TECHNICAL REPORT

03

Updated flooding and hydrology assessment report

NARROMINE TO NARRABRI PROJECT

ARTC Inland Rail

Narromine to Narrabri Project

Updated Flooding and Hydrology Assessment Report

Revision 9

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E-1 Executive summary

E-1.1 The proposal

Inland Rail will provide a freight rail corridor between Melbourne and Brisbane. It is a major national program that will enhance Australia's existing national rail network and serve the interstate freight market. Australian Rail Track Corporation Ltd (ARTC) ('the proponent') is seeking approval to construct and operate the Narromine to Narrabri section of Inland Rail ('the proposal').

The proposal consists of about 306 kilometres of new single-track standard gauge railway with crossing loops. Changes to some roads, public utilities and ancillary infrastructure are also included to facilitate construction and operation of the new railway.

The proposal is critical State significant infrastructure and is subject to approval by the NSW Minister for Planning and Public Spaces under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The proposal is also determined to be a controlled action under the Commonwealth *Environment Protection and Biodiversity and Conservation Act 1999* (EPBC Act), and requires approval from the Australian Minister for the Environment.

The proposed rail alignment between Narromine and Narrabri is show in in Figure E-1.

E-1.2 This report

This updated Flooding and Hydrology Assessment Report has been prepared on behalf of ARTC to support the Response to Submissions report and combined Preferred Infrastructure / Amendment Report for the proposal. Submissions received on the EIS in February 2021 have been reviewed and additional investigations and studies have been undertaken by ARTC to inform responses to the comments received and to update this report.

It includes a review of relevant legislation, consideration of the existing conditions, an impact assessment to determine the significance of hydrology, geomorphology and flooding impacts as a direct result of the construction and operation of the proposal. Recommended mitigation and management measures have been identified in response to the impact assessment findings.

E-1.3 Inland Rail – Narromine to Narrabri Reference Design

A reference design for the proposal was developed over four years, between 2018 and 2021. This included extensive consultations with local councils, authorities, landowners and other key stakeholders. Impacts from flooding were a key consideration in this process. The rail alignment crosses rivers and major watercourses on bridges or viaducts which will have a minimal impact on existing flood flows. Approximately 600 reinforced concrete box culverts are proposed at minor watercourses. Culverts have been sized to allow flood waters through the rail embankment, including consideration of potential debris blockage. Flood relief culverts have also been included within flood plains to allow flood levels to equalise on either side of the rail embankment.

The reference design formed the basis for assessment of environmental impacts, including potential impacts from flooding.

Figure E.1 **Inland Rail Narromine to Narrabri Route Alignment**

E-1.4 Consultation

ARTC has consulted extensively with key stakeholders, landowners and the community during development of the reference design.

- In 2016 landowner meetings and inspections of selected waterway crossings were undertaken following a period of heavy rain and local flooding.
- Between July 2019 and March 2020, 117 landowner meetings were undertaken along the alignment to discuss various aspects of the proposal, including historical flooding, flooding impacts on business operations and residential properties and access to farm water supply.
- In March 2020, 8 community drop-in sessions were held in Narrabri, Baradine, Curban, Gilgandra and Narromine attended by community members, council representatives and members of NSW parliament.
- Presentations were provided to the Narrabri Floodplain Risk Management Committee on 28 April 2020 and 8 June 2021. The project was also presented to the Narromine Floodplain Risk Management Committee on 3 September 2020 and 17 June 2021.
- Between July 2020 – Nov 2020 ARTC held meetings with landholders directly impacted by the final rail corridor, including those whose property or properties were predicted to have potential above floor afflux impacts.
- Draft EIS stakeholder briefings were held during August 2020. These included five briefings with the N2N Community Consultative Committees, Government agencies, local government and the general public.
- In April 2021, voluntary property acquisition discussions commenced. Flood mapping was provided to landowners.
- In August 2021, telephone meetings were held with 18 individual landowners from Narrabri, Bohena Creek, Curban and Narromine regarding afflux and duration increases at their properties. 16 of these landowners expressed no concern with this information and two landowners requested additional information and survey.
- On 25 August 2021 a meeting was held with local residents and representatives from Narrabri Shire Council to discuss historical flooding at Bohena Creek.
- Briefings with N2N Community Consultative Committees were held on 28, 29 and 30 March 2022 to provide a project update and Response to Submissions Report and Preferred Infrastructure/Amendment Report.
- Briefings with Local and Regional Emergency Management Committees along the alignment between February and June 2022. Attendees at these briefings included NSW Fire and Rescue, NSW Police, SES and NSW Ambulance
- During March 2022, ARTC attempted telephone contact with landowners with drainage control areas on their properties and followed up with maps of the relevant drainage control areas via email and post.
- During March 2022 ARTC presented the project to Narrabri Shire Council councillors and the Narrabri Chamber of Commerce.
- ARTC and DPE held 13 Hydrology Working Group meetings and a number of technical meetings between from April 2021 to July 2022 to provide clarifications on the approach, methodology and outcomes of the updated flooding and hydrology assessment.

Information collected from the above consultation activities was used to check results from the flood modelling and to update this report.

E-1.5 Flood modelling

Flood modelling used standard industry computer models to compare existing against developed conditions. Catchment hydrology and rainfall runoff modelling used RORB models and flood modelling used TUFLOW software. The flood modelling procedures, model calibration and output results were independently reviewed as part of this work.

Flood modelling results were analysed using a geographic information system (GIS) and the relevant maps illustrating the flooding impacts before and after the proposal are appended to this report.

Fourteen separate TUFLOW hydraulics models developed to cover the alignment. These were calibrated against observed stream data, including:

- Narromine (NFM) was calibrated against flood events of August 1990, August 1998, November 2000 and November 2010
- Narrabri (Narrabri) was calibrated against regional flood events of February 1995, February 1971 and July 1998, and the local catchment flood events of December 2004 and February 2012.

Reference was made to existing flood studies by Narrabri and Narromine councils and meetings were held with Councils and their consultants to discuss these. Preliminary flood mapping for the 1% AEP event was also shown to the landowners and feedback was sought on the level of accuracy of the flood maps.

E-1.6 Flooding assessment criteria – Quantitative Design Limits (QDLs)

Quantitative design limits (QDLs) have been set in consultation between ARTC and the NSW Department of Planning and Environment (DPE) as a basis for assessing potential changes from flooding. The QDLs nominate limits for acceptable differences between existing modelled flood conditions and predicted changes after development. They cover:

- Afflux: The change in water level between existing and developed conditions
- Velocity: The change in velocity, and potential for erosion and scour
- Hazard: The change in hazard, measured as the depth of flow multiplied by the velocity
- Duration: The change in flood duration

The reference design was developed to limit impacts from flooding and to minimise changes from existing conditions. Where practical, the design has complied with the QDL limits. However, over a distance of 306 kilometres, there are some areas where it has not been possible to meet the QDLs and departures have been identified within this report.

As the design progresses to the detailed design phase, the QDL departure areas would be reviewed to either eliminate or reduce the impacts. This process would involve collecting more detailed ground survey, consultation with affected landowners and design development, such as changing culvert sizes and spacings, specifying erosion mitigation works etc.

E-1.7 Drainage Control Areas

As part of this flooding and hydrology assessment update, drainage control areas have been included at approximately 200 drainage structures to provide additional space in which to manage QDLs during detailed design and construction. The drainage control areas extend 50 metres downstream of the rail corridor and 15 metres upstream and have been located where there is potential for design flow velocities to exceed the QDL limits beyond the rail corridor boundary in the 1% AEP (1 in 100 year) flood event. The type of erosion mitigation measures, such as adjustments to culvert spacings, rock rip rap or vegetation management and the extents of the drainage control areas would be confirmed during detailed design. This would also take into account local soil conditions and site-specific assessments of the erosive threshold velocity and erosion risk. Following these assessments, the size of the drainage control areas could be refined.

E-1.8 Flooding impacts – Afflux

Potential changes to existing flood regimes after development of the proposal were assessed against the QDLs for events up to and including the 1% Average Exceedance Probability (AEP) (commonly known as the 1 in 100 year flood).

In general the reference design largely complies with the afflux QDLs, apart from the departures noted below.

E-1.8.1 Afflux – Impacts on habitable buildings

The towns of Narromine and Narrabri are at risk of flooding in the 1% AEP event under existing conditions. Several properties elsewhere along the route could also be flooded above floor level under existing conditions. In total, 2570 habitable buildings were identified as being at risk of flooding above floor level in the 1% AEP event under existing conditions.

Following construction of Inland Rail, there would be afflux QDL exceedances at 23 of these 2570 habitable buildings in floods up to and including the 1%AEP event, where flood levels would increase by more than 10 mm. Of these, there are 21 habitable buildings with QDL exceedances in the 1% AEP event and two habitable buildings with QDL exceedances in flood events less than the 1%AEP event. The total number of afflux QDL departures is therefore 23 habitable buildings. A summary of the number of afflux QDL departures for habitable buildings is provided in Table E-1 and Figure E-2.

E-1.8.2 Afflux – Impacts on Non-Habitable Buildings

In total, 3628 non-habitable buildings were identified as being at risk of flooding in the 1% AEP event under existing conditions.

Following construction of Inland Rail, there would be afflux QDL exceedances at 28 of these 3628 non-habitable buildings up to and including the 1%AEP event, where flood levels would increase by more than 20mm. Of these, there are 23 non-habitable buildings with afflux increases of more than 20 millimetres in the 1% AEP event and five non-habitable buildings with afflux increases of more than 20 millimetres in flood events less than the 1% AEP. A summary of the number of afflux QDL departures for non-habitable buildings is provided in Table E-1 and Figure E-2.

Table E-1 Afflux – Summary of QDL compliance for habitable buildings

Parameter	Land use or setting / scenario	QDL Afflux limit	Number of buildings		
			Buildings Flooded above floor level (1%AEP existing conditions)	Buildings complying with QDL (1%AEP with proposal)	Buildings with departures from QDLs (All events up to 1%AEP)
Afflux	Habitable buildings	10mm	2570	2547	23*
	Non-habitable buildings	20mm	3628	3602	28 *

*(*Note: Some buildings have afflux greater than10mm / 20mm in the 2% and 5%AEP events, but not the 1%AEP event. Numbers in the above table in the right hand column are totals for buildings affected in all flood events considered up to, and including the 1%AEP)*

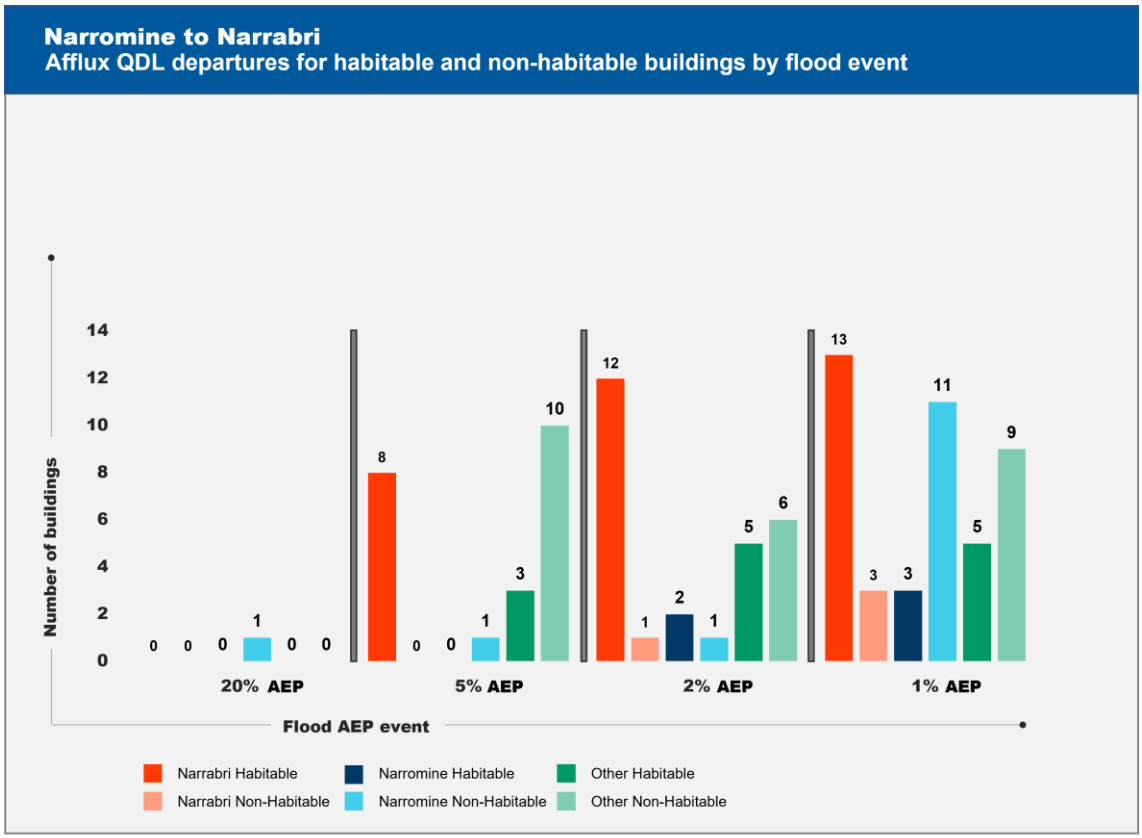


Figure E-2 Afflux – Summary of QDL compliance for buildings (all flood events)

E-1.8.3 Afflux – Impacts on other areas and roads

The effects of increased flood depths on urban and infrastructure land, agricultural land and other non-urban land, including forestry are summarised in Table E-2 for the 1% AEP event. Detailed mapping of the impacts is contained in Appendix I.

Table E-2 Summary of Afflux QDL departures for other land uses and roads (1%AEP event (with culvert blockage applied))

QDL Parameter	Land use or setting / scenario	Flood extents – existing conditions[1]	QDL Criteria	Area / length departing from QDLs
Afflux	Urban and infrastructure land	1946 ha	100 mm	1.61 ha
	Agricultural land	61,668 ha	200 mm	120.6 ha
	Forest and unimproved grazing land	64,457 ha	300 mm	367.2 ha
	Classified roads managed by TfNSW	48.6 km	50 mm	2.1 km
	Highways and sealed roads >80 km/hr	90.3 km	50 mm	6.0 km
	Unsealed roads and sealed roads < 80 km/hr	1250.0 km	100 mm	26.2 km

Note: 1. Flood extents are within limits of TUFLOW models and do not include areas / lengths outside of model boundaries.

E-1.8.4 Afflux – Impacts at Narrabri

Feedback on the EIS is that there is general concern about the potential impacts from construction of a rail viaduct structure downstream of the town of Narrabri.

Predicted above floor flooding depths at habitable properties in Narrabri that have an afflux greater than 10 millimetres in the 1% AEP events are shown in Figure E-3. These properties are located along Wee-Waa Road and are currently at risk of flooding in events less than the 1% AEP.

The detailed design will investigate mitigation measures to reduce or eliminate afflux at these properties.

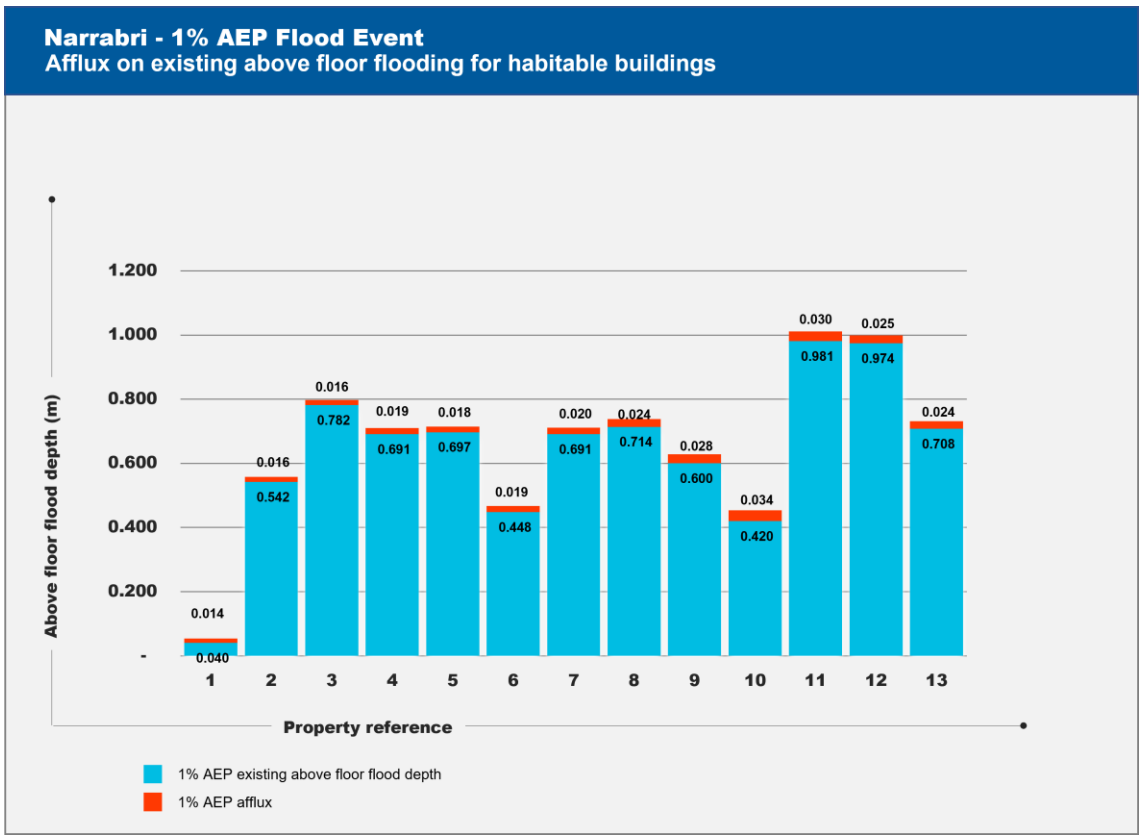


Figure E-3 Narrabri QDL departures afflux >10 millimetres above habitable floors

Comments received on the EIS also related to the potential for flood debris to collect on the piers of the proposed new rail viaduct and for this to increase the risk of properties being flooded. The Narrabri TUFLOW flood model was used to model debris blockage at the viaduct piers, equivalent to a five per cent reduction in flow area. Results indicated that this would have an impact of around 2 millimetres in the 1% AEP flood event and would not affect the results of the QDL assessment.

The recent flood event of December 2021 provides an indication of the potential impacts from bridges in Narrabri. There are two existing bridge structures that cross the Namoi River and Narrabri Creek, for the existing railway and the Newell Highway respectively. Photographs taken during the November 2021 flood event indicate that floodwaters were not impeded by debris collecting on the bridge piers, as can be seen in Figure E-4.

Figure E-4 Narrabri flooding under existing rail bridge, 30 November 2021

E-1.8.5 Change in number of habitable buildings at risk of above floor flooding in Narrabri

The Narrabri TUFLOW flood model was used to compare the number of buildings at risk of flooding under existing conditions and after construction of the proposal. This model includes the proposed Narrabri viaduct that would have spans of between 25 metres and 33 metres between piers. The underside of the viaduct would be above the 1% AEP flood level, allowing flood waters to pass under the structure.

Figure E-5 shows a frequency distribution for depth of above floor flooding for habitable buildings in Narrabri for the 5% AEP, 2% AEP and 1% AEP events. Figure E-6 shows the same information for a cumulative count of habitable buildings flooded above floor level. This analysis illustrates that for all flood events up to the 1% AEP the impacts on the existing flood risk in Narrabri from construction of the proposed rail viaduct are expected to be minimal.

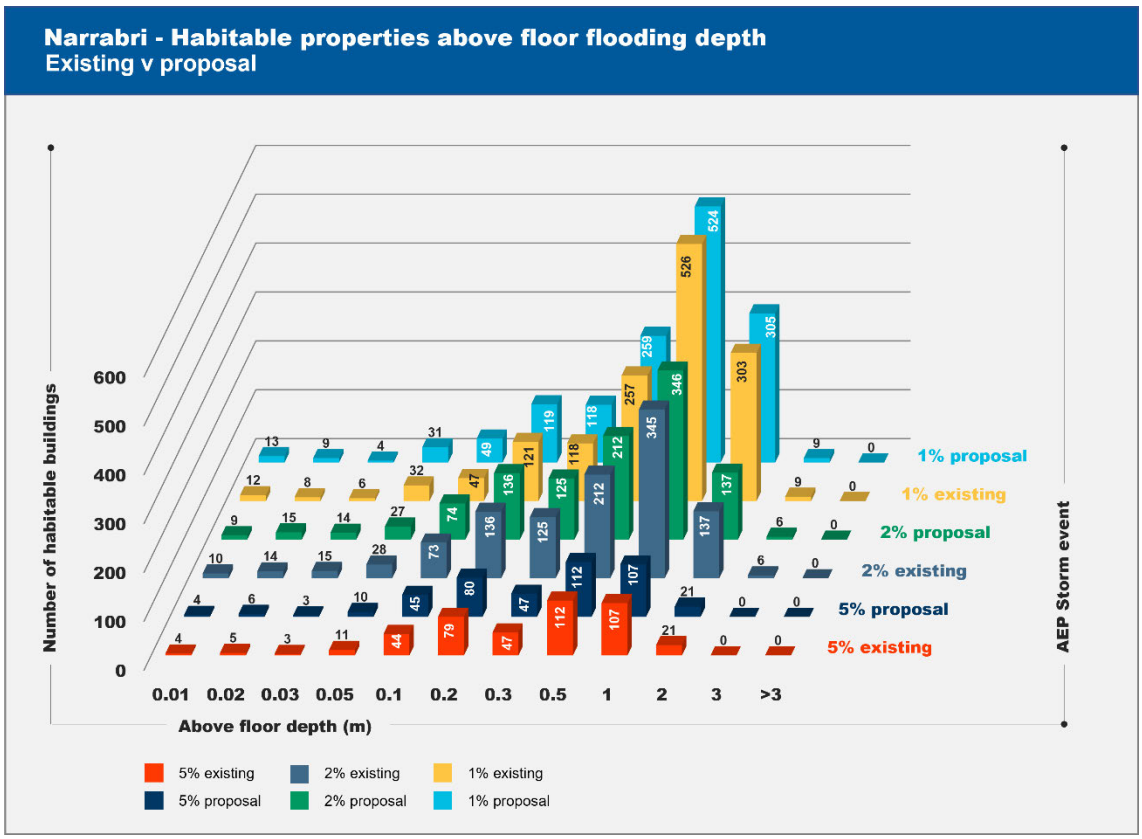


Figure E-5 Narrabri habitable properties above floor flooding depth existing v proposal

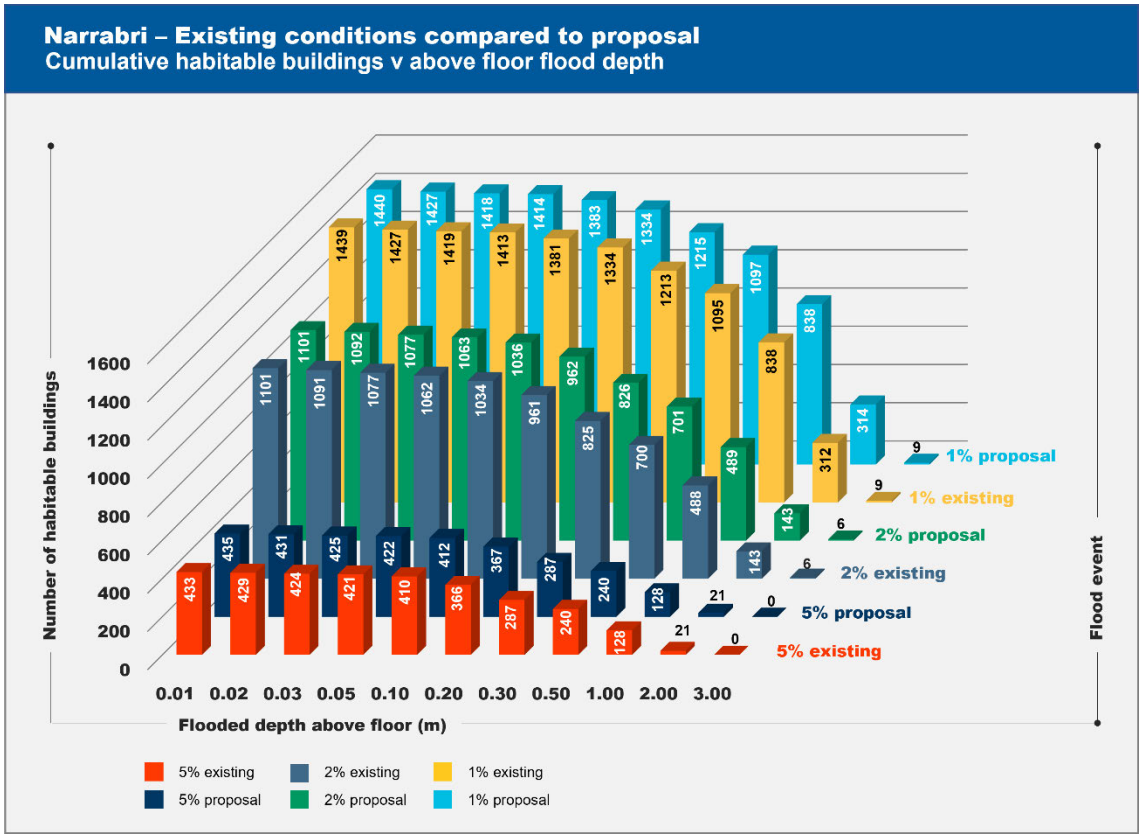


Figure E-6 Cumulative number of habitable buildings v above floor flood depth

E-1.9 Flooding impacts – scour / erosion (flow velocity)

Changes in flood flow velocities could occur at bridges and culverts under the proposed rail embankment. Bridges generally span over rivers and defined watercourses and impacts would be generally limited to local effects around bridge piers and abutments. These would be reviewed as part of the detailed design and, where required, erosion protection provided within the rail corridor.

Changes in flood flow velocities would more likely occur at culvert structures through flood waters being concentrated upstream and downstream of the structures. These changes could result in erosion and scour. At the reference design stage of the project, it has not been practical to undertake detailed site assessments of all 600 culvert locations to assess the erosive threshold velocity (ETV) on the basis of the local conditions. A conservative value for the ETV of 0.5m/s has therefore been used for the impact assessment presented in this report. This is equivalent to the velocity at which sandy loams and fine gravels would be mobilised in a bare soil environment.

As part of the additional investigations completed for this report, an experienced geotechnical engineer and a geomorphologist inspected a range of proposed bridge and culvert locations along the alignment. On-site observations and soil testing found that many creek banks and floodplains have a high clay content. These were assessed to have an ETV generally between 1 m/s and 2 m/s. It was also noted that the channel geomorphology and vegetation cover have a significant influence on potential erosion.

At the detailed design stage, further site investigations will be carried out to assess ETVs at bridges and culverts together with the geomorphic potential for erosion. These results would be used to re-evaluate the detailed design against the scour/erosion QDLs. To demonstrate that this is feasible, separate TUFLOW models were developed to provide fine grid modelling of velocities at 24 culvert locations and the results were compared to the QDLs using the site assessed ETVs. These results showed that 23 of the 24 culverts analysed comply with the scour/erosion QDLs when site assessed ETVs are used. Similar results would be also expected for other culvert locations along the alignment in the detailed design phase.

E-1.10 Flooding impacts – flood hazard

Flood hazard is calculated as the product of depth (d) and velocity (v). Hazard categories are defined in Australian Rainfall and Runoff (2019), as shown in Figure E-7.

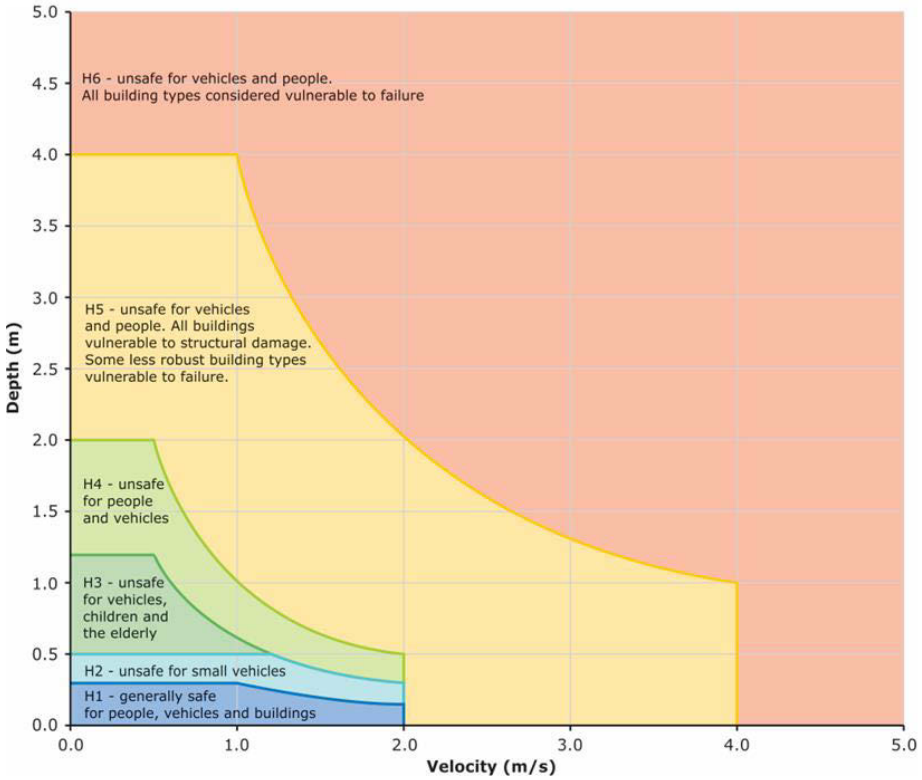


Figure E-7 Flood Hazard Categories (Australian Rainfall and Runoff, 2019)

The hazard QDL criteria for residential buildings, urban infrastructure, sealed road and highways permits a 10 per cent increase in d.v product where the value exceeds 0.10 m^2/s. Elsewhere a 20 per cent increase in the d.v product is permitted.

A summary of departures from the QDL hazard criteria is provided in Table E-3. It should be noted that 2570 habitable buildings and 3627 non-habitable buildings comply with the QDL.

Table E-3 Summary of Hazard QDL departures (1% AEP with culvert blockage included)

Parameter	Land use or setting / scenario	QDL Criteria	Departures from QDLs
Flood hazard	Habitable buildings	10% increase on existing	Nil
	Non-habitable buildings	10% increase on existing	4
	Urban and infrastructure land	10% increase on existing	4.17 hectares
	Sealed roads (>80 km//h, excluding TfNSW roads)	10% increase on existing	4.0 kilometres
	Classified roads managed by TfNSW	10% increase on existing	1.4 kilometres
	Elsewhere (other land)	20% increase on existing	714 hectares
	Unsealed roads	20% increase on existing	18.0 kilometres

E-1.11 Flooding impacts – flood duration

The key flood duration QDLs criteria are:

- A five per cent increase in flood duration at habitable buildings with existing above floor flooding
- A 10 per cent increase if flood levels for habitable buildings with below floor flooding and other locations.

Analysis of the flood modelling results indicates that 11 habitable buildings with above floor flooding and 1 habitable building with below floor flooding exceed the duration QDLs. There is also one property with an existing 1% AEP flood duration of less than an hour that increases to over an hour with the proposal, but the increase is less than five per cent. This also does not comply with the QDLs.

Impacts on the 11 buildings with above floor flooding and a duration increase of more than five per cent are shown in Figure E-8.

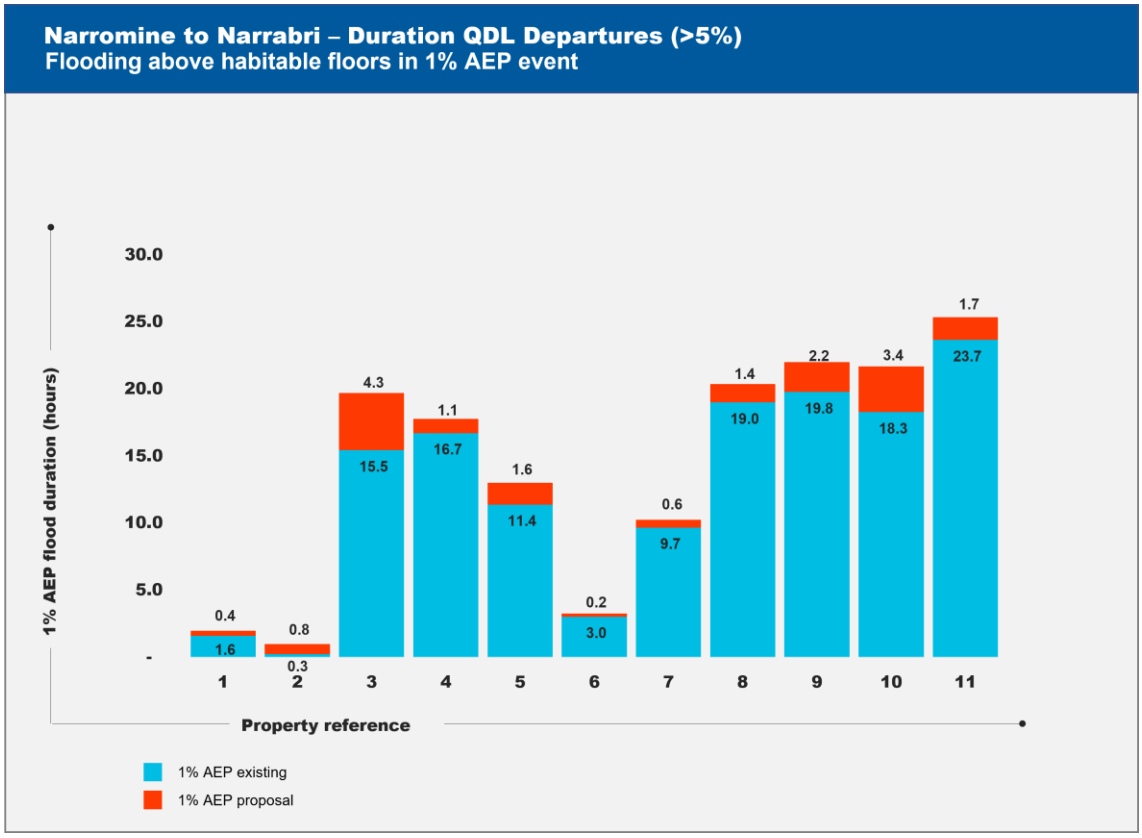


Figure E-8 Duration QDL departures for 11 properties with above floor flooding

Minor flood duration QDL departures were also identified on roads and other areas, such as cropping grazing or forestry. These are mapped in the figures in Appendix I and summarised in Table E-4.

Table E-4 Flood duration QDL departures (1% AEP with blockage applied at culverts)

Parameter	Land use or setting / scenario	Criteria	Departs from QDLs
Flood duration	Habitable floors	< 5% (refer to section 3.2.2 for details)	13
	Classified roads managed by TfNSW	No new flooding, otherwise 10% increase in inundation duration	0.5 kilometres
	Highways and sealed roads >80 km/hr	Varies, 10% increase on existing	2.0 kilometres
	Sealed roads < 80 km/hr and all unsealed public roads	Varies, 10% increase on existing	19.3 kilometres
	Elsewhere	Varies, 10% increase on existing	1036 hectares

E-1.12 Rare flood events greater than the 1% AEP

In addition to considering flood impacts against the QDLs for floods up to and including the 1% AEP, flood risks in rarer events were considered, particularly relating to impacts on the towns of Narrabri and Narromine. Locations where rare flood events could overtop the proposed railway were also reviewed with respect to potential failure of the rail embankment resulting in loss of life through increased flooding downstream.

E-1.12.6 Narrabri – Rare flood events

For Narrabri, Figure E-9 shows the number of buildings at risk of flooding in the 0.2% AEP (1 in 500 year) and the probable maximum flood (PMF). The horizontal axis shows the depth of above floor flooding and the vertical axis shows the number of habitable buildings that are at risk of flooding above this depth.

Under existing conditions there would be approximately 2470 buildings at risk of flooding above floor level in the 0.2% AEP event and around 3036 buildings at risk in the PMF event. The TUFLOW flood modelling results indicate that these numbers are not expected to change significantly with the proposal.

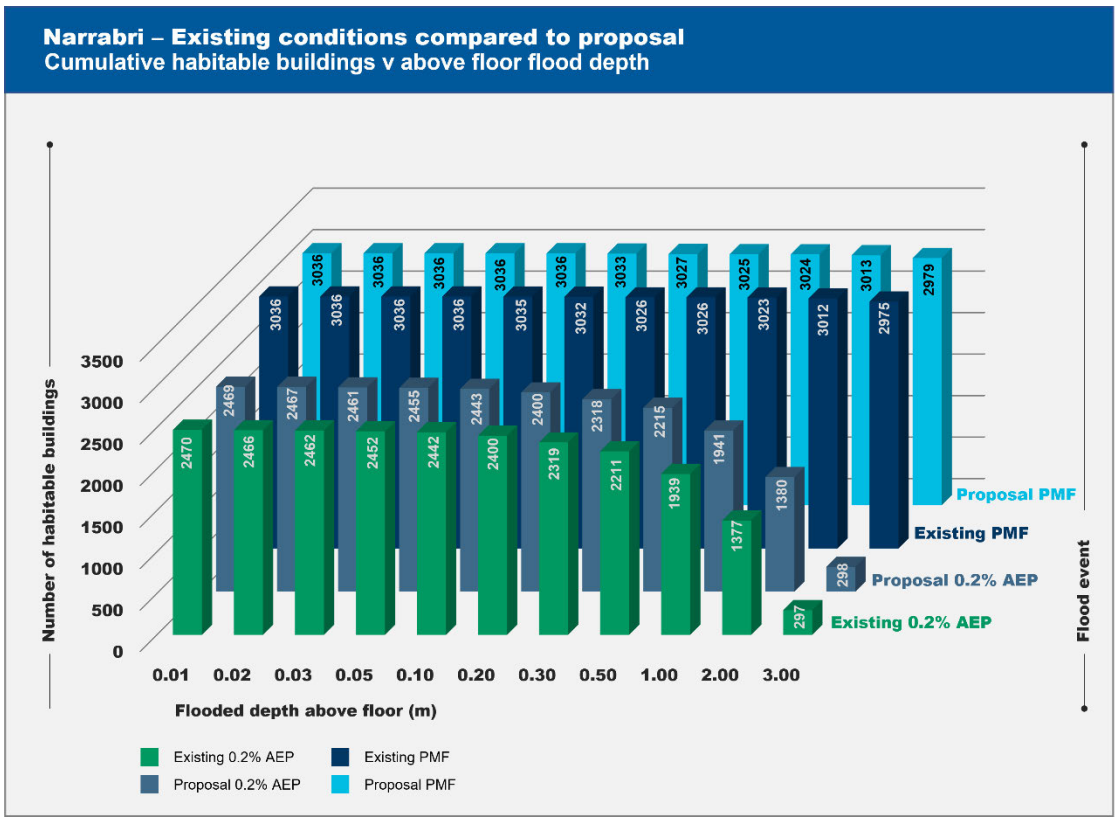


Figure E-9 Narrabri – Cumulative number of habitable buildings flooded, by flood depth in extreme floods

E-1.12.7 Narromine – Rare flood events

At Narromine, the proposed railway alignment is upstream of the town and is located along the southern and eastern sides of the Backwater Cowal floodplain. An analysis of impacts on above floor flooding for residential and commercial buildings in the 0.2% AEP event and PMF event indicated no significant changes to flood risk for buildings would be expected at Narromine in extreme events. There are currently around 1632 buildings at risk of above floor flooding in the 0.2% AEP event and 1949 buildings in the PMF event. This situation would not change after construction of the proposal.

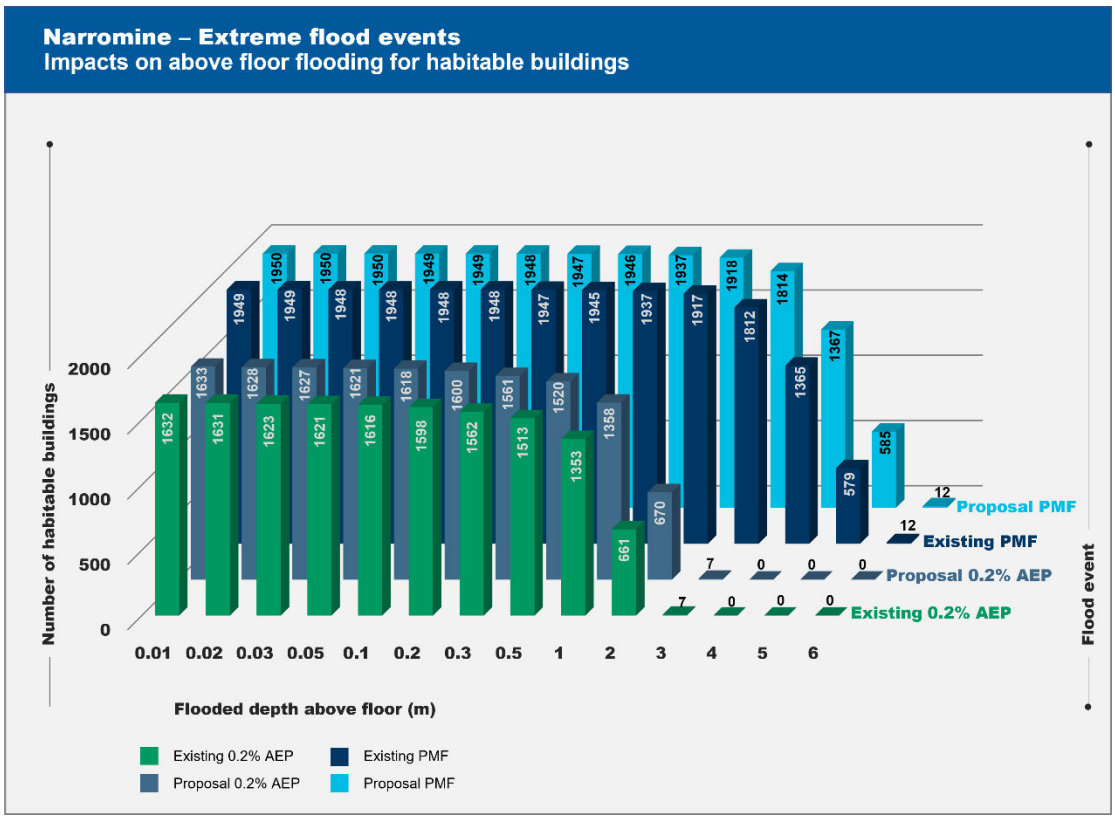


Figure E-10 Narromine – Cumulative number of habitable buildings flooded, by flood depth in extreme floods

E-1.13 Rail Embankment Overtopping

The railway embankment will be designed to be above the 1% AEP flood level. For floods higher than this, water could flow through the ballast and ultimately over the top of the rails. Bridges and culverts are provided at river and creek crossing and flood relief culverts are provided in flood plains. Should overtopping of the rail embankment occur, it is expected that water levels would rise on both sides of the embankment and submerge the track.

Checks on potential overtopping locations were carried out for the 1% AEP, 1% AEP + blockage, 0.2% AEP and 0.05% AEP events.

Locations were identified where there could be potential for the railway embankment to overtop, particularly at road level crossings and when 100 per cent blockage factors have been applied to culverts in the reference design. These will be further investigated as part of the detailed design to remove the overtopping risk in the 1% AEP event, including with blockage factors applied to culverts, as per Australian Rainfall and Runoff, 2019.

Checks on overtopping in the 0.2% AEP and 0.05% AEP events identified additional overtopping locations. No significant risks to life or property were identified resulting from overtopping at these locations.

The railway embankment failure mechanism in an overtopping event is dependent on local conditions, including the embankment height, batter slopes, vegetation / slope protection, upstream and downstream water levels and flood flow paths. The risk of failure of the railway embankment due to overtopping in floods greater than the 1% AEP event will be reviewed as part of the detailed design.

E-1.14 Geomorphology

An assessment of fluvial geomorphology and response to flooding was carried out for watercourses which could be impacted by the proposal. This considered channel and floodplain morphology, variability of stream power and stabilising / destabilising factors such as the presence of channel and riparian vegetation, artificial alteration and existing structures. These factors were used to establish the likely sensitivity of the assessed watercourses to change. The geomorphological assessment found that although the proposal has the potential to impact watercourses, impacts are considered to be minor. The reference design has considered preservation of site-specific natural watercourse flow and sediment transport characteristics. This work would be refined further during detailed design.

A detailed assessment of Erosion Potential and Fluvial Geomorphology has been carried out and is included as Appendix O. This report provides site-specific field-based assessments of a range of different watercourses to establish the fluvial geomorphology and soil erosion potential. It also notes that other variables, in addition to velocity, should be considered in the assessment such as watercourse geomorphology, vegetation cover, geotechnical soil characteristics and flow / sediment variability.

E-1.15 Recommended mitigation measures

Changes to the existing flood regime resulting from the proposal have been evaluated against the QDLs for afflux, scour/erosion, hazard and duration. The assessments presented in this report have found substantial compliance with the respective criteria. At the reference design stage however, some QDL departures have been identified and reported. These will be further reviewed in detailed design and measures take to avoid, minimise or manage flooding impacts, including:

- The proposal would continue to be refined during detailed design to mitigate impacts on existing flooding conditions up to and including the 1% AEP event. Designs for bridge and culvert structures, including Narrabri Viaduct, would continue to be developed to comply with the QDLs, so far as is reasonably practicable.
- Watercourse and floodplain geomorphology would be considered, particularly where watercourses have been identified as sensitive to change, where existing erosion has been observed and where QDL exceedances have been identified.
- Further flood modelling would be undertaken during detailed design to confirm compliance with QDLs.
- Construction planning and the layout of construction work sites and compounds would be carried out with consideration of overland flow paths and flood risk, avoiding flood liable land and flood events where practicable.
- A flood and emergency response plan would be prepared and implemented as part of the CEMP. The plan would include measures, process and responsibilities to minimise the potential impacts of construction activities on flood behaviour as far as practicable. It would also include measures to manage flood risks during construction and address flood recovery during construction.
- A geomorphological monitoring program would be implemented in accordance with the soil and water management plan as part of the Construction Environmental Management Plan.

At locations where it is not practicable to meet the QDLs, ARTC will manage these departures in accordance with the conditions of approval.

Glossary and abbreviations

Acronym/term	Definition
Annual exceedance probability (AEP)	The chance of a flood of a nominated size occurring in a particular year. The chance of the flood occurring is expressed as a percentage and, for large floods, is the reciprocal of the ARI. For example, the 1% AEP flood event is equivalent to the 100 year ARI flood event.
AETV	Assessed erosive threshold velocity
AHD	Australian Height Datum
ARR	Australian Rainfall and Runoff
ARTC	Australian Rail Track Corporation
ASS	Acid Sulfate Soils
ASRIS	Australian Soil Resource Information System
BCD	Biodiversity Conservation Division
BoM	Bureau of Meteorology
CC	Climate change
CEMP	Construction environmental management plan
DECC	Department of Environment and Climate Change (former)
DECCW	Department of Environment Climate Change and Water (former)
DEM	Digital Elevation Model
DIPNR	Department of Infrastructure, Planning and Natural Resources (former)
DPE	Department of Planning and Environment (formerly DPIE)
DPI	Department of Primary Industries (former)
DPIE	Department of Planning, Industry and Environment (former, now DPE)
DTM	Digital terrain model
EIS	Environmental Impact Statement
ELVIS	Elevation Information System – Elevation and Depth – Foundation Spatial Data available from http://elevation.fsdf.org.au/
EP&A Act	*Environmental Planning and Assessment Act 1979*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ETD	ARTC's technical note which provides the design requirements for greenfield and brownfield rail developments.
ETV	Erosion threshold velocity
FFA	Flood frequency analysis
FLIKE	A computer program used for flood frequency analysis
FM	Flexible mesh
FPL	Flood Planning Level
GIS	Geographical Information System
HPC	Heavily Parallelised Compute used by TUFLOW
JacobsGHD	JacobsGHD IR Joint Venture

Acronym/term	Definition
LEP	Local environmental plan
LGA	Local government area
LWD	Large Woody Debris
MIKE	A range of software products released by Danish Hydraulic Institute to analyse, model and simulate movement of water. MIKE11 is a one dimensional hydrodynamic computer model and MIKE FLOOD includes a wide selection of specialised one dimensional and two dimensional flood simulation engines to model flood behaviour in channels, floodplains and coastal areas.
NFM	Narromine flood model
NSW	New South Wales
OEH	Office of Environment and Heritage (former)
The proposal	Defined as the construction and operation of the Narromine to Narrabri section of Inland Rail.
the proposal site	Defined as the area that would be directly affected by construction of the proposal (also known as the construction footprint). It includes the location of proposal infrastructure, the area that would be directly disturbed by the movement of construction plant and machinery, and the location of the compounds and laydown areas that would be used during construction.
PMF	Probable maximum flood is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood producing catchment conditions.
QDL	Quantitative design limit
Rail corridor	The corridor within which the rail tracks and associated infrastructure would be located.
RAFTS	RAFTS (xpratfs) is a runoff routing model that is used for hydrologic and hydraulic analysis of storm water drainage and conveyance systems.
RCP	Representative concentration pathways
RFFE	A computer based Regional Flood Frequency Estimation model developed at the Western Sydney University for Australian Rainfall and Runoff project.
RORB	RORB is a rainfall runoff and streamflow routing computer program that calculates catchment losses and streamflow hydrographs resulting from rainfall events.
SEARs	Secretary's Environmental Assessment Requirements
SES	State Emergency Service
SRTM	Shuttle Radar Topography Mission
TUFLOW	TUFLOW is a computer program which is used to simulate free-surface flow for flood and tidal wave propagation. It provides coupled one dimensional and two dimensional hydraulic solutions using a powerful and robust computation.

1 Introduction

1.1 Background

1.1.1 Inland Rail and the proposal

The Australian Government has committed to delivering a significant piece of national transport infrastructure by constructing a high performance and direct interstate freight rail corridor between Melbourne and Brisbane, via central-west New South Wales (NSW) and Toowoomba in Queensland. Inland Rail is a major national program that will enhance Australia's existing national rail network and serve the interstate freight market.

The Inland Rail route, which is about 1,700 kilometres long, involves:

- Using the existing interstate rail line through Victoria and southern NSW
- Upgrading about 400 kilometres of existing track, mainly in western NSW
- Providing about 600 kilometres of new track in NSW and south-east Queensland.

The Inland Rail program has been divided into 13 sections, seven of which are located in NSW. Each of these projects can be delivered and operated independently with tie-in points on the existing railway.

Australian Rail Track Corporation Ltd (ARTC) ('the proponent') is seeking approval to construct and operate the Narromine to Narrabri section of Inland Rail ('the proposal').

The proposal consists of about 306 kilometres of new single-track standard gauge railway with crossing loops. The proposal also includes changes to some roads to facilitate construction and operation of the new section of railway, and ancillary infrastructure to support the proposal.

The proposal would be constructed to accommodate double-stacked freight trains up to 1,800 metres long and 6.5 metres high. It would include infrastructure to accommodate possible future augmentation and upgrades of the track, including a possible future requirement for 3,600 metre long trains.

The land requirements for the proposal would include a new rail corridor with a minimum width of 40 m, with some variation to accommodate particular infrastructure and to cater for local topography. The corridor would be of sufficient width to accommodate the infrastructure currently proposed for construction, as well as possible future expansion of crossing loops for 3,600 metre long trains. Clearing of the proposal site would occur to allow for construction and to maintain the safe operation of the railway.

1.1.2 Approval and assessment requirements

The proposal is critical State significant infrastructure and is subject to approval by the NSW Minister for Planning and Public Spaces under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The proposal is also determined to be a controlled action under the Commonwealth *Environment Protection and Biodiversity and Conservation Act 1999* (EPBC Act) and requires approval from the Australian Minister for the Environment.

An Environmental Impact Statement (EIS) was prepared to support ARTC's application for approval of the proposal in accordance with the requirements of Division 5.2 of the EP&A Act. The EIS addressed the environmental assessment requirements of the Secretary of the (then) Department of Planning, Industry and Environment (DPIE) (now the Department of Planning and Environment (DPE)) ('the SEARs'), dated 9 September 2020.

The EIS was placed on public exhibition by DPIE for a period of 62 days, commencing on 8 December 2020, and concluding on 7 February 2021.

The EIS was also prepared to support ARTC's application for approval of the proposal under the EPBC Act.

The EIS was supported by a range of technical reports, which provide detailed assessments of the potential impacts of the proposal as they relate to the key environmental issues defined by the SEARs. This included Technical Report 3 – Flooding and Hydrology Assessment.

1.1.3 Responding to submissions and proposed amendments

During the exhibition period, interested stakeholders and members of the community were able to review the EIS online or at display locations, participate in consultation and engagement activities, and make a written submission to the DPIE for consideration in its assessment of the proposal.

ARTC has prepared a Response to Submissions report to respond to submissions received during the exhibition period.

During and following public exhibition of the EIS, ARTC has undertaken further investigations and is proposing a number of design amendments to the proposal. The aim of these amendments is to address issues raised during consultation and in submissions, and to further minimise the potential impacts of the proposal so far as is practicable.

A summary of the proposed amendments is provided in Table 1.1. Further information is provided in the combined Preferred Infrastructure / Amendment Report.

Table 1.1 Summary of amendments

Proposal feature	Proposed amendment
Crossing loops	Relocation of the seven crossing loops to new locations to minimise overall impacts.
Public level crossings	Changes to public level crossing numbers, locations and treatments due to changes to crossing loop locations, updated traffic data and refinement of sight distances.
Public road closures	Reduction in the number of public road and access tracks that would need to be closed, mainly as a result of the crossing loop relocations.
Public road realignments	Changes to the public roads requiring realignment to minimise property impacts.
Temporary workforce accommodation	Changes to the locations of the Narromine North and Baradine temporary workforce accommodation facilities based on consultation with key stakeholders. Mobile accommodation facilities are now proposed be provided within some of the general compounds for improved flexibility on the workforce approach.
Construction and operation footprints	Adjustments to the construction and operational footprints to accommodate the above amendments and to minimise the amount of disturbance where possible. In addition, drainage control areas have been added at a number of culverts to provide sufficient space outside the rail corridor to manage flow velocities.

1.1.4 Additional investigations and studies

Between exhibition of the Inland Rail, Narromine to Narrabri EIS from December 2020 to February 2021 and this Updated Flooding and Hydrology Assessment Report, ARTC has undertaken additional investigations and studies to support responses to EIS submissions and to improve the assessment and reporting of flooding impacts. Monthly Hydrology Working Group (HWG) meetings have been held with the NSW DPE. These meetings were attended by DPE's independent hydrologist and representatives from DPE and ARTC and have provided direction for the following scope:

- Consideration of impacts resulting from potential blockage of culverts in accordance with *Australian Rainfall and Runoff* (Ball et al., 2019).
- Development of Quantitative Design Limits (QDLs) to provide a basis for assessment of changes and in afflux, velocity, hazard and duration between existing and operational conditions.
- Extensive analysis of flow velocity changes upstream and downstream of culverts and bridges to estimate the risk of erosion and scour during flood events.
- Inclusion of drainage control areas (DCAs) at approximately one third of the culvert locations to provide an additional 50 metres downstream and 15 metres upstream of the rail corridor in which to mitigate changes in flow velocities.
- Site investigations by a geotechnical engineer and geomorphologist to visit selected culvert locations, sample soils, review the geomorphological form of the channel and to estimate the potential for erosion. These findings were also compared to locations near the alignment where existing soil erosion was observed.
- Selected TUFLOW flood models were developed to include “fine grid” modelling at culvert locations with the high flow velocities. These examples demonstrated that the 10 metre calculation grid used in the EIS reference design can be refined to a 2.5 metre grid in the detailed design to provide four times the level of detail for velocity modelling at critical locations, where required.
- Further analysis of extreme flood events was undertaken to review locations where the rail embankment could be overtopped by floodwaters, leading to potential washout of the embankment.
- At Narrabri, impacts from local flooding of Mulgate Creek and associated catchments have been reported separately from regional flooding of the Namoi River and Narrabri Creek.
- Additional sensitivity analysis was carried out on the Narrabri Viaduct to assess changes to flood impacts if the structure were to be extended to the north.
- Flood impacts at Narrabri were also updated to consider the risk of increased afflux if flood debris became lodged on the viaduct piers.
- Further reviews were undertaken against the Floodplain Management Plan for the Macquarie Valley Floodplain (2021) and the Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020.
- Further information was provided to clarify the basis for the selection of a 1% AEP formation flood planning level (FPL) as nominated by ARTC for the proposal.
- More detailed flood mapping for impacts assessed against the QDLs.
- Telephone meetings (noting COVID travel restrictions) with 18 individual landowners in Narrabri, Bohena Creek, Curban and Narromine regarding afflux and duration increases at their properties.

- Telephone meetings with landowners and Narrabri Council to discuss flood modelling at Bohena Creek. Presentation of an alternative flood analysis for Bohena Creek based on this feedback and historical records from the Bohena Creek flow gauging station.

In addition to the above, general flood model updates were completed for the following:

- Amendments and other proposed design refinements noted in Table 1.1.
- Addition and modification of culverts to the south east of Narromine to reduce flooding impacts and afflux.
- Refinements to flood models to address minor issues identified in the independent review undertaken by BMT.

This report provides an update to the EIS Technical Report 3 – Flooding and Hydrology Assessment to reflect the above.

1.2 The proposal

1.2.1 Location

The proposal would be located between the towns of Narromine and Narrabri in NSW. The proposal would link the Parkes to Narromine section of Inland Rail located in central west NSW, with the Narrabri to North Star section of Inland Rail located in north west NSW.

The location of the proposal is shown in Figure 1.1.

1.2.2 Key features

The key design features of the proposal (as amended) include:

Rail infrastructure

- A new 306 kilometre long rail corridor between Narromine and Narrabri
- A single-track standard gauge railway and track formation within the new rail corridor
- Seven crossing loops, at Burroway, Balladoran, Armatree/Tonderburine, Mt Tenandra, Baradine, The Pilliga and Bohena Creek
- Bridges over rivers and other watercourses (including the Macquarie River, Castlereagh River and the Namoi River/Narrabri Creek system), floodplains and roads
- Level crossings
- New rail connections and possible future connections with existing ARTC and Country Regional Network rail lines, including a new 1.2 kilometre long rail junction between the Parkes to Narromine section of Inland Rail and the existing Narromine to Cobar Line (the Narromine West connection).

Road infrastructure

- Road realignments at various locations, including realignment of the Pilliga Forest Way for a distance of 6.7 kilometres
- Limited road closures.

The key features of the proposal are shown in Figure 1.2.

Ancillary infrastructure to support the proposal would include signalling and communications, drainage, drainage control areas, signage and fencing, and services and utilities.

Further information on the proposal is provided in the combined Preferred Infrastructure / Amendment Report.

Figure 1.1 **Location of the proposal**

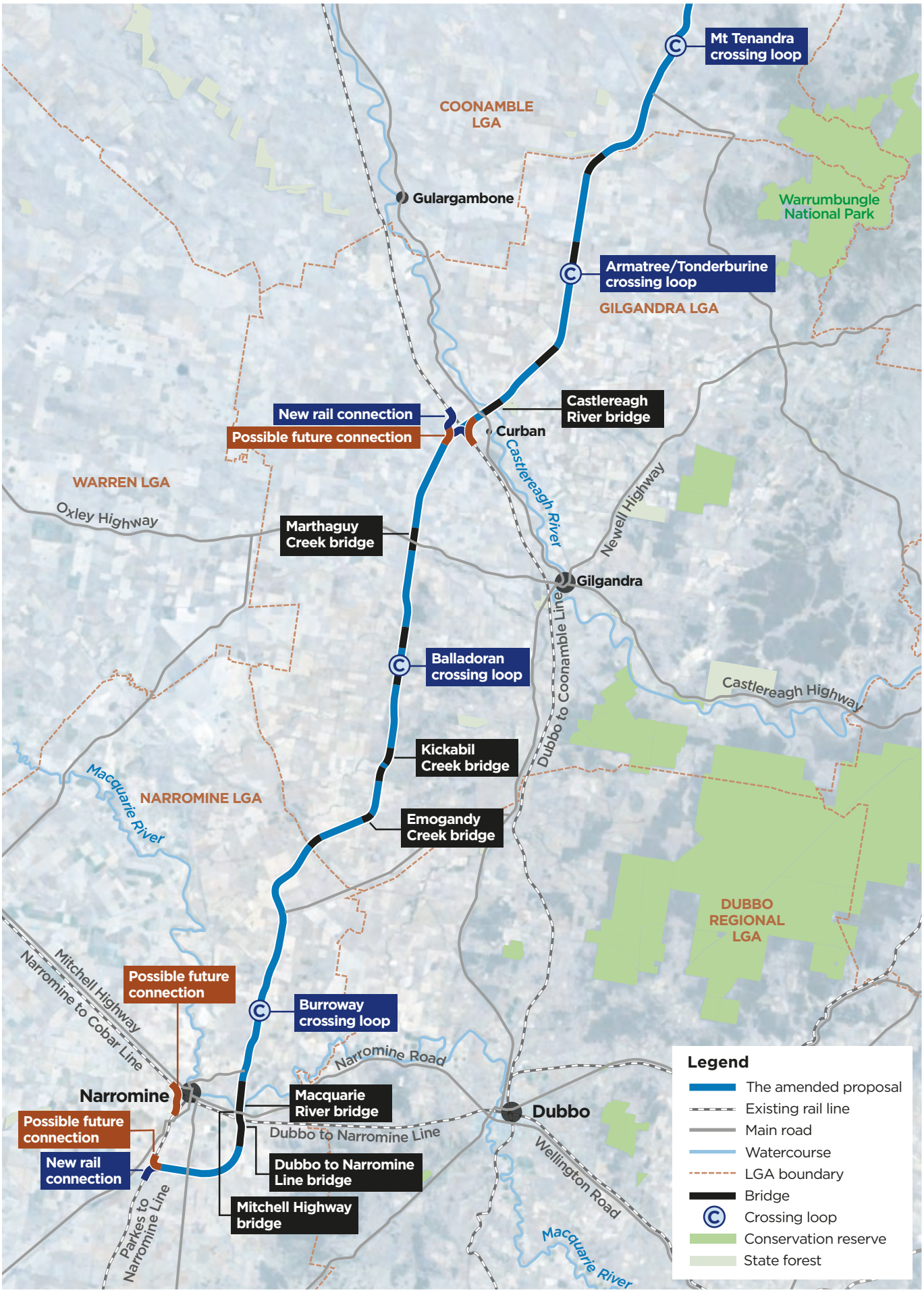


Figure 1.2 **Key features of the proposal (map 1)**

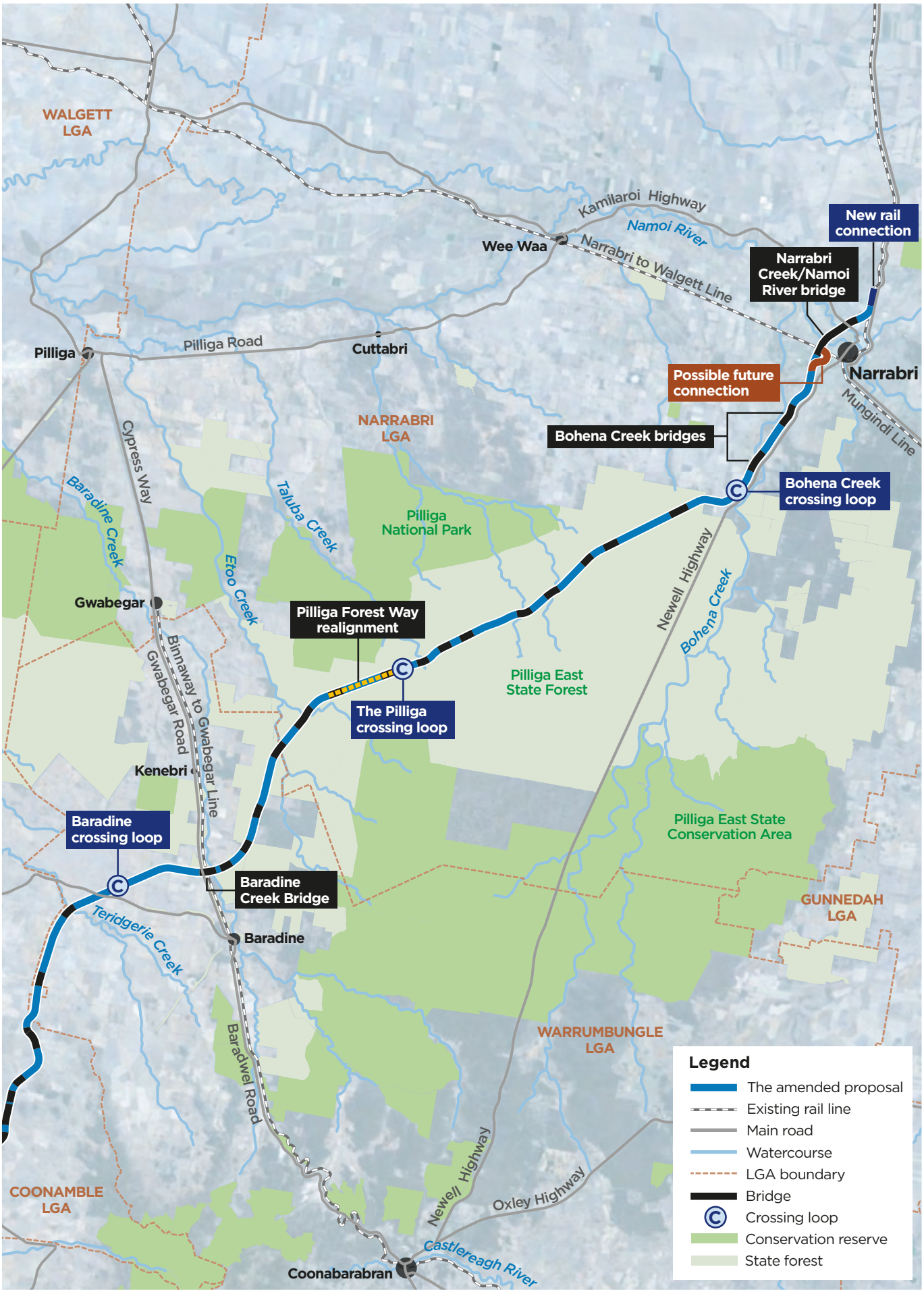


Figure 1.2 **Key features of the proposal (map 2)**

1.2.3 Construction overview

An indicative construction strategy has been developed based on the current reference design to be used as a basis for the environmental assessment process. Detailed construction planning, including programming, work methodologies, staging and work sequencing would be undertaken once construction contractor(s) have been engaged and during detailed design.

Timing and work phases

Construction of the proposal would involve five main phases of work as outlined in Table 1.2. It is anticipated that pre-construction activities would commence in late 2022. Construction is expected to take about four years to complete.

Table 1.2 Main construction phases and indicative activities

Phase	Details
Pre-construction	• Establishment of areas to receive early material deliveries • Delivery of certain materials that need to be brought to site before the main construction • Utilities relocations
Site establishment	• Establishment of key construction infrastructure, work areas and other construction facilities • Installing environmental controls, fencing and site services • Preliminary activities including clearing/trimming of vegetation
Main construction	• Construction of the proposed rail and road infrastructure, including earthworks, track, bridge and earth works
Testing and commissioning	• Testing and commissioning of the rail line and communications and signalling systems
Finishing and rehabilitation	• Demobilisation and decommissioning of construction compounds and other construction infrastructure • Restoration and rehabilitation of disturbed areas

Key construction infrastructure

The following key infrastructure is proposed to support construction of the proposal (as amended) (see Figure 1.3):

- Borrow pits:
  - Borrow pit A – Tantitha Road, Narromine
  - Borrow pit B – Tomingley Road, Narromine
  - Borrow pit C – Euromedah Road, Narromine
  - Borrow pit D – Perimeter Road, Narrabri
- Three main compounds, which would include a range of facilities to support construction ('multi-function compounds'), located at:
  - Narromine South
  - Curban
  - Narrabri West
- Temporary workforce accommodation for the construction workforce:
  - Within the Narromine South multi-function compound
  - Narromine North
  - Gilgandra
  - Baradine
  - Within the Narrabri West multi-function compound.

Other construction infrastructure would include a number of smaller compounds of various sizes located along the proposal site, concrete batching plants, laydown areas, welding yards, a concrete pre-cast facility and groundwater bores for construction water supply.

Further information on the indicative construction methodology and the infrastructure required to support construction is provided in the combined Preferred Infrastructure / Amendment Report.

1.2.4 Operation

The proposal would form part of the rail network managed and maintained by ARTC. Train services would be provided by a variety of operators. The proposal is expected to be operational in 2026. Inland Rail as a whole would be operational once all 13 sections are complete, which is estimated to be in 2027.

It is estimated that the proposal would be trafficked by an average of 10 trains per day (both directions) in 2026, increasing to about 14 trains per day (both directions) in 2040. This rail traffic would be in addition to the existing rail traffic using other lines that the proposal interacts with.

The trains for Inland Rail as a whole would be a mix of grain, bulk freight, and other general transport trains. Total annual freight tonnages would be about 10 million tonnes in 2027, increasing to about 17.5 million tonnes in 2040.

Train speeds would vary according to axle loads, and range from 80 to 115 kilometres per hour.

1.3 Purpose and scope of this report

1.3.1 Overview

Additional assessments of the potential hydrology, flooding and geomorphology impacts of constructing the proposal have been undertaken since exhibition of the EIS. The assessments have been undertaken to assist with considering and responding to issues raised in submissions and during consultation with stakeholders, assessing the impacts of the proposed amendments and to further progress commitments made in the EIS. The Technical Report 3 - Flooding and Hydrology Assessment, originally prepared to support the EIS, has been updated based on the additional assessments undertaken.

The purpose of this report is to assess the potential impacts to hydrology, flooding and geomorphology from the operation and construction of the proposal. The report:

- Provides an updated assessment of the proposal as amended in Table 1.1 and including the additional investigations and studies described in Section 1.1.4
- Addresses the relevant SEARs outlined in Table 1.3
- Addresses issues raised in submissions outlined in Table 1.4
- Addresses issues raised by DPIE's (now DPE) independent reviewer outlined in Table 1.5
- Describes the existing environment with respect to hydrology, flooding and geomorphology
- Assesses the impacts of constructing and operating the proposal on hydrology, flooding, and geomorphology conditions within the vicinity of the proposal
- Recommends measures to mitigate and manage the impacts identified.

The methodology for the assessment is described in Section 3.

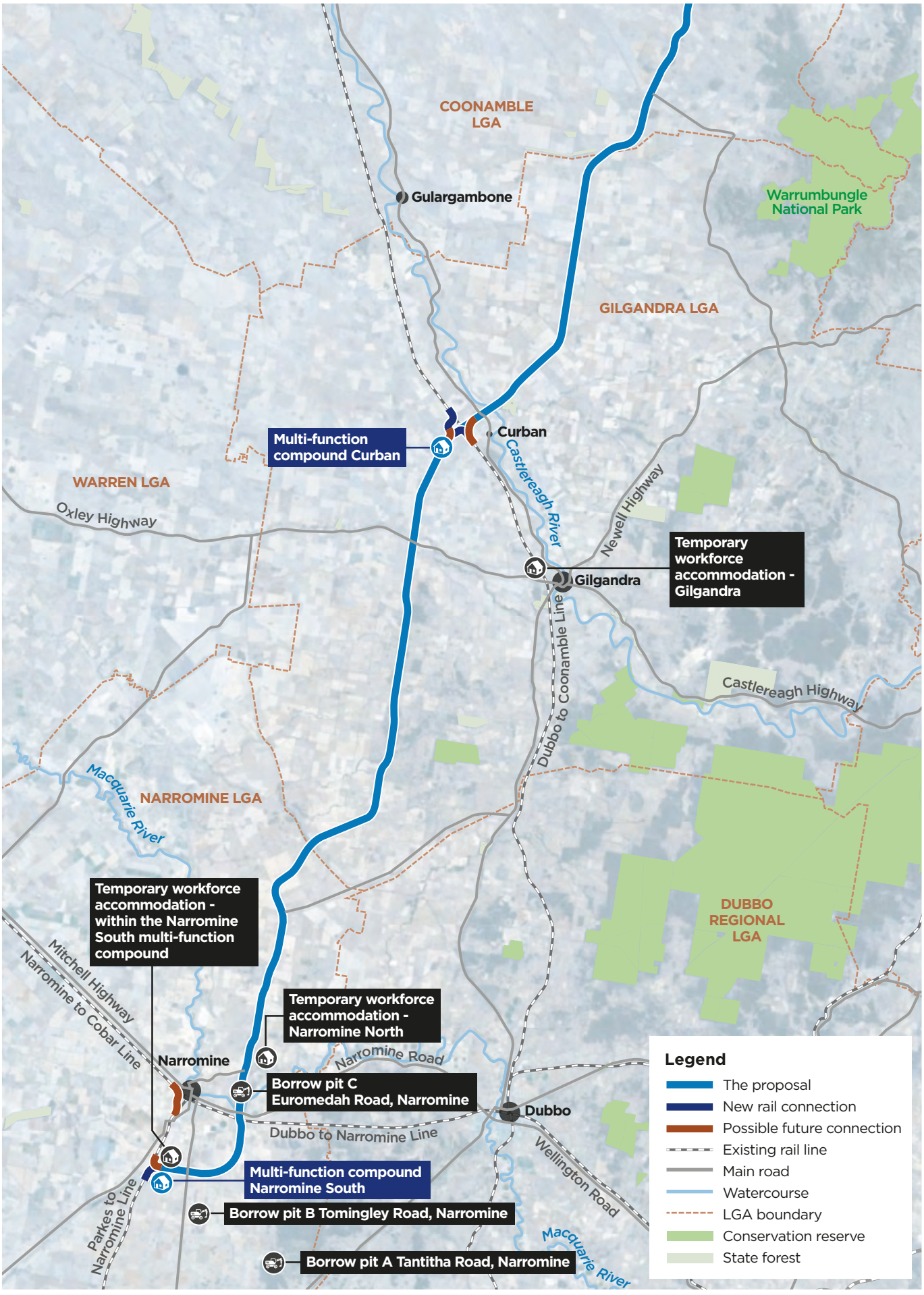


Figure 1.3 **Key construction infrastructure (map 1)**

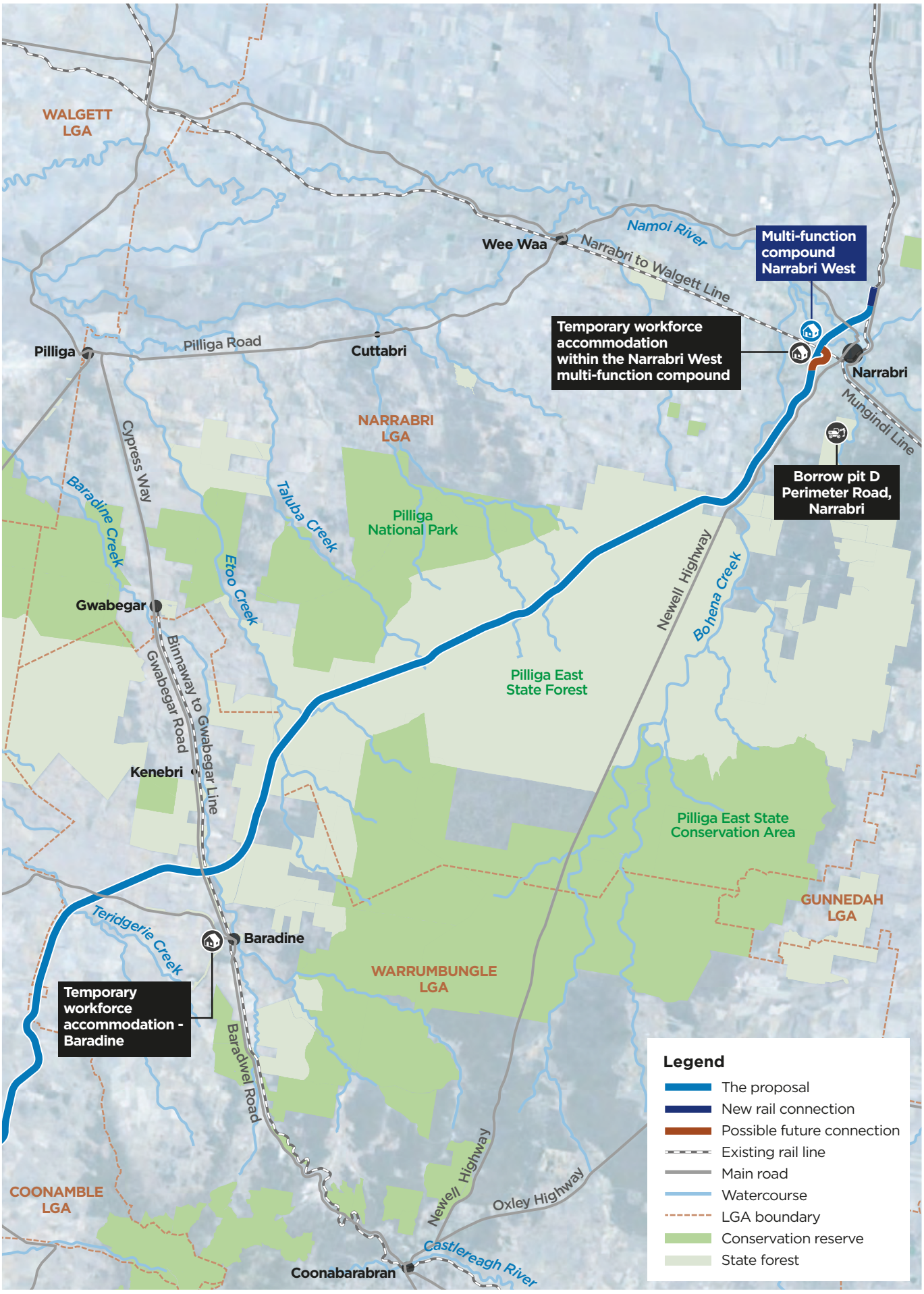


Figure 1.3 **Key construction infrastructure (map 2)**

1.3.2 SEARs

Table 1.3 provides a summary of the SEARs relevant to the flooding and hydrology assessment and provides a reference to where the information can be found within this report.

Table 1.3 SEARs relevant to this assessment

SEAR number	Requirements	Where addressed in this report
9.1	The Proponent must describe the existing flooding characteristics and assess flooding impacts on property and public safety. The assessment must include, but not necessarily be limited to:	Section 5.2 describes the existing flooding characteristics. Section 6.1 and Section 7.3 provide assessments of flooding impacts during construction and operation, respectively.
	a. The location and size of all existing and proposed pipes, culverts, viaducts and bridges, and the locations and annual exceedance probabilities (AEPs) of flows that overtop the existing formation and rail;	Section 3.6.2 provides figures showing the location of all proposed culverts and bridges. Appendix A provides details of the proposed culvert and bridge sizes. Section 5.2.5 described the flooding impacts to existing rail lines under existing conditions. Section 7.12 describes the risks of rail formation overtopping.
	b. The existing and proposed topography in all flood prone areas, including the indicative locations, and typical horizontal and vertical dimensions of spoil mounds. Where there is uncertainty about the total spoil volume, upper and lower bounds must be estimated;	Section 3.3.3 describes the existing topography and data used to define the existing terrain in the flood models. Section 3.6.1 describes the proposed topography.
	c. Describe and justify the proposed flood planning level (FPL) for the project including the AEP of the flood which will overtop the formation and rail. The FPL must consider adjacent infrastructure such as road crossings whose flood immunity is determined by the project's FPL;	Section 3.2.1 describes the flood immunity, i.e. flood planning level, adopted for the proposal.
	d. Assess the existing hydrology, geomorphology and flooding characteristics of all watercourses within and adjacent to the project area. This includes locating and assessing flowpaths emanating from existing culverts, pipes and bridges under the rail formation, or from overtopping of the existing formation in large storms;	Section 5.2 provides an assessment of the existing hydrology and flooding characteristics. Section 5.3 provides an assessment of the existing watercourse geomorphology.
	e. Develop and justify quantitative design limits on potential adverse flooding, hydrological and geomorphological impacts resulting from the project. These are to consider land use and include afflux, velocity, extent, duration, hazard, scour potential, etc;	Section 3.2.2 identifies the quantitative design limits (QDLs) adopted for the proposal.

SEAR number	Requirements	Where addressed in this report
	f. Carry out geotechnical and geomorphological investigations to assess the propensity for scour, erosion and geomorphological changes to occur within any watercourses or overland flowpaths affected by the project;	Section 3.10 describes the methodology for assessing geomorphology impacts. Section 6.2 and Section 7.14 outline the geomorphological investigations and assessment for construction and operation respectively.
	g. Consider the impacts of floods up to the probable maximum flood including consideration of flood risks to people and property resulting from failure of the rail formation or washouts of ballast;	Section 7.3 provides an assessment of flooding impacts during operation. Section 7.12 provides an assessment of the risk of overtopping and failure of the rail formation.
	h. Prepare preliminary engineering designs of the velocity dissipation or other mitigation works that are proposed to avoid adverse offsite scouring or geomorphological impacts on the adjoining land downstream of the project area, adjacent to locations where pipes, culverts or bridges are proposed or where the rail formation may be overtopped;	Section 7.2.6 provides typical engineering designs of culvert and bridge scour protection measures to avoid adverse scour impacts.
	i. At locations along the rail route, identify the width of land between the toe of the formation and the downstream boundary of the project area, that is available for the construction of these mitigation works; and	Section 7.2 identifies the width of rail corridor available for construction. The proposal boundary and rail corridor are shown on mapping in Appendix I.
	j. Where there is insufficient width of project land available for these works, clearly identify the extent of additional land beyond the project boundary that may be required, including the locations where easements over land or acquisition of land may be required.	Section 7.2 identifies the width of rail corridor available for construction, including scour protection works. Drainage control areas have been included at a number of locations to manage flow velocities beyond the rail corridor boundary.
9.2	The Proponent must model the impacts of the project on flood behaviour, including the existing, during construction and post construction (i.e. Operational) flooding conditions for a full range of flood events up to and including the probable maximum flood. The assessment must include consideration of the impacts of climate change and differing storm durations, and include but not necessarily be limited to:	Section 6.1 describes the flood impact assessment for the construction phase. Section 7.3 describes the flood impact assessment for the operational phase.
	a. Utilising hydrologic and hydraulic models that are consistent with current best practice and utilise topographic and infrastructure data that is of sufficient spatial coverage and accuracy to ensure the resultant models can accurately assess existing and proposed water flow characteristics;	Section 3.4.1 describes the hydrology models utilised for the assessment. Section 3.4.2 describes the hydraulic models developed and used for the assessment.

SEAR number	Requirements	Where addressed in this report
	b. Having these models independently peer-reviewed with the review findings published in the EIS;	Section 3.9 and Appendix A describe the independent review of the flood models.
	c. Assessing any detrimental increases in the potential flood affectation, scouring or geomorphological changes to other properties, assets and infrastructure, over a full range of flood durations and flood frequencies;	Section 7.3 assesses potential flood impacts to properties and infrastructure in the operational phase. Section 7.14 assesses the potential geomorphology impacts in the operational phase.
	d. The extent to which the project alleviates or exacerbates the flood impact the existing rail infrastructure has on property or people;	Section 7.3 assesses the flood impact the proposal has on property and people. Section 7.12.4 details assesses impacts on the Narromine to Dubbo rail line at Webbs Siding.
	e. An assessment of the consistency (or inconsistency) with the applicable Council or OEH floodplain management plans. The requirements of these plans must be discussed with OEH and the Council:	Section 7.6 and 7.8 describe the consistency with relevant floodplain management plans.
	f. Assessing whether each component of the project is compatible with the flood hazard of the land and the hydraulic functions of flow conveyance, floodway and flood storage;	Section 7.6 assesses the compatibility with the flood hazard and hydraulic functions.
	g. Assessing existing upstream and downstream flow, level, velocity, hazard and scour potential, and changes following the decommissioning of the borrow pits and downstream flowpaths (location, discharges and velocities);	Section 6.1.1 describes the proposed borrow pits and their rehabilitation strategy. Section 7.3 assesses flood impacts during the operational phase once the borrow pits are decommissioned.
	h. Quantifying and evaluating changes in flood safety risks on private and public land including roads and pathways;	Section 7.3.3 provides a quantitative assessment of flood impacts including assessment of flood hazard, and changes to flooding of existing roads, highways and rail lines.
	i. Assessing any impacts that the project may have upon existing community emergency management arrangements for flooding. These matters must be discussed with the State Emergency Service and applicable Council; and	Section 7.9 assesses potential impacts the proposal may have on existing emergency management arrangements for flooding.
	j. Evaluating any social and economic impacts that the project may have on the community as a consequence of changes to flooding, hydrology and geomorphology.	Section 7.10 provides an evaluation of potential social and economic impacts of the proposal as a result of changes to flooding.

1.3.3 Submissions

Submissions raised a range of issues in relation to Technical Report 3. Detailed responses to all issues are provided in the Response to Submissions report. Table 1.4 provides a summary of the issues raised that are directly relevant to the information provided in this updated flooding and hydrology assessment and provides a reference to where the information can be found within this report.

Table 1.4 Issues raised in submissions relevant to this assessment

Issue category	Issue summary	Where addressed in this report
Blockage of drainage structures	A blockage factor for culverts and bridge piers should be included in accordance with recommendations in *Australian Rainfall and Runoff*	Section 3.7.4
Climate change assessment	The assessment should include an allowance for climate change	Section 3.7.3
Construction impacts	Worst-case construction scenarios were underestimated because ground conditions following flooding would result in significant issues for construction	Section 6.1.1
Consultation	Provide information on extent of consultation in relation to impacts to farm water supply	Sections 4.2.3 and 4.8
	Confirm extent of consultation with SES etc in relation to emergency management arrangements	Sections 4.5 and 4.8
	Lack of public consultation and use of local knowledge has led to underestimation of impacts	Section 4
Design – bridges	Bridge lengths are inadequate to cater for flood flows	Section 3.6
Design – culverts	Culverts need to be designed to not damage nearby public assets (e.g. roads)	Section 3.6
	Culverts need to maintain water flow to farms	Sections 3.6, 4.2.3, and 7.10.2.
	Culverts will not be maintained and would become blocked	Section 3.7.4
	Culverts would not be adequate, in terms of their location, number and size, for managing flood water	Section 3.6
Emergency management	Provide information about emergency arrangement impacts where areas are now subject to high hazard	Section 7.9
	Provide information in relation to impacts to emergency management arrangements	Sections 7.2 and 7.9
Flood studies / plans	The modelling overestimates the number of buildings impacted in Narrabri and near Bohena Creek under existing conditions. The predicted results are different to those in the draft *Bohena Creek Flood Study* (WRM, 2019b)	Section 3.3.5

Issue category	Issue summary	Where addressed in this report
	The proposal should be assessed against the relevant criteria in the: • *Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020* • Draft *Floodplain Management Plan for the Macquarie Valley Floodplain 2018*	Sections 2.2.6 and 0
	The proposal doesn't comply with the recently completed floodplain management plan for Narrabri	Sections 2.2.7, 3.3.5, 7.7.2 and 7.8.2
	The proposal doesn't comply with the Narrabri Local Environmental Plan 2012 flooding considerations	Section 2.2.4
	The proposal needs to adequately consider the proposed Narromine town levee as detailed in *Narromine Town Levee Concept Design* (SMEC, 2019)	Sections 3.3.5 and 7.8.1
Flow redistribution	Provide information of any flow redistributions within floodplains and between watercourses and associated impacts	Sections 7.2 and 0
Flood management objectives	The proposal doesn't comply with the proposed flood management objectives	Section 3.2.2 and 7.3
	Provide justification for the proposed flood management objectives	Section 3.2.2
	Provide a methodology which outlines how the impacts to buildings will be mitigated	Section 3.2.2
	The proposed flood management objectives should be more prescriptive	Section 3.2.2
Mapping	Provide more detailed mapping to enable councils and landholders to understand impacts	Section 4.8.1 and Appendix I
Methodology – culverts / bridges	Provide details of the parameters that have been applied to model culverts and bridges	Sections 3.6, 3.7.4 and Appendix J
Methodology – flow data	Provide the flood frequency analysis for the gauging stations used in the assessment	Appendix J
	Provide information regarding the reliability of the rating curves	Appendix J
	Provide information on the parameters used to estimate flows for the major catchments	Appendix J
Methodology – ground level roughness	Confirm the ground level roughness values (Manning's 'n') used in the modelling and undertake a sensitivity analysis	Appendix J
Methodology – Mulgate Creek	Mulgate Creek and local tributary flooding were not included in the flood modelling	Sections 3.5.3 and 1.1
Methodology – rainfall data	Rainfall data used doesn't include the 1955 event	Section 3.3.2 and Appendix J
	Confirm the assessment is based on sub-daily rainfall storm events	Section 3.3.2 and Appendix J

Issue category	Issue summary	Where addressed in this report
	Confirm the upper catchment inflows have been derived using the hydrology model results and a 'rain-on-grid' approach	Section 3.4
Methodology – site specific conditions	The modelling doesn't consider site specific conditions at Sappa Bulga Ranges and the Warrumbungles Ranges	Section 3.4 and Appendix J
	The modelling is based on incorrect assumptions regarding the flood immunity of the existing Dubbo to Narromine rail line which could result in a major failure of the embankment	Section 3.4 and Appendix J
Operational impacts – general	Additional information on buildings impacted by increased flooding in all events should be provided	Sections 7.3 and 7.4
	Provide information on the impacts to forestry areas	Sections 7.3 and 7.4.
	Provide information on the impacts to farming properties	Section 7.3, 7.4 and 7.10.2
	Provide information on the potential risk to human lives and stock	Sections 7.3, 7.9 and 7.10
	Provide assessment of impacts when the proposal is overtopped	Section 7.12
	Provide information on impacts to existing rail lines	Sections 7.3 and 7.4.
	Provide information on impacts to roads	Sections 7.3 and 7.4.
Velocity and scour	Velocity modelling is incorrect as it predicts a reduction downstream of the culverts	Sections 7.2, 7.3 7.14, Appendix O and Appendix P
	Erosion caused by culverts would cause damage, including to soils, infrastructure and local roads	Section 7.2 and 7.3, Appendix O and Appendix P
	Provide additional information on proposed velocity mitigation	Section 7.2 and 7.3, Appendix O and Appendix P
	Provide additional information regarding velocities following implementation of mitigation	Section 7.2, Appendix O and Appendix P

1.3.4 DPIE technical review

An technical review on behalf of DPIE (now DPE) raised a range of issues in relation to Technical Report 3. Table 1.5 lists these issues and provides a reference to where the information can be found within this report.

Table 1.5 Issues raised by DPIE's technical reviewer relevant to this assessment

Item	Issue	Where addressed in this report
1	**Flood Immunity / Flood Planning Level (FPL)**	
1.1	The Item 9.1c of the SEARs require ARTC to "Describe and justify the proposed flood planning level (FPL) for the project including the AEP of the flood which will overtop the formation and rail" [s1.3 p10]. This hasn't been done or hasn't been done adequately.	Section 3.2.1 and Appendix M
1.2	In the absence of a proper description and justification of the FPL, the reviewer suggests that the Project should be designed so that trains can continue to operate should flood waters rise to the level of the 1% AEP flood plus 0.3 metre freeboard or the 1% AEP flood level under climate change, whichever is higher. (The reference design presented in the EIS may already meet this standard).	Section 3.2.1 and Appendix M
1.3	The EIS states "The flood planning level for the proposal has been determined based on achieving a minimum flood immunity for the 1% AEP event with due consideration of adjacent infrastructure" [s3.2.1 p23]. However the term "flood immunity" is not defined in Technical Report 3. The term needs to be clarified.	Section 3.2.1 and Appendix M
1.4	The term "flood planning level" (FPL) is also not defined. The NSW Floodplain Development Manual (Manual) defines FPL as the design flood level with a freeboard, usually 0.5 m. The freeboard used by ARTC appears to be zero but this needs to be clarified.	Section 3.2.1 and Appendix M
1.5	The justification provided at [s3.2.1 p23] that a 1% AEP immunity is required by the Manual is incorrect. The Manual does not mandate use of the 1% AEP event.	Noted
1.6	The EIS states that the Project "needs to achieve a high level of reliability so that it is a competitive freight transport solution. The proposed flood planning level is essential in order for the proposal to meet these requirements" [s3.2.1 p23]. Nevertheless the reviewer notes that on other sectors of the Inland Rail, flood immunity standards lower than 1% AEP have sometimes been adopted and therefore it is unclear how different flood immunity standards have been applied on different sectors and yet still achieve a "high level of reliability".	Section 3.2.1 and Appendix M

Item	Issue	Where addressed in this report
1.7	During a major flood, as water rises above the top of the formation, water will start to pass through the ballast. As the water level rises further, the propensity for water to wash away ballast will increase. Assuming significant erosion of ballast does not occur, water may eventually rise high enough to overtop the rail itself. Thus various critical water levels can be defined, i.e.: (i) top of formation (ii) level at which ballast commences to erode (iii) top of rail; and two further levels (iv) level at which train operations are halted due to flood waters (which may be lower or higher than any of the above levels) (v) level at which failure of the formation commences to occur The EIS would benefit from a thorough description of the impact of floods on train operations and the vulnerability of the rail infrastructure to flood damage. Identifying these critical water levels should be part of such a description.	Sections 3.2.1 7.12, Appendix K and Appendix M
1.8	Without an assessment of the level described in 1.7(iv) above, the true impact of flooding on the reliability of the Project cannot be assessed. It may likely be in excess of 1% AEP but this can't be determined from Technical Report 3.	Sections 3.2.1, 7.12 and Appendix M
1.9	Further, confusion arises within Technical Report 3 when the term "overtopping" is used without referencing whether this is overtopping of the formation or the rail line, e.g. [s7.1.12 p164].	Section 7.12
2	**Quantitative Design Objectives (QDOs) for Flood Impact Assessment (Now Quantitative Design Limits QDLs)**	
2.1	The reviewer disagrees with the way that the QDOs have been defined and the proposed approach to their use both prior to approval and post-approval. In the reviewer's opinion, the QDOs and their proposed application provide an inadequate basis to ensure the construction and operation of the Project will not result in unacceptable flood impacts. They provide inadequate safeguards to the wider community that unacceptable flood impacts will be avoided if the Project is approved.	Section 3.2.2
2.2	Technical Report 3 considers many of the QDOs as "targets" which the reference design in the EIS has attempted to achieve "as far as practical". The reviewer disagrees that this approach provides adequate safeguards to prevent unacceptable flood impacts arising from implementation of the Project.	Section 3.2.2

Item	Issue	Where addressed in this report
2.3	Based on the usual approach for major infrastructure projects in NSW (including other Inland Rail sectors), the reviewer understands that: (i) prior to approval: various metrics associated with the potential off-site flood impacts of an infrastructure project are defined and considered during environmental impact assessment. These metrics define the maximum flood impact which is considered to be acceptable to third parties and the public sector. These metrics are defined by considering a range of direct and indirect flood damages, in addition to broader environmental impacts occasioned by flooding. (ii) post-approval: these metrics become triggers for the level of impact, which if exceeded, require additional mitigation measures to be implemented. The scope of such mitigation measures usually requires separate negotiation and agreement by the affected third parties. This may involve construction of site-specific mitigation works, payment of compensation, acquisition of additional corridor land or other measures to ensure that an acceptable off-site impact is achieved.	Noted
2.4	These metrics are critically important to the community as they provide confidence that the maximum level flood impacts which the Minister has assessed to be acceptable in issuing an approval, will not be exceeded during the construction and operation of the Project, unless alternative arrangements are agreed with the affected third parties. Consequently the metrics are clear numerical limits which cannot be varied by the proponent.	Noted
2.5	The definition and proposed application of the QDOs in the EIS is inconsistent with the metrics described above. Many of the QDOs are not numerical limits and may be varied by ARTC subsequent to approval to ensure they are “practicable”.	Noted
2.6	The reviewer recommends that the Quantitative Design Limits (QDLs) reproduced in Appendix A should be used both prior to and post approval for Narromine to Narrabri. These QDLs are those previously used for the Narrabri to North Star (SP1) sector. In the reviewer’s opinion, there is no proper basis to vary these QDLs for the Narromine to Narrabri project.	Section 3.2.2
3	**Flood Modelling**	
3.1	Comprehensive flood modelling has been undertaken comprising some 14 TUFLOW hydraulic models in addition to hydrologic models. With the exception of the modelling of Bohena and Mulgate Creeks, the reviewer considers this modelling is likely to be of a good standard although, as noted in paragraph 3.7 below, there is currently insufficient documentation to confirm this.	Appendix J

Item	Issue	Where addressed in this report
3.2	JacobsGHD's use of a 10 metre grid size will be sufficient to simulate flood behaviour and to assess the flood level and flow distribution changes caused by the Project. Smaller watercourses with dimensions of the order of 10 metres are unlikely to be adequately represented in the TUFLOW models but nevertheless this may not be significant for the purposes of the EIS.	Section 7.2 and Appendix P
3.3	However the velocities of flows at the downstream boundary of the rail corridor will only be crudely represented. This is because the distance between the culvert outlets and the corridor boundary is of the same order as the model grid size. Consequently the velocity changes at the corridor boundary are unlikely to be accurate.	Section 7.2 and Appendix P
3.4	Therefore insufficient information has been presented to determine whether there is enough distance available within the corridor to sufficiently attenuate the water velocities exiting from culverts in order to satisfy the velocity QDLs at the corridor boundary. Because of this ARTC is unable to address SEARS 9.1j which requires *"Where there is insufficient width of project land available for these works, clearly identify the extent of additional land beyond the project boundary that may be required, including the locations where easements over land or acquisition of land may be required".*	Section 7.2 and Appendix P
3.5	Concerns remain over whether the rail corridor is sufficiently wide to contain the necessary velocity attenuation structures that will be required downstream of some culvert outlets. The function of these structures is to expand and redistribute the concentrated flows exiting the culverts, in order to achieve the velocities that would previously have been present at the corridor boundary without the Project in place.	Section 7.2 and Appendix P
3.6	To address this short coming, separate finer scale hydraulic modelling should be undertaken of a few representative culvert locations. These should be chosen to examine the potential range of outlet situations along the rail alignment and to demonstrate that the 40 metre wide corridor is sufficiently wide to contain the velocity attenuation structures necessary to satisfy the velocity QDLs at the corridor boundary. (The reviewer notes that the details provided in Technical Report 3 [s7.1.7 p156] are scour protection structures for the corridor land and are not velocity attenuation structures).	Section 7.2 and Appendix P
3.7	There has been an extensive amount of hydrologic and hydraulic modelling undertaken but only very limited details of these models are presented in Technical Report 3. The level of reporting falls well short of what is normally provided and is insufficient to allow the modelling to be reviewed except at a superficial level. Model parameters are not reported, nor is sufficient information provided regarding the calibration and validation of the models to allow the credentials of the models to be verified. An assessment of the accuracy of rating curves that have been relied upon has not been presented nor have details been provided of the flood frequency analyses used in model calibration.	Appendix J

Item	Issue	Where addressed in this report
3.8	The reviewer notes that BMT have been engaged to independently peer review the hydrology and hydraulic models. It appears that some of their review tasks could only be undertaken through provision of additional information from JacobsGHD.	Section 3.9 and Appendix B
	Consequently the reviewer has had to rely on BMT's documentation of this additional model information because of the shortcomings in the model documentation provided in Technical Report 3.	Appendix B and Appendix J
3.9	The reviewer notes that JacobsGHD have adequately responded to the review comments provided by BMT.	Noted
3.10	Nevertheless BMT's review was limited to some models and their review report states that "the scope of the review is a verification of the basic model elements, and as such must not be taken as a comprehensive review of the models nor the flood study or assessment". Consequently the reviewer recommends that either the model reporting deficiencies in the EIS be rectified or BMT be engaged to undertake a comprehensive review in sufficient detail for them to be able to verify that the hydrologic and hydraulic models are fit for purpose.	Section 3.9, Appendix B
3.11	In regard to modelling through the Narrabri area, there are deficiencies in the modelling of both Bohena Creek and Mulgate Creek. The Bohena Creek deficiencies are discussed in paragraph 4.2(i) below.	Noted
3.12	The deficiencies within Mulgate Creek arise because the flood impacts associated with this creek have not been separately assessed and reported in the EIS. Mulgate Creek has historically been the source of numerous flood problems for Narrabri and therefore it is surprising that this system has not received greater attention in the EIS. In addition, because the highest affluxes resulting from the Project occur on the Mulgate Creek side of Narrabri near the Ascot sheds and along the Wee Waa Road, it is imperative that the flood impacts associated with Mulgate Creek flooding be examined and reported.	Sections 1.1, 3.5.3 7.5.6, and Appendix N
4	**Consultation with Narromine and Narrabri Councils**	
4.1	Based on the documentation in Technical Report 3 and the reviewer's liaison with Narromine and Narrabri Shire Councils, it appears that there has been inadequate consultation with these Councils during the preparation of the EIS.	Section 4
	The reviewer has reached this conclusion because of three significant omissions from the EIS:	

Item	Issue	Where addressed in this report
4.2	(i) Bohena Creek Flood Study (draft): – refer document (f) above which was prepared by WRM for Narrabri Shire Council. It appears that ARTC are unaware of this study which was prepared in October 2019. The EIS predictions of flooding in Bohena Creek are much more extensive than suggested by this Council study. Further the predictions within Table 5.3 [s5.2.3 p96] of 72 buildings within Bohena Creek being inundated above floor level in a 20% AEP flood event is unlikely to be accurate. This indicates to the reviewer that the level of consultation with this Council has been inadequate. (The result of revising the Bohena Creek hydrology will likely show that the Project is not as severely constrained by this creek as was reported in the EIS).	Sections 3.3.5, 0 and Appendix Q
	(ii) Webbs Siding flood mitigation option: – for a number of decades there have been proposals to provide additional waterway openings in the Main Western Railway Line on the southern bank of the Macquarie River at Webbs Siding, immediately to the east (i.e. upstream) of the proposed Narromine to Narrabri alignment. This will achieve very significant flood mitigation benefits for Narromine which has a serious flood problem. The current option, which the reviewer understands is part of the 'Preferred Flood Mitigation Scheme' adopted by Narromine Shire Council's Floodplain Risk Management Committee, involves the construction of 125 reinforced concrete box culverts (RCBCs) each 3.6 metres wide and 0.9 metres high. When constructed, this would allow an additional 450 metres to 600 metres width of breakout flows from the Macquarie River to be directed towards the Narromine to Narrabri alignment. These Webbs Siding culverts have not been considered in Technical Report 3. This indicates to the reviewer that the level of consultation with this Council has been inadequate.	Sections 3.3.5, 4.8.2 and 7.12.4
	(iii) *Narrabri Floodplain Risk Management Study & Plan (FRMS&P):* – the reviewer understands the FRMS&P has been in preparation for a number of years. FRMS&Ps are prepared by local councils and are key components of the flood risk management process outlined within the NSW Floodplain Development Manual. Although not yet formerly adopted, the reviewer would have expected ARTC to have consulted with the Council and reported the key implications of the FRMS&P when developing the Narromine to Narrabri proposal and preparing the EIS.	Sections 2.2.7, 3.3.5, 4.8.2 and 1.1.1
5	**Inadequate Consultation with Affected Land Owners and the Wider Community**	
5.1	There are very significant flood problems within the Project area. The townships of Narrabri and Narromine have around 6000 buildings inundated above floor level in a 1% AEP flood event. Narrabri is arguably NSW's most flood affected town.	Noted
5.2	Given the significance of flood risk issues and the potential for the Project to adversely impact the community, the reviewer expected more comprehensive information to be presented in the EIS and a greater level of community consultation to have been carried out.	Section 4

Item	Issue	Where addressed in this report
5.3	Whilst a large number of maps have been prepared and a further set of finer scale flood maps for Narromine and Narrabri have been included, much detail is not shown or is difficult to determine due to the scale of mapping, the data ranges used to present flood impacts, and the failure to depict buildings within the maps. Details of the embankments and piers associated with the massive 3.9 kilometre viaduct through Narrabri are also not mapped clearly.	Sections 3.6.2 and 4.8.1, Appendix I, Appendix L and 7.1.
5.4	Whilst with a few exceptions the flood modelling in the EIS appears to be of a good standard, aspects of the assessment and reporting of the flood impacts of the Project are inadequate. For example:	Noted
	(i) there is no mapping which shows the location of flood sensitive receptors. Overall the reviewer considers the mapping provided to be insufficient to allow property owners to assess the flood impacts of the Project on their individual holdings;	Section 4.8.1, Appendix H, Appendix I and 7.1
	(ii) whilst the numbers of buildings with floors inundated by more than 10 millimetres in a 1% AEP event is reported [s7.1.3 p149], the numbers of buildings inundated to greater depths are not reported and statistics are not given. This tends to mask the significance of the inundation in the one per cent event;	Section 7.3
	(iii) there are very significant impacts in floods rarer than 1% AEP. These impacts receive only cursory attention and further information is required. For example, in a 1% AEP climate change event, some additional 622 buildings are inundated above floor level by more than 10 millimetres as a result of the Project [s7.1.3 p147]. This is almost a tenfold increase in building floors adversely affected;	Section 7.4
	(iv) in the 0.5% AEP, 0.2% AEP and probable maximum flood (PMF), the numbers of floors inundated by more than 10 millimetres increases from 71 to 95, 3070 and 7035, respectively [s7.1.3 p147]. These are huge increases which receive scant attention in Technical Report 3.	Section 7.4
6	**Project Impacts in Narrabri in 1% AEP Flood**	
6.1	In a 1% AEP event, the Project has very significant impacts to existing buildings in Narrabri – refer Figure 2.2b in Appendix H of Technical Report 3. These occur particularly in the northern part of town near the Ascot sheds and along Wee Waa Road, and are well in excess of the QDLs. Data provided to the reviewer by JacobsGHD for these impacted buildings show a large number do not utilise surveyed floor levels and therefore there is some uncertainty regarding the assessment presented in the EIS.	Sections 3.2.2, 3.3.6 and 7.2. ARTC has surveyed floor levels where practical
6.2	The reviewer doesn't understand why the viaduct's embankments have not been widened to alleviate the flood impacts in this part of town.	Section 7.5.5
6.3	The reviewer considers the number and severity of the flood impacts within Narrabri to be unacceptable.	Sections 3.2.2, 7.3 and 7.5

Item	Issue	Where addressed in this report
6.4	The reviewer is also concerned that the impacts documented in the EIS have ignored hydraulic blockage of the viaduct's piers by flood debris, or blockage of fencing for the rail corridor (if any is proposed). Once these blockages are included, the flood impacts through Narrabri in a 1% AEP event will increase further.	Sections 3.7.4 3.7.5 and 7.5.4
7	**Inadequate Consideration of Impacts to Buildings in Floods Larger than 1% AEP**	
7.1	The QDLs relate to all floods up to the 1% AEP event. Nevertheless the NSW Floodplain Development Manual and SEARs 9.1g require that the "impacts of floods up to the probable maximum flood" must also be considered.	Section 7.4
7.2	In some of the Inland Rail sectors this is not an onerous requirement however for the Narromine to Narrabri Project very large increases in the numbers of impacted buildings occur for floods larger than 1% AEP – refer paragraph 5.4(iv) above.	Section 7.4
7.3	This issue is very evident within Narrabri where there are so many flood affected buildings – refer to the reviewer's approximate mapping of flood sensitive receptors in Appendix B. It is clear that the Project has the potential to impact many thousands of buildings in extreme floods. As is evident from Appendix B the increased inundation to some buildings will exceed 0.5 metres in a PMF event.	Section 7.4
7.4	This issue has received inadequate consideration in Technical Report 3. Statistics of the numbers of buildings and the increased depths of inundation for various rare events are not provided. The socio-economic impacts have not been adequately assessed. The increased flood damage costs and the potential increased personal safety risks caused by the Project in these events have not been quantified.	Sections 7.4 and 7.10
7.5	The reviewer considers this to be a serious shortcoming of the EIS.	Noted
8	**Access for People, Stock and Machinery during Floods**	
8.1	The construction of an elevated rail may provide an opportunity for improved emergency access for flood affected communities (e.g. through Narrabri). There is no information provided in Technical Report 3 to indicate whether there has been liaison with the NSW State Emergency Service (SES) about this issue and whether measures to improve emergency flood access should be included.	Sections 4 and 7.9
8.2	The implementation of the Project may disrupt access within or between farms, including for disruption to emergency access for stock and machinery during floods. This issue does not appear to have been addressed in Technical Report 3.	Section 7.9

Item	Issue	Where addressed in this report
9	**Blockage Assumptions for Culvert and Bridge Design**	
9.1	As a matter of normal design practice for culverts and bridges, an allowance for blockage should be included. Australian Rainfall and Runoff, 2019 (ARR) provides procedures for the calculation of the blockage allowance to be utilised during design. This results in the sizes of culverts and bridges being increased in order to provide the same hydraulic capacity without any blockage.	Section 3.7.4
9.2	All culverts and bridges in the reference design utilised in the EIS have been sized without any blockage allowance. Technical Report 3 has considered blockage only as a 'sensitivity check' [s7.1.14 p164]. It has not included any allowance for blockage in the sizes of culverts and bridges used to determine the flood impacts of the Project and in the assessment of flood immunity and overtopping. The reviewer considers the failure to include for blockage in the sizing of the reference design to be deficient and contrary to normal practice.	Section 3.7.4
9.3	Consequently the entire design needs to be revised to include for blockage.	Section 3.7.4
9.4	Whilst in respect of culverts this will mean that their sizes need to be increased, these changes will also alter the width of culvert banks and will change flow behaviour in more frequent flood events. As flood impacts need to be assessed for both blocked and unblocked conditions over the full spectrum of floods up to 1% AEP, there will likely need to be other changes to culvert configurations (e.g. raised culvert inlet sills) in order to comply with the QDLs during more frequent floods.	Section 3.7.4
9.5	In respect of bridges, their spans are so large that the propensity for any blockage of the entire span is improbable and proper design will likely show such blockage can be ignored. Nevertheless some blockage of piers will need to be included. Whilst this impact will normally be small, it will likely be significant through Narrabri where a very long viaduct is proposed.	Section 3.7.4
9.6	The blockage allowance will also need to take account of any proposed fencing of the rail corridor. Fencing is not described in Technical Report 3 but may have significant impacts on flood behaviour in some locations (e.g. if proposed through Narrabri).	Section 3.7.4
10	**Flood Impacts during Construction**	
10.1	Given the serious flood risks which currently exist in Narrabri and Narromine, there is potential for very adverse impacts if a major flood should occur during construction.	Section 6
10.2	Modelled flood impacts during construction are discussed in [s6.1.2 p120] and Appendix F of Technical Report 3. The reported construction impacts represent only a modest increase over the operational impacts. If these impacts have been accurately assessed, the reviewer expects that they can be adequately managed through the preparation and implementation of the proposed construction environmental management plan (CEMP).	Noted

Item	Issue	Where addressed in this report
10.3	There are no maps presented to show the location and extent of the construction activities included within the flood models for this assessment. These should be provided. The reviewer is surprised that the construction impacts in areas such as Narrabri aren't significantly larger than those reported in Technical Report 3.	Section 3.7.2 and 6
10.4	The reviewer holds concerns that the methodology used for the viaduct construction through Narrabri may involve unacceptable flood risks to upstream residents and business owners. Further details are required to demonstrate that the flood risks during construction can be properly managed.	Section 6.1
11	**Consideration of Risks to Life in Extreme Floods due to Embankment Collapse**	
11.1	SEAR 9.1g requires ARTC to "Consider the impacts of floods up to the probable maximum flood including consideration of flood risks to people and property resulting from failure of the rail formation or washouts of ballast [s1.3 p10]."	Section 7.12 and Appendix K
11.2	Technical Report 3 has attempted to address this requirement [s7.1.13 p164] but has not adequately assessed the risks to people and property as required by the SEARs.	Section 7.12 and Appendix K
11.3	The collapse of large sections of the rail embankment during extreme floods, such as a 0.05% AEP event, has been acknowledged in the EISs of other Inland Rail sectors. In the opinion of the reviewer, there will likely also be a risk of this occurring at locations along the Narromine to Narrabri alignment although the probabilities of such events may be rare.	Section 7.12 and Appendix K
11.4	In order to assess these risks it is first necessary to determine the water levels upstream and downstream of the rail embankment which would cause rapid erosion of the ballast and formation, or potential geotechnical failure of the embankment. These are geotechnical considerations which have no doubt been assessed by ARTC's geotechnical experts but are not reported in Technical Report 3. Once these critical conditions are known, ARTC's flood engineers could assess the probability of such conditions occurring (if any) and the locations along the Narromine to Narrabri alignment where failure could occur (if any).	Section 7.12 and Appendix K
11.5	Once this information is available, the risk to life in areas immediately downstream of the rail alignment could be assessed and where necessary, appropriate flood emergency response measures and/or structural design measures, could be identified to manage the flood risk to acceptable levels.	Section 7.12 and Appendix K
12	**Geomorphological Impacts**	
12.1	A comprehensive desktop assessment of geomorphological impacts has been undertaken using the river styles approach. This assessment indicated that all the watercourses had 'moderate' to 'high' geomorphic fragilities.	Noted

Item	Issue	Where addressed in this report
12.2	Slightly more than half of the assessed watercourses had a 'high' fragility and as such would be highly susceptible and sensitive to geomorphic adjustment. Consequently it is very important that velocity and flow distribution changes resulting from the Project be properly assessed and mitigated where necessary.	Sections 7.2. 7.14, Appendix O and Appendix P
13	**Farm Dams**	
13.1	The introduction of new culverts and the creation of new flowpaths are likely to be a concern to some landowners because of the potential impacts on farm dams, agricultural productivity and farm operations. It is unclear whether the locations of all existing farm dams have been identified and whether the resultant changes to water inflows to these dams have been assessed.	Sections 4.2.3 and 7.10.2
13.2	Whilst the QDLs do consider changes in velocities and durations during floods at the rail line, any changes in the water supply yield of farm dams will be primarily dependent on the volumes delivered to the dams. Although compliance with the velocity and duration QDLs will likely mitigate most farm dam impacts, further consideration of the yields from farm dams will be required once the location and importance of the farm dams have been identified.	Sections 3.2.2, 4.2.3 and 7.10.2

1.4 Structure of this report

The structure of the report is outlined below:

- Section 1 – provides an introduction to the report
- Section 2 – provides an overview legislation, policies and guidelines application to this assessment
- Section 3 – describes the methodology and approach for the assessment
- Section 4 – provides a summary of community consultation carried out for the hydrology and flooding assessment
- Section 5 – provides a summary of the existing flooding and hydrological conditions
- Section 6 – presents a summary of the potential impacts associated with construction of the proposal
- Section 7 – presents a summary of the potential impacts associated with operation of the proposal
- Section 8 – provides recommended mitigation and management measures
- Section 9 – concludes the key findings and recommendations from the investigation.

2 Legislation and policy context

A range of legislation, policy and guidelines directs the way water resources are managed in NSW. Key documents relevant to the proposal are outlined below.

2.1 Legislation

2.1.1 Water Management Act 2000 and Water Act 1912

Two key pieces of legislation for management of water within NSW are the *Water Management Act 2000* and the *Water Act 1912*. These Acts control the extraction of water, the use of water, the construction of works such as dams and weirs and the carrying out of activities in or near water sources in NSW. The provisions of the *Water Management Act 2000* are being progressively implemented to replace the *Water Act 1912*. Since 1 July 2004, the new licensing and approvals system has been in effect in those areas of NSW covered by commenced water sharing plans, which are made under the *Water Management Act 2000*.

A controlled activity approval under the *Water Management Act 2000* is required for certain types of developments and activities that are carried out in or near waterfront land. However, under the EP&A Act an activity approval (including a controlled activity approval) under section 91 of the *Water Management Act 2000* is not required for State significant infrastructure, such as the proposal. However, the design and construction of the proposal would take into account the NSW Office of Water's guidelines for controlled activities on waterfront land.

Development on floodplains is now managed under the *Water Management Act 2000,* having previously been managed under Part 8 of the *Water Act 1912.* The floodplain management provisions under the *Water Act 1912* have transitioned to the *Water Management Act 2000*, including the provisions of floodplain management plans and 'flood works' i.e. works that affect, or are likely to affect, flooding and/or floodplain functions.

Following introduction of the *Water Management Act 2000*, water sharing plans were developed that cover part of all of the proposal:

- *Water Sharing Plan for the Castlereagh River Unregulated and Alluvial Water Sources 2011*
- *Water Sharing Plan for the Macquarie Bogan Unregulated and Alluvial Water Sources 2012*
- *Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011*
- *Water Sharing Plan for the Murray-Darling Basin Porous Rock Groundwater Sources 2011*
- *Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003*
- *Water Sharing Plan for the Macquarie and Cudgegong Regulated Rivers Water Source 2016*
- *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012.*

A water sharing plan is generally in place for 10 years, but may be suspended from time to time under Section 49(a) of the Act due to severe water shortages.

To preserve water resources in river and groundwater systems for the future, the competing needs of the environment and water users are to be balanced. Water sharing plans establish rules for sharing water between the environmental needs of the river or aquifer and water users (for town water supply, rural domestic water supply, stock watering, industry and irrigation). The relevant requirements of these Acts have been considered in this assessment.

2.1.2 Dams Safety Act 2015

Safety of dams has been administered under the *Dams Safety Act 1978* (1978 Act) for the last forty years. In the absence of regulations, the Dams Safety Committee administered the 1978 Act by publishing guidance material for dam owners. The 1978 Act also had very limited penalty provisions.

In 2015, the *Dams Safety Act 2015* (2015 Act) replaced the 1978 Act. The 2015 Act requires a dams safety regulation to be enacted for dam owners to follow. The 2015 Act and Dams Safety Regulation 2019 commenced on 1 November 2019. The 2015 Act and Regulation include provisions to ensure that any risks to public safety, environment and assets relating to dams are of a level that is acceptable to the community. The Regulation identifies that a dam or proposed dam that is a prescribed dam within the meaning of the 1978 Act immediately before the repeal of that Act is a declared dam.

For the purposes of the 2015 Act, a dam or proposed dam may be declared to be a declared dam if:

- The dam has a dam wall that is more than 15 metres high.
- Is a dam that, if there were to be a failure of the dam, would cause major or catastrophic level of severity of damage or loss, or endanger the life of a person.

The 2015 Act would be applicable if works associated with the proposal function like a dam and any potential failure of the works would result in unacceptable risks to public safety, environment and assets. The relevant requirements of the 2015 Act have been considered in this assessment.

2.2 Policies and planning controls

2.2.1 NSW Flood Prone Land Policy

The NSW Flood Prone Land Policy is produced within section 1.1 of the *Floodplain Development Manual* (DIPNR, 2005). The manual highlights the requirements consistent with the *Water Act 1912* to manage the risks resulting from natural hazards in order to reduce the impact of flooding on individual owners and occupiers of flood-prone property and to reduce private and public losses resulting from floods. The manual "*promotes the use of a merit approach which balances social, economic, environmental and flood risk parameters to determine whether particular development or use of the floodplain is appropriate and sustainable*".

2.2.2 Flood Planning Guideline

On 31 January 2007 the NSW Planning Minister announced a guideline for development control on floodplains (the "Flood Planning Guideline"). An overview of the Flood Planning Guideline and associated changes to the EP&A Act and Environmental Planning and Assessment Regulation 2000 (EP&A Regulation) was issued by the then Department of Planning in a Planning Circular dated 31 January 2007 (Reference PS 07-003). The Flood Planning Guideline issued by the Minister in effect relates to a package of directions and changes to the EPA Act, EP&A Regulation and *Floodplain Development Manual* (DIPNR, 2005).

This Flood Planning Guideline confirms that unless there are "exceptional circumstances", councils are to adopt the 100 year flood (i.e. 1% AEP flood) as the flood planning level for residential development, with the exception of some sensitive forms of residential development such as seniors living housing. The Flood Planning Guideline does provide that controls on residential development above the 100 year flood may be imposed subject to an "exceptional circumstance" justification being agreed to by the Department of Natural Resources and the Department of Planning (both now incorporated into the Department of Planning, Industry and Environment (DPIE) (now DPE)) prior to the exhibition of a draft local environmental plan or draft development control plan.

DPE are currently proposing to provide an updated Flood Prone Land Package to provide land use planning advice to councils, however this has not yet been implemented at the time of finalising this report.

2.2.3 NSW Climate Change Policy Framework

The *NSW Climate Change Policy Framework* (OEH, 2016) summarises how the NSW Government intends to support the reduction of emissions to reduce the effects of climate change, and measures to adapt to the risks associated with climate change.

One of the policy directions is to reduce risks and damage to public and private assets in NSW arising from climate change. This has been considered in the design and assessment of the proposal by considering the projected climate for the year 2090 when carrying out the flood modelling (refer Section 3.7.3).

2.2.4 Local environmental plans

Local environmental plans (LEPs) are the principal planning controls for local councils, summarising permissible land uses throughout the local government area (LGA). The proposal is located within the Narromine Shire, Gilgandra Shire, Coonamble Shire, Warrumbungle Shire and Narrabri Shire Council LGAs and the current LEPs that are relevant to the proposal.

The LEPs include a clause on flood planning. The objectives of this clause are to:

- Minimise the flood risk to life and property associated with the use of land
- Allow development on land that is compatible with the land's flood hazard, taking into account projected changes as a result of climate change
- To avoid significant adverse impacts on flood behaviour and the environment.

The flood planning clause applies to:

- Land identified as "flood planning area" on the Flood Planning Map
- Other land at or below the flood planning level which is defined as the level of a 1:100 average recurrent interval (i.e. 1% AEP) flood event plus 0.5 metres freeboard.

The flood planning clause identifies that development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development:

- Is compatible with the flood hazard of the land
- Is not likely to significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties
- Incorporates appropriate measures to manage risk to life from flood
- Is not likely to significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses
- Is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

The provisions of these LEPs does not apply to State significant infrastructure projects, such as the proposal. The proposal will be assessed against the quantitative design limits (QDLs) that have been revised since the EIS was exhibited and are provided in Table 3.1. These QDLs apply outside the rail corridor, for events up to and including the 1% AEP flood event. The limits have been established in consultation with DPE and are based on relevant policies, planning controls and guidelines, other Inland Rail projects, and similar infrastructure projects in NSW.

2.2.5 Development control plans

Development control plans (DCPs) summarise the design guidelines that should be followed by developments within an LGA. DCPs typically include specific requirements for different land uses (e.g. rural, residential, and commercial), with respect to building envelopes, boundary offsets, stormwater management, driveway and road geometry, and other development features. DCPs also often contain controls for development on flood prone land, such as minimum floor levels for new buildings and flood effects caused by the development on other properties.

DCPs for the Narromine Shire, Gilgandra Shire, Coonamble Shire, Warrumbungle Shire and Narrabri Shire Council LGAs are applicable to the proposal. While the provisions of these DCPs do not apply to State significant infrastructure projects, such as the proposal, the relevant matters have been considered in this assessment.

2.2.6 Floodplain management plans

Floodplain management plans are being developed for rural floodplains as part of the transition from the floodplain management provisions of the *Water Act 1912* to the provisions of the *Water Management Act 2000* (Section 2.1.1).

Floodplain management plans provide the framework for coordinating flood work development to minimise future changes to flooding behaviour, improve the environmental health of floodplains, and increase awareness of the risk to life and property from the effects of flooding. Floodplain management plans establish management zones and rules that provide clarity about where flood works can be constructed on the floodplain and streamline the approval process for new and amended flood works.

Flood work approvals may be required to construct or use works situated in or near a river or floodplain and which are likely to have an effect on the distribution or flow of floodwater in times of flood. Examples of flood works include barrages, causeways, cuttings, embankments, levees to prevent inundation of flood waters, building pads and below ground channels.

While the provisions of floodplain management plans do not apply to State significant infrastructure projects, such as the proposal, the relevant matters have been considered in this assessment.

Existing floodplain management plans near the proposal are described below.

Floodplain Management Plan for the Macquarie Valley Floodplain 2021

The *Floodplain Management Plan for the Macquarie Valley Floodplain 2021* (NSW Government, 2021) applies to the area of the Macquarie Valley Floodplain that extends from about 25 kilometres north of Carinda to seven kilometres east of Narromine. The plan has been prepared under the *Water Management Act 2000* and commenced on 20 September 2021. The plan replaces the *Macquarie River (Narromine to Oxley Station) Floodplain Management Plan 2008*.

The proposal is located at the eastern extremity of the designated floodplain for the plan. The proposal intersects Management Zone CU which represents the urban area of Narromine where there is a separate floodplain risk management study and plan in place (Section 2.2.7).

Assessment criteria in the plan for approval of flood works in Management Zone CU that are relevant to drainage and hydraulic impacts on adjacent and other landholdings include:

- Maintain adequate drainage
- Redistribution of peak flood flow by no more than five per cent
- Flood levels increases no more than 100 millimetres
- Flow velocity increase of no more than 50 per cent, or by an amount that is likely to have more than a minimal impact on soil erodibility, taking into account the ground cover
- Minimise flood level increase and impact on high value infrastructure.

Consideration of the proposal against these criteria is provided in Section 7.6.

Floodplain Management Plan for the Upper Namoi Valley Floodplain 2019

The *Floodplain Management Plan for the Upper Namoi Valley Floodplain 2019* (NSW Government, 2019) is under the *Water Management Act 2000* and commenced on 7 June 2019. The plan covers the Namoi River and several of its major tributaries upstream of Narrabri.

The downstream boundary of the plan is located at the junction of the Namoi River and Jacks Creek, about 3.5 kilometres south east (upstream) of Narrabri. The proposal is located outside the designated floodplain of this plan and as such, is not considered further in this assessment.

Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020

The *Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020* (NSW Government, 2020) commenced on 11 September 2020. The plan covers the Namoi River from Narrabri to Walgett. The upstream boundary of the plan is at the junction of the Namoi River and Jacks Creek and adjoins the boundary of the *Floodplain Management Plan for the Upper Namoi Valley Floodplain.*

The Plan applies to construction and demolition of existing or proposed flood works including an access road, a supply channel, a stock refuge, an infrastructure protection work, an ecological enhancement work, an Aboriginal cultural value enhancement work and a heritage site enhancement work within the Lower Namoi Valley Floodplain.

Two design floods are defined in the Plan: The large design flood is the historic flood event of January/February 1971 flood (4% AEP flood event at the Namoi River at Mollee gauge GS 419039). The small flood event is the historic flood event of December 2004 flood (13% AEP at the Namoi River at Mollee gauge GS 419039).

The floodway network defined in the Plan is based on observed and modelled flood behaviour both for the small and large design floods. Areas with the depth-velocity product threshold of greater than or equal to 0.2 m^2/s are categorised as floodways in the Plan. Five peak discharge calculation locations for the historic flood event of 1971 are defined in the Plan and the location nearest to the proposal is located at Wee Waa.

The Plan identifies six management zones. The proposal intersects with the following management zones:

- Lower Namoi Management Zone AD includes areas of the floodplain where a significant discharge of floodwater occurs during floods, with relatively high flood flow velocity and depth. These areas are generally characterised by defined channels and banks.
- Lower Namoi Management Zone B includes areas of the floodplain that are important for the conveyance of floodwater during large flood events and for the temporary pondage of floodwaters during the passage of a flood.
- Lower Namoi Management Zone CU – includes urban areas where there is either a flood study, a floodplain risk management study, floodplain risk management plan, or areas that are protected by flood mitigation works, such as town levees.

Different rules and assessment criteria apply for approval of flood works in each Management Zone. In general, approval of any flood works within the management zones need to maintain adequate flood connectivity to flood dependent ecological assets, facilitation of fish passage, flood-dependent Aboriginal cultural values and flood-dependent heritage sites. In addition, hydraulic criteria based on changes in flood level, flow distribution, velocity and product of flood depth and velocity are also applicable to each management zone which are identified below.

Specific rules apply to the approval of new flood works, amending existing flood works and approval of certain other flood works within Management Zone AD. New flood works within Management Zone AD include the following:

- An access road
- A supply channel
- A stock refuge
- An infrastructure protection work
- An ecological enhancement work
- An Aboriginal cultural value enhancement work
- A heritage site enhancement work.

Approval of certain other flood works within Management Zone AD provides flexibility to landholders to reduce the width of the Lower Namoi Management Zone AD in localised areas (where the variation in width is justified by hydraulic modelling results), while maintaining the hydraulic integrity of the floodway network. A condition for approval of certain other flood works is that the flood work needs to be located on a flood flow corridor within the Lower Namoi Management Zone AD on the landholding on which the work is located is identified, and maintained, within the following range of maximum depth velocity products across the width of the flood flow corridor:

- Where there is an area of the landholding with an existing maximum depth-velocity product greater than or equal to 0.7 m^2/s, from that maximum depth-velocity product to a depth-velocity product of at least 0.5 m^2/s or less.
- Where there is an area of the landholding with an existing maximum depth-velocity product greater than or equal to 0.6 m^2/s but less than 0.7 m^2/s, from that maximum depth-velocity product to a depth-velocity product of at least 0.4 m^2/s or less.
- Where there is an area of the landholding with an existing maximum depth-velocity product greater than or equal to 0.5 m^2/s but less than 0.6 m^2/s, from that maximum depth-velocity product to a depth-velocity product of at least 0.3 m^2/s or less.

Approval of flood works within Lower Namoi Management Zone B needs to ensure that changes in flow distribution are less than five per cent, afflux is less than 0.2 metres, changes in velocity are less than 50 per cent and the proposed flood works have minimal impact on soil erodibility.

Approval of flood works within Lower Namoi Management Zone CU needs to maintain adequate flood connectivity to flood dependent ecological assets, facilitation of fish passage, flood-dependent Aboriginal cultural values and flood-dependent heritage sites. The proposed flood works need to ensure that changes in flow distribution are less than five per cent, afflux is less than 0.2 metres, changes in velocity are less than 50 per cent and the proposed flood works have minimal impact on soil erodibility.

Consideration of the proposal against these criteria is provided in Section 7.6.

2.2.7 Floodplain risk management plans

Floodplain risk management plans are generally prepared for urban floodplains to address the existing, continuing and future flood risk in accordance with NSW Government's Flood Prone Land Policy (Section 2.2.1) and Flood Planning Guideline (Section 2.2.2).

While the provisions of floodplain risk management plans do not apply to State significant infrastructure projects, such as the proposal, the relevant matters have been considered in this assessment.

Existing floodplain risk management studies and plans near the proposal are described below.

Consideration of the proposal against these floodplain risk management plans is provided in section 7.6.

Narromine Town Floodplain Risk Management Study and Plan Update

The main objective of the Narromine Town Floodplain Risk Management Study and Plan Update (Lyall & Associates, 2021) was to review the Narromine Floodplain Risk Management Study and the Narromine Floodplain Risk Management Plan, both of which were prepared by Lyall & Associates in 2009. Other objectives of the Narromine Floodplain Risk Management Study and Plan Update were to:

- Refine the definition of flooding at Narromine using contemporaneous computer modelling techniques
- Reassess the impacts of flooding on the community
- Review existing Council policies as they relate to development of land in flood liable areas
- Consider options for the management of flood affected land
- Develop a contemporaneous Floodplain Risk Management Plan for the town.

The Plan is based on the following mix of measures which have been given a provisional priority ranking according to a range of economic, social, environmental and other criteria set out in the report (Lyall & Associates, 2021):

- **Measure 1** – Update wording in the Narromine Local Environmental Plan 2011 (Narromine LEP 2011).
- **Measure 2** – Improvements to planning and development controls for future development in flood prone areas through the update of Narromine Shire Development Control Plan 2011 (Narromine Shire DCP 2011). The minimum habitable floor level for residential land use types is the level of the 1% AEP flood event plus freeboard, whereas for commercial and industrial land use types the minimum habitable floor level is to be as close to the 1% AEP flood level plus freeboard as practical but no lower than the 2% AEP flood level plus freeboard. The minimum habitable floor level for flood vulnerable residential development, critical utilities and uses, and essential community facilities located on the floodplain at Narromine is the 0.5% AEP flood event plus 0.5 metres freeboard.
- **Measure 3** – Improvements to emergency response planning.
- **Measure 4** – Increase public awareness of the risks of flooding in the community.
- **Measure 5** – Design and construction of a levee along the southern bank of the Macquarie River in combination with the upgrade of the existing railway culverts at Webbs Siding.
- **Measure 6** – Development and implementation of a Vegetation Management Plan for the banks of the Macquarie River at Narromine.

Narrabri Floodplain Risk Management Study and Plan

A floodplain risk management plan for Narrabri is currently being prepared. The following reports have been prepared as a part of development of the floodplain risk management study and plan:

- *Narrabri Floodplain Risk Management Study and Plan, Volume I: Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully* (WRM, 2019a).
- *Narrabri Floodplain Risk Management Study and Plan, Volume I: Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully, Addendum 1 – February 2020 Validation* (WRM, 2020a).
- Draft *Narrabri Floodplain Risk Management Study and Plan, Volume II: Floodplain Risk Management Study* (WRM, 2020b).

These reports are summarised in more detail in Section 3.3.5.

2.2.8 Local flood plans

Local flood plans, prepared by the State Emergency Service (SES) as part of broader local disaster plans, outline the preparations, responses and recovery actions that are to be undertaken prior to, during and following a major flood event. A number of local flood plans have been prepared for the area within the vicinity of the proposal:

- *Gilgandra Shire Local Flood Plan* (SES, 2008)
- *Warrumbungle Shire Flood Emergency Sub Plan* (SES, 2013)
- *Narromine Shire Flood Emergency Sub Plan* (SES, 2014)
- *Narrabri Shire Flood Emergency Sub Plan* (SES, 2015).

Assessment of the proposals impact on emergency management arrangements in the local flood plans is provided in Section 7.9.

2.3 Guidelines

2.3.1 Australian Rainfall and Runoff

Australian Rainfall and Runoff (Ball et al., 2019) (ARR 2019) is a national guideline for the estimation of design flood characteristics in Australia. The approaches presented in ARR 2019 are essential for policy decisions and projects involving:

- Infrastructure such as roads, rail, bridges, dams and stormwater systems
- Flood management plans for urban and rural communities
- Flood warnings and flood emergency management
- Estimation of extreme flood levels.

Reference was made to ARR 2019 in developing the methodological framework for assessing potential impacts of the proposal on hydrology, flooding and water quality.

2.3.2 Floodplain Risk Management Guide

The NSW Office of Environment and Heritage has developed this guide (OEH, 2019) to assist local councils to transition to ARR 2019 when developing and implementing floodplain risk management plans under the process outlined in the *Floodplain Development Manual* (DIPNR, 2005). New South Wales has developed a range of specific advice and techniques including the following that take precedence over ARR 2019:

- Estimating initial and continual losses, pre-burst and burst losses in NSW Catchments
- Consideration of climate change impacts
- Defining the PMF for flood risk management purposes
- Review and update of rating curves at river gauge locations
- What to look for in reviewing studies and models for transition to ARR 2019.

2.3.3 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia

Australian Disaster Resilience Handbook 7, Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (Australian Institute for Disaster Resilience, 2017) provides guidance on best practice in flood risk management in Australia. This handbook aims to encourage practice that works towards the vision that *floodplains are strategically managed for the sustainable long-term benefit of the community and the environment, and to improve community resilience to floods*.

The handbook promotes the consideration and management of flood impacts to existing and future development within the community and it aims to improve community flood resilience using a broad risk management hierarchy of avoidance, minimisation and mitigation to:

- Limit the health, social and financial costs of occupying the floodplain
- Increase the sustainable benefits of using the floodplain
- Improve or maintain floodplain ecosystems dependent on flood inundation.

The handbook emphasises the need for understanding flood behaviour so that the full range of flood risk to the community can be understood, effectively communicated and, where practical and justifiable, mitigated. The handbook facilitates informed decisions on the management of this risk, and economic investment in development and infrastructure on the floodplain.

2.3.4 Flood hazard

Flood preparedness, flood hazard and emergency management guidelines have been developed and are available from the SES local flood plans (Section 2.2.8) (2008, 2013, 2014 and 2015). The *Australian Disaster Resilience Handbook 7, Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (Australian Institute for Disaster Resilience, 2017) and ARR 2019 also provide guidelines in respect to hazard categorisation (Figure 2.1) and management.

These guidelines were considered in defining existing flood hazard (H1 to H6 identified in Figure 2.1) for the full range of flood events. In order to provide a consistent and simplified commentary on impacts of the proposal on flood hazard, flood hazard categories H1 and H2 are referred to as “low” hazard and flood hazard categories H3 to H6 are referred to as “high” hazard.

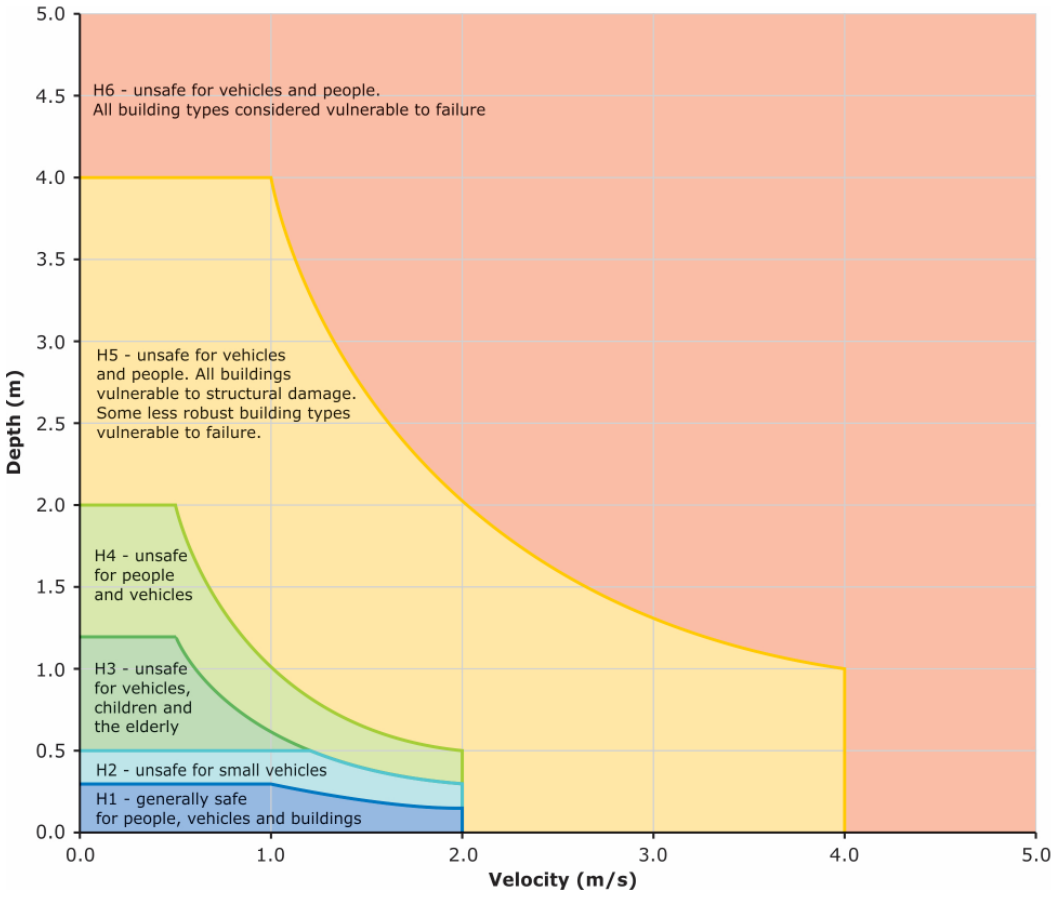


Figure 2.1 Combined flood hazard curves (ARR 2019)

2.3.5 Engineering standards and guidelines

The reference design has been developed in accordance with relevant engineering standards and guidelines. In particular:

- ARTC Code of Practice – Section 10 – Flooding (ETG-10-01, ARTC 2006)
- ARTC Code of Practice – Section 10 – Flooding Technical Note (ETC-10-02, ARTC 2016)
- ARTC's *Engineering Practices Manual, Civil Engineering, Track Drainage – Design and Construction* (RTS3433, ARTC, 2013)
- Australian Standard AS7637:2014 – Hydrology and Hydraulics.

The Inland Rail *Climate Change Risk Assessment Framework* (ARTC, 2019) provides a standard approach to climate change risk assessment and mitigation across all Inland Rail projects. In accordance with the framework a specific climate change risk assessment was undertaken for the proposal. The framework is consistent with a number of other guidelines including:

- *AS 5334-2013 Climate change adaptation for settlements and infrastructure – a risk-based approach and satisfy climate risk*
- *AS/NZS ISO 31000-2009 Risk management – principles and guidelines*
- The climate adaptation requirements of the ISCA infrastructure sustainability rating tool
- ARTC's Inland Rail Project Risk Management Framework
- *Floodplain Risk Management Guidelines – Practical Consideration of Climate Change* (DECC, 2007).

It has also taken into consideration state specific guidance documents, such as Transport for NSW's *Climate Risk Assessment Guidelines* (TfNSW, 2018), which in turn, has been informed by *Climate Change Impacts & Risk Management A Guide for Business and Government* (Australian Greenhouse Office, 2006).

3 Assessment methodology

3.1 Definitions

3.1.1 Study area

The study area for the hydrology and flooding investigation is considered the area that may be affected (directly or indirectly) by the proposal (Figure 3.1). The analysis focussed on watercourses and associated floodplains that the proposal would cross.

Regional floods, typically due to flooding from major rivers and watercourses, affect a significant portion of the three river basin catchments in the study area – the Macquarie River, Castlereagh River and Namoi River basins as detailed in Section 5.1.1.

3.1.2 Terminology

Hydrology

Hydrology refers to the estimation of runoff from a catchment. Runoff is generated when rainfall hits the ground. For any given catchment, the relationship between rainfall and runoff can be used to predict peak flow rates at a nominated discharge point by considering the catchment's characteristics including, but not limited to, its area, terrain, soil type, shape, land use, vegetation coverage, areas of inundation and water storage. Surface water in the study area mainly comprises ephemeral watercourses and the regulated Macquarie and Namoi rivers.

Hydraulics

Hydraulics is the term given to the study of water flow in waterways. In particular, the evaluation of flow parameters such as water level and velocity.

Flood event

A flood event can be either:

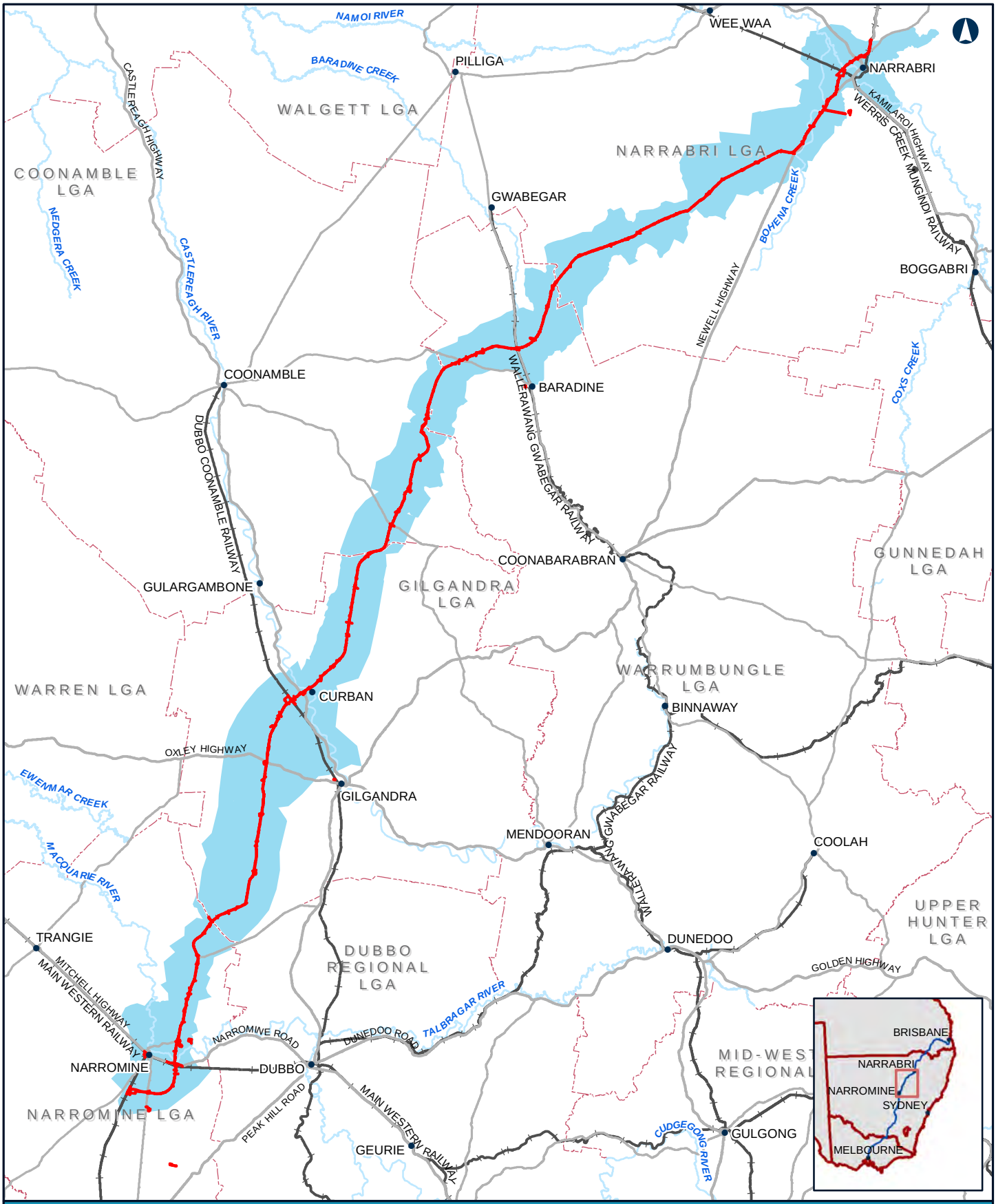
- A historical flood event for which information on rainfall, flood extent, flood levels, stream flow data is available.
- A design flood, based on a statistical analysis of long-term flow records from stream gauges or modelling of the flood response to design (synthetic) rainfall events.

The relative magnitude of a design flood event is generally described in terms of an annual exceedance probability (AEP), which relates to the likelihood of a flood of a given size (or larger) occurring in any given year. For example, a 5% AEP flood event has a five per cent (one in 20) chance of occurring in any given year. Historical flood events may be compared with a design flood event to obtain an estimate of the likelihood (in terms of AEP) of that specific event occurring.

Average recurrence interval (ARI) was a term used previously to define the probability of design flood events. It was defined as the average period between occurrences equalling or exceeding a given value. The use of terms such as "recurrence interval" and "return period" are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years.

Structure

A structure in this report usually refers to a culvert or bridge that allows water to pass under an embankment (such as a rail embankment). Structures many be either single cell (one opening) or multi-cell (multiple openings).



NARROMINE TO NARRABRI Study Area Figure 3.1

0 10 20
Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:1,100,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Flood Study Area
- LGA Boundary
- Railway

INLAND RAIL ARTC

The Australian Government is delivering Inland Rail through the Australian Rail Track Corporation (ARTC), in partnership with the private sector.

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3.2 Flood planning level and quantitative design limits

3.2.1 Flood planning level

For the Inland Rail (IR) program, ARTC has defined the flood planning level (or flood immunity) as follows for greenfield works:

"Flood immunity and serviceability limit state AEP shall be 1% at the shoulder corner of the formation capping" (ARTC ETD-10-02 – Track and Civil Code of Practice – Section 10).

ARTC's decision to nominate this as the Flood Planning Level (FPL) took into consideration the following:

1. The need to provide an adequate level of flood immunity to minimise route disruptions, not just from an individual catchment perspective, but also from a network operations perspective.
2. The need to attain a level of flood immunity that was broadly consistent with current infrastructure planning approaches and standards.
3. The need to avoid excessively high levels of formation flood immunity which could increase flood risk to external receptors during extreme events (notwithstanding the fact that other engineering constraints can often dictate the rail vertical alignment in floodplain locations).
4. The need to consider cost optimisation, noting the project is financed through government funding.
5. The need to consider the potential effects of climate change over the lifetime of the proposal.
6. The need to consider hydrologic and hydraulic uncertainty.
7. The need to set an FPL that facilitates management of flood risk to the floodplain/floodplain receptors, and to the rail line.

Further supporting information for the adopted 1% AEP FPL is provided in the Technical Note in Appendix M.

The embankments have been designed so that the 1% AEP is no higher than the formation shoulder. In most areas the embankments are higher than this to allow for such things as grade separations, geotechnical stability of the embankment and smooth grading of the alignment. The only areas where the formation may be lower than the 1% AEP flood level is at the southern and northern tie-ins to the existing tracks. The minimum free board between the top of rail (LOW RAIL on cross sections) and the 1% AEP flood level and will always be at least 640 millimetres (250 millimetres ballast, 220 millimetres sleeper, 170 millimetres rail).

An assessment of flood events that would overtop the proposal is provided in Section 7.12.

3.2.2 Quantitative design limits

Since exhibition of the EIS closed in February 2021, ARTC and DPE have continued to progress criteria for evaluating modelled changes in flood behaviour between existing and developed conditions. In the EIS, these criteria were referred to as Flood Management Objectives (FMOs) and covered changes in flood afflux, velocity (scour and erosion), hazard and duration. These objectives have been developed to provide a suite of quantitative design limits that can be used to measure changes against.

Changes in evaluation criteria between the previous FMOs and the new QDLs have resulted in differences in the number of affected buildings and land areas reported in this Updated Flooding and Hydrology Assessment Report from the previous version that was exhibited as Technical Report 3. In particular, buildings have now been classified as having habitable floors or non-habitable floors and the change in flood behaviour reported against these.

The QDLs are listed in Table 3.1. They:

- Apply to land outside the proposal boundary and to roads and level crossings within the rail corridor.
- Do not apply to model noise. Model noise is an artefact of the modelling process and does not provide any useful information and is not the same as model tolerance.
- Apply to any flood up to and including the 1% AEP event and of any duration.
- Include allowance for modelling uncertainties and tolerances.
- Do not apply to post-development scenario areas of:
  - For flood hazard, locations where post-development case dv product is less than 0.1 m2/s
  - For flood duration, inundated areas less than 100 m^2

Where flooding impacts from the reference design have been assessed as being within these limits, the change in flood behaviour is considered to be minimal.

With regard to flood impact to public roads, and acknowledging the QDLs set out in Table 3.1, network trafficability / route severance / inundation-depth considerations may justify case-specific increases to the QDL, in agreement with the relevant road authority.

The following definitions apply to the QDLs:

- Afflux means the increase in flood level resulting from implementation of the proposal.
- Erosive threshold velocity (ETV) means the velocity at which water movement has the potential to create scour or erosion. The erosive threshold of the soil/ground cover/vegetative conditions shall be established from an assessment by a suitably qualified specialist. In the absence of such assessment being undertaken an erosive threshold of 0.5 m/s shall be assumed.
- Flood hazard means the increase in depth-velocity product (dv) and/or flood hazard category (H) resulting from implementation of the proposal.
- Flood duration means the increase in duration of inundation resulting from implementation of the proposal.
- Habitable floors (also referred to as habitable buildings) are defined consistent with the use of this term in the *Floodplain Development Manual* (DIPNR, 2005). In a residential situation this comprises a living or working area such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. In an industrial, commercial or other building, this comprises an area used for an office or to store valuable possessions, goods or equipment susceptible to flood damage in the event of a flood.
- Non-habitable floors (also referred to as non-habitable buildings) are all floor areas other than habitable floors as defined in Table 3.1.
- Urban and infrastructure land includes surrounds of residential buildings, other urban, open space recreational land and infrastructure (excluding sensitive infrastructure).
- Rail corridor means the railway infrastructure landholdings and land burdened by a registered instrument to the rail corridor, for example by an easement, covenant or other restriction of use.
- Residential buildings includes premises in urban or built-up areas, and houses on rural residential and on rural properties.
- Scour/erosion potential means the increase in flood velocity resulting from implementation of the proposal.

- Sensitive infrastructure consists of fixed public infrastructure essential to operate in emergency events, such as water treatment plant, telecommunications and electricity substations.

Managing QDL departures

Where changes in flood behaviour caused by the proposal exceed the agreed QDLs, a more detailed assessment would be completed as part of the detailed design and, where practical, the reference design would be modified to reduce the flooding impacts within the QDL criteria.

At locations where it is not practicable to meet the QDLs, ARTC will manage these departures in accordance with the conditions of approval.

Table 3.1 Quantitative design limits

(These QDLs are only applicable beyond the rail corridor (including drainage control areas), unless otherwise noted, and do not apply to model noise[1])

Parameter	Land use or setting / scenario	Performance limit	Key changes from QDOs nominated in Technical Report 3 (December 2020)
Afflux (i.e. increase in flood level resulting from implementation of the proposal)	Habitable floors and sensitive infrastructure[2]	10 mm increase[3]	No change
	Non-habitable floors[2]	20 mm increase	Increased from previous objective of 10 mm
	Urban and infrastructure land – the Surrounds of residential buildings, other urban, open space recreational land and infrastructure (excluding sensitive infrastructure)	100 mm increase	Decreased from previous objective of 200 mm
	Agricultural	200 mm increase	No change
	Other non-urban land -–Forest and unimproved grazing land	300 mm increase	Decreased from previous objective of 400 mm
	Classified roads managed by Transport for NSW[4]	50 mm on areas flooded under existing conditions. Otherwise no increase[5]	New criteria added for TfNSW classified roads
	Highways and sealed roads >80 km/hr[4]	No afflux where aquaplaning risk exists and remains unmitigated. Otherwise 50 mm increase.	Increased from previous objective of 10 mm and note re aquaplaning included
	Unsealed roads and sealed roads < 80 km/h[4]	100 mm increase	Changed from previous criteria of 10% change in length of overtopping
Scour / erosion potential (i.e. increase in flood velocity resulting from implementation of the proposal)	Sealed surfaces – ground surfaces that have been sealed or otherwise protected against erosion. This includes roads and most urban, commercial, industrial, recreational and forested land.	20% increase in velocity where existing velocity already exceeds 1 m/s[6]	Change – quantitative limit rather than site assessed and with reference to NSW Blue Book. Velocity increases limited to 1 m/s or 20% increase on existing velocity.
	Other areas including watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas	An erosion threshold velocity (ETV) is to be adopted through a site specific assessment(s) conducted by an experienced geotechnical or scour/erosion specialist.[7] An ETV of 0.5 m/s is to be adopted in the absence of a site specific assessment(s). Where existing velocity exceeds ETV, velocity is limited to a 0.025 m/s increase. Where existing velocity is less than ETV, velocity is limited to the lesser of: • ETV • 20% increase in existing velocity or 0.5 m/s, whichever is greater	Change – quantitative limits rather than reference to NSW Blue Book. Velocity increases limited to lesser of 20% increase on existing velocity or the ETV.
Flood hazard (i.e. increased in depth velocity- product (dv) and/or flood hazard category resulting from implementation of the proposal) (does not apply where dv <0.1 m^2/s)	Urban, commercial, industrial, highways and sealed roads[4]	10% increase in dv	Change – Limit of 10% increase in dv, rather than a target of minimising increases in flood hazard
	Classified roads managed by Transport for NSW[4]	10% increase in dv where this does not result in an increase in hazard category. Otherwise, no increase.[8]	New criteria added for TfNSW classified roads.
	Elsewhere	20% increase in dv	Change – Limit of 20% nominated, rather than a target of minimising increases in flood hazard

[1] Model noise is an artefact of the modelling process and does not provide any useful information and is not the same as model tolerance. All modelling noise exclusions are to be reviewed by the independent reviewer during detailed design
[2] Habitable floors/rooms are defined consistent with the use of this term in the NSW Floodplain Development Manual. In a residential situation this comprises a living or working area such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. In an industrial, commercial or other building, this comprises an area used for an office or to store valuable possessions, goods or equipment susceptible to flood damage in the event of a flood.
[3] 10 mm has been set to provide a margin for modelling uncertainties/tolerances. The intent of this requirement is that existing flood levels above floor level do not increase
[4] Including where located within rail corridor (including drainage control areas)
[5] Any afflux on newly inundated section of road must be negotiated with the roads authority during detailed design.
[6] Local variations in velocity can exceed 20% change provided that when assessed over a 30m wide flowpath, the velocity change on average does not exceed 20%.
[7] Shear stress assessments may be used as an alternative method from which to describe the erosion threshold in a specific environment (i.e. soil type, depth, velocity). An erosion threshold shear stress (**ETSS**) can be used as an alternative to the ETV to ensure the erosion threshold is not exceeded beyond the limits of this velocity QDL. (If the ETSS is used, compliance with the limiting increases in velocities specified within this QDL are also required).
[8] Any variation must be negotiated with the roads authority during detailed design

Parameter	Land use or setting / scenario	Performance limit	Key changes from QDOs nominated in Technical Report 3 (December 2020)
Flood duration	Habitable floors[2]	Where existing above floor flooding is: • less than 1 hour in flood duration, the post-development flood duration shall not exceed 1 hour • greater than 1 hour in duration, up to 5% increased inundation duration Where existing below floor flooding is: • less than 1 hour in flood duration, the post-development flood duration shall not exceed 1 hour • greater than 1 hour in duration, up to 10% increased inundation duration	Change – QDL values quantified, rather than a target of minimising increases
	Classified roads managed by Transport for NSW[4]	No increase in duration of flood inundation to sections of road not already inundated[8]. Otherwise 10% increase in inundation duration.	New criteria added for TfNSW classified roads
	Highways and sealed roads >80 km/hr[4]	10% increase in inundation duration.	Change – QDL values quantified, rather than a target of minimising increases
	Elsewhere	Where existing inundation is less than 1 hour in flood duration, the post-development flood duration shall not exceed 1 hour. Where existing inundation is greater than 1 hour in flood duration, up to 10% increase in duration of inundation No duration limits apply to newly flooded land no greater than 1000 m^2 in area	Change – QDL values quantified, rather than a target of minimising increases

3.3 Review of available data

3.3.1 Local government areas

The proposal is located within the Narromine, Gilgandra, Warrumbungle, Coonamble and Narrabri LGAs.

3.3.2 Climate

The Central West region of NSW has a warm temperate climate, with large variations between summer and winter temperatures. Summers are hot and sunny with rainfall typically occurring as thunderstorms or short and intense storm events. Winters are cool and sunny with occasional cold fronts that bring periods of prolonged light rainfall.

A number of long-term Bureau of Meteorology (BoM) meteorological recording stations are located within or adjacent to the study area (refer to Figure 3.2), as listed in Table 3.2.

Table 3.2 Meteorological recording stations

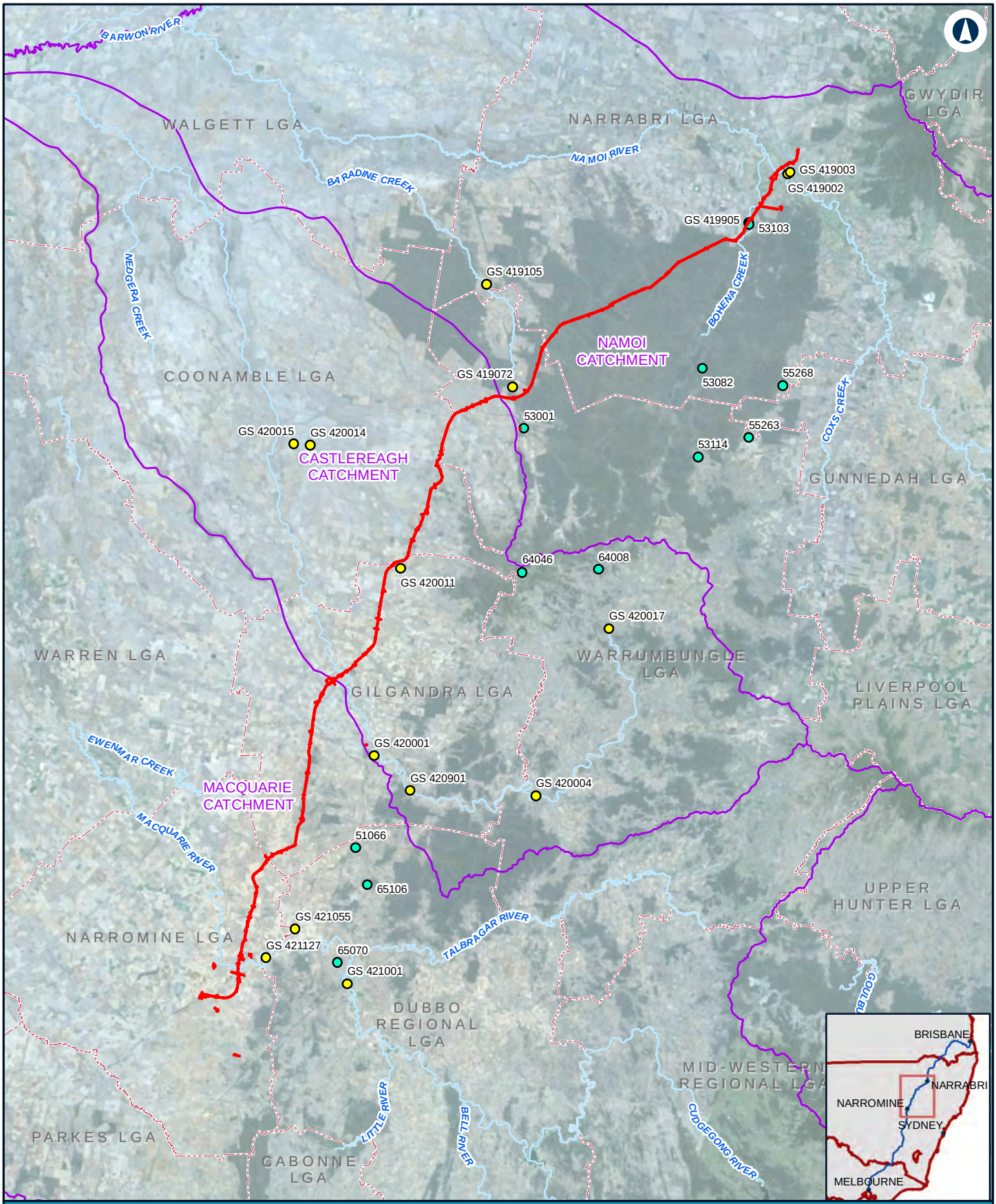
Station ID	Station name	Historical reporting period
420003	Belar Creek at Warkton	1951 to present
421078	Macquarie River at Burrendong Dam	1967 to present
421146	Gum Cowal at bifurcation	1987 to present
421148	Cudgegong River at Windamere Dam	1986 to present
421178	Molong Creek at downstream Borenore Creek	2002 to present
421198	DPI-Orange auto weather station	2017 to present
064015	Mendooran Post Office	1886 to present
064024	Gilgandra	1902 to present

The mean annual rainfall recorded at these stations varies along the proposal site. The average annual rainfall is about 640 millimetres. Rainfall occurs relatively uniformly throughout the year, with higher variability during summer and autumn due, in part, to the influence of the *El Nino Southern Oscillation* (i.e. the El Nino – La Nina cycle).

Design rainfalls

Rainfall depths for the design events between 50% AEP and 0.05% AEP were extracted from BoM's 2016 Design Rainfall Dataset for each catchment. Assessment of the design rainfall is in accordance with *Australian Rainfall and Runoff* (Ball et al, 2019) and includes consideration of sub-daily rainfall events and high intensity short duration events. Design storm events with durations ranging from 15 minutes up to 168 hours were considered to ensure the critical duration was represented in the flood modelling (refer to the calibration report in Appendix J for further information). Probable maximum precipitation depths were estimated based on the *Generalised Short- Duration Method* (BoM, 2003). Rainfall depths for the 0.01% AEP event were estimated based on log-normal interpolation technique presented in ARR 2019.

It is recognised that the 1955 flood event was the largest recent flood event in this region. While the rainfall and streamflow gauge records do not include this event, the assessment has been undertaken in accordance with *Australian Rainfall and Runoff* (Ball et al, 2019), which provides an appropriate methodology for the estimation of floods in the absence of any site-specific information.



NARROMINE TO NARRABRI Rainfall and streamflow gauging stations Figure 3.2

0 20 40 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:1,367,020
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Major river catchment
- Watercourse
- Rainfall Gauge
- Stream Gauge

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3.3.3 Terrain

Four sets of topographical data covering the study area were obtained:

- Survey model obtained through Light Detection and Ranging (LiDAR) survey and aerial imaging
- Elevation Information System (ELVIS)
- Digital Elevation Model (DEM) obtained through Shuttle Radar Topography Mission (SRTM)
- Localised site survey

The adopted terrain model is presented in Figure 3.3, which shows the general landform adjacent to the study area. This was formed from LiDAR (where available) and SRTM outside the LiDAR corridor.

LiDAR

A topographic survey model was obtained through LiDAR imaging provided by ARTC. The LiDAR data provided by ARTC was captured by AAM Pty Ltd in 2015, 2017 and 2018. Data validation showed a vertical accuracy (root mean square error) of 0.079 metres and a standard deviation of 0.078 metres.

ELVIS

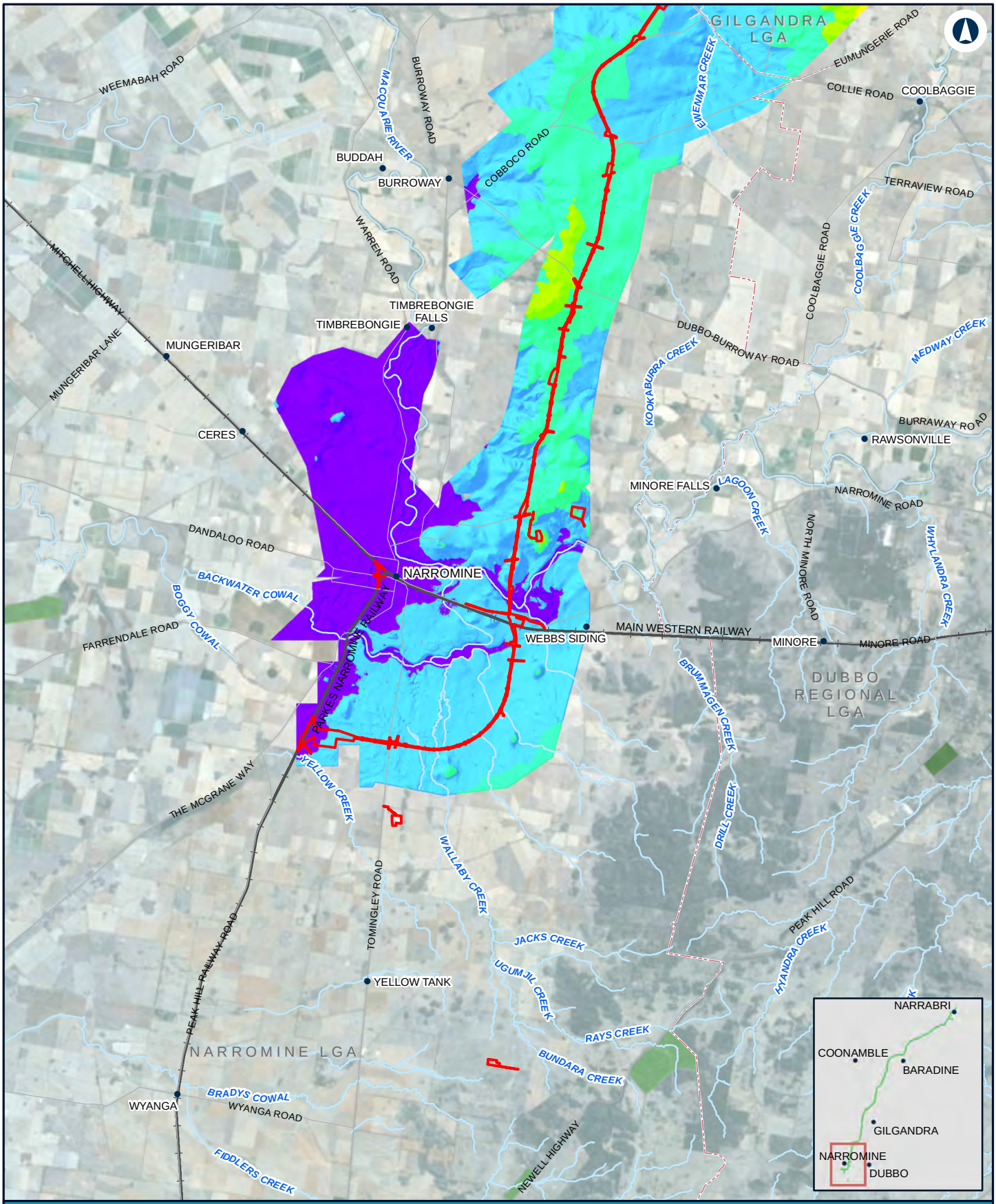
The Geoscience Australia provides processed one metre and five metre DEMs for most of NSW through ELVIS (www.elevation.fsdf.org.au). These DEMs are based on LiDAR and other surveys undertaken on behalf of state and federal governments. These DEMs were used to supplement LiDAR data provided by ARTC to represent terrains for the hydraulics models.

Shuttle radar

Topographic data generated by the SRTM program was used for terrain outside the LiDAR corridor where necessary to define broader catchment boundaries. The resolution of the Digital Elevation Model is about 30 metres. The reported vertical accuracy of the data is plus or minus 10 metres

Site survey

As part of investigations for the proposal, existing culverts, bridges, channel cross sections and historic flood marks identified by landowners were surveyed in May 2019. The surveyed features are located on Crown land, road reserves and private properties with land access was available. In total, 46 culverts were surveyed and geographical coordinates, basic dimensions, field notes and photographs were captured for each culvert. Geographical coordinates, basic dimensions, field notes and photographs were also collected for eight bridges. Twenty channel cross sections were surveyed. Landowners provided information on historic flood levels for two locations. One historic flood mark is located in Narromine and the other historic flood mark is located in Narrabri. It is to be noted that the survey was based on the NSW CORS / SmartNet network, where the typical expected horizontal accuracy is plus or minus 50 metres.



NARROMINE TO NARRABRI Corridor and catchment topography Figure 3.3a

0 3.5 7 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:248,130
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- 300.1 - 320

Elevation (m AHD)

- 200.1 - 220
- 220.1 - 240
- 240.1 - 260
- 260.1 - 280
- 280.1 - 300

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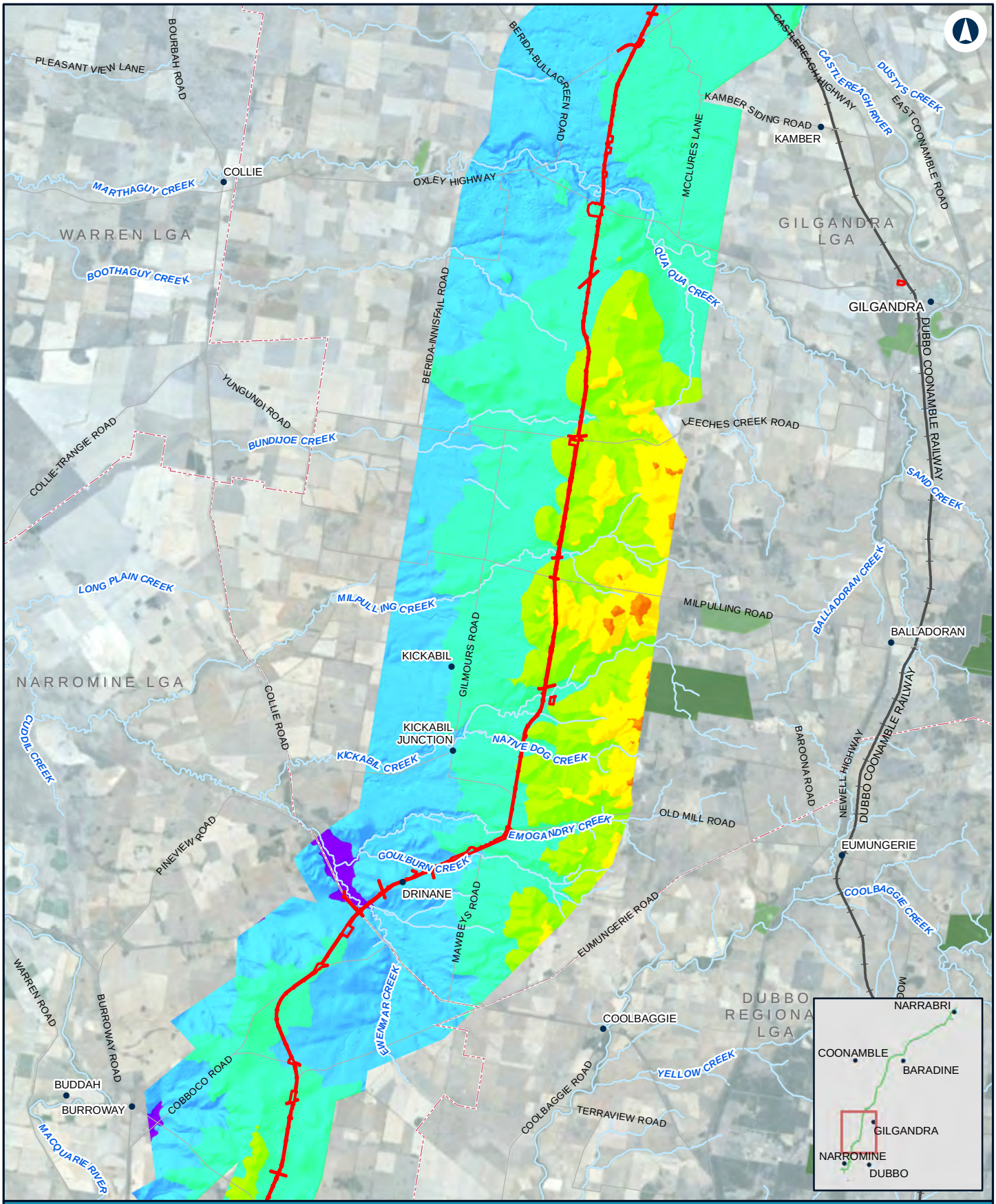

NARROMINE TO NARRABRI Corridor and catchment topography Figure 3.3b

0 3.5 7 Km

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:248,130
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- **Elevation (m AHD)**
- 200.1 - 220
- 220.1 - 240
- 240.1 - 260
- 260.1 - 280
- 280.1 - 300
- 300.1 - 320
- 320.1 - 340

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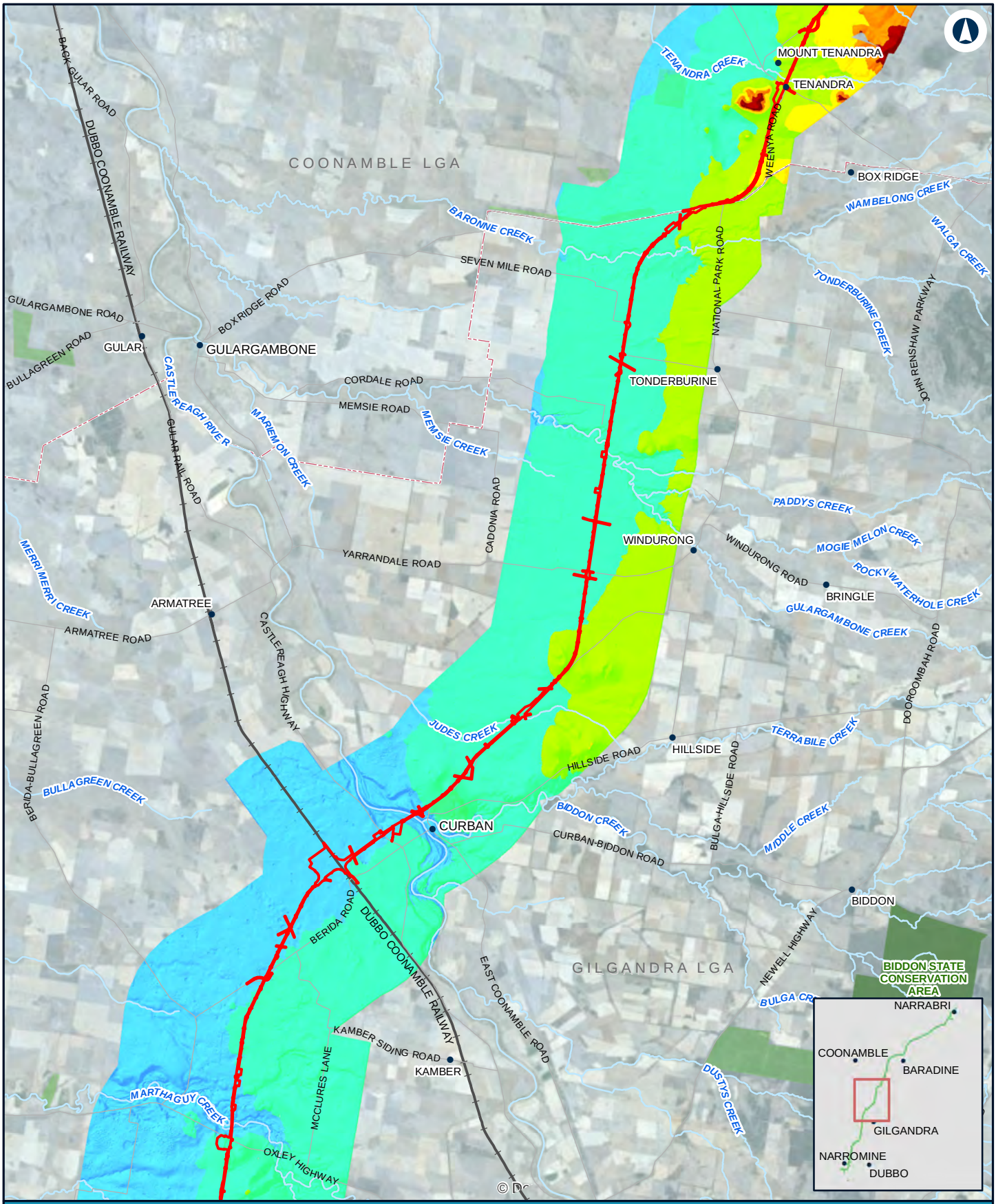

NARROMINE TO NARRABRI Corridor and catchment topography Figure 3.3c

0 3.5 7 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:248,130
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- **Elevation (m AHD)**
- 200.1 - 220
- 220.1 - 240
- 240.1 - 260
- 260.1 - 280
- 280.1 - 300
- 300.1 - 320
- 320.1 - 340
- 340.1 - 420

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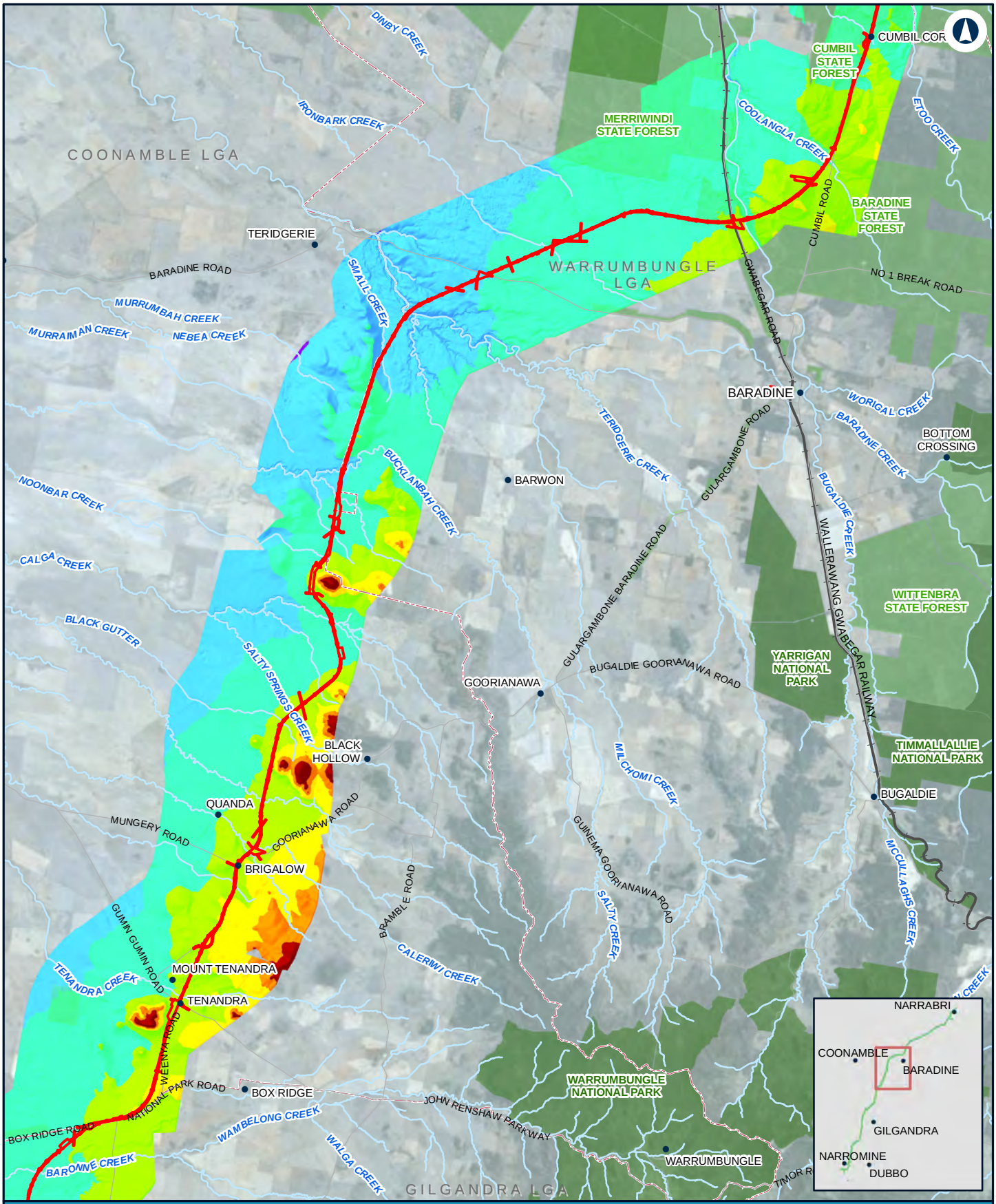

NARROMINE TO NARRABRI

Corridor and catchment topography

Figure 3.3d

0 3.5 7 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:248,130
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- **Elevation (m AHD)**
- 220.1 - 240
- 240.1 - 260
- 260.1 - 280
- 280.1 - 300
- 300.1 - 320
- 320.1 - 340
- 340.1 - 420

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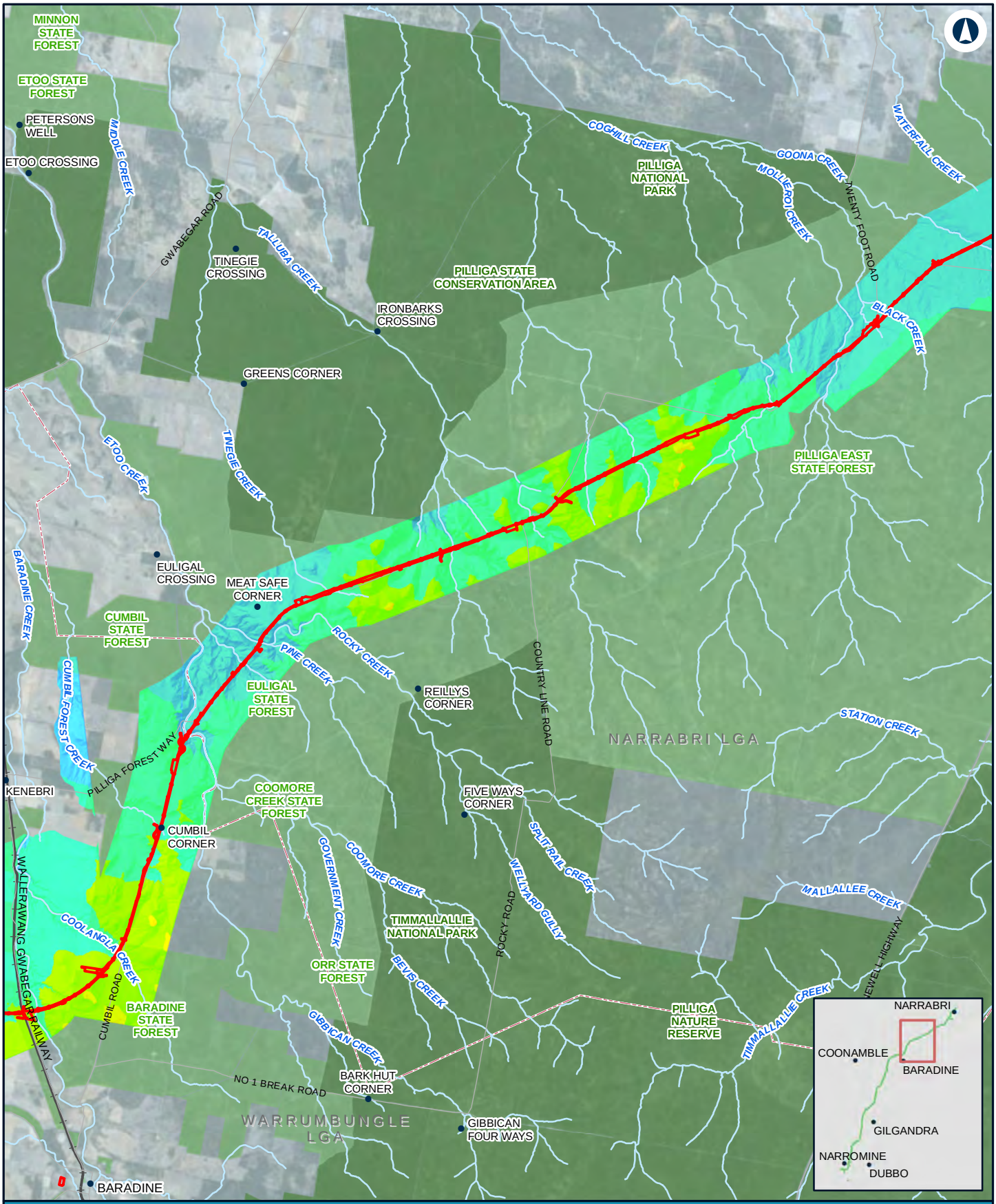

NARROMINE TO NARRABRI Corridor and catchment topography Figure 3.3e

0 3.5 7 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:248,130
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- **Elevation (m AHD)**
- 184.1 - 200
- 200.1 - 220
- 220.1 - 240
- 240.1 - 260
- 260.1 - 280
- 280.1 - 300
- 300.1 - 320

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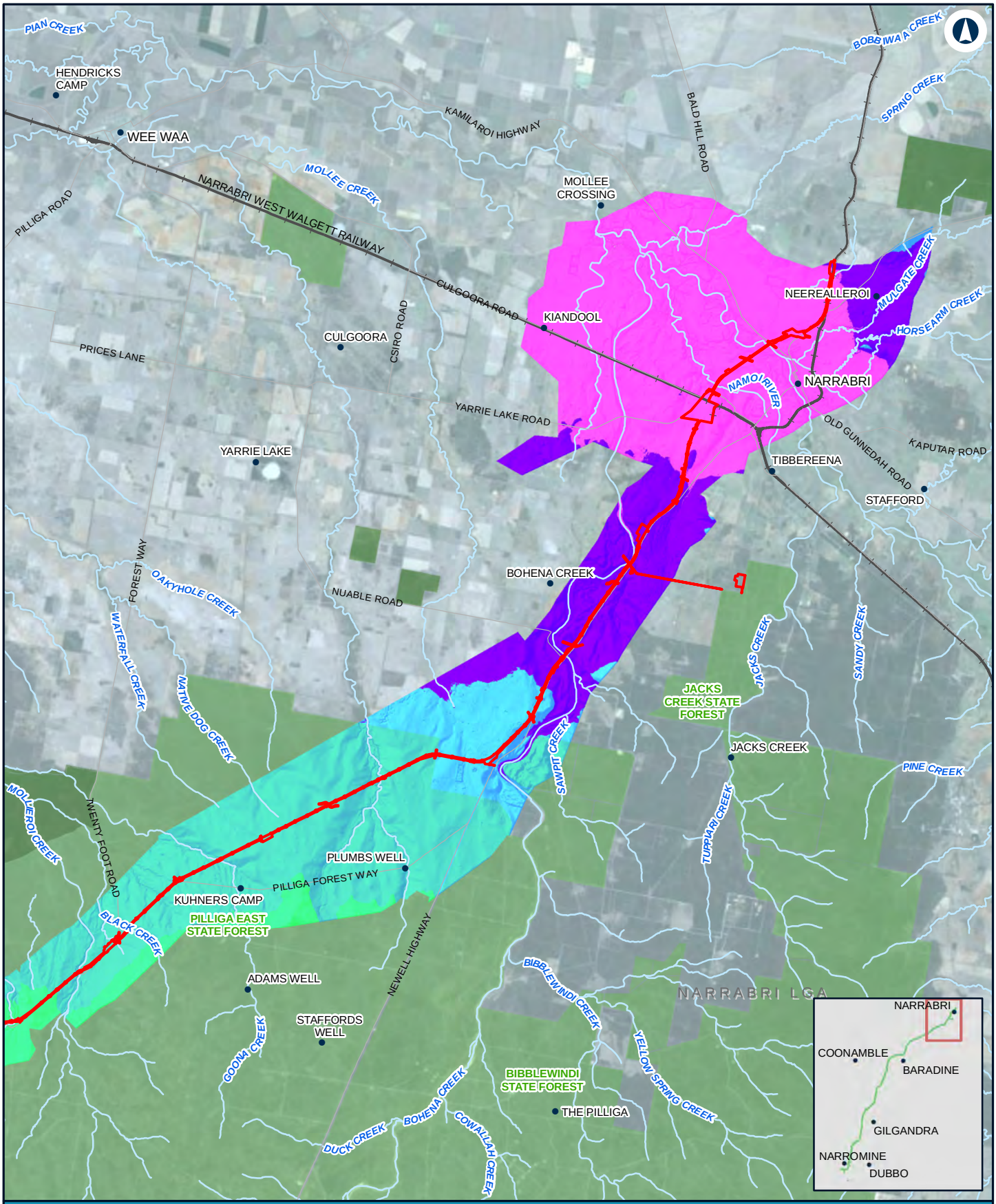

NARROMINE TO NARRABRI Corridor and catchment topography Figure 3.3f

0 3.5 7 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:248,130
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- 280.1 - 300

Elevation (m AHD)

- 184.1 - 200
- 200.1 - 220
- 220.1 - 240
- 240.1 - 260
- 260.1 - 280

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3.3.4 Stream gauge data

Historical flood level and flow data was extracted from publicly available databases (http://waterinfo.nsw.gov.au/, https://realtimedata.waternsw.com.au/ and PINNEENA (a surface and groundwater monitoring database released by NSW Government). The extracted data was then subject to a flood frequency analysis (refer to the calibration report in Appendix J for further information) to determine the magnitude of design floods based on the historical data.

The gauging stations (refer to Figure 3.2) considered in the analysis are listed in Table 3.3.

Table 3.3 Flow gauging station considered in assessment

Station No	Station Name	Gauging period	Catchment area (km^2)
419002	Namoi River at Narrabri	1890 to 2015	25,400
419003	Narrabri Creek at Narrabri	1891 to present	24,400
419905	Bohena Creek at Narrabri	1995 to present	2,180
419072	Baradine Creek at Kenebri No. 2	1995 to 2011	995
419105	Baradine Creek at Gwabegar	2011 to present	-
421001	Macquarie River at Dubbo	1966 to present	19,600
421127	Macquarie River at Baroona	1986 to present	25,700
420001	Castlereagh River at Gilgandra	1909 to 2000	6,350
420004	Castlereagh River at Mendooran	1968 to present	3600
420011	Baronne Creek at near Gulargambone	1983 to 1999	398
420014	Magometon Creek (Site 3) at near Coonamble	1969 to 2002	540
420015	Warrana Creek at Warrana	1969 to 2002	583
420017	Castlereagh River at Hidden Valley	1980 to present	1166
420901	Castlereagh River at Lucas Bridge	1999 to present	-
421055	Coolbaggie Creek at Rawsonville	1980 to present	626

3.3.5 Previous flood studies and models

At the commencement of this investigation publicly available historical flood information was sourced. Available information was limited to the major rivers within the study area. During this investigation there has been consultation with Councils, agencies and landowners to obtain further information on both historical flooding, design flood predictions and current studies.

Below is a summary of the publicly available recent flood studies relevant to the proposal.

Narrabri Floodplain Risk Management Study and Plan, Volume I: Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully

The *Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully* (WRM, 2019a) updated the *Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully* (WRM, 2016) which examined the regional flooding from the Namoi River (catchment area 25,400 square kilometres and local catchment flooding from Mulgate Creek (catchment area 202 square kilometres) and Long Gully (catchment area 28 square kilometres) at Narrabri.

The stage discharge rating curve was reviewed in detail and the rating curve was updated through hydraulic modelling (WRM, 2016). The regional design discharges at Narrabri were estimated from an annual series flood frequency analysis of the combined recorded flows at the two stream gauges (Namoi River at Narrabri (GS419002) and Narrabri Creek at Narrabri (GS419003)). All available flood information for Narrabri dating back to 1890 (126 years from 1890 to 2015) was included in the analysis. A Log-Pearson Type III distribution was fitted to the annual series of recorded (and inferred) peak flood discharges at Narrabri using the Bayesian inference methodology recommended in ARR 2019 using the TUFLOW FLIKE software. The 1% AEP design discharge at Narrabri was estimated at 4,860 m^3/s, which was slightly lower than the historical 1955 flood of the Namoi River. The estimated AEP of the 1955 flood is between one per cent and 0.5 per cent.

The design discharges from the catchment areas of Mulgate Creek and Long Gully were updated (WRM, 2019a) using a XP-RAFTS model and guidelines presented in ARR 2019. XP-RAFTS design discharge estimates for the local catchments were validated against results from Regional Flood Frequency Estimate (RFFE) program (Ball et al, 2019).

A ground surface digital terrain model (DTM) of the floodplain around Narrabri was provided by NSW Government Land and Property Information. The DTM was based on LiDAR data captured in January 2014. The DTM and surveyed topographic data were used to develop a computer based MIKE-FLOOD FM (flexible mesh) hydrodynamic model to simulate the flow behaviour of the Namoi River, Narrabri Creek and local creeks within the study area. The MIKE-FLOOD FM model was calibrated against three regional flood events of February 1955, February 1971 and July 1998 and two local flood events of December 2004 and February 2012.

Hydraulic modelling of the study area was undertaken to derive design flood levels, depths and extents for the 20%, 10%, 5%, 2% and 1% AEP flood events and an extreme flood. Preliminary flood hazard mapping and flood emergency response classifications were also prepared.

This flood modelling data (WRM, 2016) and the report were available for this assessment. Review of the MIKE-FLOOD FM hydraulics model indicated significant updates would be needed to make the model suitable for assessing flood behaviour for the proposal. Hence, a new TUFLOW hydraulics model was developed for Narrabri, consistent with other hydraulic models developed for the entire proposal. Details on the hydraulic model development are provided in Section 3.4.2.

Narrabri Floodplain Risk Management Study and Plan, Volume I: Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully, Addendum 1 – February 2020 Validation (WRM, 2020a)

Narrabri and surrounds experienced heavy rainfall between 7 to 10 February 2020. Modelled flood behaviour for the flood event of February 2020 was validated against anecdotal reports. A reasonably good representation of the depth and extent of the February 2020 flood was predicted by the MIKE-FLOOD FM model along Horsearm Creek and Doctors Creek. Predicted flood extents along lower Mulgate Creek appear to be moderately overestimated. Predicted peak flood levels are in reasonable agreement but on average marginally lower than the anecdotal data.

Draft Narrabri Floodplain Risk Management Study and Plan, Volume II: Floodplain Risk Management Study (WRM, 2020b)

The draft *Narrabri Floodplain Risk Management Study and Plan* (WRM, 2019b) has been prepared for Narrabri Shire Council to manage the existing, future and continuing and future flood risk at Narrabri. This draft report was made available to ARTC in August 2021. As the report has not yet been formally endorsed by Narrabri Shire Council, a detailed summary is not provided within this report.

The township of Narrabri is prone to flooding from the Namoi River and from the local creek catchments of Mulgate Creek/Horsearm Creek and Long Gully. Flooding in the Namoi River poses the greatest flood risk for most residents, but the main Narrabri town area and the Narrabri North Industrial Estate have significant exposure to both regional and local catchment flooding.

Draft Bohena Creek Flood Study

The draft *Bohena Creek Flood Study* (WRM, 2019b) was prepared for Narrabri Shire Council to investigate and define existing flood risk at a proposed development site between Yarrie Lake Road and Culgoora Road. The extents of the WRM (2019b) study are located within the study area for the proposal.

The primary focus of the study was to map the flood risk for the design events across the proposed development site. An XP-RAFTS hydrologic model and TUFLOW hydraulic model calibrated to two historical flood events, the September 1998 event and December 2004 event, were developed for the assessment.

Further commentary on flood estimates from Bohena Creek is provided in Section 7.6.

Baradine

The *Teridgerie Creek at Baradine Floodplain Risk Management Study and Plan* (Lyall & Associates, 2012) defines flood behaviour of Teridgerie Creek for the township of Baradine. The study area includes the upper reach of the creek and includes the western parts of the township.

The extents of this study are not within the study area for the proposal.

Gulargambone

The *Gulargambone Flood Study Report* (Jacobs, 2016) defines flood behaviour for the township of Gulargambone due to flooding from the Castlereagh River and Gulargambone Creek.

The extents of this study are not within the study area for the proposal.

Gilgandra

The *Gilgandra Floodplain Management Study* (Lyall & Associates, 1996) provides a summary of the flood behaviour of the Castlereagh River, within the vicinity of Gilgandra. The largest historical flood occurred in 1955, reaching a height of 10.05 metres at the local river gauge. Lyall & Associates (1996) estimates that this event was about equivalent to the 1% AEP flood event. The 1955 flood resulted in significant flooding of the township, damaging commercial and residential properties.

The study presents a number of options for the management of future flood events, ranging from the installation of a flood warning system to the construction of a levee. These options were reviewed by the *Review of Gilgandra Floodplain Risk Management Study* (URS, 2012) (as discussed above), who recommended a scoping study to investigate the feasibility of various levee options, including temporary flood levees, and adoption of flood planning levels within the township.

Flood models and data from this study were not available for use in this assessment.

Narromine

The *Narromine River Bank Levee Feasibility Study* (Lyall & Associates, 2013) examined flood events around Narromine. Narromine has an existing levee that provides protection against the more frequent and smaller floods but is expected to overtop during flood events larger than the 1% AEP event.

Flood models developed by Lyall & Associates for the 2013 feasibility study were provided by Narromine Shire Council for use in this study. The TUFLOW hydraulics model provided by Council has been extended, principally to include the Backwater Cowal within the two-dimensional model domain, and the updated TUFLOW model has been re- calibrated to the historical events.

Following the above feasibility study, the *Narromine Town Levee Concept Design* (SMEC, 2019) presents the results of an investigation and the preliminary design for a new levee that protects the main part of the town of Narromine and its aerodrome from a 1% AEP flood event. The proposed levee is located within the study area for the proposal.

The report provides an assessment of four levee alignment routes, a discussion on the freeboard analysis for adopting an appropriate design crest level, geotechnical investigation and design, and a concept design of the levee options.

Preliminary design details and drawings were prepared with the crest level of the levee options set at 0.75 metres above the 1% AEP flood level. Quantity estimates and a separate Preliminary Environmental Investigation (PEI) report were also prepared.

The report recommends subsequent community consultation, a thorough environmental impact statement, and further hydraulic modelling should be completed prior to progressing to detailed design.

Macquarie River Floodplain Management Plan

The *Draft Floodplain Management Plan for the Macquarie Valley Floodplain 2018* (Department of Industry, 2018) assessed flood behaviour in the lower reaches of Ewenmar Creek and Marthaguy Creek. The study area for the proposal is located at the eastern extremity of the designated floodplain for the plan. The hydrology and hydraulics models utilised in the assessment of flood behaviour for Ewenmar Creek and Marthaguy Creek were not available for use in this assessment.

3.3.6 Building floor levels

Surveyed floor levels of buildings, where available, have been used to define depth of flooding above floor levels of buildings. Surveyed floor levels were used for approximately 2,800 buildings based on surveyed levels provided by Narrabri Shire Council or survey undertaken by ARTC. In the case of buildings without surveyed floor levels, ground levels at the centroid of buildings have been extracted from the best available DEM to define floor levels of buildings on the assumption that floor levels are located 0.3 metres above ground level. This was checked against surveyed floor level data provided by Narrabri Shire Council and found to provide a good estimation of floor levels.

In accordance with the mitigation measures (Section 8) additional survey, assessment and modelling would be undertaken during detailed design to confirm the floor levels of buildings and determine if the proposal could be modified so that flooding characteristics are not worsened or minimised as far as practicable, up to and including the 1% AEP event.

3.4 Flood modelling

Hydrologic and hydraulic computer models were used to simulate flows (with rain on grid inputs) and flood behaviour in all watercourses crossed by the proposal. Hydrologic models are used to represent the upstream catchment areas and simulate the rainfall and runoff processes to derive flood hydrographs. Hydraulic models are then used to translate these flood hydrographs into flood levels, flow velocities and the extent of flood inundation.

The modelling undertaken for the flooding and hydrology assessment considered flows in all catchments in accordance with the methodology in ARR 2019. The modelling included a comprehensive calibration and validation process to determine appropriate model parameters.

A summary of the hydrologic and hydraulic model development and calibration is provided in Section 3.4.1 and Section 3.4.2, while a detailed hydrology and hydraulics model calibration report is provided in Appendix J.

3.4.1 Hydrological modelling

Hydrological modelling and analysis provides a means for identifying contributing catchment areas and estimation of runoff and streamflow generated by the catchment areas upslope of the study area. The length of the proposal site meant that the rainfall runoff response of hundreds of ungauged catchments needed to be estimated.

A tiered method for the estimation of runoff response of each sub- catchment area was adopted utilising the available topographic data as follows:

- Rainfall-runoff models and hydrological analyses provided by local councils were reviewed and where practical updated and used to estimate the local catchment hydrology based on the methods outlined in ARR 2019. An XP- RAFTS model representing the catchment areas of Mulgate Creek and Long Gully was provided by Narrabri Shire Council (WRM, 2016). This XP-RAFTS model was reviewed and considered suitable for use in this study.
- For the major watercourses, where sufficient historical streamflow data is available, at-site flood frequency analyses (FFA) were undertaken (refer to the calibration report in Appendix J for further information), based on the methods outlined in ARR 2019 to estimate peak flows for flood events up to and including the 0.5% AEP event.
- For the remaining catchment areas, new rainfall-runoff hydrology models were developed.

Model selection

The runoff- routing model RORB developed by Laurenson and Mein (2010) was selected for developing new hydrology models for this study. RORB is identified as one of the suitable hydrology models in ARR 2019. RORB is one of the most widely used models of its type in Australia, and consequently there is a good deal of information available on the value of model parameters for a wide range of catchments. RORB is a general runoff and streamflow routing program that is used to calculate flood hydrographs from rainfall and other channel inputs. It subtracts losses from rainfall to determine rainfall excess and routes this through catchment storages to produce streamflow hydrographs at points of interest. The model is spatially distributed, non- linear, and applicable to both rural and urban catchments. It makes provision for both temporal and areal distribution of rainfall as well as losses, and can model flows at any number of points throughout the catchment.

Model configuration

RORB hydrology models were developed for the catchment areas of waterways crossed by the proposal excluding the catchment areas of Mulgate Creek and Long Gully Creek for which XP-RAFTS hydrology models were provided by Narrabri Shire Council.

Sub-areas for the RORB model were delineated using the SRTM data combined with a GIS layer of watercourses and satellite imagery. The sub-areas within each RORB model are defined to coincide with watershed boundaries and stream junctions. At the catchment scale, the proportion of imperviousness represented by houses and roads are considered negligible and therefore are not included in the models. All links are defined as natural channel type. Sub-areas for the RORB model and channel lengths were measured in GIS.

Model calibration

In the case of gauged catchments, excluding the catchment areas of the Macquarie, Castlereagh and Namoi river basins, RORB hydrology models for Baradine Creek, Bohena Creek and Coolbaggie Creek, an intended donor catchment which is not crossed by the proposal, were calibrated and verified against recorded stream flow data. Generally, at least, three historical flood events were selected for calibration and verification of the RORB models for gauged catchments. The events were selected though a review of the available stream flow and sub-daily rainfall data.

Estimation of runoff hydrographs for design storm events

Design hydrographs for a range of flood events from the 50% AEP to the probable maximum flood (PMF) event were estimated using the methods provided in ARR 2019.

Based on calibration and verification results, and in consideration of recommendations in ARR 2019, the hydrology models were parameterised as follows:

- Calibrated models – median rainfall losses and median model parameter values from calibration results and rainfall losses for the PMF event based on ARR 2019.
- Uncalibrated models – a conservative approach was adopted in selecting rainfall losses based on calibration results from adjacent catchment (where available) and ARR 2019 Data hub losses. RORB model parameter values were based on ARR 2019. The same XP- RAFTS model parameter values used in the council flood study for Narrabri (WRM, 2016) were adopted in this assessment.

The ensemble event method of peak discharge estimation, as detailed in Chapter 3.3.2 of Book 4 of ARR 2019, was adopted for selecting peak discharges, critical storm durations and temporal patterns for all points of interest. Points of interest include inflow locations defined in the TUFLOW hydraulics models and watercourses crossed by the proposal.

In the case of the Macquarie, Castlereagh and Namoi river basins, the following approach was adopted to estimate runoff hydrographs for the full range of flood events up to and including the PMF:

- Peak flows for flood events up to and including the 0.5% AEP event were based on at-site FFA. Hydrographs simulated by the RORB models were scaled based on the FFA.
- Peak flows for the PMF event were estimated based on PMF estimates for South Eastern Australia and maximum observed floods in the world (Nathan et al, 1994) for similar sized catchments. Peak flows for flood events between the 0.5% AEP and the PMF event were estimated through interpolation.
- Peak flows for intermediate events between 0.5% AEP and the PMF event were estimated through log-normal interpolation.
- Hydrographs simulated by the RORB models were scaled based on the adopted peak flows.

Validation of design discharge estimates

Calibrated RORB models

Estimated peak discharges for the full range of flood events between 50% AEP and the 1% AEP event were compared against at-site FFA results and the RFFE tool, provided by ARR 2019.

Uncalibrated RORB models

Estimated peak discharges for the full range of flood events between 50% AEP and the 1% AEP event were compared against the RFFE tool, provided by ARR 2019.

3.4.2 Hydraulics modelling

Rainfall runoff hydrographs simulated by hydrology models were input into hydraulics models to define flood levels, flood depths and velocities in the channels and on the floodplains which are traversed by the proposal.

Model selection

TUFLOW (BMT, 2018), which is a combined one-dimensional (1D) and two-dimensional (2D) hydraulics model, was used in this assessment for developing new hydraulics computer models. TUFLOW is an industry-standard flood modelling platform identified in ARR 2019.

Model development

Fourteen TUFLOW hydraulics models were developed using the available topographic and land use data to define flood behaviour along the proposal. Extents of the hydraulics models are shown in Figure 3.4 and the extent of the proposal covered by each hydraulics model is shown in Table 3.4. Each hydraulics model covers a portion of the proposal site and an area of the floodplain upslope and downslope sufficient to capture any potential upstream breakouts, changes in flood behaviour due to the proposal and relatively free from backwater influences.

Table 3.4 Extent of the proposal represented in each hydraulics model

TUFLOW model	Description	Start chainage (km)	End chainage (km)
Narromine Flood Model (NFM)	Macquarie River and Wallaby Creek	547.00	569.40
N2N14	Minor watercourses	566.39	594.88
N2N13	Ewenmar Creek to Bundijoe Creek	593.34	624.82
N2N11-12	Boothaguy Creek to Castlereagh River	623.91	657.63
N2N10	Judes Creek to Gulargambone Creek	654.34	681.24
N2N9	Baronne Creek to Tenandra Creek	677.64	697.45
N2N8	Mungery Creek to Calga Creek	696.95	717.56
N2N7	Noonbar Creek to Coolangla Creek	717.56	754.75
N2N6	Cumbil Forest Creek to Tinegie Creek	754.75	775.67
N2N5	Talluba Creek	775.67	785.82
N2N4	Rocky Creek to Coghill Creek	785.82	797.54
N2N23	Mollieroi Creek to Bundock Creek	797.54	818.86
N2N1	Bohena Creek	818.86	843.89
Narrabri	Namoi River and Narrabri Creek	833.70	853.00

The adopted grid size for all TUFLOW models is 10 metres. The hydraulics model topography was defined from DEMs provided by ARTC (refer Section 3.3.3) and DEMs extracted from ELVIS (refer Section 3.3.3). Surface roughness was based on typical industry standard values for different land use types identified from GIS layers (e.g. land use and planning layers for NSW) and aerial photography, and was adjusted through the model calibration process (refer to the calibration report in Appendix J for further information).

Bridges were generally modelled in two dimensions as flow constrictions. In general, a generic approach in combination with blockage due to piers at the new bridges was adopted for all but NFM and Narrabri TUFLOW models. A detailed analysis was undertaken to define energy loss coefficients for the proposed Macquarie River and Narrabri bridges. Typically, culverts were modelled as one-dimensional elements to capture the hydraulic response of each culvert and to allow for the simple modification of the number of culverts and dimensions. Details on the existing culverts and bridges were sourced from the hydraulics models for Narrabri and Narromine provided by councils, topographic survey undertaken for the proposal, information from Transport for NSW and identified based on a review of terrain data and aerial imagery.

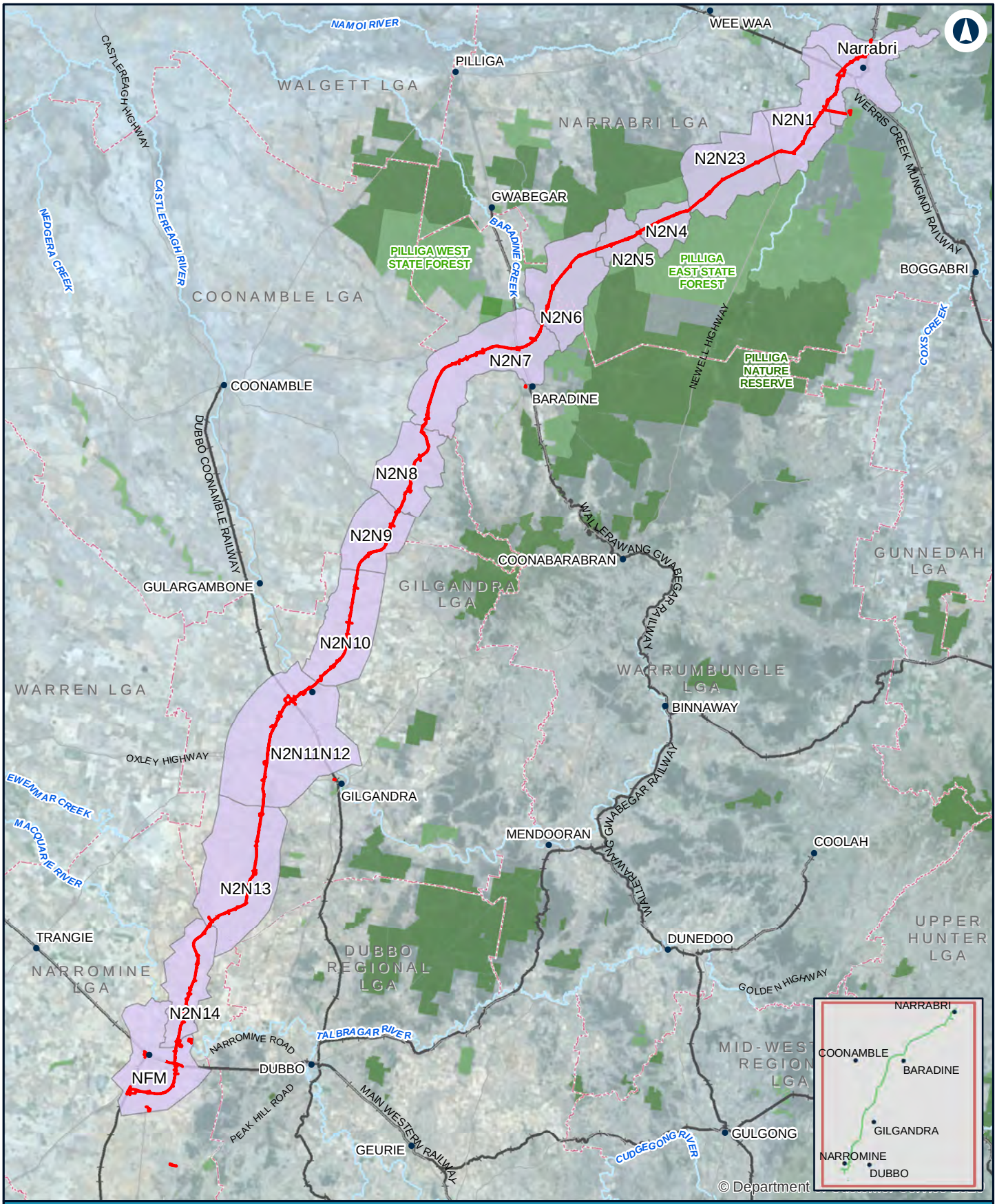
Model calibration and verification

Five TUFLOW hydraulics models were calibrated against observed stream data as follows:

- Narromine (NFM) was calibrated against flood events of August 1990, August 1998, November 2000 and November 2010.
- Baronne Creek (N2N9) was checked against the flood events of January 1995 and July 1998.
- Baradine Creek (N2N7) was calibrated against flood events of July 1998 and December 2007.
- Bohena Creek (N2N1) was calibrated against flood events of July and September 1998.
- Narrabri (Narrabri) was calibrated against regional flood events of February 1995, February 1971 and July 1998, and the local catchment flood events of December 2004 and February 2012.

In general, acceptable calibration results were achieved for all five TUFLOW models.

Limited stream data was available to verify three TUFLOW models. The models for Narromine (NFM) and Narrabri (Narrabri) were verified against flood behaviour modelled in council flood studies for design flood events. The Bohena Creek (N2N1) model was verified against the current stage and discharge rating curve adopted by WaterNSW for the stream gauge located at Newell Highway bridge (gauging station number 419905). Satisfactory verification results were obtained for the three TUFLOW models.



NARROMINE TO NARRABRI Hydraulic model extents Figure 3.4

0 10 20 Km

Coordinate System: GDA 1994 MGA Zone 55

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LEGEND

- The proposal
- Hydraulic model extent

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3.4.3 Design flood event simulation

The TUFLOW hydraulic models were used to define existing flood behaviour for the range of design flood events using flood hydrographs simulated by the RORB hydrology models (Section 3.4.1). Model results were processed to define peak flood depths, peak flood levels, peak velocities, flood hazard categories and duration of inundation above 0.5 metres depth of flooding for all channels and floodplains crossed by the proposal at 10 metre grids. The 0.5 metres depth of flooding was selected for duration of inundation analysis on the basis of the following considerations:

- A typical depth of flooding likely to impact on land uses such as crops, pastures and grazing.
- Buildings with slab on ground are likely to be impacted by flooding.
- A 0.5 metres freeboard above the 1% AEP event is typically adopted by local councils for defining flood planning level for residential development.

A geo-database was created in GIS for each selected design flood event to identify peak flood depths, peak flood levels, peak velocities, flood hazard categories and duration of inundation above 0.5 metres depth of flooding for further analysis. The geo-databases were used to generate flood maps and define flood behaviour along the proposal site.

3.4.4 Landowner validation of modelled flood behaviour

As part of consultation activities with landowners (refer Section 4.2), flood maps prepared for the existing 1% AEP event were presented to 117 landowners to confirm acceptance of modelled flood behaviour. Eighty landowners confirmed reasonable accuracy of the flood mapping, seven landowners identified the need for partial updating of flood mapping and eleven landowners requested revision/ updating of flood mapping. Nineteen landowners had no comments or declined to comment on the acceptability of flood mapping.

A review of responses provided by two landowners identifies that local flood behaviour in minor water courses and localised obstructions (e.g. banks, vegetation etc.) need to be represented in detail to update flood mapping in two localised areas. Five landowners did not provide any information to explain the reasons for partial updating of the maps. Differences between observed and modelled flood behaviour in localised areas were also identified as the main reason for revision/updating of flood mapping by two landowners.

The owner of a property in Narromine identified that the property was flooded during the flood event of 1955 which was equivalent to about a 1% AEP event. However, the property is not impacted in the modelled 1% AEP event. A review of the available information (Bewsher, 1998) suggests that floodwaters broke out from the Macquarie River near Webbs Siding in the 1955 flood event due to failure of the railway embankment. These floodwaters moved through the railway culvert and over the washed out section of the railway line and joined with Backwater Cowal. Differences between the 1955 observed flood behaviour and modelled flood behaviour are likely to be due to how the existing rail embankments are represented in the flood model. The flood modelling for the proposal is based on the existing embankment at Webbs Siding remaining during a flood and would not be washed out due to overtopping of the embankment.

A separate study was however completed to model flood behaviour if the existing Narromine to Dubbo rail line were to be overtopped and fail during an extreme flood event in the future. Results are presented in Section 7.12.

All other embankments within the study area are assumed to remain standing during a flood which is considered the most appropriate approach given the high degree of uncertainty in trying to predict or simulate the failure of embankments due to flooding.

3.5 Updated flood modelling for the PIR

The following updates to the flood modelling have occurred for the PIR.

3.5.1 Narromine TUFLOW model

The factors used to scale inflow hydrographs in the Narromine TUFLOW model have been updated based on BMT's independent review. The updated factors have resulted in minor reduction in peak inflows for the selected sub-catchments. Additional hydraulic structures have been included in the TUFLOW model to reduce afflux, particularly parallel to Pinedean Road.

3.5.2 TUFLOW models N2N14, N2N13, N2N11-12, N2N10 and N2N9

The RORB hydrology models have been updated and the TUFLOW models updated to remove double routing of inflow hydrographs as per BMT's Independent review comments. In addition, the N2N11-12 TUFLOW model has been updated to reflect a minor change in the alignment at Nancarrows Road, to the south of the Oxley Highway.

3.5.3 Narrabri model – Mulgate Creek local catchment flooding

In order to be consistent with the Narrabri Floodplain Risk Management Study, flood behaviour for Narrabri has been assessed separately due to local catchment flooding and regional flooding. The Narrabri TUFLOW model was run separately to simulate flood behaviour due to regional flooding in the Namoi River at Narrabri and local catchment flooding in Mulgate Creek and Long Gully. No flooding in Mulgate Creek and Long Gully was considered for simulating regional flooding for Narrabri. However, minor flows in the Namoi River were included for simulating local catchment flooding for Narrabri. Peak discharges in the Namoi River were adopted from council flood study (WRM, 2016) for all flood events up to the 1% AEP event and the PMF event. Discharges for flood events between the 1% AEP event and the PMF were interpolated. A comparison of predicted flood depth maps due to local catchment flooding between this study and council flood study (WRM, 2019a) showed that flood extents for the 1%, 5% and 20% AEP events are generally similar between the two studies.

3.6 Design process

3.6.1 Formation and structures design

The TUFLOW hydraulic models representing the existing conditions were updated to represent the proposed works for the operational phase of the proposal. In particular, the rail formation, culverts, bridges, roads and other works which have the potential to impact on flood behaviour were represented in the TUFLOW models. It is not proposed to construct any permanent spoil mounds within the proposal site. The management of excess spoil from the proposal, including reuse in rehabilitation of borrow pits, is discussed further in the EIS.

An iterative approach was used to identify the size of each structure required to minimise the flood impacts associated with the proposal. The TUFLOW models representing the operational phase of the proposal were initially run for the selected design flood events to satisfy the flood immunity requirement for the proposal and then several iterations were undertaken to minimise flooding impacts in the 1% AEP event. A schematic summarising the design process for the identification of the required culverts and bridges is included Figure 3.5. The term 'exit' used in the figure refers to the completion of the design process once afflux values were within the target range, or minimised as far as practical, using feasible structure sizes.

Culverts and bridges have been located around existing drainage lines, watercourses and within floodplains and associated overflow areas. This will minimise changes to natural flow patterns and water flow within and to farms. All culverts would be designed to minimise risks of any damage to surrounding land and infrastructure and would include appropriate scour protection as described in Section 7.4. the potential for blockages of bridges and culverts has been considered as described in Section 3.7.4.

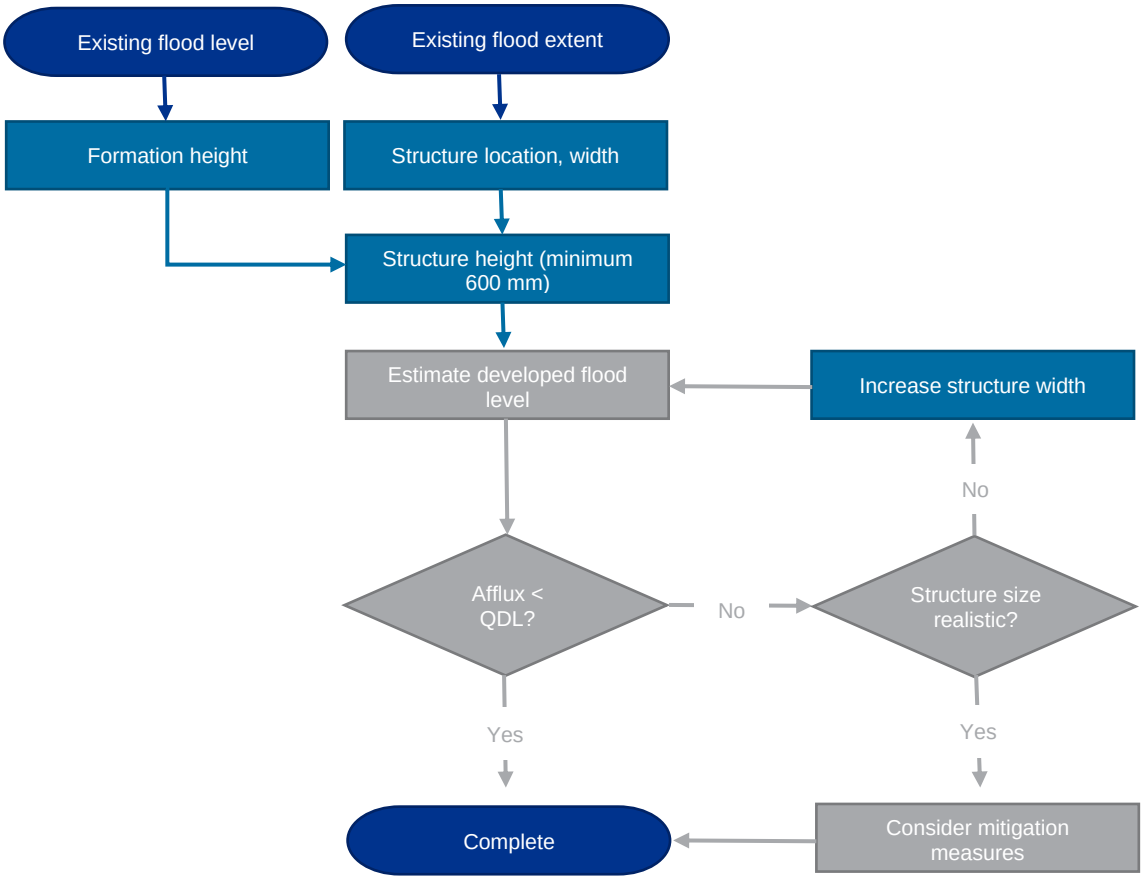


Figure 3.5 Indicative design process

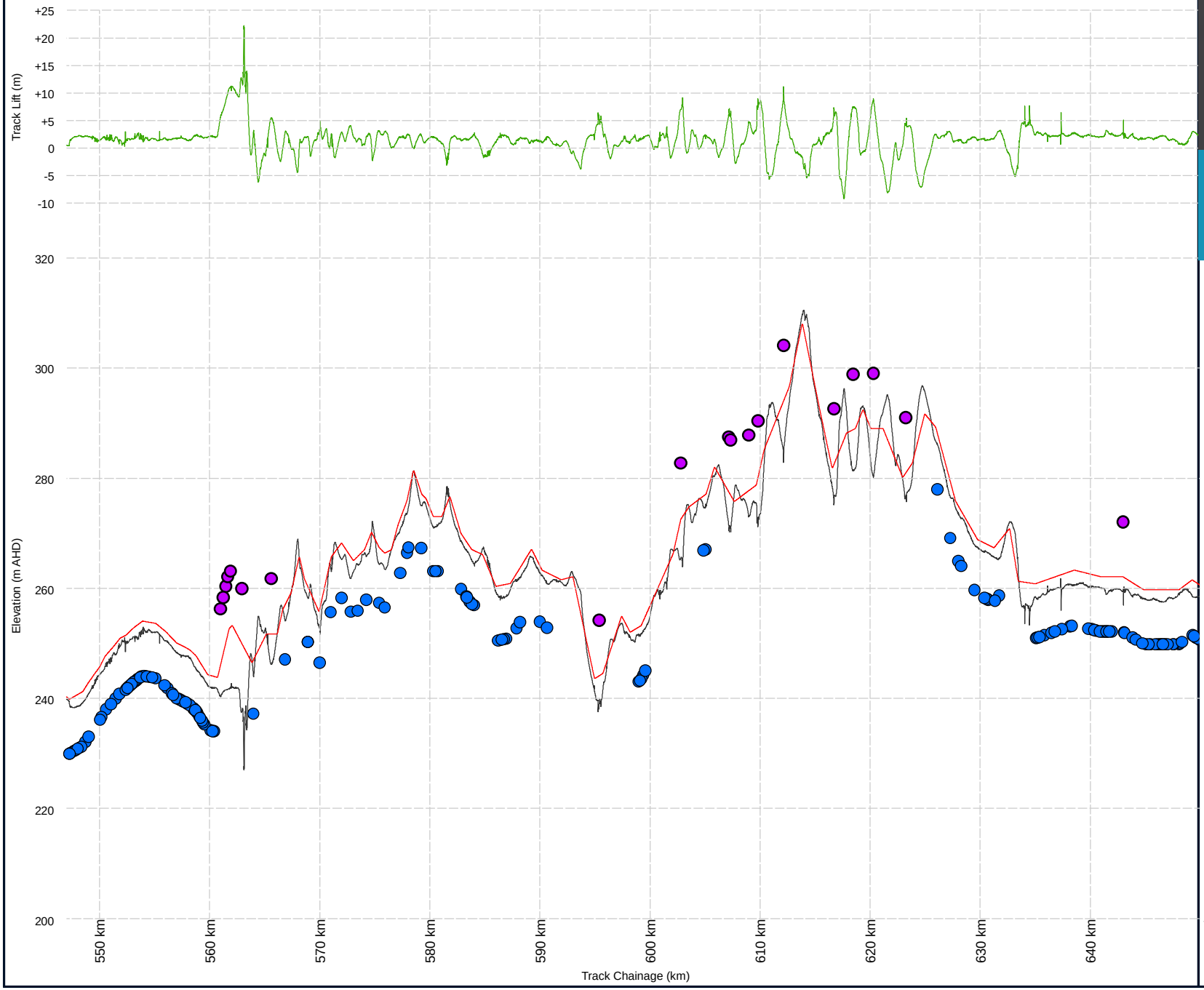
3.6.2 Proposed bridges and culverts

The proposal includes about 630 banks of culverts of varying types and sizes and 75 bridges along the proposal site.

Figure 3.6 provides the existing natural surface along the proposed alignment, and the design track long section and associated structures (offset eight metres below the track level for clarity).

Figure 3.7 shows the locations of proposed culverts and bridges for the proposal while details of the proposed culverts and bridges are provided in Appendix A.

Mapping showing the pier and embankment locations for the Narrabri bridge is provided in Appendix L. Refer to the Map Book for further details regarding construction and design features of the proposal.



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NARROMINE TO NARRABRI

Design track alignment

Figure 3.6a

LEGEND

- Bridges (Elevation not shown)
- Culverts (Elevation not shown)
- Design
- Natural Surface
- Track Lift

Coordinate System: GDA 1994 MGA Zone 55

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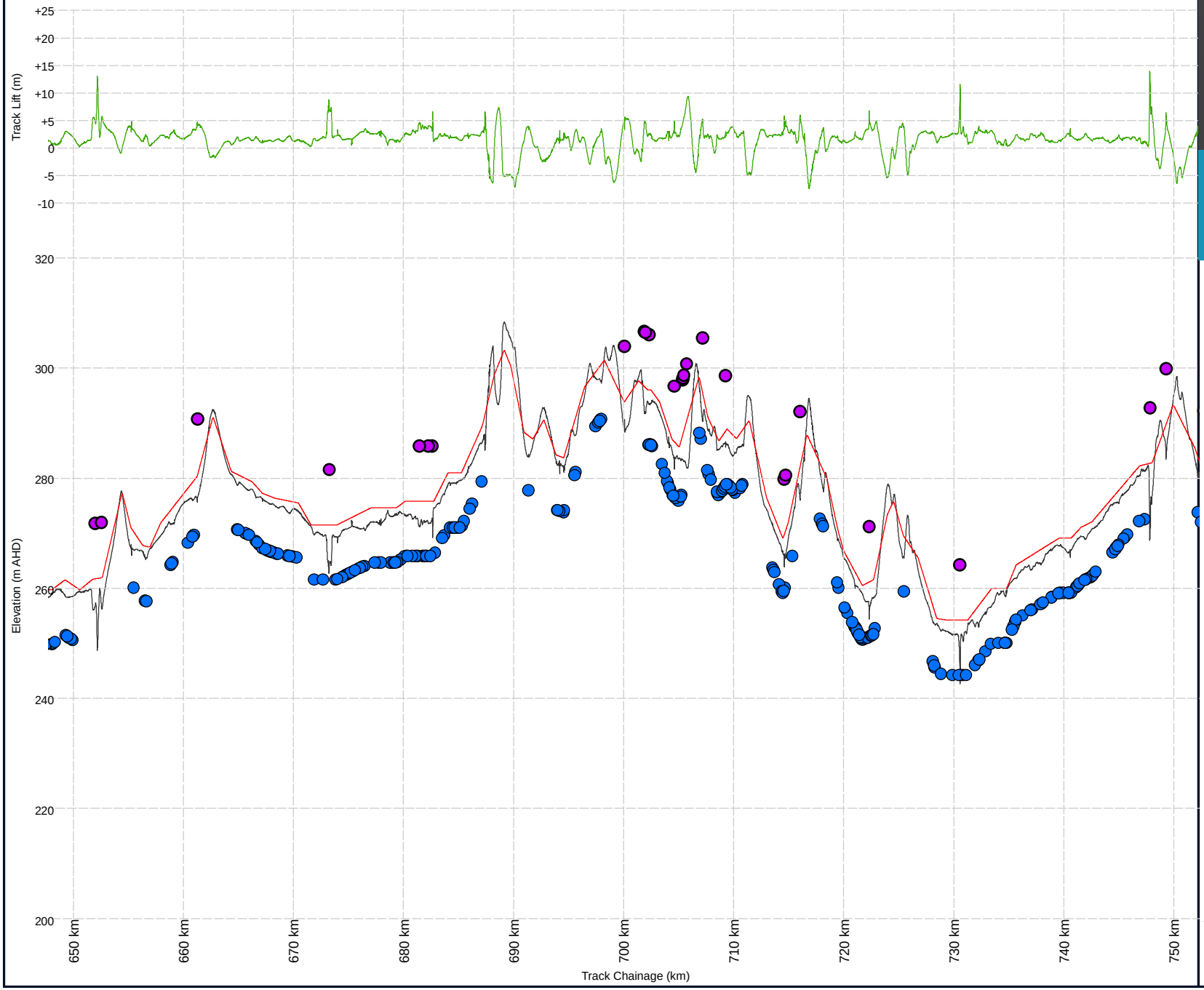

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NARROMINE TO NARRABRI

Design track alignment

Figure 3.6b

LEGEND

- Bridges (Elevation not shown)
- Culverts (Elevation not shown)
- Design
- Natural Surface
- Track Lift

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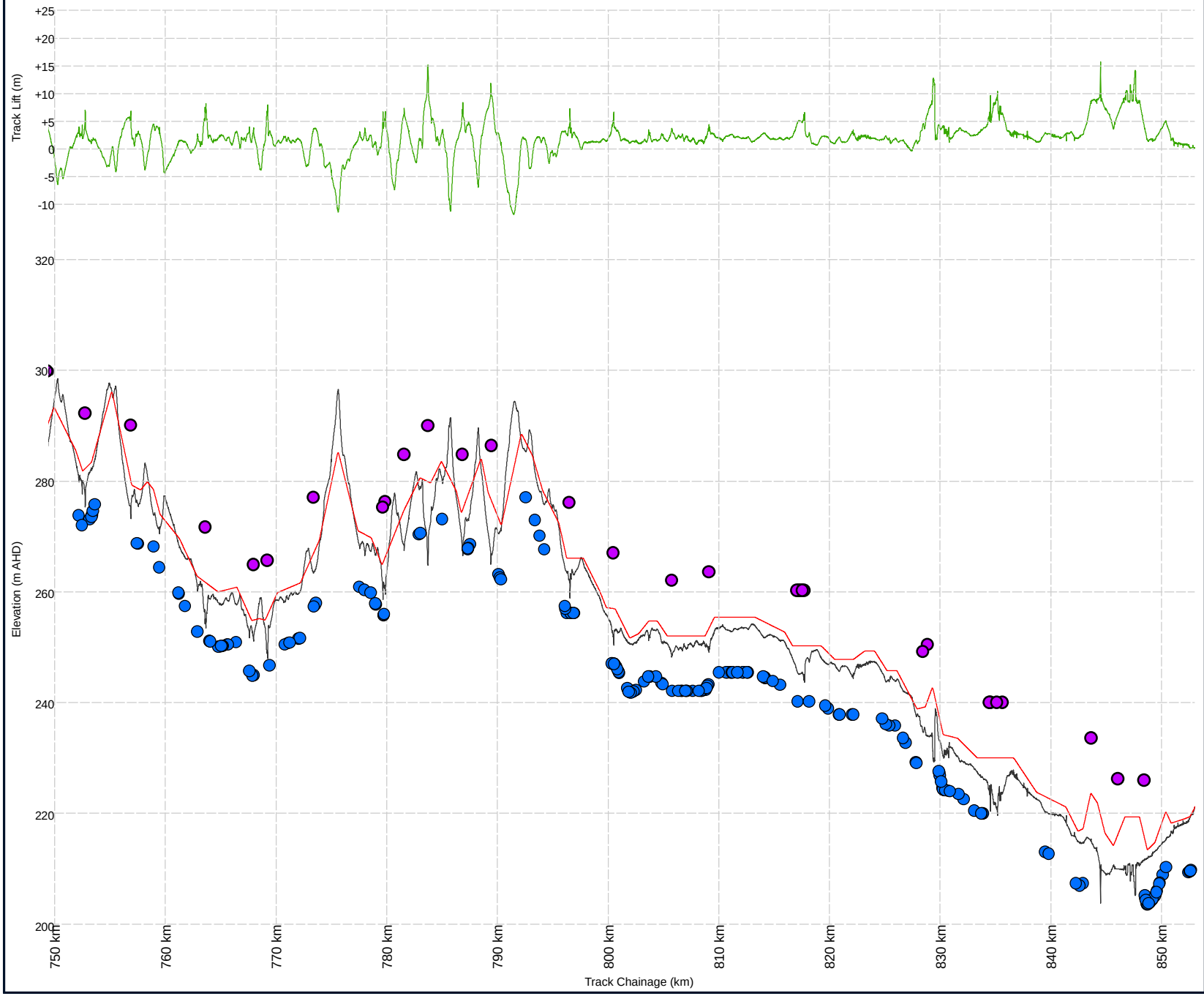

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NARROMINE TO NARRABRI

Design track alignment

Figure 3.6c

LEGEND

- Bridges (Elevation not shown)
- Culverts (Elevation not shown)
- Design
- Natural Surface
- Track Lift

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NARROMINE TO NARRABRI Proposed structure locations Figure 3.7a

0 4 8 Km

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LEGEND

- Bridge
- Culvert
- Alignment
- Watercourse
- Railway
- Road

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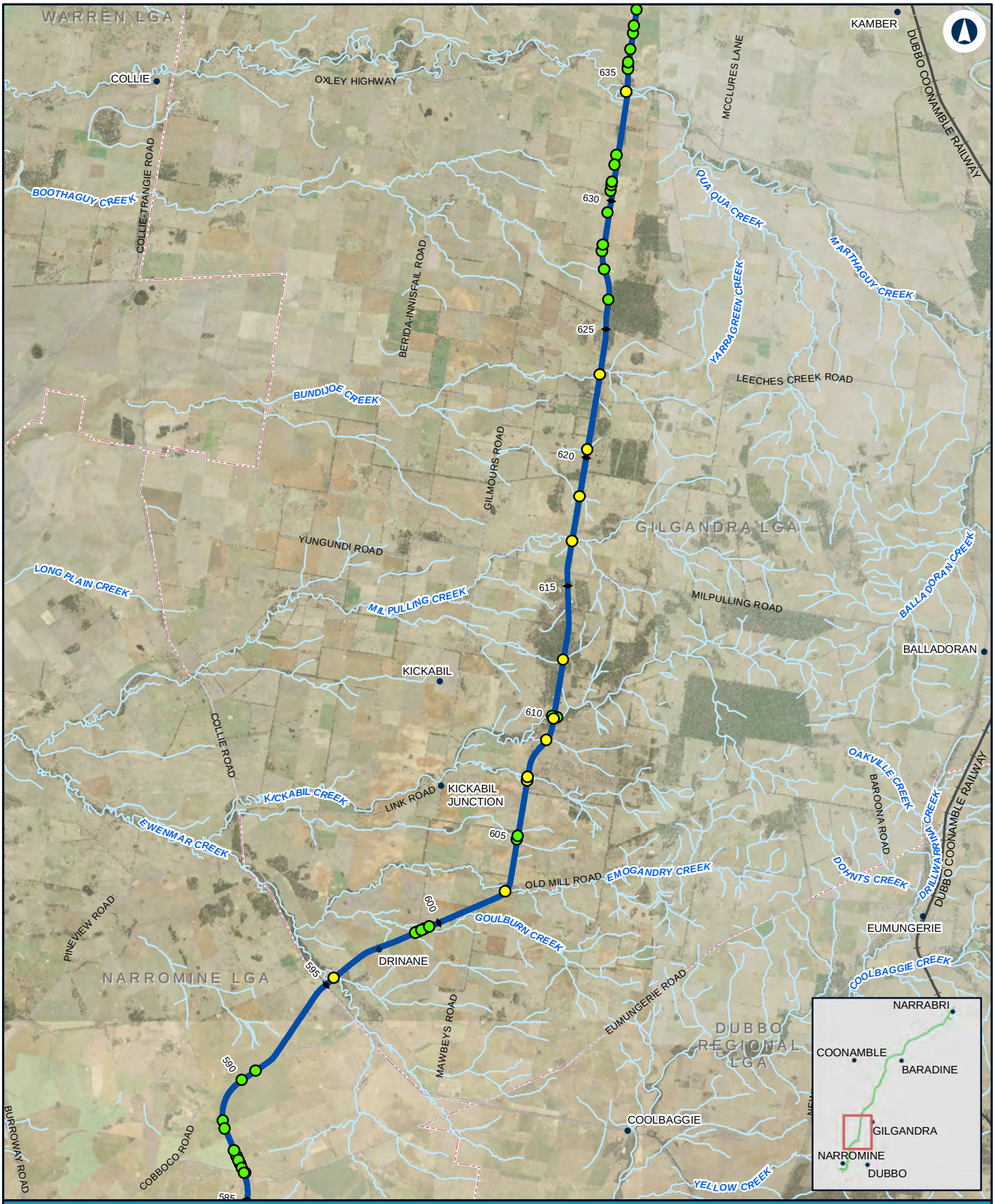

NARROMINE TO NARRABRI

Proposed structure locations

Figure 3.7b

0 4 8 Km

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LEGEND

- Bridge
- Culvert
- Alignment
- Watercourse
- Railway
- Road

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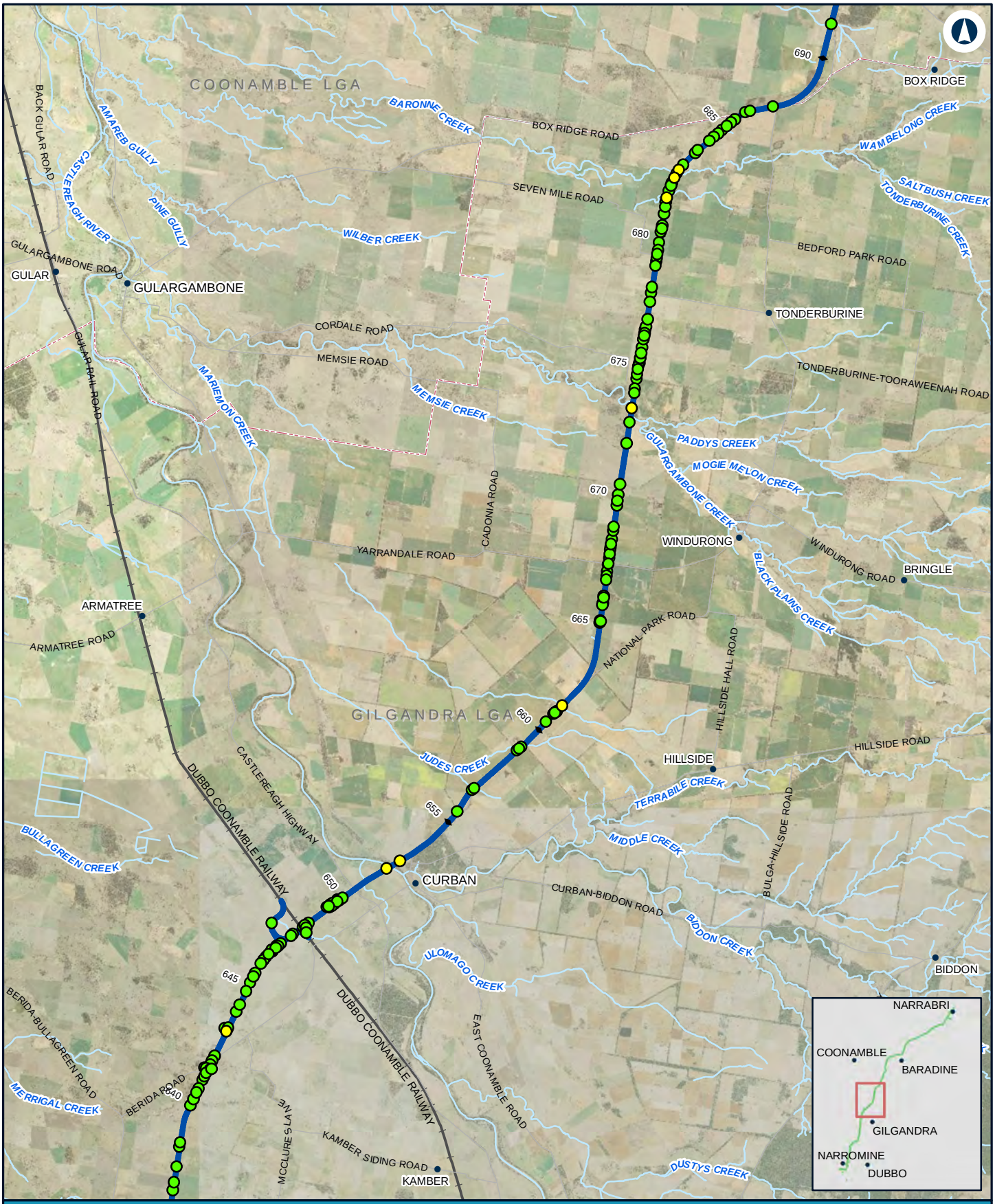

NARROMINE TO NARRABRI

Proposed structure locations

Figure 3.7c

0 4 8 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 10/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- Bridge
- Culvert
- Alignment
- Watercourse
- Railway
- Road

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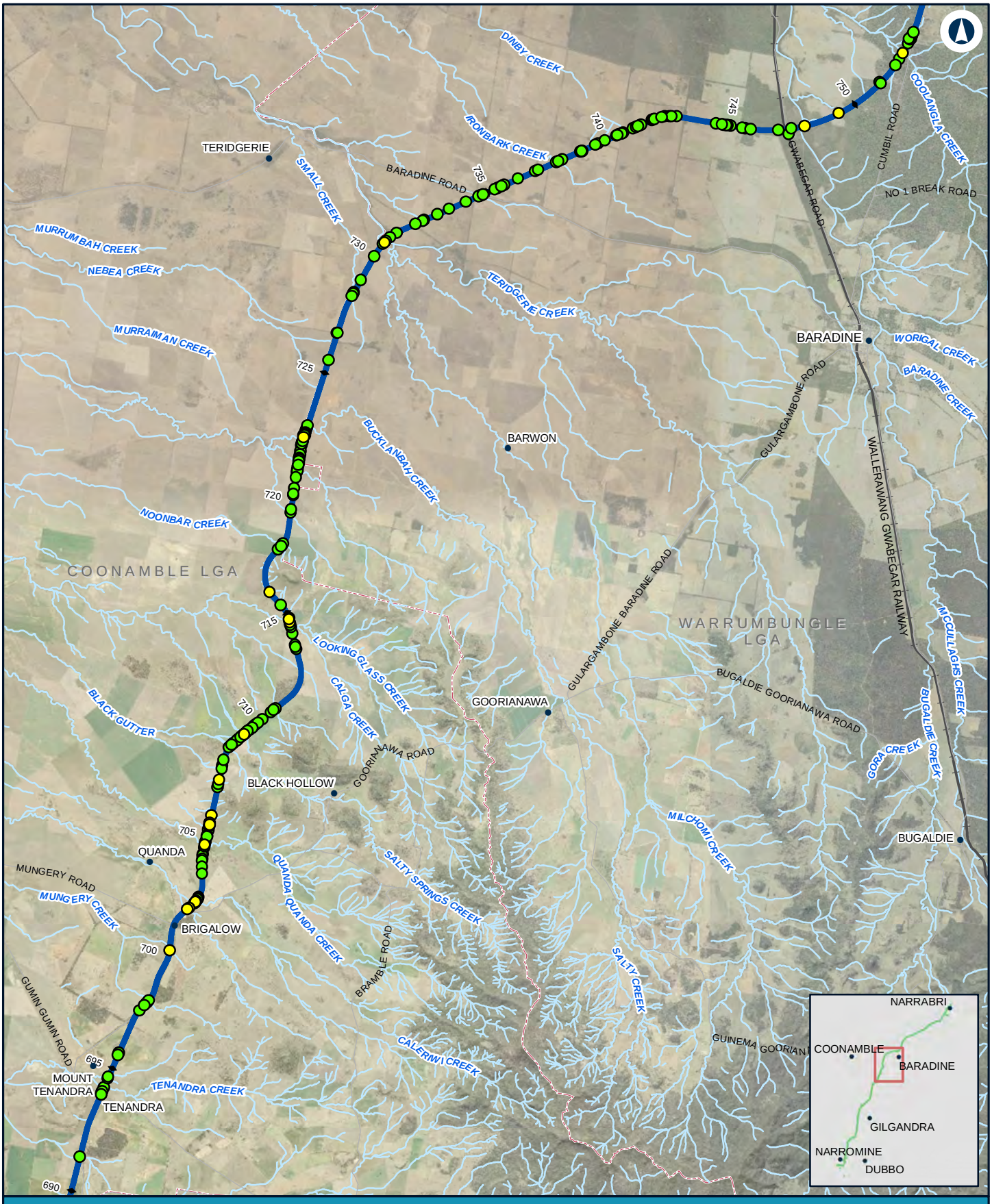

NARROMINE TO NARRABRI

Proposed structure locations

Figure 3.7d

0 4 8 Km

Coordinate System: GDA 1994 MGA Zone 55

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LEGEND

- Bridge
- Culvert
- Alignment
- Railway

Date: 10/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS;

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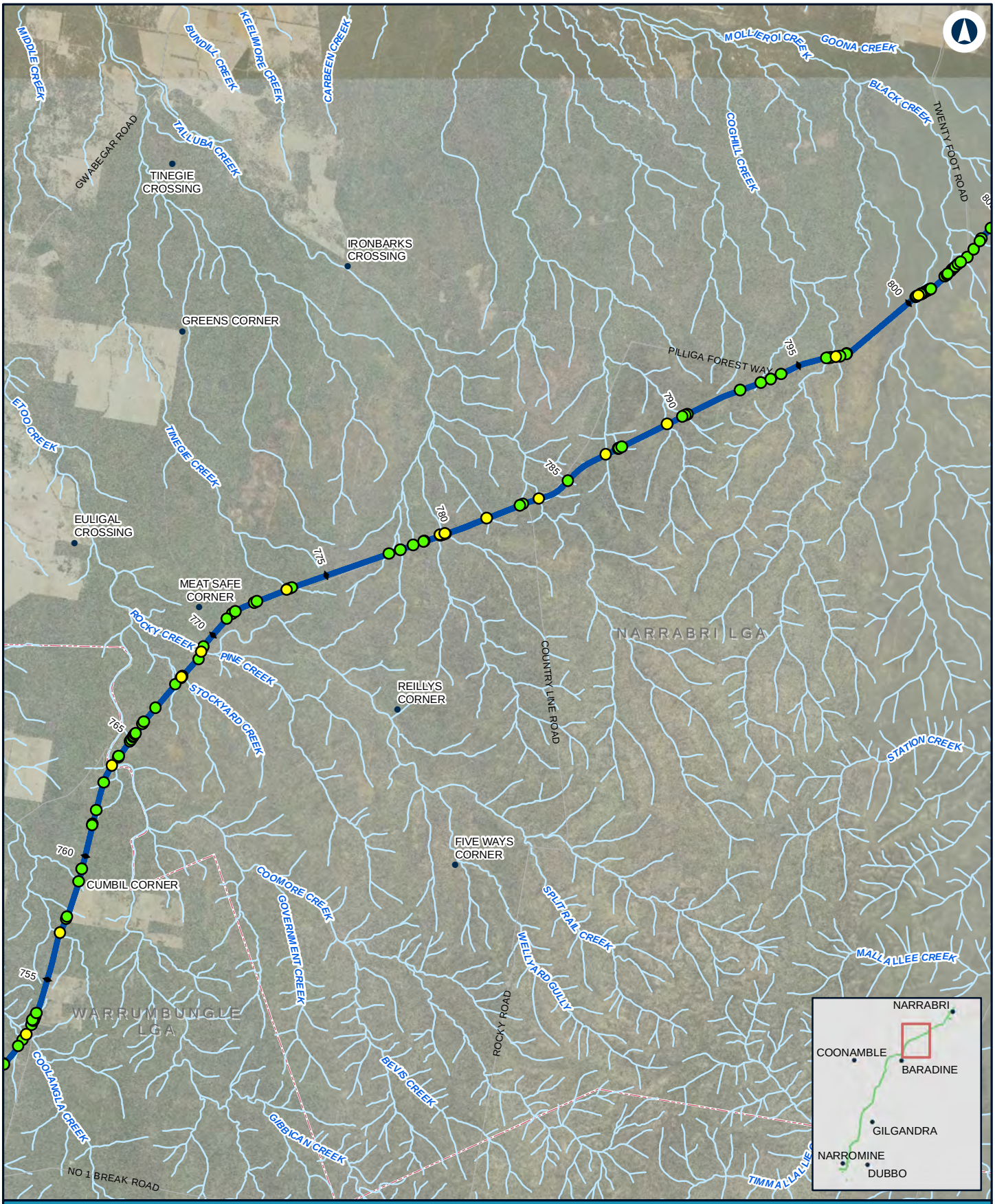

NARROMINE TO NARRABRI Proposed structure locations Figure 3.7e

0 4 8 Km

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Date: 10/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- Bridge
- Culvert
- Alignment
- Road

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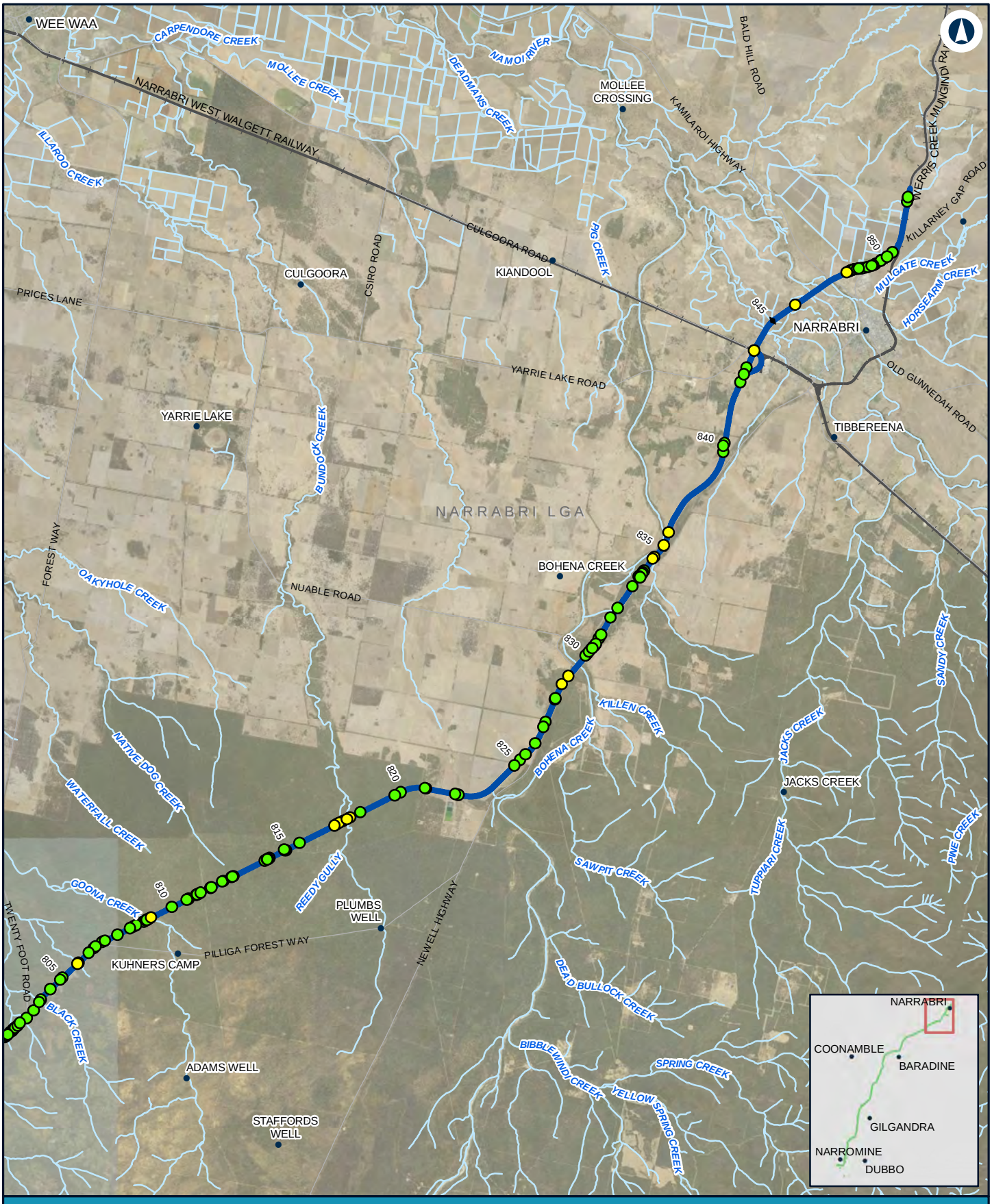

NARROMINE TO NARRABRI Proposed structure locations Figure 3.7f

0 4 8 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 10/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- Bridge
- Culvert
- Alignment
- Watercourse
- Railway
- Road

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3.7 Flood impact assessment

3.7.1 Operational phase

The TUFLOW models were updated for the operational phase to represent the rail formation, culverts, bridges, roads and other works for the proposal. The updated TUFLOW models were run for a range of design flood events up to and including the PMF event. TUFLOW modelling results were saved in geo- databases for assessing flooding impacts for the operation phase. Impacts of the proposal were assessed against the QDLs (for events up to and including the 1% AEP event) and against existing conditions for rarer events (for events up to the PMF).

3.7.2 Construction phase

Temporary construction works for the proposal were reviewed to identify a hydraulic critical scenario related to construction. A preliminary construction methodology has been developed to inform the development of the hydraulic (TUFLOW) model.

The construction methodology has included the following key elements for consideration in development of a corresponding hydraulic model for testing of impacts:

- Embankment – construction of all embankments is complete
- Culverts and bridges – construction of all culverts and bridges are close to completion
- Crane pads – one for small bridges and two for large bridges are yet to be removed
- Earthworks for all construction compounds are complete
- All construction phase sediment basins are present
- All capping/ballast and topsoil storage areas are in operation

A conservative hydraulic (TUFLOW) model has been developed for testing of performance for the 20% AEP, 5% AEP and 1% AEP events. Impacts were assessed against existing conditions. The model has been developed by representing the operational phase in addition to the key construction phase elements listed above as follows:

- Rail embankments – all embankments are typically immune to flooding in the 1% AEP event.
- Crane pads – one for small bridges and two for large bridges (yet to be removed) located within the model to be sited immediately adjacent to the watercourses/creeks as a conservative scenario for assessment purposes. The assessment is based on crane pads being progressively removed on a span-by-span basis following completion of erection of each spans associated substructure and superstructure. The platforms have been represented as a full obstruction at one metre above existing ground level.
- Construction compounds have been modelled as platforms filled to above the 5% AEP flood level.
- Sediment basins have been modelled to incorporate associated bunding to a height of 2.5 metres above existing ground level.
- Capping/Ballast and Topsoil stockpile areas have been modelled with a mound height above the 5% AEP flood level.
- The model has incorporated the completed rail embankment including culverts.

Works represented in the construction phase flood models for Narromine and Narrabri are shown in Figure 3.8.

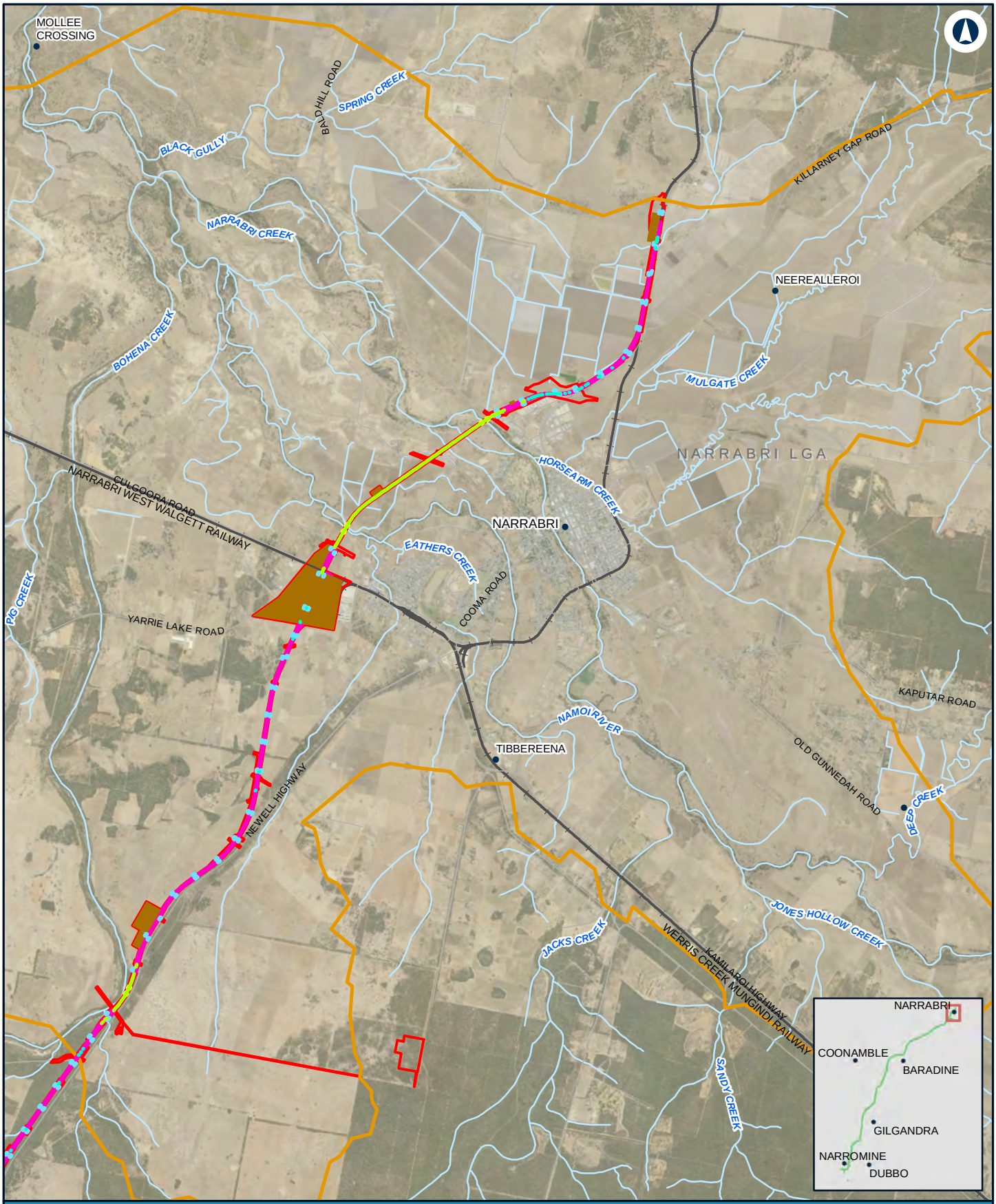
Actual construction methodology including consideration of possible temporary waterway crossings or fencing (sediment or other) would be completed as part of future phases of the project when details of proposed treatments and programming of work is established.

3.7.3 Climate change

Impacts due to climate change were assessed for the 1% AEP event using guidelines from ARR 2019 and in accordance with the Inland Rail *Climate Change Risk Assessment Framework* (ARTC, 2019) and climate change risk assessment for the proposal. A representative concentration pathway (RCP) 8.5 by the year 2090 was used, representing the upper range projection of greenhouse gas concentrations in the atmosphere, as adopted by the IPCC in 2014. This scenario was modelled by applying a 22.8 per cent increase in rainfall depth to both the existing and design cases.

The same runoff routing parameter values, spatial and temporal distribution of rainfall, and rainfall losses adopted in the simulation of the 1% AEP event were also adopted for the climate change scenario.

Results showing the potential increased afflux resulting from climate change and provided in Appendix G.



NARROMINE TO NARRABRI Construction phase works represented in the flood models - Narrabri Figure 3.8a

0 1 2 Km

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Date: 4/08/2022 Paper: A4
Author: JacobsGHD Scale: 1:92,500
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- Culvert
- Bridge
- Top soil and ballast compound
- Crane pad
- Sediment dam
- Embankment

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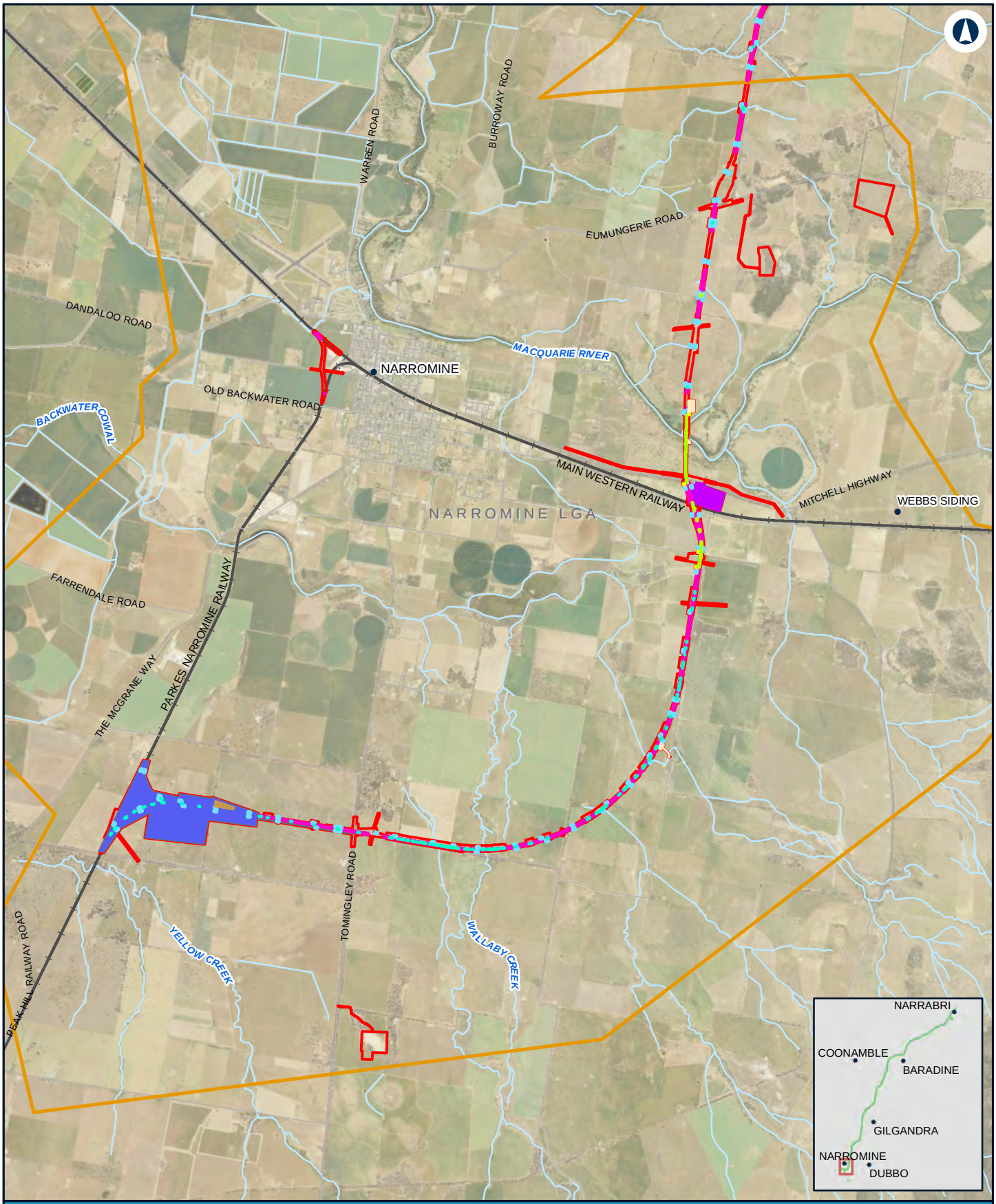

NARROMINE TO NARRABRI Construction phase works represented in the flood models - Narromine Figure 3.8b

0 1 2 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 4/08/2022 Paper: A4
Author: JacobsGHD Scale: 1:90,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- Culvert
- Bridge
- Crane pad
- Minor compound
- Multi-function compound
- Sediment dam
- Structure compound
- Topsoil
- Embankment

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3.7.4 Blockage

Approach

A blockage assessment was undertaken in accordance with current industry guidance in ARR 2019. The approach adopted an assessment framework that considered the catchment potential for debris loading for each individual structure. The nature of existing land use on the upstream catchment area of each structure was reviewed and the potential for debris was considered to derive an L10 debris factor. Sediment sizes were estimated based on predominant soil types to assess the sediment load (non-floating debris). A blockage factor was calculated for each structure based on the risk or potential for blockage to occur due to both floating and non-floating debris using the guidelines provided in ARR 2019.

Factors considered in the risk assessment include:

- Debris types
  - Floating/non-floating
  - Debris size
- Debris availability
  - Land use (forest versus grazing, etc.)
  - Predominant soil type
- Debris mobility and transportability
  - Catchment slope
  - Modelled flow velocities.
- Size of structure waterway areas versus debris size.

Bridges

Bridges are typically multi-span and the minimum and maximum spans between bridge piers for all proposed bridges is 14 metres and 33 metres respectively. The spans are large openings, and as per Table 6.6.6 of ARR 2019 bridge spans are considered unlikely to be blocked by floating debris that would significantly impede flood flows. There is no guidance in ARR 2019 due to floating debris collecting on bridge piers. Notwithstanding the requirement of ARR 2019 and noting the sensitivity of the town of Narrabri to flooding, a sensitivity check was undertaken to assess potential afflux impacts due to floating debris collecting on the viaduct piers.

Culverts

Estimated blockage factors for culverts range between zero and 100 per cent, depending on the culvert location and assessed risk rating. Culverts with blockage factors of 100 per cent are located within the Pilliga forest areas and near Mount Tenandra. The sizes of all culverts and bridges for the proposal and the adopted blockage factors are provided in Appendix A.

The proposal design has been undertaken in accordance with ARTC and other relevant standards and guidelines. The vertical alignment (i.e. height above ground) of the track is required to minimise slope changes to provide an even grade for train operations. The number and size of culverts were also selected to limit the afflux at the rail corridor boundary.

The adoption of a minimum 25 per cent blockage factor was considered at the reference design stage. However, the N2N alignment passes through large areas of cropping and grazing land where the potential for debris blockage is very low. It was therefore considered more appropriate to follow the ARR 2019 guidelines rather than varying this approach by setting a minimum blockage factor.

A geomorphological site investigation undertaken in early 2022 identified partial blockage of existing culverts at Ewenmar, Goulburn and Emogandry Creeks along Old Mill Road. Opening heights for these culverts vary between 0.3 to 0.4 metres. The existing roads are low-level crossings which are overtopped during minor flood events and do not promote self-cleansing flows through the culverts. The site investigation also identified that other works have also resulted degradation of the natural geomorphic function of these creeks. Detailed design will include geomorphologic technical input to the culvert design which will promote self-cleansing flow velocities and reduce the risk of sediment blockage.

Culverts where the ARR 2019 blockage factor risk were assessed as 100 per cent will be reviewed in detailed design and mitigation measures will be adopted to reduce the risk of blockage, such as debris deflection structures, including additional culverts or changing culverts to bridges.

Sensitivity to design blockage

The differences in modelled impacts between the “all clear” and “with blockage” scenarios generally resulted in minor changes and no additional habitable buildings were identified as being impacted.

Analysis of the flood modelling and building floor level data shows that in the existing situation there a total of 6205 buildings within the study area that are flooded above floor level in the 1% AEP flood event. Of these total number of buildings, 2,574 are habitable and 3,631 are non-habitable.

The modelling also shows the proposal results in a minor net reduction in the total number of buildings flooded above floor level in the 1 AEP. With the proposal, 6,187 buildings (2,565 habitable and 3,622 non-habitable) are flooded above floor in the 1% AEP ‘all clear’ scenario, and 6,188 buildings (2,565 habitable and 3,623 non-habitable) are flooded above floor level in the 1% AEP ‘with blockage’ scenario. Hence, one additional non-habitable building is affected with the with blockage scenario.

There would be no discernible change (i.e. a change within ±10 millimetres) in 1% AEP flood depth above floor level at the vast majority, approximately 98 per cent, of buildings already flooded above floor level.

In relation to land uses and roads, reported afflux impacts are not sensitive to blockages except for impacts to other non-urban lands and local roads that are unsealed or less than 80 km/hour. Compared to ‘all clear’ conditions, blockages cause only a minor to negligible increase in afflux impacts on agricultural land and highways. Blockages also cause a moderate reduction in the area of urban and infrastructure land affected by afflux exceeding the QDL. There are increases in area affected by afflux exceeding the QDLs for agricultural and other non-urban land.

The outcomes discussed above are attributed to the additional design conveyance capacity within culvert banks by virtue of the track vertical geometry and the initial design criteria based on an afflux to 200 millimetres at the rail corridor boundary. The exception is within the Pilliga Forest where 100 per cent blockage factors have been applied.

Adoption of blockage in hydraulic modelling

Impacts of blockages on the flood immunity, afflux and other QDLs for the proposal were assessed for the 1% AEP event, being representative of the highest magnitude impacts relative to the QDLs (Section 7.3). During detailed design, blockage factors will be applied across all flood events

3.7.5 Fencing

The proposed fencing strategy is to provide fencing everywhere except areas that include:

- Long culverts (defined as culverts longer than 3 cells)
- Forests such as the Pilliga East State Forest
- Bridges and viaducts
- Road crossings
- Adjacent road corridors.

The fencing is expected to be a typical stock fence similar to other existing fences located on the floodplains. Fences are not expected to have any significant influence on flood behaviour and so have not been represented in the flood models.

3.8 Consultation

Consultation with the community and stakeholders was undertaken for the proposal to collect information on historical flood behaviour, validate modelled flood behaviour, and to understand perceptions of the community and stakeholders on potential impacts of the proposal on flood behaviour. Further details on consultation activities carried out and considered in the flood assessment are provided in Section 4.

3.9 Independent review of flood models

Hydrologic and hydraulic models for the reference design were independently reviewed by BMT in accordance with SEARs 9.2(b) prior to submission of the EIS in November 2020. By nature of the review process, information was supplied to BMT for review, and additional information was provided as required to enable the review to be completed. At the time of EIS exhibition, the majority of BMT's comments had been responded to, but a few remained outstanding. These have since been addressed and the models have been updated and re-run for the results presented in this updated report.

The updated flood models for the proposal have again been independently peer reviewed by BMT. The Hydrology and Hydraulics Model Calibration Report was also independently reviewed. The updated independent reviews of the flood models and Calibration Report are provided in Appendix B.

The updated independent review found that generally the hydrological modelling undertaken for the proposal is consistent with the relevant guidelines and is appropriate for the reference design phase of the proposal. Recommendations have been provided in relation to minor refinements of the hydraulics models and these would be undertaken during detailed design.

3.10 Geomorphological watercourse assessment methodology

3.10.1 Recent site based assessments

Geomorphological studies undertaken as part of the EIS and Technical Report 3 – Flooding and Hydrology Assessment were based on results of geotechnical investigations to inform a high level sensitivity assessment of erodible soils. Reference was made to River Styles classifications and published hydraulic modelling studies that provide guidelines for maximum permissible velocities in a range of soil conditions.

Further work has now been completed to support this Updated Flooding and Hydrology Assessment Report, including site-specific assessments of geotechnical soil erodibility at selected locations along the proposal. The watercourse sensitivity assessments in Appendix E have been updated to reflect the additional investigations and studies. Results of the additional assessment findings are contained within the Erosion Potential and Fluvial Geomorphology Report (Appendix O).

3.10.2 Assessment of existing conditions

A description of the existing conditions for the geomorphology of the watercourses traversed by the proposal has been compiled based on a review of available spatial data and information, including field observations by surface water quality and geotechnical teams. Information used included:

- State-wide River Styles Spatial Layer (NSW Office of Water, 2012) and associated River Styles Assessments reports completed for larger watercourses of the Namoi, Castlereagh and Macquarie Catchment Areas (GHD, 2010; Lampert and Short, 2004).
- Assessment of available imagery (including aerial photographs and ground-level photographs obtained during the EIS process) to assess reach-scale historic change (where available) and contemporary planform morphology, both to confirm the River Styles classifications and to assess river geomorphology and geomorphic functioning in relation to the proposal impacts.
- Available 1:250,000 geology and soils mapping to assess relative floodplain and channel erodibility, including state-wide Australian Soils Classification (ASC), Australian Soils Resource Information System (ASRIS) and Office of Environment and Heritage (OEH) soils maps.
- Geotechnical investigation information and reports for the proposal including an assessment of geological domains and geotechnical units along the proposal corridor.

In earlier versions of this chapter, the geomorphology was solely assessed using the River Styles information listed above. The River Styles® framework (Brierley and Fryirs, 2003) is a river characterisation process that allows interpretation of river form and behaviour. The River Style of a stream that exists at any one point within a valley is dependent upon a large number of physical factors upstream, downstream and adjacent to the point of assessment. These factors determine the geomorphic character and behaviour of the reach and a river's physical behaviour determines how it is to be managed.

River Styles assessments were available for 40 out of 81 assessed watercourses, typically for the larger creeks and rivers. However, it was found that some designated River Styles no longer correctly described the existing condition of the watercourses. In some cases, the description was not accurate, particularly for meandering creeks. It appears that a macro-scale assessment of sinuosity was used, rather than an active channel-scale. This gives an inaccurate impression of geomorphic processes acting. For example, those reaches assessed as "low sinuosity', but which were observed to have a highly sinuous active channel, were dominated by lateral erosion and meander migration. In these cases, the River Style was not altered, but greater weighting was placed on the site-specific observations made for this proposal.

3.10.3 Geomorphic condition

River Styles classifications were used as a basis for assessing the overarching existing channel condition, recovery potential and fragility (sensitivity to change). Given the history of anthropomorphic change, few watercourses within the study area qualify as 'good' geomorphic condition. River Styles assessments require a 'good' condition channel to have high geomorphic and habitat diversity (including diverse bed roughness / forms and presence of diverse in-channel vegetation, including LWD), with a broad, diversely vegetated riparian corridor and floodplain connectivity. This is not achievable along many Australian watercourses, and would not have occurred naturally in some cases. For example, watercourses with bed sediment (typically sand) slugs are said to be in poor geomorphic condition, although some sand-bed creeks, such as Etoo Creek, have been classed as moderate condition. However, these sand slugs are likely to occur naturally from an abundant supply of upstream sediment from e.g. highly weathered, shallow sandstones. Flood events mobilise higher volumes of such sediment, which are then transported episodically downstream. Indicators of poor condition using the River Styles classification may, in reality, demonstrate that the watercourses are well-adapted to their highly variable flow regimes and high sediment load. The River Styles assessment has, therefore, been used as indicator of relative reach-scale geomorphic character, with more emphasis placed on site-specific observations and use of the stability assessment described in Section 3.10.4.

3.10.4 Channel stability assessment methodology

The proposal is being assessed against the QDLs (section 3.2.2). However, this assessment has also considered the geomorphological condition and potential impacts to existing watercourses around the proposal site.

Typically, fluvial geomorphology assessments (e.g. River Styles) use stream power to assess the excess energy available to do work, i.e. the capacity of the stream to transport sediment, which also influences flow erosivity. This parameter was used to both compare erosivity between watercourses, and also to assess the likely impact of the proposal. Ideally, stream power at bank full discharge is calculated, using the following equations.

$$\Omega=\rho gQS, \text{ and } \omega=\Omega/w$$

Where:

- Ω =stream power
- ρ = density of water (1000kg/m^3)
- g = acceleration due to gravity (9.8m/s^2)
- Q = bankfull discharge (bankfull area (depth (d) x width(w) x velocity)
- S = bedslope ratio (rather than %)
- ω = unit stream power

Results for the 20% AEP were used as an estimate of bank-full conditions, noting that there would be potential for this to vary, depending on specific creek characteristics and in particular for ephemeral (non-perennial) creeks. The flood extents for the 20% AEP flood were checked and supported this assumption (i.e. the majority of flood flows were contained within the creek channels). Stream power values for the 1% AEP flood were also calculated for comparison purposes. Discharge (Q) was calculated from the flow width (corresponding to the structure width for culverts and the 1% AEP for bridges) and modelled mean average channel depth / velocity with all other required variables taken from the flood model outputs. ω was used as a preference, rather than Ω, to compare the unit-averaged available energy of watercourses in the study area, as this gave a better indicator of relative sensitivity.

3.10.5 Watercourse sensitivity

The method outlined in Sections 3.10.1-3.10.3 were used to derive a sensitivity rating for each assessed watercourse at the proposal crossing point. This rating was based on a simple low-to-high ranking system for the following variables.

- Flow Erosivity: Bank-full (20% AEP) Stream Power and Maximum (1% AEP) Velocity.
- Stabilisation: Density of in-channel / riparian vegetation.
- Channel Erodibility: River Style fragility, presence of existing erosion, geotechnical soil properties.

The stream power and maximum velocity were split into 5 classes, rather than 3. These variables varied between watercourses, and it was felt that the additional classes would give a better comparative overview. This method of assessment enabled a straightforward comparison of existing and design flood outputs.

3.10.6 Erosive threshold velocities

Erosive threshold velocities are provided in a range of standard engineering design guidelines for different soil types and vegetation cover. Site investigations have also been carried out along the proposed alignment by an experienced geotechnical engineer and geomorphologist to assess the erosion potential of the main soil types between Narromine and Narrabri.

This section of the Updated Flooding and Hydrology Assessment Report has been updated to reflect these investigations.

Review of standard industry erosion threshold velocity guidelines

The erosion potential assessment has reviewed standard industry guidelines, including:

- Austroads Guide to Road Design (Part 5, 2021 and Part 5B, 2013)
- Best Practice Erosion and Sediment Control (International Erosion Control Association, Australasia (IECA, 2008)
- Landcom ‘Blue Book’: Managing Urban Stormwater: Soils and Construction (2004)
- Hydraulic Engineering Circulars (HEC) 14, 18 and 23
- Gippel *et al.* (2008); White *et al.* (2014); Gippel (2020).

These design guidelines consider the threshold velocity at which erosion is likely to occur in a range of soil conditions and flood durations. The extent of vegetation cover is also taken into account, as this helps to bind soils together and also reduce velocities.

There are some differences between the reviewed guidelines but, for the soil conditions between Narromine and Narrabri, the guideline erosion threshold velocities can be summarised as:

- Between 1.0 m/s to 2.0 m/s for stiff to hard clays.
- Up to 0.5 m/s for silts and sands with no vegetation cover. Note that in many locations this material is naturally mobile in channel beds and limiting velocities to less than 0.5 m/s may increase the risk of sedimentation.
- Between 1.5 m/s to 2.5 m/s or more if there is good vegetation cover.
- 2.0 m/s for shallow flows across grassy floodplains.

Site specific geotechnical soil erodibility and erosion threshold velocity assessment

In geotechnical analysis, it is usual to use more than one method for estimating engineering parameters. Judgement and site knowledge is then used to decide the most appropriate parameters to be adopted. An assessment of the theoretical erosion potential was undertaken at 23 selected sites along the alignment based on four established methods:

(1) The Erodibility Index Method (Annandale, 1995).

(2) Design of Reinforced Grass Waterways (CIRIA Report No. 116, Hewlett *et al.*,1987).

(3) The relationships between critical velocity and mean grain size (Briaud, 2008).

(4) Indirect relationship between the erodibility of a soil and its plastic index observed from research works by Hanson *et al.* (2010, 2011), Wahl *et al.* (2009), and Shewbridge *et al.* (2010).

Results indicated that:

- Channel banks and floodplains with a high clay content were estimated to have erosion threshold velocities ranging from 1.2 m/s at Wallaby Creek, to 4.5 m/s at CH697.901, with the average being around 2.1 m/s.
- Channel boundary materials with a high silt and sand content are expected to be more erodible (i.e. moderate erodibility) than clay-rich soils (low erodibility). Loose sand bed material is highly erodible.
- Dispersive erosion associated with soils tested as dispersive was not commonly observed at the study sites.

Further details on the engineering guidelines noted above and the site based assessments are contained in Appendix O.

4 Consultation

Consultation with the community and stakeholders was undertaken for the proposal to collect information on historical flood behaviour and to understand perceptions of the community and stakeholders on potential impacts of the proposal on flood behaviour. Feedback from this consultation, as summarised below, has been considered in the flood modelling undertaken for the proposal.

4.1 Community consultation undertaken in 2016

A site inspection and community consultation were undertaken by Kellogg Brown & Root Pty Ltd (KBR) as part of phase 1 investigations for the proposal. The site inspection commenced in September 2016 following a period of heavy rain and local flooding. Seven landholder meetings and inspections of selected waterway crossings were completed during the site inspection.

Key outcomes from consultation with landowners relevant to the proposal are summarised below.

4.1.1 Brooks Road, Curban

The owner of the property was interviewed with key notes as follows:

- The worst flooding occurred in 1955 and 1998.
- The depth of flooding at the entrance of the property was 1.6 metres in 1998.
- The runoff was reported as being fairly quick and the land is very susceptible to erosion.
- It was also reported that a scour hole greater than one metre deep was formed during a storm event after a new road was built in their paddock.

4.1.2 Yarrandale Road, Curban

A meeting was held with a group of landowners who identified flood breakout locations along Yarrandale Road and provided photos of flood inundation at “Karoona” property during the 2010 flood event.

4.1.3 Goorianawa Road, Black Hollow

The owner of the property was interviewed with key notes as follows:

- Localised flooding was observed in 2016 on 20 June, 5 July, 11 July, 22 July, 7 August, 2 September, 14 September and 19 September.
- It was reported that widespread flooding occurred after major storm events and flood waters passed through the property quickly.
- Flood flows were mainly sheet flows with high sediment loads.
- Quanda Creek passes through the property and occasionally breaks its banks and typically flooding occurs every two to four years.
- Flood waters came close to garage door of the property.

4.1.4 Island Road, Narrabri

The owner of the property identified that the property was not flooded in the 1955 flood. The owner also noted that the Narrabri Golf Club is located on a higher ground and the golf course is used for helicopter landing to provide flood relief.

4.2 Meetings with landowners in 2019 and early 2020

Between July 2019 and March 2020, ARTC carried out meetings with landowners along the alignment to discuss various aspects of the proposal, including historical flooding, flooding impacts on business operations and residential properties and access to farm water supply. In total, land owners of 117 properties were consulted during these meetings. Preliminary flood mapping for the 1% AEP event was also shown to the landowners and feedback was sought on the level of accuracy of the flood maps.

4.2.1 Flood impacts on business operations

Business operations of 79 properties were impacted during floods. Flood events of 2016 (54 properties), 1955 (34 properties) and 2010 (21 properties) were identified as the most common years of flooding by property owners. Business operations of eight and six properties were impacted due to flood events of 2019 and 1998 respectively.

The flood event of 2016 was identified as the worst flood event impacting on business operations by 33 respondents and 27 respondents identified the flood event of 1955 as the worst flood event impacting on business operations. Six respondents identified the flood event of 2019 as the worst event to impact on business operations. Flood events of 2010 and 1998 were identified as worst flood events impacting business operations by four respondents.

It was common for property owners to report two or more flooding events at a property, and as many as eight events were reported for any one property. The most commonly reported impacts to businesses from flooding include minor to major fence damage, erosion, ponding around crops (leading to crop damage) and vehicular bogging. Impacts were reported to last from two to four weeks in some cases, to as little as twelve hours. On average, respondents described boggy conditions lasting around one week.

Some landowners provided images of flooding events on their properties demonstrating the extent of the impacts experienced. A property owner located on the Newell Highway at Bohena Creek reported to have experienced flooding in 1955, 2004, 2010, and 2016. They reported two days of restricted access to the property during flooding events due to the driveway being inundated to depths of 0.5 metres (refer to Figure 4.1). A property owner located on Seven Mile Road, Tonderburine experienced restricted vehicular access to their property after a flood event due to soil erosion (refer to Figure 4.2).

Figure 4.1 Inundated driveway

Figure 4.2 Soil erosion

4.2.2 Flood impacts to residential property

Eleven residential properties reported to be impacted by flooding and details on the impacted properties are provided in Table 4.1. Seven properties reported impacts during the flood events of 1955, 2000, 2016, and in 2019. Of the seven properties, five properties were impacted by the flood event of 1955 and one of the properties impacted by the flood event of 1955 experienced damage to fencing during the flood event of 2019. A shed was flooded in 2000 and mud flow occurred in one property during the flood event of 2016. One house was raised after the 1955 flood. Landowners did not identify years in which the remaining properties were impacted. One shed was subject to above floor flooding for a duration of 36 to 48 hours. Access to properties were impacted as private roads, local roads or main roads were subject to inundation for up to two weeks.

Table 4.1 Impacts of flooding on residential properties

Property ID	Year impacted	Nature of damage	Flood mark available
2632396	2019 1955	Fence damaged. Approximately 1.5 metres flood depth in the Cowal in 2016. Approximately 7 feet (over 2 m) flood depth in 1955 (impacted house and shed).	House and shed
4113621	NA	Shed inundated	Flood mark on the wall of shed
3773953	1955	House was inundated (up to 1 foot or 0.3 m). Since then house has been raised on brick piers.	NA
3773179	2000	Sheds were inundated up 5 inches (greater than 10 cm). It took 36-48 hours to dissipate.	Yes, please see maps
2638454	NA	As per flood maps: “Koorang” house + sheds were flooded.	As per flood maps
2638455	NA	As per flood maps: Koorang house + sheds have flooded.	As per flood maps
2655693	1955	Water was as high as 0.5 metres in 1955 (advised by neighbour).	NA
2655534	1955	House was inundated with flood depth being as high as one metre from the ground.	Flood marks present behind lining boards. Owner has had these flood marks surveyed.
3776289	1955	House was subject to approx. 0.5 metres depth of flooding.	NA
3530213	2016	Water/mud ran over the back cement (100 millimetres). Water came through laundry.	NA
2955424	NA	NA	NA

4.2.3 Impacts of the proposal on-dams and farm water supply

Landowners were queried whether any existing water flows to their properties need to be maintained for irrigation. Seventy landowners either did not provide a response or responded “no”. A total of 47 landowners identified the need to have existing water flows maintained on their properties. A number of landowners provided details on their private dams and other on-farm irrigation infrastructure.

The environmental impact statement for the proposal has recognised and assessed potential impacts to existing farm dams downstream of the proposal. The reference design has aimed to minimise these impacts by placing culverts and bridges so that existing flow paths and distributions would be maintained as far as practicable. The flood modelling of the operational phase has showed existing flow paths would largely by maintained.

At the reference design stage it is not possible to design individual treatments for impacts on farm dams and local drainage systems as these are generally specific to land uses and farming operations. During detailed design, impacts on farm dams and local drainage systems would be assessed in consultation with individual landowners. Treatment measures would then be designed on a property by property basis, taking into account land use and other specific requirements. The intent would be to minimise potential impacts on land uses and properties as far as reasonably practicable in accordance with mitigation measure contained in the EIS: "*Farm water pipelines, dams and drainage channels would be replaced or reinstated to ensure continuity of stock and domestic water supplies prior to removal of existing impacted infrastructure*".

4.3 Community drop-in sessions

Eight community drop-in sessions were held in March 2020 in Narrabri, Baradine, Curban, Gilgandra and Narromine. These sessions provided the broader community an opportunity to engage and ask questions regarding the proposal. Many of the sessions were attended by directly and indirectly impacted land holders, along with local representatives from councils and a representative of NSW Parliament. At these sessions various discussions were held and enquiries were made regarding potential flooding impacts from the proposal.

Representatives from Narrabri Shire Council attended a drop-in session on 9 March 2020 and requested that further engagement occur with the Narrabri Floodplain Committee. Consultation with the Narrabri Floodplain Committee subsequently occurred in April 2020 (refer Section 4.5).

A representative of State Member, Roy Butler, attended the Narrabri Drop-in session. It was expressed that local input into the flood modelling was needed. This was achieved via the additional consultation occurring with the Narrabri Floodplain Committee in late April 2020.

Discussions were held with officers from Gilgandra Shire Council on 11 March 2020 regarding the proposal and potential impacts to council assets. These discussions were focussed on Gilgandra Shire Council's concerns regarding the potential scour risk to assets. ARTC advised that the impact of the proposal would be minimised due to the design objectives that had been adopted.

4.4 Consultation with Transport for NSW

A meeting was held on 28 November 2019 at Roads and Maritime Services (now Transport for NSW) Parkes office to discuss potential flooding impacts of the proposal on Newell Highway in the vicinity of Bohena Creek. The main objective of the meeting was to gather early input from Roads and Maritime Services on potential flooding impacts on Newell Highway due to the proposal.

Flood mapping for four flood events (1%, 2%, 5% and 20% AEP) without and with the proposal were provided to Roads and Maritime Services before the meeting. Roads and Maritime Services generally agreed that changes to the existing flood depth, flood hazard and duration of inundation on Newell Highway were generally minimal as a result of the proposal. They advised that the section of Newell Highway at Spring Creek was subject to frequent flooding. They also indicated that a heavy duty pavement upgrade of Newell Highway planned for 2024 could consider a flood immunity for the 20% AEP flood event.

4.5 Consultation with Floodplain Risk Management Committees

A meeting was held with the Narrabri Floodplain Risk Management Committee on 28 April 2020 and the Narromine Floodplain Risk Management Committee on 3 September 2020 to discuss the approach to the flooding assessment undertaken for the proposal. The Narrabri Floodplain Risk Management Committee includes members of Narrabri Shire Council, SES, and OEH.

4.6 Stakeholder meetings in mid to late 2020

Between July 2020 and November 2020, ARTC held a number of meetings with landholders directly impacted by the final rail corridor. At these meetings landowners were provided updated property maps, clearly showing the location of the final rail corridor. The meetings also covered flood modelling results (flood levels with the proposal), operational noise, access, visual impacts, property acquisition and construction infrastructure.

ARTC also engaged with landowners whose property or properties where predicted to have potential above floor afflux impacts. During this engagement, ARTC explained the flood model and proposal structures nearby, the predicted impacts and possible mitigation measures. Examples of the information shown to landowners are provided in Figure 4.3.

Consultation also continued with Local and State Government entities, community and business groups, and other key stakeholders. All the feedback gathered, where applicable, was used to inform both the design and EIS process.

4.7 Draft EIS stakeholder briefings

Draft EIS stakeholder briefings were held during August 2020. These included five briefings with the N2N Community Consultative Committees, Government agencies, local government and the general public.

Online sessions included details about the proposal and EIS overview and a focus on EIS topics including biodiversity, Aboriginal heritage, flooding and hydrology, water resources, noise and vibration (construction and operation), land use and property, social and economic and traffic and access. Excluding the Community Consultative Committees briefing, 94 people attended the sessions. Questions asked by the community varied and included topics such as flooding, construction water use and legacy aspects. The briefings included attendees from Councils, SES and DPIE (now DPE) BCD Flood Management Division.

4.8 Consultation following EIS exhibition

4.8.1 Meetings with landowners

Property acquisition discussions

Transport for NSW has appointed ARTC to act as a representative for the purposes of negotiating agreements for the acquisition of land for Inland Rail. The acquisition (including the acquisition of land by agreement) will be done in accordance with the *Land Acquisition (Just Terms Compensation) Act 1991*.

In April 2021 ARTC commenced voluntary property acquisition discussions with landowners directly impacted by the rail corridor. These meetings focused on the property acquisition process which included the predicted impacts caused by the proposal. Information supplied to landowners included mapping of the 20% AEP and 1% AEP flood events and covered areas such as afflux, existing duration, changed duration, existing velocity and changed velocity. These additional impacts are taken into consideration during the acquisition process.

These detailed maps provide the landholders with a clear understanding of the flooding impacts at their specific properties. An example of the information shown to landowners is provided in Figure 4.3.

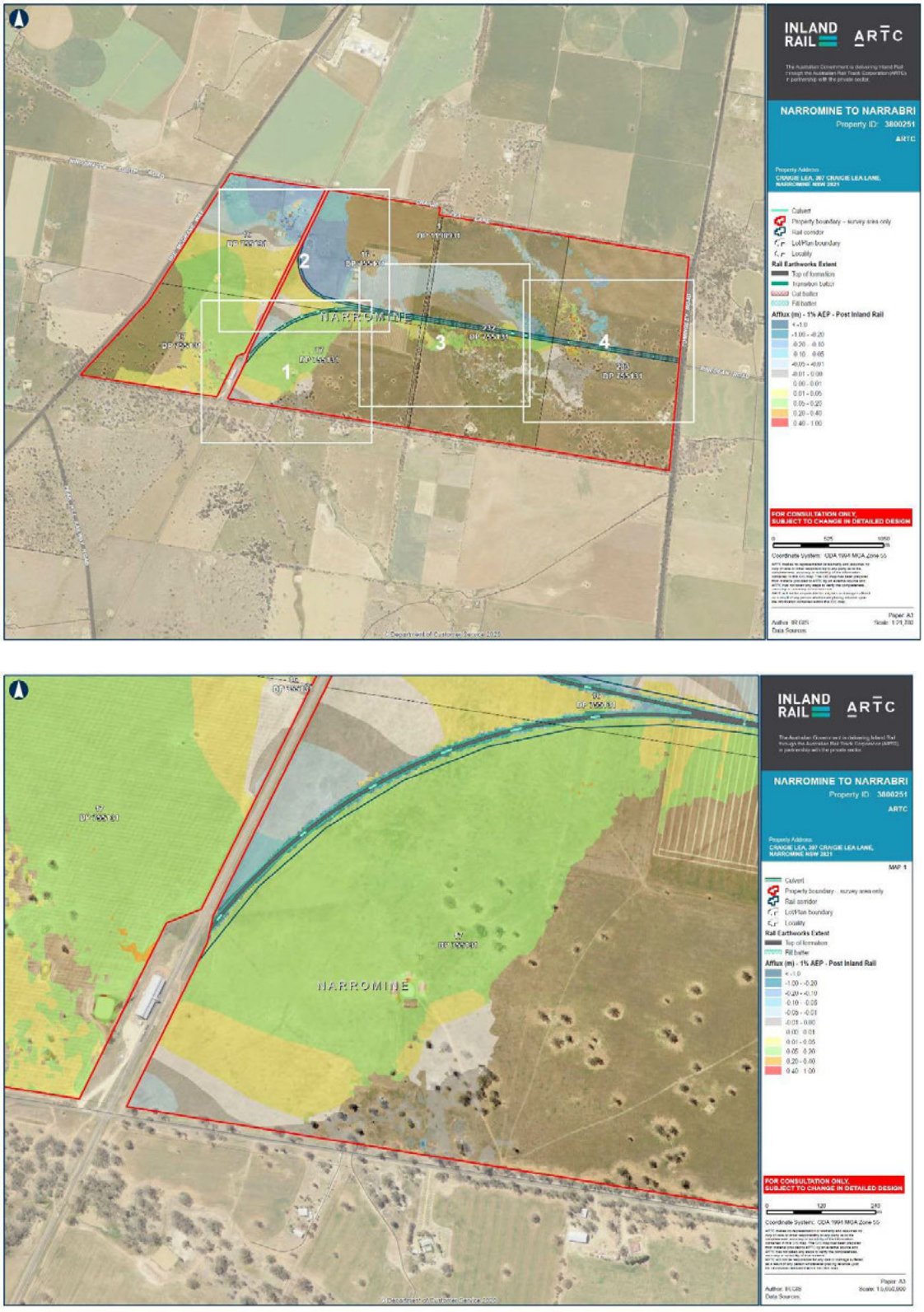


Figure 4.3 Examples of detailed property specific flood mapping

Afflux impact to structures

There are some residential, industrial and other structures predicted to experience above floor flooding and more than 10 millimetres of afflux following construction of the proposal. During August 2021, ARTC held telephone meetings with 18 individual landowners in Narrabri, Bohena Creek, Curban and Narromine regarding afflux and duration increases at their properties. The predicted flooding increases were minor and, as such, 16 of the landowners advised that they had no concerns. One landowner requested further modelling following detailed design and the other was concerned about cumulative increases in flood levels over time and requested a floor level survey of his residence.

In most cases these structures were already significantly affected by flooding and landowners expressed a neutral sentiment to changes proposed due to minor overall impact.

At locations where it is not practicable to meet the QDLs, ARTC will undertake the process detailed in Section 3.2.2.

Drainage control areas

ARTC has attempted telephone contact applicable landowners with drainage control areas on their properties and provided maps with identified drainage control areas via email and post during March 2022. The key issue for landowners is the additional land-take, rather than the predicted velocity exceedances. ARTC note this and will, wherever possible, reduce the size or eliminate the need for drainage control areas through assessment of erosion potential, geomorphological studies and cost-effective engineering solutions.

4.8.2 Meetings with councils and floodplain risk management committees

Narromine

A joint meeting occurred with Narromine Shire Council staff and Narromine Floodplain Risk Management Committee on 17 June 2021. The flood plain committee had completed their own modelling of the Inland Rail alignment. This aligned closely to the impacts predicted by the ARTC flood model. There was a request for ARTC to coordinate the proposal with the future Narromine flood mitigation works being considered by Council. These works would include a new levee to protect the town of Narromine and additional flood relief culverts under the existing Narromine to Dubbo Railway at Webbs Siding.

ARTC undertook to consider additional scour protection as part of the detailed design at new bridges immediately downstream of Webbs Siding.

Narrabri

A joint meeting occurred with Narrabri Shire Council staff and the Narrabri Floodplain Risk Management Committee on 8 June 2021. The meeting included discussion around the updated flood model for the proposal. A request was made for ARTC to coordinate with the committees planned flood mitigation measures. A key area of interest was where the proposal runs parallel to the Newell Highway to the north of Narrabri. The committee identified some proposed works to increase drainage capacity under the Newell Highway. As part of this discussion, ARTC agreed that during detailed design coordination will continue with Council.

On 25 August 2021 a meeting was held with local residents and representatives from Narrabri Shire Council to discuss historical flooding at Bohena Creek. The residents provided information regarding observations of historical flood events at the meeting. The general opinion from Council and residents is that the modelling results for the proposal are conservative and it is possible that sandy conditions within the Pilliga forests reduce the rainfall runoff into the creek.

The reliability of historical data from the Bohena Creek gauging station is however questionable at high flows and without further data it is not therefore possible to categorically confirm which method provides the most likely estimate of flood flows. With this in mind, results presented in this report are based on more conservative estimates derived from the procedures in *Australian Rainfall and Runoff* (Ball et al, 2019). An alternative analysis is also considered in Appendix Q that is based on scaled flow data from the Bohena Creek gauge and is more consistent with the *Bohena Creek Flood Study* (WRM, 2019b) and the feedback received from consultations with the local community and Narrabri Council.

During March 2022 ARTC presented the project to Narrabri Shire Council councillors and the Narrabri Chamber of Commerce.

4.8.3 DPE – Hydrology Working Group Meetings

ARTC has had regular consultation with DPE to respond to comments and clarifications on flood modelling undertaken for the EIS. A total of 13 Hydrology Working Group meetings were held between March 2021 and July 2022. A number of technical meetings were also held between DPE's technical reviewer and ARTC's hydrologists to address specific aspects of the flood modelling and results.

The outcomes of these meetings and technical discussions are included in this Updated Flooding and Hydrology Assessment Report.

4.8.4 Community consultation committee meetings

Briefings with N2N Community Consultative Committees were held on 28, 29 and 30 March 2022. The briefings provided an update on post-EIS activities and the upcoming lodgement of Response to Submissions Report and Preferred Infrastructure/Amendment Report.

4.9 Flood model refinements

Feedback received from community and stakeholder consultations was used to check results from the TUFLOW flood models. Photographic evidence showing actual flood levels and extents was checked against the model predictions to confirm that the outputs reflect observed flood behaviour.

Following exhibition of the EIS, the submissions received were reviewed by ARTC and, where appropriate, flood models were adjusted to reflect the comments made as described in Section 3.5.

As part of the engagement with the Narrabri Floodplain Risk Management Committee, it was recommended that proposal further consider flooding from Mulgate Creek and local tributaries. This has been undertaken and is provided in Section 7.5.6.

4.10 Ongoing and future consultation

As described above ARTC has actively consulted with the community on flooding and hydrology.

The approach to mitigating flooding and hydrology impacts includes continued consultation with Councils, SES, DPE Biodiversity Conservation and Science Division (BCD) – Flood Management Division, floodplain risk management committees and local emergency management committees. Ongoing engagement with local landowners will also be undertaken and will include a range of topics as outlined below.

4.10.1 Property acquisition discussions

As outlined in Section 4.8.1, ARTC has commenced voluntary property acquisitions.

Formal property acquisition discussions commenced with landowners in March 2022. This includes discussions of flooding and hydrology, farm dams and drainage control areas with any impacts considered as part of the property valuation and compensation process.

4.10.2 Detailed design consultation

Additional landowner and stakeholder consultations will provide key inputs into the detailed design process.

At the local authority level, detailed assessments would be required for interfaces with existing infrastructure, such as roads, drainage, water and sewer.

Detailed designs would also consider minor drainage systems from local contour drains, banks and channels. ARTC has commissioned additional LiDAR survey to provide an updated assessment of the landscape surrounding the proposal. This information will include recent changes to the landscape to help improve flood modelling accuracy and allow for targeted discussions during landowner consultations.

ARTC's primary objective will be to refine the detailed design to meet the QDLs (Section 3.2.2) for the proposal. It is expected as part of this process that the flood impacts on surrounding properties will be reduced.

The detailed design engagement will include further ground truthing of the flood model for both the existing and operational conditions. At this stage ARTC will also consider in further detail the locations of existing flow paths, contour banks and dams and how any potential impact to these can be minimised.

5 Existing environment

5.1 Regional context

5.1.1 Regional catchments and watercourses

The proposal is located within the major regional water catchments of the Macquarie River basin, Castlereagh River basin, and Namoi River basin; all of which are located within the Murray-Darling Basin.

Macquarie River catchment

The Macquarie River is a perennial river and major tributary of the Barwon River. The river starts in the Great Dividing Range near Oberon and is formed by the junction of the Fish River and Campbells River upstream of Bathurst.

The Macquarie River flows northward through steep gorges before flowing into Burrendong Dam upstream of Wellington, which regulates downstream flows. The river then flows through Wellington, enters the Central West subregion upstream of Dubbo and passes through Dubbo and Narromine. Downstream of Narromine a complex system of anabranches and distributary creeks connects the Macquarie and Bogan rivers.

Downstream of the Macquarie Marshes the Macquarie River is joined by the Castlereagh River, then flows into the Barwon River upstream of Brewarrina. The Barwon River is a tributary of the Murray Darling Basin, meeting the Darling River near Bourke.

The proposal crosses the Macquarie River along the eastern outskirts of Narromine. The total upstream catchment area of the Macquarie River is 25,900 square kilometres and represents the largest upstream catchment area for a waterway crossing the proposal.

Castlereagh catchment

The Castlereagh River is a non-perennial (intermittent) river, which rises in the Warrumbungle Ranges and flows through Coonabarabran before entering hilly country. The river then flows through Binnaway, Mendooran, Gilgandra, Gulargambone and Coonamble and joins the Macquarie River downstream of the Macquarie Marshes. At Warrington, the river becomes less defined, becoming a series of pools and meandering, braided flow pathways, before becoming more defined around Youendah before meeting the Macquarie River west of Walgett.

The proposal crosses the Castlereagh River about five kilometres north-east of the Coonamble Railway, at chainage 651.7. The total upstream area of the Castlereagh River is 6,630 square kilometres.

Namoi River catchment

The Namoi River is a perennial river, which starts in the western slopes of the Great Dividing Range flowing westwards through Lake Keepit towards Boggabri, Narrabri and Wee Waa, before meeting the Barwon River at Walgett. The Barwon River is a tributary of the Murray Darling Basin, meeting the Darling River near Bourke.

The Namoi River basin is well drained by the Namoi River and its tributaries for most areas east of Pilliga. The surface drainage network extends through different landscape units ranging from uplands with steep terrain to flat low-lying alluvial plains (Lampert and Short, 2004).

The proposal crosses the Namoi River west of Narrabri. The total upstream catchment area of the Namoi River is 25,400 square kilometres.

5.1.2 Catchments and watercourses

In addition to the regional scale catchments discussed above, a number of local scale catchment watercourses cross the proposal. These range from small, unnamed tributaries with catchments of less than one square kilometre to large watercourses with upstream catchment areas exceeding 2,000 square kilometres (e.g. Bohena Creek).

Table 5.1 presents a list of the catchments, sub-catchments and named watercourses, including their respective flow type and hierarchy (derived through BoM Geofabric Surface Hydrology dataset), which are mapped as intersecting the proposal.

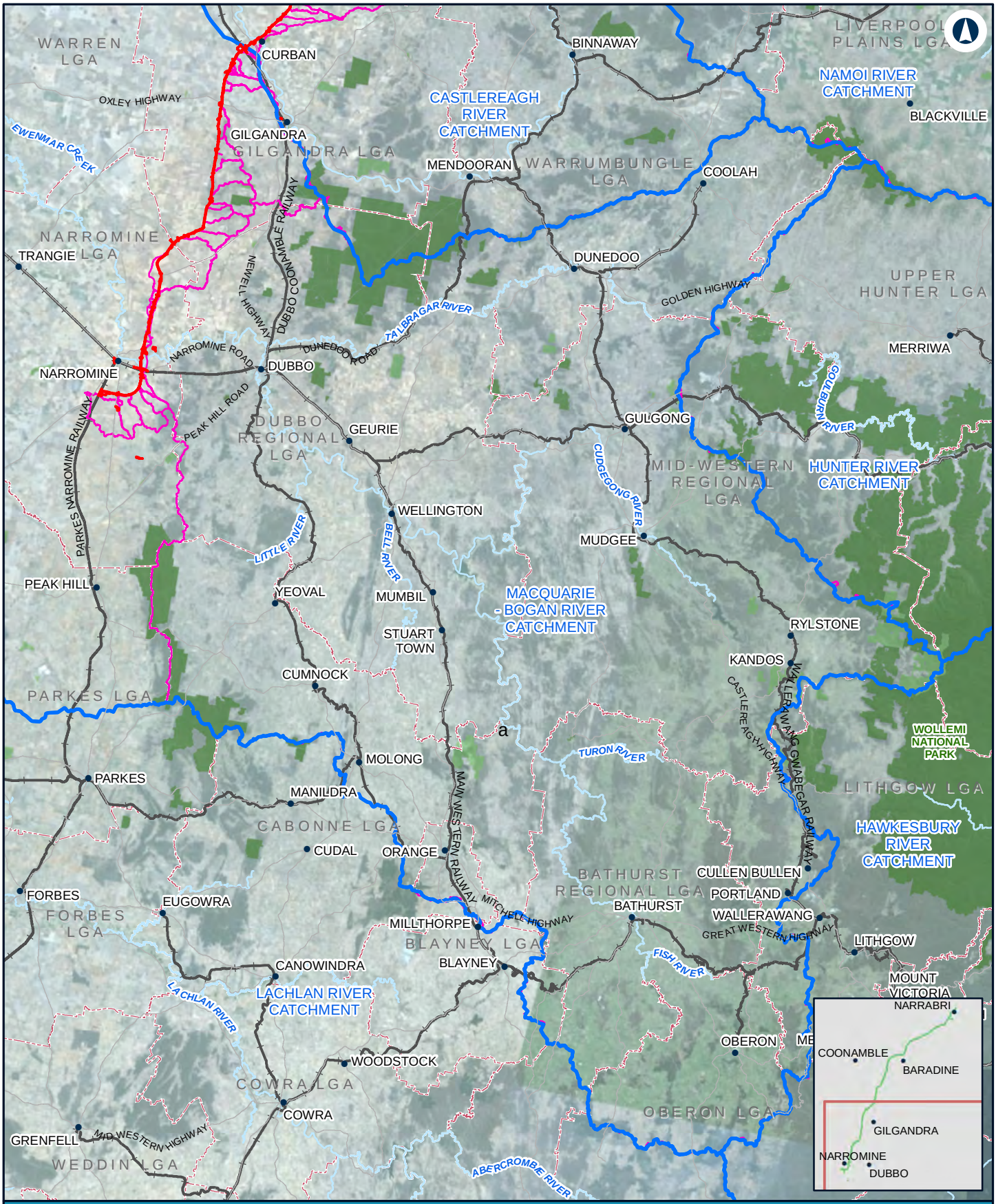
The catchments areas associated with sections of the alignment were delineated based on the SRTM DEM (Section 3.3.3). Catchment areas presented in Table 5.1 are shown in Figure 5.1. Each of these catchments was further divided into sub-catchments for the purpose of modelling.

Table 5.1 shows that the majority of watercourses comprise minor watercourses with non-perennial (ephemeral / intermittent) flow conditions. Only two major perennial watercourses (Macquarie River and Namoi River) are intersected.

Table 5.1 Local catchments and watercourses intersecting the proposal

Basin	Catchments/Watercourses	N2N Chainage (km)	Upstream catchment area (km^2)	Flow type/ hierarchy
Macquarie River basin	Yellow Creek	-	57	Non-Perennial - Minor
	Wallaby Creek	553.99	132	Non-perennial - Major
	Unnamed tributary of Backwater Cowal (South)	556.19	40	Non-Perennial - Minor
	Unnamed tributary of Backwater Cowal (North)	557.85	28	Non-Perennial - Minor
	Macquarie River	562.35	25,927	Perennial - Major
	Ewenmar Creek	595.24	146	Non-Perennial - Minor
	Goulburn Creek	599.20	25	Non-Perennial - Minor
	Emogandy Creek	602.66	38	Non-Perennial - Minor
	Native Dog Creek	607.15	15	Non-Perennial - Minor
	Pint Pot Gully	608.93	5	Non-Perennial - Minor
	Kickabil Creek	609.72	60	Non-perennial - Major
	Milpulling Creek	616.68	39	Non-perennial - Major
	Bundijoe Creek	623.23	19	Non-Perennial - Minor
	Marthaguy Creek	633.68	410	Non-Perennial - Major
Castlereagh River basin	Castlereagh River	651.73	6,691	Non-perennial - Major
	Judes Creek	659.20	24	Non-Perennial - Minor
	Gulargambone Creek	673.08	242	Non-Perennial - Minor
	Baronne Creek	682.60	399	Non-Perennial - Major
	Tenandra Creek	694.20	40	Non-Perennial - Minor
	Mungery Creek	700.02	11	Non-Perennial - Minor
	Caleriwi Creek	702.34	46	Non-Perennial - Major
	Quanda Quanda Creek	704.59	46	Non-Perennial - Minor

Basin	Catchments/Watercourses	N2N Chainage (km)	Upstream catchment area (km^2)	Flow type/ hierarchy
	Black Gutter	708.47	3	Non-Perennial - Minor
	Salty Springs Creek	709.27	29	Non-Perennial - Minor
	Calga Creek	714.59	51	Non-Perennial - Minor
	Noonbar Creek	718.17	1	Non-Perennial - Minor
	Bucklanbah Creek	722.29	138	Non-Perennial - Minor
	Small Creek	728.11	6	Non-Perennial - Minor
	Teridgerie Creek	730.50	388	Non-Perennial - Major
	Ironbark Creek	737.89	11	Non-Perennial - Minor
Namoi River basin	Baradine Creek	747.77	946	Non-Perennial - Major
	Coolangla Creek	752.71	42	Non-Perennial - Minor
	Cumbil Forest Creek	758.97	7	Non-Perennial - Minor
	Etoo Creek	763.46	319	Non-Perennial - Major
	Stockyard Creek	767.94	17	Non-Perennial - Minor
	Rocky Creek	769.14	181	Non-Perennial - Minor
	Tinegie Creek	773.37	2	Non-Perennial - Minor
	Talluba Creek	779.64	45	Non-Perennial - Minor
	Cubbo Creek	783.65	68	Non-Perennial - Minor
	Rocky Creek	789.38	18	Non-Perennial - Minor
	Coghill Creek	796.41	80	Non-Perennial - Major
	Mollieroi Creek	800.45	104	Non-Perennial - Major
	Black Creek	803.65	18	Non-Perennial - Minor
	Goona Creek	809.11	52	Non-Perennial - Minor
	Bundock Creek	817.65	106	Non-Perennial - Minor
	Bohena Creek	828.22	2,064	Non-Perennial - Major
	Namoi River	844.12	25,169	Perennial - Major
	Narrabri Creek	847.63	-	Perennial – Major (a flood runner of the Namoi River)
	Mulgate Creek	852.57	78	Non-Perennial - Minor



NARROMINE TO NARRABRI Waterways and catchments - Macquarie River Catchment Figure 5.1a

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Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:1,250,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Waterway
- Major river catchment
- Catchment area

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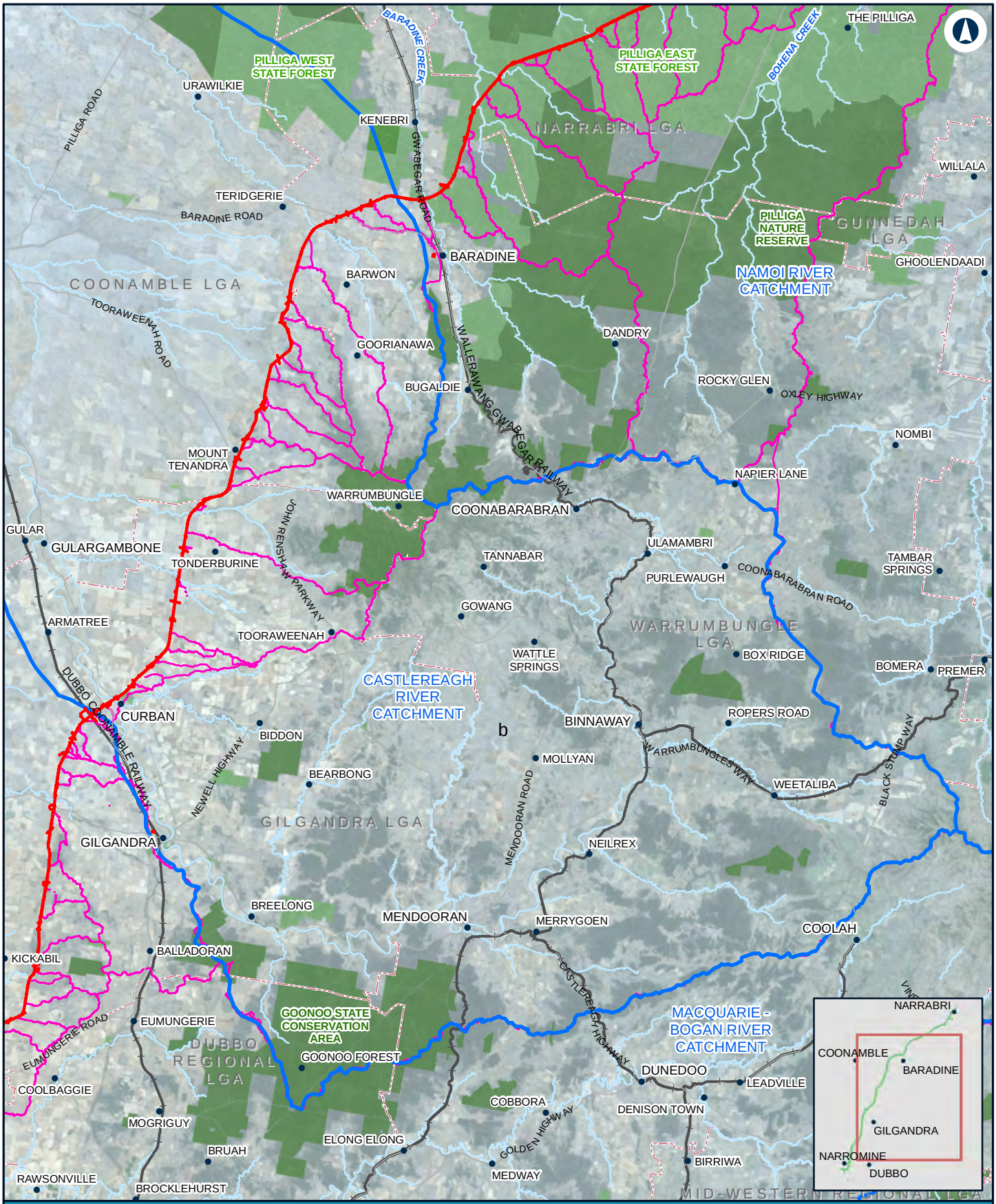

NARROMINE TO NARRABRI Waterways and catchments - Castlereagh River Catchment Figure 5.1b

0 10 20 Km

Coordinate System: GDA 1994 MGA Zone 55

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Author: JacobsGHD Scale: 1:750,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Waterway
- Major river catchment
- Catchment area

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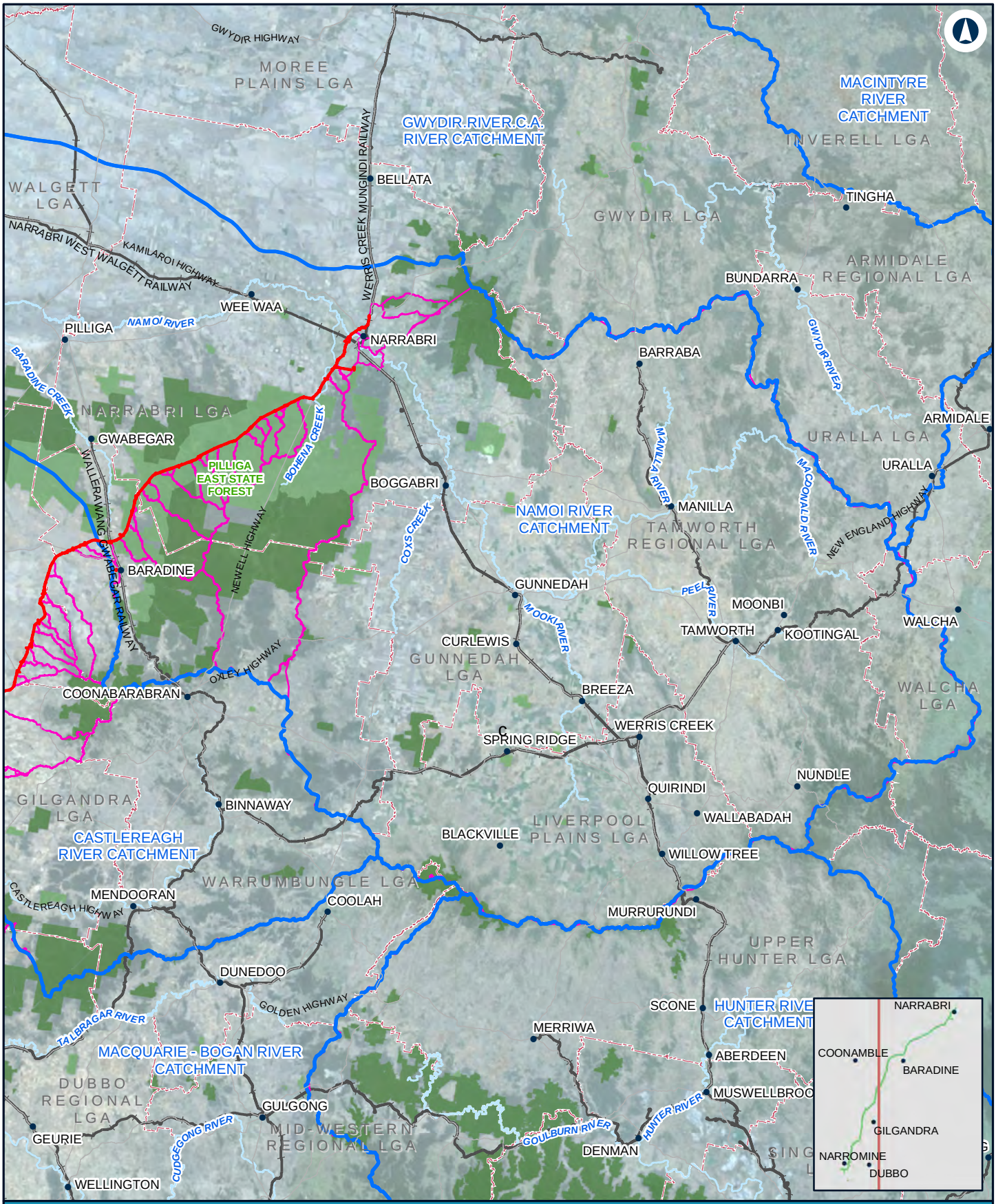

NARROMINE TO NARRABRI — Waterways and catchments - Namoi River Catchment — Figure 5.1c

0 30 60 Km

Coordinate System: GDA 1994 MGA Zone 55

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Author: JacobsGHD Scale: 1:1,500,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Waterway
- Major river catchment
- Catchment area

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5.1.3 Rainfall

Figure 5.2 to Figure 5.4 present statistical measures of monthly rainfall at selected long-term BoM rainfall monitoring stations located along the proposal. Examination of mean annual rainfall indicates seasonal variations corresponding with a relatively 'wet' summer period (November – March) and relatively 'dry' winter period (April – October). Mean monthly rainfall varies between a high of about 80 millimetres during January to a low of about greater than 40 millimetres in August. Average annual rainfall varies between 554 and 678 millimetres.

Rainfall conditions during drier / drought years (10 percentile conditions) shows a greater variability along the proposal and less significant seasonal influence. Rainfall conditions during dry/drought years may vary between highs of about 15 millimetres during the summer period and lows of less than 5 millimetres during the winter period. Annual rainfall under 10 percentile conditions varies between 298 and 444 millimetres.

Rainfall conditions during wetter / flood years (90th percentile conditions) shows similar seasonality in trend to average rainfall conditions. Rainfall conditions during wet/flood years may vary between highs of about 150 millimetres during the summer period and lows of about 75 millimetres during the winter period. Annual rainfall under 90th percentile conditions varies between 764 and 945 millimetres.

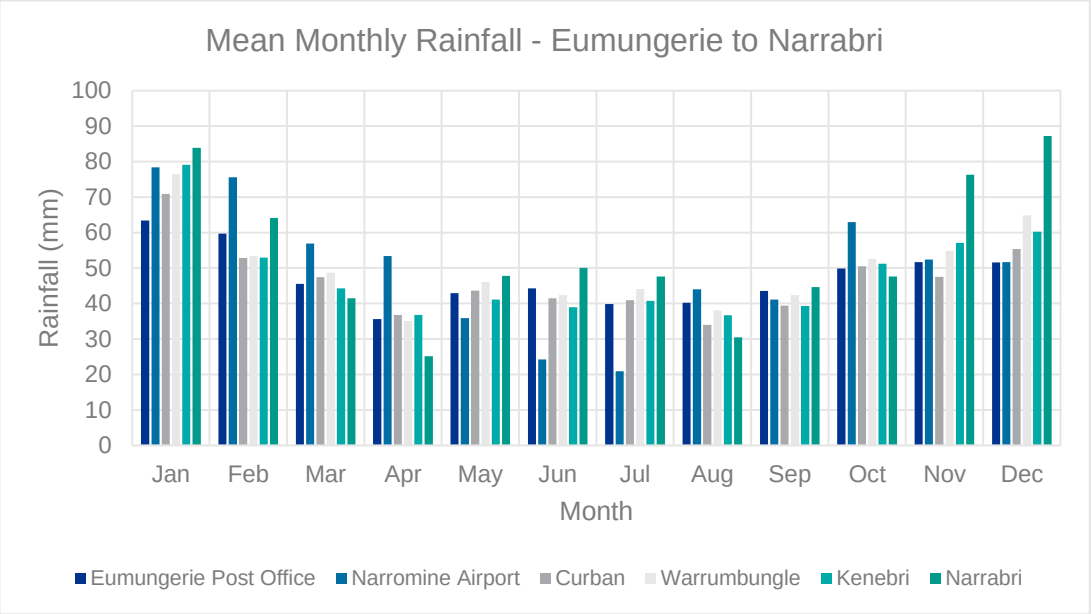

Figure 5.2 Mean monthly rainfall – Eumungerie to Narrabri

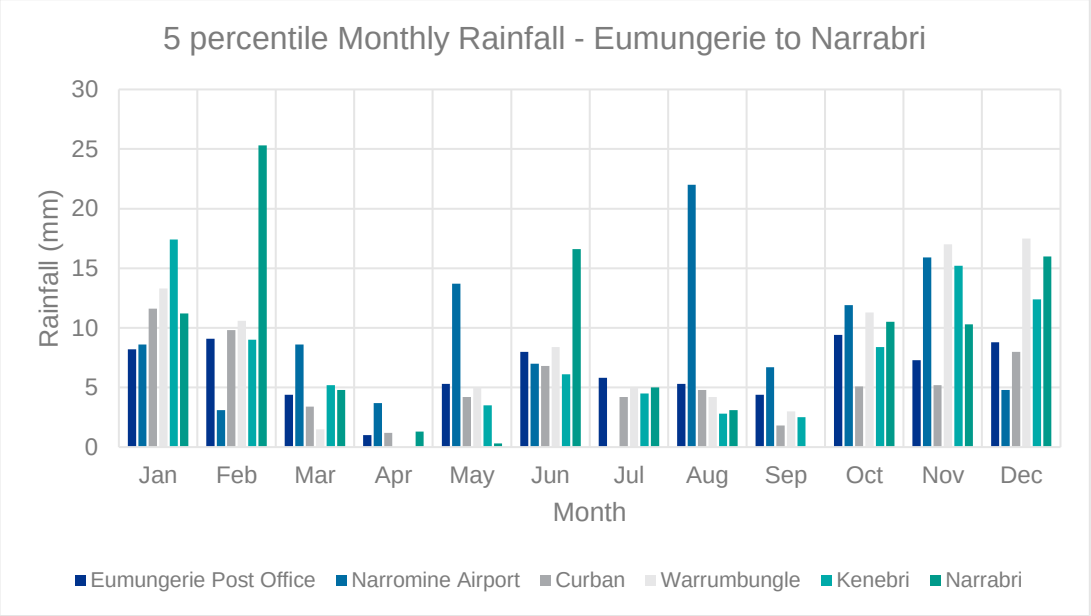

Figure 5.3 5 percentile monthly rainfall – Eumungerie to Narrabri

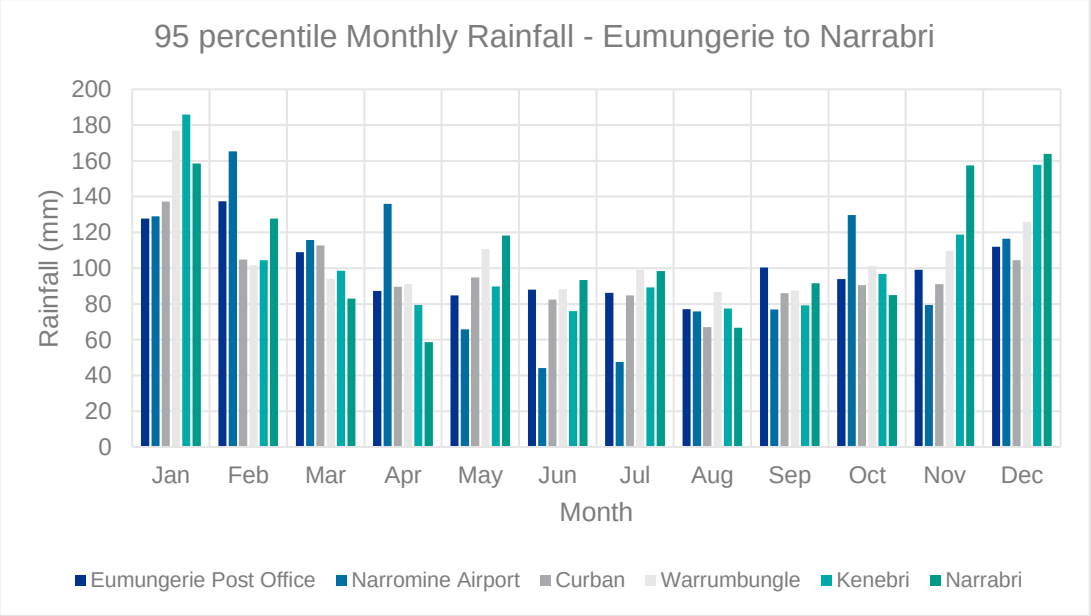

Figure 5.4 95 percentile monthly rainfall – Eumungerie to Narrabri

5.1.4 Evaporation

Figure 5.5 presents average monthly evaporation rates for the proposal alignment. Evaporation rates show marked seasonality between a summer maximum of approximately 280 millimetres per calendar month and a winter minimum of approximately 55 millimetres per calendar month. Average monthly evaporation rates typically exceed average monthly rainfall year-round, resulting in semi-arid conditions (aridity index of approximately 0.29) over an annual period.

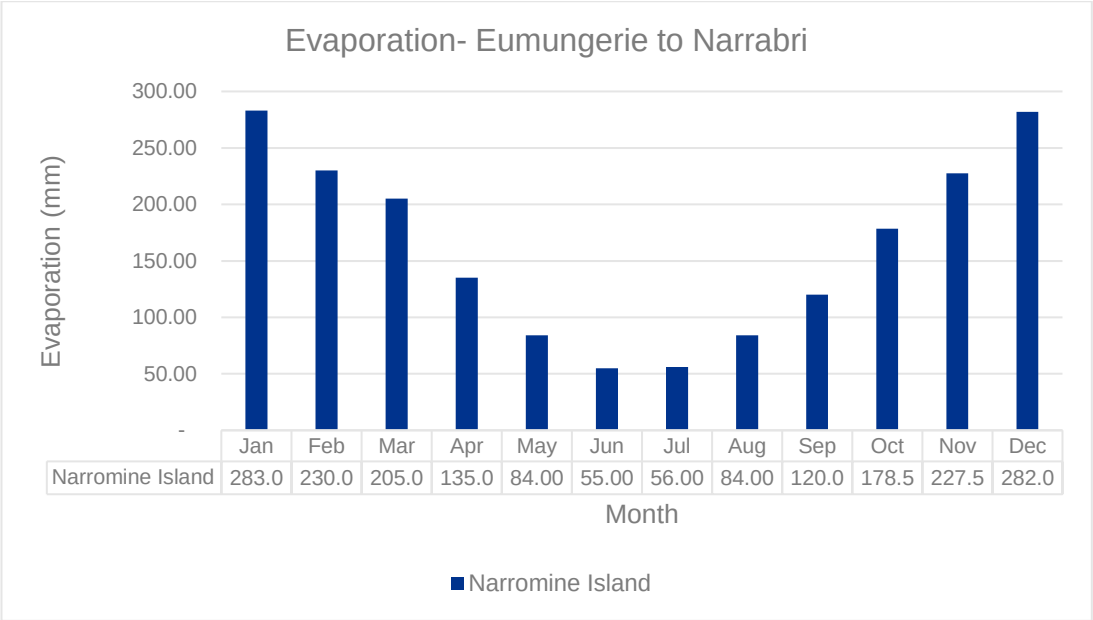

Figure 5.5 Monthly evaporation – Eumungerie to Narrabri

5.1.5 Land use

The land surrounding the study area primarily comprises agricultural uses, particularly cotton, wheat, and livestock. These industries have resulted in significant clearing of the landscape. This clearing has an impact on the resulting storm flows by lowering the catchment roughness (a measure by which surface flow in impaired by the surface type (refer to the Hydrology and Hydraulic Models Calibration Report in Appendix J for further information)), which quickens the catchment's response time to rainfall and results in shorter, more intense catchment flows.

In addition to the agricultural land uses, areas of bushland in the form of national park or State forest result in relativity small pockets of uncleared native vegetation within the contributing catchments.

Relatively small and localised pockets of urban areas exist centred around Narromine, Gilgandra, Baradine and Narrabri.

Figure 5.6 shows the land uses along the proposal site along with forestry reserves, conservation reserves and national parks. As shown, the flatter portions of the catchments are generally used for agricultural uses.

NARROMINE TO NARRABRI

Land Use

Figure 5.6

0 25 50 Km

Coordinate System: GDA 1994 MGA Zone 55

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Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Watercourse
- Railway
- Road

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5.1.6 Geology and soils

General

The proposal site is typically located within the Lachlan Fold Belt. Near surface materials include Tertiary to Quaternary alluvium and colluvial deposits over Jurassic sedimentary rocks with Cainozoic mafic volcanic outcrops intermittently along the proposal site.

The geology includes a variety of Jurassic to recent sediments along with the volcanic ranges of the Warrumbungles and Nandewar Range. It includes both highly fertile basalt derived soils and very poor soils of the Pilliga sandstones. Soil erosion, salinity and soil structure decline are noted as the major soil issues of the area.

Additional detailed information is outlined within the EIS.

Soil groups and characteristics

Office of Environmental and Heritage (OEH) soil mapping data indicates that soil types along the proposal site can be best described in four broad areas which share a similar suite of soil types:

- Narromine to the Oxley Highway – the main soil types are dominated by 'red brown earths, red earths and solodic soils'.
- Oxley Highway to Baradine – the main soil types are dominated by 'grey, red and brown clays (vertosols), black earths (vertosols), red brown earths, red earths and non-calcic brown soils'.
- Baradine to Narrabri – the main soil types are dominated by 'solodic soils and earthy sands'.
- Narrabri – the main soil types in the vicinity of Narrabri are dominated by 'solodic soils' south of Narrabri and 'grey, red and brown clays (vertosols) and black earths (vertosols)' close to Narrabri.

Descriptions and examples of these soil groups are provided in Table 5.2. The dominant Great Soil Groups are shown in Figure 5.7.

Table 5.2 Major soil groups

Soil group	Sub-group	Description
Cracking clays (Vertosols)	Black earths	Characterised by deep, high plasticity, clays that crack significantly when dry and swell when wet. Gilgais are commonly present. Commonly formed on weathered basalt rocks, or from alluvial clays sourced from the weathered basalt. Clay often "sodic" and prone to dispersive erosion.
	Grey brown clays	
	Grey red brown clays	
Duplex soils (also known as texture contrast soils)	Solodic soils	Characterised by texture contrast soils which comprise an upper pale (bleached) silt/ sand horizon (A2 horizon) abruptly overlying a clay-rich horizon. Commonly formed on weathered sedimentary rocks and the older Quaternary alluvium/colluvium. Clay-rich horizon typically "sodic" and prone to dispersive erosion.
	Podzolic soils	
	Non-calcic brown soils	

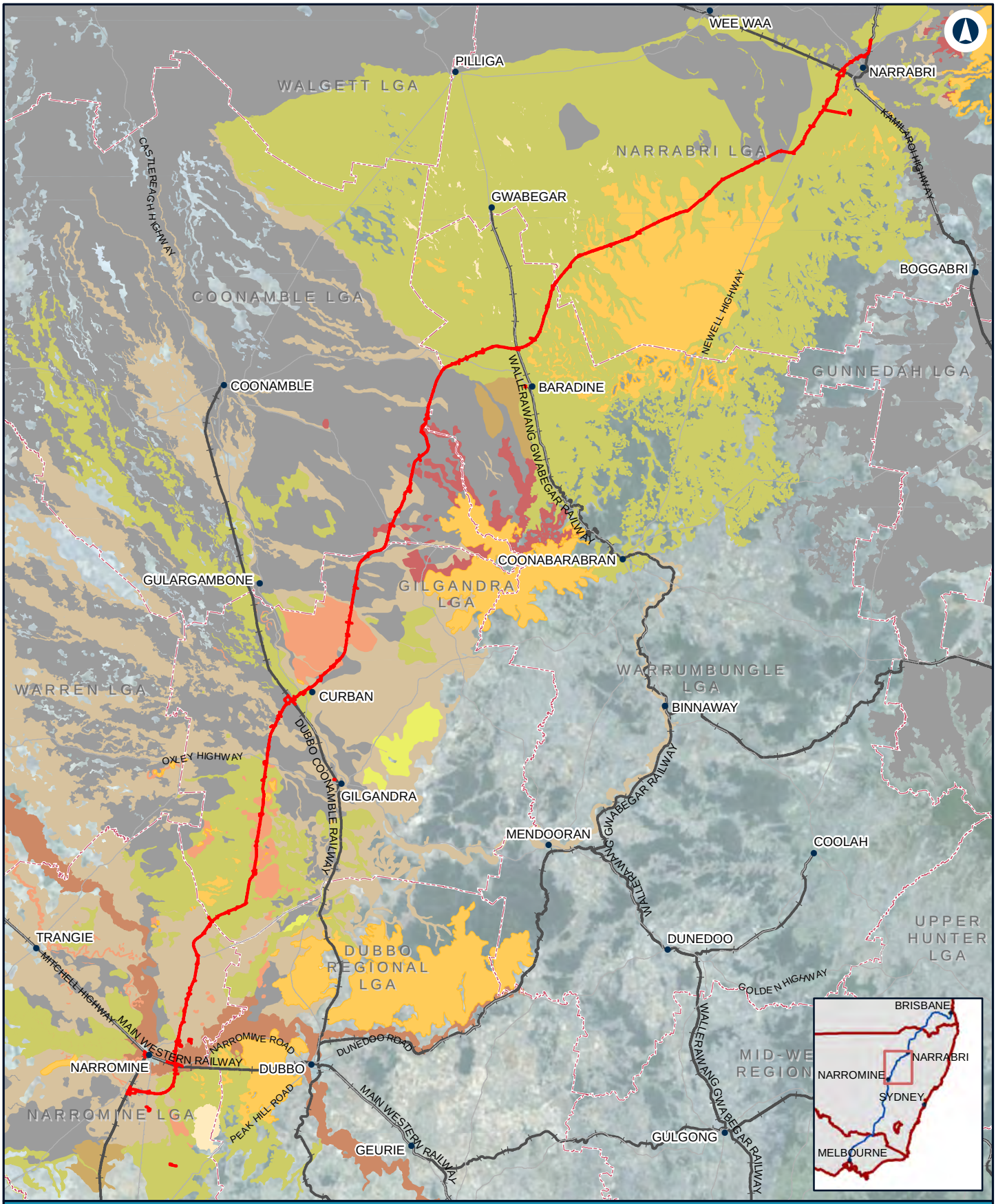
Soil group	Sub-group	Description
Non-cracking clays	Red earths	Characterised by massive sandy textured, porous, earthy soil materials with generally gradual boundaries. Commonly formed on better drained weathered sedimentary rocks and better drained and/or younger Quaternary alluvium. Earthy sands are characterised by uniform profiles of coherent, clayey sands which are dominantly red in colour but in some cases yellow. These soils are usually deep and are characterised by uniform sand texture and a massive, single-grained structure.
	Red brown earths	
	Brown earths	
	Earthy sands	
Alluvial soils	Recent alluvium	Mostly associated with current stream and river courses. Comprise alluvial sands, silts and clays with little or no soil profile development. Exhibit significant variations in engineering character from soft/ loose to stiff/dense.

Geotechnical investigations undertaken along the alignment for the reference design confirmed these soil classifications. Further geotechnical investigations carried out both prior to and during detailed design will further refine soils classifications and locations of such soils.

Acid sulfate soils

Acid Sulfate Soil (ASS) Risk Maps from the Australian Soil Resource Information System (ASRIS) database were reviewed to ascertain the potential ASS risk to the proposal. Given the location, distance from the coast, elevation (about 200 metres AHD) and that the review of ASRIS indicated there was typically ‘no known occurrence’ or a ‘low probability‘ of occurrence of ASS within the majority of the proposal site, the likelihood of ASS being present is considered low. However, it should be noted that although occurrence of ASS within the majority of the proposal is considered low and unlikely, ASRIS did indicate a ‘high probability’ of ASS around the Macquarie, Castlereagh and Namoi Rivers.

Additional detailed information is outlined in the EIS.



NARROMINE TO NARRABRI Soil landscape Figure 5.7

0 20 40 Km

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Author: JacobsGHD Scale: 1:40,000,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Railway
- Road
- Chromosols
- Dermosols
- Ferrosols
- Kandosols
- Kurosols
- Kurosols, Natric
- Rudosols
- Rudosols and Tenosols
- Sodosols
- Vertosols

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5.2 Flooding

5.2.1 Design flows

Peak discharges simulated by the hydrology models upstream of the proposal for all AEP events have been analysed to estimate peak discharge, storm duration and temporal pattern for each point of interest along the proposal. Storm durations ranging from 15 minutes to 168 hours were assessed for all flood events to ensure the critical duration was represented. Adopted peak discharge and critical storm duration for each flood event for each point of interest along the proposal are presented in Appendix B.

5.2.2 Design flood behaviour

Flood behaviour under existing conditions has been modelled for a range of design flood events from the 20% AEP up to the PMF. The existing 1% AEP flood extents along the length of the proposal are shown in Figure 5.8, and the following flood mapping is provided in Appendix C:

- flood depths – Figures 1.1a to 1.8n
- flood velocity – Figures 2.1a to 2.8n
- flood duration – Figures 3.1a – 3.8n
- flood hazard – Figures 4.1a – 4.8n

Flood mapping at Narrabri shows the envelope of peak regional flooding and local catchment flooding.

More detailed flood mapping for the existing 1% AEP flood extents is provided in Appendix H for Narromine and Narrabri.

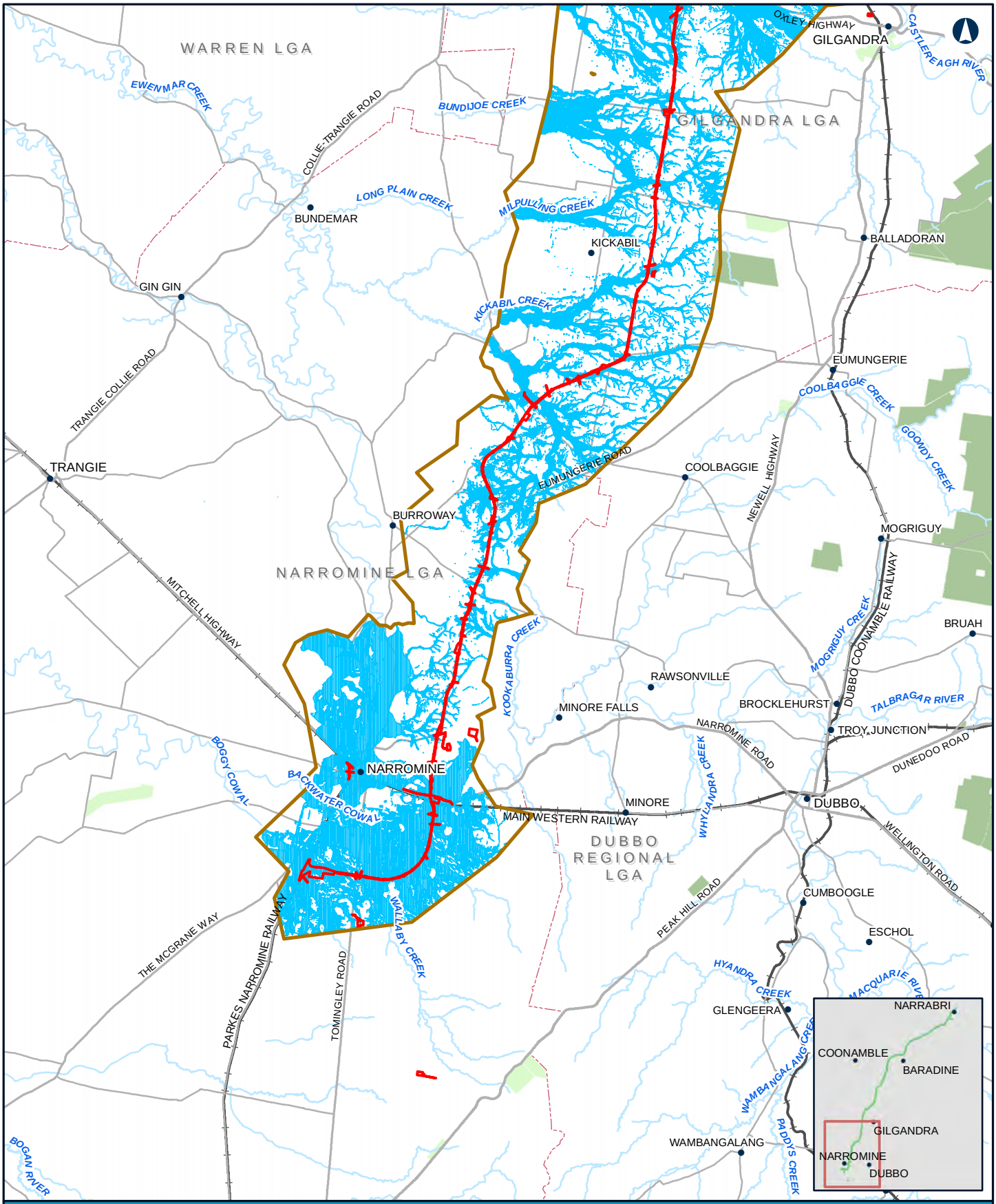
Flood mapping for Narrabri local catchments (Mulgate Creek etc) is presented in Appendix M.

Detailed flood mapping at the property level has been presented to landowners by ARTC as discussed in Section 4.

Inundation of buildings, roads, railways, and major land uses are discussed in Sections 5.2.3 to Section 5.2.6.

The extents of each flood model are listed in Table 3.4 and shown on Figure 3.4.

Flood hazard categories are based on those provided in Figure 2.1.



NARROMINE TO NARRABRI Existing 1% AEP flood extents Figure 5.8a

0 8 16 Km

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Author: JacobsGHD Scale: 1:400,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent

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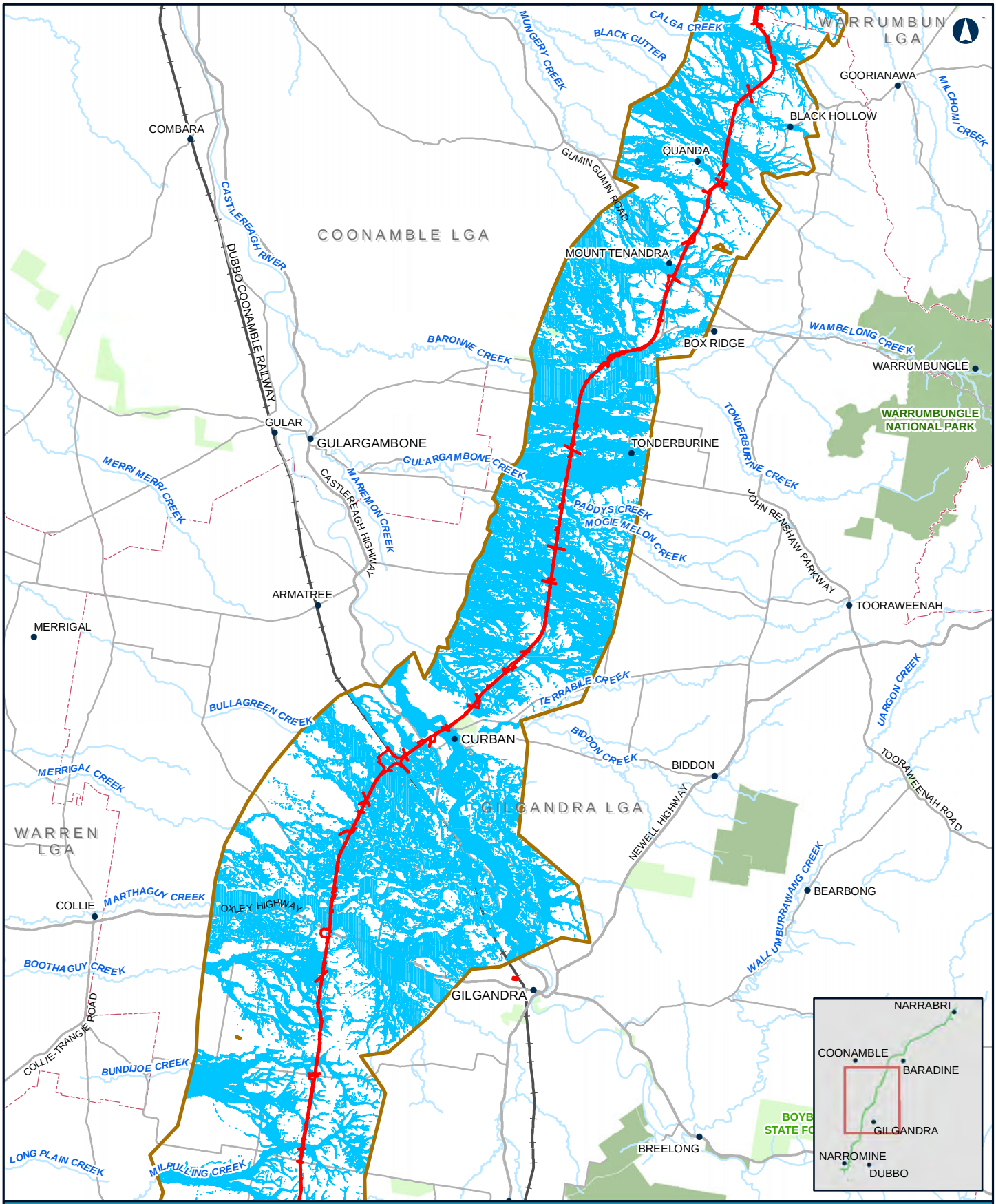

NARROMINE TO NARRABRI Existing 1% AEP flood extents Figure 5.8b

0 8 16 Km

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LEGEND

- The proposal
- Study area
- Flood extent

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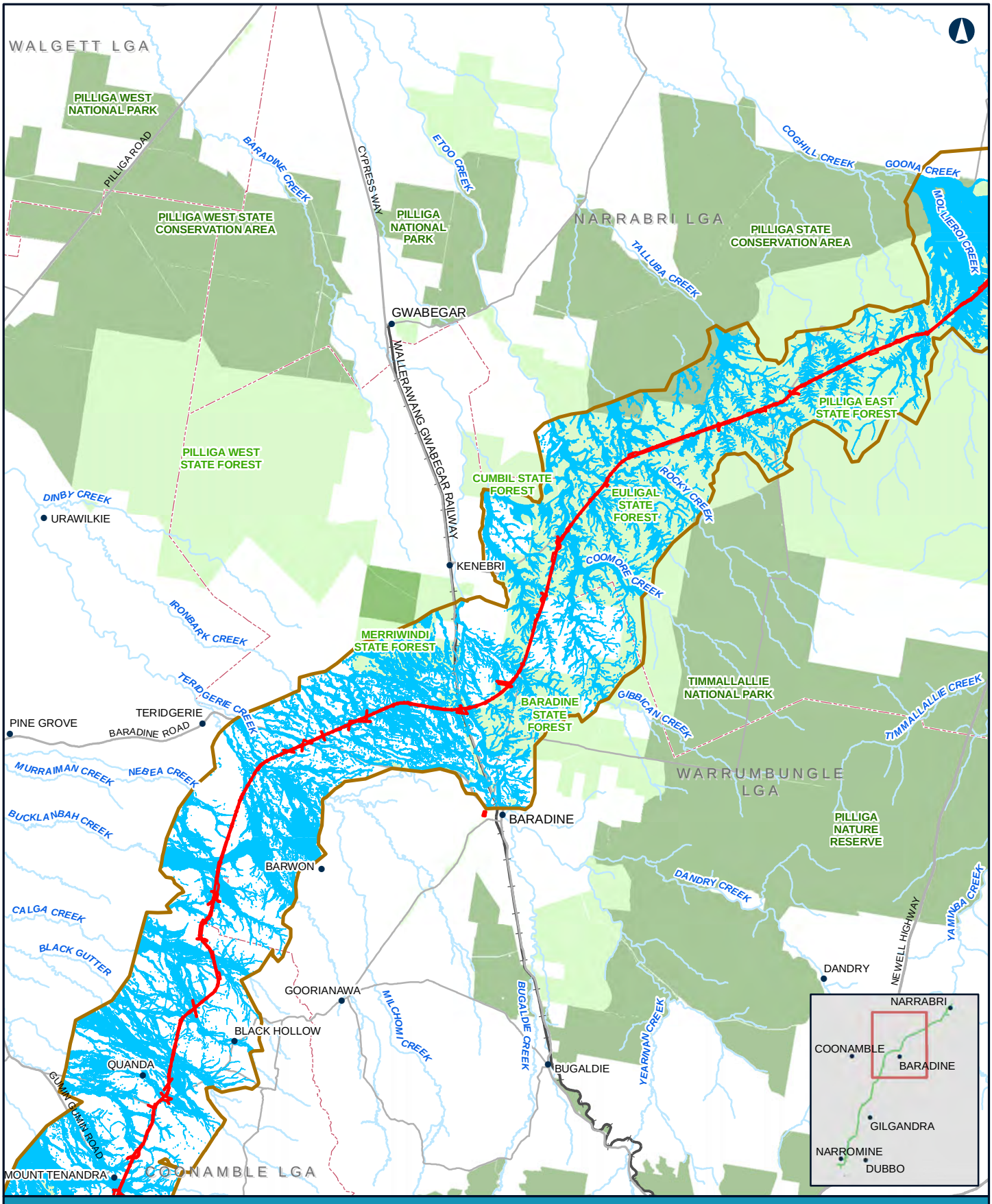

NARROMINE TO NARRABRI Existing 1% AEP flood extents Figure 5.8c

0 8 16 Km

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LEGEND

- The proposal
- Study area
- Flood extent

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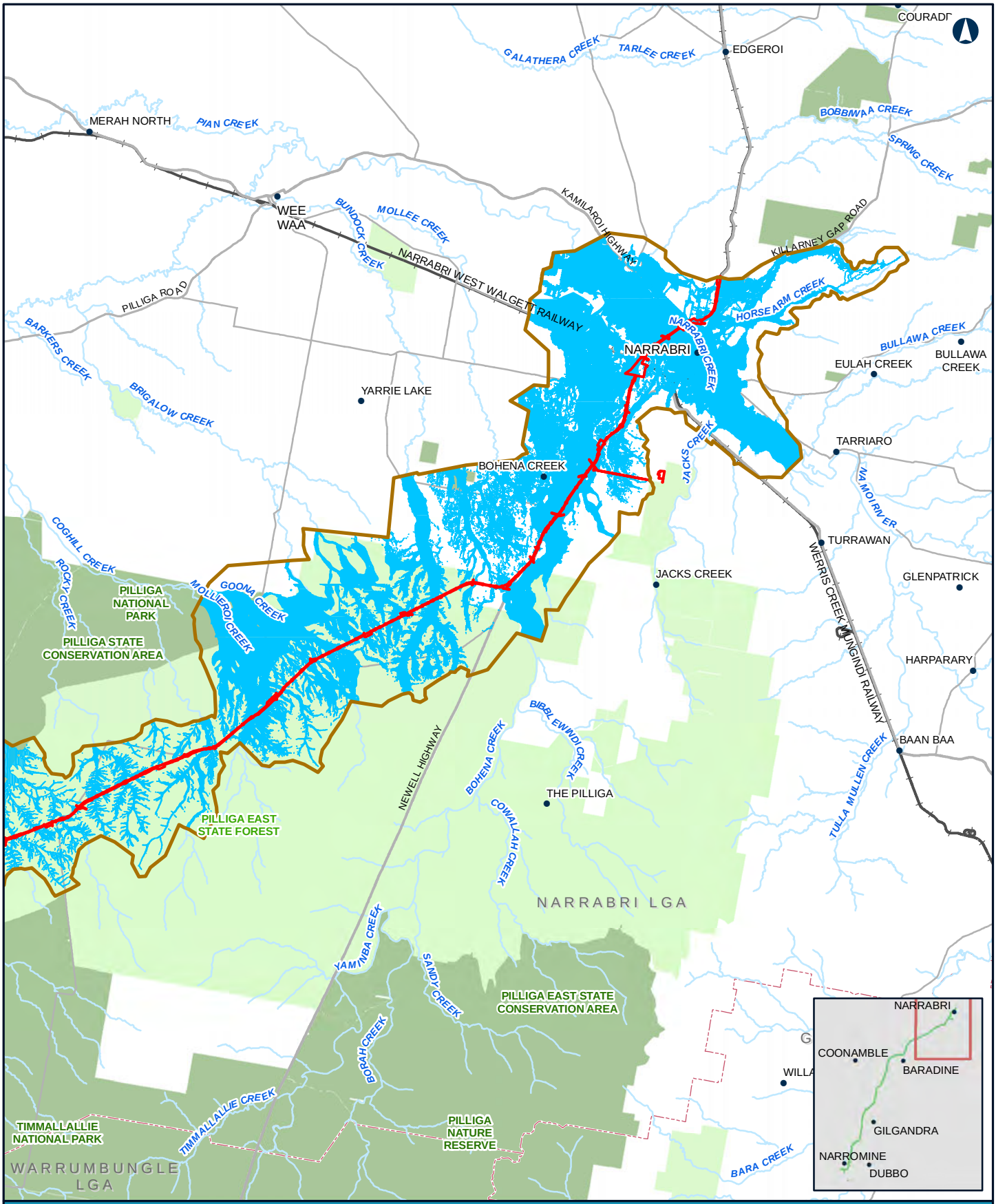

NARROMINE TO NARRABRI

Existing 1% AEP flood extents

Figure 5.8d

0 8 16 Km

Coordinate System: GDA 1994 MGA Zone 55

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Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent

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5.2.3 Inundation of buildings

Geo-databases containing flood modelling data have been interrogated to identify peak flood levels, peak flood depths, flood hazard categories and duration of inundation of lands where the buildings are situated.

For the purposes of this assessment and to align with the QDLs agreed with DPE (see Section 3.2.2) buildings are classified as either habitable or non-habitable.

Building floor levels are based on surveyed data where available, otherwise they have been estimated as described in Section 3.3.6.

It is to be noted that there are no buildings located within the N2N4 and N2N5 model domains, that generally cover the Pilliga forest.

Above floor flooding

A summary of all types of habitable and non-habitable buildings subject to above floor flooding under existing conditions for the selected flood events is provided in Table 5.3 and Table 5.4 respectively. It is to be noted that no buildings located within N2N23 model domain are subject to above floor flooding in any event up to and including the PMF event.

Across the modelled flood events, under existing conditions:

- A total of 13 habitable buildings are subject to above floor flooding in the 20% AEP event increasing up to 5267 habitable buildings in the PMF event.
- A total of 121 non-habitable buildings are subject to above floor flooding in the 20% AEP event increasing up to 7177 non-habitable buildings in the PMF event.
- The majority of both habitable and non-habitable buildings subject to above floor flooding under existing conditions are located near or within Narromine, Curban, Baradine and Narrabri.

Across all model domains the maximum depths of flooding above floor level are:

- Habitable buildings – 0.79 metres in the 20% AEP event, 3.31 metres in the 1% AEP event and 8.9 metres in the PMF event.
- Non-habitable buildings – 2.42 metres in the 20% AEP event, 6.09 metres in the 1% AEP event and 10.24 metres in the PMF event.

Table 5.3 Number of habitable buildings subject to above floor flooding (number with surveyed floor levels shown in brackets) – existing conditions

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	2	6	13	1068	1484	1380	1632	1949
N2N14	0	0	2	3	3	3	3	6
N2N13	1	2	2	2	5	5	8	19
N2N11-12	1	3	8	9	11	11	13	52
N2N10	0	1	1	1	1	1	1	21
N2N9	0	0	0	0	1	1	1	10
N2N8	0	0	0	0	0	0	0	6
N2N7	0	1	1	1	7	5	13	84
N2N6	0	0	0	0	0	0	0	1
N2N5	0	0	0	0	0	0	0	0
N2N4	0	0	0	0	0	0	0	0
N2N23	0	0	0	0	0	0	0	0
N2N1	9	33 (4)	43 (4)	47 (4)	57 (5)	56 (5)	61 (5)	83 (5)
Narrabri	0	433 (396)	1101 (996)	1439 (1309)	2340 (2179)	2002 (1848)	2470 (2306)	3036 (2777)
Total	**13**	**479 (400)**	**1171 (1000)**	**2570 (1313)**	**3909 (2184)**	**3464 (1853)**	**4202 (2311)**	**5267 (2782)**

Table 5.4 Number of non-habitable buildings subject to above floor flooding (number with surveyed floor levels shown in brackets) – existing conditions

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	11	46	86	1207	1747	1591	1961	2622
N2N14	2	16	16	16	18	18	19	29
N2N13	4	13	26	31	43	37	54	123
N2N11-12	11	43	56	71	94	81	113	326
N2N10	1	1	1	3	10	7	12	143
N2N9	3	7	9	11	20	17	20	68
N2N8	2	2	2	2	8	5	10	55
N2N7	1	5	9	12	32	28	47	312
N2N6	1	2	2	2	2	2	2	16
N2N5	0	0	0	0	0	0	0	0
N2N4	0	0	0	0	0	0	0	0
N2N23	0	0	0	0	0	0	0	0
N2N1	67 (6)	167 (18)	200 (19)	211 (19)	247 (19)	237 (19)	256 (19)	383 (19)
Narrabri	18	775 (5)	1790 (15)	2062 (16)	2444 (19)	2331 (18)	2540 (19)	3100 (22)
Total	**121 (6)**	**1077 (23)**	**2197 (34)**	**3628 (35)**	**4665 (38)**	**4354 (37)**	**5034 (38)**	**7177 (41)**

Flood hazards

Flood hazards on lands where the above impacted buildings are situated have been assessed. The number of habitable and non-habitable buildings and their surrounds subject to high flood hazard category (H3, H4, H5 and H6) within each TUFLOW model domain are shown in Table 5.5 and Table 5.6 respectively. The total percentages of habitable and non-habitable buildings subject to high flood hazard generally increase with increased magnitude of flooding. In the case of the PMF event, about 99 per cent of the habitable buildings impacted by flooding are subject to high flood hazard. Approximately 46 per cent of the impacted habitable buildings are subject to high flood hazard in the 20% AEP event.

Table 5.5 Number of impacted habitable buildings (subject to above floor flooding) located on lands subject to high flood hazard – existing conditions

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	0	0	3	748	1293	1130	1560	1944
N2N14	0	0	0	0	1	0	2	3
N2N13	1	1	2	2	2	2	4	17
N2N11-12	1	1	4	8	10	9	11	43
N2N10	0	0	0	0	0	0	0	18
N2N9	0	0	0	0	0	0	0	8
N2N8	0	0	0	0	0	0	0	3
N2N7	0	0	0	1	4	4	10	84
N2N6	0	0	0	0	0	0	0	1
N2N5	0	0	0	0	0	0	0	0
N2N4	0	0	0	0	0	0	0	0
N2N23	0	0	0	0	0	0	0	0
N2N1	4	32	39	40	53	50	57	83
Narrabri	0	202	864	1304	2201	1835	2341	3028
Total	**6**	**236**	**912**	**2103**	**3564**	**3030**	**3985**	**5232**
% of total habitable buildings	**46%**	**49%**	**78%**	**82%**	**91%**	**87%**	**95%**	**99%**

Note 1: subject to above floor flooding (see Table 5.3).

Table 5.6 Number of impacted non-habitable buildings (subject to above floor flooding) located on lands subject to high flood hazard – existing conditions

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	0	13	31	863	1503	1324	1833	2613
N2N14	0	4	9	10	12	12	13	27
N2N13	2	4	11	17	29	28	37	104
N2N11-12	5	20	41	56	75	67	85	285
N2N10	0	0	1	1	1	1	1	111
N2N9	1	3	7	7	9	7	8	61
N2N8	0	0	0	0	0	0	1	34
N2N7	1	1	2	5	23	23	31	288
N2N6	0	2	1	2	2	2	2	16
N2N5	0	0	0	0	0	0	0	0
N2N4	0	0	0	0	0	0	0	0
N2N23	0	0	0	0	0	0	0	0
N2N1	38	146	175	187	222	216	237	376
Narrabri	10	504	1494	1892	2345	2205	2433	3060
Total	**57**	**697**	**1772**	**3040**	**4221**	**3885**	**4681**	**6975**
% of total non-habitable buildings [1]	**47%**	**65%**	**81%**	**84%**	**90%**	**89%**	**93%**	**97%**

Note 1: subject to above floor flooding (see Table 5.4).

Duration of inundation

The average duration of flooding above 0.5 metres depth of flooding near habitable and non-habitable buildings subject to above floor flooding is presented in Table 5.7 and Table 5.8 respectively for each TUFLOW model domain and each flood event.

Buildings (habitable and non-habitable) and surrounds located within NFM, N2N11-12 and Narrabri model domains are subject to the longest average duration of inundation of up to 84 hours. The average duration of inundation is typically much less for all other models.

Table 5.7 Average duration (hours) of inundation at habitable buildings and surrounds above 0.5 metres depth of flooding – existing conditions

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	0	0	13	32	47	46	52	84
N2N14	0	0	0	0	1	0	1	3
N2N13	7	9	6	6	7	7	4	4
N2N11-12	66	68	23	19	20	20	19	14
N2N10	0	0	0	0	0	0	0	2
N2N9	0	0	0	0	0	0	0	3
N2N8	0	0	0	0	0	0	0	1
N2N7	0	0	0	3	4	4	3	5
N2N6	0	0	0	0	0	0	0	2
N2N5	0	0	0	0	0	0	0	0
N2N4	0	0	0	0	0	0	0	0
N2N23	0	0	0	0	0	0	0	0
N2N1	5	8	10	13	12	12	15	10
Narrabri	0	35	36	32	40	38	42	58

Table 5.8 Average duration (hours) of inundation at non-habitable buildings (subject to above floor flooding) and surrounds above 0.5 metres depth of flooding – existing conditions

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	0	19	25	33	47	46	51	80
N2N14	0	1	2	2	2	2	2	3
N2N13	6	5	3	2	3	2	3	4
N2N11-12	28	11	8	9	9	9	9	11
N2N10	0	0	3	3	4	3	4	2
N2N9	6	5	4	6	6	7	8	4
N2N8	0	0	0	0	0	0	2	2
N2N7	3	6	5	5	4	4	5	4
N2N6	0	4	6	8	10	9	11	4
N2N5	0	0	0	0	0	0	0	0
N2N4	0	0	0	0	0	0	0	0
N2N23	0	0	0	0	0	0	0	0
N2N1	5	10	11	14	14	14	19	10
Narrabri	39	35	37	33	41	38	42	57

5.2.4 Inundation of roads

All highways and other named roads have been analysed to identify flooded sections of each highway / road located within each TUFLOW model domain. Flood hazards, and duration of flooding above 0.5 metres flood depth were also analysed.

Flooding of highways

Five highways are located within fourteen TUFLOW domains in the close proximity of the proposal as follows:

- Mitchell Highway (NFM TUFLOW model)
- Castlereagh Highway (N2N11-12 TUFLOW model)
- Oxley Highway (N2N11-12 TUFLOW model)
- Newell Highway (N2N1 and Narrabri TUFLOW models)
- Kamilaroi Highway (Narrabri TUFLOW model).

The lengths of each highway subject to flood inundation for the selected flood events are shown in Table 5.9. In total, about 2.6 kilometres of the Newell Highway is subject to flooding in the 20% AEP event in the proximity of Bohena Creek. About 1.5 kilometres of the Oxley Highway, 0.3 kilometres of the Castlereagh Highway, and about 0.5 kilometres of the Mitchell Highway are also subject to flooding in the 20% AEP event. All highways are impacted in the 5% AEP event.

Table 5.9 Length (kilometres) of highways subject to flooding – existing conditions

Highway	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Mitchell Highway	0.5	0.5	0.6	9	9.2	8.9	10.6	13.7
Castlereagh Highway	0.3	1.1	3.1	3.4	4.1	3.6	5.1	23.7
Oxley Highway	1.5	2.6	3.2	3.8	4.5	4.4	4.8	11.1
Newell Highway (N2N1)	2.6	9	10.7	11.1	11.7	11.6	11.8	16.5
Kamilaroi Highway	0	1.1	2.1	2.8	4.6	3.6	5.9	13.5
Newell Highway (Narrabri)	0	0.1	1.5	1.7	2.5	2.3	3	8.7

Table 5.10 shows per cent length (within the model domain) of each inundated highway subject to high flood hazard (H3, H4, H5 and H6 identified in Figure 2.1). Sections of the Oxley Highway, Newell Highway (Bohena Creek) and Kamilaroi Highway are impassable in the 20% AEP event due to high flood hazard and sections of the Castlereagh Highway and Newell Highway (Narrabri) are also impassable in the 5% AEP event. All highways are impassable in the 1% AEP event.

Table 5.10 Per cent length of inundated highways subject to high flood hazard – existing conditions

Highway	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Mitchell Highway	0	0	0	87	91	92	93	100
Castlereagh Highway	0	55	45	85	76	86	69	96
Oxley Highway	80	65	75	82	85	80	85	92
Newell Highway (N2N1)	85	99	100	99	100	100	100	99
Kamilaroi Highway	100	91	76	64	72	78	81	100
Newell Highway (Narrabri)	0	0	67	70	70	70	63	100

The maximum duration of flooding above 0.5 metres flood depth for each highway is shown in Table 5.11. Durations of inundation for all highways and flood events vary between 32 and 94 hours, indicating these highways may be impassable for extended periods when flooded.

Table 5.11 Maximum duration (hours) of inundation of highways above 0.5 metres depth of flooding – existing conditions

Highway	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Mitchell Highway	0	0	0	48	66	61	73	94
Castlereagh Highway	75	77	78	78	79	78	79	43
Oxley Highway	60	68	72	74	72	72	73	53
Newell Highway (N2N1)	45	47	43	50	51	50	51	58
Kamilaroi Highway	79	76	71	59	60	60	60	61
Newell Highway (Narrabri)	0	0	53	32	42	37	44	58

Flooding of other named roads

A summary of flood immunity, high flood hazard (H3, H4, H5 and H6 identified in Figure 2.1) and duration of inundation for other named roads (i.e. excluding highways) located within the TUFLOW model domains is presented in Table 5.12. In the 20% AEP event, about 170 kilometres of named roads are subject to flooding, 29 per cent length of the flooded roads are subject to high flood hazard and the average duration of flooding above 0.5 metres depth of flooding is 16 hours. In the 1% AEP event, about 443 kilometres of named roads are subject to flooding, 59 per cent length of the flooded roads are subject to high flood hazard and the average duration of flooding above 0.5 metres depth of flooding is 23 hours.

Table 5.12 Summary of flooding on named roads – existing conditions

Event	Total length of roads flooded (km)	% of flooded road subject to high flood hazard	Average duration of inundation (hour)	Maximum duration of inundation (hour)
20% AEP	170	29%	16	111
5% AEP	287	44%	21	96
2% AEP	355	52%	23	94
1% AEP	443	59%	23	95
1% AEP + CC	524	64%	26	97
0.5% AEP	500	63%	25	96
0.2% AEP	554	65%	26	96
PMF	953	99%	52	99

5.2.5 Inundation of existing rail lines

Existing rail lines have been analysed to identify flooded sections of each rail line within each TUFLOW model domain. Duration of inundation relate to flooding above 0.5 metres flood depth at the toe of the existing rail embankments output from the TUFLOW flood model.

Except for very minor sections of the Main Western Line (Dubbo to Narromine and Narromine to Cobar Lines) and the Narrabri to Walgett Line (Narrabri) all the remaining rail lines located within the TUFLOW model domains are subject to flooding in the 20% AEP event as shown in Table 5.13. The Main Western Line is overtopped in the 5% AEP event and the Narrabri to Walgett Line (Narrabri) is overtopped in the 2% AEP event.

Table 5.13 Length (kilometres) of existing rail line flooded – existing conditions (from LiDAR survey)

Rail line	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Main Western Line	<0.1	0.1	0.1	2.3	6.8	6	9.2	14.3
Parkes to Narromine Line	1.4	2.4	2.8	5.9	6.5	5.9	7.2	11.7
Dubbo to Coonamble Line	0.5	0.9	1.3	1.5	2.3	1.7	3	22.5
Binnaway to Gwabegar Line (non-operational)	0.3	0.6	1	1.3	4.6	3.6	5.3	16.1
Narrabri to Walgett Line (N2N1)	2.6	5.8	6.4	6.6	7.1	7	7.4	8.8
Narrabri to Walgett Line (Narrabri)	<0.1	<0.1	0.2	0.4	2.2	0.9	2.9	4.3
Mungindi Line	0.6	1.6	3.4	4.1	6.6	5.6	7	13.1

Maximum durations of inundation for each line within the TUFLOW model domains are shown in Table 5.14. All existing rail lines are subject to varying degrees of duration of inundation across nearly all events.

Table 5.14 Maximum duration (hours) of flooding of railway above 0.5 metres depth of flooding at the toe of rail embankment – existing conditions

Rail line	20% AEP	5% AEP	2% AEP	1% AEP	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Main Western Line	109	95	96	97	81	95	84	97
Parkes to Narromine Line	110	96	92	94	97	93	94	99
Dubbo to Coonamble Line	0	6	14	15	17	16	17	30
Binnaway to Gwabegar Line (non-operational)	26	44	26	26	27	27	28	29
Narrabri to Walgett Line (N2N1)	39	42	45	45	49	49	49	25
Narrabri to Walgett Line (Narrabri)	80	71	70	53	51	51	53	58
Mungindi Line	105	87	87	68	68	67	68	68

5.2.6 Inundation of major land uses

A summary of major land uses for all areas included in the TUFLOW models domains is presented in Table 5.15. Cropping is the dominant land use (48 per cent) and represents almost half of the total area represented in the TUFLOW models, followed by grazing and pasture (29 per cent) and forests (20 per cent).

Table 5.15 Significant land uses

Land use	Total area (ha)	%
Forests	74,712	20%
Grazing, pasture	107,732	29%
Cropping	180,062	48%
Horticulture	342	0.1%
Residential and farm infrastructure	3870	1%
Transport, communication	2004	0.5%
Water, marsh, wetland	2290	0.6%
Services, utilities, water treatment	593	0.2%
Others	488	0.1%
Total	**372,095**	**100%**

Forested lands

Forested areas subject to different depths of flooding are shown in Table 5.16. About 11,234 hectares of forested lands are subject to flooding in the 20% AEP flood event. In the case of the PMF event, 53,906 hectares of forested lands are impacted by flooding.

Table 5.16 Forested lands subject to different flood depths – existing conditions

Event	Inundated areas (ha)					Total
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	
20% AEP	7025	2054	1189	695	271	**11,234**
5% AEP	10,279	2860	2337	1079	587	**17,142**
2% AEP	12,608	3173	2917	1391	753	**20,842**
1% AEP	13,580	3500	3318	1652	952	**23,003**
1% AEP + CC	15,784	4244	3742	2244	1305	**27,319**
0.5% AEP	15,293	4010	3604	2060	1203	**26,170**
0.2% AEP	16,505	4356	4193	2509	1523	**29,086**
PMF	21,135	7057	7284	9222	9208	**53,906**

Forested lands subject to different duration of flood inundation above 0.5 metres depth are shown in Table 5.17. Generally, the majority of the forested areas are subject to less than 24 hours of inundation above 0.5 metres flood depth.

Table 5.17 Forested lands subject to different duration of flood inundation above 0.5 metres depth – existing conditions

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	352	484	676	557	58
5% AEP	714	1047	1267	824	125
2% AEP	769	1306	1749	1166	48
1% AEP	908	1456	2203	1229	107
1% AEP + CC	1132	1535	2915	1512	179
0.5% AEP	1033	1366	2750	1484	217
0.2% AEP	1419	1634	2923	1858	376
PMF	7714	8944	6973	1724	374

Grazing area

Grazing areas subject to different depths of flooding are shown in Table 5.18. About 22,787 hectares of grazing areas are subject to flooding in the 20% AEP flood event and almost half of the flooded areas are subject to up to 0.25 metres depth of flooding. In the case of the PMF event, 70,378 hectares of grazing areas are impacted by flooding and the majority of the flooded areas are subject to greater than one metre flood depth.

Table 5.18 Grazing areas subject to different flood depths – existing conditions

Event	Inundated areas (ha)					Total
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	
20% AEP	10,944	4434	3451	2203	1756	**22,787**
5% AEP	12,913	5723	5662	5296	3799	**33,393**
2% AEP	13,898	5770	6198	6497	5582	**37,945**
1% AEP	14,849	6104	6387	7153	6763	**41,256**
1% AEP + CC	16,122	6987	6938	7525	9799	**47,371**
0.5% AEP	15,770	6734	6659	7732	8605	**45,500**
0.2% AEP	16,250	7057	7441	7782	10,937	**49,467**
PMF	10,589	7354	11,736	15,008	25,691	**70,378**

Grazing areas subject to different duration of flood inundation above 0.5 metres depth are shown in Table 5.19. The majority of the grazing areas are subject to less than 24 hours of inundation above 0.5 metres flood depth.

Table 5.19 Duration of flood inundation of grazing areas above 0.5 metres depth – existing conditions

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	595	1210	1877	1193	2511
5% AEP	821	1630	4159	2513	5619
2% AEP	1067	1727	4134	4189	7150
1% AEP	1184	1768	3977	4637	8731
1% AEP + CC	1828	2042	4097	5277	11,021
0.5% AEP	1589	1902	3961	5339	10,208
0.2% AEP	2000	2467	4206	4439	13,051
PMF	8360	10,689	10,470	6953	16,561

Cropping lands

Cropping lands subject to different depths of flooding are shown in Table 5.20. About 28,299 hectares of cropping lands are subject to flooding in the 20% AEP flood event with most of this subject to up to 0.25 metres depth of flooding. In the case of the PMF event, 113,263 hectares of cropping lands are impacted by flooding and the majority of the flooded areas are subject to less than one metre flood depth.

Table 5.20 Cropping lands subject to different flood depths – existing conditions

Event	Inundated areas (ha)					Total
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	
20% AEP	22,024	3814	1658	698	105	**28,299**
5% AEP	29,747	6750	3096	1531	545	**41,668**
2% AEP	33,682	8576	4635	2538	1330	**50,762**
1% AEP	37,585	10,791	6067	4194	2082	**60,719**
1% AEP + CC	40,811	13,307	7885	5369	3583	**70,954**
0.5% AEP	39,800	12,423	7187	5221	2932	**67,563**
0.2% AEP	42,360	13,902	9096	6124	4332	**75,813**
PMF	22,032	19,619	28,393	23,397	19,822	**113,263**

Cropping lands subject to different duration of flood inundation above 0.5 metres depth are shown in Table 5.21. The majority of the cropping lands are subject to less than 24 hours of inundation above 0.5 metres flood depth.

Table 5.21 Duration of flood inundation for cropping lands above 0.5 metres depth – existing conditions

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	347	555	650	336	593
5% AEP	743	1003	1388	656	1411
2% AEP	1075	1280	1919	1438	2829
1% AEP	1480	1339	2186	2279	5099
1% AEP + CC	2117	1717	2307	2376	8351
0.5% AEP	1934	1479	2148	2492	7321
0.2% AEP	2550	1883	2605	2587	9955
PMF	20,817	14,901	9642	7672	20,440

Horticultural lands

There are only 342 hectares of horticultural lands within the TUFLOW model domains. About ten per cent (refer to Table 5.22) of the horticultural lands are subject to flooding in the 2% AEP event and 303 hectares of horticultural lands are subject to flooding in the PMF event.

Table 5.22 Horticultural lands subject to different flood depths – existing conditions

Event	Inundated areas (ha)					Total
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	
20% AEP	0	1	5	0	0	**6**
5% AEP	2	4	4	4	4	**18**
2% AEP	5	6	11	11	7	**41**
1% AEP	8	25	92	108	10	**242**
1% AEP + CC	5	13	59	167	12	**257**
0.5% AEP	9	11	71	154	11	**255**
0.2% AEP	4	8	36	179	31	**258**
PMF	3	3	8	32	257	**303**

Horticultural lands subject to different duration of flood inundation above 0.5 metres depth are shown in Table 5.23. The majority of horticultural lands are subject to longer than 24 hours of flood inundation above 0.5 metres flood depth in flood events larger than the 2% AEP event.

Table 5.23 Duration of flood inundation for horticultural lands above 0.5 metres depth – existing conditions

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	1	2	2	0	0
5% AEP	0	0	5	0	6
2% AEP	1	3	3	5	18
1% AEP	0	2	11	28	167
1% AEP + CC	0	1	7	4	227
0.5% AEP	0	1	7	6	223
0.2% AEP	0	0	6	5	235
PMF	0	0	8	5	284

5.3 Geomorphology

5.3.1 Geomorphological Setting

The landscape of the study area and region is heavily influenced by both geology and fluvial process / form interaction. Higher elevation areas, such as the Warrumbungles, Pilliga Forest uplands and Mount Kaputar, have been eroded over millennia. This material has been transported downslope by a dense network of drainage channels and sheetwash. Watercourse morphology is strongly controlled by sediment source characteristics; underlying soils; proximity to upland areas (both in terms of bed slope and stream order); and presence of vegetation, as summarised in Table E1, Appendix D.

An assessment of the existing condition of each waterway crossing the proposal was carried out using the methodology outlined in Section 3.10. The watercourse crossings were divided into several distinct categories, based on the geomorphic sections identified as part of the geotechnical investigations (JacobsGHD, April 2020), River Style and geomorphological characteristics as outlined below.

Table 5.24 Geomorphic sections

Geomorphic Section	Location and Chainage
Macquarie Floodplain	Start (547 km) to Macquarie River (563.5 km)
Undulating Agricultural Plains	To Collie Road (595 km)
Keelindi Alluvial Plains	To Oxley Highway (633.5 km)
Basaltic Alluvial Plains	To Castlereagh River (653 km)
Basaltic Colluvial Plains	To Box Ridge Road (686 km)
Basalt Mesa Plains	To Teridgerie Creek (731 km)
Pilliga Plains	To Kenebri Road / Cumbil State Forest (747.5 km), including Mollee Creek to the East
Pilliga Forest	To Twenty Foot Track (822 km)
Namoi Floodplain	To end (853 km)

A summary of each of the geomorphic sections and the associated watercourse types is provided below and within Appendix D.

Macquarie Floodplain – 547 km-563.5 km

The floodplains of the Macquarie River are underlain by Ordovician metasediments and Devonian granite of the Lachlan Fold Belt, with deep alluvial soils. Watercourses in the area comprise:

- Overland flood flows which currently flow uncontrolled across fields.
- Wallaby Creek, an anastomosing (multi-channel), low energy, sand bed channel, although the proposal crosses a single-channel section. The incised channel is perched slightly above the surrounding land, indicating broad levees.
- Macquarie River, a moderate sinuosity, high energy, sand bed channel deeply incised into bedrock. The banks are moderately well vegetated, with large woody debris (LWD) providing habitat and geomorphic variability, although invasive willows are present.

Undulating Agricultural Plains –563.5 km-595 km

This section is characterised by undulating topography, rising to the north. The soils in this area are particularly erodible, and vegetation cover is typically sparse. Watercourses in the area are small, low energy channels comprising:

- Overland flood flows which currently flow uncontrolled across fields and grassland.
- Minor Creeks, whose morphology depends on vegetation cover. Indistinct swales occur where grassland is intact, whereas slightly incised, meandering creeks and gullies occur in areas of sparse vegetation.

Keelindi Alluvial Plains –595 km-633.5 km

This section is characterised by broad alluvial plains with variable depth, erodible soils. The floodplain of Ewenmar Creek has particularly deep alluvial deposits. Watercourses in the area are typically low to moderate energy, incised channels, as follows:

- Slightly incised, anastomosing, densely vegetated sand bed creeks, including Ewenmar Creek and Goulburn Creek.
- Slightly to moderately incised, highly sinuous meandering channels, such as Emogandry Creek, Native Dog Creek, Kickabil Creek, Milpulling Creek, Bundijoe Creek. Generally well-vegetated within the channel but without a well-developed riparian corridor.
- Pint Pot Gully: Incised gully system, with actively headcutting gullies upstream of crossing.

Basaltic Alluvial Plains –633.5 km-653 km

This section is a depositional alluvial plain and alluvial backplain with soils originating from the basaltic Warrumbungle ranges to the east. Watercourses in the area comprise:

- Marthaguy Creek, an incised highly sinuous, multi-channel, low energy anastomosing system.
- Castlereagh River, which is the highest energy system along the entire alignment, with ω calculated at over 660W/m. The river is also well-known for having high sub-surface flows through the deep sandy bed material. Despite this, the river is far narrower than the neighbouring anastomosing and sinuous planform watercourses. Flows are contained within a deeply incised, variable sinuosity trench, with a high, mobile sand bedload. During high flows, flooding is deep and swift. However, there is no visible erosion along the study reach.

Basaltic Colluvial Plains –653 km-686 km

This section is characterised by an extensive colluvial outwash plain of Vertosols (deep cracking clays) from the Warrumbungle ranges to the east. Watercourses in the area are variable, with no characteristic morphology, ranging from the grassy swale of Judes Creek to the deep, broad Gulargambone Creek. Gullying and sheet wash erosion are common close to the larger watercourses. The characteristics of the major watercourses in this section are:

- Minor Creek at 661.275 kilometres, which is an incised, broad, sandy, braided river, more typical of those in the Pilliga Forest. Bedrock outcrops in the banks.
- Gulargambone Creek, which is a broad, sinuous channel, showing evidence of recent meander migration. The system has a high ω but low U_{max}, supported by the gravelly sand bed material with a distinct clay drape (typically deposited during the final stages of a flood).
- Baronne Creek, which shows a significantly different morphology to the nearby Gulargambone Creek. This has a far narrower, but equally sinuous channel, with active meanders and recent bank failures. Surface expressions of large palaeochannels may be seen, and it is possible that this channel has been artificially narrowed by agricultural activity.

Basalt Mesa Plains and Pilliga Plains –686 km-747.5 km

The Basalt Mesa Plains wind around the distinct basalt mesa landforms, e.g. Tabletop Mountain. The Pilliga Plains are similar in morphology, despite their origin being the sandstone Pilliga uplands. The area is characterised by extensive alluvial and colluvial plains, which are prone to sheetwash and some gullying during flooding. Swales and creeks are typically low in energy, unless stated. The characteristics of the major watercourses in this section are:

- Minor grassy swales and imperceptible channels flowing across croplands or pasture, including Black Gutter Creek, Small Creek and Ironbark Creek. Mollee Creek has also been included in this section, as it is geomorphologically similar.
- Slightly incised to moderately incised, sinuous, sand bed channels, such as Tenandra Creek, Caleriwi Creek, Quanda Quanda Creek, Calga Creek and Bucklanbah Creek. Caleriwi Creek appears to be recovering, with in-channel vegetation establishment and reduction in bank angles, whereas the other creeks appear to be more actively eroding. Tenandra Creek, Calga Creek and Quanda Quanda Creek have moderately high energy systems than the other watercourses, and are more deeply incised. In-channel and floodplain vegetation are typically sparse. Tenandra Creek has been straightened, with levees constructed to constrain the new alignment.
- Salty Springs Creek is morphologically similar to the creeks above with a moderate energy, highly sinuous slightly incised channel. However, it appears to have been straightened for agriculture through the study reach, and sits slightly above the surrounding floodplain.
- Teridgerie Creek is far larger, with a higher energy system than the other creeks in this section. However, it shares a similar incised, sinuous morphology and sandy bed. The channel and floodplain are well-vegetated, but gullying and denudation can be seen downstream of the crossing.

Pilliga Forest – 747.5 km-822 km

This section is characterised by undulating topography and dense woodland. Soils are typically highly erodible, either because they are dispersive or loose sand transported from the sandstone Pilliga uplands to the east. Soils are typically shallow, particularly on topographic highs. Sandy paleochannels (sand monkeys) indicate that channels are prone to avulsion, which is unsurprising, given the sediment-laden overland flood flows which wind through the woodland during flooding. Appear to be many small channels wandering through the forest which concentrate overland flows and transport sediment from the uplands to the southwest. The woodland has variable vegetation cover, ranging from dense trees and understorey to very little ground-level vegetation. It is anticipated that dense understorey vegetation would affect the direction of flood flows.

The characteristics of watercourses in this section are as follows:

- The majority of larger creeks within the Pilliga Forest are broad, low or irregular sinuosity, sand bed channels. These range in size from the very broad channel (>300 metres wide) of Etoo Creek, broad channels of Rocky Creek 1 and Bundock Creek (>100 metres wide) and moderately sized channels (about 50 metres wide) such as Coolangla Creek, Stockyard Creek, Talluba Creek, an Unnamed Creek at CH783.653 kilometres, Rocky 2 Creek, Coghill Creek and Mollieroi Creek. Smaller sand bed creeks also exist.
- Baradine Creek flows along the edge of this section, and has bedrock outcrops within its banks, creating a very deep, relatively narrow high energy channel. It is similar in morphology to the sand bed creeks of the Pilliga, but is deeper, with a better defined low flow channel, which appears multi-channel and braided in places.

- Tinegie Creek has been identified as having a chain of ponds morphology. However, the channel is imperceptible and this morphology was not observed on aerial photographs or on site. Bundock Creek has also been identified as a chain of ponds morphology. However, it appears to be morphologically similar to the sand bed channels. Some pools are visible, but these appear to be located along the outer banks of meander bends, and could be associated with pool / riffle sequences rather than being a strict chain of pools morphology.

Namoi Floodplain –822 km-853 km

This section is characterised by widespread flooding at northern extent of the proposal alignment associated with the Bohena, Namoi and Narrabri Rivers. These are a broad system with interconnected flood channels with in-channel and floodplain splay deposits. The floodplain is dissected by a combination of highly sinuous incised channels, headcutting gully systems, sheetwash erosion and areas of denuded topsoils.

- The chain of ponds Bohena River is appreciably different in morphology and functioning compared to the other rivers along the alignment. Flood modelling indicates large eddies and secondary currents, which can cause reverse flows in places. The right bank is high and steep, with bedrock present in places, whereas the left bank is lower angled and prone to flood overflows. Therefore, the variably located and spaced ponds appear to be a function of the unusual flow structure.
- The Namoi River and Narrabri Creek are both large, meandering, incised gravel-bed systems. Armoured bars (i.e. in-channel sediment stores protected by the coarser fraction of bed material) are present. Flood flows have both eroded gully systems and deposited splays on the floodplain, indicating a complex flood flow structure.

5.3.2 River Styles classifications

The available River Styles mapping and reports indicated 10 different River Styles in four broad categories as summarised in Appendix E. As discussed in Sections 3.10.1, 3.10.2, 3.10.3 and 5.3.1, there were discrepancies between the recorded River Style and description and the observed geomorphological properties of watercourses at the proposal crossing sites from the site assessments completed in February 2022. The site specific reach-scale and point-scale geomorphological properties were considered to be more appropriate for the scale of reach likely to be impacted by the Project rather than the broader River Styles assessments. Hence a greater emphasis has been placed on the site specific assessments in this report.

5.3.3 Existing impact of waterway structures on watercourse geomorphology

Watercourses in the study area cross a number of roads through culverts and under bridges. The high erodibility of soils results in sheetwash and erosion of unsurfaced tracks.

Some of the smaller creeks within the study area pass through shallow culverts which are causing flow pooling and sediment deposition upstream. Examples include the road culverts close to the proposal alignment for Ewenmar Creek, Kickabil Creek, Tenandra Creek and Judes Creek.

The majority of smaller creeks within the Pilliga Forest have no formal road crossings: flows run over the tracks through the forest.

The larger rivers in the study are currently crossed by road bridges. Comparison of available historic aerial imagery and the present day indicate that the existing bridges do not appear to have a significant impact on the creek morphology, other than the rail bridge crossing Narrabri Creek. This has caused flow diversion, upstream sedimentation and bank erosion adjacent to and downstream of the large bridge pier.

5.3.4 Existing watercourse sensitivity

An assessment of watercourse sensitivity was carried out, using the methodology outlined in Section 3.10.5. This assessed the erosivity of flows, stabilising effect of in-channel and floodplain vegetation and erodibility of channel materials. The next sections discuss the effect that these different aspects can have on watercourses (with stream power and velocity already discussed in Section 3.10. The full sensitivity assessment is provided in Appendix D).

Effect of planform morphology on watercourse behaviour

There are several different planform morphologies within the study area, which each behave differently in response to flows.

- Meandering, sinuous watercourses tend to erode laterally along the outer bank of a bend. The focus of erosion is typically just after the apex of a bend, with associated sediment deposition forming point bars along the inner bank.
- Anastomosing watercourses are those composed of many wandering, semi-independent channels, separated by large islands, generally excised from the continuous floodplain. The anabranch tend to remain static, or avulse to occupy minor channels following floods.
- Low sinuosity, sand bed watercourses act as conveyor belts for the high supply of sediment from sandstone uplands to the east. The loose sand is easily mobilised, and subsurface flows can occur below the channel bed.
- Chain of ponds watercourses are now relatively rare within Australia. These channels comprise irregular deep, permanent pools separated by vegetation-stabilised bars (Rutherfurd *et al.,* 2000). The morphology is typically stable unless disturbed by changes to flow or sediment regime.

Effect of geology and soils on fluvial geomorphology

As noted in sections 5.3.1, 5.3.2 and 5.3.3, soils and underlying geology vary over the 306 kilometre alignment length between Narromine and Narrabri. Furthermore, soil types vary within watercourses and are typically characterised by easily mobilised sediment within creek beds to more resistant in-situ soils within the banks and floodplains.

In February 2022, assessments were undertaken at 23 representative sites by a geotechnical engineer and geomorphologist to assess the erosion potential at 23 representative sites along the route (ref Appendix O). Results from these investigations, together with observations along the route, found that majority of the proposed watercourse crossings had clay rich banks and floodplains.

In some locations, features usually associated with dispersive soils were observed, such as rilling, gullying and seepage erosion. These areas generally comprised higher proportions of sand and occasionally silt. Erosion was more evident where natural conditions had been disturbed and vegetation removed.

Bedrock outcrops were observed in a number of watercourses. As bedrock is more resistant than soil, outcrops would erode more slowly, although sections of the channel where bedrock is not present may be subject to preferential erosion.

Effect of vegetation and land-use on fluvial geomorphology

Since European Settlement in the early 1800s, the majority of the diverse natural vegetation of the area has been cleared or thinned for cropping and grazing (Lampert and Short, 2010). Remnant vegetation is limited to areas which are unable to be used for agriculture, logging or grazing, whether from inaccessibility, unsuitable topography or poor soil fertility. A large area of woodland has been protected in the Pilliga Forest. Even this seemingly intact area has been significantly altered by anthropomorphic management alteration. Prior to European Settlement, the vegetation in this area was regularly burned, and much of the vegetation relies on fire to regenerate. Post-European settlement, the area was heavily logged and has only been allowed to recover since the creation of broad areas of protected State Forest. The dense contemporary woodland is, therefore, relatively recent regrowth.

Vegetation has a significant influence on river process and form, whether within the channel, floodplain, riparian corridor or interfluves (land between watercourses). Vegetation has the following main effects:

- Subsurface roots stabilise near-surface sediments and absorb groundwater.
- Surface vegetation increases surface roughness, which attenuates flow velocities and reduces rainfall / runoff times. Appropriate in-channel vegetation (i.e. not overly dense or sparse) promotes geomorphic and habitat diversity. This includes both established live vegetation and large woody debris (LWD).

Therefore, if vegetation is removed, watercourse discharge becomes more 'flashy' (i.e. peak flows increase and are reached more rapidly) and erosive.

Sections of the proposal cross land used for cropping. In these areas, vegetation cover is seasonal, with bare soils being present when crops are sown, followed by good ground cover as they grow.

Sub-reach variability in velocity and stream power

The assessment of geomorphological watercourse sensitivity also looked at the existing maximum velocity (Vmax) and stream power (ω) within specific reaches that were likely to be impacted by the proposal: i.e. at the railway centreline and the edges of the rail corridor, approximately 20 metres upstream and downstream of the alignment. This assessment was conducted to determine the existing variability in these parameters, i.e. Whether there was a general pattern in certain watercourse morphologies; whether there was a general increase in velocity and stream power; or whether site-specific conditions were of importance. The assessment indicated that there was considerable variability between watercourses, but both Vmax and ω only showed minor change within the assessed sub-reaches. Therefore, the assessment indicated that site-specific conditions are influential.

Sensitivity Assessment

The sensitivity assessment indicated the following patterns (see also Appendix D, Table E3):

- High sensitivity watercourses were associated mainly with the larger incised, sinuous creeks within the Keelindi Alluvial Plains and Basalt Mesa / Pilliga Plains sections. These rivers have high to very high velocities and stream power and are actively eroding. These watercourses are as follows: Macquarie River, Native Dog Creek, Milpulling Creek, Bundijoe Creek, Castlereagh River, Gulargambone Creek, Baronne Creek, Tenandra Creek, Mungery Creek, Quanda Quanda Creek, Salty Springs Creek, Calga Creek, Teridgerie Creek, Baradine Creek, Talluba Creek and the Namoi River.

- Medium sensitivity watercourses were typically moderately large creeks, with equally moderate modelled velocities and / or stream power. This includes the broad, low to medium energy creeks of the Keelindi Alluvial Plains, Basalt Mesa Plains and Pilliga Forest, together with larger low energy watercourses such as Marthaguy Creek, Etoo Creek and Bohena Creek. The chain of ponds creeks, Bohena Creek and Bundock Creek scored near the top of the medium sensitivity bracket, and these should be considered separately given their morphology.
- Low sensitivity watercourses were identified as being low energy, low velocity overland flows or minor watercourses. These were largely unnamed watercourses or overland flow within the Basalt Mesa Plains and Pilliga Forest. Named low sensitivity watercourses were Judes Creek, Black Gutter Creek, Small Creek, Cumbil Forest Creek, Stockyard Creek, Black Creek, Goona Creek and Mollee Creek. Although Tinigie Creek is defined as a chain of ponds River Style, aerial imagery and site observations indicated an imperceptible watercourse with no visible existing erosion. Therefore, this watercourse is considered low sensitivity.

In comparison, the River Styles fragility assessments indicated that watercourses were generally of medium to high fragility. Watercourses classified as moderate sensitivity but high fragility included Ewenmar Creek, Emogandy Creek, Kickabil Creek, Marthaguy Creek, Judes Creek, Caleriwi Creek, Black Gutter Creek, Small Creek, Etoo Creek, Tinegie Creek, Bundock Creek and Bohena Creek. However, as explained previously, this assessment is specifically looking at the sub-reach attributes associated with the study area, rather than the catchment and reach-scale dynamics of the River Styles assessments.

6 Construction impact assessment

6.1 Flooding

6.1.1 Potential flood impacts

Potential risks

Construction activities have the potential to worsen flooding conditions for a given flood event when compared to both existing and operational conditions. It is anticipated that overall construction would take about 48 months, subject to weather conditions. Construction activities typically impose a larger footprint on the floodplain due to the need to provide temporary structures outside the operational footprint, which would be removed following the completion of construction activities.

Without the implementation of appropriate management measures, inundation of the construction footprint by floodwater has the potential to:

- Cause damage to the works and delays in construction programming
- Pose a safety risk to construction workers
- Detrimentally impact the downstream waterways through the transport of sediments and construction materials by floodwaters
- Obstruct the passage of floodwater and overland flow through the provision of temporary measures such as construction compounds and stockpiles, which in turn could exacerbate existing flooding conditions.

The following sections describe the construction activities that have the greatest potential to affect the existing flood conditions and an assessment of their potential impacts.

Earthworks

The earthworks associated with the construction of the railway embankment would cause flow constriction and a minor loss of flood storage. The flow constriction caused by the railway embankment would have a greater effect on flood behaviour compared to the minor loss of floodplain storage. The inundation of the earthworks by floodwater also has the potential to cause scour of disturbed surfaces and the transport of sediment and construction materials into the receiving waterways. It would therefore be necessary to plan, implement and maintain measures to manage the diversion of floodwater either through or around the construction areas.

Construction compounds

Construction compounds located on the floodplain, particularly in areas of high hazard, pose a safety risk to construction personnel. It would therefore be necessary to locate site facilities outside high hazard areas with safe evacuation routes.

Based on the EIS design there are 67 construction compounds proposed along the length of the proposal. Of those, 27 would be affected by 1% AEP flooding, and 25 would be affected by 5% AEP flooding. For ancillary sites with flood immunity less than 5% AEP, a flood and emergency response plan would be prepared. This plan should consider likelihood of flooding, evacuation routes, warning times, and potential impacts from the compound flooding.

Stockpiles

Stockpiles located on the floodplain have the potential to obstruct floodwater and alter flooding patterns. Inundation of stockpile areas by floodwater can also lead to large quantities of material being washed into the receiving waterways.

Bridge construction

In-stream works required to construct new bridges over the major rivers are exposed to the impact of flooding as higher flow velocities generally occur in the river channels compared to overbank or floodplain areas. Temporary structures required to construct the bridges such as crane pads, barges, scaffolding etc. have the potential to be washed away in a flood event causing damage downstream by colliding into other structures.

These in-stream works can also have an impact on flood levels influencing flood behaviour and potentially result in flood impacts that are greater than operational phase, depending on the stage of construction.

Temporary sediment basins and waterway crossings

Temporary sediment basins would be required during construction to capture runoff from disturbed construction areas and prevent sedimentation and pollution of downstream receiving waters. The temporary sediment basins would typically be located near receiving watercourses and consist of an earth embankment to provide the necessary storage capacity. The sediment basin embankments located on the floodplain have the potential to obstruct floodwater and alter flooding patterns.

Temporary creek crossings would also be required during construction to allow construction vehicles to drive between the banks of creeks. Temporary crossings may include low lying causeways, consisting of a low-level trafficable weir with culverts conveying low flows. The temporary crossings would remain dry during normal creek flow conditions when the water is low but could become covered by water in times of floods.

Borrow pits

Four borrow pits would be established on private land for the supply of fill material for construction of the proposal. The borrow pit locations are not known to be subject to flooding in events up to the 1% AEP flood event. During construction, water at the borrow pits would be managed as follows:

- Up slope diversion drains would convey clean water around the site.
- Sedimentation basins would collect all dirty water (including any groundwater seepage) from disturbed areas within the site.

Water contained within sediment basins would be discharged to the nearest watercourse prior to or immediately following forecast rainfall events that are likely to produce basin inflows. Appropriate scour protection would be provided at the outlets. The basins would include overflow bypass structures to enable stormwater discharge during heavy storm events where the design capacity of the sediment basins may be exceeded. Alternatively, water may be re-used (as a supplementary source to the primary water supply) during construction for activities such as dust suppression. All erosion and sediment measures would be implemented at the sites in accordance with the principles and requirements in *Managing Urban Stormwater – Soils and Construction, Volume 1* (Landcom, 2004) and *Managing Urban Stormwater: Soils and Construction Volume 2C Unsealed Roads* (Department of Environment and Climate Change NSW, 2008a).

Following extraction of all required material from the borrow pits, all facilities would be removed and the pits would be stabilised and rehabilitated. Rehabilitation of the borrow pits would be undertaken in accordance with the borrow pit rehabilitation strategy and the approach outlined in the EIS. It is proposed to use excess material (that does not meet design specifications or cannot be feasibly used within the rail formation) from the main construction works to assist with the reshaping of the borrow pits. The borrow pits would be returned to their original condition as far as is reasonably practicable or otherwise as agreed with the landholder. In addition to this, the final landform shall be safe, stable, non-polluting, sustainable, and free-draining to as close as practicable, the pre-existing conditions.

The *ARTC Inland Rail Narromine to Narrabri Borrow Pit Rehabilitation Strategy* (JacobsGHD, 2020b) establishes objectives, performance indicators and indicative completion criteria, and outlines a monitoring program to ensure the completion criteria are met. These would be further refined during detailed design to ensure the sites are rehabilitated to an appropriate standard and to ensure that all flow paths are stable and appropriate scour protection is provided where required.

Construction planning and management

The location and layout of construction work sites and compounds would be prepared with consideration of overland flow paths, avoiding flood liable land where practicable to avoid detrimental impacts. In addition, construction planning would consider potential impacts to construction activities as a result of flood events, such as restricted accessibility to work areas due to ponded water or soft ground conditions.

Prior to construction, a flood and emergency response plan would be prepared and implemented as part of the construction environmental management plan (CEMP). The plan would document how the risks to life and property within and outside the rail corridor would be safely managed during construction. The plan would:

- Be prepared by an experienced flood emergency response specialist
- Be consistent with best practice and the NSW Floodplain Development Manual
- Document the changes in flood behaviour that mat result in adverse impacts to life and property
- Include measures, process and responsibilities to minimise the potential impacts of construction activities on flood behaviour as far as practicable
- Include measures to manage flood risks during construction and address flood recovery during construction
- Provide information to enable relevant agencies (such as councils, SES) and potentially impacted landholders to prepare for management of flood emergencies.

6.1.2 Modelled flood impacts

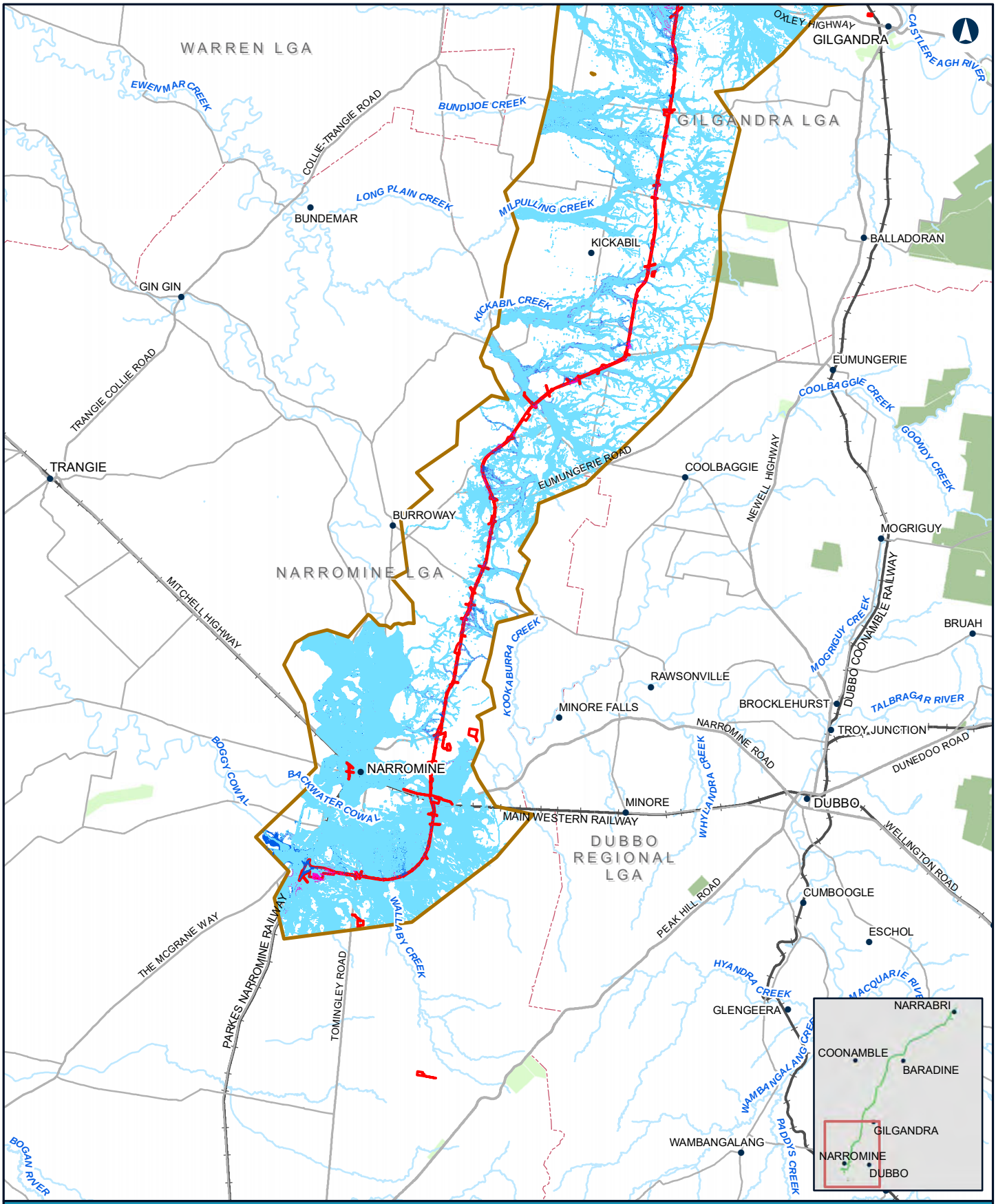
The configuration and staging of construction works have been reviewed to assess potential flooding impacts during construction of the proposal. For the purpose of quantifying the potential construction phase flood impacts, a critical (or worst case) stage of construction has been identified as described in Section 3.7.2.

The flood models were updated to represent the construction works based on the above assumptions. All models were run for the 20%, 5% and 1% AEP events.

Flooding extents for the 1% AEP event during construction are shown in Figure 6.1. Mapping of flood impacts during the construction stage are provided in Appendix F.

While the findings of this initial assessment provide an indication of the potential impacts of construction activities on flood behaviour, further investigation would be carried out during detailed design, as layouts and construction staging strategies are further developed.

It should also be noted that all construction infrastructure is temporary and the assessment should be read in context of the likelihood of a flood of a given AEP occurring during the construction period. In addition, given the short duration of construction relative to the operational life of the proposal, these impacts should be considered in context of the predicted operational impacts detailed in Section 7. The chance of occurrence of a given AEP flood event during the construction period (four years) is significantly lower than the operational phase life of the proposal. The chance of occurrence of a 1% AEP flood event for the construction phase and the operational phase are approximately 4.9 per cent and 63.4 per cent respectively. However, the chance of occurrence of a 20% AEP flood event for the construction phase and the operational phase are approximately 67.2 per cent and 100 per cent respectively.



NARROMINE TO NARRABRI Change in 1% AEP flood extent – Construction Figure 6.1a

0 8 16 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 8/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:400,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent
- Was wet now dry
- Was dry now wet

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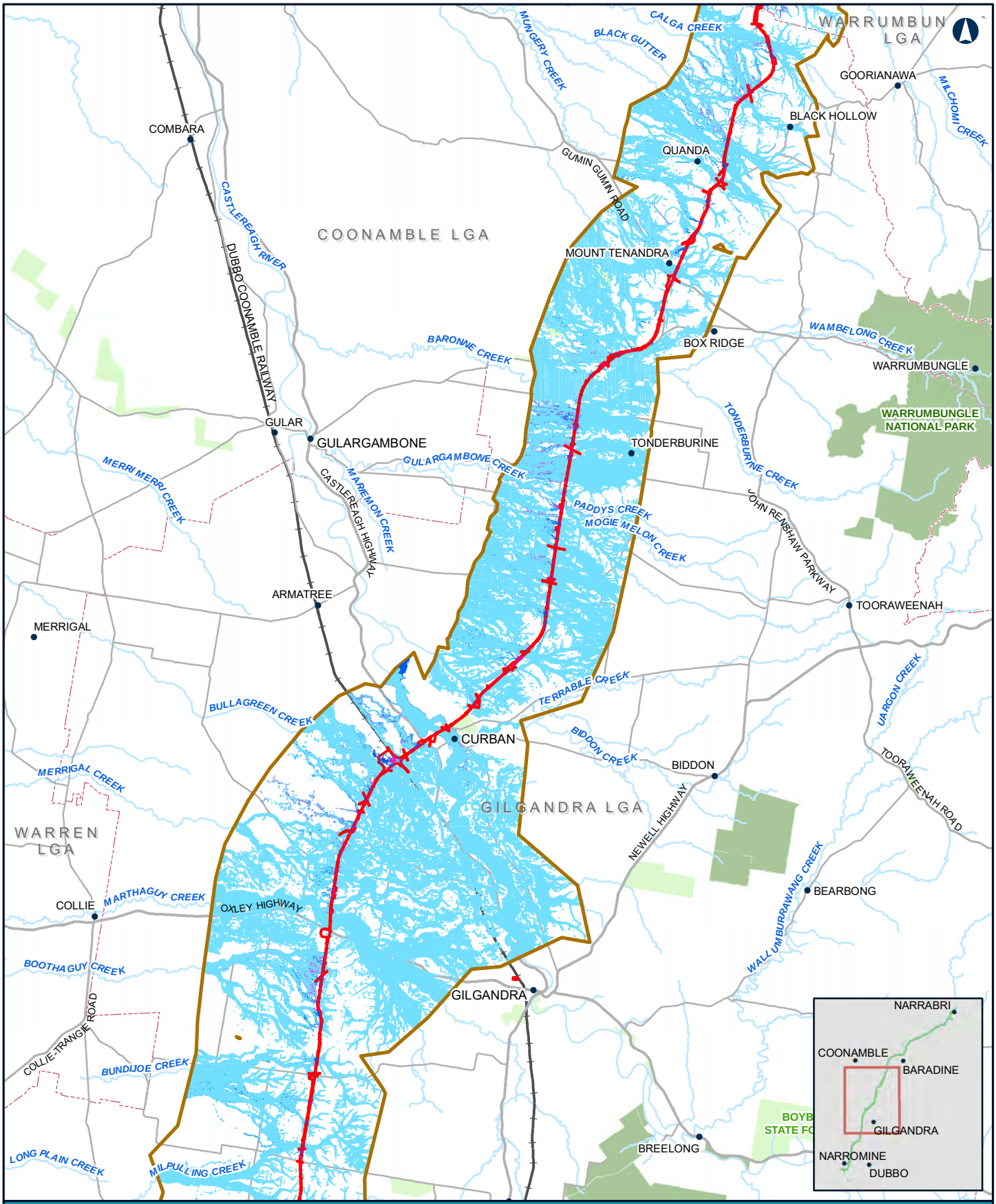

NARROMINE TO NARRABRI Change in 1% AEP flood extent – Construction Figure 6.1b

0 8 16 Km

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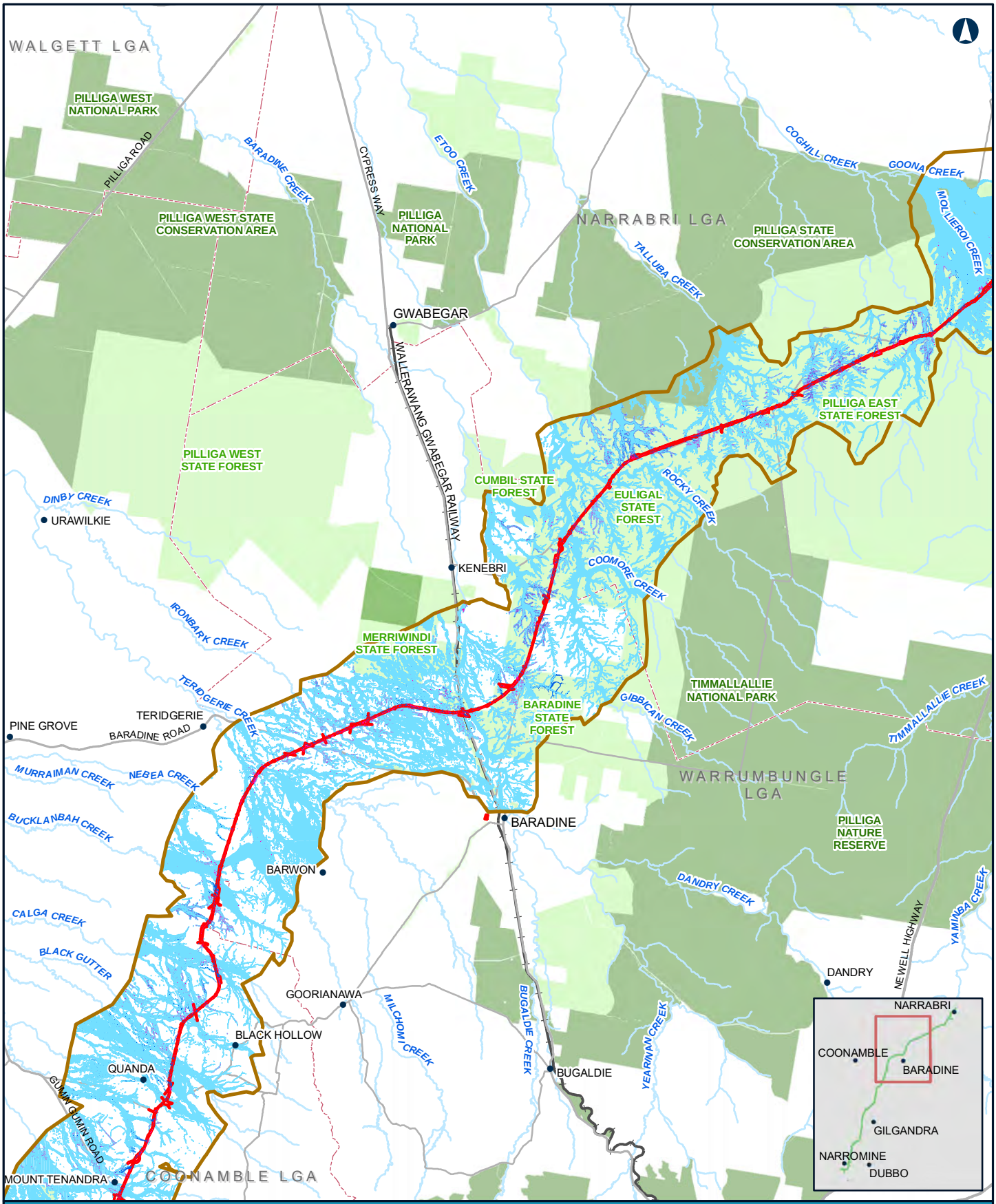

NARROMINE TO NARRABRI Change in 1% AEP flood extent – Construction Figure 6.1c

0 8 16 Km

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Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent
- Was wet now dry
- Was dry now wet

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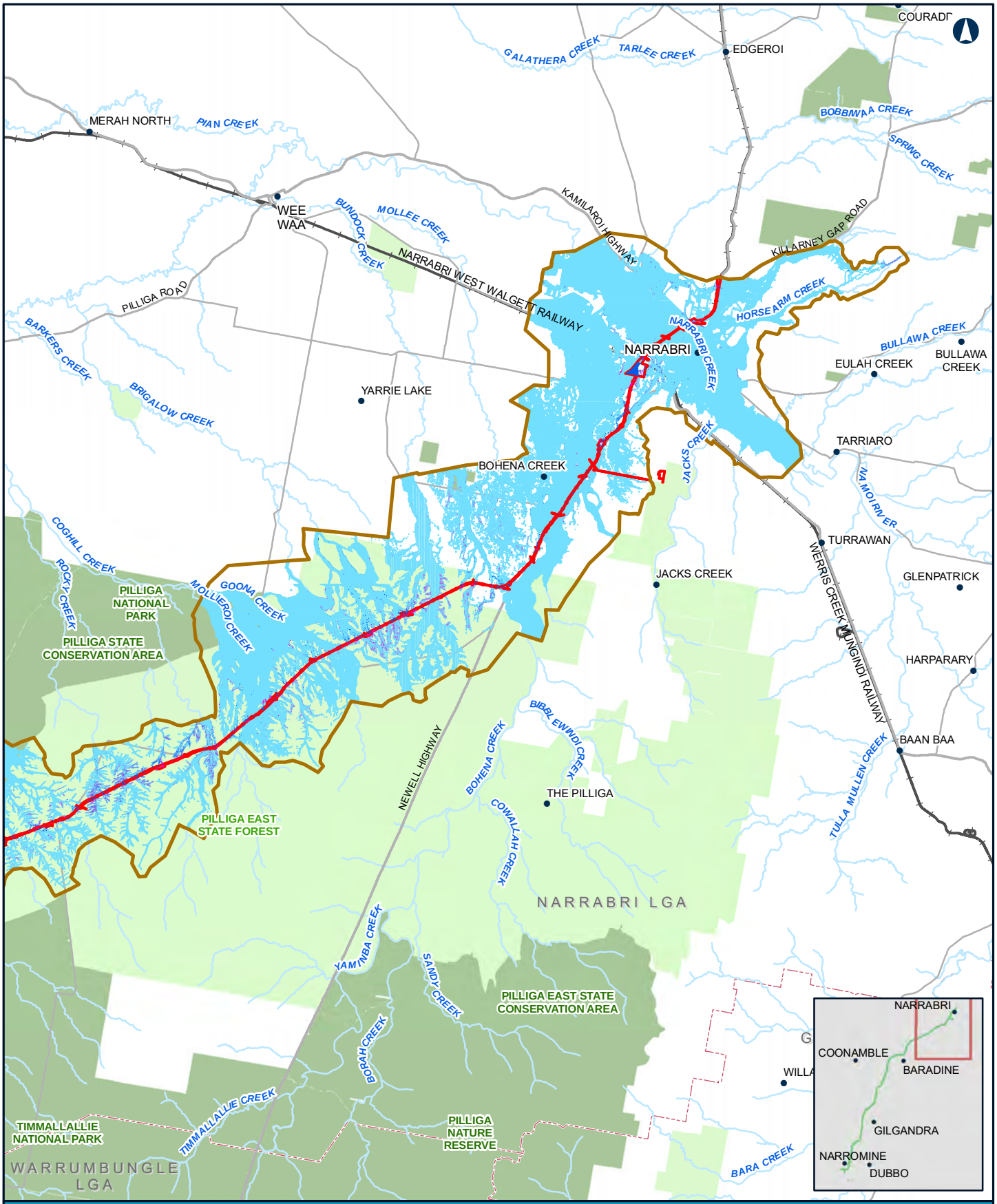

NARROMINE TO NARRABRI Change in 1% AEP flood extent – Construction Figure 6.1d

0 8 16 Km

Coordinate System: GDA 1994 MGA Zone 55

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Author: JacobsGHD Scale: 1:400,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent
- Was wet now dry
- Was dry now wet

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6.1.3 Impacts to buildings

Geo-databases containing flood modelling data have been interrogated to identify peak flood levels, peak flood depths, flood hazard categories and duration of inundation of lands where the buildings are situated.

For the purposes of this assessment and to align with the QDLs agreed with DPE (see Section 3.2.2) buildings are classified as either habitable or non-habitable.

Building floor levels are based on surveyed data where available, otherwise have been assumed as described in Section 3.3.6.

Above floor flooding

Habitable buildings

The number of habitable buildings with above floor flooding within each TUFLOW model domain which are impacted by more than 10 millimetres increase in depth during the construction phase are shown in Table 6.1.

In total, one, 15 and 32 habitable buildings are impacted during the construction phase in the 20%, 5% and 1% AEP flood events respectively. The majority of the impacted habitable buildings in the 20% AEP flood event are located at Narromine, while the majority of the impacted habitable buildings in the 5% and 1% AEP flood events are located at or near Narrabri. Of the impacted habitable buildings, one, two and four are newly flooded above 10 millimetres in the 20%, 5% and 1% AEP flood events respectively.

Compared to the number of habitable buildings subject to above floor flooding under existing conditions (13 in the 20% AEP event, 481 in the 5% AEP event and 2574 in the 1% AEP event (Table 5.3)), the construction impacts are minor.

Table 6.1 Number of habitable buildings subject to above floor flooding and impacted by more than 10 millimetres afflux (number with surveyed floor levels shown in brackets) - construction phase

TUFLOW model	20% AEP	5% AEP	1% AEP
NFM	1	1	5
N2N14	0	0	0
N2N13	0	0	0
N2N11-12	0	0	2
N2N10	0	0	0
N2N9	0	0	0
N2N8	0	0	0
N2N7	0	0	0
N2N6	0	0	0
N2N5	0	0	0
N2N4	0	0	0
N2N23	0	0	0
N2N1	0	5 (3)	8 (3)
Narrabri	0	13 (10)	17 (16)
Total	**1**	**19 (13)**	**32 (19)**

Non-habitable buildings

The number of non-habitable buildings with above floor flooding within each TUFLOW model domain which are impacted by more than 20 millimetres increase in depth during the construction phase are shown in Table 6.2.

In total, five, 22 and 44 non-habitable buildings are impacted during the construction phase in the 20%, 5% and 1% AEP flood events respectively. The majority of the impacted non-habitable buildings are located at Narromine and at or near Narrabri. Of the impacted non-habitable buildings, five, three and six are newly flooded above 20 millimetres in the 20%, 5% and 1% AEP flood events respectively.

Compared to the number of non-habitable buildings subject to above floor flooding under existing conditions (121 in the 20% AEP event, 1077 in the 5% AEP event and 3628 in the 1% AEP event (Table 5.4)), the construction impacts are minor.

Table 6.2 Number of non-habitable buildings subject to above floor flooding and impacted by more than 20 millimetres afflux (number with surveyed floor levels shown in brackets) – construction phase

TUFLOW model	20% AEP	5% AEP	1% AEP
NFM	5	7	19
N2N14	0	0	0
N2N13	0	0	0
N2N11-12	0	0	4
N2N10	1	0	0
N2N9	0	0	0
N2N8	0	0	0
N2N7	0	0	0
N2N6	0	0	0
N2N5	0	0	0
N2N4	0	0	0
N2N23	0	0	0
N2N1	0	17 (10)	17 (4)
Narrabri	0	0	5 (2)
Total	**6**	**24 (10)**	**45 (6)**

Flood hazards

Habitable buildings

The number of above impacted habitable buildings and their surrounds subject to high flood hazard category (H3, H4, H5 and H6) within each TUFLOW model domain are shown in Table 6.3.

In total, one, four and 27 habitable buildings are impacted during the construction phase in the 20%, 5% and 1% AEP flood events respectively. The majority of the impacted habitable buildings are located at Narromine and at or near Narrabri.

The number of impacted habitable buildings where the hazard has changed from low to high are one, one and two for the 20%, 5% and 1% AEP flood events respectively. None of the buildings are newly impacted.

Compared to the number of habitable buildings impacted under existing conditions (6 in the 20% AEP event, 236 in the 5% AEP event and 2103 in the 1% AEP event (Table 5.5)), the construction impacts are minor.

Table 6.3 Number of impacted habitable buildings (subject to above floor flooding and afflux greater than 10 millimetres) located on lands subject to high flood hazard – construction phase

TUFLOW model	20% AEP	5% AEP	1% AEP
NFM	1	1	4
N2N14	0	0	0
N2N13	0	0	0
N2N11-12	0	0	2
N2N10	0	0	0
N2N9	0	0	0
N2N8	0	0	0
N2N7	0	0	0
N2N6	0	0	0
N2N5	0	0	0
N2N4	0	0	0
N2N23	0	0	0
N2N1	0	3	6
Narrabri	0	0	15
Total	**1**	**4**	**27**
% of total habitable buildings [1]	**100%**	**27%**	**84%**

Note 1: subject to above floor flooding (see Table 6.1)

Non-habitable buildings

The number of above impacted non-habitable buildings and their surrounds subject to high flood hazard category (H3, H4, H5 and H6) within each TUFLOW model domain are shown in Table 6.4.

In total, five, 19 and 36 non-habitable buildings are impacted during the construction phase in the 20%, 5% and 1% AEP flood events respectively. The majority of the impacted non-habitable buildings are located at Narromine and at or near Narrabri.

The number of impacted non-habitable buildings where the hazard has changed from low to high are five, ten and nine for the 20%, 5% and 1% AEP flood events respectively. None of the buildings are newly impacted.

Compared to the number of non-habitable buildings impacted under existing conditions (57 in the 20% AEP event, 697 in the 5% AEP event and 3040 in the 1% AEP event (Table 5.6)), the construction impacts are minor.

Table 6.4 Number of impacted non-habitable buildings (subject to above floor flooding and afflux greater than 20 millimetres) located on lands subject to high flood hazard – construction phase

TUFLOW model	20% AEP	5% AEP	1% AEP
NFM	5	6	12
N2N14	0	0	0
N2N13	0	0	0
N2N11-12	0	0	4
N2N10	0	0	0
N2N9	0	0	0
N2N8	0	0	0
N2N7	0	0	0
N2N6	0	0	0
N2N5	0	0	0
N2N4	0	0	0
N2N23	0	0	0
N2N1	0	13	16
Narrabri	0	0	4
Total	**5**	**19**	**36**
% of total non-habitable buildings [1]	**100%**	**86%**	**82%**

Note 1: subject to above floor flooding (see Table 6.2).

Duration of inundation

Habitable buildings

The average duration of flooding above 0.5 metres depth of flooding near the above impacted habitable buildings were analysed for each TUFLOW model domain and each flood event.

For most habitable buildings inundated in existing conditions the average durations in the construction phase don't change. The duration of flood inundation at nine habitable buildings is increased by more than 10 per cent in the 1% AEP event with the majority of the impacted buildings being located within Narrabri TUFLOW model domain. No habitable buildings experience an increase in duration of more than 10 per cent in the 20% AEP and 5% AEP events.

Non-habitable buildings

The average duration of flooding above 0.5 metres depth of flooding near the above impacted non-habitable buildings were analysed for each TUFLOW model domain and each flood event.

For most non-habitable buildings inundated in existing conditions the average durations in the construction phase don't change. The duration of flood inundation at two and 20 non-habitable buildings are increased more than 10 per cent in the 5% AEP and 1% AEP events respectively and the majority of the impacted buildings being located within or near Narromine and Narrabri. No habitable buildings experience an increase in duration of more than 10 per cent in the 20% AEP event.

6.1.4 Impacts to roads

All highways and other named roads have been analysed to identify flooded sections of each highway / road located within each TUFLOW model domain. Flood hazards, and duration of flooding above 0.5 metres flood depth were also analysed.

Highways

The change in lengths of each highway subject to flood inundation for the selected flood events are shown in Table 6.5. As shown in Table 6.5, no additional lengths of highways are overtopped in the 20%, 5% and 1% AEP events during the construction phase (apart from negligible increases for the Oxley Highway and Newell Highway (N2N1) in the PMF event).

Table 6.5 Change (%) in length of highways subject to flooding – construction phase

Highway	20% AEP	5% AEP	1% AEP
Mitchell Highway	0%	0%	0%
Castlereagh Highway	0%	0%	0%
Oxley Highway	0%	0%	<5%
Newell Highway (N2N1)	0%	0%	<5%
Kamilaroi Highway	0%	0%	0%
Newell Highway (Narrabri)	0%	0%	0%

Table 6.6 shows change in length (within the model domain) of each inundated highway subject to high flood hazard (H3, H4, H5 and H6 identified in Figure 2.1). There are no changes apart from very minor changes for the Newell Highway (N2N1) in the 20% AEP and 1% AEP events.

Table 6.6 Change (%) in length of inundated highways subject to high flood hazard – construction phase

Highway	20% AEP	5% AEP	1% AEP
Mitchell Highway	0%	0%	0%
Castlereagh Highway	0%	0%	0%
Oxley Highway	0%	0%	0%
Newell Highway (N2N1)	<5%	0%	<5%
Kamilaroi Highway	0%	0%	0%
Newell Highway (Narrabri)	0%	0%	<5%

The change in maximum duration of flooding above 0.5 metres flood depth for each highway is shown in Table 6.7. There are no changes apart from very minor changes for the Oxley Highway in the 5% AEP event and the Newell Highway (N2N1) in the 1% AEP event.

Table 6.7 Change (%) in maximum duration of inundation of highways above 0.5 metres depth of flooding – construction phase

Highway	20% AEP	5% AEP	1% AEP
Mitchell Highway	0%	0%	0%
Castlereagh Highway	0%	0%	0%
Oxley Highway	0%	<5%	0%
Newell Highway (N2N1)	0%	0%	<5%
Kamilaroi Highway	0%	0%	0%
Newell Highway (Narrabri)	0%	0%	0%

Other named roads

A summary of flood impacts on named roads for the construction phase for the 20%, 5% and 1% AEP events is presented in Table 6.8.

This shows no increases in the total length of overtopping of named roads for all flood events assessed. Changes in lengths subject to high hazard and the average and maximum durations of inundation are all less than 10 per cent.

Table 6.8 Summary of change (%) in flood impacts on named roads – construction phase

Event	Change in total length (%)	Change in total length subject to high hazard (%)	Change in average duration of inundation (%)	Change in maximum duration of inundation (%)
20% AEP	0%	<10%	<10%	<10%
5% AEP	0%	<10%	0%	0%
1% AEP	0%	<10%	0%	0%

6.1.5 Impacts to existing rail lines

Impacts of the proposal on overtopping of the existing railways during the construction phase have been assessed for the 20%, 5% and 1% AEP events. Table 6.9 shows that overtopping lengths for most existing lines remains unchanged during construction. Overtopping lengths are reduced for the Parkes to Narromine line while they are increased for the Dubbo to Coonamble Line

Table 6.9 Change (%) in overtopping length of rail lines – construction phase

Rail line	20% AEP	5% AEP	1% AEP
Main Western Line	0%	0%	0%
Parkes Narromine Line	-21%	-33%	-20%
Dubbo to Coonamble Line	20%	11%	7%
Binnaway to Gwabegar Line (non-operational)	0%	0%	0%
Narrabri to Walgett Line (N2N1)	0%	-2%	0%
Narrabri to Walgett Line (Narrabri)	0%	0%	0%
Mungindi Line	0%	0%	0%

Impacts of the proposal on maximum duration of overtopping of the existing railways during the construction phase have been assessed for the 20%, 5% and 1% AEP events. Table 6.10 shows that the change in duration of inundation is less than five per cent for all flood events.

Table 6.10 Change (%) in maximum duration (hours) of flooding of railway above 0.5 metres depth of flooding – construction phase

Rail line	20% AEP	5% AEP	1% AEP
Main Western Line	0%	0%	<5%
Parkes to Narromine Line	<5%	0%	0%
Dubbo to Coonamble Line	0%	0%	0%
Binnaway to Gwabegar Line (non-operational)	<5%	0%	0%
Narrabri to Walgett Line (N2N1)	0%	0%	0%
Narrabri to Walgett Line (Narrabri)	0%	0%	0%
Mungindi Line	<5%	0%	0%

6.1.6 Impacts to major land uses

Forested lands

Impacts of the proposal to flooding depths during the construction phase on forested lands is shown in Table 6.11. When compared to the existing conditions (Table 5.16) there are negligible changes, with an overall minor reduction of 142 hectares in the 1% AEP event.

Table 6.11 Forested lands subject to different flood depths – construction phase

Event	Inundated areas (ha)					
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	Total
20% AEP	6978	2035	1188	693	271	**11,166**
5% AEP	10,226	2852	2313	1079	586	**17,055**
1% AEP	13,469	3491	3300	1651	951	**22,861**

Impacts of the proposal to flooding duration during the construction phase on forested lands is shown in Table 6.12. When compared to the existing conditions (Table 5.17) there are negligible changes in all events modelled.

Table 6.12 Forested lands subject to different duration of flood inundation above 0.5 metres depth – construction phase

Event	Inundated Forested land (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	347	485	675	559	59
5% AEP	700	1032	1266	827	127
1% AEP	905	1446	2187	1233	111

Grazing area

Impacts of the proposal to flooding depths during the construction phase on grazing areas is shown in Table 6.13. When compared to the existing conditions (Table 5.18) there are negligible changes, with an overall minor reduction of 128 hectares in the 1% AEP event.

Table 6.13 Grazing areas subject to different flood depths – construction phase

Event	Inundated areas (ha)					Total
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	
20% AEP	10,847	4446	3453	2208	1753	**22,707**
5% AEP	12,773	5671	5627	5334	3798	**33,203**
1% AEP	14,833	6038	6318	7173	6767	**41,128**

Impacts of the proposal to flooding duration during the construction phase on grazing areas is shown in Table 6.14. When compared to the existing conditions (Table 5.19) there are negligible changes in all events modelled.

Table 6.14 Duration of flood inundation of grazing areas above 0.5 metres depth – construction phase

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	598	1216	1880	1188	2510
5% AEP	812	1633	4171	2511	5619
1% AEP	1155	1766	3955	4646	8730

Cropping lands

Impacts of the proposal to flooding depths during the construction phase on cropping lands is shown in Table 6.15. When compared to the existing conditions (Table 5.20) there are negligible changes, with an overall minor reduction of 166 hectares in the 1% AEP event.

Table 6.15 Cropping lands subject to different flood depths – construction phase

Event	Inundated areas (ha)					Total
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	
20% AEP	21,752	3790	1611	728	105	**27,985**
5% AEP	29,399	6707	3046	1559	550	**41,261**
1% AEP	37,616	10,752	5965	4121	2099	**60,553**

Impacts of the proposal to flooding duration during the construction phase on cropping lands is shown in Table 6.16. When compared to the existing conditions (Table 5.21) there are negligible changes in all events modelled.

Table 6.16 Duration of flood inundation for cropping lands above 0.5 metres depth – construction phase

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	331	547	666	321	600
5% AEP	726	1001	1405	633	1421
1% AEP	1432	1311	2170	2195	5116

Horticultural lands

Impacts of the proposal to flooding depths during the construction phase on horticultural lands is shown in Table 6.17. When compared to the existing conditions (Table 5.22) there are negligible changes across all events modelled.

Table 6.17 Horticultural lands subject to different flood depths – construction phase

Event	Inundated areas (ha)					Total
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m	
20% AEP	0	1	5	0	0	**6**
5% AEP	1	2	7	4	4	**19**
1% AEP	8	25	89	110	10	**242**

Impacts of the proposal to flooding duration during the construction phase on horticultural lands is shown in Table 6.18. When compared to the existing conditions (Table 5.23) there are negligible changes across all events modelled.

Table 6.18 Duration of flood inundation for horticultural lands above 0.5 metres depth – construction phase

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
20% AEP	1	2	2	0	0
5% AEP	0	2	6	1	6
1% AEP	0	1	13	28	167

6.2 Geomorphology

The anticipated impacts to the watercourses and their floodplains have been discussed in Section 6.1, particularly within Section 6.1.1. This includes the proposed management of construction activities, including earthworks, compounds, stockpiles and borrow pits, which are designed to limit impact to waterways.

6.2.1 General construction

Ground disturbance and sedimentation

Construction earthworks activities would expose bare soils that could be eroded by rainfall and gully formation. Sediment runoff could affect water quality, including:

- Increased sediment input into watercourses leading to increased flow turbidity and localised changes to channel functioning and bedforms / planform (depending on the size of sediment eroded: clay tends to remain in suspension for a considerable period of time, whereas sands are redeposited as soon as flow velocities decrease below the mobilisation threshold. Substantial increases in sediment supply in watercourses which are not currently supply unlimited could cause formation of sediment slugs and changes to in-channel habitat.
- Interstitial habitat in bed substrates could be affected if infilled with fine sediment.

The construction erosion and sediment control plan, and emergency management plan for spills would be implemented to avoid such adverse impacts.

Vegetation clearance

Clearance of riparian and instream vegetation would reduce the attenuating effect on velocities and stabilising influence on soils. Removal could also create preferential pathways for runoff and associated erosion. Adverse impacts are more likely along the following watercourses:

- Watercourses which are currently densely vegetated and assessed as being of high sensitivity, such as Teridgerie Creek and Baradine Creek
- Watercourses which are moderately densely vegetated (either in-channel or floodplain) and high sensitivity, including the Macquarie River, Castlereagh River, Quanda Quanda Creek and Calga Creek
- Watercourses subject to particularly high velocities (other than those previously mentioned), such as Baradine Creek and the Namoi River
- Chain of pools watercourses, such as Bohena Creek, which could see localised adverse impacts to in-stream morphology.

Some of the above identified watercourses are predicted threatened species habitat (DPI, 2022) and exhibit key aquatic habitat features including instream aquatic vegetation in good condition, LWD, sand bars, pools and riffles at the proposal crossing locations (refer to Aquatic Ecology Assessment Technical Report 2 (JacobsGHD, 2020)), In particular, Macquarie River, Castlereagh River, Baradine Creek, Bohena Creek and Namoi River are likely to provide good quality aquatic habitat for species (permanently in perennial watercourses and when water is available in ephemeral streams). As such, suitable management measures to minimise erosion impacts from instream and riparian vegetation clearance will be implemented at these highly sensitive sites. It is expected, however, that Quanda Quanda Creek at the proposal crossing does not provide suitable instream aquatic habitat despite being identified as predicted threatened species habitat. Nevertheless, Quanda Quanda Creek may exhibit more significant aquatic habitat further downstream, therefore adequate erosion and sediment controls will be implemented at this site prior to clearance and throughout construction.

Teridgerie Creek and Calga Creek are not predicted threatened species habitat but are mapped Key Fish Habitat (KFH) (DPI, 2022) (refer to Aquatic Ecology Assessment Technical Report 2 (JacobsGHD, 2020)). Broadly, both watercourses may provide some instream habitat for native aquatic species when water is available. These creeks at the proposal crossing locations, however, are predicted to act more like a drainage channel within the floodplain rather than KFH. Impacts to aquatic habitat in these watercourses are therefore considered minor at the proposal location and downstream erosion and sedimentation of habitat features downstream would be negligible.

Creation of new flow paths

Construction activities which intercept existing flow paths, such as tracks, earthworks and in-stream activities, could result in diversion or constriction of these flows. Impacts are more likely in areas of uncontrolled overland flow or in creeks which have highly mobile sand beds. Existing sections where overland flows are uncontrolled and could result in creation of new flow paths include the Macquarie and Namoi Floodplains, the Basaltic Colluvial Plains and within the Pilliga Forest, particularly to the west of Coghill Creek.

Where construction access tracks are orientated parallel to the direction of in-channel floodplain or overland flows, these will tend to function as preferred flow paths, potentially triggering erosion. This could result in diversion of flow paths away from their existing alignment.

Effective flow diversion and management would minimise the likelihood of creation of new flow paths during the construction phase of the proposal.

6.2.2 In-stream construction

By their very nature, culverts and bridge pier footings result in direct disturbance to the bed and banks of watercourses and floodplains. Section 6.1.1 discusses the potential impact of temporary structure wash-away. Other construction activities, such as temporary waterway crossings would also directly impact channels. This could result in several adverse impacts, including:

- Generation of sediment and in-stream turbidity, potentially leading to alteration of aquatic habitat features such as infilling pools
- Bed scour, bank erosion or deposition around temporary structures, depending on the localised flow dynamics
- Localised alteration of channel morphology.

6.2.3 Rehabilitation

The highest risk of adverse impact during construction would be after disturbance and prior to successful rehabilitation. A key factor in watercourse rehabilitation success is revegetation of the riparian corridor (Rutherfurd *et al*., 2000). An assessment of the vegetation density for each watercourse is shown in Table E1, Appendix D. Rehabilitation of each watercourse reach or floodplain area impacted by the expanded construction footprint would aim to provide a balance between vegetation that matches the adjacent reaches, that can withstand the anticipated shear stresses and provides sufficient bank (and bed, where appropriate) stability to avoid increased erosion. In poor soil areas, ‘soft’ engineered stabilisation of surfaces, such as jute mesh or coir logs could be required. These systems could also be used on steeper slopes (e.g. bare bank faces) while vegetation is becoming established.

7 Operational impact assessment

7.1 General

The flood models described in Section 3.4 have been used to assess the magnitude and extents of changes in flood regimes during the operational phase of the proposal.

The QDLs described in Section 3.2.2, have been used to assess the potential impacts of the proposal against existing conditions for flood afflux, velocity, hazard and duration for floods up to and including the 1% AEP event.

At the reference design stage of the project it has not been possible to fully comply with all of the QDLs over the 306 kilometre length of the project. This being so, there are some departures from the QDLs that are reported in this Updated Flooding and Hydrology Assessment Report. These QDL departures have been used as a basis for assessing the flooding impacts from the proposal. Where flow velocities exceed the QDLs beyond the rail corridor boundary, drainage control areas have been included within the proposal boundary to provide additional space to reduce velocities and manage potential erosion and scour risks.

As the design is developed and more detailed survey information is collected, ARTC will undertake further consultation with relevant authorities, land owners and the community and the design will be refined to reduce the number of QDL departures.

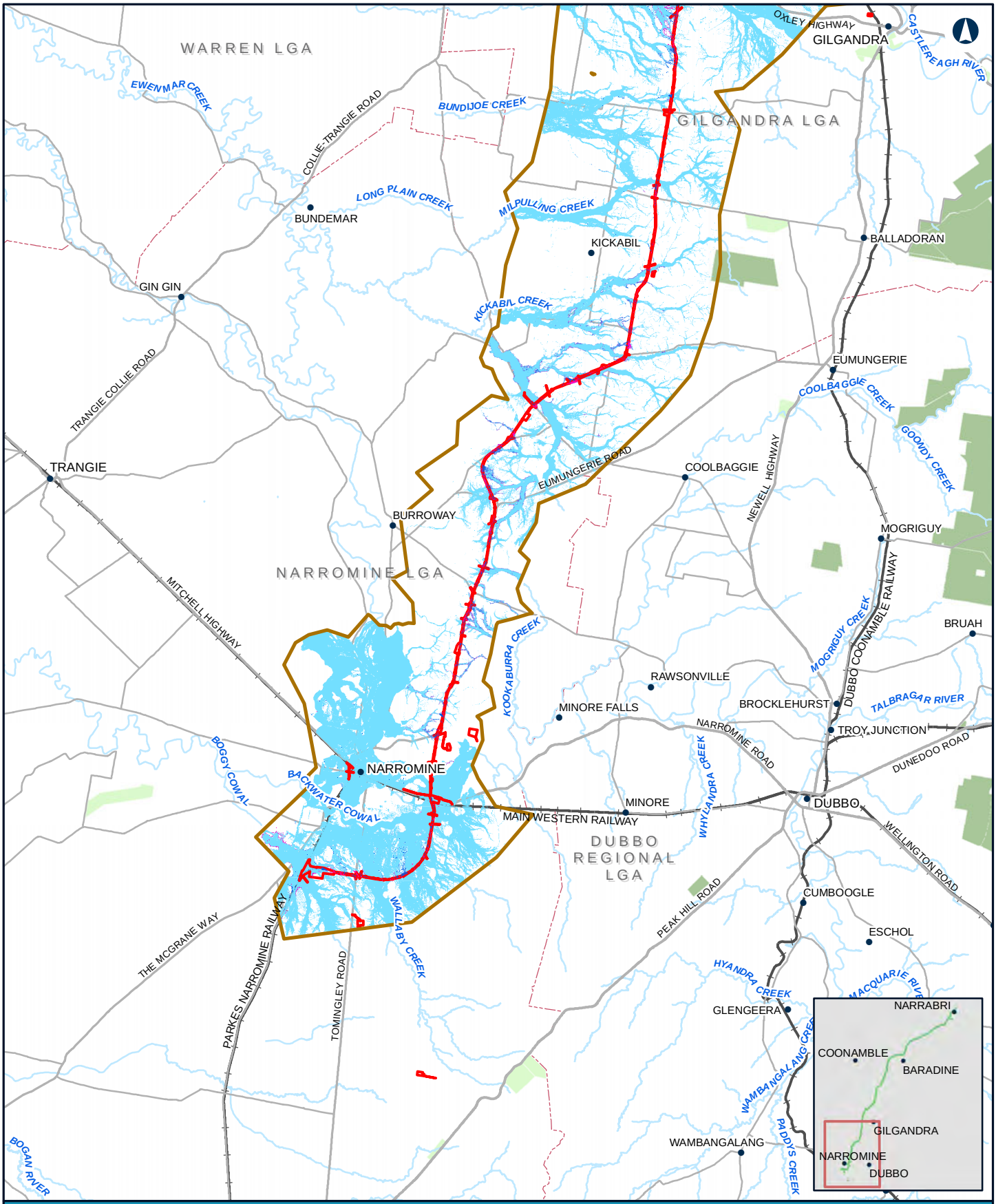
Predicted flooding extents for the 1% AEP event during operation are shown in Figure 7.1. Mapping of flood impacts during the operational stage for the full range of flood events assessed is provided in Appendix G and includes the following:

- Change in peak flood level (afflux) – Figures 1.1a to 1.8n
- Change in velocity – Figures 2.1a to 2.8n
- Change in duration – Figures 3.1a – 3.8n
- Change in flood hazard – Figures 4.1a – 4.8n.

More detailed flood mapping for the 1% AEP event during operation is provided in Appendix H for Narromine and Narrabri. Detailed mapping of QDL non-conformances are provided in Appendix I.

Web based mapping of the existing flood extent and afflux for the 1% AEP is also available on ARTC's Inland Rail web site at the link below.

https://inlandrail.artc.com.au/where-we-go/projects/narromine-to-narrabri/consultation/



NARROMINE TO NARRABRI Change in 1% AEP flood extent - Operational with Blockage Figure 7.1a

0 8 16 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 10/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:400,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent
- Was dry now wet
- Was wet now dry

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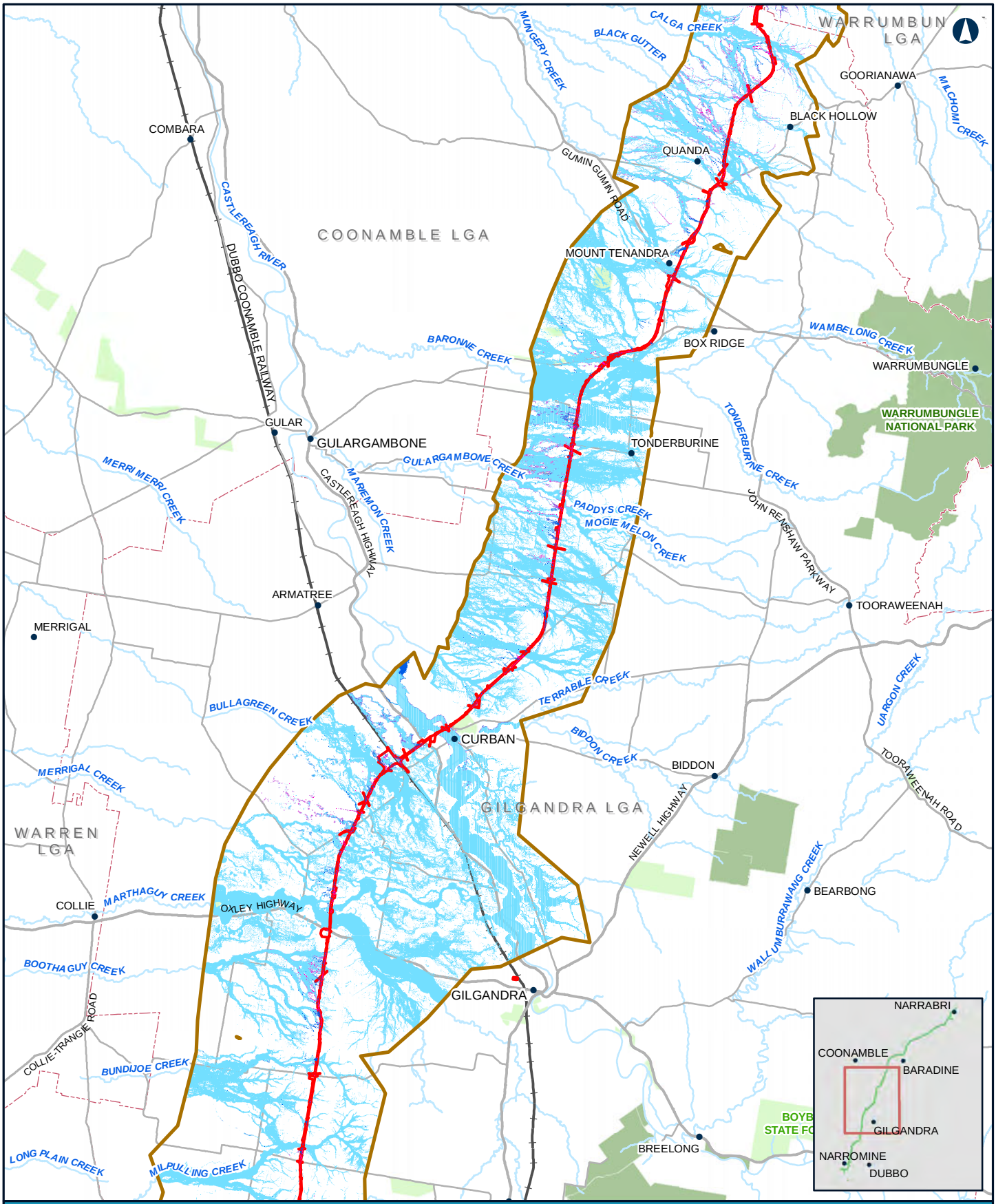

NARROMINE TO NARRABRI Change in 1% AEP flood extent - Operational with Blockage Figure 7.1b

0 8 16 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 10/09/2021 Paper: A4
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LEGEND

- The proposal
- Study area
- Flood extent
- Was dry now wet
- Was wet now dry

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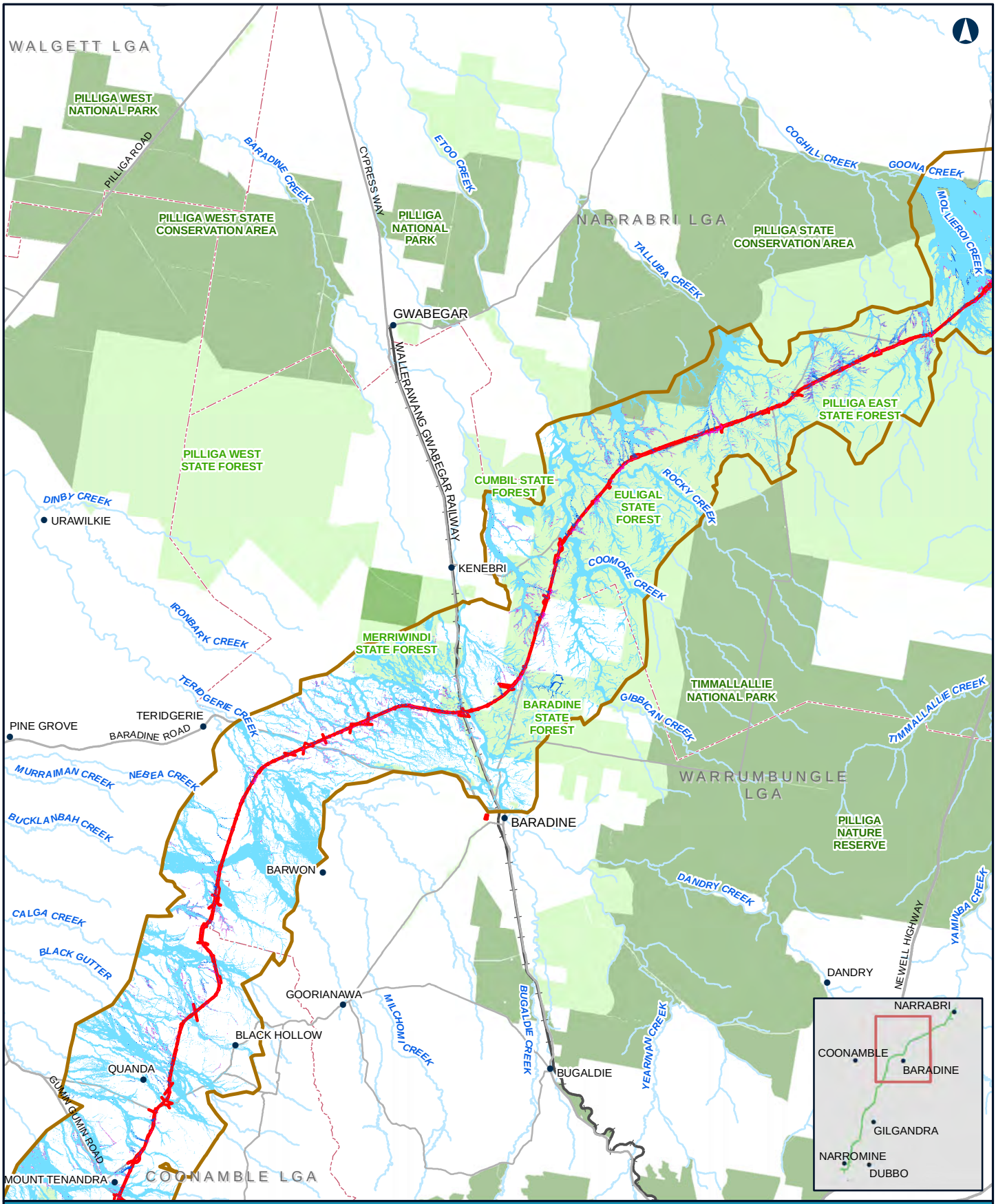

NARROMINE TO NARRABRI Change in 1% AEP flood extent - Operational with Blockage Figure 7.1c

0 8 16 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 10/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:400,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent
- Was dry now wet
- Was wet now dry

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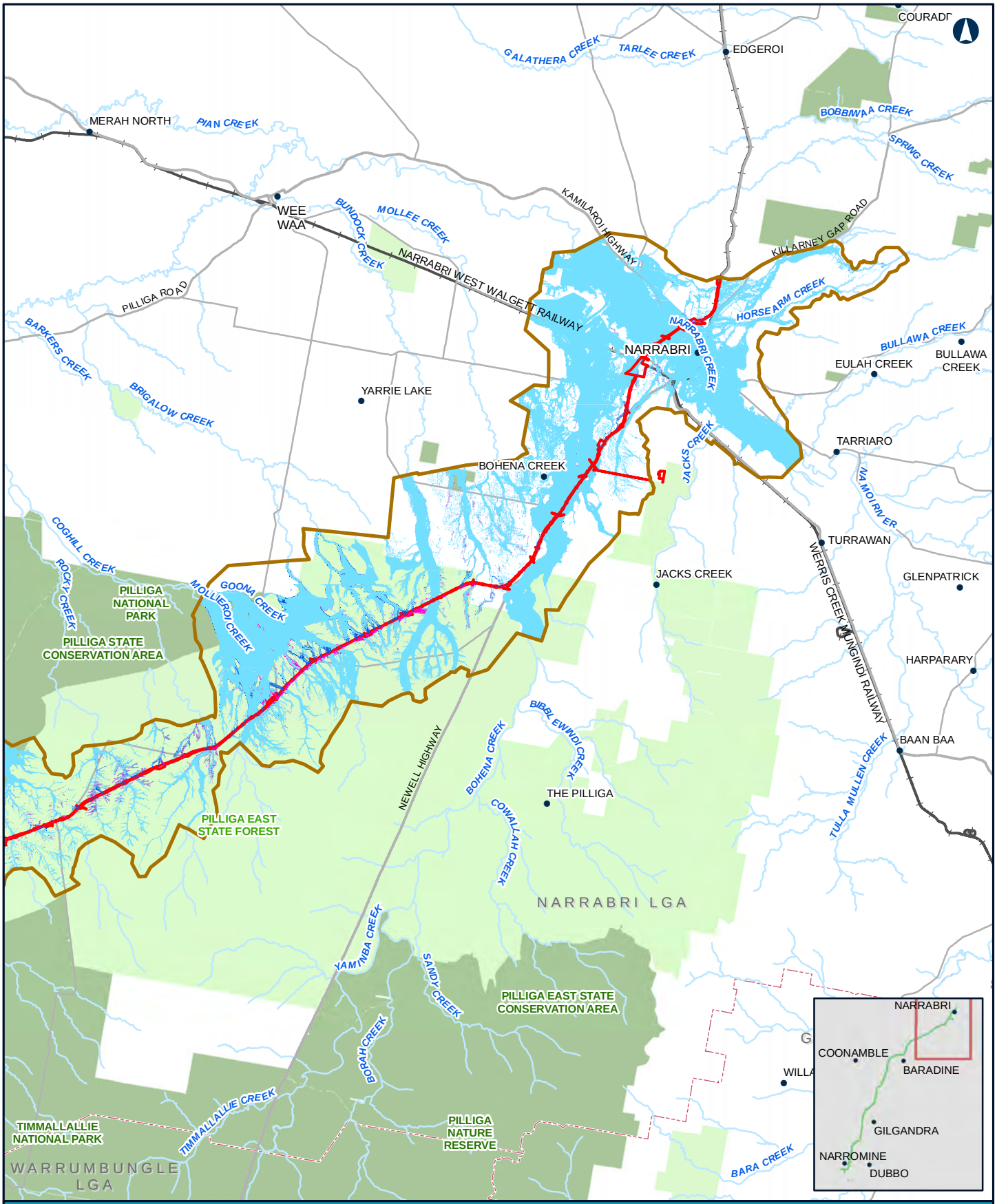

NARROMINE TO NARRABRI

Change in 1% AEP flood extent - Operational with Blockage

Figure 7.1d

0 8 16 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 10/09/2021 Paper: A4
Author: JacobsGHD Scale: 1:400,000
Data Sources: Basemap layers: NSWSS;

LEGEND

- The proposal
- Study area
- Flood extent
- Was dry now wet
- Was wet now dry

INLAND RAIL ARTC

The Australian Government is delivering Inland Rail through the Australian Rail Track Corporation (ARTC), in partnership with the private sector.

G:\22\19593\GIS\GIS_2500_N2N_v2\Maps\Deliverables_SPIR\EIS\Flooding_Hydrology\2500_EISFlooding014_ChangeFloodExtent_1Percent_Blockage.mxd

7.2 Flow velocities – erosion and scour considerations

7.2.1 General

Where flood waters are channelled through bridges and culverts under the rail embankment, flow velocities could change and there is a risk of erosion within drainage channels or on flood plains. Reduced velocities could also result in sedimentation.

The erosion risk will depend on a number of factors, including the increase in flow velocity, changes in velocity between creek channels and the flood plain, erodibility of natural soils and any existing erosion protection such as rock rip-rap or vegetation cover, that will help to bind the soils together and prevent erosion.

At bridges, the impacts on existing flood flow conditions are generally small and there would be only minor changes to existing conditions. These would typically be constrained to localised effects around the bridge piers and abutments. Scour protection would be provided to safeguard the integrity of the structure in accordance with the relevant design codes and Australian standards.

At culverts, flood flows can be more restricted, resulting in increases in flow velocities that could continue beyond the rail corridor boundary. These locations have been reviewed as part of this Updated Flooding and Hydrology Assessment Report and the proposal area has been increased to provide additional space for flow velocities to attenuate naturally, or for mitigation works to be included in the detailed design to reduce velocities to comply with the QDLs. These areas are referred to as drainage control areas.

Drainage control areas have been included at approximately 200 culvert locations to provide additional space in which to manage erosion and scour protection measures during detailed design and construction. The drainage control areas extend 50 metres downstream of the rail corridor and 15 metres upstream and have been located where there is potential for design flow velocities to exceed the QDLs beyond the rail corridor boundary in the 1% AEP (1 in 100 year) flood event.

7.2.2 Scour/Erosion Potential (Velocity) QDLs

At the reference design stage of the project, consistent QDL parameters have been applied across the full length of the proposal, independent of soil type and vegetation cover. The lower bound QDL velocity threshold has been set at 0.5 m/s with a 0.025 m/s increase on existing velocities permitted above this value (refer to section 3.2.2).

7.2.3 Velocity increases beyond the rail corridor boundary

Changes in flow velocities between existing and developed conditions were calculated using the TULFOW flood models. Results for the 1% AEP flood event indicated that at some culvert locations, changes in flow velocities could exceed the velocity QDLs outside of the rail corridor boundary.

7.2.4 Drainage control areas

Further analysis was therefore undertaken to calculate the additional distance required downstream of each culvert for the maximum design velocity within each culvert to reduce to a value that would be compliant with the velocity QDL.

In locations where a velocity QDL exceedance was identified, the proposal boundary was extended beyond the rail corridor boundary by creating drainage control areas, as shown in Figure 7.2.

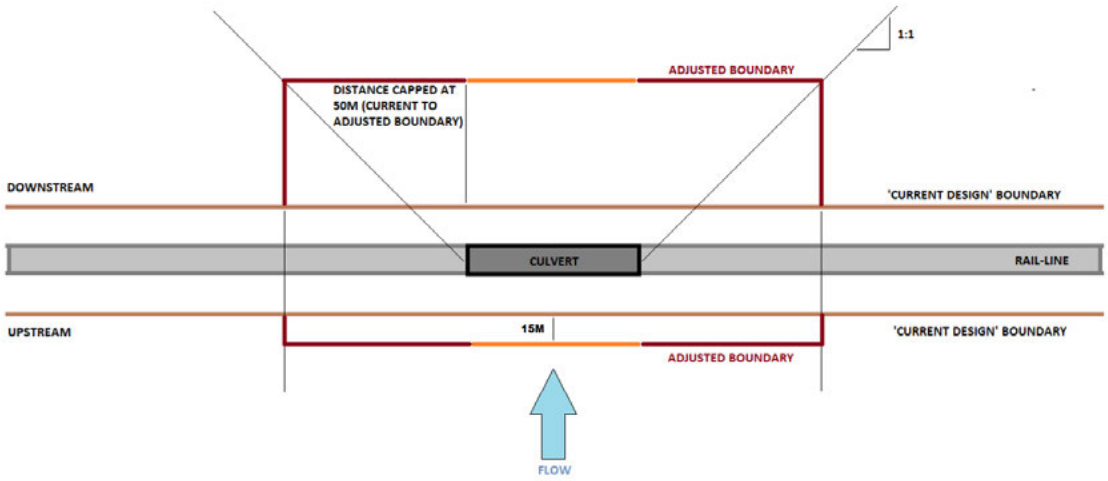


Figure 7.2 Schematic diagram of drainage control area

These areas have been referred to as drainage control areas. Analysis results indicated that approximately 80 per cent of downstream flow velocities would reduce to less than the QDL within a 50 metres distance beyond the rail corridor boundary. The drainage control area extents were therefore capped 50 metres downstream or the rail corridor boundary. A drainage control area extension of 15 metres on the upstream side of affected culverts was also included to provide space to manage potential velocity increases as water enters the culvert. The drainage control areas were reviewed against property boundaries and environmental constraints to reduce potential impacts. They were then rationalised and amalgamated for culverts that were in close proximity to one another to facilitate property adjustments and minor changes to culvert spacings in detailed design to assist with velocity reductions.

The result was a series of approximately 200 drainage control areas that extend 50 metres downstream of the rail corridor boundary and 15 metres upstream. The drainage control areas will provide additional space beyond the rail corridor to provide erosion and scour protection

The change in velocity outside of the rail corridor has been assessed against the QDLs provided in Section 3.2.2.

7.2.5 Detailed design mitigation

As the design is developed, more information will be collected on topographical survey, local soil conditions and their erosion characteristics to allow the flood models to be refined. This information will then be used to determine whether there is a risk of erosion and if so, the type of protection required to limit velocity changes from the project to be within the QDLs.

Potential design solutions that could be considered, in addition to providing industry standard scour protection, to minimise residual flooding impacts include:

- Replacing culverts with bridges
- Increasing the number of culverts and/or further distribution of culverts
- Energy dissipation devices
- Extending scour protection into private land in consultation and agreement with landowners
- Construction of diversion bunds or drainage to protect buildings and land areas.

The final design solution would be subject to detailed design and further consultation with individual landowners. Following these assessments, the size of the drainage control areas could be reduced, if the QDLs can be complied with in a smaller area.

7.2.6 Scour and erosion protection within the rail corridor

The new rail corridor would have a minimum width of 40 metres, with some variation to accommodate particular infrastructure and to cater for local topography. Culverts are constructed with headwalls within the footprint of the rail embankment. In general, there is a distance of approximately 14 metres between the face of the culvert and the rail corridor boundary. This may vary in places depending on the local topography, rail embankment height and maintenance access road requirements.

Where required, scour protection would be provided at culvert outlets within the rail corridor (including drainage control areas) in accordance with current design guidelines. A typical layout and section of scour protection that would be provided at culvert outlets is shown in Figure 7.3 and Figure 7.4. This will be refined during detailed design on a case by case basis, taking into account the culvert outlet flow velocity, soil conditions and other factors such as continuity of the rail maintenance access road. Further examples of scour protection implemented on other sections of the Inland Rail program are provided in Section 8.2.

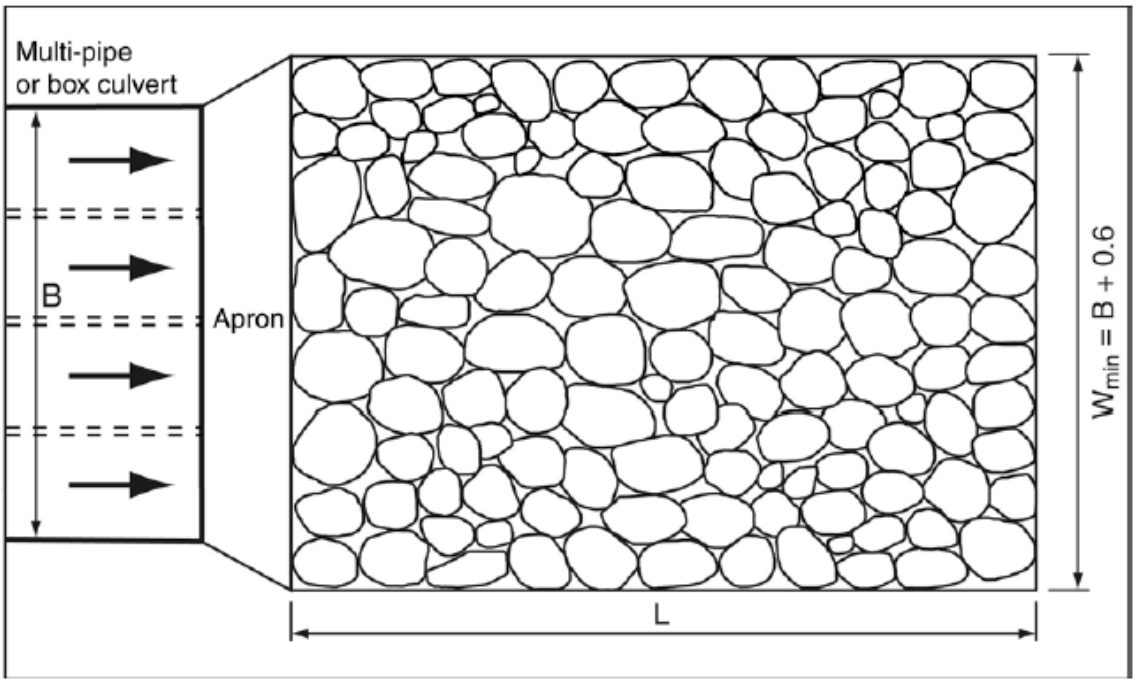


Figure 7.3 Typical plan layout of culvert scour protection (Catchments & Creeks Pty Ltd)

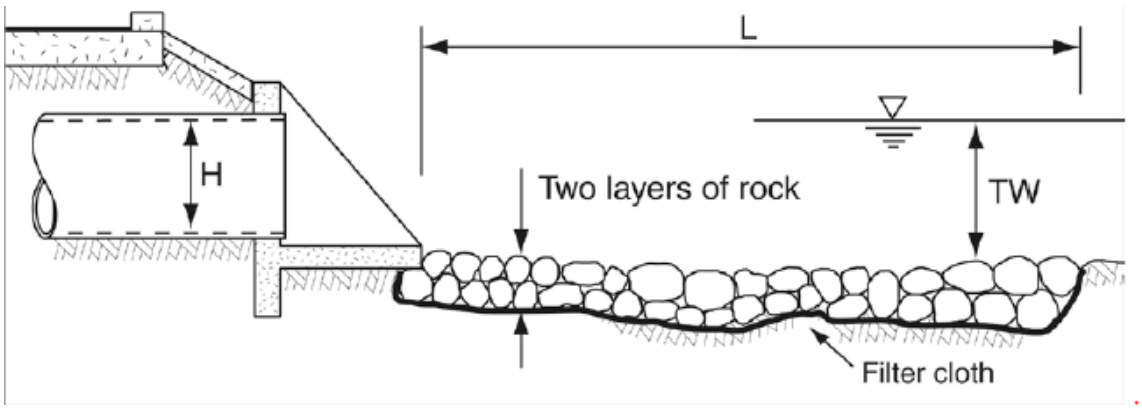


Figure 7.4 Typical section of culvert scour protection (Catchments & Creeks Pty Ltd)

For bridges in water courses, scour protection would be provided at piers and abutments in accordance with design guidelines and Australian Standards. Typical sections of scour protection provided at a bridge abutment and pier are shown in Figure 7.5 and Figure 7.6.

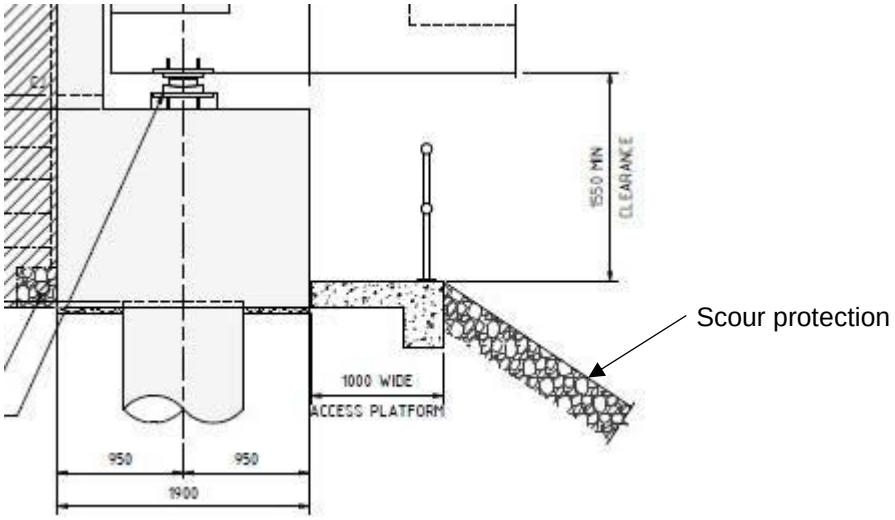


Figure 7.5 Typical scour protection at bridge abutments

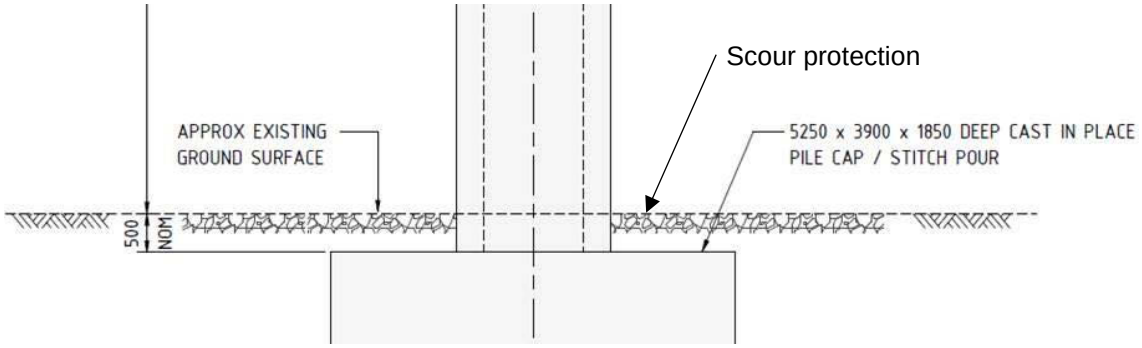


Figure 7.6 Typical scour protection at bridge piers

7.3 Assessment of impacts against QDLs

The impacts of the proposal have been assessed against the QDLs (Section 3.2.2) that cover a range of hydraulic parameters including afflux, velocities, hazard and duration. The QDL assessment has identified the number of buildings, area of land uses and length of roads where the various QDLs are exceeded in the 20%, 5%, 2%, and 1% AEP flood events. Results for the 1%AEP event include the application of blockage factors at culverts, as discussed in Section 3.7.4). Detailed mapping of QDL non-conformances are provided in Appendix I.

Refer to Section 7.4 for an assessment of rare flood events (i.e. those greater than the 1% AEP event).

7.3.1 Afflux

As described in section 3.3.6, surveyed floor levels of buildings, where available, have been used to define depth of flooding above floor levels of buildings. Surveyed floor levels were used for approximately 2,800 buildings based on surveyed levels provided by Narrabri Shire Council or survey undertaken by ARTC. In the case of buildings without surveyed floor levels, ground levels at the centroid of buildings have been extracted from the best available DEM to define floor levels of buildings on the assumption that floor levels are located 0.3 metres above ground level. This was checked against surveyed floor level data provided by Narrabri Shire Council and found to provide a good estimation of floor levels.

Habitable buildings (also referred to as habitable floors)

The number of habitable buildings within each flood model where afflux exceeds the QDL (afflux greater than 10 millimetres (see section 3.2.2)) are shown in Table 7.1. The results show that no habitable buildings are impacted more than the QDL in the 20% AEP event and 21 habitable buildings are impacted in the 1% AEP (with blockage) event. The impacts to habitable buildings in the 1% AEP (with blockage) event occur at four key locations – Narromine, Curban, Bohena Creek, and Narrabri. In total 23 habitable buildings are impacted across all models and events. The majority of habitable buildings impacted in the 1% AEP (with blockage) event are at Narrabri.

Compared to the number of habitable buildings subject to above floor flooding under existing conditions (13 in the 20% AEP event, 481 in the 5% AEP event, 1172 in the 2% AEP event and 2574 in the 1% AEP event (Table 5.3)), the operational impacts are relatively minor.

Table 7.1 Number of habitable buildings where afflux exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)	Total impacted (all events) [1]
NFM	0	0	2	3	4
N2N14	0	0	0	0	0
N2N13	0	0	0	0	0
N2N11-12	0	0	2	2	2
N2N10	0	0	0	0	0
N2N9	0	0	0	0	0
N2N8	0	0	0	0	0
N2N7	0	0	0	0	0
N2N6	0	0	0	0	0
N2N5	0	0	0	0	0

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)	Total impacted (all events) [1]
N2N4	0	0	0	0	0
N2N23	0	0	0	0	0
N2N1	0	3	3	3	3
Narrabri	0	8	12	13	14
Total	**0**	**11**	**19**	**21**	**23**

1 The total across all events represents those impacted by >10 millimetres. Where a habitable building is impacted in more than one event it is only counted once.

The number of habitable buildings subject to different afflux ranges (greater than 10 millimetres) and above floor flooding are shown in Table 7.2. The results show that for nearly all impacted habitable buildings the afflux is less than 50 millimetres, with one habitable building experiencing a maximum afflux of 58 millimetres.

Table 7.2 Number of habitable buildings where afflux exceeds the QDL – afflux range – operational phase

Afflux range (m)	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
0.01 - 0.02	0	9	13	12
0.02 - 0.03	0	1	6	5
0.03 - 0.05	0	0	0	3
0.05 - 0.10	0	1	0	1
0.10 - 0.20	0	0	0	0
0.20 - 0.30	0	0	0	0
0.30 - 0.50	0	0	0	0
0.50 - 1.00	0	0	0	0
1.00 - 2.00	0	0	0	0
Total	**0**	**11**	**19**	**21**

Further details on changes in flood levels for habitable buildings are shown in Table 7.3. The results show that:

- 23 habitable buildings are impacted across all models and events, of which 11 are residential and 12 are commercial / industrial.
- 19 separate landowners are impacted.
- One residential building is newly flooded above floor by 4 millimetres (afflux of 11 millimetres) in the 1%AEP event. Flooding is below floor for lesser flood events.
- All other impacted habitable buildings are subject to above floor flooding under existing conditions between 40 millimetres to 1.48 metres and would experience afflux varying from 11 to 58 millimetres.

Therefore, overall the operational impacts to habitable buildings where the QDL is exceeded are relatively minor. The design would continue to be refined during detailed design where practicable to not worsen existing flooding characteristics. Where it is not practicable to meet the QDLs, ARTC would implement the process detailed in Section 3.2.2.

Table 7.3 Details of habitable buildings where afflux exceeds the QDL – operational phase 1%AEP Flood (including blockage)

TUFLOW model	Property ID	Lot / DP	Structure type	Existing conditions		With proposal	
				Depth above floor (m)	AEP event when QDL exceeded	Afflux (m)	Depth above floor (m)
NFM	2673051	DP/12//747703	Residential	-0.007	1% AEP (with blockage)	0.011	0.004
	2673050	DP/11//747703	Residential	0.282	1% AEP (with blockage)	0.058	0.340
	3418082	DP/51//233201	Residential	0.131	1% AEP (with blockage), 2% AEP	0.020	0.151
	3688385	DP/18//755119	Residential	0.060	2% AEP	0.011	0.071
N2N11-12	2639037	DP/10/7/758962	Residential	1.177	1% AEP (with blockage)	0.043	1.220
		DP/1/7/758962	Commercial/Industrial	1.155	1% AEP (with blockage)	0.047	1.202
N2N1	2654398	DP/164//1012802	Residential *	1.33	1% AEP (with blockage)	0.020	1.350
	3632487	DP/4//757084	Residential *	0.806	1% AEP (with blockage)	0.017	0.823
	2654581	DP/1//860120	Residential *	0.923	1% AEP (with blockage)	0.020	0.943
Narrabri	3906968	DP/4//1204378	Residential *	0.040	1% AEP (with blockage)	0.014	0.054
	2660103	DP/12//843	Residential *	0.542	1% AEP (with blockage)	0.016	0.558
	3885997	DP/2//1204378	Residential *	0.782	1% AEP (with blockage)	0.016	0.798

TUFLOW model	Property ID	Lot / DP	Structure type	Existing conditions		With proposal	
				Depth above floor (m)	AEP event when QDL exceeded	Afflux (m)	Depth above floor (m)
	2660106	DP/10//843	Commercial/Industrial *	0.691	1% AEP (with blockage)	0.019	0.710
		DP/9//843	Commercial/Industrial *	0.697	1% AEP (with blockage)	0.018	0.715
	3905396	DP/1//1204378	Commercial/Industrial *	0.448	1% AEP (with blockage)	0.019	0.467
		DP/7//843	Commercial/Industrial *	0.691	1% AEP (with blockage)	0.020	0.711
	2660108	DP/6//843	Commercial/Industrial *	0.714	1% AEP (with blockage)	0.024	0.738
	3366367	DP/2//1119813	Commercial/Industrial *	0.600	1% AEP (with blockage)	0.028	0.628
	3366366	DP/1//1119813	Commercial/Industrial *	0.420	1% AEP (with blockage)	0.034	0.454
	2660111	DP/1021//849024	Commercial/Industrial *	0.981	1% AEP (with blockage)	0.029	1.010
	2660112	DP/2//516681	Commercial/Industrial *	0.974	1% AEP (with blockage)	0.025	0.999
		DP/1//516681	Commercial/Industrial *	0.708	1% AEP (with blockage)	0.024	0.732
	2657679	DP/10/90801	Commercial/Industrial	0	5% AEP	0.056	0.056

Note: * Indicates building floor level surveyed

Non-habitable buildings (Also referred to as non-habitable floors)

The number of non-habitable buildings within each flood model where afflux exceeds the QDL (afflux greater than 20 millimetres (see Section 3.2.2)) are shown in Table 7.4. Results show one non-habitable building impacted at Narromine in the 20% AEP event and a total of 23 non-habitable buildings impacted in the 1% AEP (with blockage) event across all models. Impacts to non-habitable buildings in 1% AEP (with blockage) event occur at the same four key locations where there are habitable building impacts – Narromine, Curban, Bohena Creek, and Narrabri. The majority of non-habitable buildings impacted in the 1% AEP (with blockage) event are located at Narromine and near Narrabri at Bohena Creek. In total 28 non-habitable buildings are impacted across all models and events.

Compared to the number of non-habitable buildings subject to above floor flooding under existing conditions (121 in the 20% AEP event, 1077 in the 5% AEP event, 2197 in the 2% AEP event and 3628 in the 1% AEP event (Table 5.4)), the operational impacts are relatively minor.

Table 7.4 Number of non-habitable buildings where afflux exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)	Total impacted (all events) [1]
NFM	1	1	1	11	11
N2N14	0	0	0	0	0
N2N13	0	0	0	0	0
N2N11-12	0	0	3	4	4
N2N10	0	0	0	0	0
N2N9	0	0	0	0	0
N2N8	0	0	0	0	0
N2N7	0	0	0	0	0
N2N6	0	0	0	0	0
N2N5	0	0	0	0	0
N2N4	0	0	0	0	0
N2N23	0	0	0	0	0
N2N1	0	10	3	5	10
Narrabri	0	0	1	3	3
Total	**1**	**11**	**8**	**23**	**28**

Note: 1. The total across all events represents those impacted by >20 millimetres. Where a non-habitable building is impacted in more than one event it is only counted once.

The number of non-habitable buildings subject to different afflux ranges and above floor flooding are shown in Table 7.5. The results show that for nearly all impacted non-habitable buildings the maximum afflux is less than 50 millimetres.

Table 7.5 Number of non-habitable buildings where afflux exceeds the QDL – afflux range – operational phase

Afflux range (m)	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
0.02 - 0.03	0	7	7	12
0.03 - 0.05	0	3	0	8
0.05 - 0.10	0	0	0	3
0.10 - 0.20	1	1	1	0
0.20 - 0.30	0	0	0	0
0.30 - 0.50	0	0	0	0
0.50 - 1.00	0	0	0	0
1.00 - 2.00	0	0	0	0
Total	**1**	**11**	**8**	**23**

Further details on changes in flood levels for non-habitable buildings are shown in Table 7.6. The results show that:

- 28 non-habitable buildings are impacted across all models and events.
- 10 separate landowners are impacted.
- One non-habitable building is newly flooded above floor by 21 millimetres (afflux of 27 millimetres) in the 1%AEP event. Flooding is below floor for lesser flood events.
- All other impacted non-habitable buildings are subject to above floor flooding under existing conditions between 85 millimetres to 1.51 metres and would experience afflux varying from 21 to 181 millimetres.

Therefore, overall the operational impacts to non-habitable buildings where the QDL is exceeded are relatively minor. The design would continue to be refined during detailed design where practicable to not worsen existing flooding characteristics. Where it is not practicable to meet the QDLs, ARTC would implement the process detailed in Section 3.2.2.

Table 7.6 Details of non-habitable buildings where afflux exceeds the QDL – operational phase

TUFLOW model	Property ID	Lot / DP	Structure type	Existing conditions		With proposal	
				Depth above floor (m)	AEP event when QDL exceeded	Afflux (m)	Depth above floor (m)
NFM	2673050	DP/11//747703	Other	0.296	1% AEP (with blockage)	0.051	0.347
		DP/11//747703	Other	0.237	1% AEP (with blockage)	0.058	0.295
		DP/11//747703	Other	0.322	1% AEP (with blockage)	0.048	0.370
		DP/11//747703	Other	0.296	1% AEP (with blockage)	0.044	0.340
		DP/11//747703	Other	0.315	1% AEP (with blockage)	0.047	0.362
	3418082	DP/51//233201	Other	0.085	1% AEP (with blockage)	0.025	0.110
		DP/51//233201	Other	-0.006	1% AEP (with blockage)	0.027	0.021
		DP/51//233201	Other	0.145	1% AEP (with blockage)	0.021	0.166
		DP/51//233201	Other	0.134	1% AEP (with blockage)	0.023	0.157
		DP/51//233201	Other	0.116	1% AEP (with blockage)	0.022	0.138
	3800251	DP/16//755131	Other	0.462	1% AEP (with blockage)	0.051	0.513
N2N11-12	Crown	n/a	Other	0.615	1% AEP (with blockage)	0.045	0.660
	2639037	DP/10/7/758962	Other	0.935	1% AEP (with blockage)	0.041	0.976
		DP/10/7/758962	Other	1.240	1% AEP (with blockage)	0.041	1.281
		DP/96//704064	Other	1.113	1% AEP (with blockage)	0.048	1.161
N2N1	2654562	DP/12//757086	Other *	1.256	1% AEP (with blockage)	0.028	1.284
		DP/12//757086	Other *	1.510	1% AEP (with blockage)	0.028	1.538
		DP/12//757086	Other *	0.493	1% AEP (with blockage)	0.027	0.520
	2654581	DP/1//860120	Other	0.589	5% AEP	0.022	0.611
		DP/1//860120	Other *	0.354	5% AEP	0.023	0.377

TUFLOW model	Property ID	Lot / DP	Structure type	Existing conditions	With proposal		
				Depth above floor (m)	AEP event when QDL exceeded	Afflux (m)	Depth above floor (m)
		DP/1//860120	Other *	0.673	1% AEP (with blockage)	0.021	0.694
		DP/1//860120	Other *	0.500	5% AEP	0.025	0.525
		DP/1//860120	Other *	0.394	5% AEP	0.023	0.417
		DP/1//860120	Other *	0.863	1% AEP (with blockage)	0.021	0.884
		DP/1//860120	Other *	0.166	5% AEP	0.022	0.188
Narrabri	2660106	DP/9//843	Other *	0.478	1% AEP (with blockage)	0.021	0.499
	3905396	DP/1//1204378	Other *	0.452	1% AEP (with blockage)	0.026	0.478
	3366367	DP/2//1119813	Other	0.435	1% AEP (with blockage)	0.035	0.470

Note: * Indicates building floor level surveyed

Urban and infrastructure land

The area (hectares) of urban and infrastructure land within each flood model where afflux exceeds the QDL (afflux greater than 100 millimetres (see Section 3.2.2)) is shown in Table 7.7.

The total area of urban and infrastructure land affected by afflux more than the QDL ranges from about 0.94 to 1.71 hectares in all the flood events assessed. The majority of urban and infrastructure land affected is located at Narromine for all events, and at Narrabri in the larger 2% AEP and 1% AEP events. The total existing flooded affected area modelled for land categorised as urban and infrastructure is 1,946 hectares in the 1% AEP event.

Table 7.7 Area (hectares) of land where afflux exceeds the QDL – urban and infrastructure land – operational phase

TUFLOW model	Existing Flooded Area (1% AEP)	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	597.22	0.70	0.77	0.74	0.33
N2N14	26.07	0.06	0.15	0.21	0.24
N2N13	72.91	0.00	0.01	0.00	0.00
N2N11-12	82.07	0.01	0.04	0.01	0.05
N2N10	90.19	0.00	0.00	0.01	0.00
N2N9	30.31	0.03	0.00	0.00	0.00
N2N8	7.73	0.01	0.00	0.02	0.02
N2N7	13.57	0.00	0.00	0.00	0.00
N2N6	0.81	0.00	0.00	0.01	0.00
N2N5	0.00	0.00	0.00	0.00	0.00
N2N4	0.00	0.00	0.00	0.00	0.00
N2N23	2.66	0.00	0.00	0.00	0.00
N2N1	226.25	0.04	0.03	0.02	0.03
Narrabri	796.00	0.04	0.27	0.70	0.94
Total	**1,945.78**	**0.94**	**1.28**	**1.71**	**1.61**

Agricultural land

The area (hectares) of agricultural land within each flood model where afflux exceeds the QDL (afflux greater than 200 millimetres (see Section 3.2.2)) is shown in Table 7.8. The total area impacted by afflux exceeding the QDL ranges from about 30 hectares in the 20% AEP event to 120.6 hectares in the 1% AEP event. The majority of agricultural land impacted is located from Narromine (NFM model) to Curban (N2N11-12 model). There are minimal impacts to agricultural land from flood model N2N6 to Narrabri. The total existing flooded affected area modelled for land categorised as agriculture is 61,668 hectares in the 1% AEP event.

Table 7.8 Area (hectares) of land where afflux exceeds the QDL – agricultural land – operational phase

TUFLOW model	Existing Flooded Area (1% AEP)	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	12,983.60	15.19	3.99	4.29	67.38
N2N14	1,992.26	0.63	2.8	6.06	7.02
N2N13	5,249.02	6.66	11.88	16.17	18.52
N2N11-12	13,344.08	1.26	4.42	6.64	8.51
N2N10	10,244.87	0.91	1.86	2.57	7.75
N2N9	4,855.75	3.21	4.07	5.45	7.72
N2N8	3,553.09	1.12	1.1	1.42	1.38
N2N7	4,927.59	1.04	1.71	1.87	2.32
N2N6	54.98	0	0	0	0
N2N5	-	0	0	0	0
N2N4	-	0	0	0	0
N2N23	73.34	0	0	0	0.005
N2N1	1,775.59	0.003	0.01	0.015	0.02
Narrabri	2,614.21	0	0.01	0	0
Total	**61,668.37**	**30.01**	**31.85**	**44.47**	**120.6**

Other non-urban land (including forest and unimproved grazing)

The area (hectares) of other non-urban land within each flood model where afflux exceeds the QDL (afflux greater than 300 millimetres (see Section 3.2.2)) is shown in Table 7.9. The total area ranges from about 14.3 hectares in the 20% AEP event to 367.17 hectares in the 1% AEP event. The majority of other non-urban land impacted is located from flood model N2N8 to N2N23 which represent grazing and state forest areas from Black Hollow to Bohena Creek. The total existing flooded affected area modelled for land categorised as “other non-urban” is 64,457 hectares in the 1% AEP event.

Table 7.9 Area (hectares) of land where afflux exceeds the QDL – other non-urban land – operational phase

TUFLOW model	Existing Flooded Area (1% AEP)	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	3,093.24	0.97	0.66	0.81	5.77
N2N14	581.40	0.21	0.39	0.58	0.71
N2N13	3,453.11	0.71	0.88	1.02	2.02
N2N11-12	7,079.68	0.53	1.22	1.27	1.39
N2N10	1,687.56	0.18	0.37	0.43	0.56
N2N9	2,413.61	1.55	2.59	3.22	3.58
N2N8	1,580.75	3.86	4.56	4.95	4.98
N2N7	6,343.96	0.94	1.57	1.73	7.86
N2N6	6,228.98	1.54	1.62	1.68	54.52
N2N5	1,590.27	0.97	1.22	1.43	30.38

TUFLOW model	Existing Flooded Area (1% AEP)	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
N2N4	1,564.69	1.61	1.83	1.93	8.65
N2N23	11,945.59	0.55	0.76	0.88	244.62
N2N1	9,393.25	0.56	0.52	0.51	2.11
Narrabri	7,500.96	0.15	2.73	0.03	0.02
Total	**64,457.04**	**14.32**	**20.92**	**20.47**	**367.17**

Classified roads managed by TfNSW

The length (metres) of classified roads managed by TfNSW within each flood model where afflux exceeds the QDL (afflux greater than 50 millimetres on areas flooded under existing conditions, otherwise no increase) (see Section 3.2.2)) is shown in Table 7.10.

The total ranges from around 240 metres in the 20% AEP event to over two kilometres in the 1% AEP event. The major impact is on the Newell Highway at Bohena Creek. Reference should also be made to the discussion on flood modelling for Bohena Creek in Section 7.6.

Table 7.10 Length (metres) of classified roads managed by TfNSW where afflux exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	23	23	28	39
N2N14	27	33	56	71
N2N13	-	-	-	-
N2N11-12	21	65	67	67
N2N10	-	-	-	-
N2N9	-	-	-	-
N2N8	-	-	-	-
N2N7	-	13	24	19
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	171	739	1,332	1,842
Narrabri	-	87	78	74
Total	241	960	1,586	2,113

Highways and sealed roads (>80 kilometres per hour)

The length (metres) of highways and sealed roads greater than 80 kilometres per hour within each flood model where afflux exceeds the QDL (afflux greater than 50 millimetres (see Section 3.2.2)) is shown in Table 7.11.

The total ranges from under two kilometres in the 20% AEP event to around six kilometres in the 1% AEP event. The majority of highways and sealed roads impacted are located at Narromine (NFM), south of Kickabil (model N2N13), and north of Curban (model N2N10). Relatively minor lengths of highways and major roads are impacted elsewhere.

In major flood events, it is probable that many sealed roads would be closed due to flooding at a number of locations, remote from the proposal. The direct impacts from Inland Rail on the overall trafficability of these roads would therefore be relatively minor due to closures elsewhere.

Table 7.11 Length (metres) of highways and sealed roads (>80 km/hr) (excluding classified roads managed by TfNSW) where afflux exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	447	742	1,009	2,212
N2N14	36	36	36	36
N2N13	638	682	737	745
N2N11-12	-	107	422	560
N2N10	790	1,334	1,596	2,361
N2N9	22	51	85	85
N2N8	-	-	-	-
N2N7	-	-	-	-
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	5	1	5	-
Narrabri	-	10	1	-
Total	**1,937**	**2,963**	**3,890**	**5,999**

Unsealed public roads and sealed roads (<80 kilometres per hour)

The length (metres) of sealed roads (less than 80 kilometres per hour) and unsealed public roads within each flood model where afflux exceeds the QDL (afflux greater than 100 millimetres (see Section 3.2.2)) is shown in Table 7.12.

The total length impacted ranges from about 4.4 kilometres in the 20% AEP event to about 26.2 kilometres in the 1% AEP event. Afflux impacts to minor and unsealed roads occur across the full length of the proposal.

Compared to the lengths of named roads (which includes both sealed and unsealed roads within the extents of the TUFLOW flood models) inundated under existing conditions (170 kilometres in the 20% AEP event, 287 kilometres in the 5% AEP event, 355 kilometres in the 2% AEP event and 443 kilometres in the 1% AEP event (Table 5.12)), the overall trafficability of these roads would be relatively minor.

Table 7.12 Length (metres) of unsealed roads where afflux exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	101	210	281	777
N2N14	208	525	655	719
N2N13	581	853	1,212	1,686
N2N11-12	456	784	984	1,068
N2N10	110	251	357	449

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
N2N9	178	250	389	531
N2N8	364	501	602	623
N2N7	441	741	1,032	1,675
N2N6	351	450	448	2,561
N2N5	485	553	623	4,127
N2N4	20	13	15	1,333
N2N23	668	655	825	9,470
N2N1	379	536	410	1,094
Narrabri	21	79	22	33
Total	**4361**	**6401**	**7855**	**26,147**

7.3.2 Scour/Erosion Potential (Velocity)

Sealed surfaces

Sealed land surfaces

The area (hectares) of sealed land surfaces within each flood model where the change in velocity exceeds the QDL is shown in Table 7.13. The relevant QDL (see Section 3.2.2) are:

- For existing velocities greater than one metre per second: up to a 20% increase in maximum post-development velocity
- For existing velocities less than one metre per second: up to a 1.2 metres per second maximum post-development velocity.

The total area ranges from about 0.9 hectare in the 20% AEP event to about 3.5 hectares in the 1% AEP event. The majority of exceedances occur within the N2N13 model. There are no velocity impacts to sealed land surfaces more than the QDLs from models N2N10 to N2N8 and at Narrabri.

Table 7.13 Area (hectares) of sealed land surfaces where change in velocity exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	0.00	0.04	0.03	0.11
N2N14	0.02	0.01	0.02	0.03
N2N13	0.18	0.36	0.90	1.35
N2N11-12	0.01	0.01	0.01	0.01
N2N10	0.00	0.00	0.00	0.00
N2N9	0.00	0.00	0.00	0.00
N2N8	0.00	0.00	0.00	0.00
N2N7	0.01	0.03	0.05	0.13
N2N6	0.13	0.16	0.20	0.18
N2N5	0.13	0.16	0.16	0.38
N2N4	0.22	0.27	0.29	0.49
N2N23	0.17	0.15	0.16	0.47
N2N1	0.05	0.15	0.31	0.38

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
Narrabri	0.00	0.00	0.00	0.00
Total	**0.92**	**1.35**	**2.13**	**3.51**

Sealed roads

The length of sealed roads within each flood model where the velocity exceeds the QDL are presented in metres in Table 7.14. The QDL criteria used are:

- For existing velocities greater than 1 metre per second: up to a 20 per cent increase in maximum post-development velocity
- For existing velocities less than one metre per second (or velocities associated with new flowpaths): up to a 1.2 metres per second maximum post-development velocity.

The total exceedance length ranges from 10 metres in the 20% AEP event to 277 metres in the 1% AEP event. There are no velocity impacts to sealed roads more than the QDL at Narrabri. The majority of sealed road velocity impacts in the 5% AEP to 1% AEP events occur at Bohena Creek (N2N1). Reference should also be made to the discussion on flood modelling for Bohena Creek in section 7.6.

Table 7.14 Length (metres) of sealed roads where change in velocity exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	0.00	7.43	12.48	35.40
N2N14	0.97	5.43	12.70	3.04
N2N13	5.06	5.06	22.07	45.32
N2N11-12	0.00	0.00	0.00	0.00
N2N10	0.00	18.44	22.04	50.15
N2N9	0.00	7.44	17.68	28.51
N2N8	0.00	0.00	0.00	0.00
N2N7	0.00	0.00	0.00	0.00
N2N6	0.00	0.00	0.00	0.00
N2N5	0.00	0.00	0.00	0.00
N2N4	0.00	0.00	0.00	0.00
N2N23	0.00	0.00	0.00	0.00
N2N1	4.11	39.52	80.62	114.87
Narrabri	0.00	0.00	0.00	0.00
Total	**10.14**	**83.32**	**167.60**	**277.30**

Other areas: unsealed surfaces: watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas

Unsealed land surfaces

At the reference design stage an ETV of 0.5m/s has been adopted throughout the alignment to assess the environment impacts in accordance with the QDLs.

Drainage control areas have been included in the proposal to provide additional areas to mitigate scour/erosion (velocity) QDL exceedances beyond the rail corridor during the detailed design. These areas extend 50 metres downstream and 15 metres upstream of the rail corridor. Approximately 200 drainage control areas are included in the proposal, as shown in the Map Book accompanying the Preferred Infrastructure Report / Amendment Report and flood mapping figures appended to this report.

The area (hectares) of unsealed land surfaces within each flood model where the change in velocity beyond the proposal footprint (including the drainage control areas) exceeds the QDL is shown in Table 7.15. The relevant QDLs (see Section 3.2.2) are:

- The ETV is to be set to 0.5 m/s in the absence of site assessments
- Where the existing velocity exceeds the ETV, the design velocity is limited to a 0.025m/s increase
- Where the existing velocity is less than the ETV, the design velocity is limited to the lesser of:
  - ETV
  - 20 per cent increase in existing velocity or 0.5 m/s, whichever is greater.

Total ranges from about 231 hectares in the 20% AEP event to about 935 hectares in the 1% AEP event (with blockage). The majority of impacts occur within the NFM, N2N8 and N2N1 models. Flood models N2N6 to N2N23 are predominantly forested areas that have a higher ETV of 1.0m/s and are reported within the sealed land surfaces in Table 7.13.

Table 7.15 Area (hectares) of unsealed land surfaces where change in velocity exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	17.43	59.39	117.51	186.50
N2N14	3.41	8.68	13.25	18.87
N2N13	31.60	38.61	49.90	60.57
N2N11-12	22.75	28.94	84.48	123.81
N2N10	13.02	23.04	35.63	51.90
N2N9	30.70	39.67	57.30	74.07
N2N8	52.23	80.58	99.11	91.75
N2N7	30.07	39.45	49.15	67.43
N2N6	2.48	2.64	3.38	2.95
N2N5	0.00	0.00	0.00	0.00
N2N4	0.00	0.00	0.00	0.00
N2N23	0.26	0.11	0.23	5.00
N2N1	23.48	244.24	194.20	245.14
Narrabri	3.42	5.26	6.63	7.25
Total	**230.85**	**570.61**	**710.75**	**935.24**

Unsealed roads

The length (metres) of unsealed roads within each flood model where the change in velocity exceeds the QDL is shown in Table 7.16. The relevant QDL (see Section 3.2.2) are:

- The ETV is to be set to 0.5 m/s in the absence of site assessments
- Where the existing velocity exceeds the ETV, the design velocity is limited to a 0.025m/s increase
- Where the existing velocity is less than the ETV, the design velocity is limited to the lesser of:
  - ETV
  - 20 per cent increase in existing velocity.

The total exceedance length ranges from about 6.5 kilometres in the 20% AEP event to about 16.4 kilometres in the 1% AEP event. QDL exceedances for scour/erosion (velocity) are reported within all TUFLOW models. The increase in length of unsealed road reported in N2N23, within the Pilliga forest, is a result of the application of 100 per cent blockage factor to some culverts in the reference design stage. This would be reviewed in detailed design and the blockage risk would be mitigated. This would then reduce the overall exceedance by approximately two kilometres.

Table 7.16 Length (metres) of unsealed roads where change in velocity exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	570.97	1,212.97	1,310.28	1,985.79
N2N14	270.63	213.50	334.51	406.23
N2N13	1,218.16	1,375.15	1,414.38	1,566.98
N2N11-12	476.81	378.33	737.46	707.80
N2N10	899.72	457.94	615.98	856.70
N2N9	199.86	645.96	631.29	642.75
N2N8	363.98	979.44	1,190.76	1,182.78
N2N7	440.55	764.83	1,011.82	1,179.57
N2N6	350.58	337.32	394.98	417.21
N2N5	484.57	173.76	281.25	1,231.25
N2N4	19.74	15.41	1.57	241.69
N2N23	667.89	833.25	953.39	4,261.43
N2N1	554.59	967.29	1,508.63	1,506.19
Narrabri	20.94	72.55	84.58	183.33
Total	**6,539.00**	**8,427.70**	**10,470.88**	**16,369.71**

Site assessed ETVs and future design development

The above results, together with the scour/erosion (velocity) mapping in Appendix I, indicate that there are velocity QDL exceedances beyond the rail corridor boundary (including the drainage control areas). ARTC will undertake further investigations, design refinements and modelling to reduce these exceedances, as far as practicable, during detailed design. In order to demonstrate how this could be achieved additional work has been undertaken as outlined below.

A geotechnical erosion specialist and a geomorphologist carried out inspections of selected bridge and culvert locations between Narromine and Narrabri to validate the ETV against local conditions. The site assessed ETVs (AETVs) obtained from the geotechnical and geomorphological studies were then used to assess compliance with the scour/erosion (velocity) QDLs.

Results of field investigations are detailed in Technical Note 17 – Erosion Potential and Fluvial Geomorphology Report in Appendix O. The findings were that soil types within a river channel vary from highly mobile river bed sands to clay rich banks and flood plains. The erosion potential for these materials is dependent on a number of factors including the velocity of water in the creeks during flood flows, local conditions such as changes in the creek bed profile, meander bends etc and vegetation cover. Site assessed ETVs for bare soils were generally above 1.0 m/s (excluding mobile sand beds in creeks) and increased to around 2.0 m/s in areas with cohesive clays. These site assessed ETV values for the channel banks and floodplains are significantly higher than the conservative default ETV of 0.5 m/s used as the basis for the QDL analysis presented above. It was recognised that sands in the creek beds could be mobilised with flow velocities of around 0.5 m/s. This occurs naturally under existing conditions and is desirable to reduce the risk of sediment build up in the water course.

In order to demonstrate how designs could be refined and the AETVs applied at the detailed design stage, TUFLOW flood models N2N9 and N2N13 were updated from 10 m grid squares to 2.5 m grid squares to provide a higher resolution for evaluating the changes in velocity between existing and design conditions. TUFLOW models N2N9 and N2N13 were selected as they contain examples of culverts that are representative of conditions across the overall project.

The TUFLOW fine grid modelling report (Technical Note 16) is contained in Appendix P. A total of 24 culvert locations were selected for more detailed analysis. These culverts were selected to be representative of locations that were more challenging in terms of achieving velocity QDL compliance. Results indicate that the design velocities at 23 culvert locations comply with the scour/erosion (velocity) QDL criteria adopting site specific assessed ETVs.

These results are considered to be representative of the broader rail alignment between Narromine and Narrabri and it is expected that as the detailed design is developed, the number of scour / erosion (velocity) QDL exceedances will reduce significantly. Assessment refinement and management measures, including mitigation opportunities have been identified for consideration during detailed design to address residual velocity QDL exceedances.

Where scour / erosion (velocity) QDL exceedances remain after the detailed design has been developed, these will be managed in accordance with the conditions of approval.

7.3.3 Flood hazard

Urban, commercial, industrial, highways and sealed roadways

Habitable buildings (also referred to as habitable floors)

There are no habitable buildings within the study area where the change in flood hazard exceeds the QDL (a 10 per cent increase in depth x velocity (dv) product (see Section 3.2.2)).

Non-habitable buildings (also referred to as non-habitable floors)

There are four buildings that are classified as non habitable within the study area where the change in flood hazard exceeds the QDL (a 10 per cent increase in dv product (see Section 3.2.2)).

Urban and infrastructure land

The area of urban and infrastructure land within each flood model where the change in flood hazard exceeds the QDL (a 10 per cent increase in dv product (see Section 3.2.2)) is shown in Table 7.17.

The total ranges from 0.75 hectares in the 20% AEP event to 4.17 hectares in the 1% AEP event (with blockage). The majority of urban and infrastructure land affected is located at Narromine and at Narrabri.

Table 7.17 Area (hectares) of land where the change in flood hazard exceeds the QDL – urban and infrastructure land – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	0.64	0.69	2.16	1.63
N2N14	0.06	0.02	0.10	0.08
N2N13	0.00	0.01	0.04	-
N2N11-12	0.01	0.02	0.03	0.02
N2N10	0.01	-	-	-
N2N9	0.01	-	-	-
N2N8	-	-	-	-
N2N7	-	-	-	-
N2N6	-	-	0.01	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	0.03	0.05	0.02	0.00
Narrabri	0.00	0.07	1.74	2.43
Total	**0.75**	**0.86**	**4.10**	**4.17**

Sealed roads (excluding classified roads managed by TfNSW)

The length (metres) of sealed roads (excluding TfNSW classified roads) within each flood model where the change in flood hazard exceeds the QDL (a 10 per cent increase in dv product (see Section 3.2.2)) is shown in Table 7.18.

The total length of highways and sealed roads impacted ranges from 874 metres in the 20% AEP event to about four kilometres in the 1% AEP (with blockage) event. The majority of impacts occur from Narromine to Curban (NFM to N2N10 models).

Table 7.18 Length (metres) of sealed roads (excluding TfNSW classified roads) where change in flood hazard exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	144	392	676	1,933
N2N14	20	20	676	23
N2N13	139	156	20	191
N2N11-12	6	72	162	71
N2N10	555	802	157	1,651
N2N9	9	28	979	74
N2N8	-	-	60	-
N2N7	-	-	-	-
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	-	-	198	15
Narrabri	-	-	-	-
Total	**874**	**1,469**	**2,928**	**3,958**

Changes in the hazard QDL category for land and roads are presented in Figures contained within Appendix I.

Classified roads managed by TfNSW

The length (metres) of classified roads managed by TfNSW within each flood model where the change in flood hazard exceeds the QDL (a 10 per cent increase in dv product (see Section 3.2.2)) is shown in Table 7.19.

The total exceedance length for classified roads managed by TfNSW ranges from 133 metres in the 20% AEP event to about 1.4 kilometres in the 1% AEP (with blockage) event. The majority of impacts occur at Bohena Creek (N2N1 model). Reference should also be made to the discussion on flood modelling for Bohena Creek in section 7.6.

Table 7.19 Length (metres) of classified roads managed by TfNSW where change in flood hazard exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	5	-	5	359
N2N14	14	59	5	65
N2N13	-	-	77	-
N2N11-12	1	1	-	1
N2N10	-	-	1	-
N2N9	-	-	-	-
N2N8	-	-	-	-

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
N2N7	-	-	-	-
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	113	267	1,033	970
Narrabri	-	60	45	25
Total	**133**	**386**	**1,167**	**1,420**

The potential increase in risk to vehicles using sealed roads only applies if the roads remain open in flood events. Many roads in the areas between Narromine and Narrabri are at risk of flooding under existing conditions and can be closed in floods greater than the 20% AEP event due to flooding not related to Inland Rail. The change in hazard does however provide an indication of locations where risks to road users could increase as flood waters rise and fall when roads are open to traffic. These locations will be further reviewed during the detailed design and discussed with the relevant road authorities to identify the critical flood prone locations on existing infrastructure that could trigger road closures and whether the proposal could impact on these.

Elsewhere

Other land

The area of other land within each flood model where the change in flood hazard exceeds the QDL (a 20 per cent increase in dv product (see Section 3.2.2)) is shown in Table 7.20.

The total ranges from about zero hectares in the 20% AEP event to about 714 hectares in the 1% AEP (with blockage) event. Flood hazard impacts to other land occurs across the full length of the proposal with the majority of impacts at Narromine (NFM model) and within the Pilliga Forest in N2N23.

Table 7.20 Area (hectares) of land where the change in flood hazard exceeds the QDL – elsewhere – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	-	103.33	120.52	213.54
N2N14	-	4.47	9.71	12.25
N2N13	-	9.20	15.37	20.31
N2N11-12	-	7.91	22.43	27.67
N2N10	-	25.94	36.47	45.05
N2N9	-	18.07	29.43	37.93
N2N8	-	14.44	20.78	22.21
N2N7	-	6.49	10.07	28.65
N2N6	-	1.92	2.47	7.82
N2N5	-	1.38	1.64	29.37
N2N4	-	1.77	1.92	14.61
N2N23	-	5.04	5.45	232.25

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
N2N1	-	67.60	16.48	21.17
Narrabri	-	1.06	3.52	1.10
Total	**-**	**268.63**	**296.26**	**713.94**

Unsealed roads

The length (metres) of unsealed roads within each flood model where the change in flood hazard exceeds the QDL (a 20 per cent increase in dv product (see Section 3.2.2)) is shown in Table 7.21.

The total exceedance length for unsealed roads ranges from 522 metres in the 20% AEP event to about 18 kilometres in the 1% AEP (with blockage) event. Flood hazard impacts to unsealed roads occur across the full length of the proposal in the 2% AEP and 1% AEP events, with the majority of impacts occurring within the N2N23 model in the Pilliga Forest.

Table 7.21 Length (metres) of unsealed roads where change in flood hazard exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	-	571	637	1,501
N2N14	46	218	637	458
N2N13	63	745	365	1,326
N2N11-12	29	467	1,004	773
N2N10	10	314	808	591
N2N9	81	305	452	399
N2N8	87	260	320	394
N2N7	97	331	359	821
N2N6	96	178	371	343
N2N5	39	86	214	2,803
N2N4	-	-	111	245
N2N23	2	457	573	7,551
N2N1	-	256	396	434
Narrabri	-	-	292	335
Total	**552**	**4,188**	**6,538**	**17,971**

7.3.4 Flood Duration

Flood duration calculations

Flood duration calculations have been undertaken within the TUFLOW hydraulic model to estimate duration of inundation above 0.5 metres depth of flooding above ground level at each 10 metre TUFLOW grid cell.

The 0.5 metre flood depth limit only applies to flood duration to account for variations in ground topography resulting in trapped low points and flood fringe anomalies in modelling results . All other QDL comparisons are based on maximum depth and maximum velocity values.

Habitable buildings (habitable floors)

The number of habitable buildings within each flood model where the change in flood duration exceeds the QDL is shown in Table 7.22. The relevant QDL (see Section 3.2.2) are:

- Where existing above floor flooding is:
  - Less than one hour in flood duration, the post-development flood duration shall not exceed one hour
  - Greater than one hour in duration, up to five per cent increased inundation duration
- Where existing below floor flooding is:
  - Less than one hour in flood duration, the post-development flood duration shall not exceed one hour
  - Greater than one hour in duration, up to 10 per cent increased inundation duration

Analysis of the flood modelling results indicates that 11 habitable buildings with above floor flooding and one habitable building with below floor flooding exceed the duration QDLs. There is also one habitable building with an existing 1% AEP flood duration of less than an hour that increases to over an hour with the proposal, but the increase is less than five per cent. This also does not comply with the QDLs.

Impacts on the 11 buildings with above floor flooding and a duration increase of more than five per cent are shown in Figure 7.7.

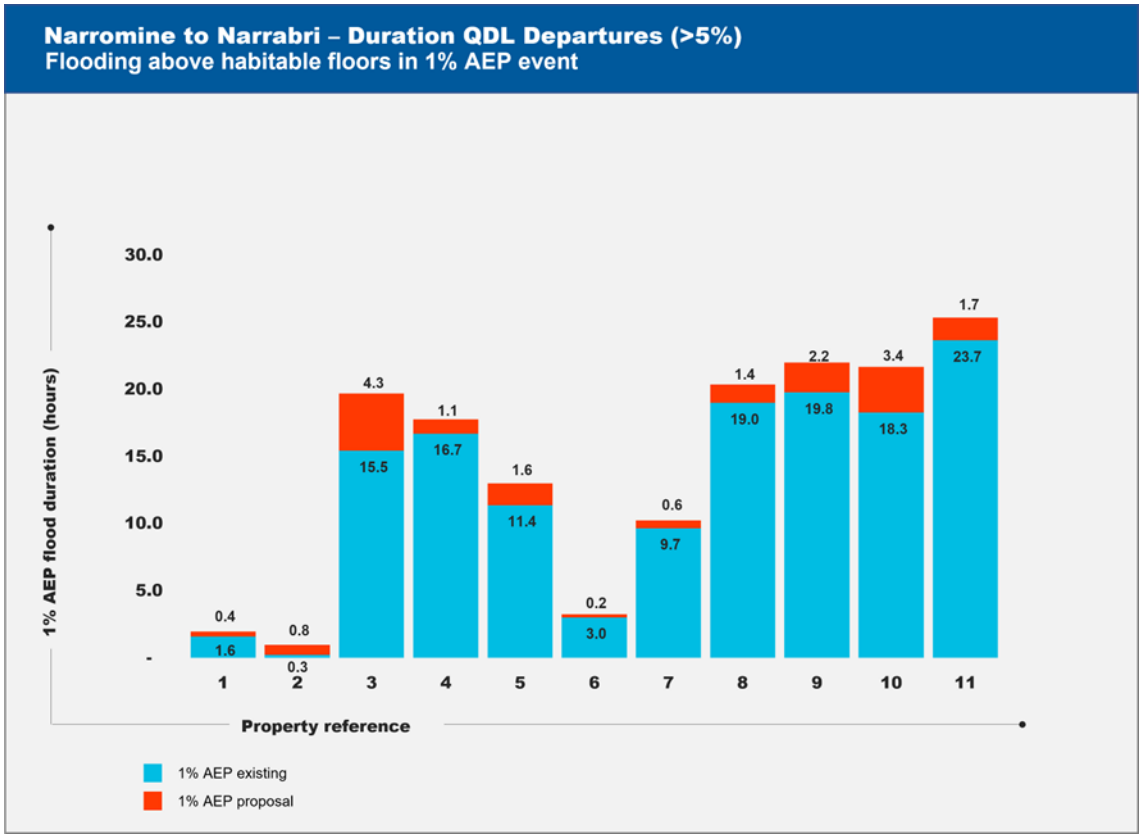


Figure 7.7 Duration QDL departures for properties with above floor flooding

Table 7.22 Number of habitable buildings where change in flood duration exceeds the QDL – operational phase

TUFLOW model	20% AEP				5% AEP				2% AEP				1% AEP (with blockage)			
	>5%[1]	>1 hr[2]	>10%[3]	>1 hr[4]	>5%[1]	>1 hr[2]	>10%[3]	>1 hr[4]	>5%[1]	>1 hr[2]	>10%[3]	>1 hr[4]	>5%[1]	>1 hr[2]	>10%[3]	>1 hr[4]
NFM	-	-	-	-	-	-	-	-	-	-	-	-	4	1	-	-
N2N14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N11-12	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
N2N10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2N1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Narrabri	-	-	-	-	4	-	-	-	8	1	1	-	6	1	1	-
Total	**0**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**10**	**1**	**1**	**0**	**10**	**2**	**1**	**0**

Notes:
1 Existing flooding above floor and existing duration >1 hour – allowable duration change is up to 5%
2 Existing flooding above floor and existing duration <1 hour – allowable duration change is up to 1 hour
3 Existing flooding below floor and existing duration >1 hour – allowable duration change is up to 10%
4 Existing flooding below floor and existing duration <1 hour – allowable duration change is up to 1 hour

Classified roads managed by TfNSW

The length (metres) of classified roads managed by TfNSW within each flood model where the change in flood duration exceeds the QDL is shown in Table 7.23. The relevant QDL (see Section 3.2.2) are:

- No increase in duration of flood inundation to sections of road not already inundated.
- Otherwise 10 per cent increase in inundation duration.

The QDLs note that any flooding duration on newly inundated sections of road must be negotiated with the roads authority.

The total length of impacted classified roads managed by TfNSW ranges from 45 metres in the 20% AEP event to about 500 metres in the 1% AEP (with blockage) event. The majority of impacts occur at Bohena Creek (N2N1 model).

Table 7.23 Length (metres) of road where change in flood duration exceeds the QDL – classified roads managed by TfNSW – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	-	-	-	105
N2N14	-	20	20	25
N2N13	-	-	-	-
N2N11-12	6	9	9	9
N2N10	-	-	-	-
N2N9	-	-	-	-
N2N8	-	-	-	-
N2N7	-	-	-	-
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	39	377	304	348
Narrabri	-	36	110	13
Total	**45**	**442**	**444**	**501**

Highways and sealed roads (>80 kilometres per hour)

The length (metres) of highways and sealed roads (excluding classified roads managed by TfNSW) greater than 80 kilometres per hour within each flood model where the change in flood duration exceeds the QDL is shown in Table 7.24. The relevant QDL (see Section 3.2.2) are:

- 10 per cent increase in duration of inundation.

The total length of highways and sealed roads impacted ranges from 481 metres in the 20% AEP event to about two kilometres in the 1% AEP (with blockage) event. The majority of impacts occur from Narromine to Curban (NFM to N2N10 models).

Table 7.24 Length (metres) of road where change in flood duration exceeds the QDL –sealed roads (excluding TfNSW roads) – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	63	157	197	825
N2N14	5	7	5	10
N2N13	305	512	553	587
N2N11-12	5	29	464	70
N2N10	93	241	297	453
N2N9	1	11	13	8
N2N8	-	-	-	-
N2N7	-	-	-	-
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	10	18	11	17
Narrabri	-	-	-	-
Total	**481**	**974**	**1,539**	**1,969**

Elsewhere

Other land

The area (hectares) of other land within each flood model where the change in flood duration exceeds the QDL is shown in Table 7.25. The relevant QDL (see Section 3.2.2) are:

- Where existing inundation is less than one hour in flood duration, the post-development flood duration shall not exceed one hour.
- Where existing inundation is greater than one hour in flood duration, up to 10 per cent increase in duration of inundation.
- No duration limits apply to newly flooded land no greater than 1,000 m^2 in area. .

The total area of other land impacted by a change in duration more than the QDL ranges from about 124 hectares in the 20% AEP event to about 1036 hectares in the 1% AEP (with blockage) event. The change in duration impacts to other land occurs across the full length of the proposal.

Table 7.25 Area (hectares) of other land where the change in flood duration exceeds the QDL – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	31.37	65.70	71.65	224.12
N2N14	0.81	2.78	3.62	4.58
N2N13	13.57	19.64	23.23	27.22
N2N11-12	5.19	15.23	90.93	41.25
N2N10	5.48	9.89	15.91	29.69
N2N9	9.37	15.29	23.98	29.74
N2N8	4.10	5.98	7.79	12.69
N2N7	5.26	8.84	12.35	25.46
N2N6	3.49	5.13	5.86	51.64
N2N5	1.95	2.44	2.80	34.94
N2N4	2.14	2.31	2.30	17.77
N2N23	19.20	23.16	19.70	390.87
N2N1	20.26	101.59	78.09	142.85
Narrabri	1.93	12.84	7.19	3.55
Total	**124.12**	**290.82**	**365.40**	**1,036.37**

Sealed roads (<80 kilometres per hour) and unsealed public roads

The length (metres) of sealed roads less than 80 kilometres per hour and unsealed public roads within each flood model where the change in flood duration exceeds the QDL is shown in Table 7.26. The relevant QDL (see Section 3.2.2) are:

- Where existing on-roadway inundation is less than one hour in flood duration, the post-development flood duration shall not exceed one hour, or as otherwise agreed by the relevant road authority.
- Where existing on-roadway inundation is greater than one hour in duration, up to 10 per cent increase in duration of inundation, or as otherwise agreed by the relevant road authority.

The total length of sealed roads (less than 80 kilometres per hour) and unsealed public roads impacted ranges from about 1.6 kilometres in the 20% AEP event to 19.3 kilometres in the 1% AEP (with blockage) event. The change in duration impacts occurs across the full length of the proposal.

Table 7.26 Length (metres) of road where change in flood duration exceeds the QDL – sealed roads (<80 km/hr) and unsealed public roads – operational phase

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP (with blockage)
NFM	207	645	786	2,577
N2N14	17	53	76	74
N2N13	254	524	764	926
N2N11-12	156	495	1,110	796
N2N10	25	60	105	156
N2N9	44	107	108	176
N2N8	36	45	87	78
N2N7	82	215	282	400
N2N6	126	114	120	1,974
N2N5	63	131	156	2,424
N2N4	5	30	50	860
N2N23	263	320	603	8,175
N2N1	314	256	408	454
Narrabri	34	418	236	259
Total	**1,627**	**3,413**	**4,891**	**19,329**

7.4 Rarer flood events greater than 1% AEP

This section considers the potential impacts from the proposal on rarer floods, greater than the 1% AEP event, especially in relation to:

- General impacts on buildings, other land and infrastructure in rarer events.
- Potential impacts on Narrabri from the proposed rail viaduct, located downstream of the town.
- Potential impacts on Narromine in rare flood events that could result in overtopping of the existing Narromine to Dubbo rail line at Webbs Siding and increased flows in the Backwater Cowal.
- Potential overtopping of the Inland Rail embankment resulting in a risk to downstream buildings or infrastructure.

The impacts of the proposal have been assessed for rare flood events (i.e. those greater than the 1% AEP event). The following sections provide an analysis of the potential impacts for a range of flood events up to the PMF.

7.4.1 Impacts to buildings

General

Rare flood events are considered to be floods greater than the 1% AEP event.

The impacts during rare flood events have been considered in terms of the differences in the number of habitable buildings flooded above floor level under existing conditions compared to with the proposal. This comparison has focussed on the towns of Narromine and Narrabri that contain the highest population densities.

The impacts of afflux during rare floods have also been considered, particularly for the town of Narrabri.

Narrabri – Rare flood events

For Narrabri, Figure 7.8 and Figure E-9 shows the number of buildings at risk of flooding in the 0.2% AEP (1 in 500 year) and the probable maximum flood (PMF). The horizontal axis shows the depth of above floor flooding and the vertical axis shows the number of habitable buildings that are at risk of flooding above this depth.

Under existing conditions there would be approximately 2470 buildings at risk of flooding above floor level in the 0.2% AEP event and around 3036 buildings at risk in the PMF event. The TUFLOW flood modelling results indicate that these numbers are not expected to change significantly with the proposal.

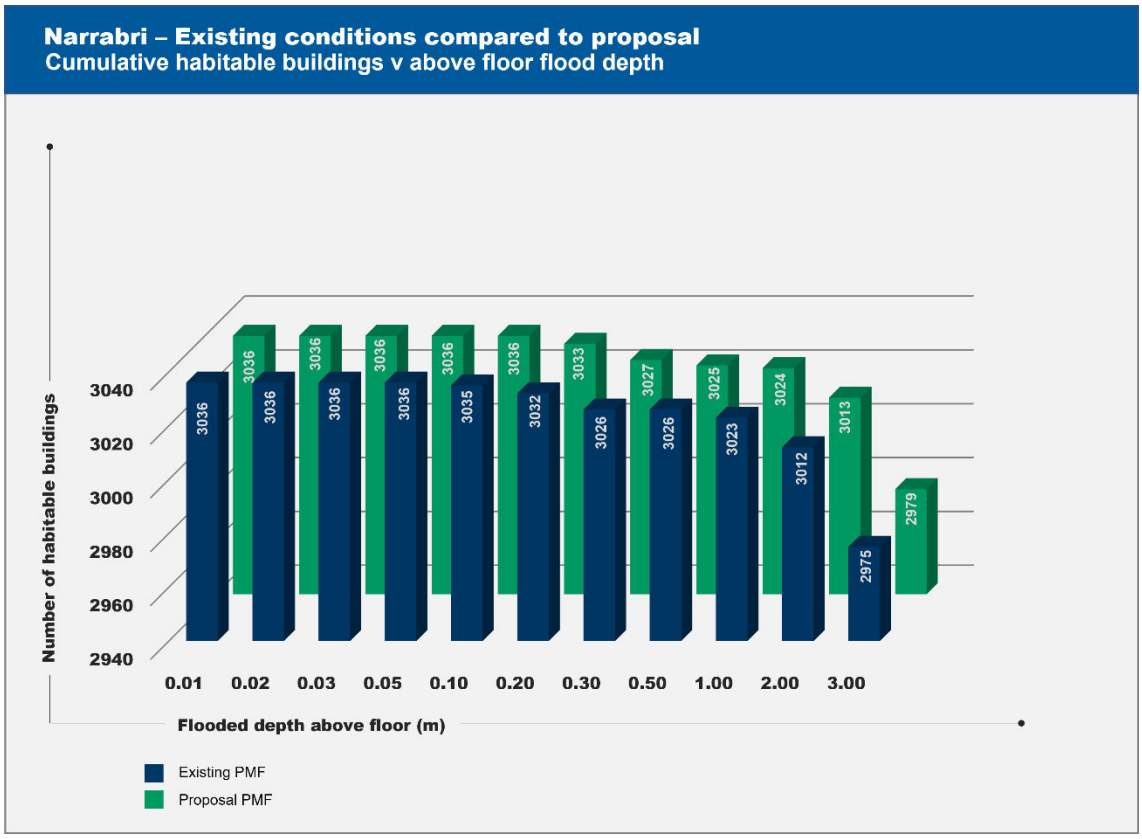


Figure 7.8 Narrabri – Cumulative number of habitable buildings flooded, by flood depth in extreme floods

Narromine – Rare flood events

At Narromine, the proposed railway alignment is upstream of the town and is located along the southern and eastern sides of the Backwater Cowal floodplain. An analysis of impacts on above floor flooding for residential and commercial buildings in the 0.2% AEP event and PMF event indicated no significant changes to flood risk for buildings would be expected at Narromine in extreme events. There are currently around 1632 buildings at risk of above floor flooding in the 0.2% AEP event and 1949 buildings in the PMF event. This situation would not change after construction of the proposal.

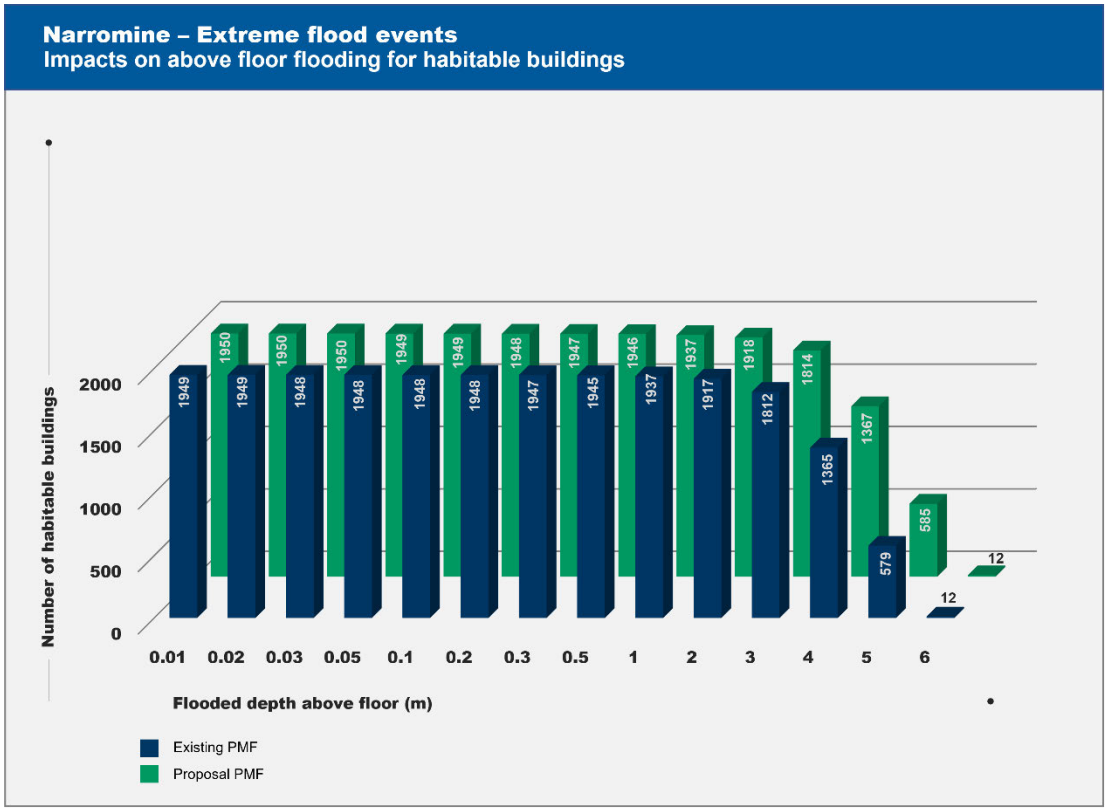


Figure 7.9 Narromine – Cumulative number of habitable buildings flooded, by flood depth in extreme floods

Afflux – above floor flooding, habitable buildings

The number of habitable buildings with above floor flooding within each TUFLOW model domain which are impacted by more than 10 millimetres increase in depth during the operational phase are shown in Table 7.27.

Compared to the number of habitable buildings subject to above floor flooding under existing conditions (3910 in the 1% AEP with climate change event, 3466 in the 0.5% AEP event, 4202 in the 0.2% AEP event and 5267 in the PMF event (Table 5.3)), the operational impacts are relatively minor.

Table 7.27 Number of habitable buildings subject to above floor flooding and impacted by more than 10 millimetres afflux (number with surveyed floor levels shown in brackets) in rare events – operational phase

TUFLOW model	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	5	3	422	43
N2N14	-	-	-	-
N2N13	-	-	-	4
N2N11-12	2	2	3	27
N2N10	-	-	-	8
N2N9	-	-	-	2
N2N8	-	-	-	2
N2N7	-	-	-	6
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	7 (1)	4 (1)	60 (5)	76 (5)
Narrabri	33 (26)	20 (18)	145 (91)	2979 (2737)
Total	**47 (27)**	**29 (19)**	**630 (96)**	**3147 (2742)**
Total flooded above floor under existing conditions	**3909**	**3464**	**4202**	**5268**

Afflux – Above floor flooding, non-habitable buildings

The number of non-habitable buildings with above floor flooding within each TUFLOW model domain with more than 20 millimetres increase in depth during the operational phase are shown in Table 7.28.

Compared to the number of non-habitable buildings subject to above floor flooding under existing conditions (4665 in the 1% AEP with climate change event, 4354 in the 0.5% AEP event, 5034 in the 0.2% AEP event and7177 in the PMF event (Table 5.4)), the operational impacts are relatively minor.

Table 7.28 Number of non-habitable buildings subject to above floor flooding and impacted by more than 20 millimetres afflux (number with surveyed floor levels shown in brackets) in rare events – operational phase

TUFLOW model	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	14	2	59	119
N2N14	-	-	-	3
N2N13	-	-	-	13
N2N11-12	8	5	9	122
N2N10	-	-	-	56

TUFLOW model	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
N2N9	-	-	-	21
N2N8	-	-	-	2
N2N7	-	-	-	46
N2N6	-	-	-	1
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	16	12	130 (19)	316 (19)
Narrabri	13 (3)	6 (2)	44 (3)	2709 (19)
Total	**51 (3)**	**25 (2)**	**242 (22)**	**3408 (38)**
Total flooded above floor under existing conditions	**4665**	**4354**	**5034**	**7177**

Hazard – Habitable buildings

The number of habitable buildings with above floor flooding subject to high flood hazard category (H3, H4, H5 and H6) within each TUFLOW model domain are shown in Table 7.29.

Compared to the number of habitable buildings and their surrounds subject to high flood hazard category under existing conditions (3564 in the one per cent with climate change AEP event, 3030 in the 0.5% AEP event, 3958 in the 0.2% AEP event and 5232 in the PMF event (Table 5.5)), the operational impacts are relatively minor.

Table 7.29 Number of impacted habitable buildings (subject to above floor flooding and afflux greater than 10 millimetres) located on lands subject to high flood hazard in rare events – operational phase

TUFLOW model	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	5	2	309	43
N2N14	-	-	-	-
N2N13	-	-	-	4
N2N11-12	2	2	3	24
N2N10	-	-	-	8
N2N9	-	-	-	2
N2N8	-	-	-	-
N2N7	-	-	-	5
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	6	3	55	76
Narrabri	22	17	89	2973
Total	**35**	**24**	**456**	**3135**

Hazard – Non-habitable buildings

The number of above floor impacted non-habitable buildings and their surrounds subject to high flood hazard category (H3, H4, H5 and H6) within each TUFLOW model domain are shown in Table 7.30.

Compared to the number of non-habitable buildings and their surrounds with high hazard flood rating under existing conditions (4221 in the 1% AEP with climate change event, 3885 in the 0.5% AEP event, 4681 in the 0.2% AEP event and 6975 in the PMF event (Table 5.6)), the operational impacts are relatively minor.

Table 7.30 Number of impacted non-habitable buildings (subject to above floor flooding and afflux greater than 20 millimetres) located on lands subject to high flood hazard in rare events – operational phase

TUFLOW model	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	5	1	43	117
N2N14	-	-	-	2
N2N13	-	-	-	11
N2N11-12	7	4	8	119
N2N10	-	-	-	52
N2N9	-	-	-	14
N2N8	-	-	-	2
N2N7	-	-	-	46
N2N6	-	-	-	1
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	12	12	121	313
Narrabri	10	5	36	2680
Total	**34**	**22**	**208**	**3357**

Duration – Habitable buildings

The average duration of flooding above 0.5 metres depth of flooding near the above impacted habitable buildings is presented in Table 7.31 for each TUFLOW model domain and each flood event. Similar to existing conditions the longest durations are observed in the NFM, N2N11-12, N2N1 and Narrabri model domains. For most habitable buildings inundated in existing conditions the average durations in the operational phase are similar.

Table 7.31 Average duration (hours) of inundation at habitable buildings (subject to above floor flooding and afflux greater than 10 millimetres) and surrounds above 0.5 metres depth of flooding in rare events – operational phase

TUFLOW model	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	32	35	37	63
N2N14	-	-	-	-
N2N13	-	-	-	7
N2N11-12	34	32	23	15
N2N10	-	-	-	2
N2N9	-	-	-	4
N2N8	-	-	-	-
N2N7	-	-	-	4
N2N6	-	-	-	-
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	12	11	15	11
Narrabri	41	38	40	57

Duration – Non-habitable buildings

The average duration of flooding above 0.5 metres depth of flooding near the above impacted non-habitable buildings is presented in Table 7.32 for each TUFLOW model domain and each flood event. Similar to existing conditions the longest durations are observed in the NFM, N2N11-12, N2N1 and Narrabri model domains. For most non-habitable buildings inundated in existing conditions the average durations in the operational phase are similar.

Table 7.32 Average duration (hours) of inundation at non-habitable buildings (subject to above floor flooding and afflux greater than 20 millimetres) and surrounds above 0.5 metres depth of flooding in rare events – operational phase

TUFLOW model	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
NFM	43	2	49	53
N2N14	-	-	-	1
N2N13	-	-	-	4
N2N11-12	20	26	20	12
N2N10	-	-	-	2
N2N9	-	-	-	4
N2N8	-	-	-	2
N2N7	-	-	-	4
N2N6	-	-	-	11
N2N5	-	-	-	-
N2N4	-	-	-	-
N2N23	-	-	-	-
N2N1	12	11	17	10
Narrabri	36	36	41	57

7.4.2 Impacts to roads

All highways and other named roads have been analysed to identify flooded sections of each highway / road located within each TUFLOW model domain. Flood hazards, and duration of flooding above 0.5 metres flood depth were also analysed.

It should be noted that the results presented below are based on flood modelling results directly relating to the proposal. They do not consider more widescale flooding, potential damage and road closures that would occur in floods greater than the 1% AEP event.

Highways – flood inundation

The change in lengths of each highway subject to flood inundation are shown in Table 7.33.

There are minor increases in lengths of flooding for the Newell Highway in the PMF event (up to 19 per cent additional length). However, the Newell Highway is already subject to extensive flooding in the PMF event under existing conditions (approximately 25 kilometres (see Table 5.9)) and as such, the additional impacts are only minor. For all other highways there are negligible changes in lengths of overtopping.

Table 7.33 Change (%) in length of highways subject to flooding in rare events – operational phase

Highway	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Mitchell Highway	0%	0%	0%	1%
Castlereagh Highway	0%	0%	2%	0%
Oxley Highway	2%	0%	0%	1%
Newell Highway (N2N1)	0%	0%	1%	11%
Kamilaroi Highway	0%	-3%	0%	0%
Newell Highway (Narrabri)	0%	0%	0%	8%

Highways – flood hazard

Table 7.34 shows change in length (within the model domain) of each inundated highway subject to high flood hazard (H3, H4, H5 and H6 identified in Figure 2.1). Across all events analysed there are negligible to minor changes in lengths subject to high flood hazard.

Table 7.34 Change (%) in length of inundated highways subject to high flood hazard in rare events – operational phase

Highway	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Mitchell Highway	0%	1%	0%	0%
Castlereagh Highway	0%	0%	2%	0%
Oxley Highway	0%	2%	0%	1%
Newell Highway (N2N1)	0%	0%	0%	7%
Kamilaroi Highway	0%	2%	0%	0%
Newell Highway (Narrabri)	-2%	0%	0%	8%

The change in maximum duration of flooding above 0.5 metres flood depth for each highway is shown in Table 7.35. Across all events analysed there are negligible changes in duration of inundation.

Table 7.35 Change (%) in maximum duration of inundation of highways above 0.5 metres depth of flooding in rare events – operational phase

Highway	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Mitchell Highway	0%	0%	0%	0%
Castlereagh Highway	0%	0%	0%	-7%
Oxley Highway	<5%	<5%	<5%	0%
Newell Highway (N2N1)	<5%	<5%	0%	0%
Kamilaroi Highway	0%	0%	0%	0%
Newell Highway (Narrabri)	0%	<5%	0%	0%

Other named roads

A summary of flood impacts on named roads is shown in Table 7.36. Across all events analysed there are negligible impacts to other named roads.

Table 7.36 Summary of change (%) in flood impacts on named roads in rare events – operational phase

Event	Change in total length (%)	Change in total length subject to high hazard (%)	Change in average duration of inundation (%)	Change in maximum duration of inundation (%)
1% AEP + CC	<10%	<10%	0%	0%
0.5% AEP	<10%	<10%	<10%	0%
0.2% AEP	<10%	<10%	0%	0%
PMF	<10%	<10%	<10%	<10%

7.4.3 Impacts to existing rail lines

Impacts of the proposal on overtopping of the existing railways are shown in Table 7.37. Across all events modelled there are negligible changes in lengths of overtopping.

Table 7.37 Change (%) in overtopping length of rail lines in rare events – operational phase

Rail line	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Main Western Line	0%	0%	0%	0%
Parkes Narromine Line	-6%	-5%	-4%	0%
Dubbo to Coonamble Line	4%	6%	0%	1%
Binnaway to Gwabegar Line (non-operational)	0%	0%	0%	-4%
Narrabri to Walgett Line (N2N1)	0%	0%	0%	1%
Narrabri to Walgett Line (Narrabri)	5%	0%	0%	-3%
Mungindi Line	-2%	-2%	0%	0%

Impacts of the proposal on maximum duration of overtopping of the existing railways are shown in Table 7.38. Across all events modelled there are negligible changes in duration of overtopping.

Table 7.38 Change (%) in maximum duration (hours) of flooding at toe of existing rail embankment above 0.5 metres depth of flooding in rare events – operational phase

Rail line	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Main Western Line	0%	<10%	0%	<10%
Parkes to Narromine Line	0%	<10%	<10%	<10%
Dubbo to Coonamble Line	0%	0%	0%	<10%
Binnaway to Gwabegar Line (non-operational)	0%	0%	0%	<10%
Narrabri to Walgett Line (N2N1)	0%	0%	0%	<10%

Rail line	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Narrabri to Walgett Line (Narrabri)	0%	0%	0%	<10%
Mungindi Line	0%	<10%	0%	<10%

7.4.4 Impacts to major land uses

Forested lands

Impacts of the proposal to flooding depths on forested lands is shown in Table 7.39. When compared to the existing conditions (Table 5.16) there are negligible changes, with an overall minor reduction of 408 hectares in the PMF event.

Table 7.39 Change (%) in forested lands subject to different flood depths in rare events – operational phase

Event	Inundated areas (ha)				
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m
1% AEP + CC	-1%	-1%	0%	-1%	0%
0.5% AEP	-1%	-1%	0%	-1%	0%
0.2% AEP	-1%	0%	-1%	-1%	0%
PMF	-1%	-2%	0%	-2%	0%

Impacts of the proposal to flooding duration on forested lands is shown in Table 7.40. When compared to the existing conditions (Table 5.17) there are negligible changes in all events modelled.

Table 7.40 Change (%) in forested lands subject to different duration of flood inundation above 0.5 metres depth in rare events – operational phase

Event	Inundated Forested land (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
1% AEP + CC	-2%	-1%	0%	0%	2%
0.5% AEP	-1%	-1%	0%	0%	1%
0.2% AEP	-3%	-2%	0%	0%	1%
PMF	0%	1%	-3%	1%	1%

Grazing area

Impacts of the proposal to flooding depths on grazing areas is shown in Table 7.41. When compared to the existing conditions (Table 5.18) there are negligible changes, with an overall minor reduction of 932 hectares in the PMF event.

Table 7.41 Change (%) in grazing areas subject to different flood depths in rare events – operational phase

Event	Inundated areas (ha)				
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m
1% AEP + CC	-1%	-1%	-1%	0%	0%
0.5% AEP	-1%	-1%	0%	0%	0%
0.2% AEP	-1%	0%	-2%	-1%	0%
PMF	0%	-1%	-6%	3%	-2%

Impacts of the proposal to flooding duration on grazing areas is shown in Table 7.42. When compared to the existing conditions (Table 5.19) there are negligible changes in all events modelled.

Table 7.42 Change (%) in duration of flood inundation of grazing areas above 0.5 metres depth in rare events – operational phase

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
1% AEP + CC	-2%	0%	0%	0%	0%
0.5% AEP	0%	0%	0%	0%	0%
0.2% AEP	-6%	-1%	0%	-1%	0%
PMF	-3%	1%	0%	0%	-4%

Cropping lands

Impacts of the proposal to flooding depths on cropping lands is shown in Table 7.43. When compared to the existing conditions (Table 5.20) there are negligible changes, with an overall minor reduction of 1014 hectares in the PMF event.

Table 7.43 Change (%) in cropping lands subject to different flood depths in rare events - operational phase

Event	Inundated areas (ha)				
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m
1% AEP + CC	-1%	0%	0%	0%	0%
0.5% AEP	-1%	0%	0%	0%	0%
0.2% AEP	-1%	-1%	-1%	0%	1%
PMF	4%	-5%	-6%	3%	2%

Impacts of the proposal to flooding duration on cropping lands is shown in Table 7.44. When compared to the existing conditions (Table 5.21) there are negligible changes in all events modelled.

Table 7.44 Change (%) in duration of flood inundation for cropping lands above 0.5 metres depth in rare events – operational phase

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
1% AEP + CC	1%	1%	1%	0%	0%
0.5% AEP	1%	0%	0%	-1%	0%
0.2% AEP	0%	3%	1%	-1%	0%
PMF	-4%	2%	0%	-2%	-1%

Horticultural lands

Impacts of the proposal to flooding depths on horticultural lands is shown in Table 7.45. When compared to the existing conditions (Table 5.22) there are negligible changes across all events modelled.

Table 7.45 Change (%) in horticultural lands subject to different flood depths in rare events – operational phase

Event	Inundated areas (ha)				
	0 m - 0.25 m	0.25 m - 0.5 m	0.5 m - 1 m	1 m - 2 m	> 2 m
1% AEP + CC	0%	0%	0%	1%	0%
0.5% AEP	0%	0%	0%	0%	0%
0.2% AEP	0%	0%	-3%	0%	3%
PMF	0%	0%	0%	0%	0%

Impacts of the proposal to flooding duration on horticultural lands is shown in Table 7.46. When compared to the existing conditions (Table 5.23) there are negligible changes across all events modelled.

Table 7.46 Change (%) in duration of flood inundation for horticultural lands above 0.5 metres depth in rare events – operational phase

Event	Inundated areas (ha)				
	0 - 3 hrs	3 - 6 hrs	6 - 12 hrs	12 - 24 hrs	> 24 hrs
1% AEP + CC	-	0%	0%	0%	0%
0.5% AEP	-	0%	0%	0%	0%
0.2% AEP	-	-	0%	0%	0%
PMF	-	-	0%	0%	0%

7.5 Narrabri Flooding Impacts

7.5.1 General

The town of Narrabri is located within the floodplain of the Naomi River and Narrabri Creek. It has been subject to flooding in the past, particularly during the 1910, 1955 flood events. TUFLOW hydraulic modelling has been used to calculate the potential changes to the existing flood regime during flood events greater than the 1% AEP.

This analysis also include checks on potential blockage of the viaduct piers by large floating debris and evaluation of design options to extend the viaduct structure further to the north, rather than using earth embankments.

7.5.2 Narrabri –Impacts during floods up to 1% AEP event

Feedback on the EIS is that there is general concern about the potential impacts from construction of a rail viaduct structure downstream of the town of Narrabri.

Predicted above floor flooding depths at habitable properties in Narrabri that have an afflux greater than 10 millimetres in the 1% AEP events are shown in Figure 7.10 and Figure E-3. These properties are located along Wee-Waa Road and are currently at risk of flooding in events less than the 1% AEP.

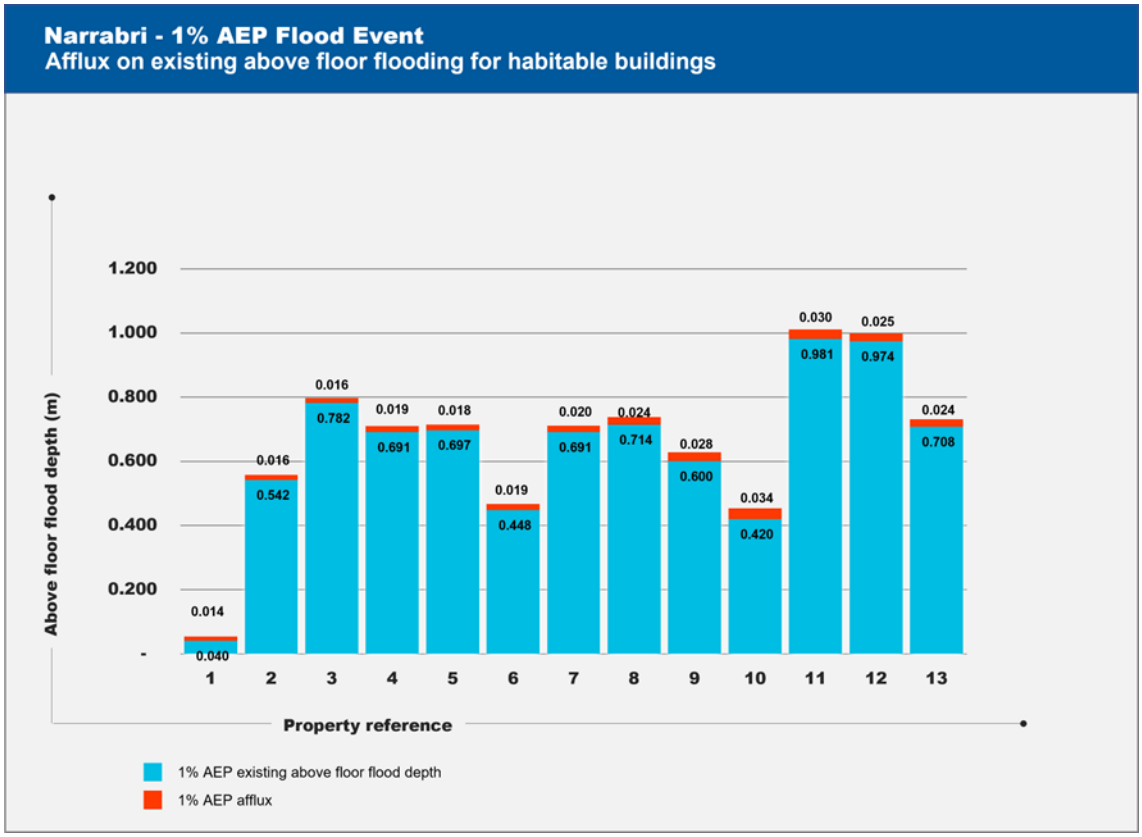


Figure 7.10 Narrabri QDL departures afflux >10 millimetres above habitable floors

Change in number of buildings at risk of flooding in Narrabri.

The Narrabri TUFLOW flood model was used to compare the number of buildings at risk of flooding under existing conditions and after construction of the proposal. This model includes the proposed Narrabri viaduct that would have spans of between 25 metres and 33 metres between piers. The underside of the viaduct would be above the 1% AEP flood level, allowing flood waters to pass under the structure.

Figure 7.11 shows a frequency distribution for depth of above floor flooding for habitable buildings in Narrabri for the 5% AEP, 2% AEP and 1% AEP events. Figure 7.12 shows the same information for a cumulative count of habitable buildings flooded above floor level. This analysis illustrates that for all flood events up to the 1% AEP the impacts on the existing flood risk in Narrabri from construction of the proposed rail viaduct are expected to be minimal.

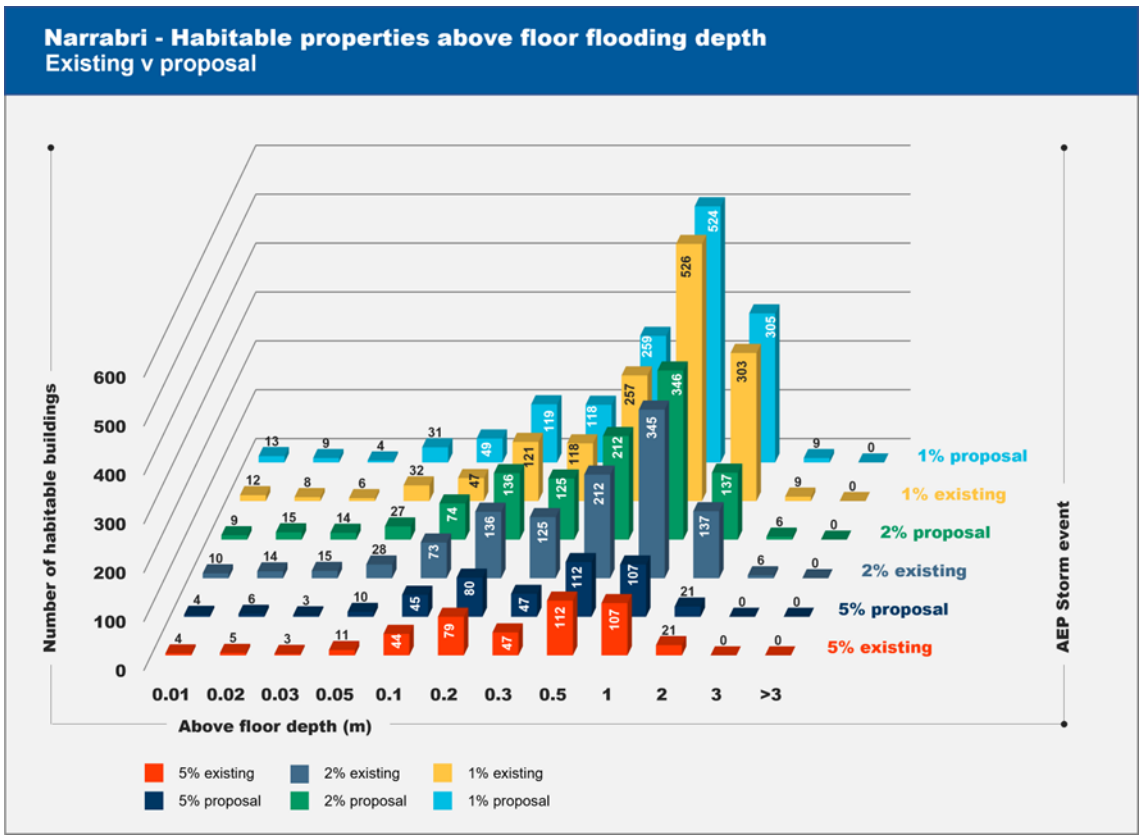


Figure 7.11 Narrabri habitable properties above floor flooding depth existing v design

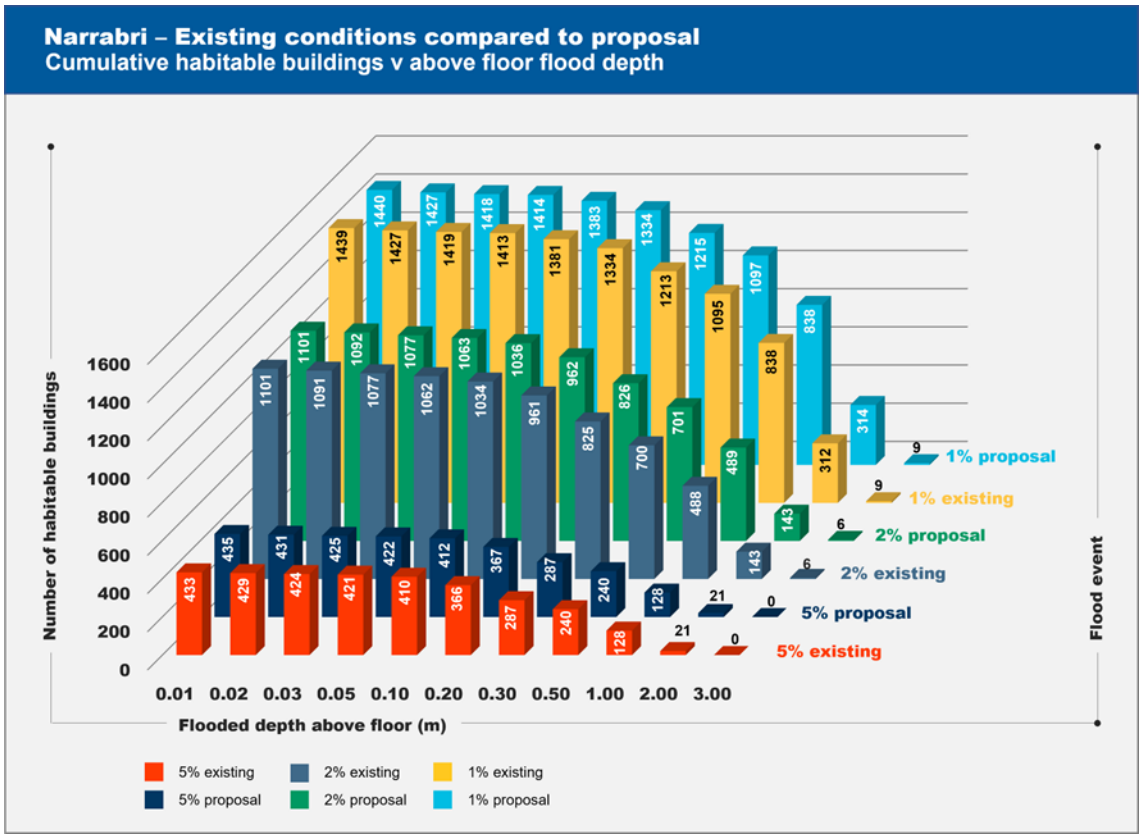


Figure 7.12 Cumulative number of habitable buildings v above floor flood depth

7.5.3 Narrabri – Flooding impacts during rarer flood events

Narrabri – Above floor flooding – habitable buildings

Further detailed analysis for habitable buildings in Narrabri was undertaken as summarised in Table 7.47. This shows that for all events modelled the majority of habitable buildings are subject to less than 100 millimetres of afflux.

Table 7.47 Number of habitable buildings subject to different afflux range above floor in Narrabri in rare events – operational phase

Afflux range (m)	1% AEP + CC	0.5% AEP	0.2% AEP	PMF
Flooded in existing conditions	2340	2002	2470	3036
0.01 - 0.02	11	8	70	93
0.02 - 0.03	12	8	24	384
0.03 - 0.05	6	4	12	1065
0.05 - 0.10	1	1	1	1028
0.10 - 0.20	0	0	3	363
0.20 - 0.30	0	0	0	38
0.30 - 0.50	0	0	0	9
0.50 - 1.00	0	0	0	0
1.00 - 2.00	0	0	0	0

This information is also shown graphically below, with the depth of flooding above floor level plotted against afflux of all affected buildings in Narrabri.

Narrabri – 1% AEP event plus climate change

Figure 7.13 shows that in the 1% AEP + climate change event,. The increase in depth resulting from construction of the viaduct is generally less than 10 millimetres. Several buildings that are subject to above floor flooding between around one metre could experience an increase of around 50 millimetres No buildings were identified where above floor flooding would be increased by more than 100 millimetres.

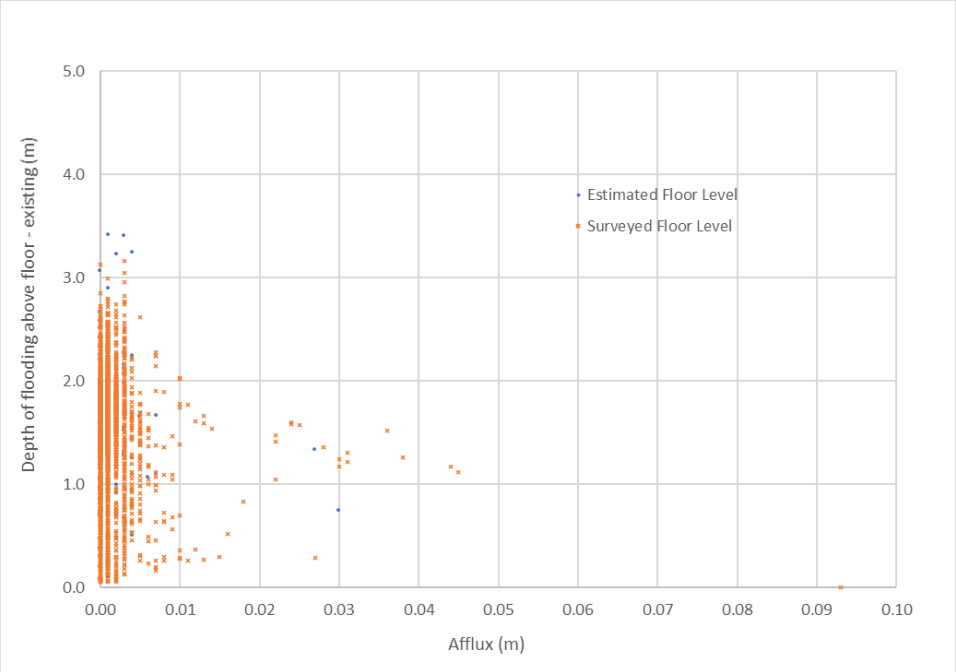


Figure 7.13 Narrabri – impacts to habitable buildings in the 1 AEP event with climate change

Narrabri – 0.5% AEP Event

Results for the 0.5% flood event are shown in Figure 7.14. These show that the maximum afflux is less than 60 millimetres in the 0.5% AEP event. All but one habitable building with an afflux greater than 0.02 metres are flooded about 1 metre above floor under existing conditions.

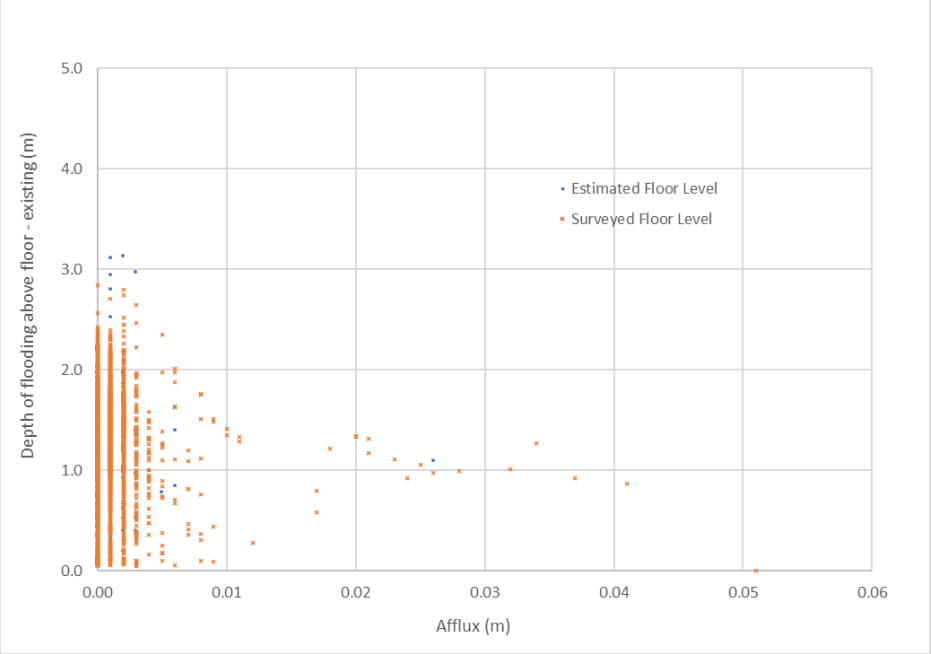


Figure 7.14 Narrabri – impacts to habitable buildings in the 0.5% AEP event

Narrabri – 0.2% AEP Event

Results for the 0.2% AEP event are shown in Figure 7.15. These show that three habitable buildings are subject to afflux greater than 60 millimetres in the 0.2% AEP event for the operational phase. The three buildings are flooded to between 0.3 metres and 0.9 metres above floor under existing conditions.

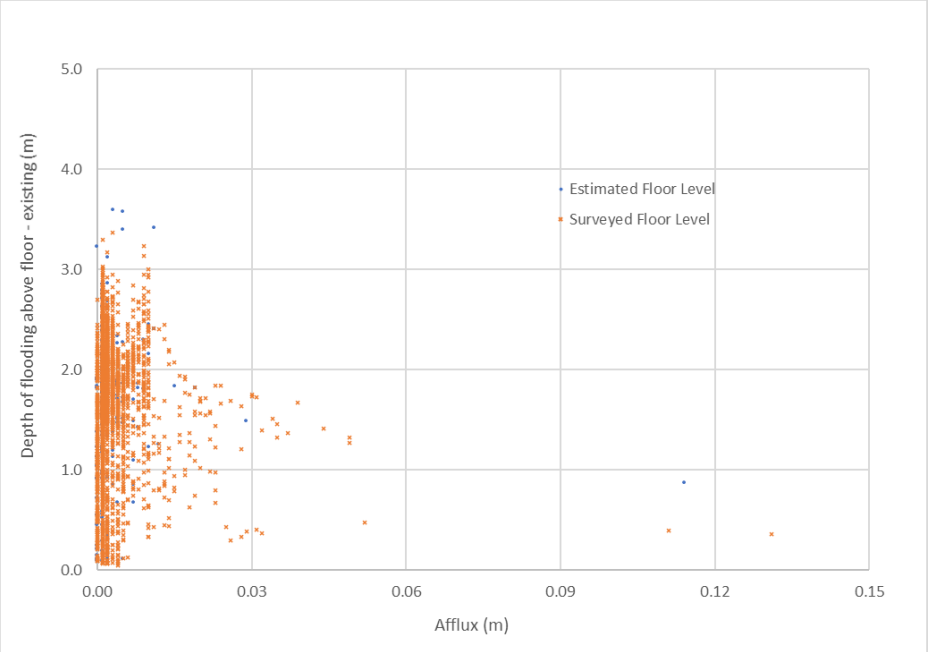


Figure 7.15 Narrabri – impacts to habitable buildings in the 0.2% AEP event

Narrabri – Probable Maximum Flood (PMF) event

Results for the PMF event are shown in Figure 7.16. These show flooding impacts to habitable buildings at Narrabri in the PMF event. The following observations are made:

- Afflux at all habitable buildings with surveyed floor levels is less than 150 millimetres.
- Almost all habitable buildings with afflux greater than 200 millimetres are flooded 2 metres above floor under existing conditions.
- Afflux at nine habitable buildings is greater than 300 millimetres and the buildings are flooded above floor between 2.7 and 4.8 metres under existing conditions.

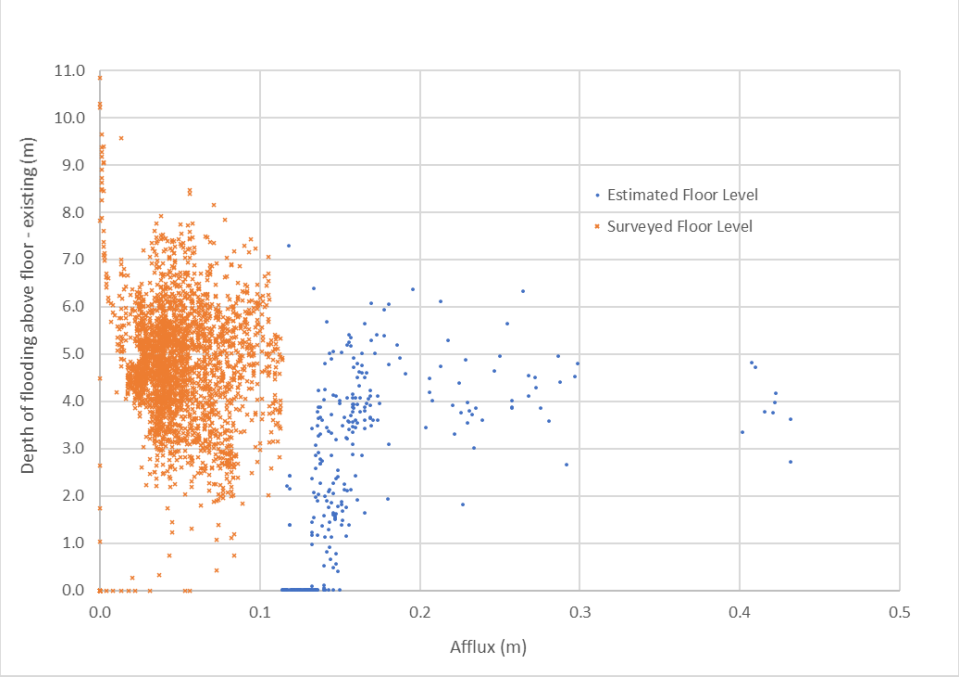


Figure 7.16 Narrabri – impacts to habitable buildings in the PMF event

7.5.4 Narrabri – Risk of additional flooding from debris blockage on viaduct pier

Application of ARR 2019, Table 6.6.6 to the Narrabri Viaduct does not result in a requirement for debris blockage factors to be applied on the viaduct piers.

A sensitivity analysis has however been carried out to check the potential for an increase in afflux upstream of the viaduct if large debris was to become trapped on the piers. This scenario was modelled within the Narrabri TUFLOW model by assuming that five per cent of the waterway area was blocked at the viaduct piers. Flood events were modelled for the 1% AEP regional flood (Namoi River) and the 1% AEP local flood (Mulgate Creek).

The sensitivity analysis indicated that, should debris be trapped on the bridge piers and reduce the waterway area by five per cent, peak water levels could increase by around 2 millimetres. Similar results were obtained for both the regional and local 1% AEP events.

There would be no changes to the QDL assessments reported in Section 7.2 due to the above blockage at the Narrabri viaduct piers.

The recent flood event of November 2021 also provides an indication of the potential impacts from bridges in Narrabri. There are two existing bridge structures that cross the Namoi River and Narrabri Creek, for the existing railway and the Newell Highway respectively. Photographs taken during the November 2021 flood event indicate that floodwaters were not impeded by debris collecting on the bridge piers, as can be seen in Figure 7.17.

Figure 7.17 Narrabri flooding under existing rail bridge, 30 November 2021

7.5.5 Narrabri – Alternative design options considered to reduce flood impacts from viaduct

Narrabri -Raising the viaduct above PMF levels

A 3940 metre long viaduct is included in the reference design to cross the Namoi River and Narrabri Creek and their floodplains at Narrabri. Soffit levels along a 1500 metre length of the viaduct are located below PMF levels. A sensitivity assessment was undertaken to assess any improvements in afflux in the PMF event if soffit levels along the proposed viaduct are raised above PMF levels.

The TUFLOW model for Narrabri for the operational phase was updated to represent the raised Narrabri viaduct in the model and the model was run for the PMF event. Afflux for the PMF event with reference design and afflux for the PMF event with the raised viaduct are shown in Figure 7.18 and Figure 7.19 respectively.

No significant changes in afflux are noticeable with the viaduct raised above the regional PMF event. Therefore it was determined that the additional cost of raising the viaduct was not warranted in terms of the flooding benefits that would be realised.

The design would continue to be refined during detailed design where practicable to not worsen existing flooding characteristics. Where it is not practicable to meet the QDLs, ARTC would implement the process detailed in Section 3.2.2.

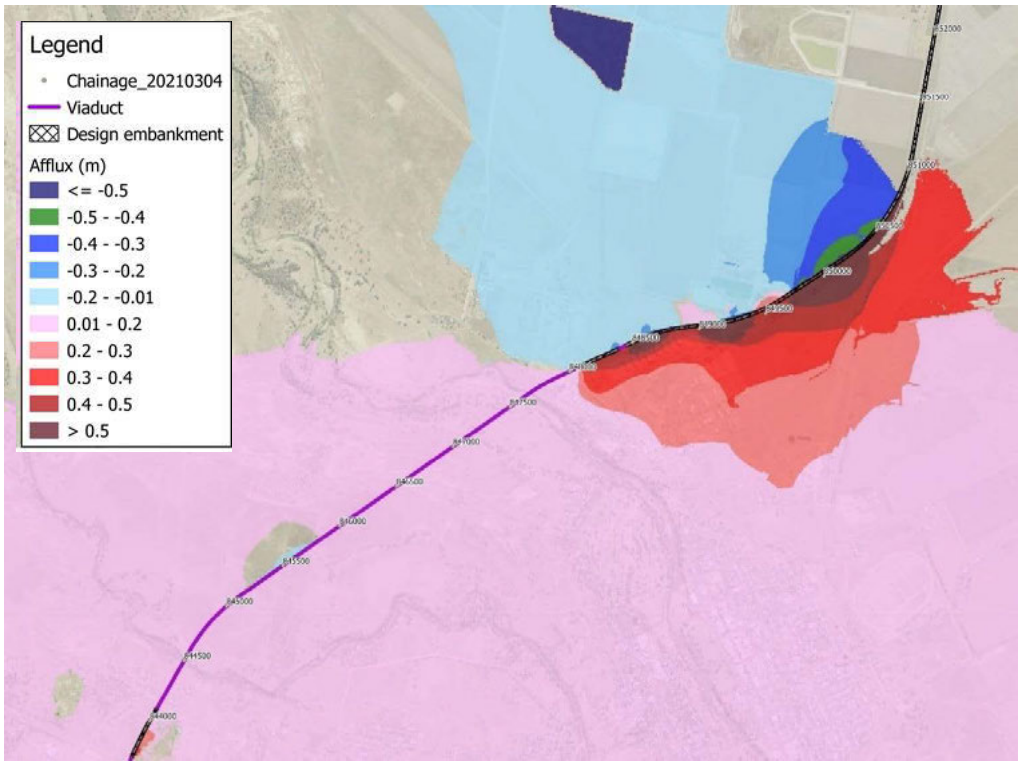


Figure 7.18 Afflux for the regional PMF event with Narrabri viaduct as per reference design

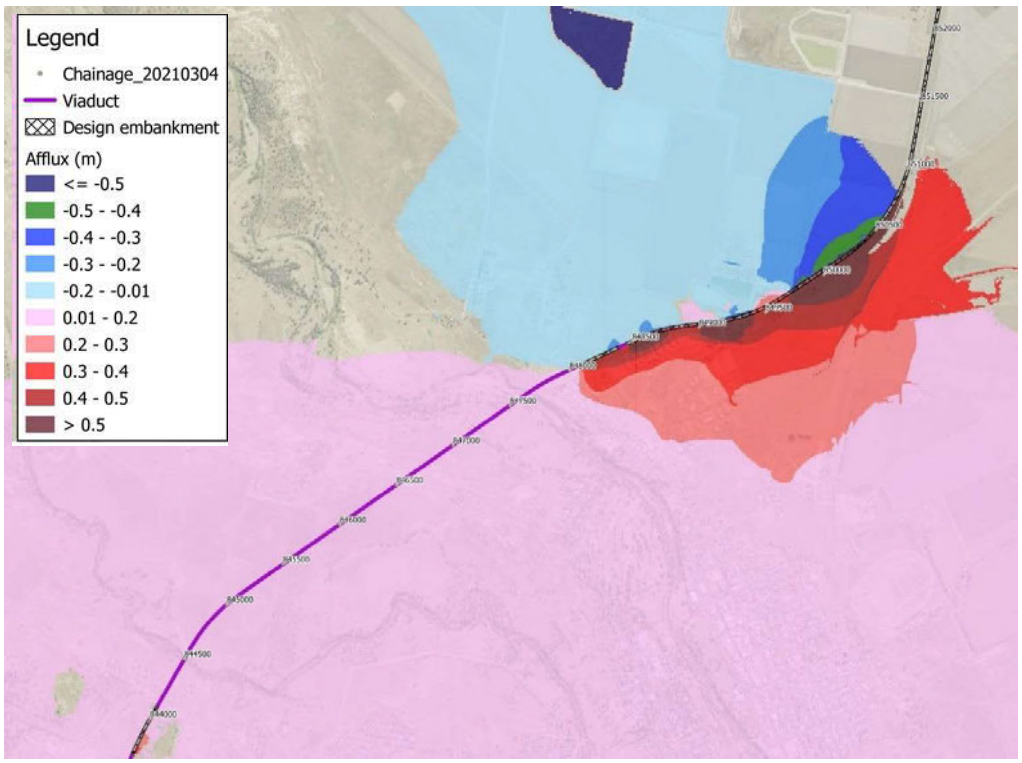


Figure 7.19 Afflux for the regional PMF event with Narrabri viaduct raised above PMF levels

Narrabri – Extension of the viaduct to the north

Two options for extending the proposed viaduct to the north were assessed. One option involved extending the viaduct about 400 metres to the north and the other option involved extending the viaduct about 1400 metres to the north. TUFLOW models with the two extended viaduct options were run for both local and regional PMF events.

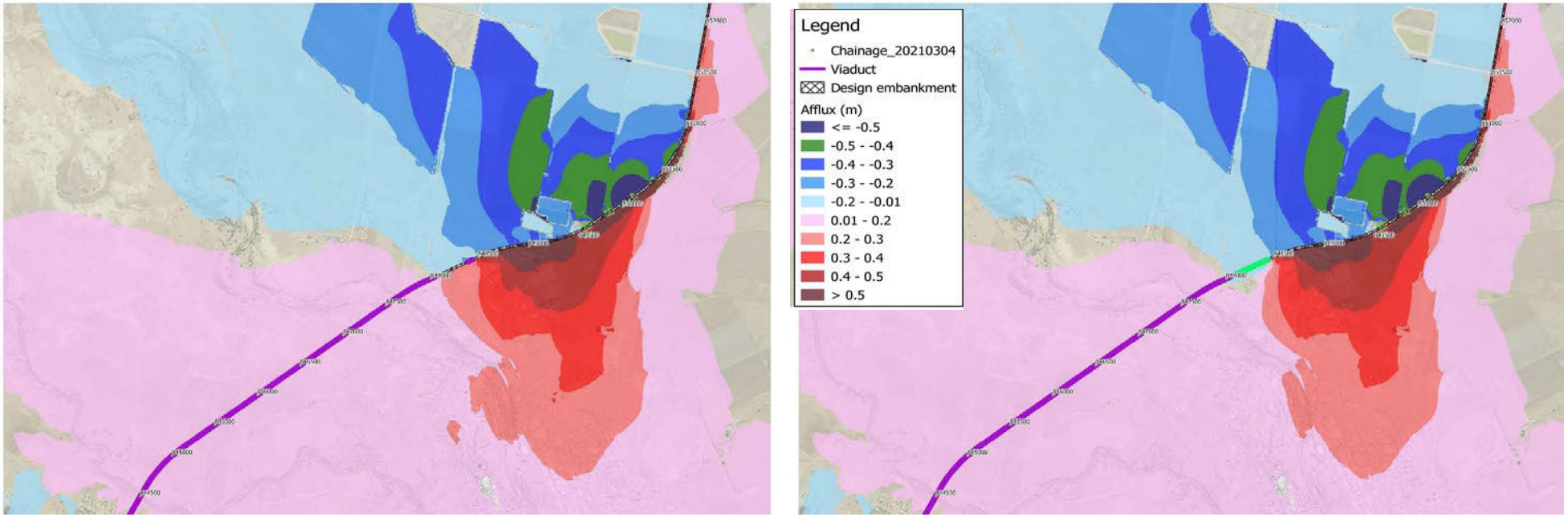
Afflux for both local and regional PMF events with the reference design and with the 400 metre extended viaduct option are shown in Figure 7.20 and Figure 7.21 respectively. These show that the 400 metre extended viaduct option results in minor reduction in areas subject to 0.2 to 0.3 metres afflux in the local PMF event. There is a negligible reduction in areas subject to afflux greater 0.3 metres in the local PMF event. However, some areas subject to 0.2 to 0.3 metres afflux in the regional PMF event are reduced and there are minor reduction in areas subject to afflux greater than 0.3 metres.

Afflux for both local and regional PMF events with the reference design and with the 1400 metre extended viaduct options are shown in Figure 7.22 and Figure 7.23 respectively. These show some reduction in areas subject to afflux greater than 0.2 metres in the local PMF event and there are some reduction in areas subject to 0.2 to 0.3 metres afflux in the regional PMF event. There are also some reduction in flooded areas which are subject to greater than 0.3 metres afflux in the regional PMF event.

Analysis indicates that habitable buildings along Wee Waa Road would be subject to more than 0.01 metres afflux in the 1% AEP event with the 1400 metre extended viaduct. These buildings are subject to flooding in the existing 1% AEP event and therefore extending the viaduct would not prevent these buildings from being flooded above floor level, it would only have a minor reduction on the afflux.

Therefore it was determined that the additional cost of extending the viaduct was not warranted in terms of the flooding benefits that would be realised.

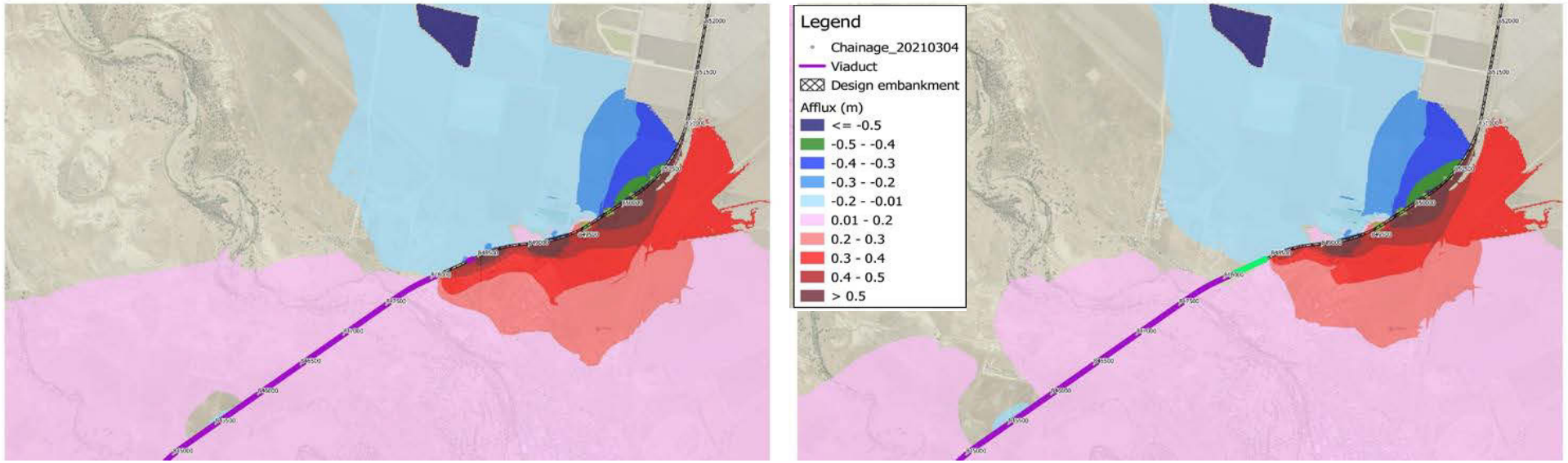
The design would continue to be refined during detailed design where practicable to not worsen existing flooding characteristics. Where it is not practicable to meet the QDLs, ARTC would implement the process detailed in Section 3.2.2.



Reference design

Reference design with 400 metre extended viaduct

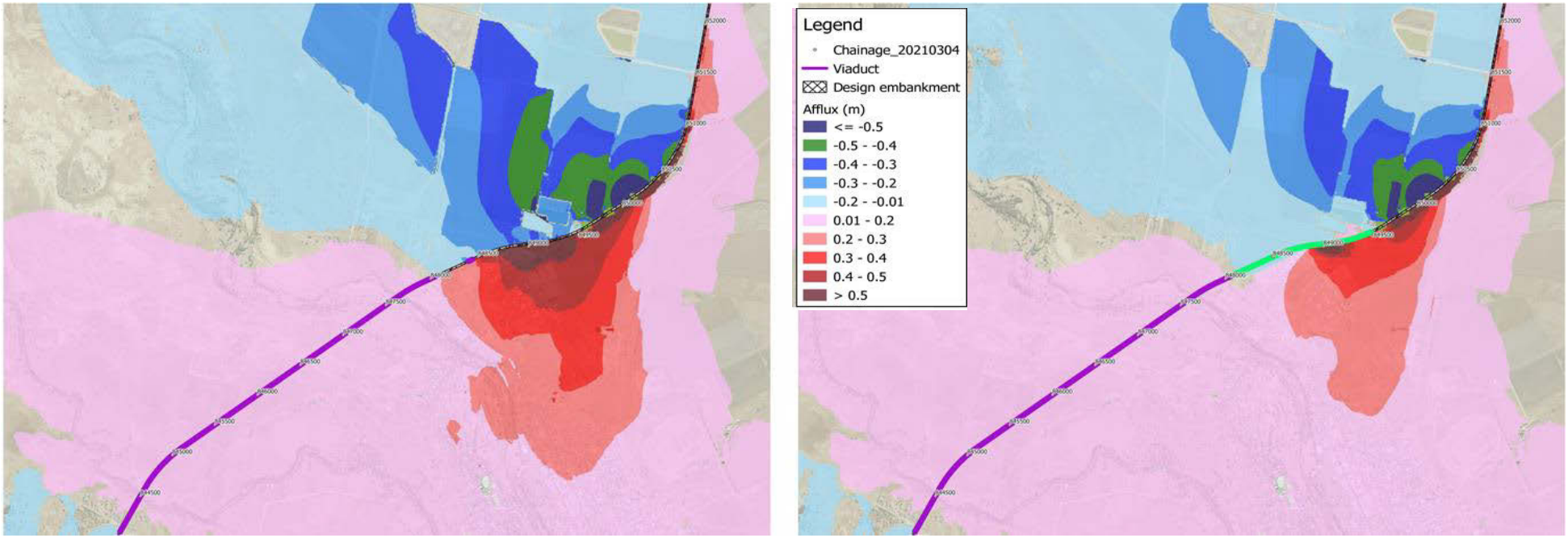
Figure 7.20 Comparison of afflux for the local PMF event – Narrabri viaduct extended 400 metres to the north



Reference design

Reference design with 400 metre extended viaduct

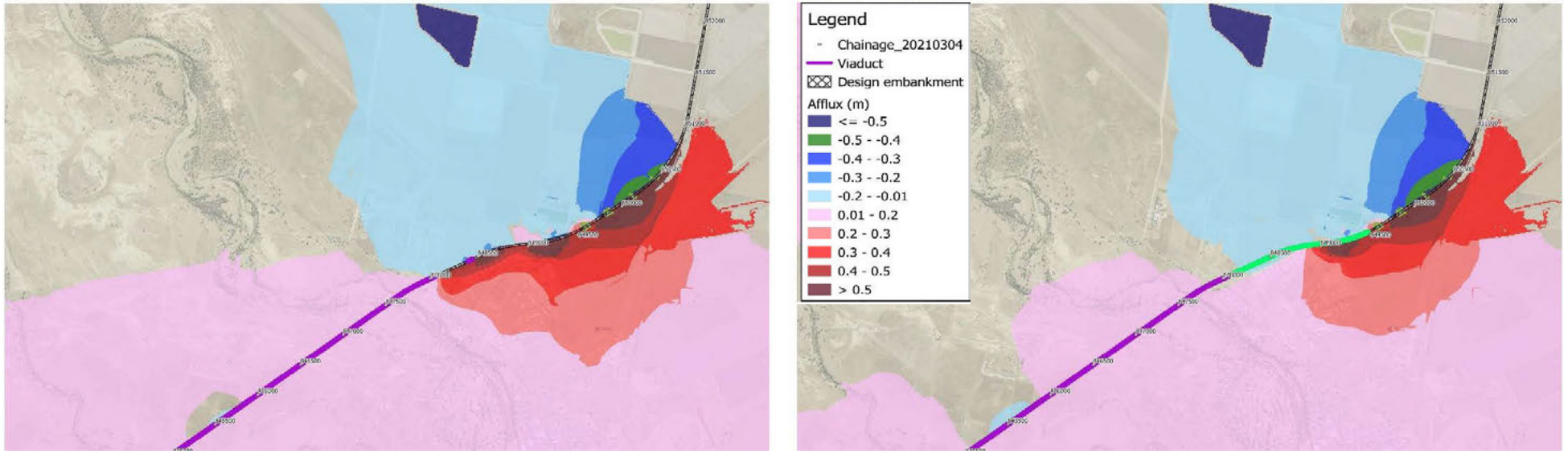
Figure 7.21 Comparison of afflux for the regional PMF event – Narrabri viaduct extended 400 metres to the north



Reference Design

Reference design with 1400 metre extended viaduct

Figure 7.22 Comparison of afflux for the local PMF event – Narrabri viaduct extended 1400 metres to the north



Reference design

Reference design with 1400 metre extended viaduct

Figure 7.23 Comparison of afflux for the regional PMF event – Narrabri viaduct extended 1400 metres to the north

7.5.6 Narrabri – Local and regional catchment flooding

At Narrabri, the timing of flood peaks from local catchment flooding (Mulgate Creek and surrounding creeks) and regional flooding (Naomi River and Narrabri Creek) is unlikely to be coincident. Flooding assessments presented elsewhere in this report have been enveloped to obtain peak flood behaviour (e.g., water level, velocity, hazard and duration) at Narrabri from both local and regional flooding and impacts of the proposal have been calculated as the difference between the enveloped peak with the proposal and the existing case.

This section provides a summary of impacts for local and regional flooding at Narrabri considered separately. Further details are provided in Appendix N.

Summaries of modelled flood impacts for habitable and non-habitable buildings are provided in Table 7.48 and Table 7.49 respectively.

Modelling results indicate that one habitable and two non-habitable buildings could be newly flooded above floor level, with an afflux of 3 millimetres, in the 1% AEP local event with blockage (Figure 7.24). It should however be noted that all three buildings are at risk of flooding from the 0.2% AEP regional flood event to a depth of 0.6m above floor level.

Also, one building that is currently modelled as flooded under existing local flood conditions would not be flooded above floor level after the proposal.

There are currently existing flooding risks from Mulgate Creek to the east of the Newell Highway, in particular at the Francis Street Industrial Estate. Flood modelling results for local and regional events indicated that these existing flood risks would not be made worse by the proposal.

Figure 7.24 Location of buildings newly flooded above floor with the proposal in the 1% AEP local catchment flood event (afflux of 3 millimetres)

Table 7.48 Narrabri – Number of habitable buildings subject to above floor flooding: local and regional events

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP +blockage	0.5% AEP	0.2% AEP	PMF
Local catchment flooding							
Existing Conditions	0	20	68	129	257	361	1361
Operational Conditions	0	20	68	130	256	360	1435
Regional catchment flooding							
Existing Conditions	0	437	1093	1404	1921	2394	3030
Operational Conditions	0	439	1093	1405	1923	2394	3030

Table 7.49 Narrabri – Number of non-habitable buildings subject to above floor flooding: local and regional events

TUFLOW model	20% AEP	5% AEP	2% AEP	1% AEP +blockage	0.5% AEP	0.2% AEP	PMF
Local catchment flooding							
Existing Conditions	2	25	143	287	525	650	2270
Operational Conditions	2	38	143	288	526	650	2319
Regional catchment flooding							
Existing Conditions	16	755	1772	2018	2241	2461	3032
Operational Conditions	16	757	1774	2019	2241	2464	3035

7.6 Bohena Creek flooding impacts

The draft *Bohena Creek Flood Study* (WRM, 2019b) was prepared for Narrabri Shire Council to investigate and define existing flooding risks at a proposed development site between Yarrie Lake Road and Culgoora Road. The extents of the WRM (2019b) study are located within the study area for the proposal.

The primary focus of the WRM study was to map the flood risk for the design events for rezoning of Council's proposed development site. An XP-RAFTS hydrologic model and TUFLOW hydraulic model were developed for the assessment and calibrated to two historical flood events, the September 1998 event and December 2004 event.

Design discharges for the 20%, 10%, 5%, 2% and 1% AEP events were estimated using methodology recommended in ARR 2019. The TUFLOW models were calibrated to stream data for the September 1998 event and December 2004 events at the Bohena Creek gauge at Newell Highway. Inflow hydrographs simulated by the XP-RAFTS model for the two historic flood events were applied to calibrate the model. The calibrated TUFLOW model was run for the selected design flood events using inflow hydrographs simulated by the XP-RAFTS model. The TUFLOW model predicted flood levels, depths and extents for the 20%, 10%, 5%, 2% and 1% AEP flood events and an extreme flood. Preliminary flood hazard mapping was also prepared. The PMF event was determined using the generalised tropical storm method revised (GTSMR) (BoM, 2004).

The source WRM flood models from the Bohena Creek flood study were not available for use in the assessment of impacts from the proposal.

For the Bohena Creek catchment, there are differences in the magnitude of the peak flow rate modelled between the flooding and hydrology assessment for this proposal and the *Bohena Creek Flood Study* (WRM, 2019b). Details on the hydrological analysis and catchment modelling undertaken by JacobsGHD for Bohena Creek are presented in the calibration report (Appendix J) and are summarised below.

Water levels and flows recorded at the Bohena Creek gauge (419905) were reviewed and considered to estimate design flows and flood levels for the proposal. In particular, historical flood information for Bohena Creek was not available during the reference design to reconcile peak discharges estimated by the RORB hydrology model against other independent estimates due to the lack of high quality recorded stream data.

The available observed data was used in conjunction with rainfall data to calibrate a RORB hydrology model for the Bohena Creek catchment. The RORB model was calibrated to observed events and was used to simulate the range of design flood events using the recommended procedures in *Australian Rainfall and Runoff* (Ball et al, 2019). In addition, the Bohena Creek hydraulic TUFLOW model was calibrated against two flood events and acceptable calibration results were achieved. ARTC has undertaken additional consultation with Narrabri Shire Council and its flooding consultants regarding the differences in peak discharges adopted in the draft *Bohena Creek Flood Study* (WRM, 2019b) and presented in Appendix J. It is to be noted that the draft *Bohena Creek Flood Study* (WRM, 2019b) undertook an at-site flood frequency analysis with the available recorded stream data to reconcile the peak discharges for the design flood events estimated by the XPRAFTS hydrology model. This reconciliation resulted in considerably lower peak discharge estimates for Bohena Creek than presented in Appendix J.

On 25 August 2021 a meeting was held with local residents and representatives from Narrabri Shire Council to discuss historical flooding at Bohena Creek. The residents provided information regarding observations of historical flood events at the meeting. The general opinion from Council and residents is that the modelling results for the proposal are conservative and it is possible that sandy conditions within the Pilliga forests reduce the rainfall runoff into the creek. With this in mind, an alternative analysis is also presented in Appendix Q that is based on scaled flow data from the Bohena Creek gauge and is more consistent with the *Bohena Creek Flood Study* (WRM, 2019b) and the feedback received from consultations with the local community and Narrabri Council.

The historical flood information for Bohena Creek provided by local residents and representatives from Narrabri Shire Council and the available recorded stream data should be used in detail design to reconcile modelled flood behaviour for the design flood events.

7.7 Consistency with floodplain management plans

The proposal crosses floodplains which are included in the following two floodplain management plans (refer to Section 2.2.6):

- Floodplain Management Plan for the Macquarie Valley Floodplain 2021
- Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020.

7.7.1 Floodplain management plan for the Macquarie valley floodplain 2021

The Floodplain Management Plan for the Macquarie Valley Floodplain 2021 is applicable to construction and demolition of existing or proposed flood works which include an access road, a supply channel, a stock refuge, an infrastructure protection work, an ecological enhancement work, an Aboriginal cultural value enhancement work and a heritage site enhancement work within the Macquarie Valley Floodplain. The proposed Macquarie River bridge which crosses the Macquarie Management Zone CU of the Plan is not a flood work. However, temporary infrastructure required to construct the bridge such as access tracks, crane pads, barges, scaffolding etc. have the potential to impact on flood behaviour.

Temporary construction infrastructure has been designed to minimise interference with flood behaviour in order to minimise impacts to surrounding land as far as practicable. Further investigations will be undertaken during detailed design to ensure that the proposed bridge and associated temporary infrastructure is consistent with the requirements for the Lower Namoi Management Zone AD, Lower Namoi Management Zone B and Lower Namoi Management Zone CU.

While the provisions of *the Floodplain Management Plan for the Macquarie Valley Floodplain 2021* do not apply to State significant infrastructure projects, such as the proposal, the relevant hydraulic assessment criteria have been considered in this assessment and are discussed below.

Change in flow distribution

The nearest peak discharge calculation location identified in the FMP in the vicinity of the proposal is located at Warren, which is situated approximately 65 kilometres north-west of Narromine. The TUFLOW model for Narromine does not extend up to Warren. Hence, peak flows have been compared at selected transects in the vicinity of Narromine for the existing conditions and post-developed condition of the proposal for the selected design flood events between the 20% and 0.05% AEP events. Location of discharge comparison and changes in peak discharge for the identified locations are shown in Figure 7.25 and Table 7.50 respectively. The maximum change in peak discharge for the operational phase of the proposal is 17 per cent at location Q7 in the 1% AEP event. The one per cent peak flows at location Q7 are 35 m^3/s and 42 m^3/s for the existing condition and post-developed condition of the proposal respectively. However, the maximum change in peak flow at location Q8, located downstream of location Q7, for all flood events is one per cent implying that the change in peak flow at location Q7 has a negligible impact downstream. Changes in peak flows are less than five per cent at other locations for all flood events. The proposal accords with the prescribed limits for change in flow distribution in the Plan at all but location Q7.

Therefore, the proposal is consistent with the criteria for no more than five per cent changes in flow distributions.

In addition, this indicates that there would be no significant impacts to flood dependent ecological assets, flood-dependent Aboriginal cultural values and flood-dependent heritage sites.

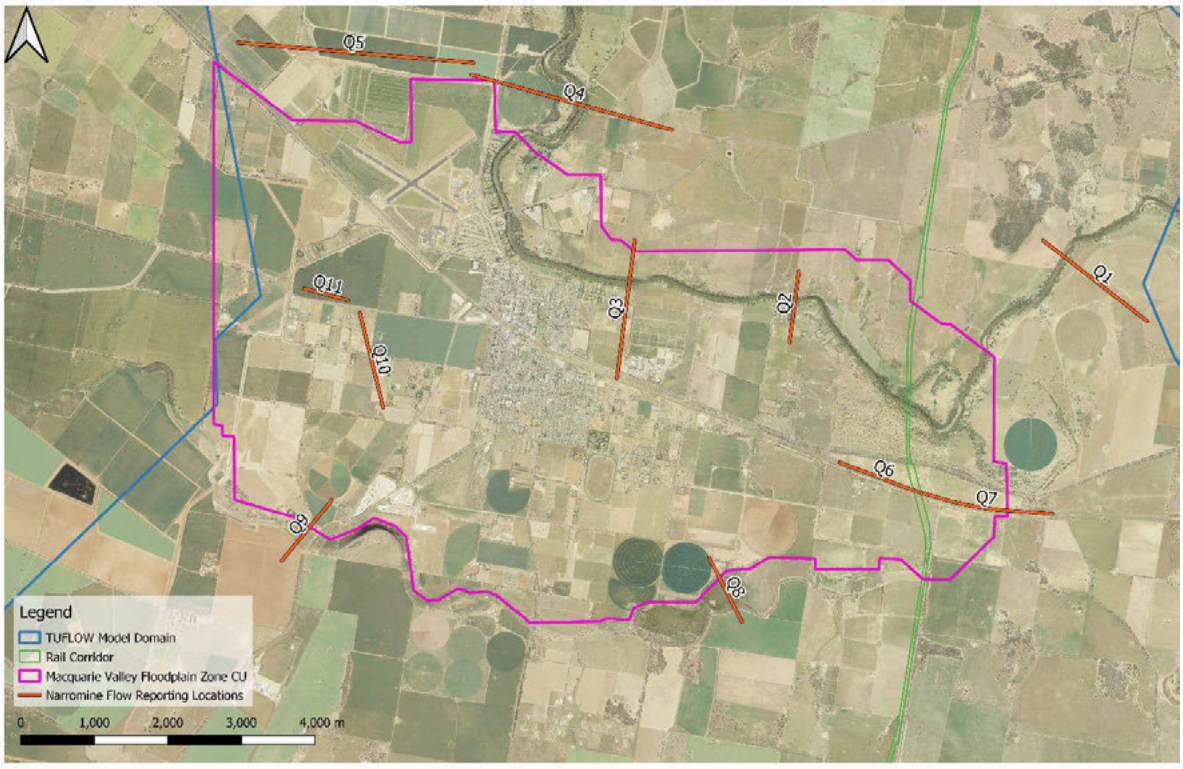


Figure 7.25 Peak flow reporting locations

Table 7.50 Peak flow for the existing condition and per cent change in peak flow for the operational phase of the proposal

Flow reporting location	Peak flow (m^3/s) – existing conditions						% change in peak flow – operational conditions					
	20% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	20% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Q1	484	1,549	2,681	4,112	5,969	8,340	0	0	0	0	0	0
Q2	484	1,540	2,670	4,005	4,655	5,509	0	0	0	0	0	1
Q3	483	1,538	2,670	3,972	4,692	5,518	0	0	0	0	0	1
Q4	483	1,536	2,666	3,645	4,010	4,373	0	0	0	0	0	0
Q5	0	0	2	149	271	830	-	-	0	-1	0	1
Q6	0	0	0	33	450	927	-	-	-	3	-5	-2
Q7	0	0	0	35	733	1,573	-	-	-	19	3	-2
Q8	119	175	227	328	1,168	2,208	0	0	0	1	0	-1
Q9	222	370	495	578	999	1,646	0	0	0	0	0	-1
Q10	0	4	7	211	484	973	0	-2	-1	-1	0	0
Q11	0	0	0	20	75	79	-	-	-	1	0	0

Afflux

Predicted afflux for the operational phase of the proposal in the 20%, 5%, 2% and 1% AEP events are shown in Figure 7.26 to Figure 7.29 which show that afflux for the four design events is less than 0.1 metres within Macquarie Management Zone CU. The afflux due to the proposal is less than the afflux defined in the Plan for Macquarie Management Zone CU and hence the proposal complies with the prescribed limits for afflux in the Plan. The afflux both upstream and downstream of location Q7 (refer to Figure 7.25) is also less than 0.01 metres.

Therefore, the proposal is consistent with the criteria of 0.1 metres afflux.

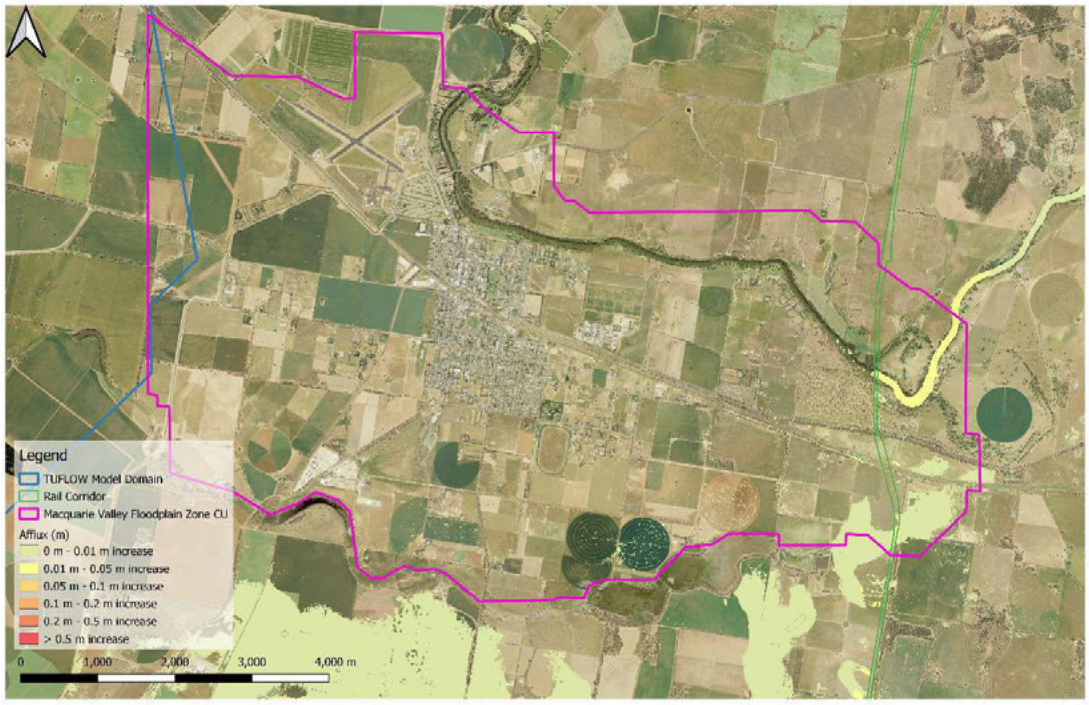


Figure 7.26 Afflux – 20% AEP event

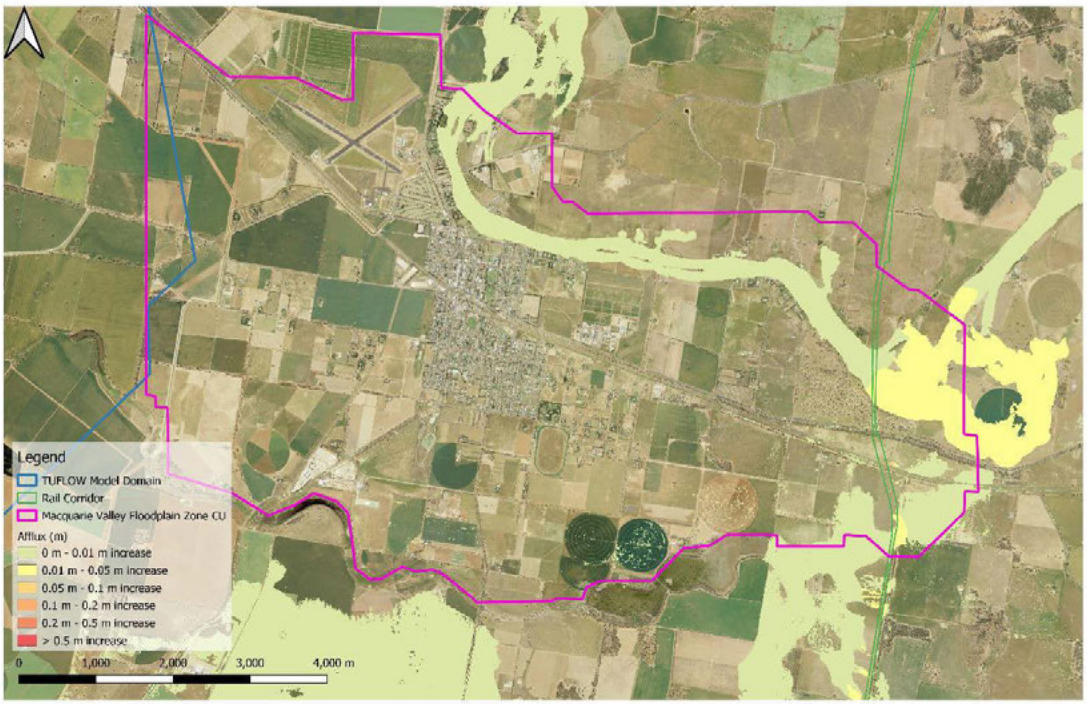


Figure 7.27 Afflux – 5% AEP event

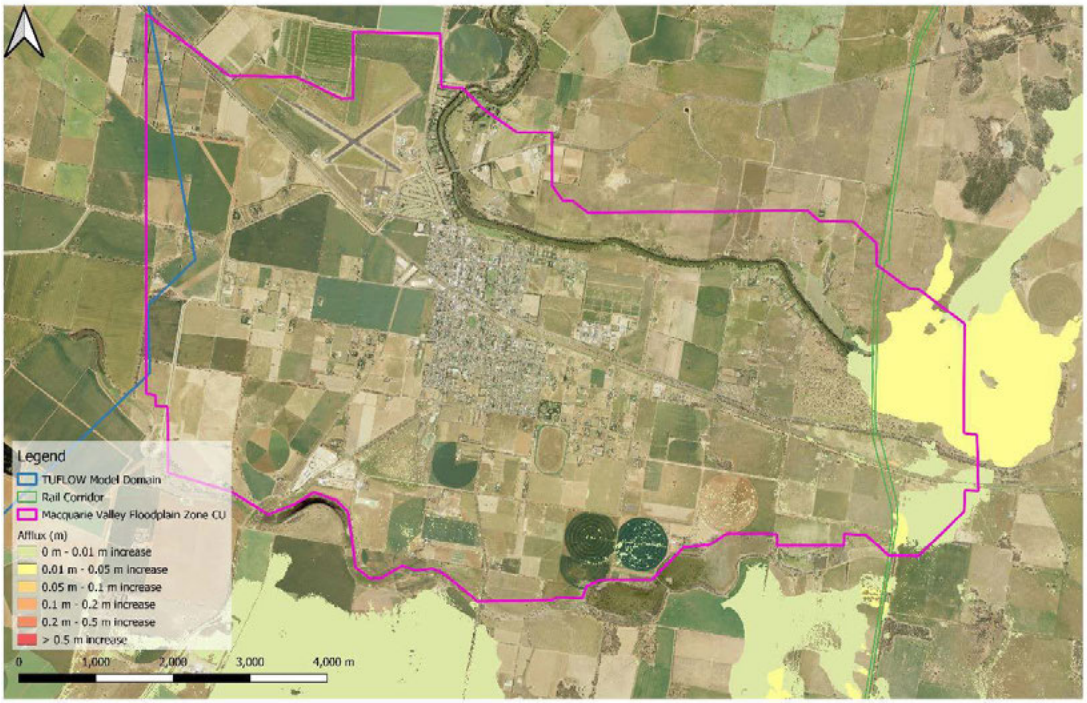


Figure 7.28 Afflux – 2% AEP event

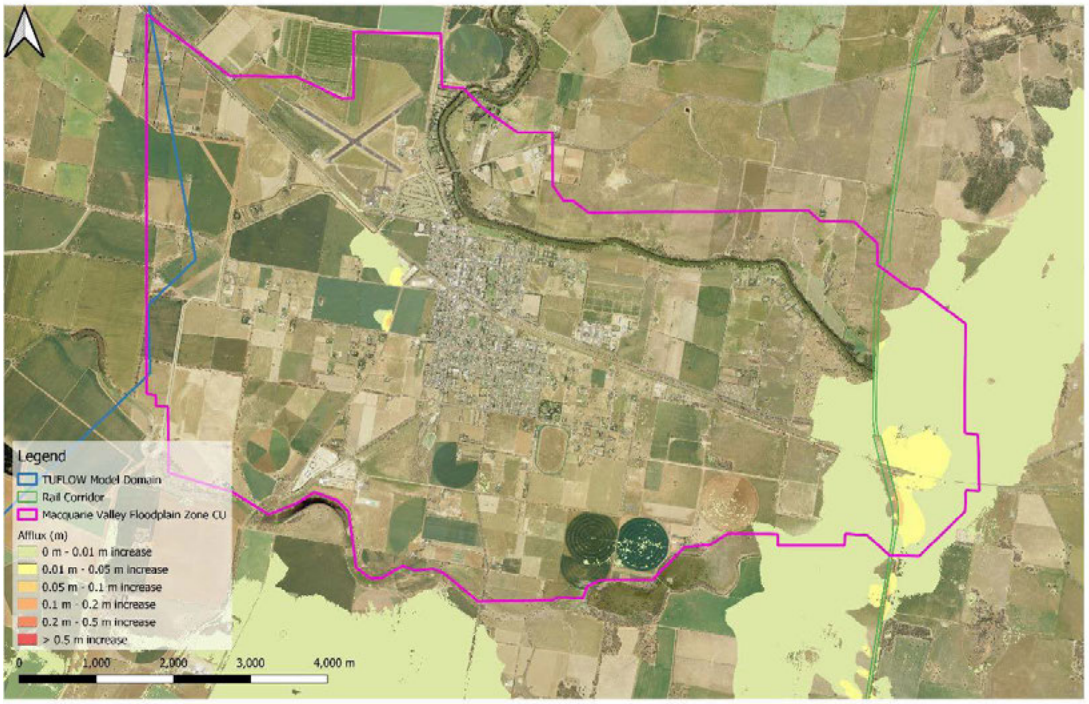


Figure 7.29 Afflux – 1% AEP event

Increase in flow velocities

Increase in peak flow velocities for the operational phase of the proposal are shown in Figure 7.30 to Figure 7.32 which show that localised increases in velocity due to the proposal in the 20%, 5% and 2% AEP flood events are limited within the proposal boundary. Increases in velocity outside the proposal boundary within Macquarie Management Zone CU are not noticeable for the three flood events. In the case of the 1% AEP event (refer to Figure 7.33), localised increase in velocity occurs outside the proposal boundary and the increase in flow velocity is more than 75 per cent of the existing velocity at a few locations. However, peak velocities with the proposal are less than 0.5 m/s at almost all locations where the increase in flow velocity is more than 75 per cent in a 1% AEP event. The peak velocity is increased more than 75 per cent upstream of location Q7 (refer to Figure 7.25). However, the change in flow velocity with the proposal downstream of location Q7 is almost negligible.

Therefore, the proposal is consistent with the criteria for no more than 50 per cent changes in flow velocities.

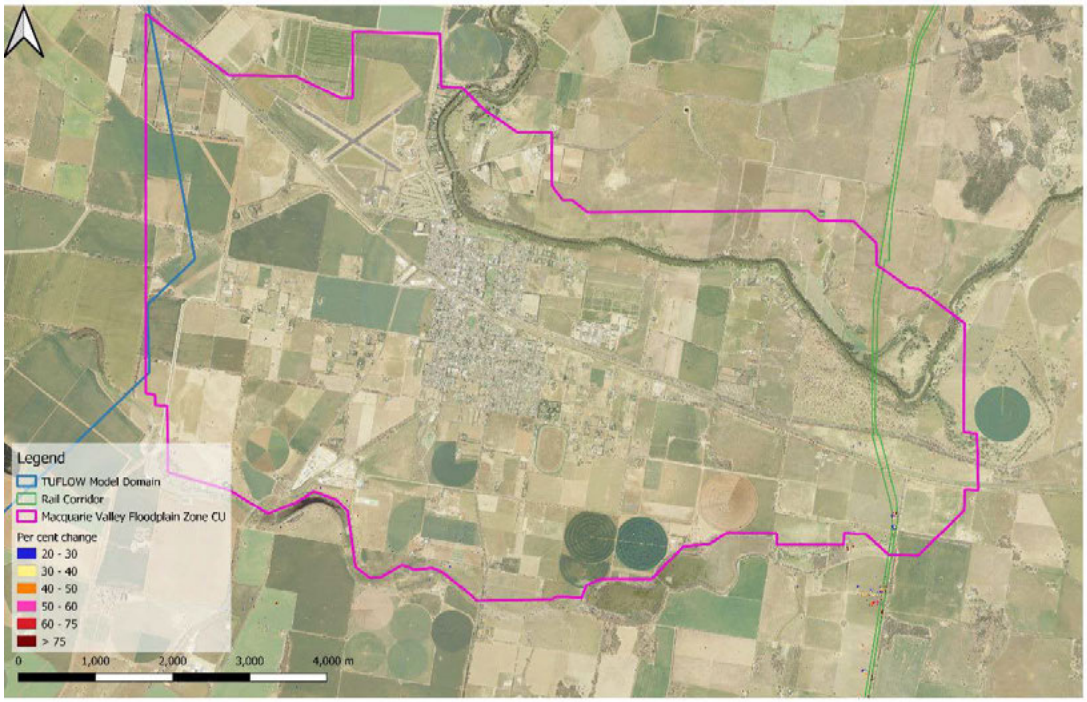


Figure 7.30 Per cent change in flow velocity – 20% AEP event

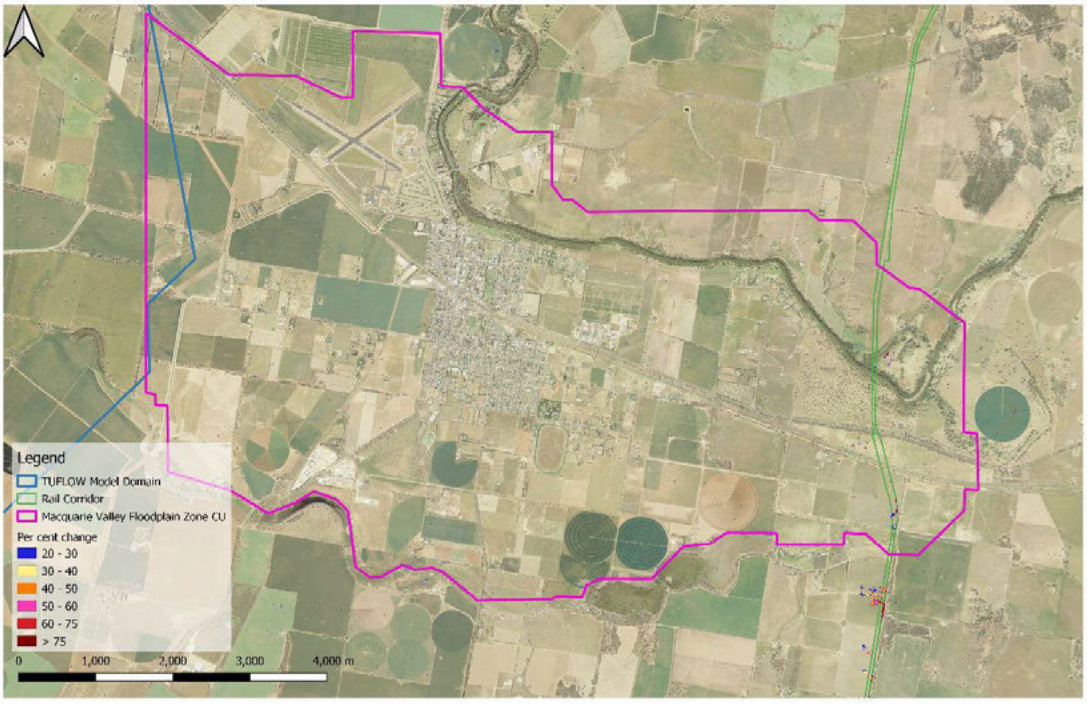


Figure 7.31 Per cent change in flow velocity – 5% AEP event

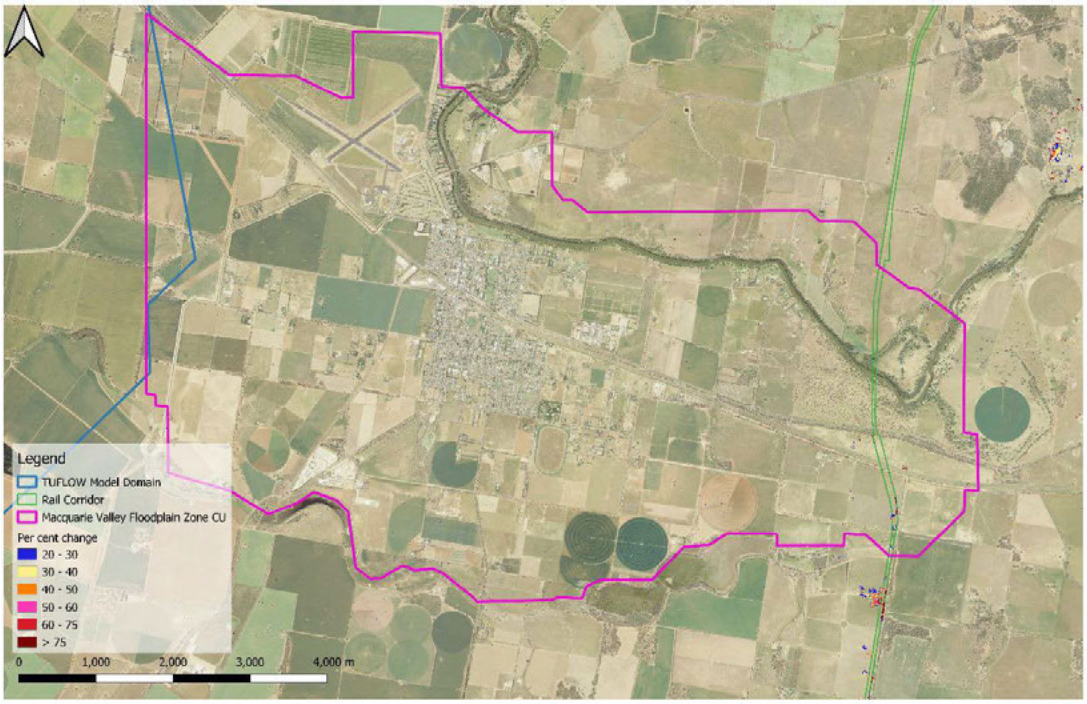


Figure 7.32 Per cent change in flow velocity – 2% AEP event

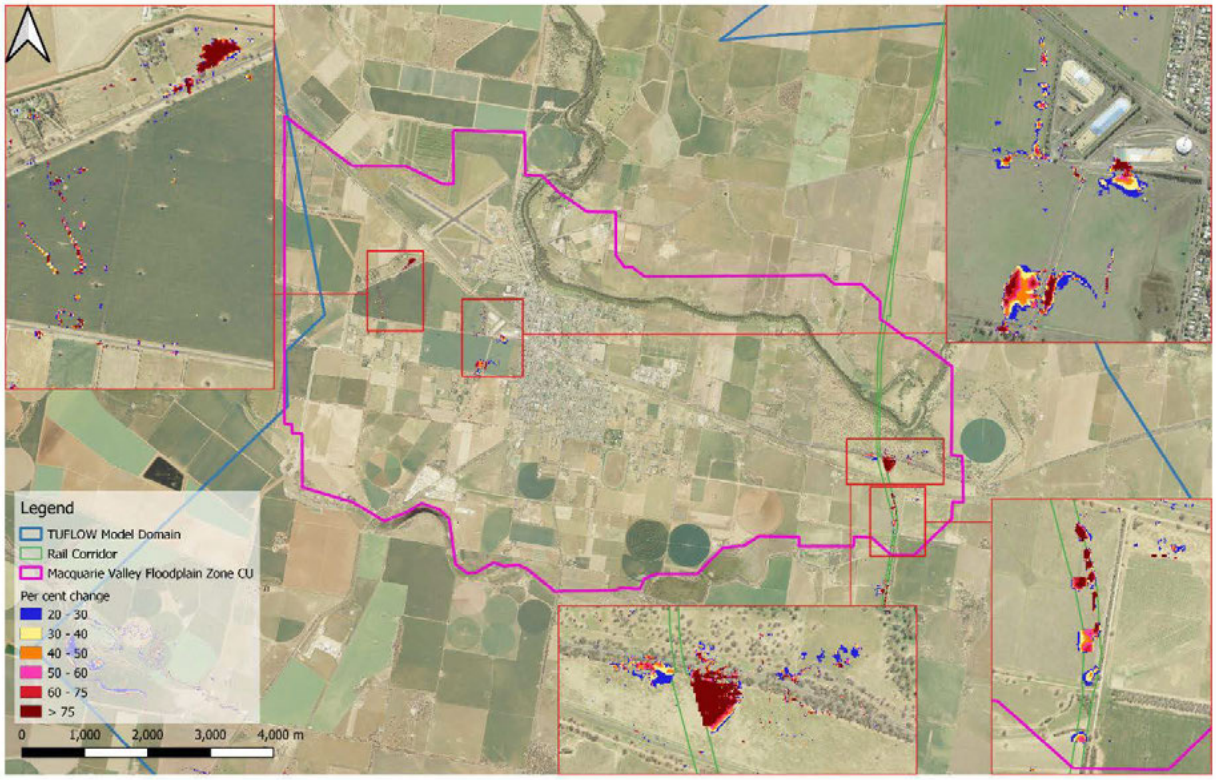


Figure 7.33 Percent change in flow velocity – 1% AEP event

Impact on high value infrastructure

The proposal has minor impacts on afflux (refer to Figure 7.26 to Figure 7.29) and changes in velocities (refer to Figure 7.30 to Figure 7.33) due to the proposal are localised along the boundary of the proposal where no high value infrastructure is located. Therefore, the proposal does not have discernible impacts on high value infrastructure.

In summary, the proposal does not have adverse impacts of flow distribution, afflux and increase in flow velocity. If necessary, scour control measures would be included in detail design to control erosion and scour at culverts.

Maintenance of adequate flood connectivity

The Ecological Assets Map for the Macquarie Valley identifies the presence of and other floodplain ecosystems in the vicinity of the proposal. Mapping prepared for Technical Report 1 – Biodiversity Development Assessment Report confirms the presence of River Red Gum tall to very tall open forest/woodland wetland on rivers on floodplains mainly in the Darling Riverine Plains Bioregion (PCT 36) along the banks of the Macquarie River which is one of the identified ecological asset types for other floodplain ecosystems in the Plan. Threatened species listed in Schedule 1 of the Order are also present in and adjacent to these waterways. No significant impacts on the species listed in Schedule 1 of the Order were identified in Technical Report 1 – Biodiversity Development Assessment Report.

The proposal has designed waterway crossings in accordance with the *Policy and Guidelines for Fish Habitat Conservation and Management* (DPI, 2013) and *Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings* (Fairfull and Witheridge, 2003). As documented in Technical Report 2 – Aquatic Ecology, clearance of instream habitat and riparian vegetation has been minimised as far as practicable, no permanent obstruction is proposed and habitat functionality would be maintained.

A number of culturally modified trees have been identified through Aboriginal Heritage Information Management System (AHIMS) database searches, as documented in Technical Report 6 – Aboriginal Cultural Heritage Assessment Report. Many are located on the floodplain and are likely to be flood-dependent.

No flood-dependent heritage sites have been identified in the vicinity of the proposal. The Non-Aboriginal Heritage assessment is documented in Technical Report 7.

Under operational conditions there are no significant changes in flooding regimes, e.g. afflux and duration near the Macquarie River, therefore no change in flood connectivity is expected for these flood-dependent ecological assets, fish passage, flood-dependent Aboriginal cultural values or flood-dependent heritage sites.

This finding is confirmed in the Technical Report 1 – Biodiversity Development Assessment Report, Technical Report 2 – Aquatic Ecology, Technical Report 6 – Aboriginal Cultural Heritage Assessment and Technical Report 7 – Non-Aboriginal Heritage.

Ground disturbance at a heritage site

The proposal is expected to generate minor changes in velocities away from the rail corridor and therefore the proposal is not likely to disturb the ground surface of a heritage site or cause more than minimal erosion to a heritage site from flooding. Drainage control areas have been included in the proposal beyond the rail corridor to provide space to attenuate velocities and manage potential erosion and scour.

7.7.2 Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020

The Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020 is applicable to construction and demolition of existing or proposed flood works which include an access road, a supply channel, a stock refuge, an infrastructure protection work, an ecological enhancement work, an Aboriginal cultural value enhancement work and a heritage site enhancement work within the Lower Namoi Valley Floodplain. The proposed Narrabri bridge which crosses the Lower Namoi Management Zone AD, Lower Namoi Management Zone B and Lower Namoi Management Zone CU of the Plan is not a flood work. However, temporary infrastructure required to construct the bridge such as access tracks, crane pads, barges, scaffolding etc. have the potential to impact on flood behaviour.

Piers for the bridge have been streamlined to minimise adverse impacts to flooding. In addition, scour protection measures would be provided for piers (refer to Figure 7.6) to ensure minimal impact on soil erodibility. Temporary construction infrastructure has been designed to minimise interference with flood behaviour in order to minimise impacts to surrounding land as far as practicable. Further investigations will be undertaken during detailed design to ensure that the proposed bridge and associated temporary infrastructure is consistent with the requirements for the Lower Namoi Management Zone AD, Lower Namoi Management Zone B and Lower Namoi Management Zone CU.

While the provisions of *the Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020* do not apply to State significant infrastructure projects, such as the proposal, the relevant hydraulic assessment criteria have been considered in this assessment and are discussed below.

Change in flow distribution

The nearest peak discharge calculation location identified in the Plan in the vicinity of the proposal is located at Wee Waa. The TUFLOW model for Narrabri does not extend up to Wee Waa. As such, peak flows have been compared downstream of the proposal for the existing conditions and with the operational phase of the proposal for the selected design flood events between the 20% AEP event and the PMF event (refer to Figure 7.34 and Table 7.51). The maximum changes in peak discharge for the operational phase of the proposal for all flood events up to and including the 0.2% AEP is one per cent at all flow reporting locations. The maximum change in peak flow is up to four per cent in the PMF event.

Therefore the proposal is consistent with the criteria for no more than five per cent changes in flow distributions.

In addition, this indicates that there would be no significant impacts to flood dependent ecological assets, flood-dependent Aboriginal cultural values and flood-dependent heritage sites.

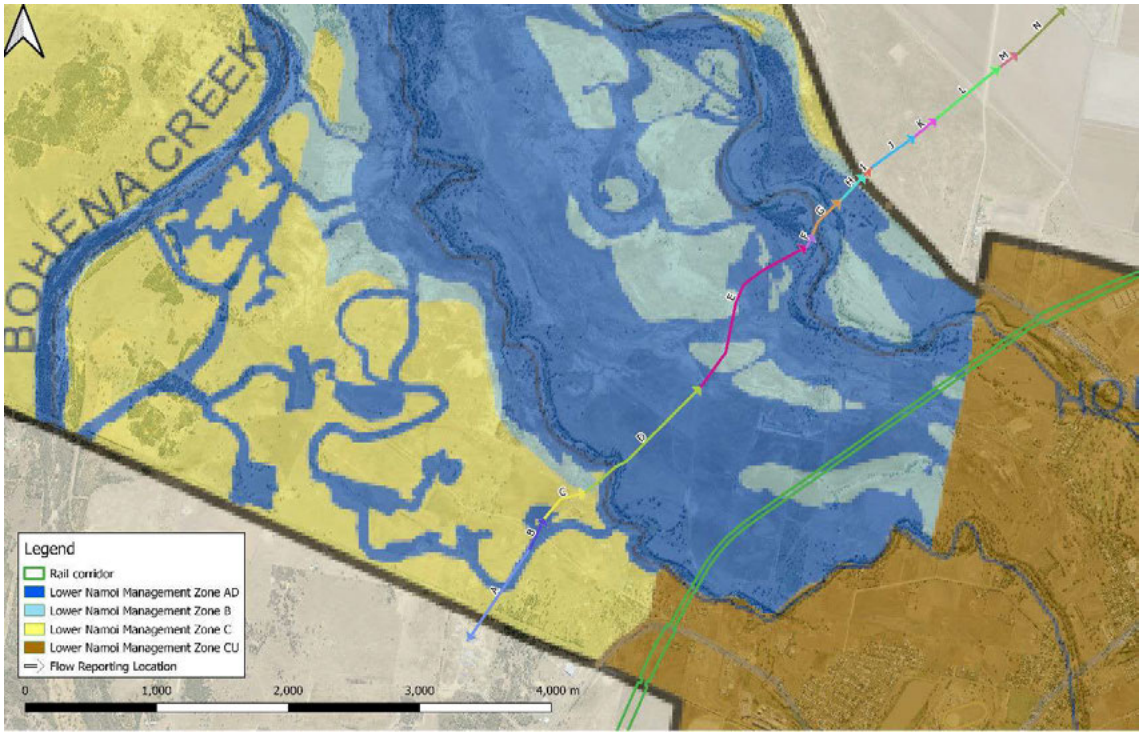


Figure 7.34 Peak flow reporting locations

Table 7.51 Peak flow for the existing condition and per cent change in peak flow for the operational phase of the proposal

Flow reporting location	Peak flow (m^3/s) – existing conditions							% change in peak flow – operational conditions						
	20% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF	20% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP	PMF
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	-	-	-	-	-	21	892	-	-	-	-	-	1	2
C	-	-	-	-	-	15	1134	-	-	-	-	-	1	3
D	231	843	1271	1538	2037	2697	9535	0	0	0	0	0	0	1
E	26	421	758	989	1434	2044	9023	0	0	0	0	0	0	1
F	-	71	98	115	144	184	677	-	0	0	0	0	0	0
G	794	1270	1458	1556	1707	1898	3635	0	0	0	0	0	0	1
H	-	242	356	426	529	664	2064	-	0	0	0	0	0	-2
I	-	14	35	50	81	127	599	-	0	0	0	0	0	-2
J	-	41	69	106	230	444	3423	-	0	0	0	0	0	1
K	-	-	16	30	78	167	1524	-	-	0	0	0	-1	-3
L	-	-	-	21	77	214	3319	-	-	-	0	0	-1	-2
M	-	-	-	-	-	-	563	-	-	-	-	-	-	-3
N	-	-	-	-	-	-	1518	-	-	-	-	-	-	-4

Afflux

Predicted afflux for the operational phase of the proposal in the 20%, 5%, 2% and 1% AEP events show that afflux for the four design events is less than 0.1 metres and afflux is mostly confined to Lower Namoi Management Zone CU (refer to Figure 7.35 to Figure 7.38).

Therefore the proposal is consistent with the criteria of 0.2 metres afflux.

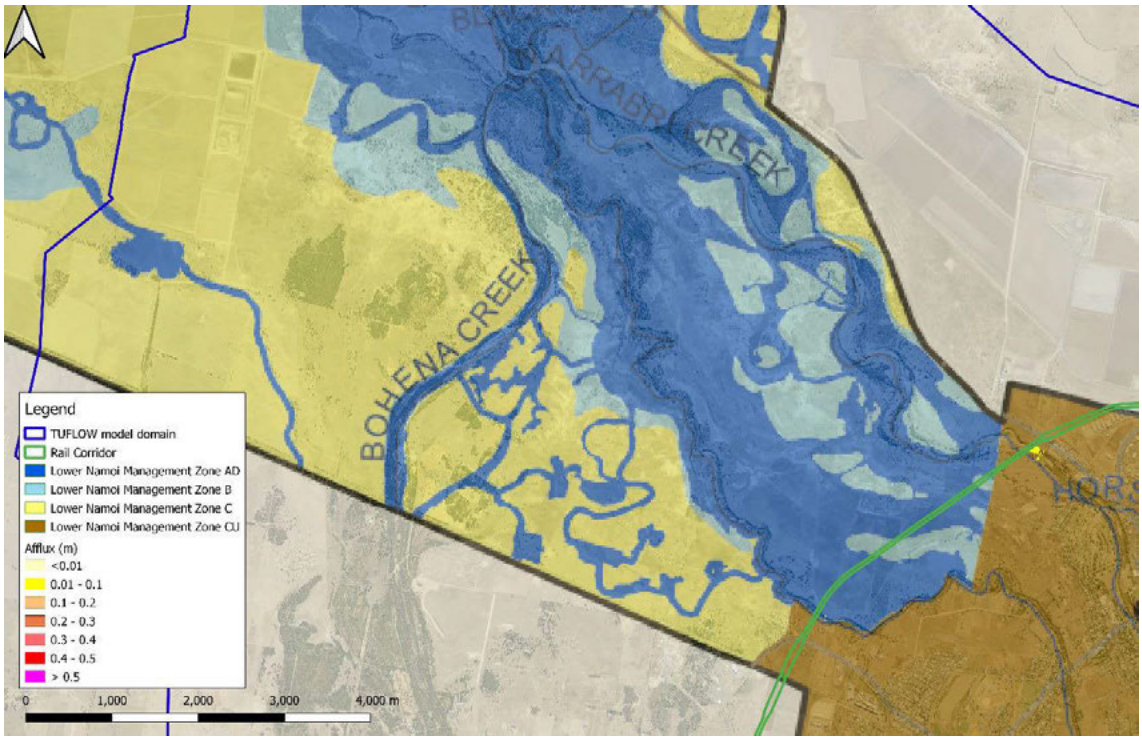


Figure 7.35 Afflux – 20% AEP event

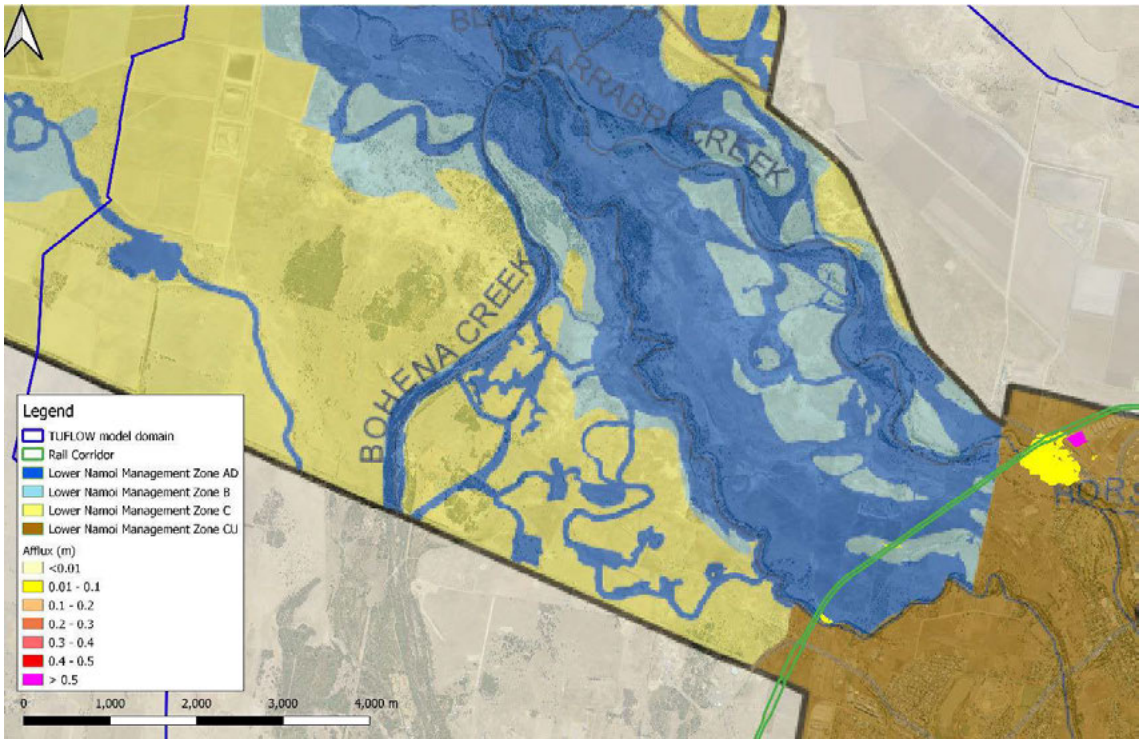


Figure 7.36 Afflux – 5% AEP event

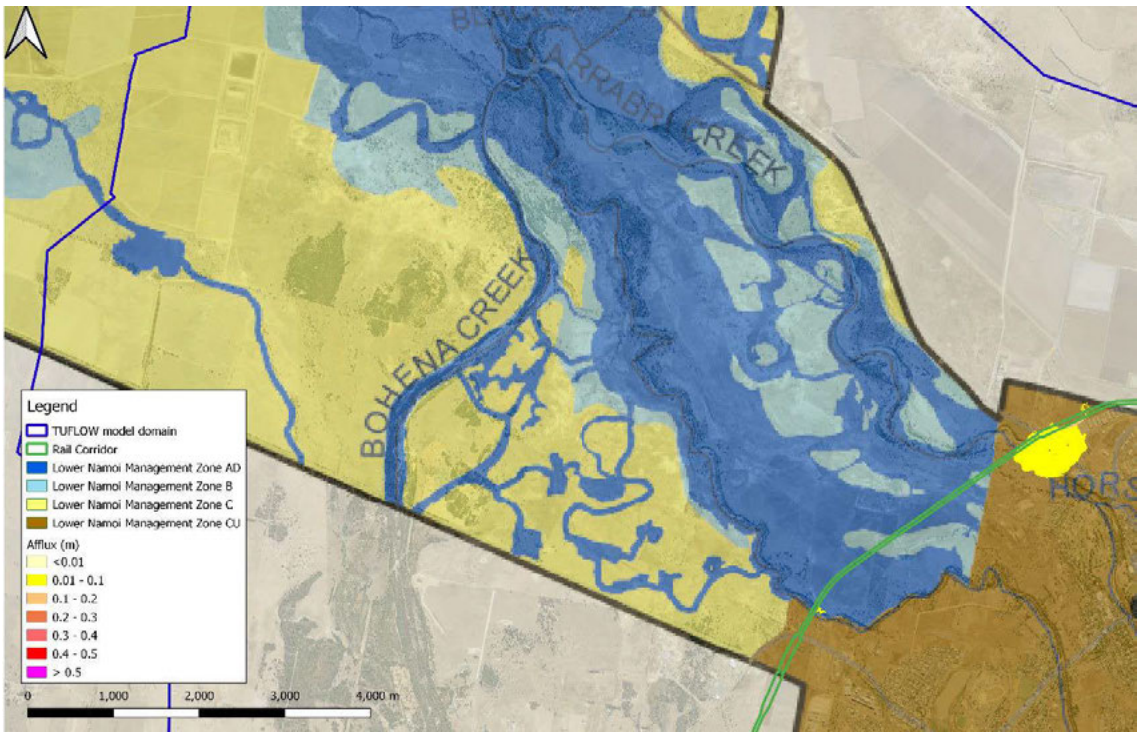


Figure 7.37 Afflux – 2% AEP event

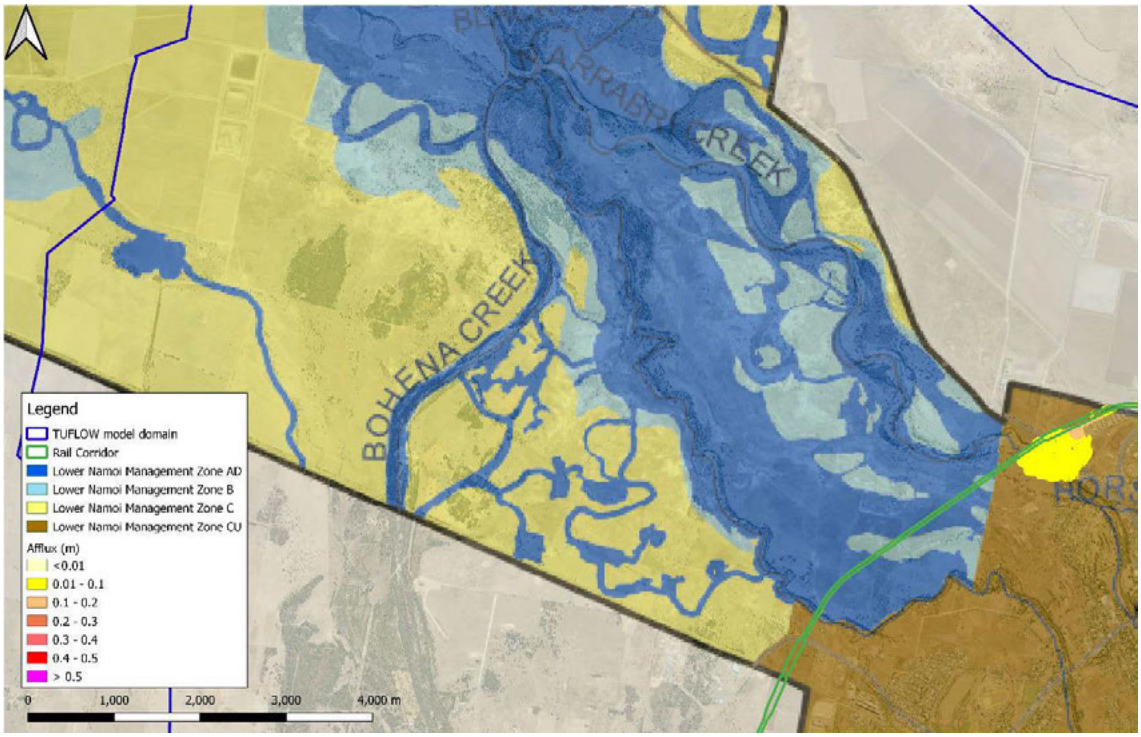


Figure 7.38 Afflux – 1% AEP event

Increase in flow velocities

The increment in flow velocity with the proposal in the 20% AEP events is almost negligible (Figure 7.39). Increase in flow velocities with the proposal in the 5%, 2% and 1% AEP events are localised at culverts located north of Narrabri Creek within Lower Namoi Management Zone CU (Figure 7.40, Figure 7.41 and Figure 7.42). Increase in flow velocities away from the proposal within Lower Namoi Management Zone AD and Lower Namoi Management Zone B are minor to negligible.

Therefore the proposal is consistent with the criteria for no more than 50% changes in flow velocities.

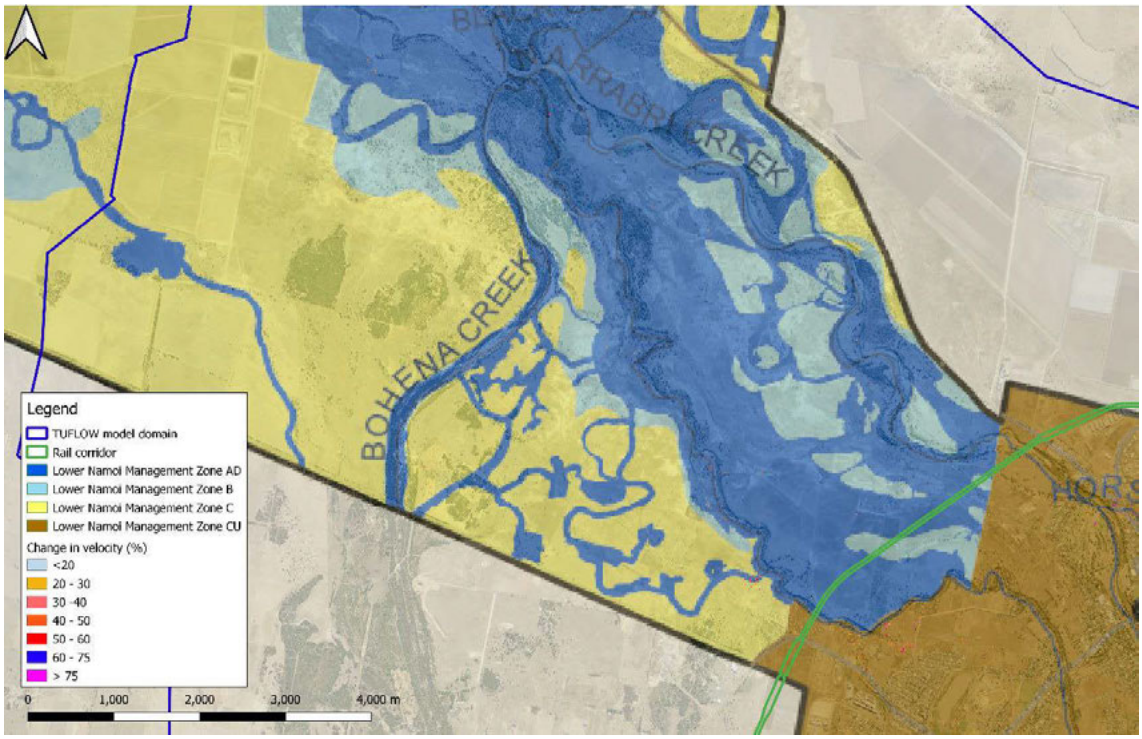


Figure 7.39 Per cent change in flow velocity – 20% AEP event

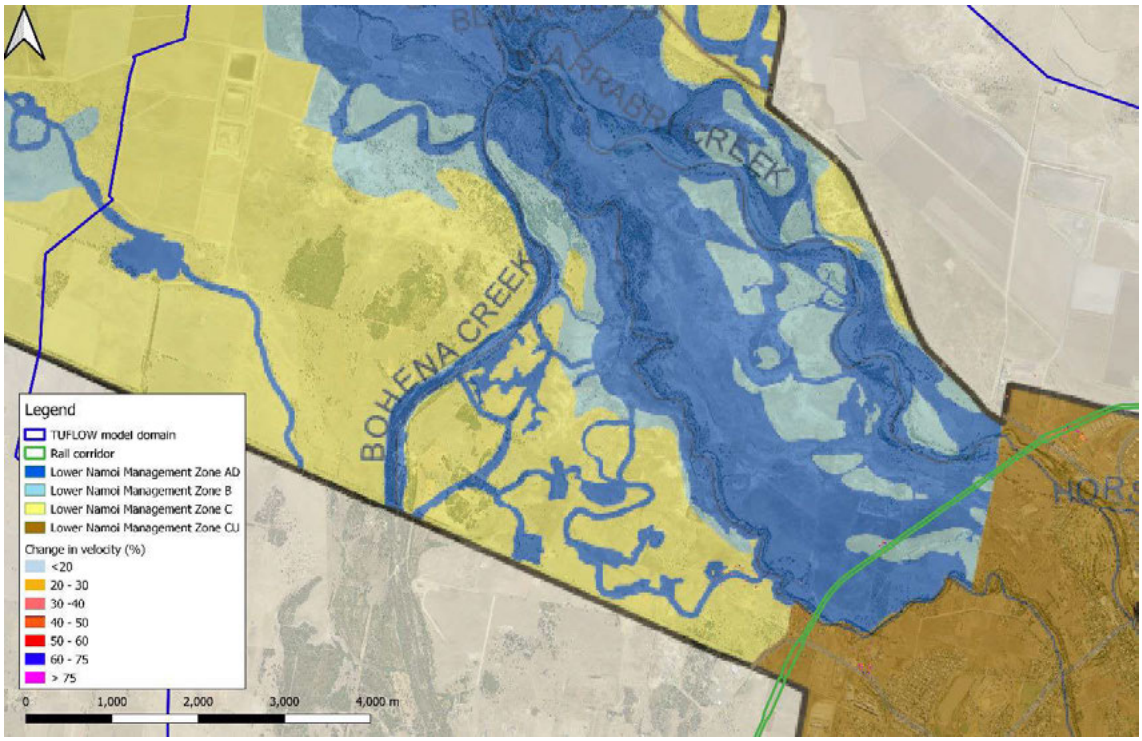


Figure 7.40 Per cent change in flow velocity – 5% AEP event

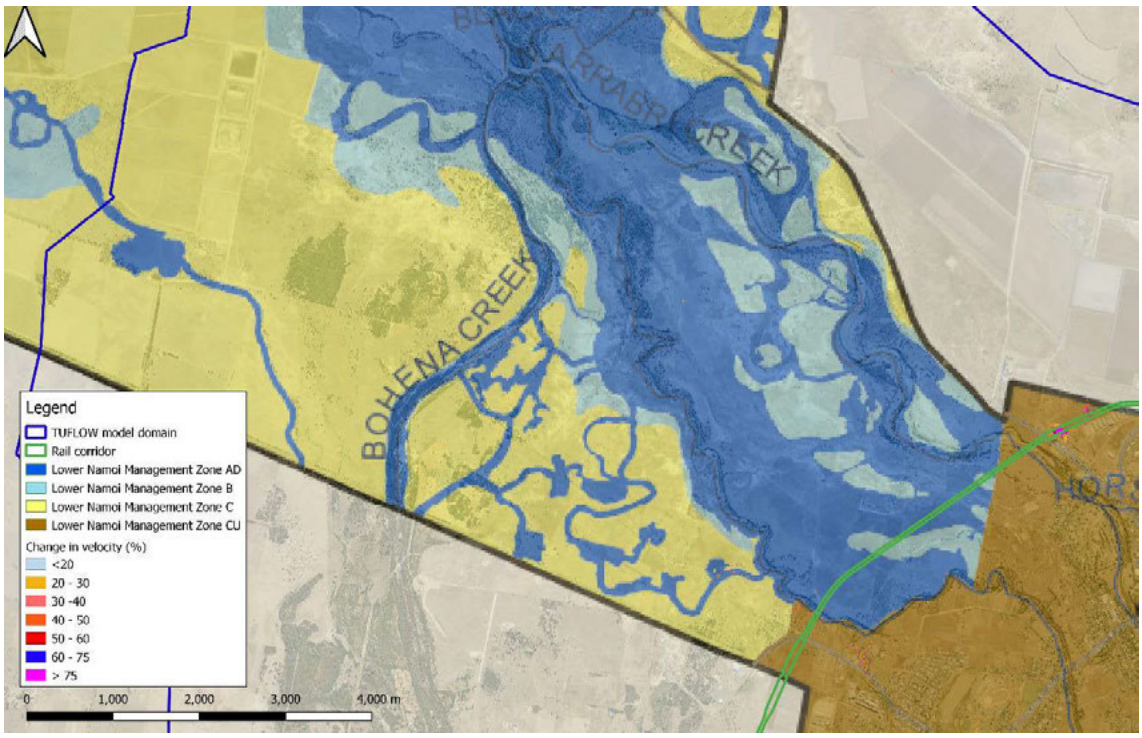


Figure 7.41 Per cent change in flow velocity – 2% AEP event

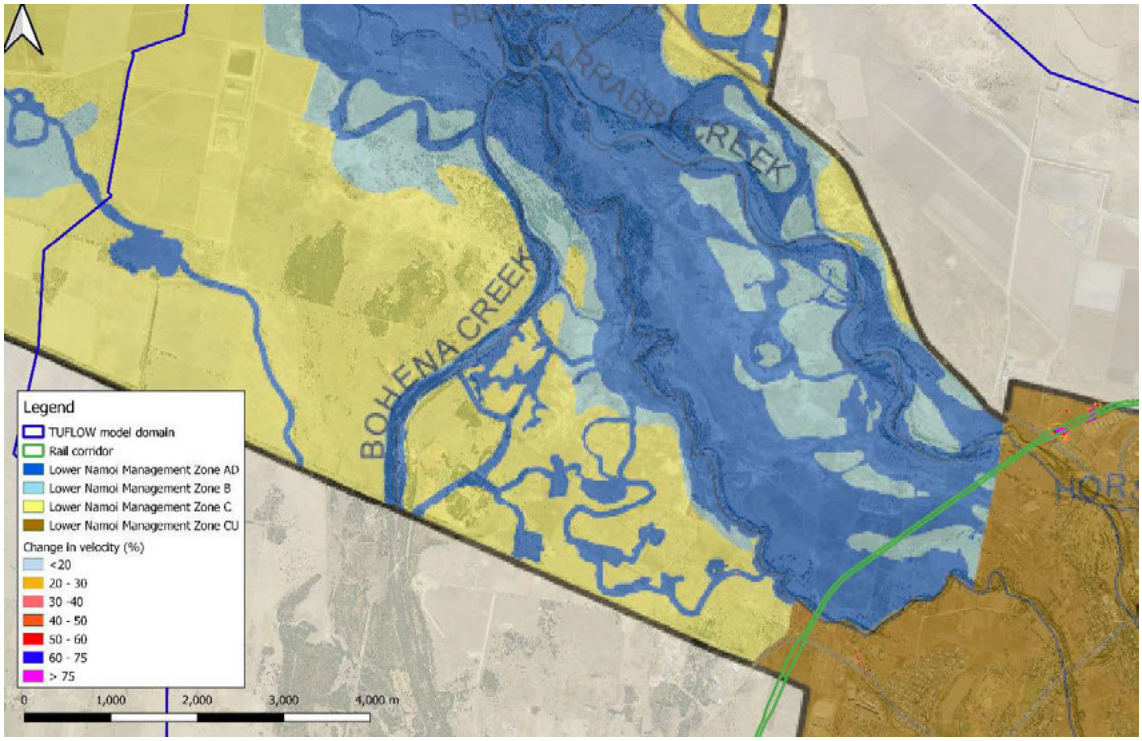


Figure 7.42 Per cent change in flow velocity – 1% AEP event

Increase in depth-velocity product

Increase in depth-velocity product with the proposal for the 20%, 5%, 2% and 1% AEP flood events show the maximum increase in depth-velocity product away from the proposal rail corridor is typically 0.05 m^2/s (refer to Figure 7.43 to Figure 7.46).

Therefore the proposal is consistent with the criteria for depth-velocity product. (refer to Section 2.2.6).

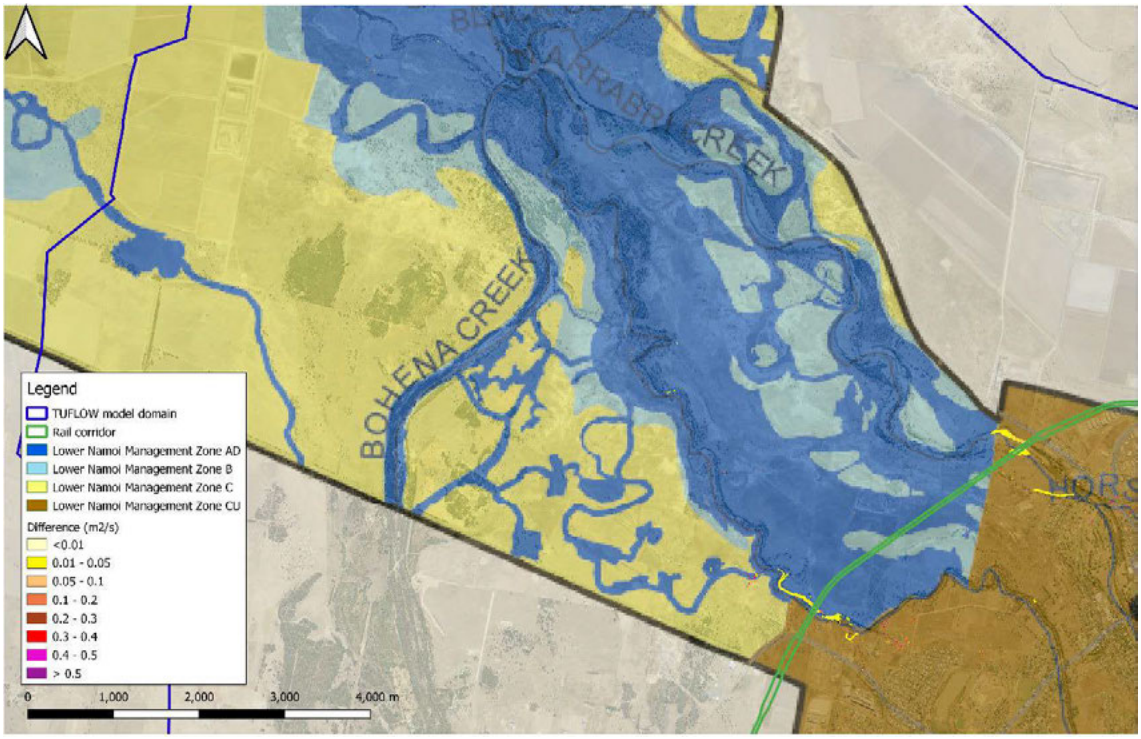


Figure 7.43 Change in depth-velocity product – 20% AEP event

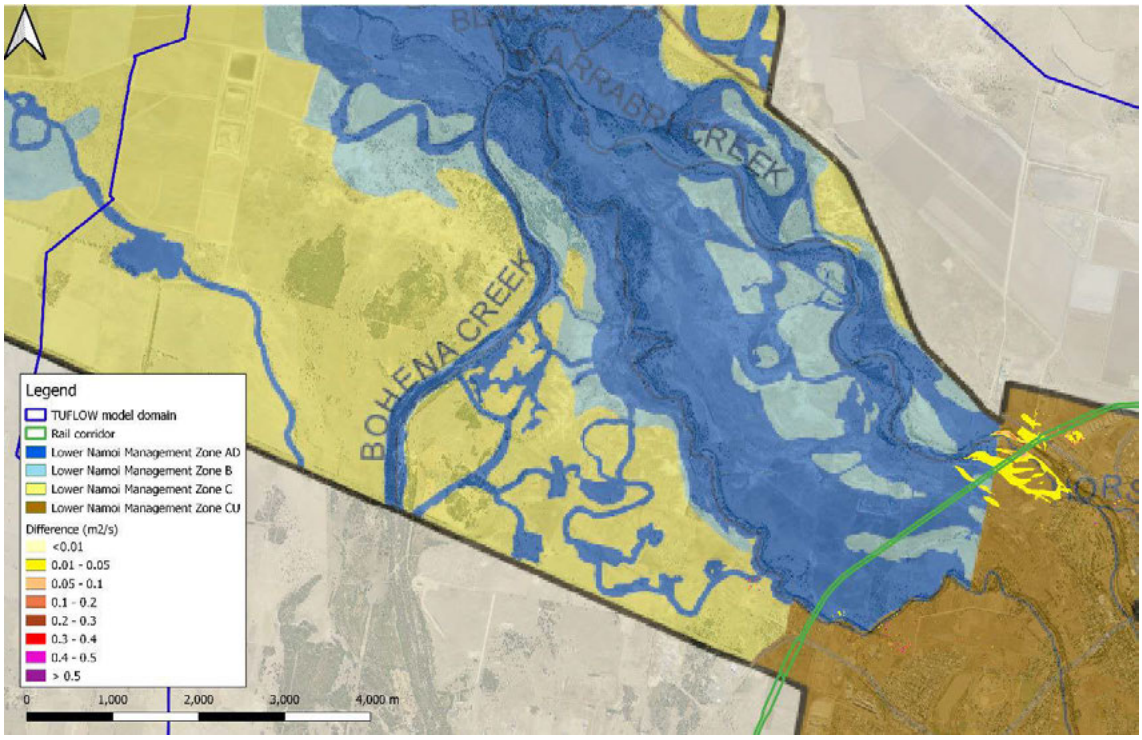


Figure 7.44 Change in depth-velocity product – 5% AEP event

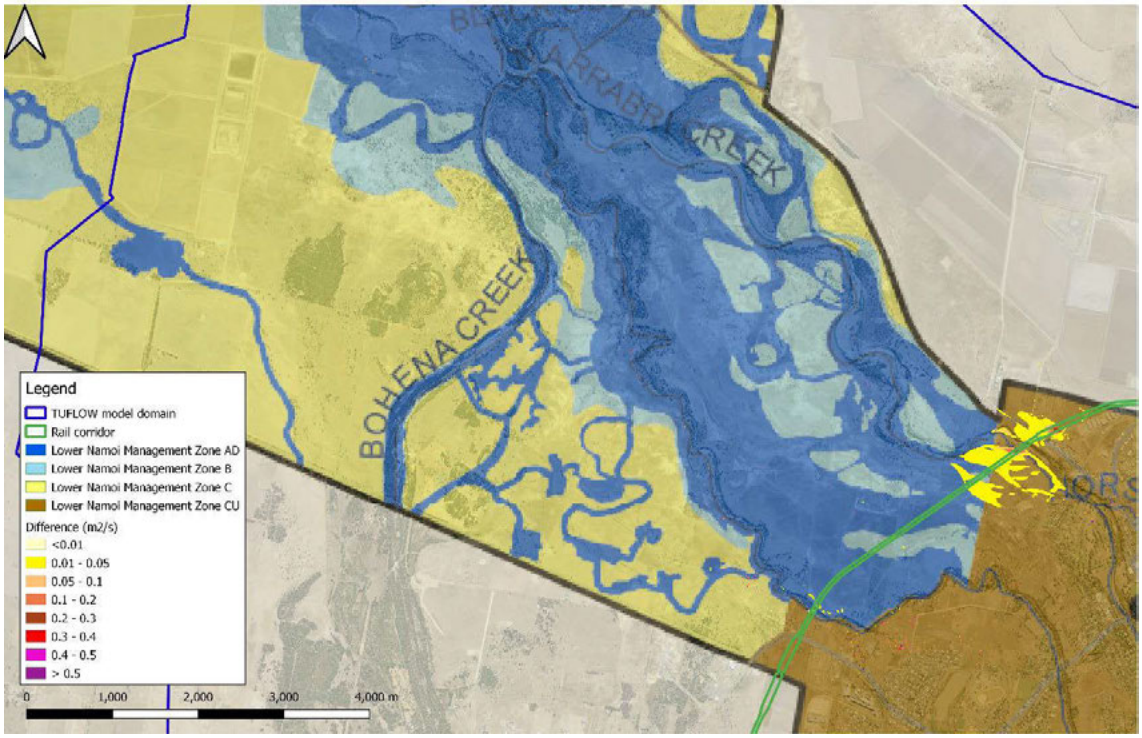


Figure 7.45 Change in depth-velocity product – 2% AEP event

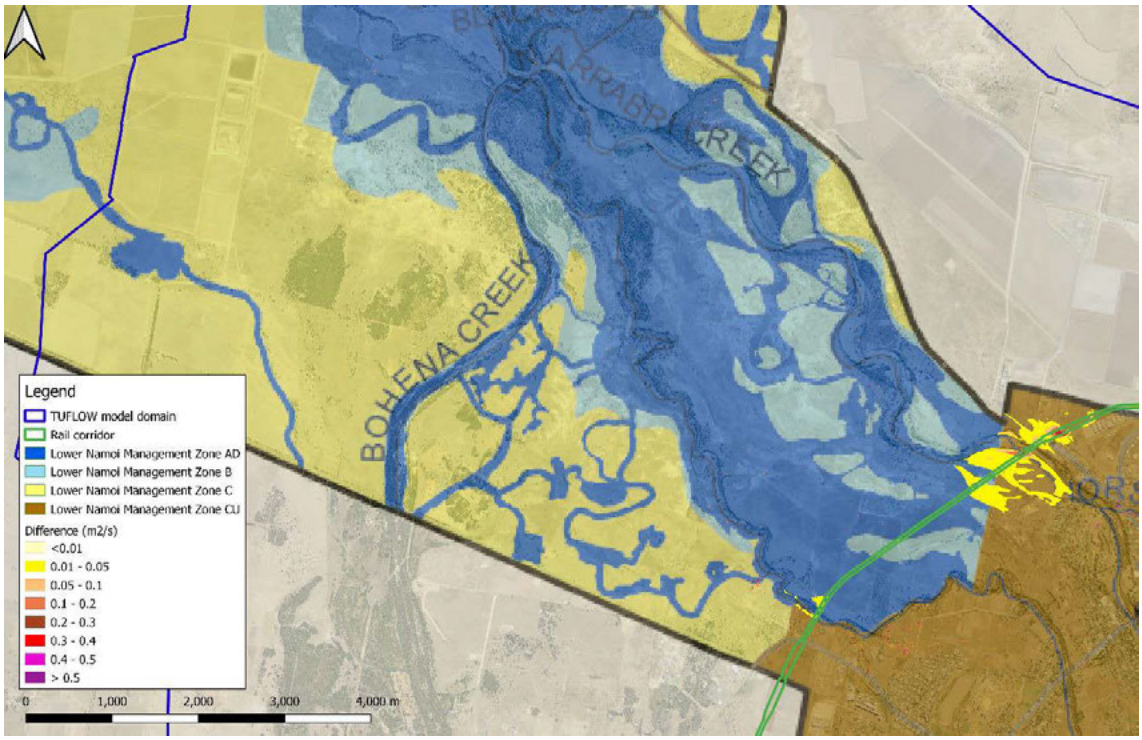


Figure 7.46 Change in depth-velocity product – 1% AEP event

Maintenance of adequate flood connectivity

The Ecological Assets Map for the Lower Namoi identifies the presence of wetlands and other floodplain ecosystems in the vicinity of the proposal. Mapping prepared for Technical Report 1 – Biodiversity Development Assessment Report confirms the presence of River Red Gum riparian tall woodland / open forest wetland in the Nandewar Bioregion and Brigalow Belt South Bioregion (PCT 78) along the banks of the Namoi River and Narrabri Creek, which is one of the identified ecological asset types for other floodplain ecosystems in the Plan. Threatened species listed in Schedule 1 of the Order are also present in these waterways.

The proposal has designed all waterway crossings in accordance with the *Policy and Guidelines for Fish Habitat Conservation and Management* (DPI, 2013) and *Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings* (Fairfull and Witheridge, 2003). As documented in Technical Report 2 – Aquatic Ecology, clearance of instream habitat and riparian vegetation has been minimised as far as practicable, no permanent obstruction is proposed and habitat functionality would be maintained.

A number of culturally modified trees have been identified through Aboriginal Heritage Information Management System (AHIMS) database searches, as documented in Technical Report 6 – Aboriginal Cultural Heritage Assessment Report. Many are located on the floodplain and are likely to be flood-dependent.

Under operational conditions there are no significant changes in flooding regimes, e.g. afflux and duration near the Namoi River and Narrabri Creek, therefore no change in flood connectivity is expected for these flood-dependent ecological assets, fish passage, or flood-dependent Aboriginal cultural values.

This finding is confirmed in the Technical Report 1 – Biodiversity Development Assessment Report, Technical Report 2 – Aquatic Ecology and Technical Report 6 – Aboriginal Cultural Heritage Assessment.

Ground disturbance at a heritage site

The proposal is expected to generate minor to negligible changes in velocities away from the rail corridor and therefore the proposal is not likely to disturb the ground surface of a heritage site or cause more than minimal erosion to a heritage site from flooding.

7.8 Consistency with Council's floodplain risk management plans

The proposal crosses floodplains which are included in the following two floodplain risk management plans (refer to Section 2.2.6):

- Narromine Town Floodplain Risk Management Study and Plan Update (Lyall & Associates, 2021)
- Narrabri Floodplain Risk Management Study and Plan (currently in preparation).

7.8.1 Narromine Town Floodplain Risk Management Study and Plan Update

The *Narromine Town Floodplain Risk Management Study and Plan Update* (Lyall & Associates, 2021) recommends implementing development controls such as the minimum habitable floor level. The minimum habitable floor level for residential land use types is defined as the level of the 1% AEP flood event plus freeboard, whereas for commercial and industrial land use types, the minimum habitable floor level is defined to be as close to the 1% AEP flood level plus freeboard as practical but no lower than the 2% AEP flood level plus freeboard. The minimum habitable floor level for flood vulnerable residential development, critical utilities and uses, and essential community facilities located on the floodplain at Narromine Town is defined as the 0.5% AEP flood event plus 0.5 metre freeboard. As the proposal will have only a minor impact on the peak 1% AEP flood levels within Narromine Town, the proposal will have no significant impact on the extent of the flood planning area and therefore the area of land to which the flood planning controls would apply.

The *Narromine Town Floodplain Risk Management Study and Plan Update* includes a measure for design and construction of a levee along the southern bank of the Macquarie River in combination with the upgrade of the existing railway culverts at Webbs Siding. The flooding assessment undertaken during development of the floodplain risk management plan (Lyall & Associates, 2021) concluded that the construction of the Inland Rail project would not compromise the level of flood protection afforded by the preferred flood mitigation scheme defined in the plan. The assessment also identified that the construction of the Reference Design of the Inland Rail proposal would result in only a minor increase in the extent and depth of inundation upstream of the rail corridor when compared to post-preferred flood mitigation scheme conditions. Therefore, the proposal would not limit or preclude the potential future levee bank works. The proposal would not preclude any further upgrades to any existing culverts under existing rail Narromine to Dubbo rail line.

The *Narromine Town Floodplain Risk Management Study and Plan Update* also *includes a*nother measure for development and implementation of a Vegetation Management Plan for the banks of the Macquarie River at Narromine. Consultation will be held with Narromine Shire Council during detailed design to ensure minimal impacts on existing vegetation along the banks of the Macquarie River due to both temporary and permanent works for the proposal.

During detailed design there would be ongoing consultation with Narromine Shire Council and DPE to further review consistency of the proposal with the Narromine Town floodplain risk management plan update.

7.8.2 Narrabri Floodplain Risk Management Study and Plan

Narrabri Shire Council has commissioned an update to the Narrabri Floodplain Risk Management Study and Plan. This work is nearing completion, but the final version has not been formally placed on public display. The proposal has therefore considered the publicly available information noted in section 2.2.7. The final version of the Narrabri Floodplain Risk Management Study and Plan will be considered as part of the detailed design and reported in the Flood Design Verification Report. Reasonable and feasible, mitigation measures will be included in the detailed design to minimise impacts on flood mitigation and management measures included in the plan.

The compatibility of the proposal with the flood hazard of the land and the hydraulic functions of flow conveyance, floodways and flood storage has been considered throughout the design process (refer Section 3.6). Firstly, an understanding of existing flood behaviour was developed including consideration of high hazard areas where significant flow conveyance occurs. This was then followed by an iterative approach to identify the minimum elevation of the rail formation, and the required location and size of hydraulic structures.

The flood models representing the operational phase of the proposal were initially run for the selected design flood events to satisfy the flood immunity requirement for the proposal. Several iterations were then undertaken to locate and size hydraulic structures required to minimise the hydraulic impacts associated with the proposal. The hydraulic structures were sized to maintain flow conveyance and to limit afflux on the upstream side of the railway in events up to the 1% AEP.

The design of each bridge and culvert structure would be further developed and refined during detailed design considering the flood hazard, and loads imposed on the structures during a flood.

7.9 Emergency management arrangement impacts

Local flood plans (refer to Section 2.2.8) outline the existing emergency management arrangements for flooding including preparedness measures before a flood, response operations during a flood, and recovery measures after a flood. The plans outline responsibilities and arrangements between SES, local and State government agencies, and community members. The proposal has the potential to impact flood response operations during a flood due to changes in flood behaviour. Any flood preparedness and recovery measures that are carried out before and after a flood has occurred would not be impacted by the proposal.

Key response measures during a flood include property protection and evacuation and traffic management. The local flood plans identify that existing property protection options are very limited in Narromine and Narrabri due to the large number of properties that can be affected by existing flooding (SES, 2014 and 2015). As identified in Section 5.2.3, there are about 1070 habitable buildings in Narromine and about 1488 habitable buildings in Narrabri that would be flooded above floor level in the existing 1% AEP event. The proposal would cause a minor increase in depth of flooding to a small proportion (about one per cent) of buildings already affected by 1% AEP flooding, but would not cause any significant increase in the number of buildings affected by flooding. Therefore, no significant impacts to the existing property protection measures identified in the relevant local flood plans are expected due to the proposal.

The existing roads and highways would be used to evacuate the community, however there are no dedicated flood evacuation routes identified within the study area. The proposal would result in negligible to minor impacts to the length and duration of flooding to roads and highways (refer Section 1.1), therefore the proposal would not result in any significant impact to existing flood evacuation, road traffic control, and road closure arrangements.

For large scale evacuation from Narrabri, existing options include via air, rail, and road (SES, 2015). During flood conditions Inland Rail trains would continue to operate until conditions are determined to render the line unsafe. Typically this would occur when floodwaters rise above the ballast. For safety reasons while trains are operating public access to the rail corridor is prohibited and the use of Inland Rail as a flood evacuation route would not be possible. Consultation carried out with the local councils regarding potential flood impacts of the proposal and emergency management arrangements for flooding is summarised in Section 4. Further consultation during detailed design would be carried out with the relevant local council and local emergency management committees, DPE, the SES and potentially impacted landholders.

Impacts of the proposal to flooding of emergency facilities are minor. The proposal results in less than 10 millimetres afflux at Narromine Hospital for all flood events up to and including the PMF event. In the case of Narrabri Hospital, the afflux in the 1% AEP event is nil and a maximum afflux of 100 millimetres in the PMF event. Both Narromine and Narrabri hospitals will be consulted during detailed design to identify any modifications required to update the current flood evacuation plans for both hospitals due to the proposal.

The proposal also has the potential to disrupt access within or between farms, including for disruption to emergency access for stock and machinery during floods. As outlined in the ARTC Inland Rail Narrabri to Narromine Agriculture and Land Use Assessment (JacobsGHD, 2020a), farming operations across the study area centralise their operations around a central 'hub' located where they are 'high and dry' which allows for all weather access. The ARTC Inland Rail Narrabri to Narromine Agriculture and Land Use Assessment (JacobsGHD, 2020a) includes an assessment of impacts such as property severance, impeded access (both internally and to public roads), and isolation of farming hubs. To minimise severance of properties and potential impacts of impeded access and isolation the design of the proposal has sought to follow property boundaries as far as practicable. In addition, the proposal would include new level crossings at intervals along the main alignment, allowing for the efficient and safe crossing of the rail corridor by vehicles, machinery and livestock (JacobsGHD, 2020a). These new level crossings could also be used during times of flood. Further refinement of property access arrangements would be carried out in consultation with local landowners during detailed design. Further discussion regarding potential impacts to agricultural activities is provided in Section 7.10.

7.10 Social and economic impacts

7.10.1 Community impacts

Social impacts of flooding on the community relate to the intangible impacts such as the stress, anxiety, and ill-health that can be associated with the effects of flood inundation. These are often caused by the disruptions that flooding has to daily life, such as property damage, clean-up work, reduced access to supplies, restricted vehicular access, potential isolation, loss of electricity and telephones, odour associated with flood water, leeches/snakes, debris and rubbish, sewage spills, the risk of infection, ponding and slow drainage (time of inundation) after the flood event.

The proposal would not cause any significant broad scale social impacts as a result of changes to flood behaviour. Locally, the proposal would impact on the general connectivity between some agricultural land parcels and movement of cattle and farm machinery between paddocks during a flood event. Most owners of farming properties may have evacuation procedures specific to their individual circumstances, which may include arrangements between neighbouring owners or family members which are not formalised or documented. ARTC is continuing to consult with property owners directly impacted by the proposal about potential property impacts and opportunities to minimise impacts on the use and functioning of rural properties. Further discussion on potential impacts to agricultural activities is provided below.

Economic impacts of flooding are those tangible financial impacts as a result of damage or loss caused by floodwaters to buildings, infrastructure, and agricultural activity, as well as costs associated with loss of wages, loss of production, and clean-up costs.

The proposal would cause some minor impacts associated with increased depth and duration of flooding to a number of buildings in Narromine and Narrabri that are already affected by flooding. These impacts would be minimised as far as practicable through further design refinement during detailed design and ongoing consultation with local emergency management committees.

The impact of the proposal on flooding to roads and rail infrastructure is generally negligible with only minor changes to the length and duration of flooding affecting existing roads and railways (refer Sections 1.1 and 0). As a result, the economic impacts of the proposal in relation to existing road and rail infrastructure damage would also be negligible.

7.10.2 Impacts to agricultural activities

The socio-economic impacts of flooding on agricultural land and agricultural production can be both positive and negative across the study area with the net effect depending on the agricultural enterprise under consideration. The general characteristics of flooding that could impact on agricultural land use are timing (season), volumes, duration (number of days) and frequency of flood events. Production impacts will change depending on the type of land use (e.g. grazing versus cropping) and also from one property to another depending on the type of enterprise and the proportion of the total property affected. The modelling under the 20% AEP flood event shows that the majority of the cropping and grazing areas are currently subject to less than 24 hours of inundation above 0.5 metre flood depth. Given the proposal would not cause any broad scale changes to flood behaviour, these potential impacts are expected to be negligible.

While the impacts from flooding could differ across the study area, above average rainfall and widespread flooding can replenish underground and surface irrigation water sources and can have a beneficial impact in future years arising from soil and water changes. While a flood will not only generate financial benefits in increased stocking rates, more assured cropping patterns and deliver greater profits, there are also significant social and environment benefits derived. These socio-economic benefits such as security of family life, economic and environmental sustainability while interdependent of each other can be apparent for some years after a flood event.

Across floodplain communities, the economic benefits associated from flooding events on agricultural land are widely recognised and the benefits gained from these flooding events may be apparent for some years after the event. A flood event usually results in guaranteed cropping in the first year, with further opportunities to establish a crop in the subsequent years. In addition, small follow up rainfall events across the study area will also be of greater benefit because of residual sub-soil moisture.

Similarly, for grazing enterprises, following a flood event, there is also the opportunity to increase stock numbers due to increases in crop and pasture production and generally cattle numbers increase more than sheep as cattle can readily adapt to wet conditions and can be more readily made available on an agistment arrangement. The benefits from increased grazing will be accrued in the first year following a flood event and then declines in subsequent years as the quality and quantity of feed available declines.

Flood events can also deliver improved ecological outcomes and can trigger dormant seed species to sprout and increase plant density while many native plants and animals are generally adapted to the natural cycles of floods and droughts that are widespread across rural and regional Australia.

The effects of flooding and the subsequent impacts on agricultural land will depend on a number of factors including velocity and flow, soil types, depth and duration of the event, amount of soil and debris deposited, the pasture species/crop type and the season or growth phase of the plants. Some of the damages caused by floods that could impact on the productivity and profitability of agricultural enterprises within the study area include:

- Potential for stock losses due mainly to issues with management
- Potential to ruin existing forage crops and pastures which may not regrow for some months
- Environmental damage, growth of woody weeds and loss of some species
- Interrupted access and interruption to management including minor damage to fencing and roadways.

Floods can impact on grazing enterprises through reduced carrying capacity on land as a result of loss of pastures and could also bring a range of animal health problems. In some areas there could be waterlogging that can reduce crop and pasture growth, promote weed incursion and potentially damage or kill pastures. While some pastures can be tolerant to waterlogging the impact of inundation and duration on pastures species includes:

- Short term duration (less than seven days) can (a) damage sensitive species and (b) can deliver subsequent benefits by wetting the soil profile to depth that enables active growth after recession.
- Medium term duration (from seven to 14 days) can severely affect sensitive species.
- Extended duration (more than 14 days) will kill introduced productive pasture species and will set back moderately tolerant species.

The modelling (Sections 7.2 and 7.4) shows that the average duration of flooding will be generally less than 24 hours in duration and therefore should avoid the medium and extended duration impacts on pasture species outlined above. The duration of flooding on agricultural land will be largely unaffected by the proposal. In addition, there would be no significant change in the extent of flooding on grazing and cropping lands. Therefore, the impact the proposal would have on flooding to cropping and grazing lands would also be minor.

Damage to pasture and crop yields are modest at low flow durations and then increase before reaching a threshold level that causes pasture and crop death. Pastures that have become severely damaged or killed might require resowing/ renovating to restore their productive capacity to pre-flooding levels. This will require direct costs of pasture re-establishment (seed, fertiliser, herbicides, machinery, labour etc.) and also the cost of providing feed for livestock for a period while the newly sown pasture becomes established and is able to be grazed again by livestock. Given the generally short term duration of flooding across the study area, it is not expected that pastures will be required to be resown or renovated following a 1% AEP flood event.

Floods can also cause environmental damage and promote weed invasions on crop and pasture land. Flood affected pastures are less vigorous and therefore less able to out-compete weeds. In addition, the flood event provides an opportunity to carry novel weed seeds onto agricultural land where they were not previously established, resulting in additional time and costs to manage. Sediment and soil properties naturally vary within a river reach, so therefore floods can also remove significant amounts of topsoil over large areas from one property and deposit it on a downstream property. Given the proposal would not cause any broad scale changes to flood behaviour, these potential impacts are expected to be negligible.

As outlined in the *ARTC Inland Rail Narrabri to Narromine Agriculture and Land Use Assessment* (JacobsGHD, 2020a), farming operations across the study area centralise their operations around a central ‘hub’ and have been located in these areas as they are ‘high and dry’ which allows for all weather access. While this key agricultural infrastructure is generally located outside of flood prone land, peak flood events can still cause damage to internal roads, fencing (including the collection of debris along fence lines) and cause equipment to bog or livestock to become isolated. Given the proposal would not cause any broad scale changes to inundation of agricultural land, these potential impacts are expected to be minor to negligible.

Flood events can also result in both interrupted access and interruption to management. Interrupted access occurs on land that is not directly flooded but which cannot be accessed by agricultural landholders during a flood event. Interrupted access is a function of the topography of the land and internal road network and the impacts can be many and varied. Interrupted access could lead to lost grazing opportunities and/or interruptions to crop and livestock husbandry that could reduce production and profitability. Given the proposal would not cause any broad scale changes to inundation of agricultural land, these potential impacts are expected to be minor to negligible.

Interruption to management is where landholders are required to divert time and energy away from their normal property management when confronted with flooding and may result in the landholder incurring additional costs to ensure the efficient operation of agricultural land. In addition, diversion of land manager time to flood management could reduce oversight of agricultural enterprises which in turn could cause production losses. Given the proposal would not cause any broad scale changes to inundation of agricultural land, these potential impacts are expected to be minor to negligible.

Subject to detailed design and construction planning, about 30 farm dams would be directly impacted by the rail corridor and may be permanently lost as a result of the proposal. About another 20 dams are located outside the rail corridor, but within the construction footprint (including drainage control areas). Where possible, dams within the construction footprint and outside the rail corridor would be retained and returned to the landowner at the completion of construction. The location of dams within the proposal site is shown in the Map Book (which is available separately).

Overall, the flooding and hydrology impact of the proposal on farming operations and activities is highly dependent on the circumstances of each farming business. In addition to general impacts such as land inundation, potential impacts include changes to emergency access for stock and machinery during floods, changes in water flows to dams and loss of dams and associated infrastructure. Measures, including any compensation or replacement works as relevant, to address these impacts would be considered during detailed design on a property-by-property basis as part of the land acquisition process in accordance with the *Land Acquisition (Just Terms Compensation) Act 1991*.

Given the proposal would not cause any broad scale changes to flood behaviour, the impact of flooding impacts on agricultural land uses as a result of the proposal are generally negligible.

7.11 Climate change impacts

The 1% AEP event has been selected for assessment of potential impacts due to climate change. This scenario involves simulation of the 1% AEP event with a 22.8 per cent increase in rainfall depth for both the existing and design cases, based on recommendation of ARR 2019 to adopt the RCP 8.5 by the year 2090 as defined in Section 3.7.3.

The same runoff routing parameter values, spatial and temporal distribution of rainfall, and rainfall losses adopted in the simulation of the 1% AEP event have also been adopted for the climate change scenario.

The 1% AEP flood levels upstream of the proposed hydraulic structures would increase by up to a maximum of 1.78 metres as a result of climate change impacts. The median increase would be 0.07 metres.

Figure 7.47 provide details of the number of habitable buildings at risk of flooding above floor level in 2090, with modelled effects of climate change, with and without Inland Rail.

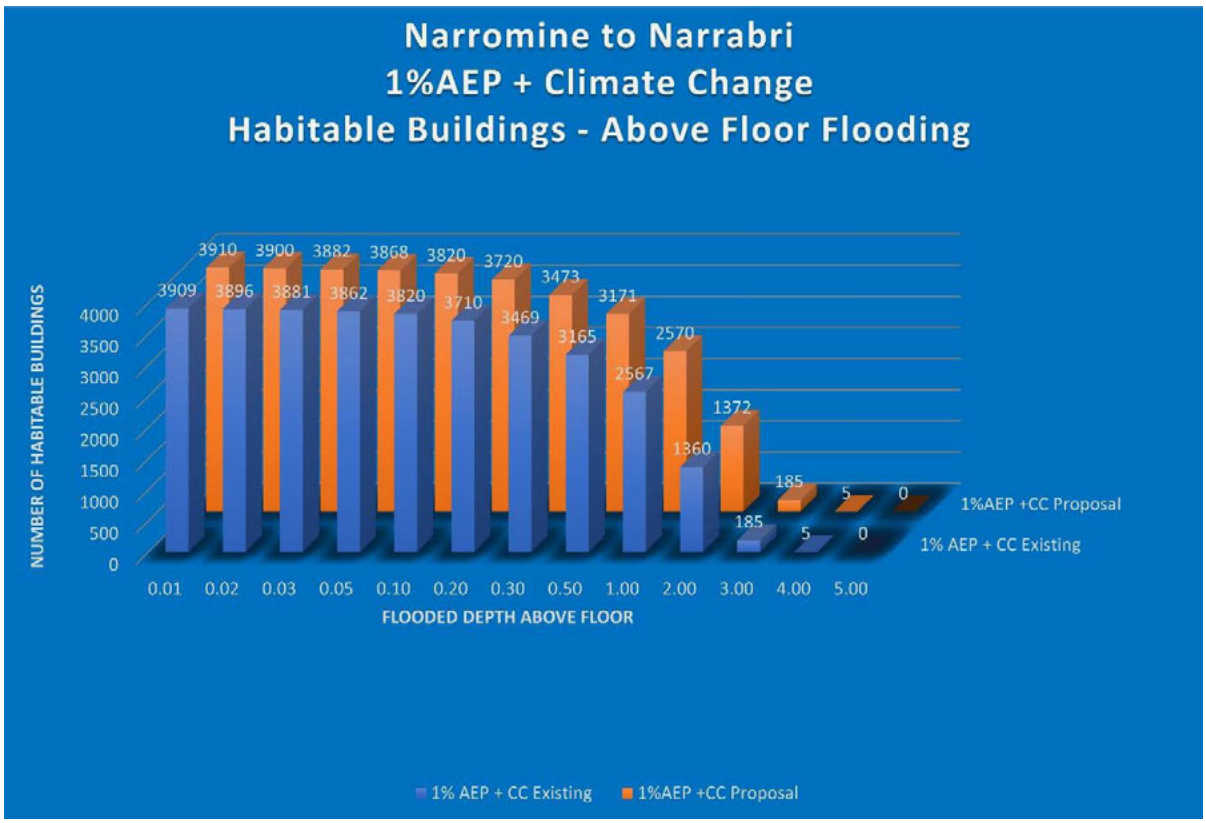


Figure 7.47 1%AEP + Climate Change – Habitable Buildings Above Floor Flooding

7.12 Risk of rail formation overtopping and failure

7.12.1 Railway embankment design and construction

A typical section for the track formation design showing the earthworks, ballast, sleepers and rail is shown in Figure 7.48. The example provided is for locations where there may be poor ground conditions and shows a layer of higher quality fill protecting the embankment face. The embankment would be vegetated and in high risk areas, additional erosion protection would be considered either through planting with species having deep roots to bind the soil, geotextile fabrics or rock rip-rap.

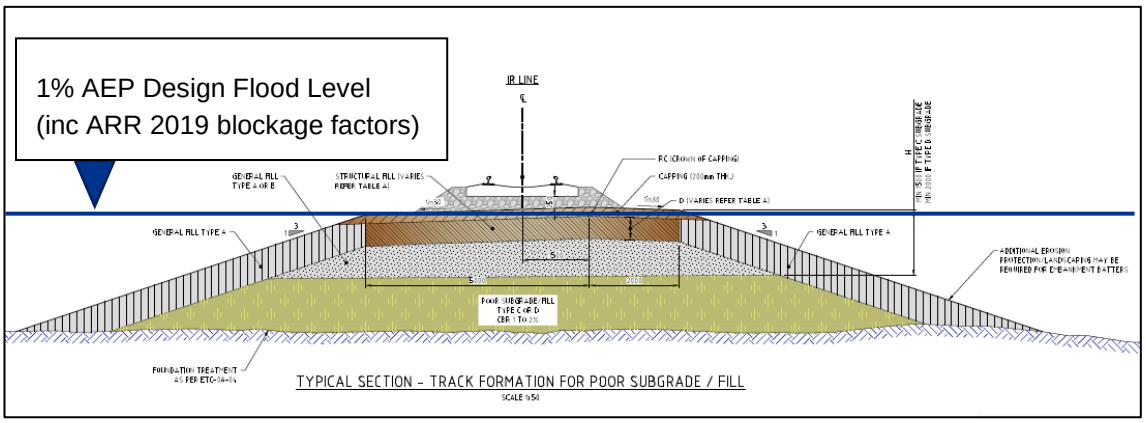


Figure 7.48 Typical formation design (poor subgrade / fill)

The layers within the rail formation are summarised in Table 7.52.

Table 7.52 Rail formation layers

Rail formation layer	Thickness	Description
Earthworks embankment	Height varies to suit rail alignment and topography	General fill layer with structural fill topping.
Capping layer	200 mm	Low permeability compacted crushed rock.
Ballast	250 mm	Graded rock approx. 40 mm
Sleepers	220 mm	Concrete sleepers spaced at 600 mm centres
Rail	170 mm	Continuously welded steel rail fixed to top of concrete sleepers.

As noted in Section 3.2.1, the design level for the 1% AEP flood level, including the application of ARR 2019 blockage factors is at the shoulder corner of the formation capping. This implies that the capping layer should not be overtopped in the 1% AEP event.

The geotechnical design for the railway embankment earthworks would be in accordance with ARTC standards and the Inland Rail Project Services Requirements.

In particular, the design would comply with ARTC's standard – Track and Civil Code of Practice – Section 10 Technical Note ETD-10-02 Section 10.1.4:

> ***10.1.4 Load Combinations for design of railway formation for Greenfield Sites***
>
> *Under the action of the design flood event, the formation shall be designed for forces exerted by hydrostatic pressure on one or both sides of the formation, in combination with coexisting rail traffic loads, when they produce more adverse effects. The effects of any draw forces exerted by flood receding waters and loss of any formation materials due to scouring shall be taken into consideration.*

7.12.2 Risk of overtopping

In flood events greater than the 1% AEP event, there is a risk that the railway formation could be overtopped. The failure mechanism of the embankment would be dependent on the specific site conditions, including the height of the embankment, construction materials / soils, depth of overtopping, batter slope, vegetation cover / surface protection, local topography, flood flowpaths and the water level in the flood plain downstream of the rail embankment.

In general terms, as water levels rise above the 1% AEP event, the capping layer would be overtopped and water would commence to flow through the ballast. The capping layer is a 200 millimetre compacted stone layer that would have some resistance to flood flows. Water would flow through the ballast and, if upstream and downstream flood levels are similar on either side of the embankment, the ballast would not be expected to erode. However, as floodwaters overtop the rail, floodwaters can damage railway tracks by scouring the ballast. In these locations, the track would be inspected after the flood recedes and train services recommenced once the track is certified as being safe. Some local minor repairs may be required, but generally the water would be expected to drain away with little, if any, damage to the track structure.

In some instances, track overtopping in events greater than the 1% AEP flood could result in local damage to the rail embankment. These events would be managed by ARTC in accordance with its NSW Lease Agreement. The damage would be assessed and repairs carried out.

7.12.3 Risks from embankment failure

The proposal passes predominantly through rural agricultural land and forestry with very low density housing. Two major population centres located within the vicinity of the project are located at Narromine and Narrabri. The project includes a 1,170 metres long viaduct across the Macquarie River and its floodplain upstream of the Narromine township. A 3,940 metres long viaduct is included in the project downstream of the township of Narrabri to cross the main channels of the Namoi River and Narrabri Creek and their floodplains. In the event of the rail embankment failing, it is therefore unlikely that there would be an additional risk to life or property at the two major population centres, over and above the existing conditions in an extreme flood event.

The highest risk of culvert blockage resulting in track overtopping would be in forested areas around the Pilliga. A rail embankment failure in these areas would disrupt Inland Rail services but is unlikely to present a risk to life or property. The risk of debris blockage from fallen trees in the Pilliga Forest will be reviewed as part of the detailed design. Mitigation measures would be adopted, such as debris deflection devices or increased culvert capacities, to eliminate track overtopping in the 1% AEP event (with blockage applied) and reduce overtopping in rarer flood events.

Locations where there is a risk of the rail embankment overtopping will be reviewed as part of the detailed design and consideration will be given to providing sacrificial low points and additional erosion protection to mitigate embankment failure. Protection measures would be site specific and consider the overall flood impacts and differential water levels on either side of the rail embankment.

Overtopping of the top of the rail formation (shoulder of embankment) was checked at the reference design stage for the:

- 1% AEP flood event, including application of ARR2019 culvert blockage factors
- 0.2% AEP event
- 0.05% AEP event

Results are presented in Appendix K and summarised below.

Overtopping in the 1% AEP event + ARR2019 blockage factors

Overtopping locations in the 1% AEP + ARR2019 debris blockage event include the following:

- To the south of Narromine, between kilometrage 547 kilometres and 548 kilometres. Overtopping in the 1% AEP event in this location is expected as the flood immunity transitions from the 5% AEP event on the Parkes to Narromine railway to the 1% AEP event on the Narromine to Narrabri section. The height of the embankment between kilometrage 547 kilometres and 548 kilometres varies between 0 metres and 1.28 metres. Two non-residential buildings and the Narwonah siding are located within close proximity of the 0.6 metres high embankment. The siding buildings are unlikely to be impacted due to failure of the 0.6 metres high embankment. However, the other two non-residential buildings could be impacted due to overtopping failure of the embankment. The McGrane Way is located approximately 1,100 metres downstream of the railway and the additional risk to people due to a potential failure of the rail embankment is considered low.
- Three isolated locations along Pinedean Road at approximately 553 kilometres, 555 kilometres and 556 kilometres. The height of the embankment varies between 0.25 metres and 1.9 metres and two residential and nine non-residential buildings are located approximately 750 metres downstream of the embankment. Additional risk to people and property due to a potential failure of the rail embankment is considered low. These locations will be further investigated during detailed design.
- Kilometrage 577 kilometres, along Eumungerie Road. The alignment is along a ridge line running parallel to Eumungerie Road and track overtopping would not be expected. Further investigations will be carried out in detailed design to confirm local drainage modelled along Inland Rail and Eumungerie Road.
- Kilometrage 622 kilometres, Leeches Creek Road level crossing. Drainage works around the Leeches Creek Road level crossing will be further investigated in detailed design to remove the overtopping risk.
- Locations within the Pilliga forest at approximately 762 kilometres, 763 kilometres, 779 kilometres, 780 kilometres, 791 kilometres, 793 kilometres, 795 kilometres, 802 kilometres-803 kilometres. Track formation overtopping in these locations has resulted from application of a 100 per cent blockage factor at culverts in these areas. This blockage risk will be reviewed and reduced in detailed design by replacing culverts with bridges or constructing debris deflection structures.

Overtopping in the 0.2% AEP event

Overtopping locations in the 0.2% AEP event would be similar to those listed above for the 1% AEP + blockage, plus:

- Kilometrage 561 kilometres – Backwater Cowal. The height of the embankment varies between 1.2 metres and 3.5 metres and one residential, and 18 non-residential buildings are located about 800 metres downstream of the embankment. Widespread regional flooding from the Macquarie River is expected in this location during extreme flood events. A potential failure of the embankment would have low risk to life and property.
- Kilometrage 672 kilometres – North of Gilgandra. Local overtopping of track formation, but no significant upstream flood extents. Negligible risk due to embankment failure resulting in additional risks to downstream properties.

- Kilometrage 849 kilometres – Auscott Sidings, level crossing to Narrabri sewage treatment plant. In this location, the track vertical alignment has been dictated by providing access to the Narrabri sewage treatment plant via a level crossing. In the regional flood event, there is widescale flooding from the Namoi River on both the upstream and downstream sides of the proposed railway. Water levels on either side of the rail embankment would therefore expected to be similar and there is a low risk of a dam break scenario occurring.

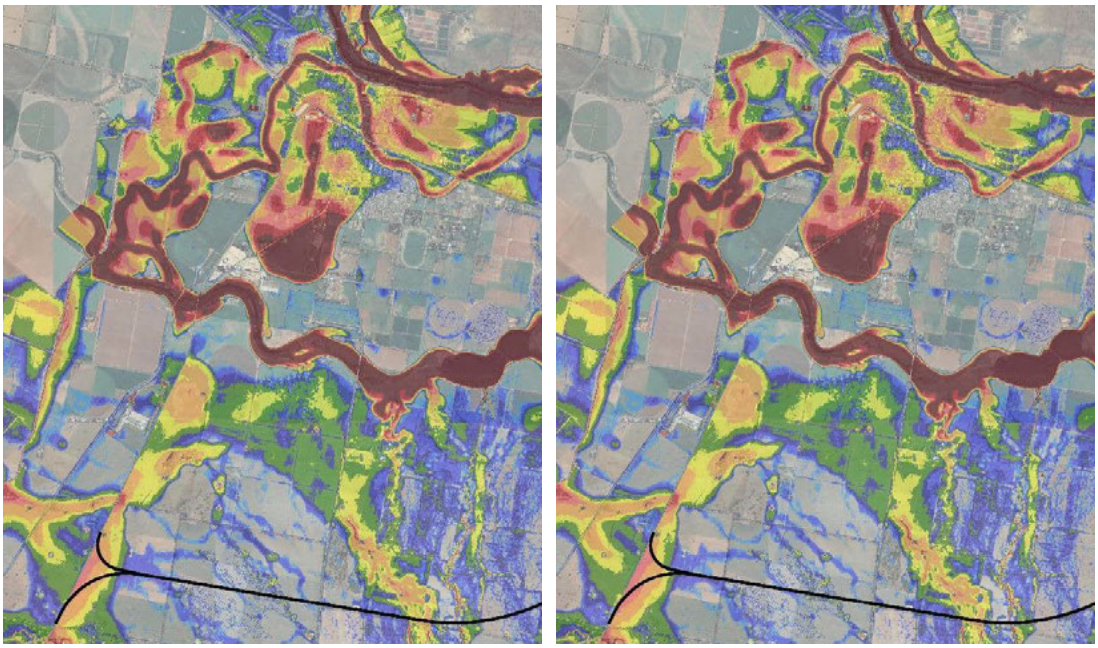
Overtopping in the 0.05% AEP event

Overtopping locations in the 0.05% AEP event would be similar to those listed above for the 0.2% AEP plus:

- Kilometrage 553 kilometres to 556 kilometres – The embankment is overtopped at a number of sections and the maximum height of the overtopped embankment is 1.75 metres. One residential and six non-residential buildings are located approximately 1,600 metres downstream of the embankment and all buildings are subject to flooding in the 0.05% AEP event under the existing conditions. Tomingley Road is located a further 500 metres downstream of the buildings and the road would be impassable in the 0.05% AEP event. Any potential failure of the embankment is expected to result in negligible additional risk to people and property located downstream of the embankment.
- Kilometrage 598 kilometres to 599 kilometres – The embankment is up to one metre high and overtopped in the 0.05% AEP flood event. Seven non-residential buildings are located 300 metres downstream of the embankment and the buildings are not subject to flooding in the existing conditions. Any potential failure of the one metre high embankment is expected to result in negligible additional risk to people and property located downstream of the embankment.
- Kilometrage 821 kilometres to 822 kilometres – The embankment is overtopped in the 0.05% AEP event due to flooding in Bohena Creek and the maximum height of the embankment is about 2.6 m. One residential and 11 non-residential buildings are located about two kilometres downstream of the overtopped sections of the embankment and the residential building and 9 non-residential buildings are subject to flooding in the 0.05% AEP event. An access track, impassable in the 0.05% AEP event, is located approximately 1,700 metres downstream of the embankment. Any potential failure of the 2.6 metre high embankment is expected to have low incremental risk to people and property located downstream of the embankment.
- Kilometrage 830 kilometres to 831 kilometres – Bohena Creek runs north along the western side of the embankment and the Newell Highway runs parallel to the embankment about 90 metres east of the embankment. The maximum height of the embankment is about 3.1 metres. Extensive flooding occurs on both sides of the embankment and the section of the Newell Highway located within the vicinity of the overtopped sections of the embankment is subject to, at least, two metres depth of flooding in the 0.05% AEP event. Hence any potential failure of the 3.1 metre high embankment is likely to have negligible additional risk to people and property.

7.12.4 Impacts on existing Narromine to Dubbo railway at Webbs Siding

Submissions received on the EIS noted that the existing Narromine to Dubbo railway had failed during the 1955 flood event. This is an existing railway operated by ARTC and is not part of the Narromine to Narrabri proposal. It was reconstructed after the 1955 flood and it is understood that it has not overtopped since that date. Potential failure of the Narromine to Dubbo rail embankment at Webbs Siding was however modelled to address the community submissions. This concluded that the existing railway is at risk of overtopping between the 2% and 1% AEP flood events and that this risk would not be increased following construction of Inland Rail. A dam breach analysis was carried out to model potential failure of the Narromine to Dubbo rail embankment at Webbs Siding for the 1% AEP and 0.5% AEP flood events. This analysis indicated that no discernible changes in flood extent or depth of flooding due to potential failure of the Narromine to Dubbo rail embankment at Webbs Siding between the Reference Design and the existing condition both in the 1% AEP (refer to Figure 7.49).



Existing condition Reference Design

Figure 7.49 Comparison of flood depths with potential failure of Narromine to Dubbo rail embankment at Webbs Siding in the 1% AEP event

7.13 Consideration of alternative alignments

Inland Rail has undergone a progressive route development and selection process since 2006, each stage refining the focus on what is required to deliver the Inland Rail program. The route options process for the proposal involved two main phases which commenced following confirmation of the initial alignment and development of the base case for Inland Rail in 2015. The process has been rigorous and involved a comprehensive review of options for a feasible route.

Flooding and hydrological considerations were taken into account in determining the study area, the narrowed focused area of investigation and finally the preferred rail corridor.

Refer to the combined Preferred Infrastructure / Amendment Report and Route Selection Summary Report for a detailed description of the route selection process and justification for selection of the preferred route.

7.14 Geomorphology

A geomorphological assessment was carried out using the method outlined in section 3.10. The risk of adverse impacts to watercourses was assessed with reference to flood modelling results for the proposal.

7.14.1 Geomorphological impacts

The proposal has been designed to preserve natural flood pathways along rivers and major watercourses. Bridges extend over watercourses and flood relief culverts are provided within the floodplains. Culverts have been provided at minor watercourses and within flood plains. In some locations, existing overland sheet flows would be conveyed by culverts through the rail embankment.

Overbank flooding during high discharge events could result in channel avulsion, i.e. when a river channel jumps from its original course to an entirely new course, often occupying a formerly minor watercourse. This type of channel movement could occur within the broad outwash plains of the Pilliga Forest and Macquarie Floodplain geomorphic units. Project structures would limit the chance of this, as the location of channels will be fixed at the alignment.

In-channel migration / avulsion of channels is likely, particularly along the broad, multi-thread systems of Gulargambone Creek, Marthaguy Creek, Castlereagh River, Bohena Creek and the Namoi River / Narrabri Creek system. However, this is a natural process, and it is not anticipated that this would be adversely impacted by the proposal.

It is possible that in-stream structures, such as culverts and bridge piers could influence flow and sediment dynamics, locally controlling sediment dynamics (patterns of erosion / deposition) and in-channel active channel migration. In general culvert invert levels would be designed to avoid upstream sedimentation and downstream scour (or vice versa).

Site specific assessments were carried out for 24 sites (see Erosion Potential and Fluvial Geomorphology Assessment in Appendix O). Further targeted site-specific assessments would be undertaken during the next phase of the Project where watercourses or overland flows have been identified requiring further geomorphological / erosion assessment or where QDLs are exceeded. This information would inform detailed design of in-stream structures to limit adverse impacts.

7.14.2 Operational watercourse sensitivity

A sensitivity assessment was carried out on 81 defined watercourses between Narromine and Narrabri using the following parameters (refer also to 3.10.5):

- Erosivity: Design values of unit stream power at 20% AEP (assumed as equivalent to bank-full) and maximum velocity at 1% AEP (as per QDLs), from the TUFLOW flood model outputs.
- Stabilisation: In-channel and riparian vegetation was assumed to remain constant, based on landscape rehabilitation within the proposal corridor and drainage control areas.
- Erodibility: watercourse fragility, existing erosion and geotechnical soil properties would stay constant.

The stream power and maximum velocities changed slightly along some of the smaller watercourses. Therefore, changes in sensitivity class were mainly seen where the existing sensitivity is close to the classification threshold. The majority of changes were within the low or very low classes, i.e. there are not anticipated to be significant increases in watercourse sensitivity during the operations phase of the proposal. The modelled change in sub-reach velocities and stream power were typically lower than the modelled existing variability over the 40 metres assessed reach for each watercourse.

In terms of geomorphic functioning, therefore, the sensitivity analysis based on flood modelling for this EIS indicates that there will be negligible impact during the operations phase of the proposal. This would be confirmed by site specific assessments as part of the detailed design, focussing on the locations where changes have been noted in Appendix A.

Table 7.53 Change in Watercourse Sensitivity

Change in watercourse stream power	Number of watercourses	Change in watercourse sensitivity	Number of watercourses
No change	75	No change	75
Very Low to Low (increase)	3	Low to Medium* (increase)	2
Low to Very Low (decrease)	2	Medium to Low (decrease)	4
Medium to Low (decrease)	1		
Total	81	Total	81

* Watercourses showing an increase from Low to Medium sensitivity were minor flows at CH552360 and CH749279

8 Recommended mitigation measures

8.1 Mitigation measures

Measures to avoid, minimise or manage impacts to flooding, hydrology and geomorphology are detailed in Table 8.1.

Table 8.1 Mitigation measures

Stage	Issue/impact	Mitigation measures
Detailed design / pre-construction	*Flooding impacts*	The design would continue to be refined where practicable to not worsen existing flooding characteristics for flood events up to and including the 1% AEP event. Detailed flood modelling would assess potential impacts to: • Building and property inundation (including floor level surveys and consideration of existing inundation levels) • Existing rail line, at rail connections • Road flood levels and extent of flooding along roads • Flood evacuation routes • Overland flow paths and storage effects of construction and operational infrastructure Flood modelling would have regard to the guidelines listed in Section 2 and the revised quantitative design limits provided in Section 3.2.2. Flood modelling, and any mitigation identified as an outcome of modelling, would consider floodplain risk management plans, and would be undertaken in consultation with the relevant local council and local emergency management committees, the Department of Planning, Industry and Environment, the NSW State Emergency Service and potentially impacted landholders.
	Downstream watercourse stability	Further modelling and site specific assessments would be undertaken during detailed design to confirm the locations downstream of culverts and within drainage control areas that require erosion protection, and to confirm the extent and type of protection required.
Construction	*Flooding impacts*	Construction planning and the layout of construction work sites and compounds would be undertaken with consideration of overland flow paths and flood risk, avoiding flood liable land and flood events where practicable.
		A flood and emergency response plan would be prepared and implemented as part of the CEMP. The plan would include measures, process and responsibilities to minimise the potential impacts of construction activities on flood behaviour as far as practicable. It would also include measures to manage flood risks during construction and address flood recovery during construction. The plan would be developed in consultation with Transport for NSW, local councils, emergency services and key affected landholders/managers (including Forestry Corporation of NSW).

Stage	Issue/impact	Mitigation measures
	Downstream watercourse stability	A geomorphology monitoring program would be implemented in accordance with the soil and water management plan. The monitoring would observe changes in the geomorphological stability of the waterways that may be attributable to the proposal and to inform appropriate management responses. Site-specific geomorphic assessments of watercourse crossings would be undertaken to inform the design process. The final design would minimise adverse impacts to geomorphic stability and functioning. Appropriate rehabilitation measures would be proposed in accordance with A Rehabilitation Manual of Australian Streams (Rutherfurd et al. 2000). 'Soft' engineering measures, such as use of vegetation would be preferred, to avoid 'hard' in-stream engineering structures, with consideration of the limited extent of direct impact. The monitoring program would be developed in consultation with the Department of Planning, Industry and Environment and with reference to the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Governments, 2018).
	Flooding impacts (temporary accommodation facilities)	The Narromine South and Narrabri West temporary workforce accommodation facilities would incorporate appropriate flood protection measures, such as elevating buildings on stilts and storing hazardous materials above the flood levels that inundate these sites.

8.2 Mitigation measures examples

ARTC has several projects across NSW with similar flooding issues. While the QDLs and conditions of approval may be different for the proposal the examples below indicate typical mitigation measures implemented by ARTC to manage flooding impacts that could not be addressed by design refinements. As explained above, each exceedance of the QDLs is considered on a case by case basis to achieve the best outcome for the landowner and ARTC.

8.2.1 Parkes to Narromine project – levee bank

As part of the Parkes to Narromine project, during detailed design, a house was identified with an afflux flood level exceedance above 10 millimetres. ARTC had already engaged with the landowner extensively and during the detailed design phase worked to develop a mitigation measure suited to their situation. While only one house on the property had a floor level exceedance, ARTC agreed to install a larger levee bank (Figure 8.1) that protected the house, the machinery shed and various other buildings and tennis court. The levee bank has not only prevented the impacts caused by the project afflux but has also meant the house, machinery sheds and other structures on the property are now protected from pre-existing flooding.

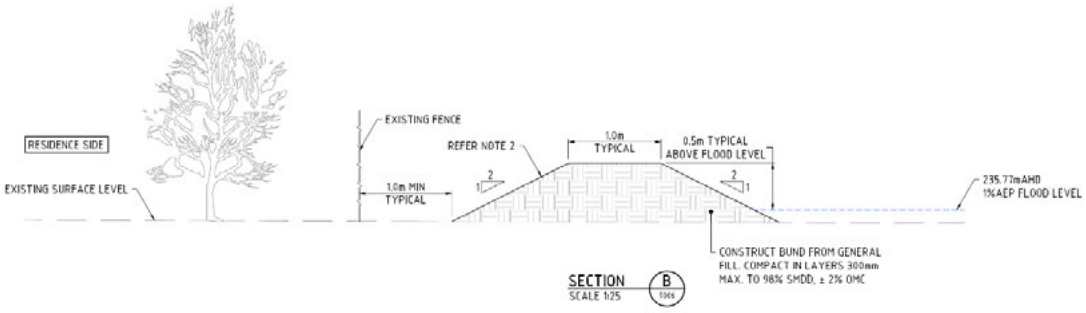


Figure 8.1 Parkes to Narromine project – levee bank example

8.2.2 Parkes to Narromine project – management of velocities and erosion

While most sections of the Parkes to Narromine project were brownfield, several concerns were raised during detailed design consultation about erosion or lack of vehicle access for landowners during wet weather. As a result, ARTC modified its design on several occasions.

As shown in Figure 8.2, ARTC extended the scour protection beyond the requirements set in the QDLs to assist the landowner in protecting a pre-existing drainage problem. The earthworks also assisted the landowner to cross the watercourse with stock during dry weather.

Figure 8.2 Parkes to Narromine project – scour protection example

In other situations, landowners had pre-existing issues traversing waterways after heavy rain which impacted their farming operations. In these cases, ARTC looked at extending scour protection into their property and adapted the design to allow the scour protection to be used as an access road (Figure 8.3). These works improved efficiencies of farming operations after wet weather.

Figure 8.3 Parkes to Narromine project – scour protection with access road example

8.3 Proposed construction monitoring program

A geomorphological monitoring program would be implemented in accordance with the soil and water management plan as part of the construction environmental management plan for the proposal. The monitoring would observe any changes in the geomorphological stability of the waterways that may be attributable to the proposal and to inform appropriate management responses. The program would be developed in consultation with DPE and relevant councils and with reference to *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Governments, 2018).

The monitoring frequency during construction would be confirmed during detailed design however would include at least monthly construction monitoring at all monitoring sites, including event-based monitoring where practicable, following wet weather events. The physical condition of bed and banks of the waterway upstream and downstream of railway culverts and bridges should be regularly monitored, particularly after flooding once the channels have returned to low or cease-to-flow conditions so to permit inspection of the condition of the waterway and instream structures. The outcomes of this monitoring would also inform asset maintenance works (i.e. removal of sediments, blockages, repair of bed and bank stabilisation works).

9 Summary of key findings and conclusion

9.1 Existing environment

The proposal traverses the catchments of the Namoi River, the Castlereagh River and the Macquarie River. While these catchments rise near the Great Dividing Range, the study area itself is characterised by moderately flat catchments and floodplains. Major land uses within these catchments include grazing, dryland cropping, forestry and conservation.

The study area is characterised by widespread flooding impacts under existing conditions, in particular near Narromine, within the Warrumbungles watershed and near Narrabri. Under existing conditions for both regional and local flooding:

- A total of 2570 habitable buildings are subject to above floor flooding in the 1% AEP event increasing up to 5267 habitable buildings in the PMF event, with the majority of these subject to high flood hazard and up to more than two days duration of inundation in the PMF event.
- A total of 3628 non-habitable buildings are impacted in the 1% AEP event increasing up to 7177 non-habitable buildings in the PMF event, with the majority of these subject to high flood hazard and up to more than two days duration of inundation.
- A total of about 48.6 kilometres of classified roads managed by TfNSW are subject to flood inundation in the 1% AEP event.
- A total of about 90.3 kilometres of other sealed roads are subject to flood inundation in the 1% AEP event.
- A total of about 1,250 km of unsealed roads are subject to flood inundation in the 1% AEP event.
- A total of about 22 kilometres of existing rail lines are subject to flood inundation in the 1% AEP event.
- About 130,000 hectares of land (within the study area) is subject to flood inundation in the 1% AEP event, including extensive areas of forestry, grazing lands and cropping lands.

9.2 Construction phase

The construction phase of the proposal has the potential to change existing flood behaviour. Construction compounds and activities such as earthworks, stockpiling, crane pads and instream works have the potential to obstruct the passage of floodwater and overland flow, which in turn could exacerbate existing flooding conditions. An assessment of potential impacts during the construction phase identified that relative to flooding under existing conditions, the construction impacts are minor.

Prior to construction, flood and emergency response plans would be prepared and implemented as part of the CEMP. The plans would include measures, process and responsibilities to minimise the potential impacts of construction activities on flood behaviour as far as practicable. It would also include measures to manage flood risks during construction and address flood recovery during construction.

9.3 Operational phase

Flooding impacts resulting from the proposal have been assessed against QDLs that have been established, in consultation with DPE. These relate to changes in afflux, velocity, flood hazard and duration. The limits are based on relevant policies, planning controls and guidelines, other Inland Rail projects, and similar infrastructure projects in NSW. Adoption of these limits minimises changes to the existing flood regimes with respect to public safety, buildings, existing highways and roads, existing rail lines and land uses.

The assessment against the QDLs (for events up to and including the 1% AEP event) are summarised in Table 9.1.

Table 9.1 Summary of QDL assessment

Parameter	Land use or setting / scenario	QDL exceedances
Afflux	Habitable buildings	23 habitable buildings
	Non-habitable buildings	28 non-habitable buildings
	Urban and infrastructure land	1.61 hectares
	Agricultural land	120.6 hectares
	Other non-urban land	367.2 hectares
	Classified roads managed by TfNSW	2.1 kilometres
	Highways and sealed roads >80 km/hr (ex TfNSW)	6.0 kilometres
	Sealed roads < 80 km/hr and all unsealed public roads	26.2 kilometres
Velocity	Sealed surfaces – sealed land surfaces	3.5 hectares
	Sealed surfaces – sealed roads	277 metres
	Unsealed surfaces – unsealed land surfaces	935.2 hectares
	Unsealed surfaces – unsealed roads	16.4 kilometres
Flood hazard	Habitable buildings	Nil
	Non-habitable buildings	4
	Urban and infrastructure land	4.2 hectares
	Classified roads managed by TfNSW	1.4 kilometres
	Highways and sealed roads (ex TfNSW)	4.0 kilometres
	Elsewhere (other land)	714 hectares
	Unsealed roads	18.0 kilometres
Flood duration	Habitable buildings	13 habitable buildings
	Classified roads managed by TfNSW	0.5 kilometres
	Highways and sealed roads >80 km/hr (ex TfNSW)	2.0 kilometres
	Sealed roads < 80 km/hr and all unsealed public roads	19.3 kilometres
	Elsewhere (other land)	1036 hectares

Overall there are no widespread departures from the quantitative design limits. When looking at the departures, within the study area the following key conclusions are made:

- Habitable buildings – 23 are predicted to be impacted by afflux. This represents about one per cent of habitable buildings subject to above floor flooding under existing conditions in the one per cent AEP event. Of the impacted habitable buildings, one is newly flooded above floor by 4 millimetres (afflux of 11 millimetres) in the one per cent AEP event. All other impacted habitable buildings are subject to above floor flooding from 40 millimetres to 1.48 metres under existing conditions and would experience afflux varying from 11 to 58 millimetres.
- Non-habitable buildings – 28 are predicted to be impacted by afflux. This represents less than one per cent of non-habitable buildings subject to above floor flooding under existing conditions in the one per cent AEP event. Of the impacted non-habitable buildings, one is newly flooded above floor by 21 millimetres (afflux of 27 millimetres) in the one per cent AEP event. All other impacted non-habitable buildings are subject to above floor flooding from 85 millimetres to 1.51 metres under existing conditions and would experience afflux varying from 21 to 181 millimetres.
- Land areas – in total 1,621 hectares of land is predicted to be impacted. This represents about 1.3 per cent of the land areas within the study area subject to flooding under existing conditions in the 1% AEP event.
- Highways and other roads – in total about 46 kilometres of highways and roads are predicted to be impacted. This represents about 9.7 per cent of highways and roads subject to flooding under existing conditions in the one per cent AEP event.

9.4 Operational phase - Rare flood event assessment

The updated assessment of the proposal against larger flood events (one per cent AEP with climate change event up to the probable maximum flood (PMF) event) identified the following key findings:

- A total of 5,267 habitable buildings are subject to above floor flooding under existing conditions in the PMF event. With the proposal, 3,147 would experience an afflux of greater than 10 millimetres and the majority are already flooded above floor under existing conditions.
- A total of 7,177 non-habitable buildings are subject to above floor flooding under existing conditions in the PMF event. With the proposal, 3,408 would experience an afflux of greater than 20 millimetres and the majority are already flooded above floor under existing conditions.
- The average duration of inundation for impacted habitable and non-habitable buildings would be similar to those experienced under existing conditions.
- There are only minor to negligible changes in flooding impacts to highways and roads, and existing rail lines.
- There are only minor to negligible changes in areas of major land uses (forestry, cropping and grazing areas) subject to flooding.

9.5 Geomorphology

The watercourses and landscape within the study area are strongly controlled by both geology and fluvial process / form interaction. The proposal traverses broad alluvial, colluvial and outwash plains, with unconfined overland flows and indistinct grassy swales. Defined watercourses are typically incised and sinuous, with several fast-flowing, high energy rivers. The construction and the operation of the proposal has the potential to impact on the watercourses within the study area. Potential impacts to geomorphology could result from:

- Bank, bed, sheetwash and gully erosion causing sedimentation of watercourses
- Removal of in-channel and riparian vegetation
- Changes to flow rates, volumes and flow paths within watercourses
- Construction of permanent culverts and bridges to cross watercourses altering flow patterns, sediment dynamics and water quality
- Runoff and erosion along the rail and road infrastructure.

Projected adverse impacts to watercourses are anticipated to be minor. A range of measures would be refined and/or implemented during detailed design, construction and operational phases of the proposal to minimise impacts to geomorphological functioning and surface water quality.

9.6 Conclusion

The assessment has found that there are no widespread flooding impacts associated with the proposal for events up to and including the PMF.

As part of the detailed design, drainage details along the rail corridor and connections with adjoining road culverts etc will continue to be developed and included within the digital terrain model. Where required, additional survey will be incorporated to confirm building floor levels, existing culvert levels and road levels that could form obstructions to flow paths. Flood models will be rerun and checked for compliance against the QDLs. Drainage structures will also be reviewed to mitigate impacts, where practical, including culvert spacings and potentially replacing culverts with bridge structures. The detailed design would again be checked for compliance against the QDLs.

At locations where it is not practicable to meet the QDLs, ARTC will comply with the conditions of approval.

With the implementation of the recommended mitigation measures, the proposal is expected to have minimal flooding and hydrology impacts.

10 References

Australian Institute for Disaster Resilience, 2017, *Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia,* Commonwealth of Australia.

Anon. 1936. *The maximum permissible velocity in open channels*. Gidrotekhnicheskoie Stroitel'stvo (Hydrotechnical Construction), Moscow, May, No. 5: 5-7.

Australian and New Zealand Governments, 2018, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.*

ARTC, 2013, *Engineering Practices Manual, Civil Engineering, Track Drainage – Design and Construction*.

ARTC, 2015, *Inland Rail 2015 – Melbourne to Brisbane Inland Rail*, *Attachment A: ARTC 2015 Inland Rail Programme Business Case*, Inland Rail Implementation Group Report to the Australian Government, August 2015.

ARTC, 2016, *Track and Civil Code of Practice – Section 10 Flooding – Technical Note ETD-10-02.*

ARTC, 2019, *Climate Change Risk Assessment Framework.*

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019, *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia.

Bewsher Consulting, 1998, *Narromine Flood Behaviour Study*, report prepared for Narromine Shire Council.

BMT, 2018, *TUFLOW Classic/HPC User Manual*, Build 2018-03-AC.

BoM, 2003, *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short- Duration Method.*

BoM, 2004, *Guide to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method.*

Brierley, G. and Fryirs, K., (2003). *The River Styles® framework: the short course conceptual book*. Department of Physical Geography, Macquarie University. GHD, 2010. Report on Central West CMA River Styles Assessment. Report written by GHD for Central West Catchment Management Authority.

Chang, H.H., 1988. *Fluvial Processes in River Engineering*. John Wiley & Sons, Inc., New York, 432 pp.

Chow, V.T. 1981. *Open-Channel Hydraulics*. McGraw Hill International Book Company. Tokyo, Japan.

DECC, 2007, *Floodplain Risk Management Guidelines – Practical Consideration of Climate Change.*

DECC, 2008a, *Managing Urban Stormwater, Soils and Construction Volume 2C: Unsealed Roads.*

DECC, 2008b, *Managing Urban Stormwater Soils and Construction, Volume 2D Main Road Construction*.

DIPNR, 2005, *Floodplain Development Manual, The Management of Flood Liable Land.*

DPI Fisheries, 2013 Update, *Policy and Guidelines for Fish Habitat Conservation and Management.*

Engineers Australia, 1987, *Australian Rainfall and Runoff 1987.*

Engineers Australia, 2016, *Australian Rainfall and Runoff 2015.*

Department of Industry, 2018, *Draft Floodplain Management Plan for the Macquarie Valley Floodplain 2018* - https://www.industry.nsw.gov.au/water/plans-programs/healthy-floodplains-project/plans/macquarie accessed on 14 December 2018.

Fairfull, S and Witheridge, G., 2003. *Why do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings.*

Fischenich, C.J. 2001. *Stability Thresholds for Stream Restoration Materials*. EMRRP Technical Notes Collection (ERDC TNEMRRP-SR-29), U.S. Army Engineer Research and Development Center, Vicksburg, MS.URL: http://el.erdc.usace.army.mil/elpubs/pdf/sr29.pdf (accessed 27 May 2005).

Fischenich, C.J. and Allen, H. 2000. *Stream management. Water Operations Technical Support Program Special Report* ERDC/EL SRW-00-1, Vicksburg, MS. URL: http://el.erdc.usace.army.mil/publications.cfm?Topic=techreport&Code=watqual (accessed 27 May 2005).

Fortier, S. and Scobey, F.C. 1926. Permissible canal velocities. *Transactions, American Society of Civil Engineers* 89: 940-956.

GHD, 2010. *Central West Catchment Management Authority*. Report on Central West CMA. River Styles Assessment. March 2010.

GHD, 2017. *Parkes to Narromine Project Environmental Impact Statement.*

Gippel, C.J. and Anderson, B.G. and Andersen, S. 2008. *Evaluation of the impacts of operating proposed infrastructure on geomorphology of the Chowilla Floodplain*. Fluvial Systems Pty Ltd, Stockton. Department of Water, Land and Biodiversity Conservation, Berri, June.

Jacobs, 2016, *Gulargambone Flood Study Report*, Final, prepared for Coonamble Shire Council.

JacobsGHD, 2020a, *ARTC Inland Rail Narrabri to Narromine Agriculture and Land Use Assessment*.

JacobsGHD, 2020b *Borrow Pit Rehabilitation Strategy*.

Lampert, G. and A. Short, 2004. *Namoi River Styles® Report. River Styles®, Indicative Geomorphic Condition and Geomorphic Priorities for River Conservation and Rehabilitation in the Namoi Catchment, North-East, NSW*.

Landcom, 2004, *Managing Urban Stormwater: Soils and Construction, Volume 1, 4th edition.*

Laurenson, E. M., Mein, R. G. and Nathan, R. J., 2010, *RORB version 6 runoff routing program user manual*. Monash University Department of Civil Engineering in conjunction with Hydrology and Risk Consulting Pty Ltd and Melbourne Water Corporation. RORB version 6.31.

Lyall & Associates, 1996, *Gilgandra Floodplain Management Study*.

Lyall & Associates, 2009, *Narromine Floodplain Risk Management Study and Plan.*

Lyall & Associates, 2012, *Teridgerie Creek at Baradine Floodplain Risk Management Study and Plan.*

Lyall & Associates, 2013, *Narromine River Bank Levee Feasibility Study*, prepared for Narromine Shire Council.

Nathan, R. J., Weinmann, P. E., and Gato, S. A., 1994, A quick method for estimating the probable maximum flood in South Eastern Australia. Water Down Under 94. *Hydrology and Water Resources Symposium I. E. Aust. Nat. Conf*. Publ. 94/10, pp. 229-234.

NSW Government 2019, *Floodplain Management Plan for the Upper Namoi Valley Floodplain 2019. https://www.legislation.nsw.gov.au/view/html/inforce/current/sl-2019-0234 accessed on 1 November 2020*

NSW Government 2020, *Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020. https://www.legislation.nsw.gov.au/view/pdf/asmade/sl-2020-539 accessed on 1 November 2020*

NSW Office of Water 2012, *River Styles Spatial Layer for New South Wales*. Bioregional Assessment Source Dataset. Viewed 13 March 2019, http://data.bioregionalassessments.gov.au/dataset/06fb694b-d2f1-4338-ab65-a707c02f11d7

OEH, undated, *Restrictions on Removal of Trees on NSW Water Courses.*

OEH, 1998, *Acid sulfate soils risk - http://data.environment.nsw.gov.au/dataset/0196CEB0-6981-42C8-BF09-1B8CA1D45624 access on 5 May 2017.*

OEH, 2016, *NSW Climate Change Policy Framework*.

Outhet, D. and Cook, N. 2004, "Definitions of Geomorphic Condition Categories for Streams." Unpublished internal draft paper for use throughout NSW by the Department of Infrastructure, Planning and Natural Resources.

Outhet, D., Young, C., Lampert, G., Short, A. and Schneider, G. 2004, "River Style Geomorphic Fragility" Unpublished internal draft paper for use throughout NSW by the Department of Infrastructure, Planning and Natural Resources and the Catchment Management Authorities.

Ritzema, H.P. (Ed.) 1994. *Drainage Principles and Applications*. ILRI Publication 16, Second Edition. International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands.

SES, 2008, *Gilgandra Shire Local Flood Plan.*

SES, 2013, *Warrumbungle Shire Flood Emergency Sub Plan.*

SES, 2014, *Narromine Shire Flood Emergency Sub Plan.*

SES, 2015, *Narrabri Shire Flood Emergency Sub Plan.*

SMEC, 2019 *Narromine Town Levee Concept Design,* prepared for Narromine Shire Council.

Sprague, C. 1999. Green Engineering: Design principles and applications using rolled erosion control products. Part Two. *Civil Engineering News*, 11.

Stallings, S.L. 1999. *Roadside ditch design and erosion control on Virginia Highways*. Masters of Science in Civil Engineering Thesis (unpublished), Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, September.

URS, 2012, *Review of Gilgandra Floodplain Risk Management Study*, prepared for Gilgandra Shire Council.

WRM, 2016, *Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully*, prepared for Narrabri Shire Council.

WRM, 2019a, *Narrabri Floodplain Risk Management Study and Plan, Volume I: Supplementary Flood Study - Namoi River, Mulgate Creek and Long Gully*.

WRM, 2019b, *Draft Bohena Creek Flood Study,* prepared for Narrabri Shire Council.

WRM 2020a, *Narrabri Floodplain Risk Management Study and Plan, Volume I: Supplementary Flood Study - Namoi River, Mulgate Creek and Long Gully, Addendum 1 – February 2020 Validation.*

WRM, 2020b, Draft *Narrabri Floodplain Risk Management Study and Plan, Volume II: Floodplain Risk Management Study.*