creek. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.15 Tabbimoble Floodway No. 1

Flood management objectives

The entire Tabbimoble Floodway No.1 catchment is forested. As such, the flood management objectives of relevance to this catchment are:

- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The increases in flood levels caused by the upgrade along the project boundary are less than 80 millimetres during all modelled flood events. No residences are expected to experience flood level impacts in this floodplain.

Flood levels are not increased downstream of the project boundary.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

There would be a minor increase in the duration of flood inundation as a result of the backup behind the embankment. The affected land is forested and the increase in the inundation period would not affect its use or productivity.

Flood velocity and direction impacts

Velocities are less than one metre per second upstream and downstream of all structures in the 100 year ARI flood event. Thus, flow velocity would be below one metre per second on land outside of the project boundary.

There would be no changes to the direction or behaviour of flooding other than the permissible constriction and expansion adjacent to waterway structures.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

In the Tabbimoble Floodway catchment, the project would have a similar rate of rise as the existing case.

There would be a reduction of warning time of up to 12 minutes downstream of the culverts around station 115.0. There are no houses impacted by the project in this area. As such, the flood warning time for residents would be unaffected.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

As this section of the project would be a duplication of the existing highway, no known evacuation routes would be severed by the project. Therefore, there would be no impact to potential evacuation in this area. The increased immunity of the highway would in most cases provide greater ability to evacuate during large flood events.

Flood hazard impacts

Flow depths under existing conditions are large. This means that the small increase in peak flood depth would not affect flood hazard. Additionally, as the area is completely forested, there is no additional risk to people, stock or property as a result of the project.

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access)would not be increased by the project.

Bed and bank stability impacts

For the creek crossing at station 115.27 at Tabbimoble Floodway No. 1, the project would duplicate the existing bridge and result in similar velocities to the existing case with risk of bank erosion unlikely.

8.4.16 Oakey Creek

Flood management objectives

The predominant land use in the Oakey Creek catchment is forest, with small clearings comprising rural residential areas. The flood management objectives of relevance to this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase with localised increases of up to 400 millimetre for short duration/ local catchment flooding acceptable over small areas (nominally less than 5 hectares) up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

Peak 100 year flood levels in the catchment are increased by the project by up to 310 millimetres along the upstream boundary of the project south of the junction with Turners Road. This is below the design objective of a maximum of 400 millimetres increase in flood levels in the 100 year ARI flood event.

The 200 year ARI flood events results show a maximum increase of around 385 millimetres upstream of the project boundary below Turners Road. The maximum impact during a 20 year ARI flood event is 140 millimetres. During a two year ARI flood event, flood levels were shown to decrease by up to 940 millimetres.

Flood levels decrease or remain about the same downstream of the project boundary in all modelled events.

The only infrastructure that was shown to be affected by the increase in flood levels during events of 20 to 200 year ARI flood events is a set of stockyards upstream of the project. One shed within this area is inundated in the 20 year ARI flood. This shed is expected to experience increases of 125 millimetres in flood level during a 200 year ARI flood event, with smaller increases in more frequent events. No residences would experience flood level impacts in this floodplain.

Flood level impact maps of the catchment for the 100 year ARI flood event are in chapter 6 of the Working paper – Hydrology and flooding.

Flood inundation duration impacts

Although there is an increase in flood levels upstream of Oakey Creek, flood inundation duration is either similar to the existing case, or decreased. This is likely a result of improvement of drainage through the project in comparison to the existing highway.

However, the local creek 100 year ARI flood events inundation period would still be much lower than the inundation duration associated with 100 year ARI Richmond River flood events.

Flood velocity and direction impacts

Velocities are less than one metre per second upstream and downstream of all structures in the 100 year ARI flood event. Thus, flow velocity would be below one metre per second on land outside of the project boundary.

There would be no changes to the direction or behaviour of flooding other than the constriction and expansion adjacent to waterway structures.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would result in a similar rate of flood rise upstream of the project as the existing case. An exception is Norton's Gully to the north, where the rate of rise would decrease from the existing case (ie floods would rise slower at this location).

The project would not reduce the flood warning time in any area. Around Norton's Gully the warning time would be increased slightly as a result of slower rates of flood rise.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

A flood refuge area exists on the western extent of a property located between Aplins Road, Red Gate Road and the existing Pacific Highway. Oakey Creek runs through this property. The refuge area itself would not be affected by increased flood levels. However, there may be a minor impact on the ability to move cattle across the property upstream of the project during peak flooding. Cattle would need to be taken further upstream to cross Oakey Creek.

Further consultation with the owner of this property is required to understand the current procedures taken during large flood events and confirm whether cattle movement would be restricted as a result of the project. Measures, such as raised stock access tracks, would be identified at this stage to adequately manage any project impacts on stock movement during floods.

As this section of the project would be a duplication of the existing highway, no other known evacuation routes would be severed by the project. Therefore, there is not expected to be any impact to the potential for evacuation in this area.

The increased immunity of the highway would in most cases provide greater ability to evacuate during large flood events.

Flood hazard impacts

The overall level of flood hazard (depth, velocity, velocity-depth product, duration of flooding, rate of rise, warning times, evacuation and flood access) would not be increased by the project.

Bed and bank stability impacts

The project does not include any bridges in this section. All watercourses are proposed to be crossed by extension or augmentation of existing culvert crossings. Appropriate scour protection would be provided upstream of, through and downstream of culvert structures.

8.4.17 Mid Richmond River

Flood management objectives

Land use within the Mid Richmond River floodplain consists of residential, agricultural (including sugar cane farm land) and forested areas. The flood management objectives for this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- Less than 50 millimetres increase in flood heights on sugar cane farm land for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses and cane land
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Photo 6: View of Richmond River confluence with Tuckean Broadwater south towards Broadwater town

Flood level impacts

The flood level impacts for the 20 year ARI flood event are presented in Figure 8-8. Flood level impact maps for the 50 year and 100 year ARI flood events are in Working paper – Hydrology and flooding.

Due to the size of the Richmond River catchment, its flows, and the long duration of flood periods, the floodwaters of the Richmond River are slow moving. As a result, the project would have little impact on peak flood levels as the slow-moving floodwaters would be able to pass unrestricted through the proposed waterway structures on the floodplain. Impacts are less than 25 millimetres increase over the entire floodplain. Increases are less than 50 millimetres in the 100 year ARI flood event.

Generally, the most significant changes in flood levels along the project are expected during a 100 year ARI flood events. Houses along the bank of Richmond River west of the project would experience increases of up to 40 millimetres, while properties east of the project would experience reductions of 50 millimetres.

In the area between Woodburn and the project (north of Tuckombil Canal), flood levels of around 840 millimetres are expected during a five year ARI flood event. This impact is due to changes to local flooding within 1.2 kilometres of the project boundary. No houses are affected by these impacts, but a shed experiences an increase in flood level, as well as the backyards of two properties south of Woodburn.

There are no houses that are affected by an increase greater than 50 millimetres in peak flood levels, as required by the flood management objectives.

The use of sugar cane and other farming land is not expected to be affected by the increases in flood level resulting from the project.

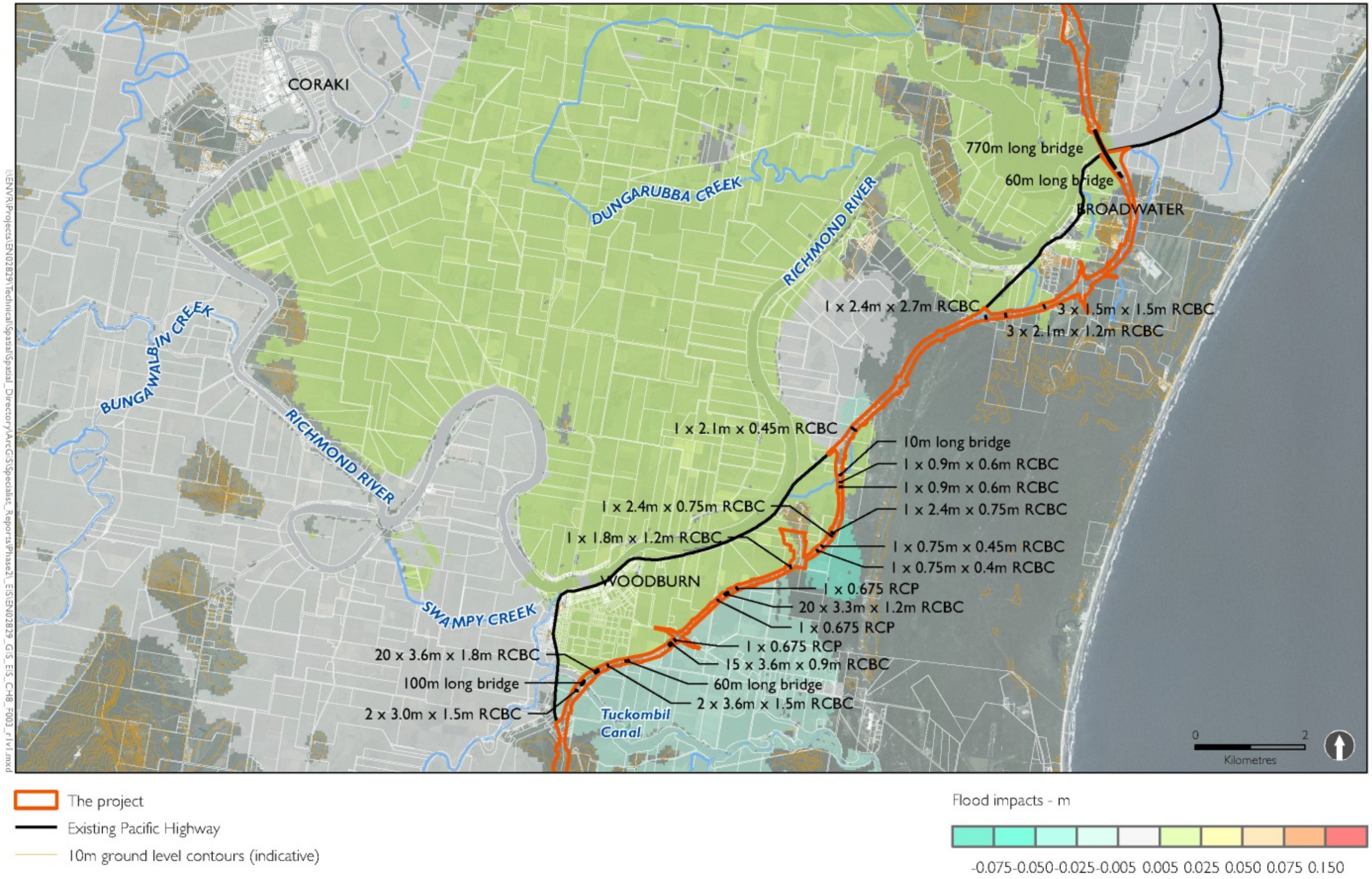

Figure 8-8: Flood impacts 20 year ARI flood event: mid Richmond River

Flood impacts to property

The sum total of average annual flood damages is expected to increase around Woodburn by around 0.8 per cent as a result of flood impacts. Increase in the sum total of average annual flood damages in Broadwater is expected to be around 1.1 per cent. Other residences and commercial properties in this area, particularly around Coraki, experience a negligible decrease in total flood damages.

The existing mean of average annual flood damages for impacted residences in this area is about $4,400 per property for Woodburn and about $3,700 per property for Broadwater.

Histograms showing the distribution of increased average annual damages and increased flood levels as a result of the project in Woodburn and Broadwater are presented in Figure 8-9 and Figure 8-10. There are no properties which experience greater than 50 millimetres increase in flood levels. Increases of less than 50 millimetres would meet the flood management objectives for the area.

Although many properties experience an increase in flood levels of 20 to 50 millimetres in these areas, the increase in average annual flood damages per property is mostly below $50. In these areas, lower impacts (less than 20 millimetres) occur in the 20 year ARI flood events while greater impacts (20 to 50 millimetres) occur in the 50 and 100 year ARI flood events.

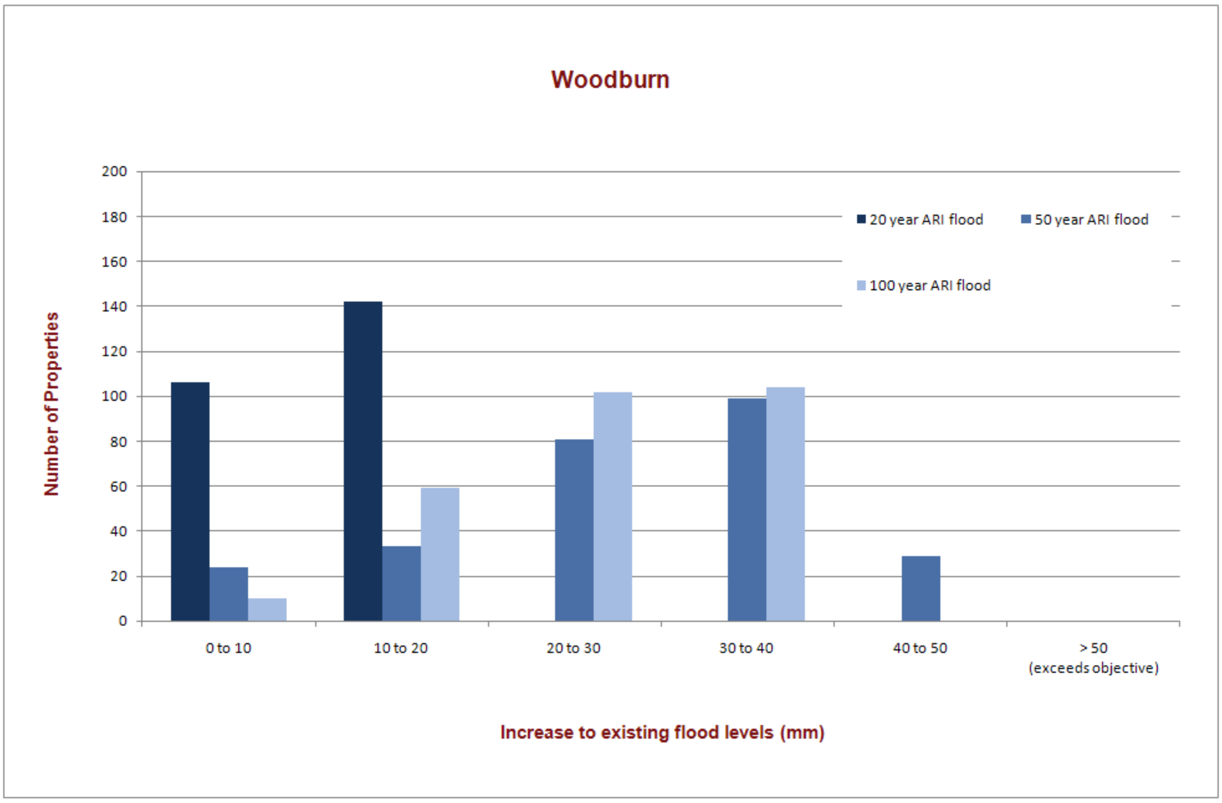

Figure 8-9: Distribution of impact on existing flood levels in Woodburn

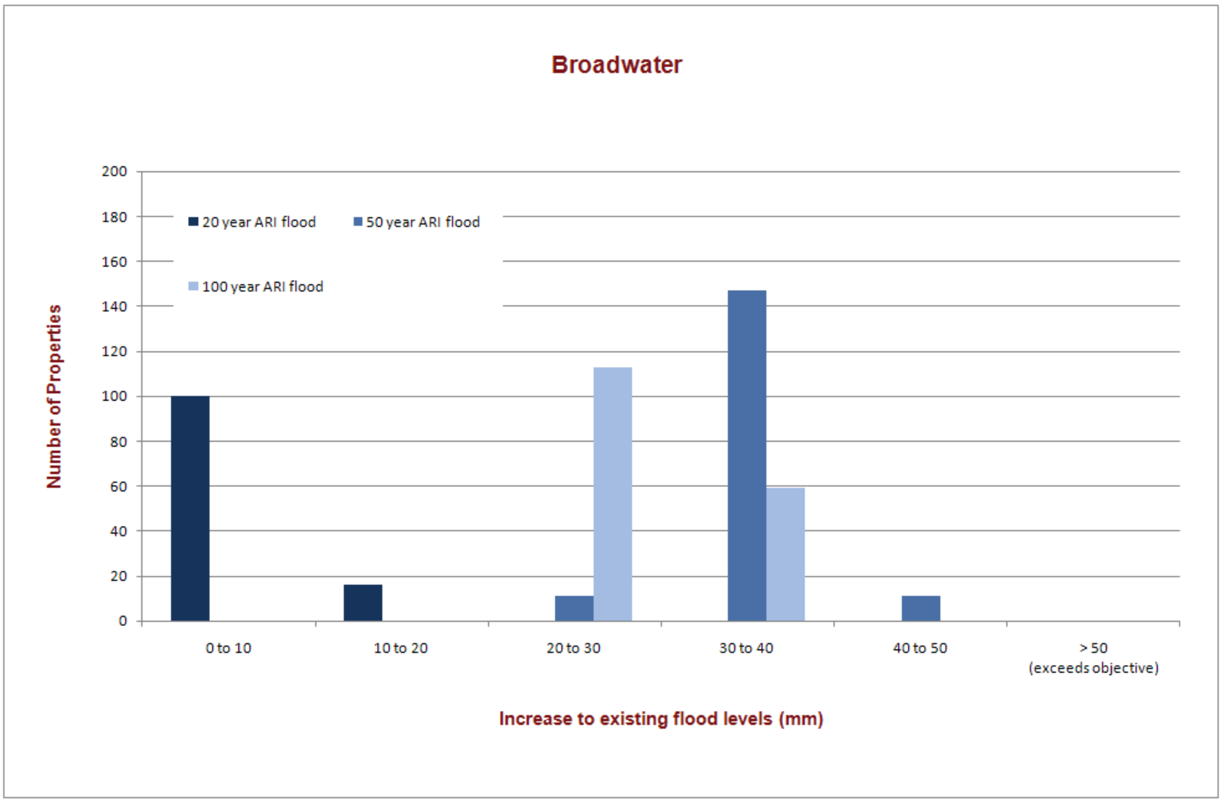

Figure 8-10: Distribution of impact on existing flood levels in Broadwater

Flood inundation duration impacts

The overall increase in time of inundation is less than five per cent throughout the mid Richmond River floodplain.

Flood velocity and direction impacts

Velocities are less than one metre per second upstream and downstream of all structures in the 100 year ARI flood event, apart from the bridge over Tuckombil Canal and the bridge over the Richmond River. Here, the change in velocities is within the 20 per cent flood management objective.

The bridge across McDonalds Creek was sized to limit the peak flood velocities in commonly occurring flood events to less than one metre per second, with the aim of minimising potential impacts on Oxleyan Pygmy Perch habitat (endangered fish species). Average velocities across the creek would be about 0.7 metres per second with the proposed bridge span of 10 metres.

Two-dimensional modelling would be undertaken at the detailed design phase to provide a better definition of velocity distribution across the channel and confirm peak velocities through the bridge at the project crossing. Modification to the current bridge design may be required to limit peak velocity impacts in consideration of Oxleyan Pygmy Perch requirements.

There would be no further changes to the direction or behaviour of flooding other than constriction and expansion adjacent to waterway structures.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

In the mid Richmond River floodplain, the project would have a similar rate of rise as the existing case for most of the floodplain. In southern Woodburn, there would be a reduction in warning time of around five hours for land between 1.1 and 1.4 metres AHD. This is not expected to have any impact on residences in Woodburn as the majority of houses are located further north, where there is no impact to rate of flood rise or warning time against the existing case.

Immediately north of Tuckombil Canal, the rate of rise would be temporarily faster than the existing case between around 0.5 metres AHD and 1.5 metres AHD. This would result in a small reduction in warning time of around two to five hours in areas that would usually experience a warning time of at least 20 hours. However, this area is used for agricultural purposes only and therefore would not affect flood warning time for any residents.

Residents of Woodburn receive advanced warning of flooding through a network of catchment inflow gauges. This means that there would still be sufficient time to prepare for flooding and there would be no additional risks to people, stock or property. Access out of low-lying properties would also be possible once floodwater reached house floor levels.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

There would be a reduction in evacuation and access time of around five hours for land between 1.1 to 1.4 metres AHD in Woodburn during the 100 year ARI flood event. It is possible, but unlikely, that one residence may be affected by this due to roads around the house being cut three to four hours earlier than the existing case. However, given flood warning time in this area for the 100 year ARI flood event is at least 24 hours, there would be sufficient warning of an approaching flood to ensure evacuation, and the time until inundation of the house itself would not be affected.

There is not expected to be any impact on the ability to evacuate other towns or residential areas in the Mid Richmond River catchment as a result of the project. The increased immunity of the highway would in most cases provide greater ability to evacuate during large flood events. Meetings with the State Emergency Services in the Richmond River area indicated that there would need to be changes to the emergency plans to accommodate the changes in highway access locations and the improved flood immunity of the highway.

The clearance under the Richmond River bridge during the peak of a flood event would be similar or higher to the clearances of the existing bridges (adjacent to the new bridges). Hence, these bridges are unlikely to cause any further impediment to boat movements during flood events associated with disaster management or evacuations.

Flood hazard impacts

There would be some increase in flood hazard in some areas of Woodburn and at other houses throughout the floodplain due to the increase in peak flood levels. However, the slow moving nature of the flooding would mean that the increased levels would pose no additional risk to people as by the time the peak of the flood reached the town, residents would either have evacuated, or be prepared to stay and not enter floodwater for the duration of the flood.

The existing flood warning system based on catchment inflows provides an indication of a significant flood event up to 24 hours in advance of the Richmond River rising at Woodburn. Therefore, there would still be sufficient time to prepare for flooding. In addition, access out of low lying properties would still be possible when floodwater reached house floor levels.

The project would have a negligible impact on the times of flood inundation and rates of floodwater rise and recession for the Richmond River. The primary reason for this is that the project would have minimal impact on the rise and fall of the river. Furthermore, the size of the floodplain structures incorporated into the project is more than sufficient to drain the floodplain, recognising the relatively slow rates of floodwater rise and recession in this part of the floodplain.

As substantial warning is available at Woodburn, any minor changes to flood hazard resulting from the project resulting from higher peak flood levels or flood levels rising earlier would not pose a risk to life, stock or property.

Bed and bank stability impacts

The project would increase velocities in Tuckombil Canal by about 10 per cent for five year ARI flood events through to 100 year ARI flood events. For the major bridge crossing of the Richmond River, the project would increase velocities in Tuckombil Canal by less than five per cent for two year ARI flood events through to 100 year ARI flood events.

It is likely that the well vegetated channel banks of both waterways could accommodate these increases in peak velocity without increased risk of erosion as the resulting velocities would be well below the threshold of two metres per second for scour on well vegetated banks.

The concept design includes bridge piers located on or near the bed and banks of both Tuckombil Canal and the Richmond River. These piers would have the potential to result in localised erosion of the bed and bank without appropriate design. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for instream works and watercourse crossings to minimise the impacts to the stability and hydrology of the watercourse.

8.4.18 Lower Richmond River

Flood management objectives

Section 11 of the project would cross the floodplain of the lower Richmond River and include crossings of Duck Creek and Emigrant Creek. The embankment of the project would tie in with the Ballina bypass and the Bruxner Highway in the area where it crosses the creeks just upstream of their confluence.

The flood impact assessment for the project considered the cumulative impacts with the project and the Ballina bypass.

Land use within the Lower Richmond River floodplain consists of residential, sugar cane farm land, agricultural and forested areas. The flood management objectives of relevance to this catchment are:

- Less than 50 millimetres increase in flood heights at houses for any assessed flood event less than and equal to 100 year ARI flood event
- Less than 50 millimetres increase in flood heights on cane farm land for any assessed flood event less than and equal to 100 year ARI flood event
- On grazing, forested and other rural areas, generally less than 250 millimetre increase up to the 100 year ARI flood event
- No more than five per cent increase in the flood duration where there are houses and cane land
- No more than ten per cent increase in the flood duration in recognition on grazing, forested and other rural lands
- Velocities to remain and below one metre per second on grazing, forested and other rural lands where currently below these figures. An increase of not more than 20 per cent where existing velocity is above these figures
- Velocity-depth products for houses, commercial premises and urban areas remain in low hazard category for children (ie less than 0.4 m^2/s based on *Australian Rainfall and Runoff*, Project 10, 2011)
- No change to the direction of watercourses or the direction of flood flows except for constriction into and expansion out of discrete openings (culverts and bridges) and constructed diversions.

Flood level impacts

The flood level impacts for the 20 year ARI flood event are presented in Figure 8-11. Flood level impact maps for the 50 year and 100 year ARI flood events are in Working paper – Hydrology and flooding.

Several houses within the Maguires Creek/Emigrants Creek floodplain are expected to experience increases of up to 40 millimetres in the 200 year ARI flood events, with smaller impacts during 20 and 100 year ARI flood events. Flood levels were found to decrease in this area during a five year ARI flood event, with no houses inundated in the existing case or due to the project.

The project is above the floodplain from Wardell to Whytes Lane so there is no impact on flooding for this section.

The raised road from Whytes Lane to Duck Creek is expected to cause some increase in peak flood levels associated with flows from the catchments to the west of the highway building up behind the project embankment. For 20, 100 and 200 year ARI flood events, these impacts are less than 30 millimetres and meet the objectives for this catchment.

The proposed culverts under Whytes Lane overpass on the western side of the highway serve to decrease flood levels upstream of Whytes Lane. A reduction in flood levels results in decreased flood storage in small floods. As such, flows in the drain channel downstream of Whytes Lane increase in the five year ARI flood event, causing impacts of up to 90 millimetres. This impact can be mitigated through detail design of the culverts to limit flow in small floods through bunding of culverts to a similar level as Whytes Lane, mimicking existing flow conditions, while not impairing flow in larger floods.

Similarly, along the floodplain areas south-west of Duck Creek (station 162 to 164) there is the potential for the project to result in increased flood inundation for small flood events. This is due to the three waterway structures under the project along this section (at stations 162.68, 163.60 and 163.84) to potentially allow floodwaters from the western side of the project to pass through to the eastern side. Currently, the existing highway serves as a levee to protect the eastern side. These bunds would serve to stop flood passing in smaller floods but would not impede flood flows for larger, rarer flood which would have overtopped the existing highway.

The bridge over Duck Creek has been designed with soffit levels above the 100 year ARI flood level. In addition, the proposed pier configuration would be more hydraulically efficient than the existing bridges. These measures are expected to reduce the losses associated with these bridges and should not adversely affect peak flood levels.

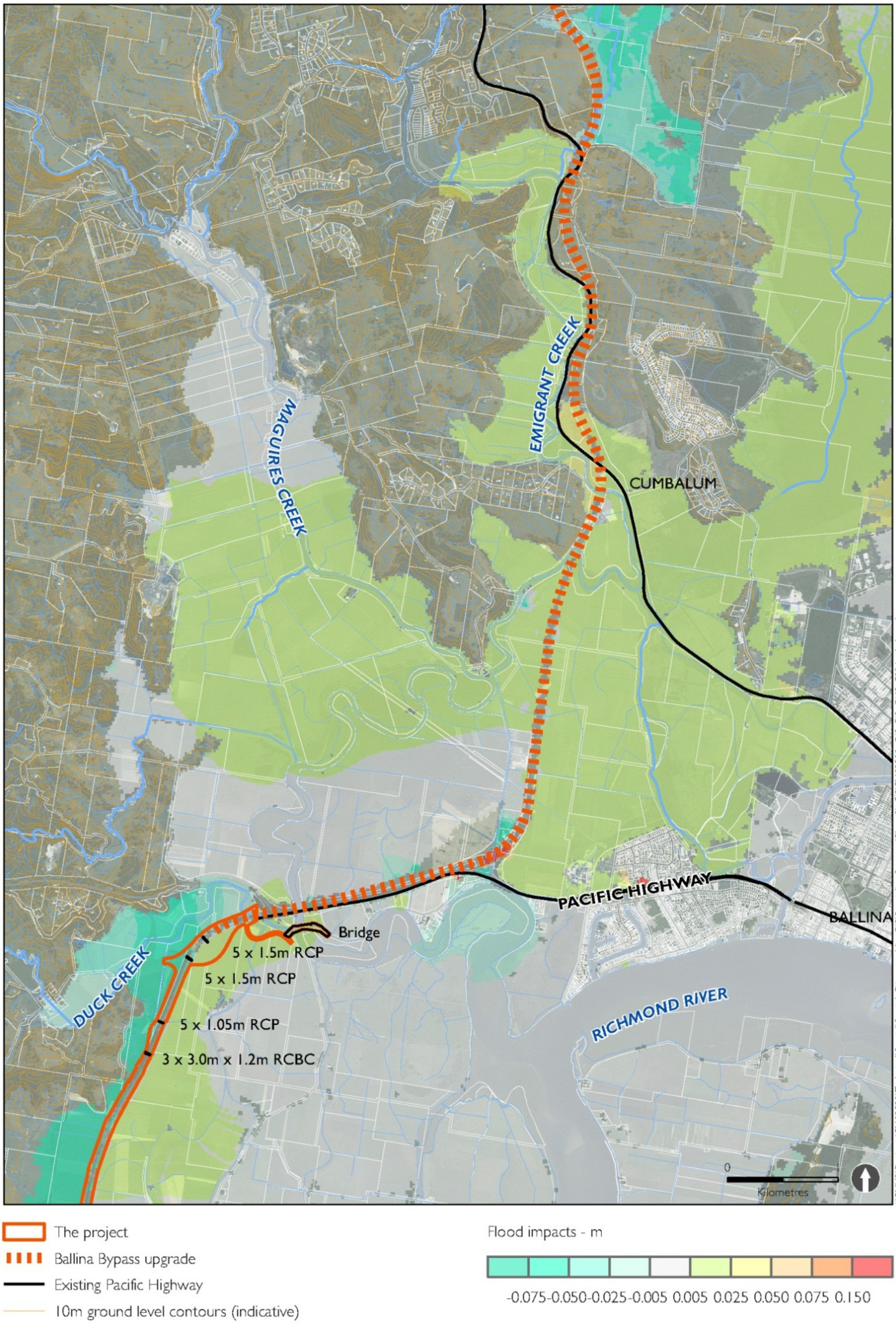

Figure 8-11: Flood impacts 20 year ARI flood event: lower Richmond River and Ballina

Flood impacts to property

The average annual flood damages is expected to increase around Ballina by around 0.6 per cent as a result of project flood impacts. However, this assessment does not consider numerous properties in Ballina that would experience a reduction in average annual flood damages due to reduced flood levels as a result of the project.

The existing mean of average annual flood damages for impacted residences in and around Ballina is about $1,700 per property.

A histogram showing the distribution of increased flood levels as a result of the project is presented in Figure 8-12. There are no properties which experience greater than 50 millimetres increase in flood levels. Increases of less than 50 millimetres would meet the flood management objectives for the area.

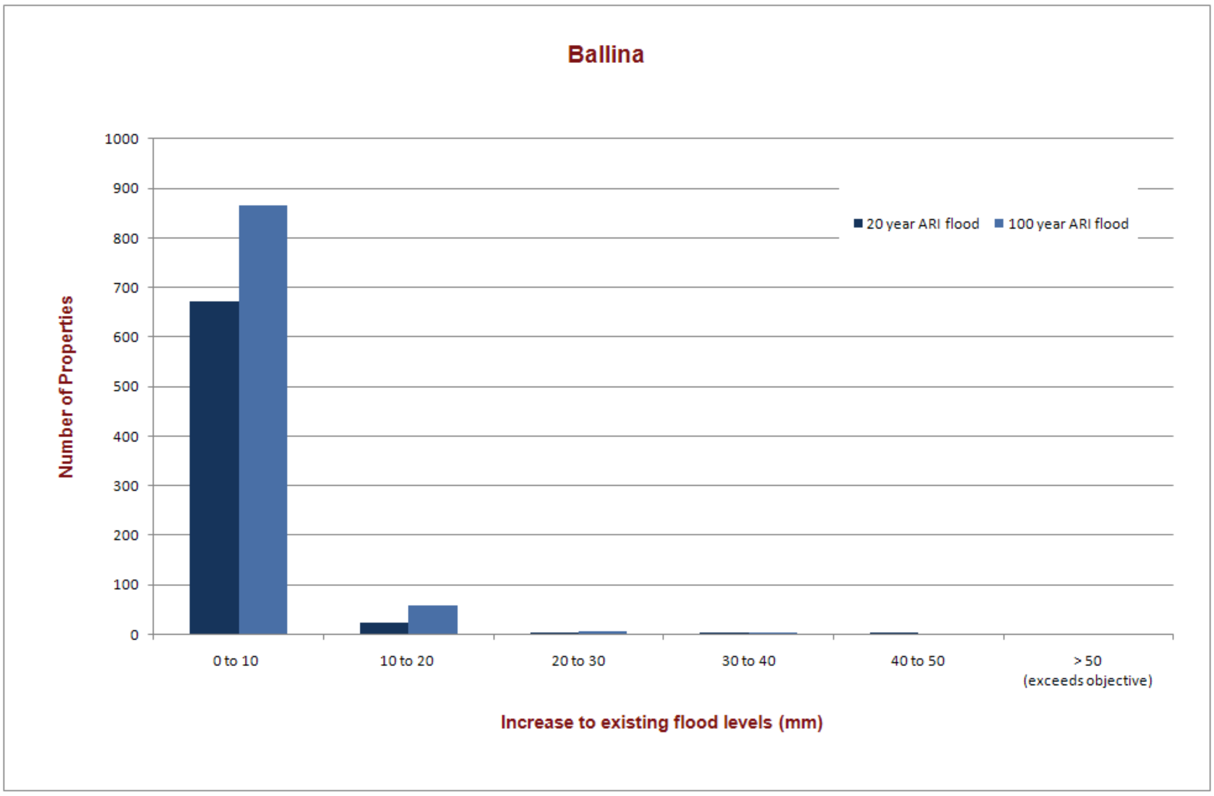

Figure 8-12: Distribution of impact on existing flood levels in Ballina and surrounding areas

Flood inundation duration impacts

Any change in inundation time as a result of the project is less than five per cent of the overall period of inundation, in line with the flood management objectives.

Flood velocity and direction impacts

There is little change in the flow regime as a result of the project, so velocity and flow direction is not greatly impacted. Velocities are less than one metre per second upstream and downstream of all structures in the 100 year ARI flood event.

Figures showing changes in velocities upstream and downstream of structures in the catchment are in Working paper – Hydrology and flooding.

Rate of flood rise and warning time impacts

The project would have a similar rate of rise as the existing case on the Lower Richmond River floodplain.

East of the project, around station 163.5, there would be a reduction in flood warning time of between five to 10 hours for land below 1.5 metres AHD. Around four kilometres along the Pacific Highway east heading into Ballina, there is also a reduction in flood warning time of up to five hours for land below 1.5 metres AHD. As the land use around these locations is agricultural, this is not expected to have any impact on flood warning time for residents.

Flood level plots for the catchment are in Working paper – Hydrology and flooding.

Flood evacuation and flood access impacts

No known evacuation routes would be severed by the project. Therefore, there is not expected to be any impact to the potential for evacuation in this area. The increased immunity of the highway would, in most cases, provide greater ability to evacuate during large flood events.

Flood hazard impacts

Given the existing depths at the houses within the Maguires Creek / Emigrants Creek floodplain are quite low, the flood hazard for these houses would not change as a result of the project. It is highly unlikely that people, stock or property would be adversely affected by the small increase (less than 50 millimetres) in peak flood levels and it is not considered that the project would have any significant impacts on flood hazard. The risk to people, stock and property relating to evacuation or emergency access would not be increased.

Bed and bank stability impacts

For the Duck Creek crossing at station 164.3, lower velocities are expected compared to the existing case with risk of bank erosion unlikely.

8.4.19 Impacts on hydrology of waterways

The project's impervious road pavement would result in minor increases to the impervious area of catchments crossed by the project. This increase would generally be small relative to the total areas of those catchments (less than two per cent).

A proportion of the runoff from these impervious road pavement surfaces would pass through water quality ponds prior to discharging into watercourses. These ponds would detain runoff for a short period of time and then slowly discharge it. This retarded flow would mitigate the impact of the increased runoff rates from the impervious areas. Hence, the impact of the project on flow regimes would not be significant.

Changes in hydrological and flooding conditions as a result of the project have the potential to impact aquatic ecosystems. The potential changes to hydrological response and/or flooding behaviour can impact on known and potential habitats of threatened fish species (such as Oxleyan Pygmy Perch and Purple-spotted Gudgeon) near the project. Potential changes can include:

- Barriers to aquatic movement
- Increase in stream and flood velocities through cross-drainage structures.

Further discussion on changes to stream and flood velocities in known or potential habitat of Oxleyan Pygmy Perch is in Section 6.19 of Working paper – Hydrology and flooding.

8.4.20 Impacts on hydrology of wetlands

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

8.4.21 Impacts on Solitary Islands Marine Park

Arrawarra Creek catchment

The project would cross the Arrawarra Gully catchment, which drains into the Arrawarra Creek catchment. Both these catchments then discharge into the Solitary Islands Marine Park. The project would result in an increase in the quantity of road runoff from the Arrawarra Gully and Arrawarra Creek catchments, with about 2.5 kilometres of road being constructed in these catchments. The Arrawarra Gully catchment is about 9.3 square kilometres and the Arrawarra Creek catchment is about 21.7 square kilometres. As such, the project would represent 0.65 per cent and 0.28 per cent of the catchment areas, respectively. It is not expected that the project would result in any discernible increase in the quantity of runoff flowing to the Solitary Islands Marine Park. Road runoff quality and proposed mitigation measures are addressed in Chapter 9 of this EIS.

Corindi River catchment

The project passes through the Corindi River catchment, crossing or passing near Corindi River, Blackadder Gully, Cassons Creek, Redbank Creek and Dirty Creek, which all drain into the Solitary Islands Marine Park.

The project within the Corindi River catchment (around 155 square kilometres) would consist of about 7.6 kilometres, increasing the impervious area (and therefore runoff quantity) in the catchment. This represents about 0.17 per cent of the total catchment area. It is not expected that the project would result in any discernible increase in the quantity of runoff flowing to the Solitary Islands Marine Park. Road runoff quality and proposed mitigation measures are addressed in Chapter 9 of this EIS.

8.4.22 Impacts on farm dams

A farm dam impact assessment has been undertaken to identify farm dams currently located in the project boundary and farm dams that are likely to be affected by a reduction in catchment area. (A reduction in the catchment area of a farm dam would occur where sections of the project are cut into elevated terrain and thereby divert stormwater runoff that would otherwise flow to the dam.) It found that:

- Fifteen dams are located within, or partially within, the project boundary. These dams would be acquired, with compensation provided to relevant landowners, as part of the land acquisition process for the project
- Ten dams are expected to experience some loss of catchment area, which would reduce the overall volume of rainfall runoff captured by the dam. While the reduction in dam inflow may not be directly proportional to the loss of catchment area, the amount of catchment area lost is considered to be a good representation of the likely degree of impact.

8.4.23 Impacts on geomorphology of waterways

While most of the impact assessment focuses on major flood events, the impacts of the project on the overall hydrology of the crossed watercourses also require consideration. Small, frequent flood flows and more common wet-season flows are critical to maintaining the hydrological regime of the watercourses. The ecology of many floodplain areas also depends on the maintenance of seasonally wet conditions.

An assessment of the impacts of the project on the geomorphology of watercourses to be crossed by bridges was carried out. This assessment was based on the existing morphology of the watercourse and the predicted changes to flood velocities due to construction of flow through discrete bridge openings. It was found that most watercourses would not experience increases in flood velocities that would instigate a change in channel form or increase the risk of erosion. However, there would be two exceptions:

- The proposed bridge crossing at the western tributary of the Coldstream River would result in a large increase in the peak flood velocities for rare flood events. A larger bridge at this location or at the Coldstream River crossing further east would reduce the velocity increases. This would need to be considered further in detailed design in conjunction with impacts on flood access in the area

- The proposed bridge crossing at Champions Creek would result in a large increase in peak flood velocities for rare flood events. Detailed design would need to consider the need for a larger bridge at this location or changing the culvert crossing 200 metres to the north to a bridge. This change would need to be considered in conjunction with the need to reduce the impacts on Somervale Road inundation (discussed above) and the costs of embankment construction on the floodplain soils.

In addition, there would be many creeks and watercourses crossed by the project where culverts (typically reinforced concrete box culverts) would be used. In some of these watercourses (such as Mororo Creek, Tabbimoble Creek and Oakey Creek) culverts are currently used to convey flows under the Pacific Highway. The culverts would not change the hydrology of these creeks.

In other locations, the culvert crossings would require an assessment at the detailed design stage, of the inlet and outlet velocities and the capacity of the watercourse to accommodate these velocities. These assessments are dependent on the final culvert size adopted in the design and a detailed understanding of the stream conditions of the watercourse. The detailed design phase would include identification of treatments required to minimise erosion due to the project and could include larger culverts to reduce velocities and/or rock protection at the inlet and outlets of the culverts.

The impacts on stream morphology of these culvert crossings would be minimised in the detailed design by designing the culverts so they cross the project at oblique angles, which would result in the inlet and outlet locations being in the watercourse (that is, shortened flow paths with culverts perpendicular to the highway direction would be avoided).

8.4.24 Impacts of creek diversions on creek geomorphology

The project would require the diversion of Picaninny Creek for about 500 metres and Everson Creek for about 200 metres.

The concept designs of these diversions aim to minimise the impacts on the geomorphology of these two creeks by adopting the following features: rock armouring, channel revegetation, and energy-dissipating structures such as a plunge pool and rock chute in the Picaninny Creek diversion.

8.4.25 Impacts of bridge piers on waterways

The project would span all major watercourses with bridges from bank to bank, including Corindi River, Cassons Creek, Pheasant Creek, Coldstream River, Pillar Valley Creek, Chaffin Creek, Champions Creek, Shark Creek, Clarence River, Serpentine Channel, Clarence River North Arm, Tuckombil Canal, McDonalds Creek, Richmond River and Duck Creek.

There would be piers located in nearly all of these watercourses. These piers would comprise a series of about 14 piles (700 millimetres to 1000 millimetres in diameter) with a spacing of about two metres in the direction of flow. If not appropriately designed, these piers would have the potential to result in localised erosion of the bed and bank. The final location of these piers would be determined in the detailed design phase together with a more detailed consideration of bridge spans. The design of these piers in waterways would be in accordance with the NSW Office of Water guidelines for in-stream works and watercourse crossings to minimise the impacts on the hydrology of the watercourse.

The impacts of the piers on flood behaviour have been simulated in the flood impact assessments described above. These assessments also included assessments of the potential for debris to block the space between the piers, and the additional flood levels that may result.

8.4.26 Probable maximum flood considerations

The probable maximum flood is an estimate of the largest possible flood for a particular catchment. While there are procedures available for estimating these flows, it needs to be recognised that the estimates have a high degree of uncertainty as they are based on extrapolation from a relatively short period of recorded rainfall and flood data.

As a guide, the probable maximum flood peak flow for local catchments of moderate size is generally considered to be in the order of three times the 100 year ARI peak flow. For the larger Clarence River and Richmond River catchments, this factor is expected to be lower due to the very high improbability of high intensity rainfall over the whole catchment at one time. In the lower Clarence River, this factor was estimated to be in the order of 1.5 times the 100 year ARI peak flow (Lower Clarence River Flood Study Review (WBM, 2004)). For the smaller Richmond River, the factor is estimated to be 2.6 times the 100 year ARI peak flow (based on ratios of rainfall intensities for the 72-hour duration rainfall event).

Regardless of the magnitude of the flood event, the issue requiring consideration is the consequence of a flood event in which the peak flows exceed the capacity of the designed waterway openings, or exceed the design flood immunity levels of the roadway.

Small to moderate catchments

For small to moderate catchments, the likely impact of the project on a probable maximum flood would be higher flood levels, particularly during the initial stages of flood rise. There would be little or no potential for re-routing of flows into other catchments because of the well-defined nature of the watercourses and floodplains.

The increases in flood levels would, however, have an upper limit. Specifically, once floodwaters overtop a significant section of the road embankment, the constriction of flow would decrease and flood levels would stabilise and eventually dissipate. This is because the weir-like flow over the road is a more efficient form of floodwater conveyance than an under-road waterway opening such as a culvert. Therefore, while there is likely to be an increase in flood levels, it is possible that the ultimate magnitude of these increases would be less than those experienced during a 100 year ARI flood event.

Clarence River and Richmond River floodplains

Sections of the project that cross the Clarence River and Richmond River floodplains would be constructed at or just above the 20 year ARI flood level. In a probable maximum flood event (or any event significantly larger than the 20 year ARI flood), long sections of the project across the floodplain would be inundated. When this occurs, the highway would need to be closed.

8.4.27 Impacts on the network of cane drains

The Clarence River and Richmond River floodplains include networks of cane drains that play a critical role in draining the land following flood events, and ensure runoff can drain to major watercourses such as the Clarence River. Maintaining adequate drainage of agricultural lands is important for property owners.

The project includes crossings that generally exceed the capacity required for cane drainage. An exception is along the Shark Creek floodplain because it experiences large volumes of backwater flooding in rare events which require drainage as the flood recedes.

Culverts incorporated into the concept design would accommodate flow for all cane drains crossed along the length of the project. In locations where several cane drains are crossed in very close proximity, such as immediately upstream or downstream of where two drains join, drains would be diverted to flow through one culvert. In some instances, the cane drains may be altered along new drainage routes.

Subsequent stages of the project would include further consideration of the required waterway structures on the Clarence River floodplain for local drainage. It is expected that the requirement for major waterway structures on the floodplain can be coordinated with the need for minor drainage structures to provide adequate cross-drainage for both types of flood events.

Photo 7: Cane drains on Chatsworth Island

8.4.28 Impacts to future development potential of land

Reduction in available land with future development potential

The project would result in small increases in the area of flood inundation in the 100 year ARI flood event. This would lead to a small reduction in the available land for future residential or commercial development. Alternatively, the impacts of the project would require higher fill levels to be used for future development areas immediately upstream of the highway. This small decrease in future land use potential needs to be balanced against the increase in development potential accruing from the project for land adjacent to the project.

Future development potential of access affected land

Land with development potential in the vicinity of the project would generally require flood access in a 100 year ARI flood event. An assessment of the flood impacts and access routes (ie public roads) was carried out. This assessment identified that there would not be any land that is currently accessible in a 100 year ARI flood event that would have this access reduced by the project.

Land south of Wants Lane in the Coldstream River area would experience an increase in flood levels in the 100 year ARI flood event. However, access for this land is via Wants Lane and the bridge across the western tributary of the Coldstream River. In a 100 year ARI Coldstream River flood event, access across this bridge would not be possible. In a 20 year ARI Clarence River flood event, this bridge is also not trafficable. Hence, the development potential of this land is limited due to existing flood access issues and this potential would not be affected by the project.

It should be noted that there are many locations where the project would result in significant improvements in flood access due to the increased flood immunity of the highway. The development potential of land in these locations would therefore be increased as a result.

8.4.29 Cumulative impacts with other projects or activities

The flood impact assessment for the section of the project that crosses the lower Richmond River floodplain considered the combined impacts of the project and the Ballina bypass. As discussed above, the project would have minor flooding impacts on the floodplain of the lower Richmond River and would meet all relevant flood impact objectives.

There is the potential for residential filling (ie raising of ground levels for residential development, resulting in loss of floodplain storage) to occur on the Clarence River floodplain at West Yamba. This is the only known filling or notable change proposed for either the Clarence River or Richmond River floodplains. This filling was assessed in conjunction with the project to define the cumulative impacts. It was found that the flood impacts of the project would be independent of those associated with the proposed filling at West Yamba. Hence, the impacts presented in this EIS are deemed to represent a cumulative impact scenario for the Clarence River floodplain.

No additional potential for cumulative impacts on flooding has been identified. The flooding impacts of the project would be confined to discrete sections of the assessed watercourse floodplains, with no regional or overarching impacts.

8.5 Assessment of climate change implications

The assessment of climate change implications for the project was assessed using sea level rise and rainfall predictions corresponding to the year 2070, which is considered to be representative of the halfway point in the 100 year design life of the project.

There are two anticipated outcomes of global warming that have the potential to change the predicted flooding impacts of the project: sea level rise, and increases in rainfall intensity. The potential impacts of these outcomes are addressed below, both separately and together.

8.5.1 Potential impacts of sea level rise

A rise in sea level has the potential to impact flood behaviour in coastal river systems as a result of higher ocean levels at the river mouths. This would result in higher levels of water immediately downstream from bridges and culverts during flooding (ie higher tailwater levels) and higher maximum flood heights for any given flood event in coastal areas. The implications of this for the project would be a decrease in flood immunity where the highway crosses coastal areas below five metres AHD, such as the Clarence and Richmond river floodplains

The sea level rise estimates for this project were based on the NSW Government's Sea Level Rise Policy Statement *(*DECCW, 2009), which identifies increases of 0.4 metres for 2050 and 0.9 metres for 2100. Based on a linear interpolation of these values, the sea level rise estimate for the year 2070 (the halfway point of the 100 year design life of the project) would be 0.6 metres.

The effects of a 0.6 metre sea level rise were examined using flood modelling. The assessment was carried out only for the two major coastal river systems crossed by the project – the Clarence and Richmond rivers.

It was found that the 0.6-metre sea level rise scenario would not impact the smaller upper catchment rivers and creeks crossed by the project.

8.5.2 Potential impacts of increases in rainfall intensity

The predicted increase in the intensity of rainfall events means that the volume rainfall corresponding to the current 100 year ARI flood event may occur more frequently. There is little data or literature to provide any certainty regarding the potential increases in rainfall intensity. Nevertheless, the implications for the project are that the flood immunity levels of carriageways may effectively be reduced.

In 2007, the (then) NSW Department of Environment and Climate Change released guidelines for consideration of climate change in floodplain management (DECC, 2007). These guidelines quoted other reports, such as CSIRO (2007), which indicated that the extreme rainfall intensity (ie 40-year ARI one-day rainfall total) may increase by five to 10 per cent for the NSW Northern Rivers area by 2070. For the purposes of this environmental assessment, the potential for a 10 per cent increase in rainfall intensity due to climate change was assumed.

It needs to be recognised that there are limits to the accuracy of current rainfall information, with corresponding implications for predicting future changes in rainfall intensities. This is due to the relatively short periods of recorded data and sparse rainfall gauge networks in the catchments crossed by the project. To illustrate the limits of data accuracy:

- Rainfall gauges with about 50 years of recorded data have a 90 percentile confidence range of 17 per cent for the 20 year ARI (one-day) rainfall estimates and 27 per cent for the 100 year ARI (one-day) rainfall estimates
- Rainfall gauges with about 100 years of recorded data have a 90 percentile confidence range of nine per cent for the 20 year ARI (one-day) rainfall estimates and 15 per cent for the 100 year ARI (one-day) rainfall estimates.

Additionally, there is a wide variation in the frequency of flood events of any given ARI (that is, there is a very wide deviation from the average in the frequency of their recurrence). For the relatively long flow record of the Clarence River (171 years from 1839 to present), for example, the four largest flood events occurred in a single 17-year period (1876 to 1893) and the next four largest flood events also occurred in a single 17 year period (1950 to 1967). Furthermore, there are two substantial periods without any floods larger than the 20 year ARI flood, one period from 1893 to 1950 (56 years) and another from 1967 to the present (43 years).

8.5.3 Potential impacts of storm surge

Flood events in the study area typically coincide with cyclonic events or east coast tropical lows, which are often accompanied by a storm surge. Flood modelling for the project has included combined flood and storm surge scenarios.

Climate change may result in an increase in the frequency and intensity of cyclonic lows, which would lead to an increase in the magnitude of storm surges. The research to date indicates, however, that there is little potential for increases to the frequency and magnitude of storm surges along this part of the coast (CSIRO, 2007).

8.5.4 Potential for tidal inundation of highway carriageways

An assessment was also made of the potential for the project to be inundated in non-flood events with a high tide. This required a consideration of the resulting sea level with the mean high water of the spring tides occurring at the end of the project life (ie the year 2120). For this scenario, an assumed sea level rise of 1.1 metres for the year 2120 was assumed based on a linear interpolation of the 0.4 metres at 2050 and 0.9 metres at 2100. This value was added to the mean high water spring tide level of 0.66 metres AHD for the region. This would result in a mean high water spring tide level of 1.76 metres AHD in 2120.

In comparison, the lowest road levels along the project would be at the Duck Creek/ Emigrant Creek area near Ballina, where the edge of the road would be around 1.72 metres AHD. This would mean that the edge of one lane in this area would have 40 millimetres of tidal inundation during the 2120 mean high water spring tide level. This indicates that the project over its design life would not be significantly impacted by the tidal inundation of carriageways.

8.5.5 Effects of rainfall intensity increase and sea level rise on flood immunity of highway carriageways

Under the assessed sea level rise scenario (0.6 metres for the year 2070, see Section 8.5.1), road embankments at a number of locations would need to be constructed slightly higher than currently proposed to meet the desired level of flood immunity (ie immunity up to and including the 20 year ARI flood event) on the Clarence and Richmond river floodplains. Specifically, the road embankments would need to be raised by:

- 0.13 metres at Shark Creek
- 0.09 metres at Chaselings and Gulmarrad basins
- 0.16 metres at Harwood Island
- 0.22 metres at Chatsworth Island
- 0.08 metres at Tuckombil Canal and Woodburn area.

However, when the assessed rainfall intensity increase and sea level rise scenario are considered together, these road embankments would need to be constructed even higher to meet the desired level of flood immunity (ie immunity up to and including the 20 year ARI flood event) on the Clarence and Richmond river floodplains.

Specifically, the road embankments would need to be raised by:

- 0.31 metres at Shark Creek
- 0.17 metres at Chaselings and Gulmarrad basins
- 0.25 metres at Harwood Island
- 0.29 metres at Chatsworth Island
- 0.27 metres at Tuckombil Canal and Woodburn area.

These required increases in embankment height would be considered further as part of the adaptive approach to climate change that is proposed in this EIS.

These increases would add to the cost of the project. It is estimated that an additional 140,000 cubic metres of material would be required to increase embankment heights to accommodate sea level rise, which would cost about $6 million. To accommodate sea level rise and increase rainfall, it is estimated that an additional 300,000 cubic metres of material would be required at a cost of about $12 million.

This estimated increase in embankment height has not been incorporated into the road design. However, the project boundaries have been designed to provide adequate space should road embankment heights be increased in the future.

Periodic pavement rehabilitation could assist in raising the embankment levels to maintain the desired flood immunity of the project if sea levels rise and rainfall intensities increase as predicted.

8.5.6 Effects of rainfall intensity increase and sea level rise on flood level impact objectives

To assess the joint effects of predicted sea level rise (0.6 metres for the year 2070, see Section 8.5.1), and rainfall intensity increases on the flood level impact objectives of the project, a series of flood assessments was carried out. Each modelled watercourse was re-assessed under climate change conditions with and without the project. These results were then compared with the flood levels under existing conditions with and without the project.

The comparisons indicated that the majority of the project would achieve the flood level impact objectives under climate change conditions.

8.5.7 Summary of climate change effects on the project

The influence of climate change on the flood immunity and flood impacts of the project was considered. It was found that:

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

8.6 Management of impacts

Measures for the management of hydrology and flooding impacts are detailed in Table 8-12. These mitigation measures are a summary of those identified in Working paper – Hydrology and flooding.

Table 8-12: Hydrology and flooding mitigation measures

Issue	Mitigation ID no.	Mitigation measure	Timing	Relevant section
Flood models	HF1	• Flood models for the Clarence, mid Richmond and lower Richmond rivers would be updated with survey data (as released by the NSW government in mid 2012).	Pre-construction	4, 5, 6, 8, 9, 10
	HF2	• The bathymetrical data on which the Clarence River flood model is based would be updated to reflect the current status of bathymetry at the relevant river crossing locations.	Pre-construction	4, 5
Operational impacts on cane drains	HF3	• Cane drain diversions would be designed and constructed in consultation with the relevant drainage unions and impacted landowners and in consideration of the potential diversions detailed in the Working Paper – Hydrology and flooding.	Pre-construction	4,8, 10
Permanent road fencing	HF4	• Any permanent fencing at culvert and bridge crossings would need to consider the potential for blockage and be designed and operated in a manner that doesn't result in impacts on flooding.	Pre-construction	All
Scour protection	HF5	• Scour protection and erosion protection measures at waterway crossings would be designed for upstream and downstream of the highway (particularly on sugarcane floodplains).	Pre-construction.	All
Waterway diversions	HF6	• Waterway diversions would be designed in a manner that the final diversion mimics to the greatest extent possible the characteristics of the waterway that is being diverted. Characteristics include flow regime, flow velocity, base material, vegetation and habitat for aquatic fauna.	Construction	All
	HF7	• Revegetation of the diversion and surrounding area would: • Be completed prior to the diversion receiving flows, in conjunction with the establishment of other scour and erosion control measures • Include planting and the establishment of appropriate vegetation communities along the channel bed and banks, using endemic native species that are able to tolerate a potentially fast-flowing environment.	Construction	All
Management of flows for aquatic habitat and movement	HF8	• Velocities of flood flows through watercourse and floodplain structures (ie bridges and culverts) would need to be assessed in areas identified as potential habitat for the Oxleyan Pygmy Perch and the Purple-spotted Gudgeon. The design of these structures would need to consider the predicted changes to watercourse and floodplain velocities from the existing case due to the project. Structure design would include reviewing flood velocities in threatened aquatic species habitat during detailed design in consultation with DPI Fishing and Aquaculture.	Pre-construction	All

Issue	Mitigation ID no.	Mitigation measure	Timing	Relevant section
Picaninny Creek diversion	HF9	• Batter stability issues would be assessed due to the nearness of the water quality basin and highway batter slopes to the creek diversion. Sufficient room would be provided on both sides of the diversion route to allow access for maintenance and to satisfy stability requirements.	Pre-construction	3
Impacts on farm dams	HF10	• Farm dams located within or partially within the project boundary would be acquired as part of the acquisition process in accordance with the *Land Acquisition (Just Terms Compensation) Act 1991*.	Pre-construction	All
	HF11	• Farm dams located outside the project boundary that would have a reduction in their catchment area due to the project would have mitigation measures applied, if possible. Potential mitigation options would include (but not be limited to) the diversion of rainfall runoff back into the farm dam through drainage routes (subject to land acquisition agreements and environmental assessment).	Pre-construction	All
Evacuation and access	HF12	• An access track would be constructed under the eastern abutment of the Coldstream River bridge at station 43.1 to assist in the movement of stock during times of flood. This access track would need to be constructed above 2.1 metres AHD and tie into the ground adjacent to the project boundary at 2.1 metres AHD.	Construction	3
	HF13	• Specific instances of flood access impacts would be assessed in consultation with individual landowners. Mitigation measures would be developed for changes in stock access routes.	Pre-construction	All
	HF14	• The level of flood immunity of Eggins Drive into Corindi would be further reviewed in consultation with Coffs Harbour City Council	Pre-construction	1
	HF15	• Appropriate flood evacuation and stock refuges for a property at approximate station 52.0 near Chaffin Creek would be further considered.	Pre-construction	3
Construction impacts on cane drains	HF16	• The potential impacts of ancillary facilities and haul roads on cane drains would be further investigated and addressed when construction compounds are confirmed. The design would need to verify that the conveyance characteristics of the cane drains are maintained by providing waterway crossings under any construction compounds and haul roads. Temporary drainage would be oversized to prevent blockages. Consultation would be undertaken with the relevant cane cooperatives drainage unions and impacted landowners to inform the development of appropriate impact mitigation measures.	Pre-construction	4, 5, 6
Goodwood Street underpass	HF17	• A drainage structure with an equivalent capacity of the current Goodwood Street underpass needs to be maintained during all flood seasons.	Construction	4

Issue	Mitigation ID no.	Mitigation measure	Timing	Relevant section
Bridge pier construction	HF18	• Any temporary infrastructure (which are not fixed) associated with the construction of bridges and bridge piers in following waterways (but not limited to) Clarence River, Clarence North Arm, Richmond River, Tuckombil Canal, would be removed from the river and floodplain during times of flood to avoid the creation of floating debris and potential blockages.	Construction	5, 8, 10
	HF19	• All works within waterways would be constructed and managed in accordance with relevant NSW Office of Water guidelines.	Construction	All
Temporary fencing	HF20	• The design of temporary fencing at culvert and bridge crossings would consider the potential for blockage and be designed and operated in a manner that does not result in impacts on flooding. This could include temporary fencing that is easily removed during flood events (where ample warning time is provided), or specifically designed fencing so the blockage of structures would not occur.	Construction	All
Climate change impacts	HF21	• The need for design modifications to address changes in flood behaviour as a result of climate change would be assessed periodically throughout the life of the project.	Pre-construction and operation	All
Impacts of ancillary facilities on flooding	HF22	• Recommendations made in Table 8-8 of Working paper – Hydrology and flooding to minimise the flood impacts of ancillary facilities would be considered in the final siting and layout of ancillary facilities.	Pre-construction	3, 4, 5, 6, 8, 10, 11
Meeting flood management objectives	HF23	• Continued application of the design objectives (road flood immunity and flood management objectives) would be required throughout the detailed design phase to provide ongoing identification and mitigation of flood impacts as a result of the project.	Pre-construction	1, 4, 5, 11
Drainage structures	HF24	• The design of drainage structures across Chatsworth Island would be further reviewed during detailed design to enable the most appropriate and cost-effective structures to be installed	Pre-construction	5
	HF25	• Regular clearing of drainage structures would be required to maintain the efficacy of structures by keeping culverts and bridges free of debris.	Operation	All
On-going consultation on drainage matters	HF26	• Continual consultation with the NSW Office of Water and relevant councils would be required during detailed design and construction regarding flooding impacts on residences and other properties.	Construction and operation	All

References

Commonwealth Scientific and Industrial Research Organisation (CSIRO) 2007, *Climate Change in the Northern Rivers Catchment*, Commonwealth Scientific and Industrial Research Organisation, Victoria, Australia.

DECCW 2009, Sea Level Rise Policy Statement, NSW Government.

Department of Environment and Climate Change (DECC) 2007, *Floodplain Risk Management Guideline: Practical Consideration of Climate Change*, NSW Government, Sydney, Australia.

Department of Environment, Climate Change and Water (DECCW) 2009, *Sea Level Rise Policy Statement*, NSW Government, Sydney, Australia.

Institution of Engineers Australia 1987, *Australian Rainfall and Runoff*, Engineers Australia, Canberra, Australia.

Sinclair Knight Merz (SKM) 2012, Working Paper – Hydrology and flooding, Sinclair Knight Merz, St Leonards, Australia.

WBM Oceanics Australia (WBM) 2004, *Lower Clarence River Flood Study Review: Final Report (Document R.B12654.001.02)*, WBM Oceanics Australia, Brisbane, Australia.

WMA Water (WMA) 2012, *Woolgoolga to Ballina Pacific Highway Upgrade – Independent review of flood modelling – Final Report*, WMA Water, Sydney, Australia.