TECHNICAL PAPER 04

Hydrology and flooding impact assessment

NARRABRI TO NORTH STAR—PHASE 2 ENVIRONMENTAL IMPACT STATEMENT

Table of contents

Table of contents (continued)

List of tables

List of figures

List of figures (continued)

Appendices

Glossary and terms of abbreviation

TERM / ACRONYM	DEFINITION
AEP	Annual Exceedance Probability. The probability that a design event (rainfall or flood) has of occurring in any 1 year period.
AHD	Australian height datum
ARTC	Australian Rail Track Corporation
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
Catchment	The area drainage by a stream or body of water or the area of land from which water is collected.
CL	Continuing Loss – a rainfall runoff modelling parameter
Construction impact zone (CIZ)	The area that would be directly impacted by construction works. 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 construction compounds, storage areas and other ancillary facilities that would be used to construct that infrastructure. The CIZ term is interchangeable with ‘proposal site’ – refer to definition of ‘proposal site’ below.
Earthworks	All operations involved in loosening, excavating, placing, shaping and compacting soil or rock.
Erosion	A natural process where wind or water detaches a soil particle and provides energy to move the particle.
FPL	Flood Planning Level
GIS	Geographic information systems
IL	Initial Loss – a rainfall runoff modelling parameter
Impact	Influence or effect exerted by a project or other activity on the natural, built and community environment.
IRDJV	Inland Rail Design Joint Venture – A joint venture of WSP and Mott MacDonald set up to deliver the Feasibility design for the project.
km	Kilometres
LiDAR	Light Detection and Ranging – a remote sensing method used to obtain ground levels.
LGA	Local government area
MIKE FLOOD	A hydraulic modelling software program
N2NS	Narrabri to North Star
NSW	New South Wales
OEH	NSW Office of Environment and Heritage is a former division of the NSW Government responsible for care of the environment and heritage in NSW. The functions of the agency were assumed by the NSW Department of Planning, Industry and Environment upon its abolishment in 2019.
(the) proposal	The proposal is the construction and operation of the N2NS Phase 2 section of Inland Rail.
(the) proposal site	The area that would be directly impacted by construction works. 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 construction compounds, storage areas and other ancillary facilities that would be used to construct that infrastructure. It is referred to as the construction impact zone (CIZ) in mapping and in the EIS sections concerning construction.

TERM / ACRONYM	DEFINITION
RORB	A hydrological modelling software program
Runoff	The amount of rainfall that ends up as streamflow, also known as rainfall excess.
Study area	The construction impact zone with a 10 km buffer
TUFLOW	A hydraulic modelling software program
WM Act	Water Management Act 2000 (NSW)
Waterway	Any flowing stream of water, whether natural or artificially regulated (not necessarily permanent).
XP-RAFTS	A hydrological modelling software program

1 Introduction

1.1 Project context and overview

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. Inland Rail involves the design and construction of a new inland rail connection, about 1,700 kilometre long, between Melbourne and Brisbane. Inland Rail is a major national proposal that will enhance Australia's existing national rail network and serve the interstate freight market.

Australian Rail Track Corporation Ltd (ARTC) is seeking approval to construct and operate the N2NS Phase 2 Moree to Camurra North ('the proposal'), which consists of upgrades to approximately 15 kilometres of rail line including construction of 1.6 kilometres of new track.

The proposal requires approval from the NSW Minister for Planning under Division 5.2 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The proposal is also a controlled action under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and requires approval from the Minister for the Environment.

This report has been prepared by WSP as part of the environmental impact statement (EIS) for the proposal. The EIS has been prepared to accompany the application for approval of the proposal and addresses the environmental assessment requirements of the Secretary of the Department of Planning, Infrastructure and Environment (the SEARs), issued on 14 October 2020.

1.2 Proposal key features

The proposal involves an upgrade of approximately 13.7 kilometres (km) of existing rail corridor between Moree and Camurra North, in addition to the construction of about 1.6 km of realigned rail corridor within a greenfield area.

Key features of the proposal are:

- enhancement of about 13.7 km of existing track through minor adjustments to the vertical and horizontal alignment, and the construction of about 1.6 km of new rail corridor, including rail embankments
- demolition and reconstruction of eight underbridges, at the Mehi River, Gwydir River, Skinners Creek, Duffys Creek and at four other un-named water courses
- installation of approximately 1,100 new flood relief box culverts along the formation
- three new signalised level crossings at Gwydirfield Road, the Rocks Road and Back Pally Road replacing the existing level crossings
- realignment and changes to six private level crossings (including closure of one private level crossing)
- new turnout between the Gwydir River and Back Pally Road, immediately north of the new Gwydir underbridge, to provide a connection to the Inland Rail/North Star line to the east and the Weemelah line to the west
- decommissioning and removal of the Camurra hairpin and associated formation through the construction of the greenfield Camurra Bypass, providing connections to the existing rail lines to the east and the Weemelah line to the west
- reconstruction of a new rail spur for the Weemelah line.

Associated works would include installation of signalling systems, signage, fencing, drainage, the relocation of services and utilities where necessary and the formation of rail maintenance access roads (RMARs) within the rail corridor adjacent to the line. The construction and operation of the proposal would also require the following ancillary facilities:

- construction access and haul roads linking to the surrounding public road network
- construction storage and laydown areas
- associated earthworks for the construction of pads for piling rigs and cranes at underbridge locations.

Additional ancillary facilities could also include mobile batch plant, accommodation for construction workers and construction water supply and storage.

The proposal would require temporary occupation and permanent acquisition of land along the alignment. A total of 27 lots would be impacted by permanent land acquisition, including approximately 4 hectares (ha) of private land within 12 lots and 9 ha of Crown Land within 15 lots.

Once operational, the proposal would form part of the rail network managed and maintained by ARTC, with trains provided by a variety of operators. Inland Rail, in its entirety, would be operational once all 13 sections are complete, which is estimated to be in 2026. Prior to this, N2NS Phase 2 would form part of the existing network serving grain operations on currently active rail lines to North Star and Weemelah. Therefore, use of the proposal section could occur prior to operation of Inland Rail. This activity would recommence following the completion of construction of the proposal and N2NS Phase 1.

Maximum train speeds would range from 80 to 115 kilometres per hour (km/h), except through Moree, where the maximum train speed would be 60 km/h due to track geometry and safety.

Based on current demand forecasting, the Narrabri to North Star Phase 2 section is expected to have an average of about 11 trains per day travelling between Camurra and Moree in 2025. This would increase to about 20 trains per day in 2040.

1.3 Study area

The proposal site, also referred to as the construction impact zone, encompasses the area directly impacted by the construction works, including the location of proposal infrastructure, the area that would be directly disturbed by movement of construction plant and machinery, and the location of construction compounds, storage areas and other ancillary facilities that would be used to construct the infrastructure.

The proposal site is shown in Figure 1-1.

The study area under consideration for the hydrology and flooding impact assessment encompasses the proposal site and all areas within a 10 kilometre buffer beyond the extent of the construction impact zone. The study area is shown in Figure 1-2. The assessment considers flooding processes that extend beyond this buffer to encompass the entire catchment of the Gwydir-Mehi river system that drains to the proposal area. However, the proposal has no effects on hydrology and flooding beyond this buffer.

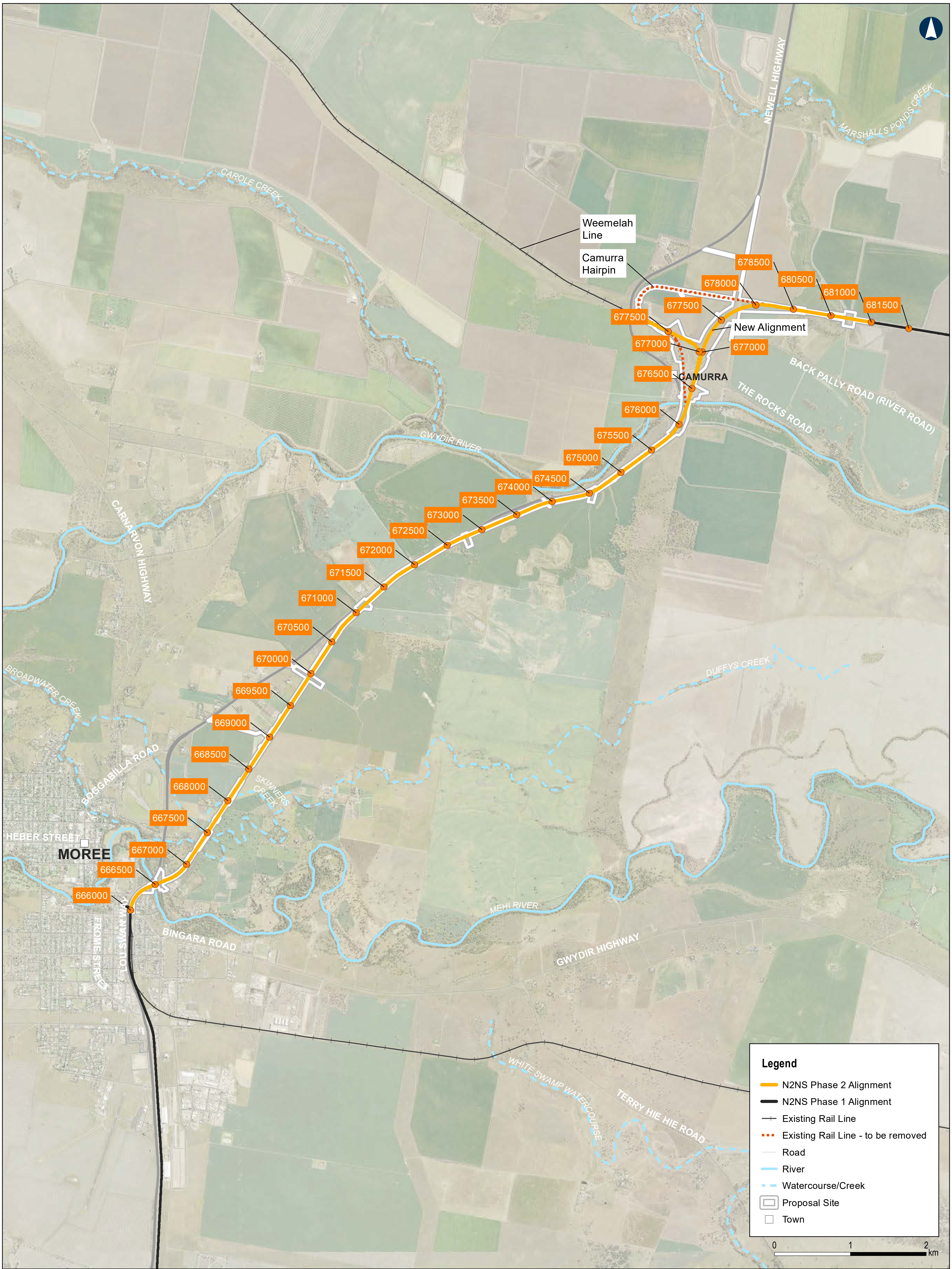

Figure 1-1 Proposal site

Data Sources: ARTC, IRDJV, LPI

Coordinate System: GDA 1994 MGA Zone 55
Scale: 1:45,000
Paper size: A3
Date: 9/23/2021
Map 1 of 1

N2NS_SP2_HF_F01_01_LocationOfProject_r2v3.mxd

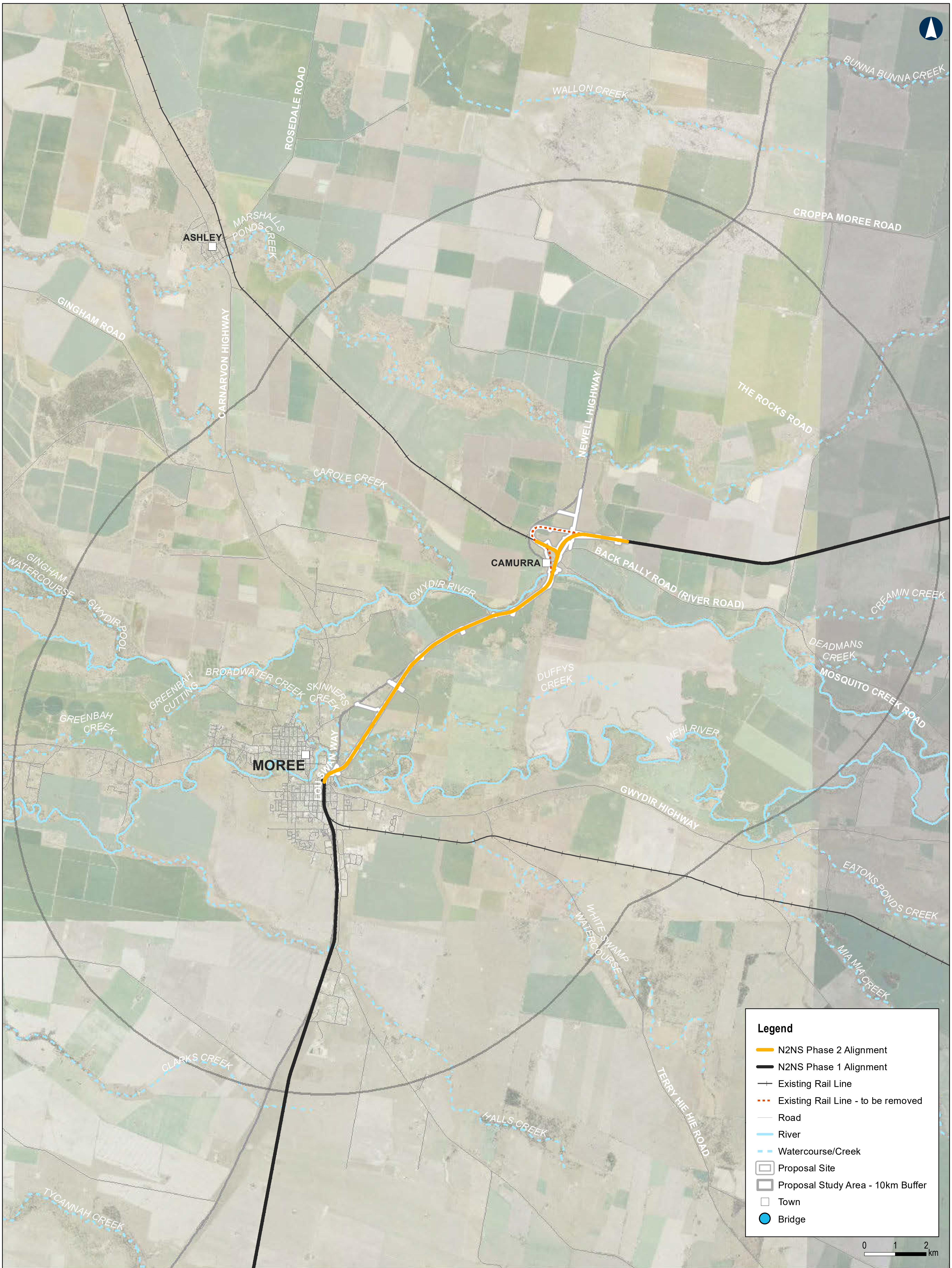

Figure 1-2 Proposal study area

Data Sources: ARTC, IRDJV, LPI

Coordinate System: GDA 1994 MGA Zone 55
Scale: 1:110,000
Paper size: A3
Date: 9/23/2021
Map 1 of 1

N2NS_SP2_HF_F01_02_ProposalStudyArea_r2v2.mxd

1.4 Project construction

Construction of the proposal would involve:

- site establishment and enabling works
- main construction works, including:
  - corridor and associated works
  - bridges and associated works
  - culvert crossings and associated works
  - level crossings and associated works
  - ancillary facilities and associated works
  - decommissioning works
  - rail systems fitout
- testing and commissioning
- finishing works.

These activities are described in more detail in Chapter 8 of the Environmental Impact Statement.

Construction of the proposal is expected to commence in 2022, subject to planning approval, and take around two years to complete.

1.5 Purpose of Technical Paper 4 and assessment requirements

The surface water environment can be impacted by changes to the drainage and flooding regime within and external to the rail corridor in areas where the rail infrastructure has an influence on the surface flow regime within rivers, creeks, drainage lines, overland flow paths and floodplains. Changes to rail infrastructure such as vertical and horizontal alignment, earthworks and drainage structures have the potential to alter flow directions and flood levels, velocities and durations in the adjacent land. Impacts of the project on drainage and flooding processes are addressed in this Technical Paper. Impacts of the proposal on other surface water aspects, such as water quality in the waterways and catchments around the rail corridor and availability of surface water for the environment and users around the corridor, are addressed in Technical Paper 5A: Surface Water Impact Assessment.

The Secretary's Environmental Assessment Requirements (SEARs) relating to surface water, and where these requirements are addressed in this Technical Paper, are outlined in Table 1-1 and Table 1-2.

Table 1-1 Secretary's Environmental Assessment Requirements for desired performance outcomes

DESIRED PERFORMANCE OUTCOMES	REQUIREMENT
3. Assessment of Key Issues* Key issue impacts are assessed objectively and thoroughly to provide confidence that the project will be constructed and operated within acceptable levels of impact. ** Key issues are nominated by the Proponent in the CSSI project application and by the Department in the SEARs. Key issues need to be reviewed throughout the preparation of the EIS to ensure any new key issues that emerge are captured. The key issues identified in this document are not exhaustive but are key issues common to most CSSI projects.*	1 The level of assessment of likely impacts must be proportionate to the significance of, or degree of impact on, the issue, within the context of the project location and the surrounding environment. The level of assessment must be commensurate to the degree of impact and sufficient to ensure that the Department and other government agencies are able to understand and assess impacts.
	2 For each key issue the Proponent must: a assess the issue (including modelling as relevant), and address and undertake the requirements specified in section 2 b describe the biophysical, social and economic environment, as far as it is relevant to that issue, including substantiated baseline data that is reflective of current guidelines where relevant c describe the legislative and policy context, as far as it is relevant to the issue d identify, describe and quantify (if possible) the impacts associated with the issue, including the likelihood and consequence (including worst case scenario) of the impact (comprehensive risk assessment), the impacts of concurrent activities within the project and cumulative impacts (parallel and sequential) with other projects e demonstrate how potential impacts have been avoided (through design, or construction or operation methodologies) f identify clear and quantifiable actions, outcomes and, where possible, performance criteria g detail how likely impacts that have not been avoided through design will be minimised, and the predicted effectiveness of these measures (against performance criteria where relevant) h detail how residual impacts will be managed or offset, and the approach and effectiveness of these measures; and i measures to monitor the avoidance, minimisation and offsetting of impacts to ensure quantified outcomes and criteria are met.
	3 Where multiple options to avoid or minimise impacts are available, they must be identified and considered, and the proposed measure justified taking into account the public interest.

Table 1-2 Secretary's Environmental Assessment Requirements for key issues

REQUIREMENT (SPECIFIC ASSESSMENT REQUIREMENTS)	REPORT REFERENCE
1 Flooding and Hydrology *Key issue and Desired Performance Outcomes:* - The project minimises changes to the existing flood regime's impacts on property, public safety and the environment resulting from alteration of the water flow characteristics of watercourses and overland flowpaths. - The project includes remedial measures to mitigate adverse water flow impacts or flood safety risks caused by the existing rail infrastructure within the project area. Construction and operation of the project avoids or minimises the risk of, and adverse impacts from, infrastructure flooding, flooding hazards, or dam failure.	
2 Description of topographic and hydrological conditions of the site and surrounding area, including:	
a Assessment of the existing hydrology and flooding characteristics of 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 flood events.	Section 4.7, Appendix A
b Description of the existing and proposed topography in areas that could be potentially affected by floodwaters. This includes the spatial location, and the horizontal and vertical dimensions of spoil mounds.	Section 4.7, Appendix A
c Carrying out of investigations to assess the propensity for scour, erosion and geomorphological changes to occur within any watercourses or overland flowpaths affected by the project.	Sections 4.4.2, 6.3.1.2, 6.3.1.12 and 6.3.1.13
3 Design parameters and features, including:	
a Description and justification of quantitative flood management objectives for flooding, hydrological and geomorphological changes resulting from the project. These objectives are to consider land use and include afflux, velocity, extent, duration, hazard and scour potential.	Section 4.6
b Description and justification of the proposed flood planning level (FPL) for the project including the AEP of the flood which will overtop the formation and rail. When establishing the appropriate FPL, consider any impacts on adjacent infrastructure and any alteration works required to improve flood immunity of affected infrastructure.	Sections 4.5, 6.1 and 6.3
c Description of the location and size of existing and proposed pipes, culverts and bridges, and the locations and annual exceedance probabilities (AEPs) of floods that overtop the existing formation and rail.	Sections 5.8, 5.9 and 6.2
d Preliminary engineering designs of the velocity dissipation or other mitigation works that are proposed to avoid adverse offsite scouring 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.	Sections 4.4.2, 6.2, 6.3.1.2 and 6.3.1.12
e At locations along the rail route, identification of 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. Where there is insufficient width of project land available for these works, clear identification of 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.	Sections 4.4.2 and 6.3.1.12
4 Pre-construction and operational phase impacts of the project on flood behaviour for a full range of flood events up to and including the PMF (including consideration of the impacts of climate change and differing storm durations), including:	
a utilisation of 2D hydrologic and hydraulic models that are consistent with ARR and 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;	Sections 4.2 and 4.3
b Identification of allowance for blockage of cross-drainage structures to be made in accordance with ARR;	Section 4.3.2.10 and Appendix D

REQUIREMENT (SPECIFIC ASSESSMENT REQUIREMENTS)	REPORT REFERENCE
c having these models independently peer-reviewed with the review findings published in the EIS;	Section 4.8 and Appendix E
d assessing any changes to the potential flood affectation, scouring or geomorphological changes to other properties, assets and infrastructure, over a full range of flood durations and flood frequencies against the proposed flood management objectives;	Section 6.3, Appendix B
e assessing changes in upstream and downstream flowpaths (location, discharges and velocities, including overland flow);	Section 6.3.1.13, Appendix B
f where the existing rail infrastructure has an adverse flood impact on property or people, the flood assessment must consider the extent to which the project alleviates or exacerbates these existing impacts;	Sections 6.3.1.5, 6.3.1.6 and 6.3.5, Appendix B
g assessing impacts of extreme floods up to the probable maximum flood (PMF) including consideration of flood risks to people and property resulting from failure of the formation or washouts of ballast.	Sections 4.2.4 and 6.3.3, Appendix B
h assessing the consistency (or inconsistency) with the applicable Council or DPIE Water floodplain management plans. The requirements of these plans must be discussed with DPIE Water and the relevant Council;	Sections 2, 4.6 and 6.3.5
i 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;	Sections 6.3.1.4, 6.3.1.7, 6.3.1.11 and 6.3.1.13, Appendix B
j assessing impacts on farm dams, agricultural infrastructure, crops and activities associated with altered hydrology including volumetric changes in water flows;	Sections 6.3.1.13 and 6.3.1.14, Appendix B
k 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	Sections 6.3.1.5, 6.3.1.6, 6.3.1.7, 6.3.1.11 and 6.3.5, Appendix B
l evaluating any social and economic impacts that the project may have on the community as a consequence of changes to flooding and hydrology including dividing or fragmentation of property and changes to property management which could lead to the loss of viability.	Section 6.3.1.15, Appendix B
5 A qualitative assessment identifying land uses and infrastructure in the vicinity of the project susceptible to flood impacts that may arise during the construction phase and measures to mitigate risks of construction impacts occurring.	Section 6.5
6 In the event that operational impacts do not meet the nominated flood management objectives, provide measures to ensure the project's detailed design meets the objectives. Alternatively:	
a demonstrate that design changes to meet objectives at a given project location are not practicable; and	Sections 4.4.1, 4.5, 6.1, 6.2 and 6.3.1, Appendix B
b describe how broad flooding objectives will still be met at a given location; and	Sections 6.3.1 and 7.2, Appendix B
c detail procedures to ensure that the flood performance is acceptable to affected parties.	Sections 6.3.5 and 7.2

1.6 Structure of Technical Paper 4

The remainder of the Technical Paper is structured as follows:

- Chapter 2 Relevant legislation, policies and guidelines – describes the legislative and policy context for the assessment, and relevant guidelines.
- Chapter 3 Available data – describes the data and sources used in the assessment.
- Chapter 4 Methodology – describes the methods used to define the baseline flooding regime and to assess potential impacts on flooding.
- Chapter 5 Baseline environment – describes the existing surface water environment relevant to flooding, including catchment characteristics, climate, existing flooding patterns, flood risks and sensitive receptors.
- Chapter 6 Impact assessment – assesses the potential impacts of the proposal on flooding during construction and operation phases. Chapter 6 also details the proposed management and mitigation measures to reduce/avoid potential flooding impacts for construction and operation phases and performance outcomes to inform the next stages of design.
- Chapter 7 Conclusions and recommendations – summary of the key findings of the Technical Paper and recommendations for further investigation and assessment at later stages of design.

2 Relevant legislation, policies and guidelines

This chapter sets out the legislation, policies and guidelines have been used to inform the assessment.

2.1 Australian Rainfall and Runoff Guidelines 2019

Australian Rainfall and Runoff Guidelines 2019 (ARR 2019) (Ball et al 2019) is a national guideline for the estimation of design flood characteristics in Australia. The aim of the guide is to provide the best available guidance and information on design flood estimation in a manner suitable for use by Australian practitioners to be able to estimate the design flood problem, flood processes, and engineering hydrology. ARR 2019 has national application and is essential for policy decisions and projects in areas as diverse as:

- infrastructure such as roads, rail, bridges, dams and storm water systems
- town planning
- mining
- developing flood management plan for urban and rural communities
- flood warnings and flood emergency management
- operation of regulated river systems; and
- prediction of extreme flood levels.

ARR 2019 includes recent advances in knowledge regarding flood processes, expanding knowledge and application of hydrologic information technology, improved information about climate change and the use of stochastic inputs and advanced methods for hydrological estimation.

2.2 AS/NZS 31000:2018 Risk Management – Principles and Guidelines

AS/NZS 31000:2018 provides principles and generic guidelines on risk management. The principles outlined in the standard can be used to assess flood risk and the standard forms the basis of the Australian Institute for Disaster Resilience (AIDR) Handbook 7 which addresses flood risk management (see next section).

2.3 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia, Handbook 7

The Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia, Handbook 7 (AIDR, 2017) has been developed to provide guidance on the national principles supporting disaster reliance in Australia. This Handbook is supported by six additional guidelines that cover specific aspects of flood risk management and a practice note to assist with land use planning.

The Handbook is intended to provide broad advice and guidance on all important aspects of managing flood risk in Australia and it provides guidance on the best practice principles.

This Handbook has been considered when developing criteria for managing flood risk from the proposal and compliments the NSW Floodplain Development Manual (DIPNR 2005) by outlining current best practices for flood risk management.

2.4 NSW Floodplain Development Manual and Flood Prone Land Policy, NSW Government, 2005

The Floodplain Development Manual (NSW Government, 2005) sets out flood risk management principles and considerations relating to the development of flood-liable land in NSW. 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.

2.5 Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in Studies, OEH, NSW Government, 2019

The Floodplain Risk Management Guide, incorporating 2016 Australian Rainfall and Runoff in Studies (NSW Office of Environment and Heritage, 2019), was developed to assist NSW floodplain management authorities and practitioners in applying the updated ARR guideline to flood studies, risk assessments and management plans in NSW. It contains specific advice on how some of the new methods in ARR2019 should be applied in NSW.

2.6 Floodplain Management Plan for the Gwydir Valley Floodplain 2016, NSW Government, 2016

The Gwydir Valley Floodplain Management Plan is made under Section 50 of the *Water Management Act 2000*. The objectives of the Plan are to:

- facilitate the orderly passage of floodwaters through the Gwydir Valley Floodplain
- minimise the risk to life and property from the effects of flooding
- maintain flood connectivity to wetlands, other floodplain ecosystems, and areas of groundwater recharge
- contribute to the protection of the ecological assets and values of the Gwydir Valley Floodplain; and
- contribute to the protection of cultural, heritage and spiritual features of the Gwydir Valley Floodplain that are significant to Aboriginal people and other stakeholders.

The proposal site is located within the following floodplain management zones established in the Plan:

- Gwydir Management Zone A: Includes major drainage lines and other areas where a significant discharge of floodwater occurs during all flood events. These areas are generally characterised by high flood flow velocity and depth.
- Gwydir 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. Its outer boundary is defined by the modelled inundation extent of the large design flood.
- Gwydir Management Zone C: Contains elevated areas or areas protected by existing flood work development.

The Plan contains mapping showing the location of the Gwydir floodway network. Floodways are key corridors that convey floodwaters. The proposal intersects three mapped floodways:

- the floodway associated with the main Gwydir River that crosses the proposal site in the vicinity of the Back Pally Road and Newell Highway intersection
- the floodway associated with combined Gwydir River and Mehi River floodplain flows that crosses the proposal site near the Moree TAFE Agricultural Skills Centre; and
- the floodway associated with the main Mehi River that crosses the proposal site north of Moree.

The Plan contains the following performance indicators which are relevant to the proposal, noting that the term ‘flood works’ in the Plan refers to access roads, levees and agricultural; irrigation infrastructure but can also apply to other infrastructure that has the potential to affect flooding:

- the extent to which flood works are impacting on the flood connectivity of ecological and cultural assets and groundwater recharge
- the change to flood connectivity to ecological and cultural assets caused by flood works constructed after commencement of the Plan
- the extent to which flood works are modifying the hydraulic behaviour of floodwaters; and
- the change to the hydraulic behaviour of floodwater caused by flood works constructed after commencement of the Plan.

The Plan also sets limits for changes to flood parameters resulting from flood works, which include the following:

- 5% redistribution of peak flood flows
- 10 cm increase in flood levels
- 50% increase in flow velocity, or lower limits to minimise impacts on soil erodibility.

These limits on flood parameter changes were assessed and are confirmed to be consistent with the flood impact criteria adopted for the proposal (refer to Section 4.6).

2.7 Review of Moree and Environs Flood Study/Floodplain Risk Management Study and Plan, Volume III – Floodplain Risk Management Plan, Moree Plains Shire Council, adopted 2019

The Moree Plains Shire Council Floodplain Risk Management Plan for Moree and Environs provides recommendations based on information gathered from the Flood Study and Floodplain Risk Management Study and Plan to reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk.

The Plan was developed in accordance with the NSW Government's Floodplain Development Manual (2005), which has been prepared to support the NSW Government's Flood Prone Land Policy. The Plan outlines a number of floodplain risk management measures in three categories:

- Structural measures, e.g. levees and house raising were investigated to reduce damage, hazard and disruption associated with the existing flood risk.
- Planning measures, such as zoning and building controls (e.g. minimum floor levels) were reviewed to reduce damage, hazard and disruption associated with future flood risks.
- Emergency response measures, such as flood warning, evacuation and recovery, were reviewed to reduce damage, hazard and disruption associated with residual flood risks after the above measures have been implemented.

The measures set out in the Plan were reviewed to ensure that the proposal will not affect the future implementation of the measures. The flood impact criteria set out in Section 4.6 were also checked against the measures to ensure that the criteria include all relevant flood parameters and the impact limits are appropriate to avoid impacts on Council's future implementation of the identified measures.

2.8 Moree Plains Local Environmental Plan (LEP) 2011

For the proposal site the Moree Plains Local Environmental Plan (LEP) 2011 is the relevant local planning instrument. Local flood planning conditions are contained in Clause 7.6. The key objectives of the conditions 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; and
- avoid significant adverse impacts on flood behaviour and the environment.

These objectives have been used to inform development of flood impact criteria for the proposal (refer to Section 4.6).

2.9 ARTC and other design guidelines

The assessment has been informed by the following design guidelines published by ARTC and other agencies:

- ARTC Inland Rail Basis of Design
- ARTC Code of Practice Section 10 Flooding – Technical Note ETD-10-02
- ARTC Code of Practice Section 10 Flooding
- ARTC Engineering Specification – Flooding – ETG-10-01
- ARTC Technical Specification – Drainage – ETC-10-01
- ARTC Technical Specification ETC-10-01: Drainage
- AS7637:2014: Railway Infrastructure – Hydrology and Hydraulics
- Austroads Guide to Road Design, Part 5: Drainage – General and Hydrology Considerations and Part 5B: Drainage – Open Channels, Culverts and Floodways, Austroads 2013
- Austroads (2013), Guide to Bridge Technology, Part 4: Design Procurement and Concept Design
- Austroads (1994), Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways; and
- US Department of Transportation Federal Highway Administration, Hydraulic Engineering Circular No.18, Evaluating Scour at Bridges, Fifth Edition (2012).

3 Available data

This chapter describes the key datasets used in the assessment.

3.1 Flood studies and models

A key reference for the project was Moree Plains Shire Council's flood study for Moree and environs (WRM, January 2017). This flood study and the associated suite of flood models have been implemented by Moree Plains Shire Council in the floodplain risk management planning process for the rivers and floodplains crossed by the proposal. The flood models include:

- Hydrological model comprising:
  - main regional river inflows to the upstream boundary of the model based on Flood Frequency Analysis (FFA) of the gauge record at Gravesend. The FFA method used in the study was based on the ARR2016 guideline. This represents the primary inflow to the model domain; and
  - local catchment inflows to the modelled area from smaller tributaries and creek systems that enter the Gwydir-Mehi floodplain downstream of Gravesend. These inflows were modelled using the XP-RAFTS hydrological modelling software program and based on the now superseded ARR1987 guideline. These inflows are significant but only constitute approximately 15% of the peak flow that passes through the proposal area.
- Hydraulic model developed in the MIKE FLOOD hydraulic modelling software program. This includes a combined one-dimensional (1D) model representation of hydraulic control structures (such as culverts), and a two-dimensional (2D) model representation of overland flow over floodplains. The flexible mesh version of the software was used to develop the model, which allows the model resolution to be increased in areas of interest or hydraulic complexity.

3.2 Topographic data

Topographic data are key inputs to flood models and impact assessments. The MIKE FLOOD model developed for Council's flood study used a topographic grid made up of the following different Digital Elevation Models (DEM):

- Gwydir 2013 AAM project LIDAR tiles (approximately 33,600 hectares surrounding Moree including 27 kilometres upstream and 7.5 kilometres downstream)
- Gwydir Extension Project LIDAR tiles (537 hectares north of Moree)
- L0086 Moree – LPI 2012 Project LIDAR tiles (944 hectares to the south-east of Moree)
- 1 metre resolution upstream DEM provided by the NSW Government (22,620 hectares) originating approximately 14 kilometres east of Moree and extending a further 26 kilometres upstream
- 1 metre resolution downstream DEM provided by the NSW Government (54,690 hectares) including Moree township and extending approximately 20 kilometres downstream of Moree; and
- The following ground point survey datasets:
  - Moree Biniguy cross-sections (2000)
  - Moree and surrounds (2006)
  - Moree and surrounds (2013)
  - Gwydirfield (2015).

Most of the above data sources were not available as separate datasets for this assessment but were integrated as a single mosaic DEM within the MIKE FLOOD model. The mosaic DEM was built from the above datasets in the following order of priority:

1. Ground point survey data
2. Gwydir 2013 AAM LiDAR
3. Gwydir Extension 2013
4. Upstream DEM
5. Moree LPI 2012 LiDAR
6. Downstream DEM.

The following datasets were available as separate datasets for this assessment:

- ARTC LiDAR survey (2017) – 0.2 metre resolution covering approximately a 1 kilometre wide strip along the project corridor (note that this LiDAR dataset was validated against ground survey and used to define the top of rail level in the flood model)
- ARTC site survey of local features and infrastructure within the rail corridor
- Gwydir 2013 AAM LiDAR (as described above); and
- Mosaic DEM from the MIKE FLOOD model.

4 Methodology

4.1 Overview

The methodology for the assessment was based on the adaptation and use of Council's flood model of Moree and Environs from the 2016 Flood Study (WRM, 2017) to establish the baseline or existing conditions flood behaviour and to test the impact of the proposal on the flood regime within the rail corridor and the adjacent land. The following sections describe the methods used to confirm the suitability of Council's flood model for use in the assessment, the adaptations made to the model for the purposes of this assessment and the method for assessing the impact of the proposal on the flooding regime and flood risk to adjacent land and assets.

4.2 Hydrological analysis

The hydrological analysis methodology involved a detailed review of Council's hydrological model to confirm that it is suitable for use in this assessment. The review included the following steps:

- review of the reported model calibration to confirm that a robust calibration process was undertaken and reliable results were obtained
- check of the FFA of the Gravesend gauge record to confirm that the main inflow to the model is defined correctly; and
- check of the changes to flows predicted by the local catchment XP-RAFTS model when updated to the latest ARR2019 guideline, to determine if this update should be adopted, given that the model is currently being used to define local council floodplain management and planning policies.

4.2.1 Calibration and validation

4.2.1.1 Review of model calibration

The Moree and Environs flood model has a hydrological component which is made up of main regional river inflow at the upstream boundary of the model at Gravesend and local catchment inflows between Gravesend and Moree. The upstream boundary inflows are derived from measured flow records at Gravesend while the local catchment inflows are modelled using the XP-RAFTS software package.

The hydrology model was calibrated by applying measured flows at the Gravesend flow gauge and corresponding measured rainfalls over the local catchments in the XP-RAFTS model. The model was calibrated to the following events (return periods noted against the events are calculated in terms of the return period of the recorded flow at the Gwydir River streamflow gauge at Gravesend Road Bridge):

- February 1955: estimated return period of 1 in 158 years
- July 1998: estimated return period of 1 in 10 years
- January 2004: estimated return period of 1 in 12 years
- November 2011: estimated return period of 1 in 14 years
- February 2012: estimated return period of 1 in 30 years.

The calibrated flows from the hydrological model were then applied to the MIKE FLOOD hydraulic model and the hydraulic model was calibrated to observed water levels and flows at numerous gauge locations for the same events, where available. The calibration process is documented in detail in the Flood Study Report (WRM, 2017).

The hydrological model accurately predicted the timing of the flood events but tended to overpredict the peak flows at the gauge sites. An example is shown below in Figure 4-1. The report suggests this lack of fit of high flows is due to the inability of the rating curves developed for the flow gauges to account for the total floodplain flow. This is a reasonable conclusion and supported by the gauge records and common issues in other regional river catchments that experience very high flows.

When the calibrated hydrological model inflows were applied to the hydraulic model, a better match to recorded flows and a very good match to recorded water levels was obtained. An example is shown in Figure 4-2.

The Flood Study Report concludes that the calibration was acceptable given the very good fit achieved by the model to in-channel flows for all calibration events and the model calibrated well to observed levels on the floodplain for the highest events of February 1955 and February 2012, and in particular, a good agreement to observed flood levels was obtained around the existing rail corridor and Newell Highway for the February 2012 event.

This review found that the model calibration process was rigorous and made best use of all available data. Given the complexity of the modelled Gwydir-Mehi system and the good calibration results achieved for four out of the five events simulated, it is considered that the model provides a sound basis for this assessment.

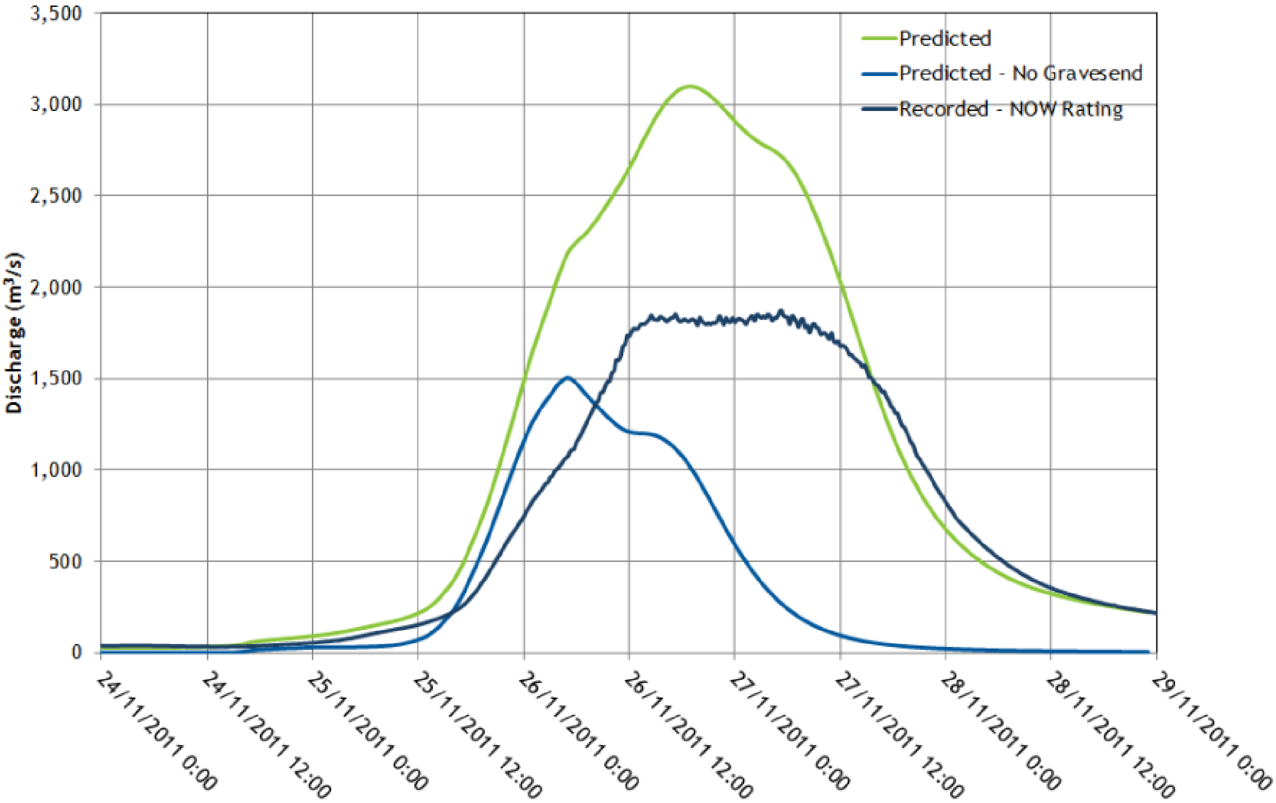

Figure 4-1 Moree and Environs flood model hydrological model calibration result at Gwydir River at Pallamallawa for November 2011 event (WRM, 2017)

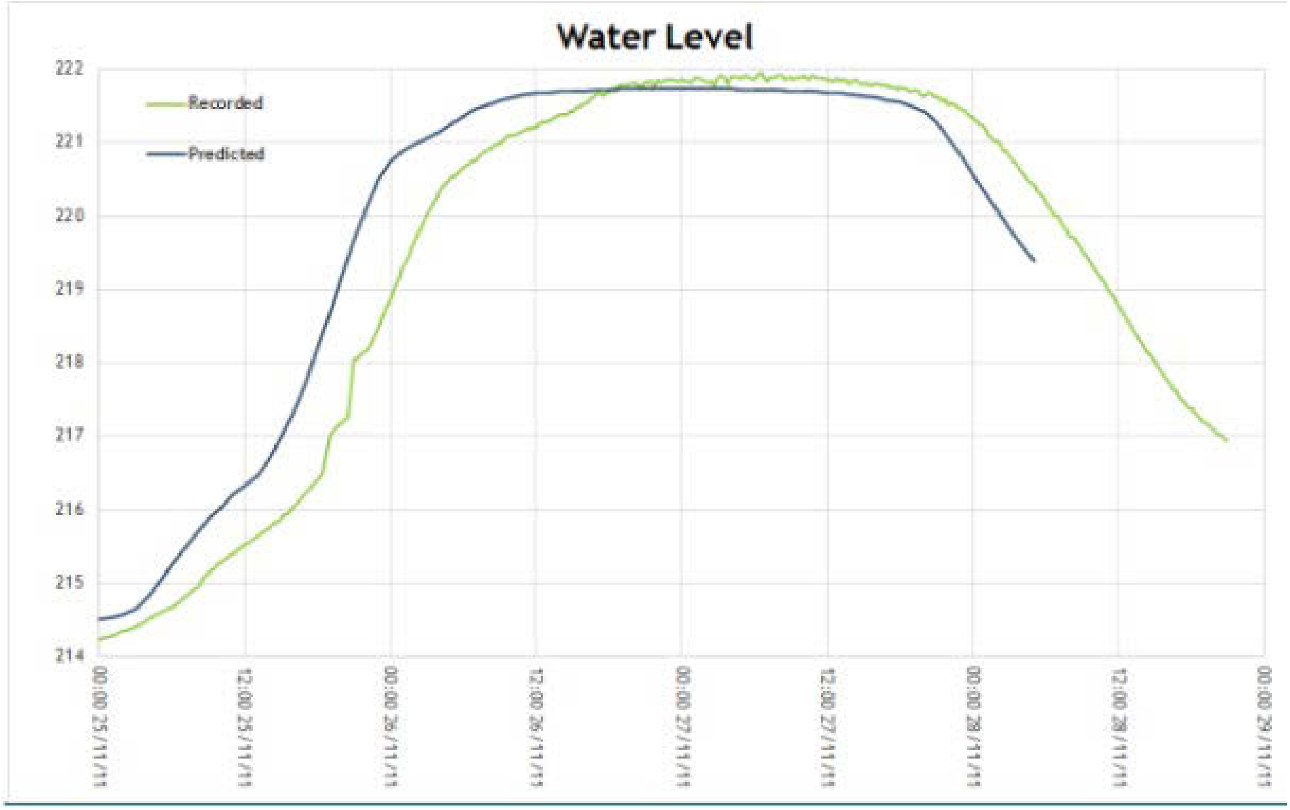

Figure 4-2 Moree and Environs flood model hydraulic model calibration result at Gwydir River at Pallamallawa for November 2011 event (WRM, 2017)

4.2.1.2 Gravesend Flood Frequency Analysis

The main river inflow at Gravesend is a key input to the model as it represents the regional river inflows from the 11,020 km^2 catchment upstream. The inflows were generated using FFA of the flow records from the Gwydir River at Gravesend Road Bridge gauge (418013) to generate peak flows which were then fitted to an inflow hydrograph shape determined from the records of historical floods.

The gauge record dates from 1936 to the present, giving a record length of 80 years. The Flood Study Report (WRM, 2017) describes a procedure that was used to supplement this data with a further 45 years of peak flow estimates by developing a correlation between the Gravesend flow record and the record for the Gwydir River at Pallamallawa (418001) which dates from 1891. Further adjustments were made to the FFA to account for the impact of Copeton Dam and additional information suggesting that the 1955 flood event was the highest on record since 1860.

A Log-Pearson Type III (LP III) distribution was fitted to the annual series of recorded (and inferred from the correlation with the Pallamallawa gauge) peak flood flows at Gravesend using the Bayesian inference methodology recommended in ARR2019 using the FLIKE analysis software. This methodology allows the user to more accurately consider historic data outside the gauged record, as well as allowing the user to censor low flows to improve the fit for the larger events.

An independent check of the FFA produced for the Flood Study was undertaken by IRDJV using the same FFA method but only the period of record dataset at the Gravesend gauge (from 1937 to 2015) as all of the additional information used by WRM in adjusting the flow series to account for Copeton Dam and the flood history to 1860 was not available from the Flood Study Report. The independent check obtained a very similar result from FLIKE, confirming that the flow estimates are reliable. Table 4-1 provides the WRM peak flows obtained from the FFA of the gauge record and the adopted flows based on the FFA of the extended dataset using all historical data and the relevant adjustments. It should be noted that the adopted flows are lower for the supplemented dataset which increases the period of record, reducing the magnitude of the peak flow estimate for any given return period. One of the bases for adopting the lower flows from the supplemented dataset was the finding of previous studies that the February 1955 flood was the highest on record since records began around 1860. This finding is supported by local Council and landowner knowledge and historical newspaper reports hosted on the Trove website (trove.nla.gov.au) which contains articles relating to flooding around Moree dating from the 1880s.

Table 4-1 Peak main river inflows at Gravesend based on FFA of gauge record only and gauge record supplemented with historical data (WRM, 2017)

EVENT	PEAK FLOW BASED ON FFA OF GAUGE RECORD (m^3/s)	PEAK FLOW BASED ON FFA OF GAUGE RECORD SUPPLEMENTED WITH HISTORICAL DATA – ADOPTED (m^3/s)
20% AEP	1,300	1,280
10% AEP	2,300	2,180
5% AEP	3,570	3,240
2% AEP	5,620	4,820
1% AEP	7,570	6,110
0.5% AEP	10,310	7,520

4.2.1.3 Local catchment XP-RAFTS model

The local catchment between Gravesend and Moree Environs extends to approximately 2,300 square kilometres and includes the following creeks and tributaries:

- Halls Creek
- White Swamp
- Marshalls Pond Creek
- Mia Mia Creek
- Eatons Ponds Creek
- Slaughterhouse Creek
- Mosquito Creek; and
- Tycannah Creek.

For the 2017 Flood Study an XP-RAFTS model was developed to represent the local catchment inflows. The XP-RAFTS model consists of total of 55 sub-catchments ranging in size from 16 square kilometres to 115 square kilometres.

The flow gauge records and the XP-RAFTS modelling demonstrate that the local catchment peaks around 12 to 15 hours earlier than the peak river inflow at Gravesend for historical events. In flood events that are widespread across the catchment, the local catchment does not govern the flood behaviour through Moree but does contribute to the peak flow, particularly in the higher events.

Figure 4-3 shows the 1% AEP event water level hydrograph result from the MIKE Flood model at the rail line crossing of the main Gwydir channel north of Moree, at approximate chainage 675 kilometres. The hydrograph demonstrates an initial peak water level occurring approximately 36 hours before the main peak level. The main peak level is approximately 600 mm higher than the initial peak level. This pattern is evident in the model inflow boundary condition at Gravesend and is likely to be due to significant local sub-catchments upstream of Moree that peak before the main river peak flow occurs from the total upstream catchment.

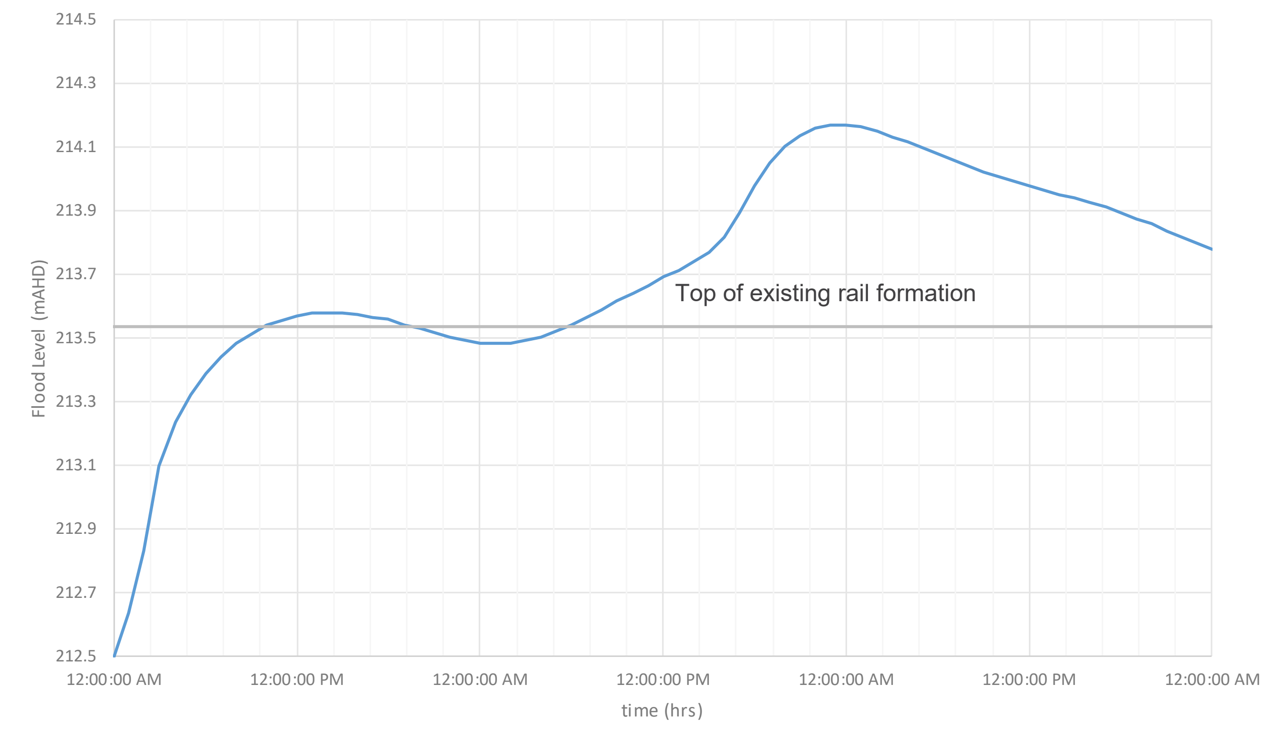

Figure 4-3 Moree and Environs flood model 1% AEP water level hydrograph at rail crossing of Gwydir River

Table 4-2 provides the peak 1% AEP design flows for the main river inflow at Gravesend and the local catchment creek systems to show the relative contribution of each catchment. The flows given in the table are for the 48-hour design storm which was found to be the critical duration (i.e. the storm duration that produces worst case flooding) for flooding through Moree and Environs.

Table 4-2 1% AEP 48 hour storm peak flows for main river and local catchments in the Moree and Environs flood model

CATCHMENT	PEAK FLOW FOR 1% AEP EVENT (m^3/s)
Main river inflow at Gravesend	6,110
Halls Creek	71
White Swamp	62
Marshalls Pond Creek	221
Mia Mia Creek	194
Eatons Ponds Creek	124
Slaughterhouse Creek	205
Mosquito Creek	558
Tycannah Creek	890

The XP-RAFTS local catchment model is based on the ARR1987 guideline, which does not include the latest rainfall intensity, frequency and duration parameters and rainfall temporal patterns provided in ARR2019. Updating the model to ARR2019 was considered, however, it should be noted that the model has been formally adopted by Moree Plains Shire Council for floodplain management planning purposes. Therefore, any changes to the established model and its associated predictions of flood behaviour need to be carefully considered given that Council is currently using the model in its floodplain management planning process.

The impact of updating the XP-RAFTS model to ARR2019 was tested by updating a sample number of upstream sub-catchments to ARR2019 and comparing the resulting flows to the original ARR1987 model. The results of this test are provided in Table 4-3. The key findings from the test were that ARR2019 produces higher flows for shorter duration storms (e.g. the 12-hour storm) which are critical in the local catchments, whereas ARR1987 produces higher flows for the 48-hour storm, which is critical for the regional catchment and which governs the worst-case flood behaviour in the study area. The ARR1987 model can therefore be considered to provide conservatively high flow values for the local catchments for the critical flood in the area around Moree.

The local catchment model does not govern flood behaviour around the rail corridor and the primary flood risk to the corridor is governed by the main river inflow at Gravesend. Therefore, for this assessment the existing ARR1987 local catchment hydrology model was adopted to be consistent with the established flood model for the area.

Table 4-3 Results of tests of updating XP-RAFTS model to ARR2019

MODEL SUB-CATCHMENT	SUB-CATCHMENT AREA (km^2)	CRITICAL STORM IN LOCAL SUB-CATCHMENT				CRITICAL STORM IN REGIONAL CATCHMENT (48 HOUR STORM)			
		STORM DURATION (hours)	ARR 1987* PEAK FLOW (m^3/s)	ARR 2019** PEAK FLOW (m^3/s)	CHANGE IN PEAK FLOW	ARR 1987* PEAK FLOW (m^3/s)	ARR 2019 MEDIAN STORM	ARR 2019** PEAK FLOW (m^3/s)	CHANGE IN PEAK FLOW
1 (upper sub-catchment of Mosquito Creek)	56.7	12	202	217	+7%	152	Storm 5	99	-35%
12 (sub-catchment of Gwydir River downstream of Gravesend)	109.2	12	335	458	+37%	253	Storm 5	197	-22%
42 (upper sub-catchment of Halls Creek)	43.4	48	51	73	+42%	51	Storm 9	56	+10%

Notes:

*ARR1987 method uses losses from the Flood Study Report (WRM, 2017) of IL = 30 mm, CL = 4.5 mm/hour

**ARR2019 method uses Ensemble Storms and losses of IL = 26 to 69 mm, CL = 0 to 0.7 mm/hour

4.2.1.4 Conclusions

The review of the Moree and Environs flood model hydrology found the following:

- The hydrological model calibration did not achieve a close agreement to the flow record, however this is very likely due to the limitations in the rating curves at the gauges and their inability to capture the entire floodplain flow. The hydraulic model calibration achieved close agreement to the water level and flow records, giving confidence that the model simulated the historical flood behaviour accurately.
- The main river inflow to the model, which governs the model predictions of regional flooding around Moree, is based on a detailed FFA that considers all available historical data and the impact of major storages in the upstream catchment. The FFA was based on the latest methods recommended in ARR2019 and was independently checked and confirmed for the purposes of this assessment.

- Local catchment inflows do not govern the regional scale flood behaviour predicted by the model but do contribute to flood behaviour for high order events. The local catchment hydrology model is based on the superseded ARR1987 guideline and was found to produce conservatively high flow estimates for the critical regional flood event. If updated to ARR2019 the model will likely produce higher flow estimates for short duration locally critical flood events, but not for the critical regional flood event which will be most critical for the assessment of the impacts of the proposal.

Based on these findings, the Moree and Environs flood model was adopted for this assessment. The model is currently the best available tool for defining flood risk within the area of the proposal and has been through a comprehensive process of review and adoption by Council as the basis for their flood risk management planning in the area.

4.2.2 Design event modelling

Table 4-4 provides the list of design flood events that were simulated for this assessment. These events were established in Council's adopted flood model and represent a reasonable range give that the regional floodplain does not fully inundate at the 10% AEP. Additional flood events, such as the 0.05% AEP which is used in bridge design, will be assessed at the detailed design stage.

Table 4-4 Hydrological design events

DESIGN EVENT ANNUAL EXCEEDANCE PROBABILITY (AEP)	APPROXIMATE EQUIVALENT AVERAGE RECURRENCE INTERVAL (ARI)
10%	10 year ARI
5%	20 year ARI
2%	50 year ARI
1%	100 year ARI
1% with climate change allowance	100 year ARI
Probable Maximum Flood (PMF)	N/A

The hydrological design events have been compared with recent significant flood events that have occurred in the catchment by comparing recorded peak flood levels in the Mehi River at Moree and Gwydir River at Yarraman Bridge to the design flood level predictions at these locations. This comparison found the following:

- February 2012 flood event: This event had an estimated return period of 1 in 30 years (approximately 3% AEP) based on the recorded peak flow at the Gravesend flow gauge and the recorded peak water levels at Moree and Yarraman Bridge.
- March 2021 flood event: This event had an estimated return period of 1 in 20 years (approximately 5% AEP) based on the recorded peak flow at the Gravesend flow gauge and the recorded peak water levels at Moree and Yarraman Bridge.

4.2.3 Climate change scenario modelling

The 1% AEP event was selected for a climate change scenario assessment. This scenario involved simulation of a 20% increase in flow for the 1% AEP event. The 20% increase is based on the adoption of the CSIRO Representative Concentration Pathway 8.5 to 2090 as per ARR2019 as an appropriate climate change scenario.

ARR2019 sets out two methods for the estimation of climate change factors: the midpoint approach and the datahub approach, which give factors of 20% and 23% respectively. As the factor is intended to increase rainfall intensity, the lower value of 20% was adopted as the Phase 2 flood model is primarily based on the input of design flows derived from streamflow gauge statistics rather than a rainfall runoff model, and applying the factor to flow rather than to rainfall is a conservative approach as it does not take into rainfall losses.

This scenario was used to test the impacts of climate change on flood immunity of the rail line and effects of the proposal on adjacent land.

4.2.4 Extreme event modelling

The Probable Maximum Flood (PMF) event was run to assess the impact of flooding on the rail corridor and the impacts of the proposal on adjacent land under an extreme flooding scenario. The PMF, or extreme flood event, was defined in the Council Flood Study (WRM, 2017) by applying a factor of 3 to the 1% AEP flow hydrograph. This method of defining the extreme event is consistent with previous flood studies of the area and is supported by ARR2019 and other international studies of extreme flood hydrology (WRM, 2017).

For the extreme event scenario the rail embankment was considered to remain intact without washout of ballast or failure of the formation earthworks. This assumption is not realistic for the existing conditions, where numerous washout of the ballast are known to have occurred during recent events. For the design scenario, ballast washout and embankment failure are likely to be highly localised given that floodplain flow velocities are below 1 m/s for the PMF event and considerable numbers of additional cross drainage structures will be installed that will relieve water pressure on the upstream side of the rail corridor.

The assumption that the rail embankment and ballast remain intact during an extreme overtopping event is conservative for the prediction of upstream impacts as any localised washouts or failures will act to reduce flood level difference across the corridor and upstream flood levels. Observations of areas where washout occurred during the February 2012 event indicated that ballast and other materials from the rail corridor were displaced by up to 50 metres from the rail corridor into the adjacent downstream properties. These observations and the predictions of relatively low velocities in extreme events (refer to flood velocity maps in Appendices A and B) suggest that washouts and embankment failures during extreme events are unlikely to produce damaging flood waves that propagate for significant distances downstream.

A more detailed failure analysis of the rail embankment under extreme overtopping events will be undertaken at the detailed design stage when the geotechnical design of the embankment is further developed.

4.3 Hydraulic analysis

For the hydraulic modelling, the MIKE flood model and its inputs were used to develop a new TUFLOW model that was capable of faster run times and more rapid testing of design options. The TUFLOW model included refinements of the model topographic representation around the rail corridor, and updates to structure representation from the ARTC survey data. The updated baseline model was then modified to test design options for the proposal. The model was built using the 2020 version of TUFLOW and adopts the Heavily Parallelised Computations (HPC) solver using the ‘quadtree’ functionality which allows variable model grid resolutions to be used rather than a fixed resolution, thereby allowing higher resolution to be used in key areas of interest or sensitivity.

The TUFLOW model was used to simulate the events listed in Table 4-4 for both existing conditions and the design case.

4.3.1 Model development and validation

4.3.1.1 Development and validation to Council’s model

The process for building and validating the new TUFLOW model was undertaken in 2 stages, as follows:

- Stage 1:
  - extract the key input data from the MIKE FLOOD existing conditions model, including hydrological inflow hydrographs, topographic grid data, rail and road/highway culvert data
  - build a new TUFLOW model using the same model domain adopting this input data with a 10 metre grid resolution and apply the inflow hydrographs at the same locations in the TUFLOW model

- check the TUFLOW model predictions of flood level against the MIKE FLOOD model predictions for the 10% and 1% AEP events. If these checks show reasonable agreement, the TUFLOW model is considered to be validated and fit for purpose for this assessment. This process involved use of the Quadtree or variable cell size function within TUFLOW to test if higher TUFLOW model resolution in the main flow channels would produce a better match to the MIKE FLOOD level predictions.
- Stage 2:
  - update the input data with more accurate or recent data (e.g. more recent LiDAR data around the rail corridor) and update the model to use the quadtree function to define a higher model grid resolution of 2.5 metres extending 100 metres upstream and downstream of the rail corridor. This process established the TUFLOW existing conditions model.

The TUFLOW model extent (purple polygon) and locations of inflows (yellow textboxes) are shown in Figure 4-4.

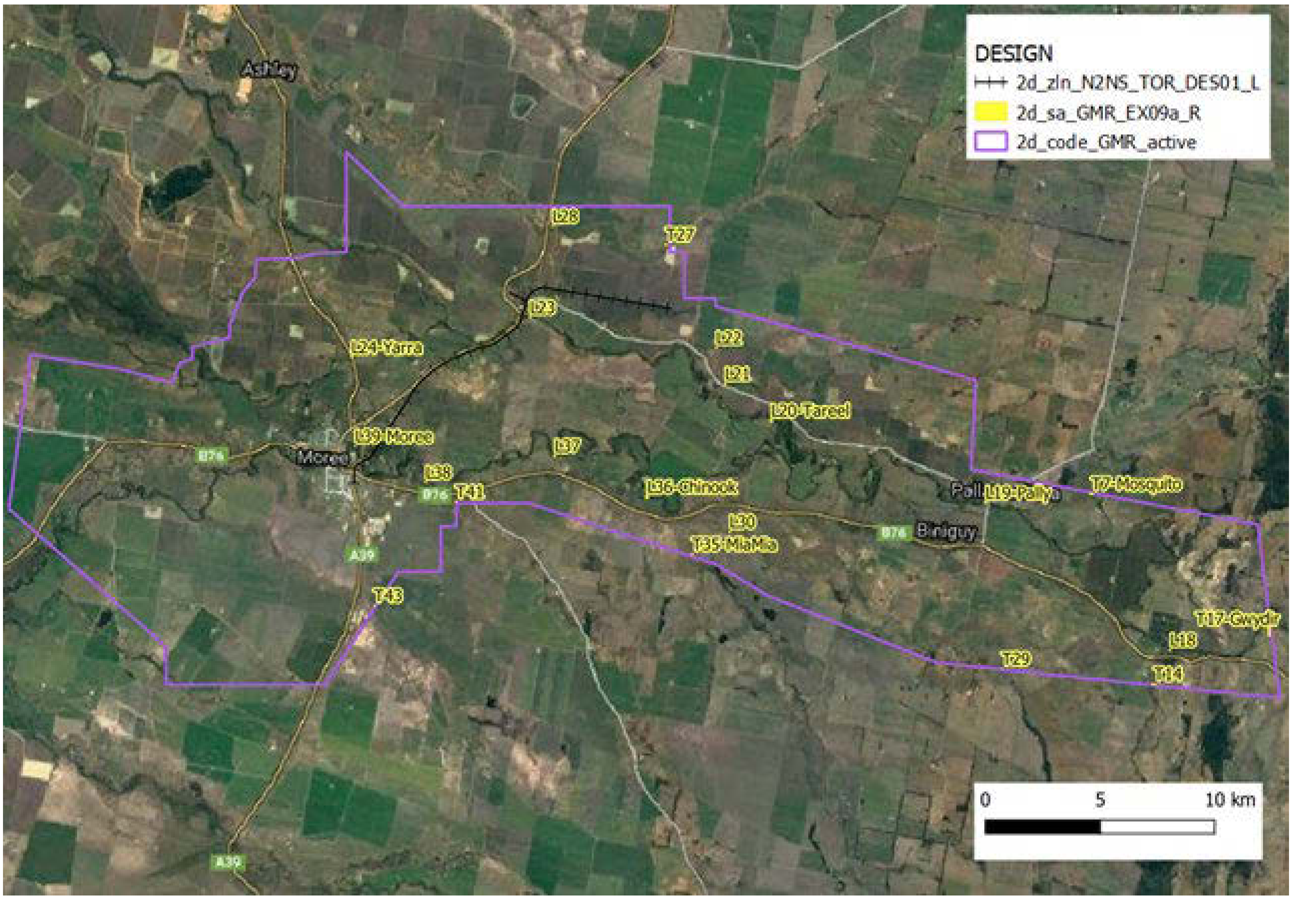

Figure 4-4 Extent of TUFLOW model and locations of inflow hydrographs

The key results of the validation of the TUFLOW model were as follows:

- good agreement (generally within 100 mm) between peak flood level predictions for the 1% AEP event
- poor agreement (300 to 500 mm variance) between peak flood level predictions for the 10% AEP event in the Gwydir channel
- differences in flow distribution between the Gwydir and Mehi in the models, with the difference more pronounced in the 10% AEP, with the TUFLOW model predicting more flow in the Mehi system than the MIKE FLOOD model.

The comparisons of peak flood levels in the models are shown in Figure 4-5 and Figure 4-6 for the 1% and 10% AEP events respectively.

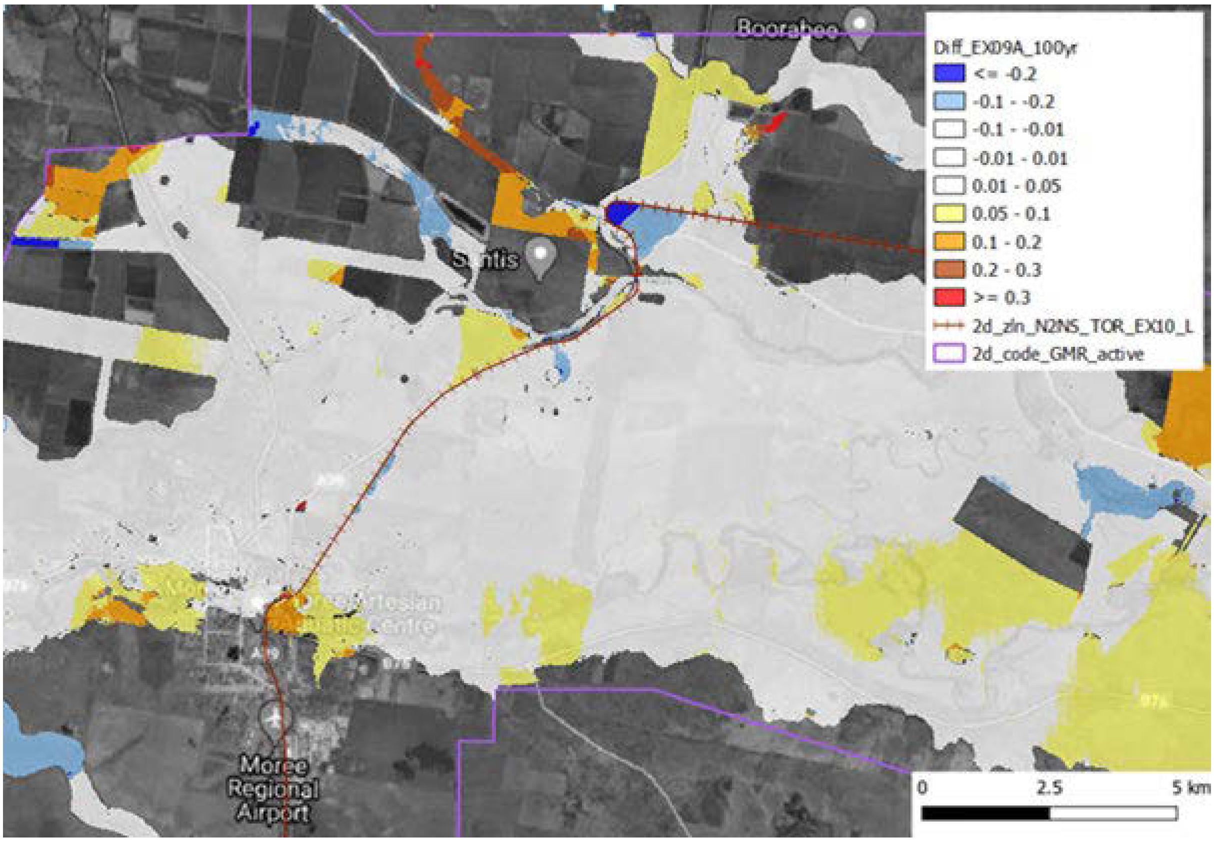

Figure 4-5 **Comparison of peak flood level between MIKE FLOOD and TUFLOW for the 1% AEP event (MIKE FLOOD flood level grid subtracted from TUFLOW flood level grid)**

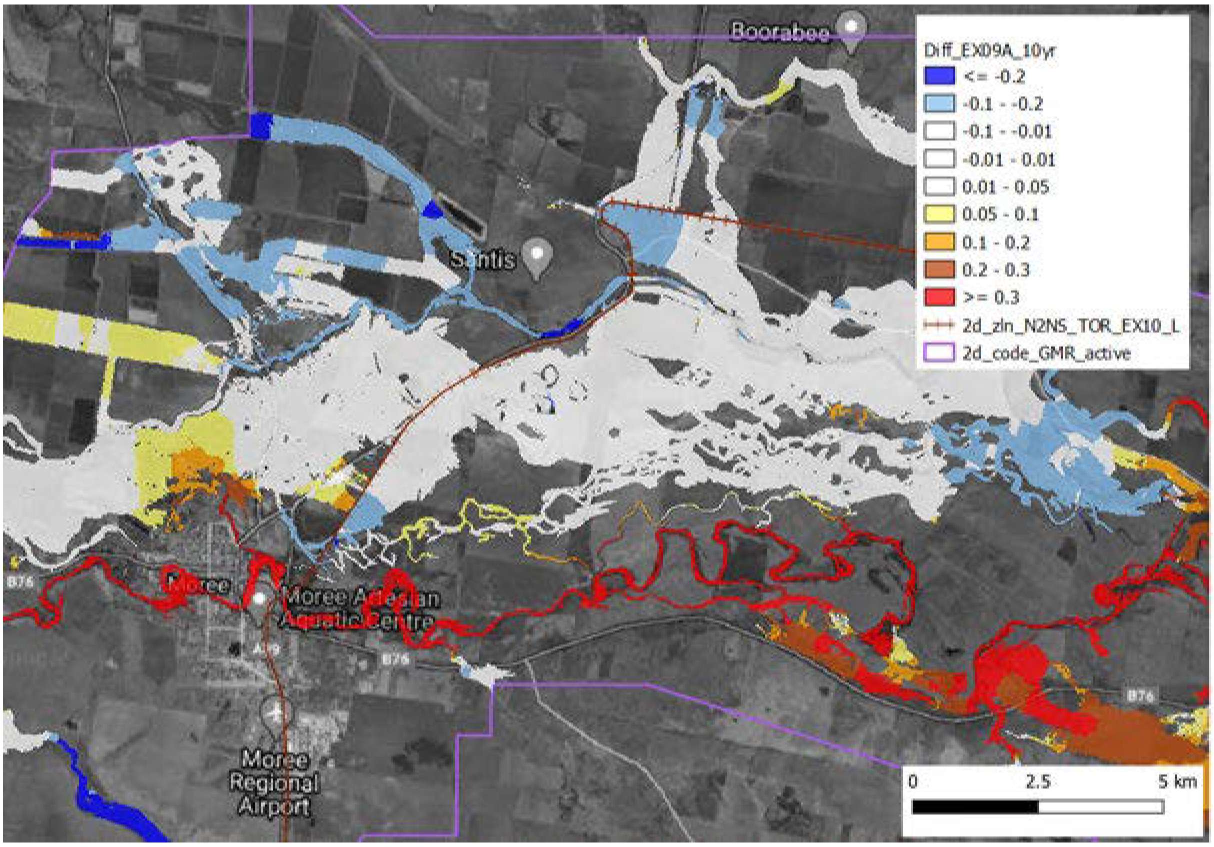

Figure 4-6 **Comparison of peak flood level between MIKE FLOOD and TUFLOW for the 10% AEP event (MIKE FLOOD flood level grid subtracted from TUFLOW flood level grid)**

A comparison of the model predictions of peak flows in each river system is provided in Table 4-5.

Table 4-5 Comparison of model predictions of peak flow at major crossings

EVENT	EXISTING MEHI RAIL BRIDGE		PEAK FLOW DIFFERENCES	EXISTING GWYDIR RAIL BRIDGE		PEAK FLOW DIFFERENCES
	MIKE FLOOD	TUFLOW		MIKE FLOOD	TUFLOW	
1% AEP	1,020 m^3/s	953 m^3/s	-7%	1,007 m^3/s	830 m^3/s	-18%
10% AEP	215 m^3/s	340 m^3/s	+58%	910 m^3/s	786 m^3/s	-14%

The discrepancies in flood level predictions between the models are primarily due to the differences in flow distribution as indicated in Table 4-5. Some differences between the models are to be expected due to the different numerical computation methods applied, and key reasons for the discrepancies in flow and level predictions are as follows:

- MIKE FLOOD flexible mesh versus TUFLOW fixed grid: The MIKE FLOOD model utilises a flexible mesh grid. This allows the model to provide detailed mesh resolution at key locations such as creek channels and at structures. The Stage 1 TUFLOW model used a fixed grid mesh which limits it to a fixed grid resolution throughout the model domain, which in this case is 10 metres (note that the Stage 2 TUFLOW model used the 'quadtree' function to refine the grid resolution around the rail corridor). In the upstream sections of the MIKE FLOOD model around Tareelaroi Weir Road and approximately 5 km west of this road a large scale mesh has been adopted for the floodplain (between 20 square metres to 40 square metres) with finer resolution around the creeks and areas of interest (10 square metres). The TUFLOW predicts significantly different flood behaviour in the upper sections of the model with increased and different breakouts from the main Gwydir channel into the Mehi channel compared to the MIKE FLOOD model. This results in a different distribution of flows at the study area, which is more pronounced in the 10% AEP event.
- Representation of hydraulic structures: The MIKE FLOOD model represents all hydraulic structures (bridges, culverts and weirs) as 1D elements. This was originally replicated in the TUFLOW but resulted in significant model instability. This was changed to more stable 2D representations of the bridge and weir structures which has resulted in a more stable TUFLOW model but is not consistent with the MIKE FLOOD approach. This has resulted in discrepancies in the hydraulic behaviour at a number of key structures. On balance, the TUFLOW model representation is considered more stable and accurate than the MIKE FLOOD model representation, particularly around structures in the upper reaches of the models.
- Topographic data: It has not been possible to source the original DEM that the MIKE FLOOD model mesh was constructed from. The TUFLOW model grid is based on a DEM output from the MIKE model mesh rather than the original DEM. This potentially limits the accuracy of the TUFLOW model DEM in the upstream area of the model and its ability to pick up underlying detail that has been built into the MIKE FLOOD model through the alignment of the flexible mesh. However, key 'DIKE' lines from the MIKE FLOOD model that control floodplain flow distributions have been replicated in the TUFLOW model using the equivalent 'zshape' lines.

In summary, there are discrepancies between the models due to the difference in flow distribution between the Gwydir and the Mehi systems in the upper sections of the models. In the absence of the original DEM used to build the MIKE FLOOD model, it is not possible to confirm which model is more accurate in this area, however, the TUFLOW model results appear to be more consistent with apparent breakout features that are visible in the aerial photography in this area. The finer grid resolution and improved representation of hydraulic structures in the upper section of the TUFLOW model could suggest that the TUFLOW model is more accurate than the MIKE FLOOD model in this area.

The discrepancies are not considered significant enough to affect the design as the model predictions of flood level are in reasonable agreement for the 1% AEP event and discrepancies in the 10% AEP event can be addressed by testing of the design under multiple event scenarios (see Table 4-4) to ensure that impacts are compliant under a range of flow distribution scenarios.

4.3.1.2 Validation against the March 2021 flood event

The Stage 1 model was also validated against the flood event that occurred in March 2021. Appendix H contains the details of this validation exercise. The following summarises the validation method and outcomes:

- Rainfall and stream flow gauge data were analysed to determine the return period of the event. This concluded that the event had a return period of approximately 1 in 20 years, or 5% AEP.
- Satellite imagery of the extent of the flooding for the event was obtained from the Copernicus Emergency Management Service (CEMS).
- The 5% AEP flood extent predicted by the Stage 1 existing conditions model was compared to the flood extent shown in the CEMS satellite imagery and the modelled 5% AEP event flood extent was found to match the observed flood extent for the March 2021 event around Moree and the wider floodplain.

While this was not a detailed model validation exercise it found that the model produces a good fit to this recent event and provides a level of confidence in the model predictions, particularly around Moree where some differences to Council's model occur for the 10% AEP event (see previous section).

4.3.1.3 Recommendations for further model calibration

At the detailed design stage it is recommended that the model is further refined and calibrated to recent significant events including the November 2011, February 2012 and March 2021 events. This calibration should involve simulation of the observed event rainfalls in the model and comparison of model estimates of flood level and flow to the observed stream gauge records in and around Moree and other records of flood levels obtained by Council as part of their 2017 Flood Study (WRM, January 2017).

4.3.2 Key hydraulic model inputs and assumptions

4.3.2.1 Culverts

As the proposed rail alignment is generally raised high than the existing alignment to improve rail flood immunity, culvert structures along the existing rail alignment have been replaced and upgraded in the design case.

Culvert structures have been represented in the hydraulic model using a 1D network type '1d_nwk' TUFLOW input. This representation of culvert provides a 1D representation of a culvert structure, transporting flows between two locations within a 2D mesh. 1D/2D connectivity has been represented with a '2d_bc' layer, defining connection between the culvert network and the 2D mesh. Where heights of culverts varied within a back of culverts, all culverts were modelled as discrete single 1D elements. In some cases where height and invert level were common these elements were grouped together as a combined 1D element.

Table 4-6 gives the Manning's 'n' values adopted for culverts.

Table 4-6 Manning's 'n' values adopted for culverts

CULVERT TYPE	MANNING'S 'n' VALUE
Corrugated Iron	0.027
Reinforced Concrete	0.013

4.3.2.2 Bridge representations

Bridge structures have been represented in the hydraulic model using a 'layered flow constriction' type TUFLOW input. This representation of the bridge structure allows a depth varied form loss coefficient to be applied to represent the different elements of the bridge structure.

The representation of the existing rail embankment and bridge abutments are included in the 2D TUFLOW model grid, and this representation inherently simulates the contraction and expansion losses as flow passes through the bridge structure. The form losses are applied uniformly across the width of the bridge structure opening, to represent the additional losses due to piers, which are not represented in the TUFLOW model grid. At bridges, that surcharge (i.e. flows that exceed the soffit level), the layered flow constriction file allows the level of the soffit to be set with an additional loss factor and blockage induced when this level is exceeded to represent surcharging of the bridge. The Form Loss coefficient (FLC) values adopted for layer one represent hydraulic losses associated with the bridge piers, and are derived using the process outlined in Section 5.4 of Austroads (1994), based on the approach from Bradley (1978). The bridge structure is generally represented with layers representing the following:

- Layer 1 – FLC value representing the bridge piers with blockage factor where required to represent reduced waterway opening. FLC value varies depending on bridge design and calculated values ranged from 0.16 to 0.55.
- Layer 2 – FLC value (1.56) representing the bridge deck and parapet with 100% blockage factor
- Layer 3 – FLC value (0.50) representing bridge safety barriers/railings with 50% blockage factor; and
- Layer 4 – Flow over the top of railings – assumed to be unimpeded.

Bridge representations in the model have been derived from survey, drawings and site photos.

The design case assumes full replacement of the existing Mehi River bridge with a new bridge structure at the same location and removal of the existing Gwydir River bridge and replacement of this bridge with a new bridge structure approximately 30 metres upstream. Both design case river bridges have clearance above the 1% AEP flood level.

4.3.2.3 Newell Highway representation – present day condition

The Newell Highway is adjacent to the rail corridor for the majority of the proposal. The elevation of the Newell Highway has been represented based on ground levels identified within the LiDAR survey used for the flood modelling. The crest of the road was enforced in the model topography using a TUFLOW '2d_zline', to ensure the highest point of the highway is represented.

Road culvert and bridge representation in the model is based on the calibrated regional MIKE model data. This data did not contain full details of the structures and estimations of some details of the road culverts were made where necessary based on site and aerial photos.

4.3.2.4 Newell Highway representation – future upgrade condition

An upgrade of approximately 5 kilometres of the Newell Highway is proposed adjacent to the proposal from chainage 668.40 kilometres to 673.40 kilometres. As both projects may be implemented within a similar timeframe, this assessment includes a cumulative flood impact assessment of both the Newell Highway upgrade and this proposal (see Section 4.7 for further details on the cumulative impact assessment). The proposed Newell Highway upgrade design, developed to 100% detailed design status, was provided by TfNSW and has been represented in the flood model as a surface grid of elevations with the crest of the road enforced in the model topography using a TUFLOW '2d_zline'.

4.3.2.5 Agricultural infrastructure

Numerous large irrigation storages are located within the floodplain in the vicinity of the proposal. Water is transferred to the storages via a combination of pumping from rivers/overland flow paths and gravity drainage through a network of irrigation channels. The channels have been represented in the model domain and convey flood flow in the model when inundated. The storages are not represented in the model domain (these areas of the 2D domain are nulled) and do not convey or store floodwaters. This is a conservative approach incorporated within the original flood model developed by Council that assumes storages will be full or partially full of water during flood events and will not reduce flood levels on the floodplain by storing floodwater.

Levees and storages undergo regular upgrades and modifications as required by landowners and their licence conditions. It is likely that some of the levees have been modified or raised since the LiDAR surveys that define the model topographic domain have been collected. However, as these features are not represented in the model, any changes to levee heights since collection of the LiDAR data do not affect the model predictions of flood behaviour.

It is noted that Council have undertaken further recent flood modelling studies to include the storages and to determine the effects of these storages on the floodplain behaviour. At detailed design the model will be updated as required to be consistent with Council's preferences for how these storages should be represented in flood studies.

4.3.2.6 Property flood protection infrastructure

Numerous residences and other buildings within the floodplain are raised on mounds or enclosed within levees to provide protection from flooding. In most cases these features are represented accurately in the model where they have been recorded in the LiDAR survey and appear as small isolated areas that remain free from flooding in extreme events. These features are highly localised and do not have a significant effect on the wider floodplain flow patterns or flood behaviour.

4.3.2.7 Boundary conditions

Hydrographs for incoming flows were replicated from the MIKE regional flood model. Incoming flows were applied on a sub-catchment scale using a '2d_sa' TUFLOW boundary for local catchment flows and using a '2d_bc' flow versus time (QT) boundary for concentrated upstream overland flow in rivers and creeks.

Water level versus flow (HQ) boundary conditions with slopes matching the outflowing channel beds were used as the downstream boundaries of the TUFLOW model. This differs from the MIKE FLOOD approach which uses water flow versus time boundaries, which was not a boundary condition option available within TUFLOW at the time the model was built. The proposal and its area of influence on the floodplain are sufficiently far from the downstream boundaries of the model that this difference in boundary condition does not affect predictions of flood behaviour in the area of the floodplain affected by the proposal.

4.3.2.8 Manning's 'n' values for floodplain areas

The Manning's 'n' values used in the hydraulic model have been adopted from the calibrated MIKE FLOOD model. The Manning's 'n' values adopted are unchanged between the existing conditions and design cases, except in locations within the project boundary, to allow representation of the future railway embankment and structures. The Manning's 'n' values adopted for the floodplain areas are provided in Table 4-7 and an overview of where these values apply is provided in Figure 4-7.

Table 4-7 Manning's 'n' values adopted for floodplain areas

LAND USE	MANNING'S 'n' VALUE
Floodplain	0.085
Riparian vegetation – general	0.075
Riparian vegetation – Lower Mehi River	0.080
Parklands and grassed areas	0.070
Open water – general	0.030
Open water – Mehi River	0.045
Buildings	0.300
Roads	0.025
Existing Rail/Airport	0.040
New Rail corridor	0.020

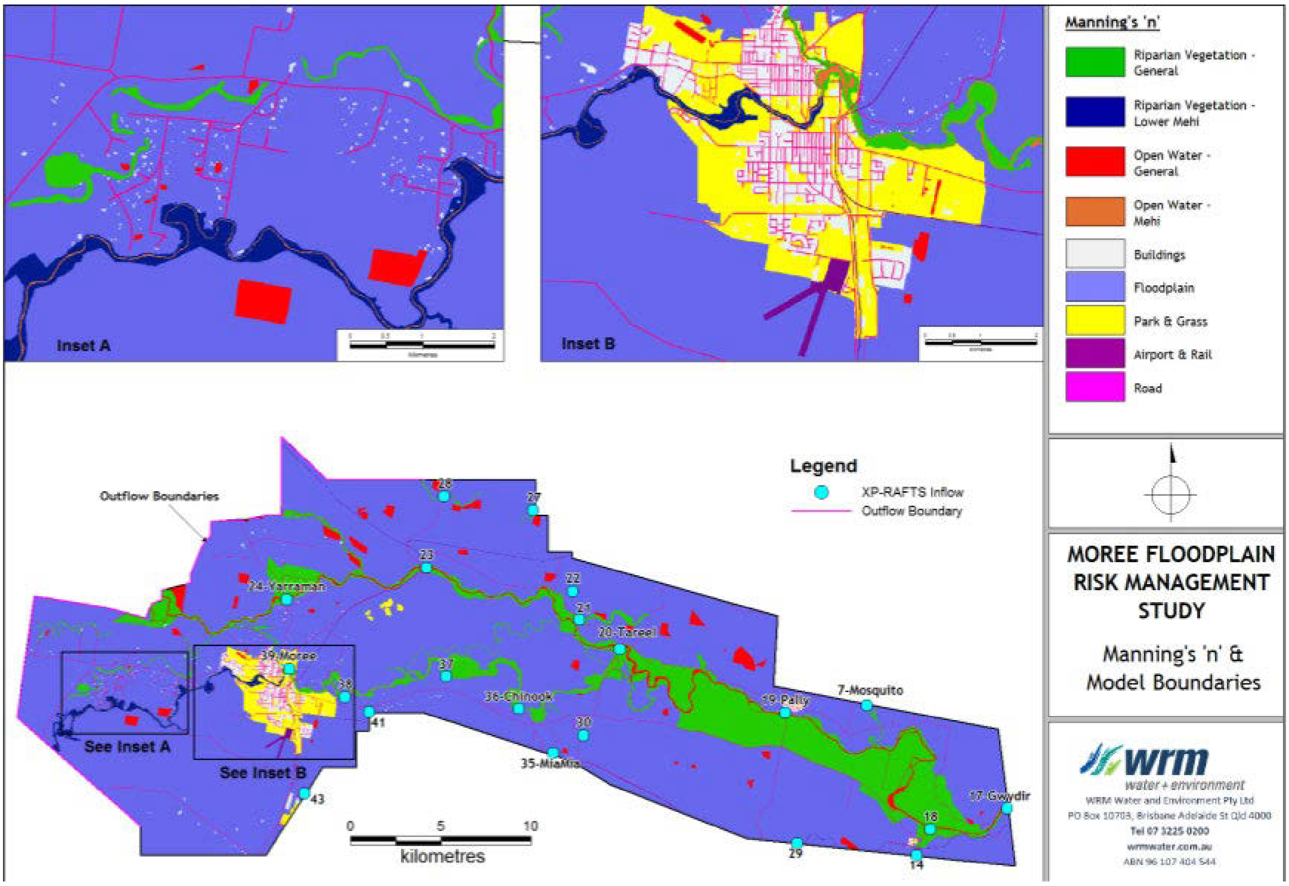

Figure 4-7 Excerpt from Council Flood Study Report showing floodplain roughness values and extents (WRM, 2017)

4.3.2.9 Grid size and timestep

A 10 metre grid size was adopted for the majority of the hydraulic domain. The TUFLOW 'quadtree' function was used to set a higher grid resolution of 2.5 metres approximately 100 metres upstream and downstream of the rail corridor to more accurately model flow distributions within the rail corridor and through the numerous additional cross drainage structures in the design.

The TUFLOW HPC modelling solution adopted for this project implemented an adaptive time step solution that allows the solution to vary the timestep and repeat timesteps as required to maintain stability when resolving the equation.

4.3.2.10 Blockage of cross drainage structures

Blockage of hydraulic structures in both existing and design scenarios has been assessed as per the recommendations of ARR 2019 (Chapter 6, Book 6, ARR2019). This assessment is a risk based analysis of the potential blockage risk and mechanism in the catchment at each cross drainage structure location. The assessment takes into consideration parameters such as:

- Debris Type and Dimensions – Whether floating, non-floating, urban or sediment debris present in the source area and its size.
- Debris Availability – The volume of debris available in the source area.
- Debris Mobility – The ease with which available debris can be moved into the stream.
- Debris Transportability – The ease with which the mobilised debris is transported once it enters the stream.
- Structure Interaction – The resulting interaction between the transported debris and the bridge or culvert structure.
- Random Chance – An unquantifiable but significant factor.

The process and assumptions adopted for the assessment are documented in detail in Appendix D. A full list of results from the blockage assessment is provided in Appendix D, with the resultant blockage values ranging from 12.5% to 25%. Based on these results, a single average blockage factor of 15% has been adopted at all cross drainage locations for both existing conditions and the design case models. This uniform assumption has been adopted to allow for efficiency in testing a high number of cross drainage design options at the EIS and reference design stage. The 15% blockage assumption was also checked against site photos of the existing drainage structures and found to be reasonable. Sensitivity testing of alternative blockage factors of 0%, 25% and 50% was also undertaken to determine how flood impacts of the proposal vary for different levels of structure blockage. The results of these sensitivity tests are discussed in Section 6.3.5.

4.4 Cross drainage hydraulic design

4.4.1 Sizing

The cross drainage structures were sized using the hydraulic models. For most of the proposal a track lift is required to provide improved rail flood immunity as the existing top of rail is overtopped in some areas at the 10% AEP event. Significant numbers of additional cross drainage structures have been provided at numerous locations to pass the flow that overtops the existing rail.

The cross drainage was designed to meet the impact criteria provided in Section 4.6. The design approach to sizing the structures was as follows:

- Locations where overtopping of the rail occurs under existing conditions were identified and new/upgraded culverts were tested at these locations to meet rail formation flood immunity requirements and upstream afflux criteria for the 1% AEP event.
- This first pass design was then tested in lower events and typically found to be too conservative by allowing too much flow through the rail corridor and causing high afflux on the downstream side for the lower events. The structure was then optimised by reducing size/number of cells and varying size and culvert floor level until the following two criteria were met:
  - the required minimum formation flood immunity was achieved; and
  - afflux impacts were reasonably balanced upstream and downstream of the corridor and across the range of events from 10% to 1% AEP.
- Once the afflux was balanced, the velocity was then checked through the structure and downstream. If the structure was found to generate velocities that exceeded 0.5 m/s over farmland downstream of the corridor then additional cells were added to increase the waterway area and reduce the velocity, or the culvert was reconfigured with different sizes and floor levels to meet the velocity impact criteria.
- The flood duration impacts were then checked and impacts across all parameters were checked for the full suite of design events (20%, 10%, 5%, 2% and 1% AEP events) and the design was re-balanced where necessary to address any localised areas of high impact.

4.4.2 Scour protection design

4.4.2.1 Culverts

The flood model predictions of culvert flood levels and velocities were used to design scour protection measures at the inlets and outlets of culverts, where necessary. The design is based on the procedure recommended in the Austroads Guide to Road Design, Part 5: Drainage – General and Hydrology Considerations (Austroads 2013), which identifies requirements for rip rap aprons, extended aprons and energy dissipaters depending on velocities, Froude Numbers and in-situ soil type. A velocity threshold of 1.6 m/s within the culverts was used to determine when scour protection is required, i.e. for velocities of 1.6 m/s or less within a culvert no scour protection is deemed necessary.

The value of 1.6 m/s was taken from Table 2.6 of the Austroads Guide and corresponds to a permissible velocity value for channel gradients up to 1% with 50% stable surface cover in an erosion resistant soil. This value is used solely to determine the need for scour at culvert inlets and outlets based on the flow velocity in the culvert. Separate to this process, the impact assessment considers changes in flood velocities in the adjacent land around the culvert and a more stringent limit of 0.5 m/s for velocity change was used to determine potential impacts in the adjacent land – refer to Section 4.6 for further details.

4.4.2.2 Bridges

The flood model predictions of flood levels and velocities at bridges were used to estimate scour depths at bridge abutments and piers to inform the geotechnical and structural design calculations and to design appropriate scour protection measures around the bridges. The design is based on the Austroads Guide to Bridge Technology, Part 8: Hydraulic Design of Waterway Structures (Austroads 2018). As per industry standards, scour protection at abutments was designed for the 1% AEP flood event while no scour protection is provided at piers as the geotechnical and structural design allows for the predicted scour depths at the piers.

4.5 Flood Planning Level and rail flood immunity

For the proposal, the Flood Planning Level (FPL) is the required flood immunity of the upgraded rail corridor set by ARTC. The flood immunity of the rail corridor is defined as the flood immunity of the Top of Formation (TOF), with the overarching requirement that the track is not to be overtopped at the 1% AEP event regardless of the TOF flood immunity. The minimum required flood immunity for the TOF is determined by the ARTC Flood Risk Assessment Working Group through application of ARTC’s Flood Risk Assessment Procedure – Upgraded Sections of Inland Rail. For this proposal the minimum TOF flood immunity has been set at the 5% AEP, with no overtopping of the rail to occur at the 1% AEP event.

Other FPLs set by Council and other authorities are also relevant to this impact assessment, in that the proposal should not affect the current standard of flood protection afforded to properties and other assets in the floodplain that have been established by other FPLs. For example, increases in flood level caused by the proposal may affect the standard of protection provided by flood protection levees or the function of irrigation storages. Flood impact criteria that aim to avoid adverse flooding impacts of the proposal on adjacent floodplain assets are discussed in the next section.

4.6 Flood impact assessment and criteria

For flood impact assessment, the results of the hydraulic model outputs for the existing and design cases have been compared using GIS software to determine the change in the following flood parameters in land adjacent to the corridor:

- flood level
- flood velocity
- flood duration
- flood hazard.

The changes in these parameters were compared to a set of assumed impact criteria and the design was modified and optimised until the impact criteria were met as far as reasonably practical.

The assumed impact criteria are presented below in Table 4-8 and are adopted from a set of criteria that may be adopted across all NSW Inland Rail projects pending agreement between ARTC and the NSW Department of Planning and Environment (DPE). The criteria have been developed based on other approved projects (such as N2NS Phase 1) with refinements intended to ensure sensible and pragmatic outcomes, such as the avoidance of inconsistencies across change limits set for the different flood risk parameters and the ability to distinguish real impacts from modelling artefacts.

The impact criteria are consistent with and similar to those set by the Conditions of Approval for the N2NS Phase 1 project which are also provided in Table 4-8 for comparison. The adopted criteria are also consistent with the policies and recommendations of the key local and regional plans described in Chapter 2, specifically the Floodplain Management Plan for the Gwydir Valley Floodplain, the Moree and Environs Floodplain Risk Management Plan and the Gwydir Moree Plains Local Environmental Plan. The criteria have been presented and explained to landowners as part of the consultation process.

A soil sampling and testing program was also undertaken at selected locations to establish the erodibility of the in-situ soils and inform the impact assessment against the QDLs for velocity. Appendix F contains the results of the soil erodibility assessment and these results are used to inform the velocity impact assessment in Chapter 6.

The QDLs will inform a detailed analysis of the impacts of the project at the detailed design stage. All aspects of the QDLs would be addressed to filter out or justify any minor impacts that remain at that stage in order to focus on material impacts that require mitigation. For the purposes of the EIS the QDLs have been used to determine the key QDL exceedances associated with the EIS/reference design that require mitigation and/or further investigation at detailed design. The QDLs in the table below are only applicable beyond the rail corridor, unless otherwise noted, and do not apply to model noise[1].

Table 4-8 Flood impact criteria

PARAMETER	LOCATION OR LAND USE	ADOPTED OBJECTIVES FOR N2NS PHASE 2	OBJECTIVES FROM N2NS PHASE 1	DIFFERENCES
Afflux i.e. increase in flood level resulting from implementation of CSSI.	Habitable floors and sensitive infrastructure	10 mm increase[2]	10 mm increase[3]	None
	Non-habitable floors	20 mm increase[2]	20 mm increase	None
	Surrounds of residential buildings, other urban, open space recreational land and infrastructure (excluding sensitive infrastructure)	100 mm increase	100 mm increase	No change in objective, N2NS Phase 1 conditions described the location or land use as 'Other urban and recreational'.
	Agricultural land	200 mm increase	200 mm increase	None
	Forest and unimproved grazing land	300 mm increase	300 mm increase	None
	Classified roads managed by TfNSW[5]	50 mm on areas flooded under existing conditions. Otherwise, no increase.[4]	Not specified	N/A
	Highways and sealed roads >80 km/hr[5]	No increase in depth where aquaplaning risk exists and remains unmitigated. Otherwise 50 mm increase.	No increase in depth where aquaplaning risk exists and remains unmitigated. Otherwise 50 mm increase.	None
	Unsealed roads and sealed roads <80 km/hr[5]	100 mm increase	100 mm increase	None

PARAMETER	LOCATION OR LAND USE	ADOPTED OBJECTIVES FOR N2NS PHASE 2	OBJECTIVES FROM N2NS PHASE 1	DIFFERENCES
Scour/Erosion Potential i.e. increase in flood velocity resulting from implementation of CSSI.	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]	20% increase in velocity where existing velocity already exceeds 1 m/s.	None
	Classified roads managed by TfNSW[5]	10% increase in velocity where existing velocity already exceeds 1 m/s.[7]	Not specified	N/A
	Other areas including watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas	An erosion threshold velocity (ETV) of 0.5 m/s is to be adopted unless otherwise determined through a site specific assessment(s) conducted by an experienced geotechnical or scour/erosion specialist.[8] 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[9] or 0.5 m/s, whichever is greater.	No velocities to exceed 0.5 m/s unless justified by site-specific assessment conducted by an experienced geotechnical or scour/erosion specialist. In addition, the increase in velocity is to be limited to 20% where the existing velocity already exceeds 0.5 m/s.	Introduction of a more stringent limit of 0.025 m/s when velocities are greater than 0.5 m/s.
Flood Hazard i.e. increase in velocity depth product (vd) and/or flood hazard category resulting from implementation of CSSI. (Does not apply where vd<0.1 m^2/s).	Urban, commercial, industrial, highways[5] and sealed roadways[5]	10% increase in vd	10% increase in vd where H1 or H2 category. 0% increase in vd where H3 or greater hazard category.	Removal of zero threshold for H3 or greater category areas.
	Classified roads managed by TfNSW[5]	10% increase in vd where this does not result in an increase in hazard category. Otherwise, no increase.[10]	Not specified	N/A
	Elsewhere	20% increase in vd	20% increase in vd	None

PARAMETER	LOCATION OR LAND USE	ADOPTED OBJECTIVES FOR N2NS PHASE 2	OBJECTIVES FROM N2NS PHASE 1	DIFFERENCES
Flood Duration i.e. increase in duration of inundation resulting from implementation of CSSI.	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.	No increase in inundation duration above floor level. 10% increase in inundation duration where below floor level and when existing inundation duration exceeds one hour. Otherwise inundation duration not to exceed one hour.	More definition added to the criteria and introduction of 5% limit for cases of above floor flooding.
	Classified roads managed by TfNSW[5]	No increase in duration of flood inundation to sections of road not already inundated.[11] Otherwise 10% increase in inundation duration.	Not specified	N/A
	Highways and sealed roads greater than 80 km/hr[5]	Forthcoming	10% increase in inundation duration.	To be confirmed. 10% limit adopted in the interim.
	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.	10% increase in inundation duration when existing inundation duration exceeds one hour. Otherwise inundation duration not to exceed one hour.	No change to limit for land subject to flooding in existing conditions. Additional qualifying statement added to address newly flooded land less than 1000 m^2 in area.

PARAMETER	LOCATION OR LAND USE	ADOPTED OBJECTIVES FOR N2NS PHASE 2	OBJECTIVES FROM N2NS PHASE 1	DIFFERENCES

Notes:

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.
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. Any afflux on newly inundated sections of road must be negotiated with the roads authority.
5. Including where located within CSSI corridor.
6. Local variations in velocity can exceed a 20% change provided that when assessed over a 30 m wide flowpath, the velocity change on average does not exceed 20%.
7. Any variation must be negotiated with the roads authority.
8. 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).
9. Local variations in velocity can exceed a 20% change provided that when assessed over a 30 m wide flowpath, the velocity change on average does not exceed 20%.
10. Any variation must be negotiated with the roads authority.
11. Any flooding duration on newly inundated sections of road must be negotiated with the roads authority.

4.7 Cumulative impact assessment

A cumulative impact assessment was undertaken to determine the flooding impacts of the project in combination with the following adjacent projects:

- Newell Highway upgrade: Approximately 4.5 km upgrade of the Newell Highway extending to the north from Stirton Road, involving raising of the highway to provide a 5% AEP flood immunity. Detailed design and a Review of Environmental Factors have been completed for this project, however, a construction date has not yet been identified.
- N2NS Phase 1: The adjacent Inland Rail project that has obtained planning approval and commenced construction. Phase 1 joins Phase 2 approximately 50 m north of the Alice Street level crossing in Moree and approximately 3 km east of the existing Camurra Hairpin.

For the cumulative impact assessment hydraulic representations of the Newell Highway Upgrade and N2NS Phase 1 earthworks and drainage designs were included in the flood model and the combined effects of the projects on flood level, velocity and duration were assessed.

4.8 Independent peer review of flood models

The flood modelling undertaken for this assessment has been independently peer reviewed by consultants BMT, who have specialist expertise in hydrological and hydraulic modelling, and in particular in the TUFLOW hydraulic modelling software program used in this assessment. Outcomes of the review are provided in Appendix E. The review supported the basis for the flood modelling and impact assessment and made the following key recommendations for detailed design:

- The EIS represents a design that is progressing towards achieving the requirements of the QDLs, but is still subject to further refinement to improve this outcome (i.e. reduction of flood impacts) during the detailed design. Non-compliances are identified, and stakeholder consultation should be initiated/continued to either provide acceptance of the results or provide further mediation (or mitigation) options to the affected stakeholders.
- Further assessments of potential rail embankment failure under extreme events at locations with sensitive receptors should be undertaken during detailed design, The results of these assessments should be included in the Flood Emergency Response Plan (FERP), including management measures to mitigate the risks to an acceptable level.
- Where QDLs cannot be reasonably achieved during the detailed design, the acceptability of the flood risks demonstrated through model refinement and sensitivity analyses will need to be accepted by ARTC, landowners and associated stakeholders for the construction phase of the Inland Rail.
- The following model improvements should be investigated at detailed design:
  - additional TUFLOW model verification, including a historic event assessment;
  - sensitivity of culvert blockage results (i.e. 0% and 25% blockage) included in the sensitive receivers assessment against the QDLs, while the 50% blockage scenario shall be used as an upper limited risk assessment; and
  - a sensitivity test using Council’s latest flood model incorporating existing levee/storage structures.

5 Baseline assessment

5.1 Overview of catchment and watercourses

The proposal is located within the Gwydir catchment, which is a sub catchment of the Murray Darling Basin. Figure 5-1 shows the major catchment areas in NSW.

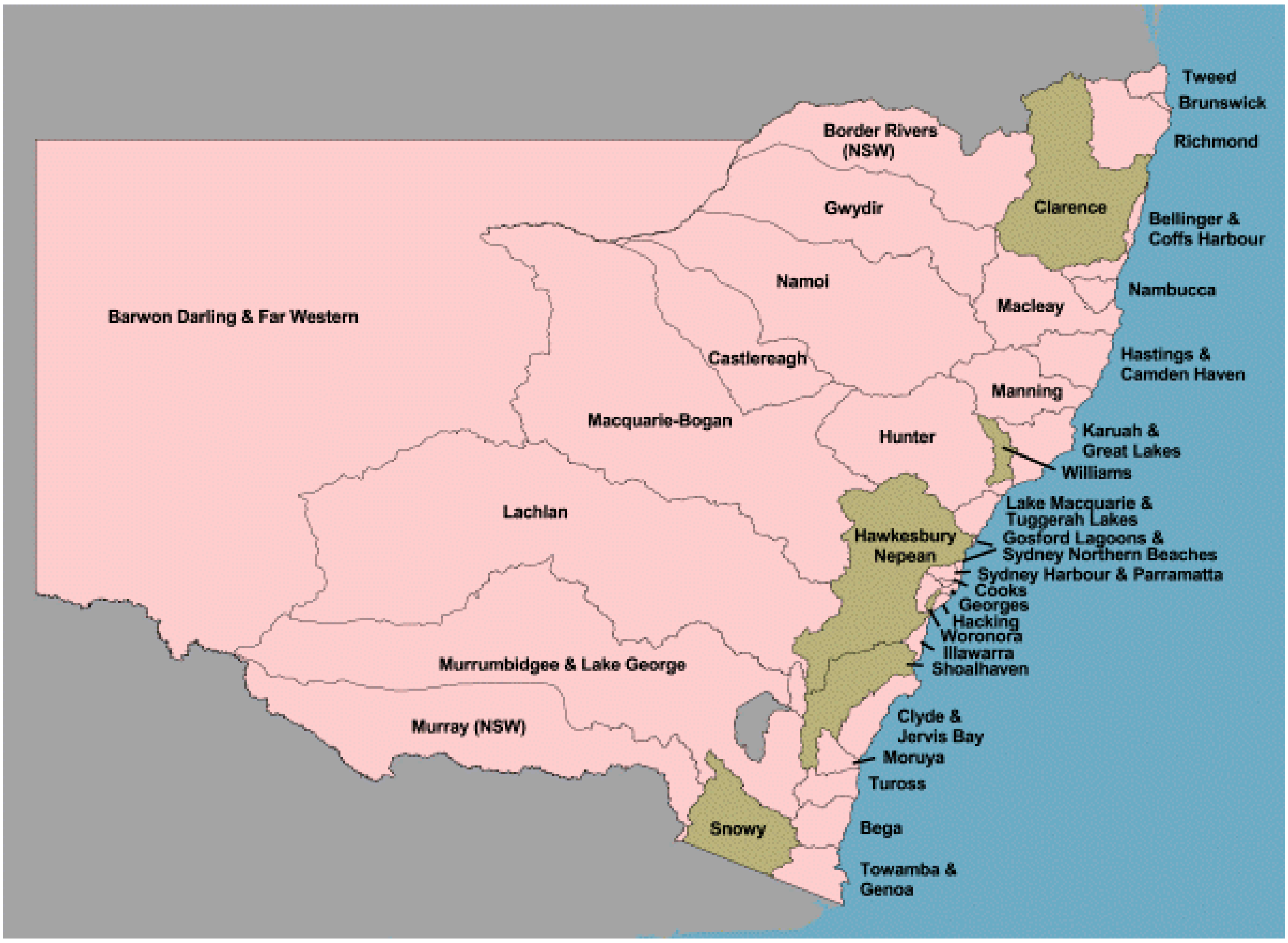

Figure 5-1 Major catchments in NSW – Source: Office of Environment and Heritage, 2006

An overview of the Gwydir catchment is provided in Figure 5-2. The Gwydir catchment is in northern New South Wales and covers 26,600 square kilometres from the Great Dividing Range in the east to the Barwon River in the west. It is separated from the Border Rivers catchment to the north by the Mastermans Range and from the Namoi catchment to the south by the Nandewar Range. The Gwydir and Mehi Rivers are the catchment's major rivers which run west 670 kilometres from Uralla and Guyra in the New England tablelands to the Barwon River. The Gwydir River intercepts the proposal site approximate 9 kilometres north of Moree and has a mean daily flow of 1,127 megalitres at Yarraman Bridge. The Gwydir catchment area upstream of Moree is 13,320 square kilometres.

A flood channel known as the Biniguy Break conveys floodwaters from the Gwydir River to the Mehi River 30 kilometres upstream of Moree. Small lagoons and depressions occur adjacent to the Mehi River, a small number of which are used as off-river storages during large floods. The Mehi River runs through Moree conveying a mean daily flow of 370 megalitres.

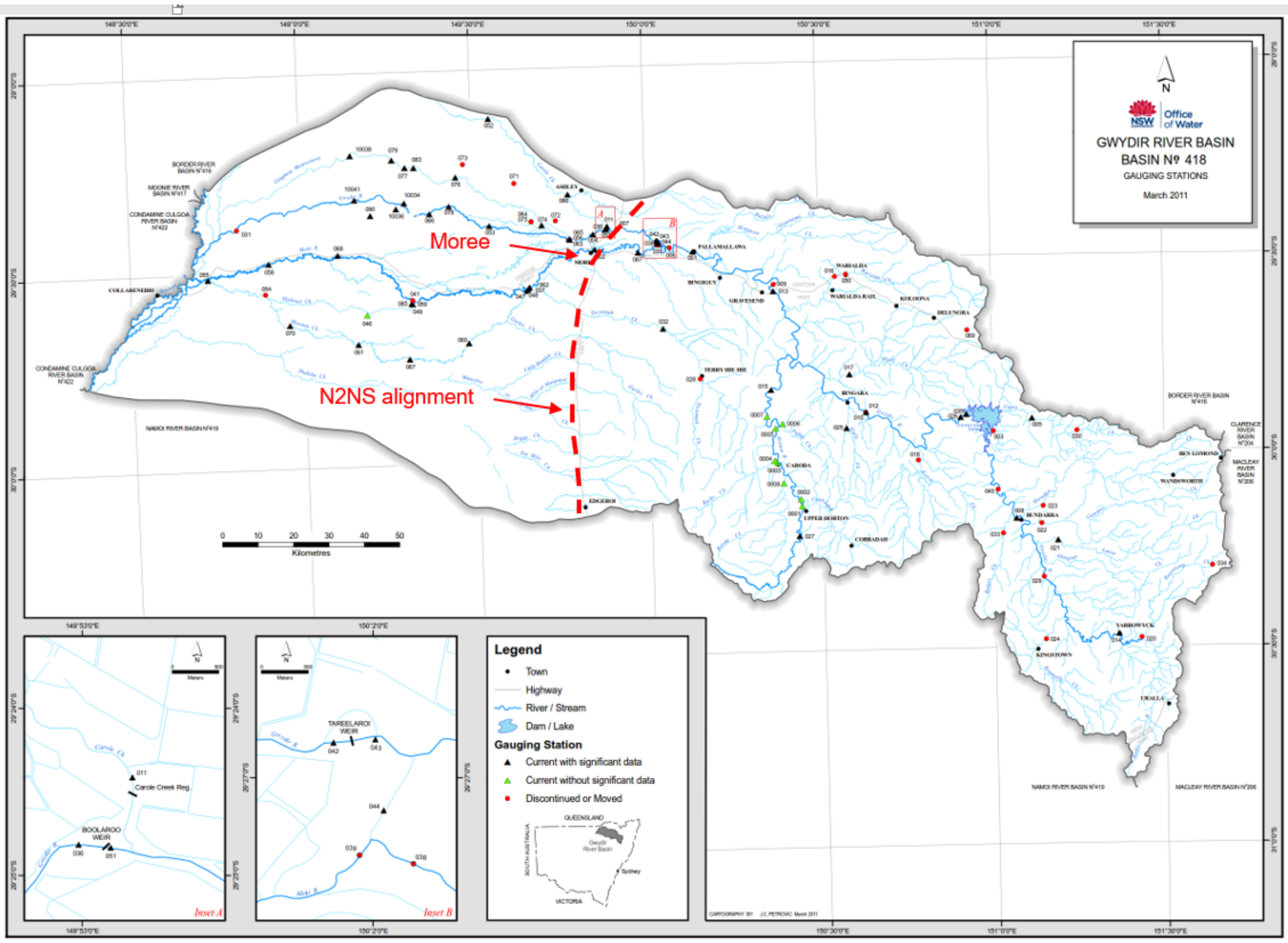

Figure 5-2 Overview of the Gwydir catchment – Source: NSW Office of Water, 2011

Figure 5-3 shows the key surface water features in the catchment draining to the proposal site. Surface water within the proposal site is conveyed within both perennial and ephemeral watercourses. The perennial watercourses in the proposal site are generally in the middle of the Gwydir catchment between upland and lowland classification. Ephemeral streams in the proposal site are generally at the top of local sub-catchments and only flow during significant rainfall events.

The named watercourses that flow through or adjacent to the proposal site include:

- Gwydir River
- Mehi River
- Marshalls Ponds Creek
- Skinners Creek; and
- Duffys Creek.

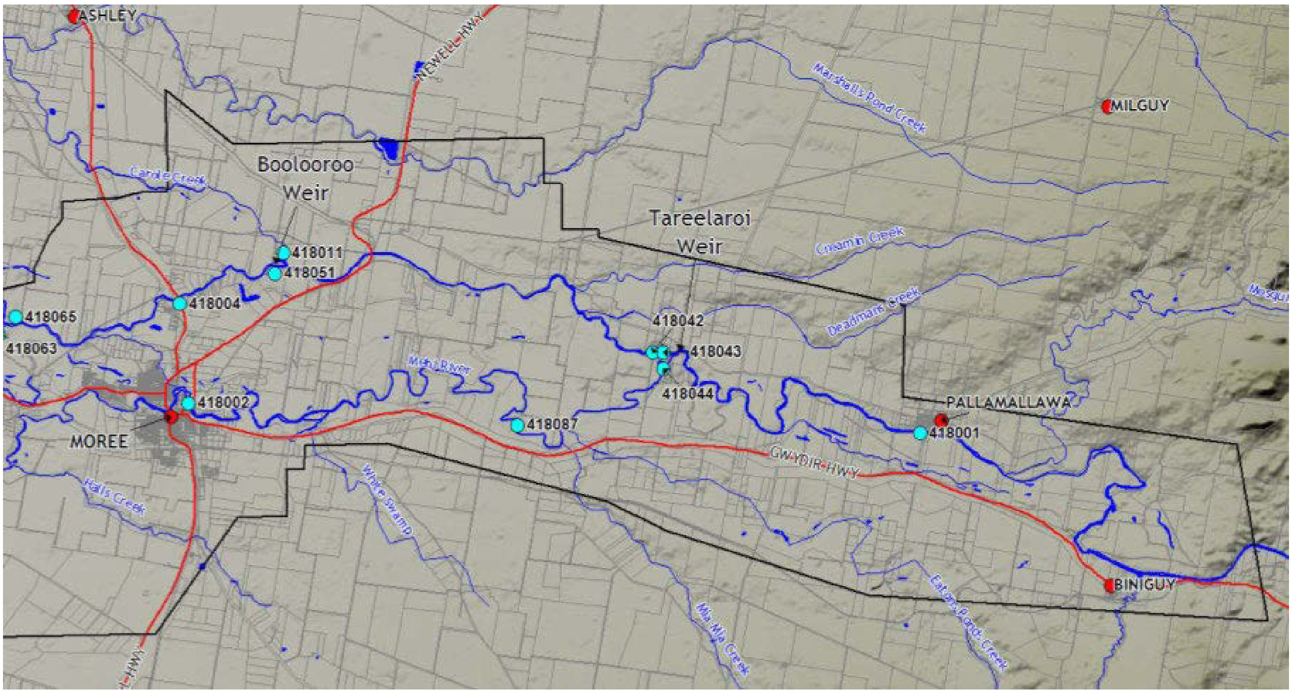

Figure 5-3 Main waterways draining to the proposal site (WRM, 2017)

5.2 Watercourse classification

Table 5-1 provides the Strahler stream order of the watercourses crossed by the alignment. The Strahler stream order classification is a "top down" system in which rivers of the first order are the outermost tributaries. If two streams of the same order merge, the resulting stream is given a number that is one higher. If two rivers with different stream orders merge, the resulting stream is given the higher of the two numbers.

First to third order streams are called headwater streams. Streams classified as fourth through sixth are medium streams are streams that are seventh order or larger are a river.

Table 5-1 indicates that most of the named minor streams that cross the proposal site are first to third order. There is also an unnamed 2nd order waterway crossing the site, 5 kilometres northeast of Moree. These minor streams feed other streams and are ephemeral where they cross the proposal site, only having flow after large rainfall events. They are unlikely to provide suitable habitat for aquatic species.

The Mehi and Gwydir River are major watercourses crossed by the proposal. Generally, medium streams and above are likely to display valuable fish habitat, and hence could support viable fish populations. Flows within the Gwydir and Mehi Rivers are primarily regulated by releases from Copeton Dam and a series of weirs downstream of the dam, most notably the Tareelaroi weir, which provides diversions from the Gwydir River into the Mehi River approximately 15 kilometres east of the proposal site.

Table 5-1 Stream order and condition of named waterways crossed by the proposal

STRAHLER STREAM ORDER	NAMED STREAMS INTERSECTING THE PROPOSAL
1st/2nd/3rd	▸ Skinners Creek ▸ Duffys Creek ▸ Marshalls Ponds Creek
4th/5th/6th	Nil
7th	▸ Mehi River ▸ Gwydir River

5.3 Irrigation storages

There are numerous large irrigation storages with elevated levees located along both sides of the proposal site. These storages are supplied by river pumping and gravity drainage via a network of irrigation channels and are used as water supply for crop irrigation and stock throughout the area. Two large storages are located in the immediate vicinity of the proposal site; near The Rocks Road, on the eastern side of the rail alignment, and near Boolooroo Weir Road, on the western side of the rail alignment.

5.4 Land uses

Moree Plains Shire Council is a local government area at the centre of the proposal site which at the 2016 census had a population of 13,159, of which, 7,383 reside in the Moree urban centre (Australian Bureau of Statistics, 2019).

North of the Moree urban centre, the proposal predominantly traverses cleared rural areas used primarily for grazing and cropping. The major agricultural industries in the area include livestock, wool, cotton and wheat. Most of the land within the proposal site has been cleared and disturbed for agricultural activities, however some residential and farm infrastructure and some patches of remnant vegetation are present. Figure 5-4 shows the land uses around the proposal site.

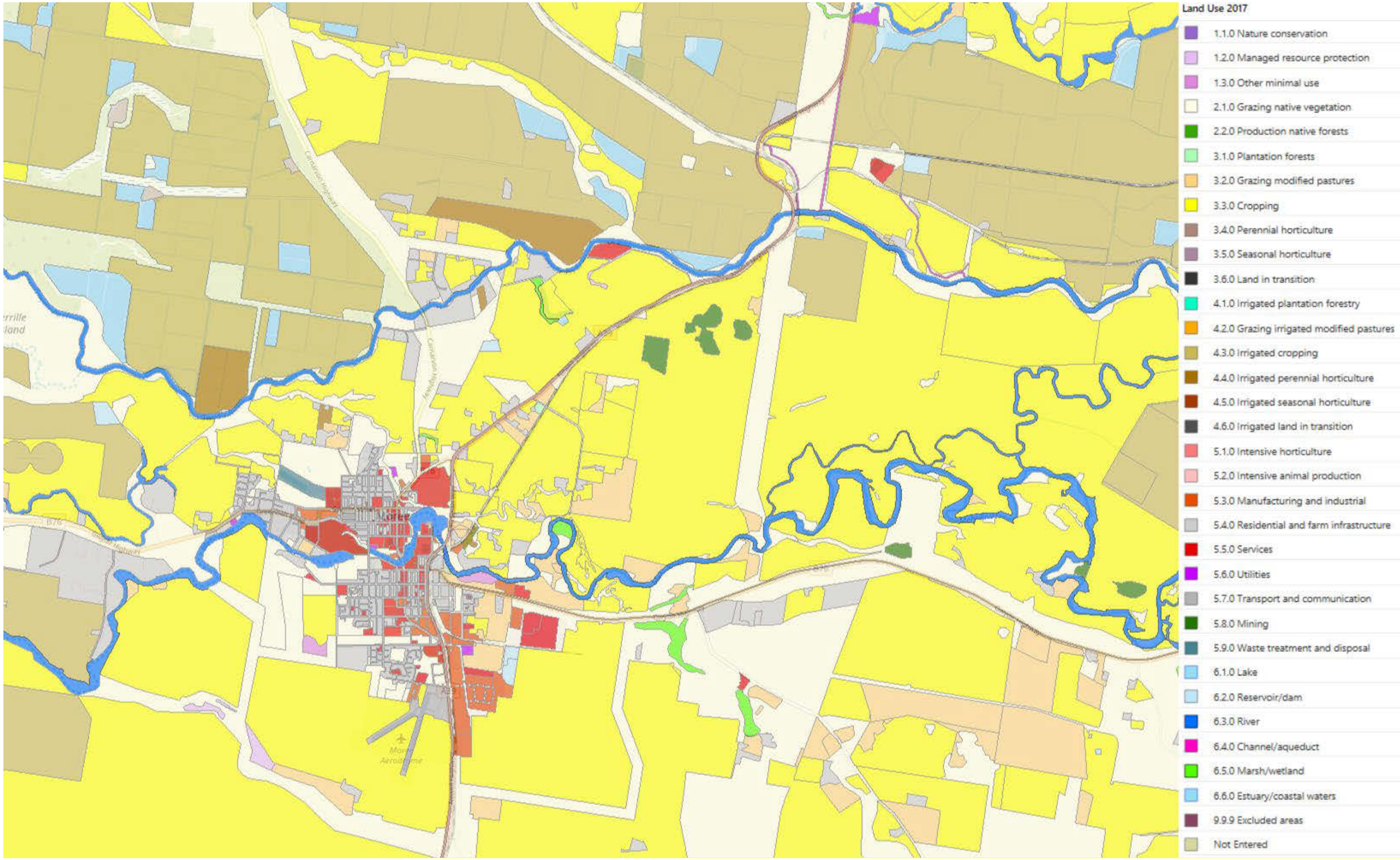

Figure 5-4 Land use in the proposed site (Department of Planning, Industry and Environment NSW Landuse v1.2, 2017)

5.5 Topography

The proposal site is located in Moree Plains Shire Council and the surrounding areas extending south to Moree Regional Airport and north to Gwydir River. The topographic information indicates that the section of the proposal north of Moree generally passes through gently sloping to level farming land west of Pallamallawa. Runoff from this area will flow to the Mehi River or Gwydir River, either directly or via ephemeral tributary creeks.

The southern portion of the proposal site passes through Moree urban centre. The terrain of Moree is generally flat and cut by numerous streams and watercourses associated with Mehi River and its tributaries, including Skinners creek and Duffys Creek. The topographic low points and watercourses flow into Mehi River on the west side of Moree, and Broadwater Creek which flows west into Gwydir River north of Moree.

5.6 Soils

5.6.1 Regional soils

A search of the DPE eSPADE website undertaken in October 2020 identified the regional soil landscape of the study area as predominantly Watercourse Road (Alluvial) landscape, with several areas of Black Creek, Mehi River and Nee Nee Creek landscapes along the creek lines (NSW Department of Minerals and Energy, 2005).

The Watercourse Road landscape is a large floodplain that is associated with the Mehi River, Carole Creek and Gingham Watercourse. The majority of this landscape lies on Quaternary alluvials of the Marra Creek formation with small pockets of meander plains facies of the Bugwah formation scattered throughout.

The Marra Creek formation is comprised of unconsolidated dark yellow clay, slightly silty with rare carbonate nodules and quartz sand, common desiccation cracks, laminations and rootlets. The Bugwah formation is comprised of unconsolidated to semi-consolidated, poorly to very poorly sorted, orange to brown to grey silt, silty clay and fine sand with common carbonate nodules, minor medium sand, ferromagnesian nodules, charcoal and salts. Very deep (150–500 centimetres (cm)), very slowly permeable and very poorly drained self-mulching Grey and Dark Grey Vertosols (Grey Clays) dominate this landscape (approximately 80 per cent).

Further details of the regional soils and geology are provided in Chapter 20 of the EIS.

5.6.2 Erodibility assessment

A soil sampling and testing program was undertaken to determine the susceptibility of soils to erosion in areas where the proposal will alter the flood velocity regime. Soil samples were taken at 10 sites along the existing rail corridor and subject to laboratory testing to determine the soil type and exchangeable sodium percentage and the results were used to establish the permissible velocities that would not cause erosion for a range of vegetation cover conditions. The sites were also inspected by a soil scientist to assess local flow paths, vegetation cover and evidence of previous scour and erosion in and around the rail corridor. The methodology and findings of the program are documented in the Erodibility Assessment Report provided in Appendix F. The key findings of this assessment are as follows:

- The predominant soil type found at the sites was light clay with sandy, medium and heavy clays noted at some locations.
- Sub-soils in the area are dispersive and have the potential to be highly erodible when subject to flooding.
- At 9 out of the 10 sampled locations the following erosion thresholds were determined:
  - Bare soil: 0.7 m/s.
  - 50% weed cover: 1.0 to 1.4 m/s.
  - 50% crop cover: 1.4 to 2.2 m/s.

- At 1 location an area of hardstand exists that has been constructed from subsoil material. This site has lower erosion thresholds than the other sites, as follows:
  - Bare soil: 0.3 m/s.
  - 50% weed cover: 0.7 to 1.0 m/s.
  - 50% crop cover: 0.7 to 1.2 m/s.

5.7 Climate and rainfall

The climate of the Northwest Plains is classified as Climate Zone 4 (hot dry summer, with cool winter). The region experiences hot and dry summers and cold to mild temperatures during the winter months. The nearest Bureau of Meteorology (BOM) weather station is located in Moree (Moree Aero, site number 053115), records mean daily temperatures from 33.0°C in January to 18.4°C in July.

Rainfall levels are usually low. Rainfall data from Moree Aero (station number 053033) shows an average annual rainfall of 558 millimetres. Rainfall data from the Pallamallawa Post Office station (station number 073124) 25 kilometres east of the proposal site shows an average annual rainfall of 612 millimetres. Rainfall recorded at Pallamallawa and Moree is typically higher from November to March.

5.7.1 Long-term rainfall

The long-term, annual cumulative deviation from mean (CDFM) rainfall for the 1996 to 2019 period at the Moree Aero station (station number 053033) is plotted in Figure 5-5. The long-term cumulative residual rainfall plots provide an indication of the broad scale trends in rainfall pattern. Periods of below average rainfall are represented as downward trending slopes while periods of above average rainfall are represented as upward trending slopes. The cumulative deviation plot shows a general upward sloping trend from 1996 to 2012, followed by a downward sloping (drying) trend until 2019.

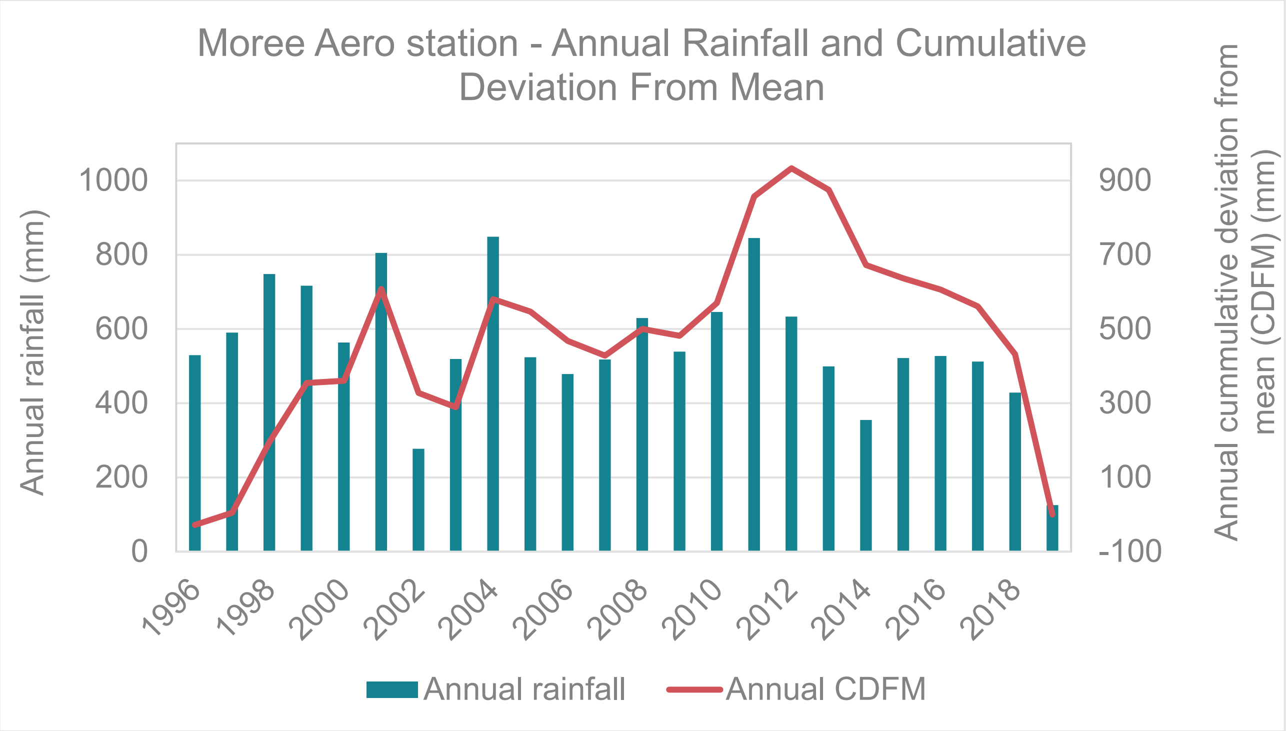

Figure 5-5 **Long-term rainfall Moree Aero station (BOM, 2020)**

The long-term, annual cumulative deviation from mean (CDFM) rainfall for the 1913 to 2019 period at the Pallamallawa station (station number 053033) is plotted in Figure 5-6. The cumulative deviation plot shows a general upward sloping trend from 2003 to 2011, followed by a downward sloping (drying) trend until 2019.

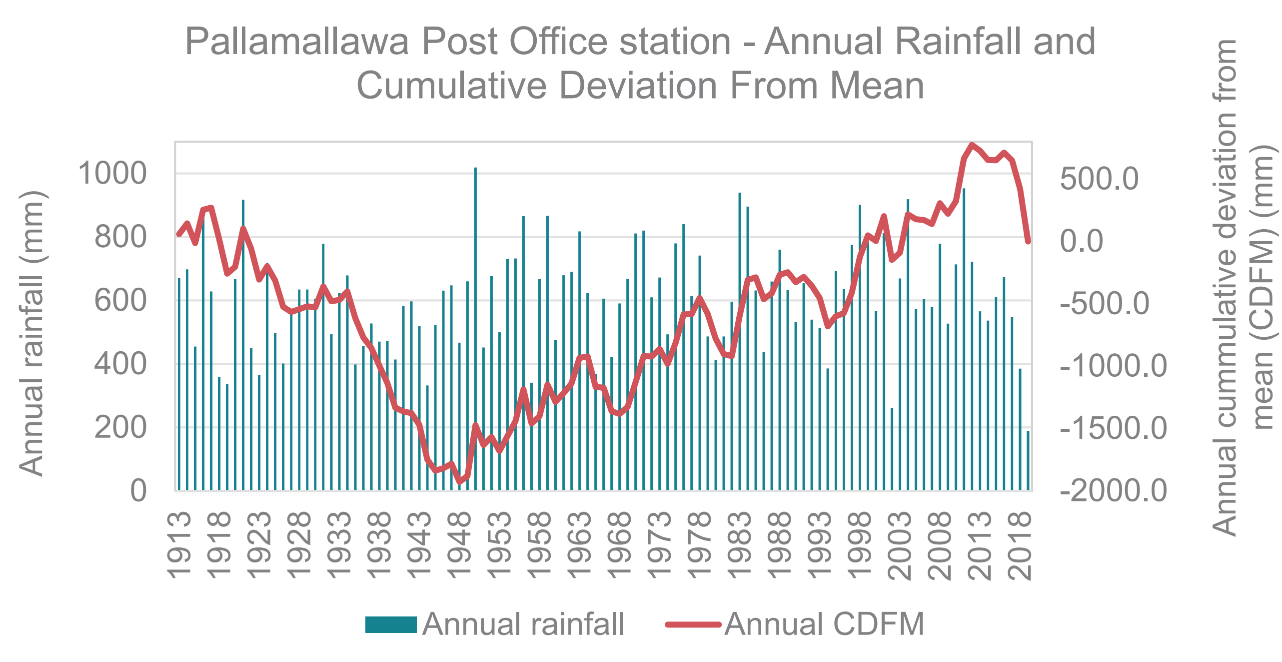

Figure 5-6 **Long-term rainfall Pallamallawa Post Office station (BOM, 2020)**

Figures 5-5 and 5-6 demonstrate that the climate at the proposal site is characterised by low annual precipitation and that the recent climatic trend for rainfall (i.e. within the last decade) is generally at or above its historic annual mean.

5.7.2 Evaporation

Evaporation data was obtained from the Moree Aero weather station (BOM 2019, station number 053115), the closest station with recorded evaporation data. The data is shown in Figure 5-7. Daily evaporation data is greatest in the months of November, December, January and February with evaporation of 9.2, 9.8, 10.1, and 9.1 millimetres/day respectively. The months of May, June and July show the lowest evaporation rates with 2.6 millimetres/day observed for June.

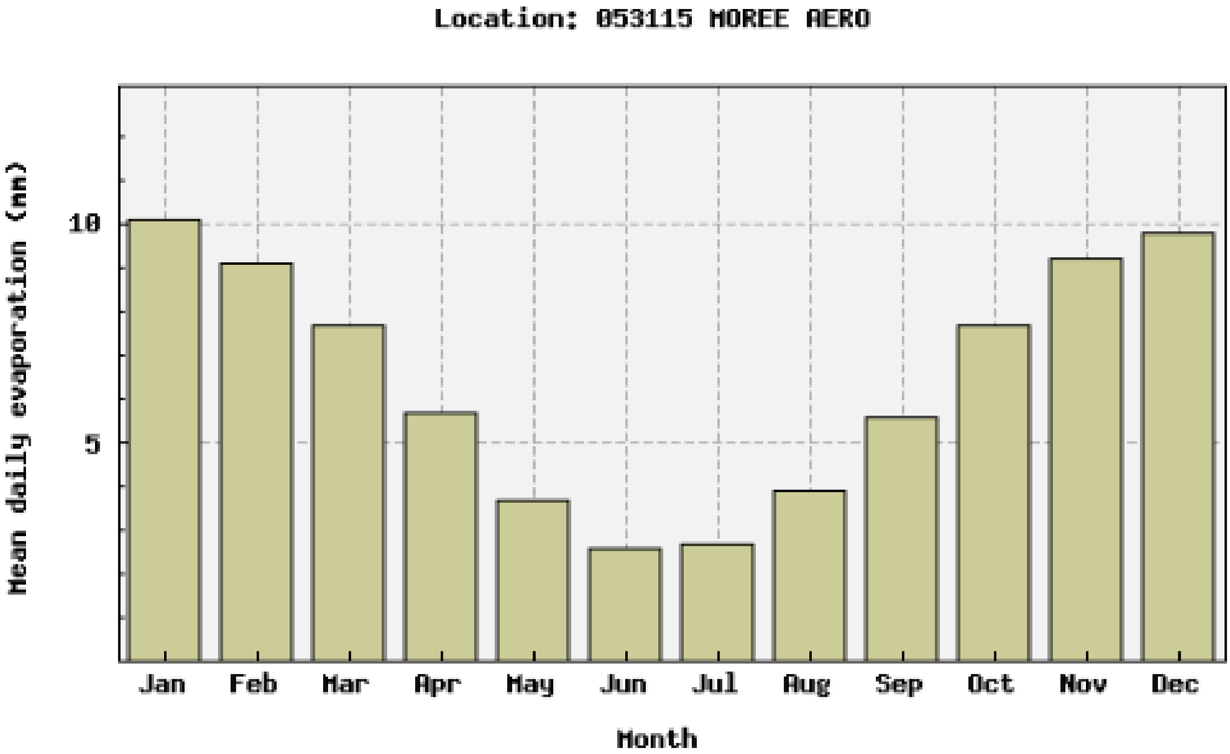

Figure 5-7 Daily average evaporation at Moree Aero Station (BOM, 2020)

5.8 Existing flooding patterns and flood risk

Appendix A contains flood maps for the area around the proposal that define the existing flooding patterns and characteristics, including extent, depth, velocity, duration and hazard. Mapping of these parameters is provided for the 10, 5, 2 and 1% AEP events, the 1% AEP event with climate change and the PMF.

The maps demonstrate the regional scale of flooding in the Gwydir-Mehi system around the proposal and the surrounding land. The floodplain approaches 9 kilometres in total width through the area for the 5, 2 and 1% AEP events, with a significantly reduced extent to approximately 5 kilometres for the 10% AEP event. Figure 5-8 shows the extent and depth of the floodplain in the 1% AEP event.

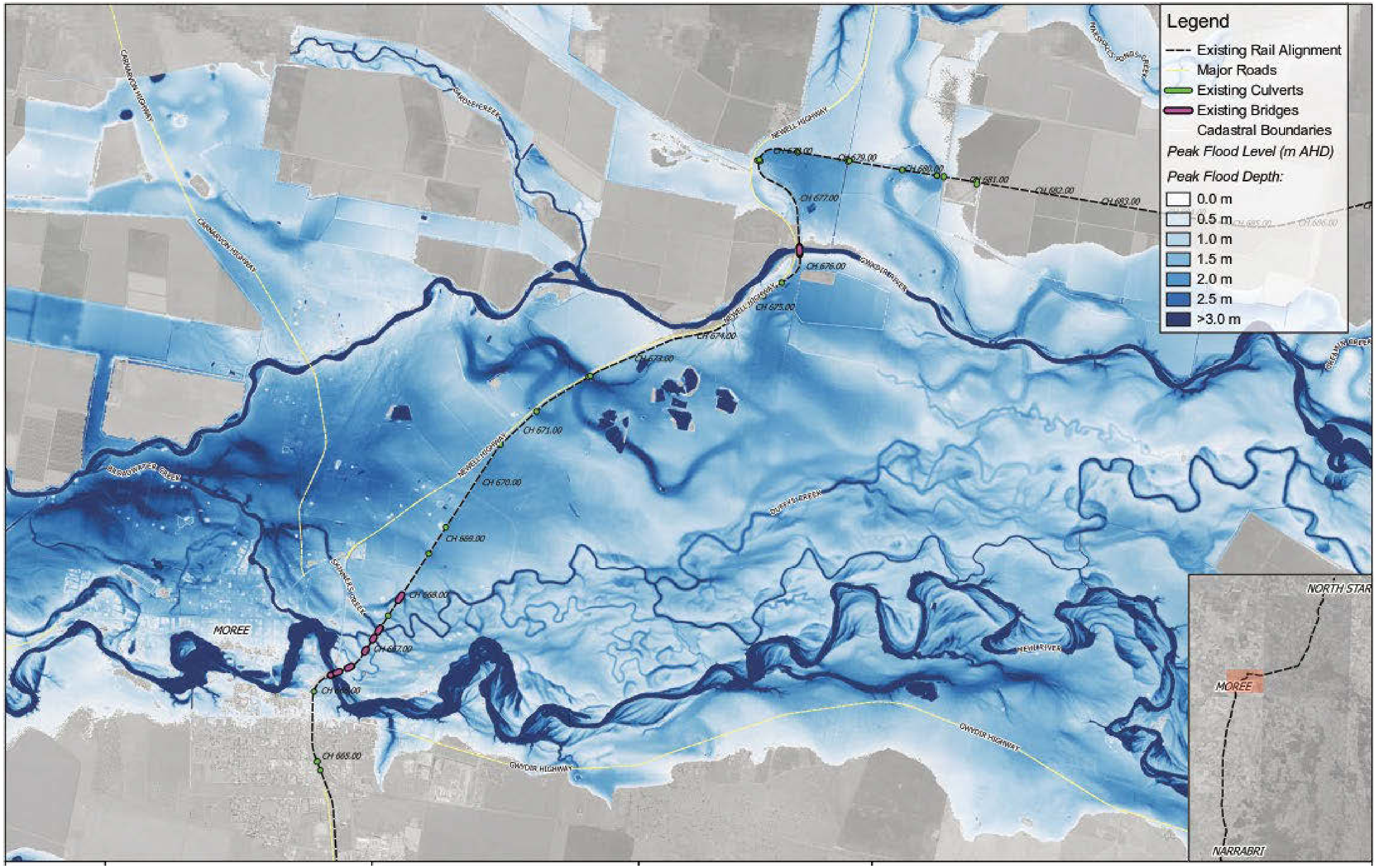

Figure 5-8 **Existing conditions 1% AEP flood extent and depth map for Moree and Environs**

Extensive areas of deep floodwaters occur, with flood depths exceeding 1 metre over most of the floodplain in large events. Under these conditions the Newell Highway and most local roads are flooded and untrafficable. A significant area of Moree township experiences flooding in the 1% AEP flood event, and most of the farmland and properties east and west of the rail corridor are susceptible to flooding. Most residences in the floodplain are elevated on mounds which prevents above floor flooding in large events.

Flood velocities throughout the floodplain are relatively low and do not exceed 1 m/s over most of the floodplain in the large events. Flood durations are long, reflecting the regional scale nature of the flood behaviour in the area, with flooding persisting for more than 72 hours following major events.

5.9 Existing rail infrastructure and flood risk

The existing rail corridor runs across the floodplain almost perpendicular to the main direction of the flood flow. A number of bridges and cross drainage culverts under the rail exist to pass floodplain flows but the existing rail diverts significant volumes floodplain flow from the Gwydir system to the north to the Mehi system to the south.

The existing top of rail has lower than 10% AEP event flood immunity in some locations and in major events extensive overtopping of the rail line occurs, with up to 6 km of rail line overtopping predicted for the 1% AEP event.

During major events flood damage of the rail occurs, with washout of rails and ballast and scouring of the rail embankment down to ground level at some locations. Washout of the rail line at approximately 15 locations occurred in the last major flood of February 2012, which had an estimated return period of 1 in 30 years based on the recorded flow at Gravesend.

Figure 5-9 shows an aerial photo of the February 2012 flood event around the Gwydirfield Road level crossing approximately 2 kilometres north of Moree. The photo shows washout of the rail over a distance of approximately 120 metres around the level crossing.

Figure 5-9 Aerial photo showing flooding around Gwydirfield Road level crossing during February 2012 flood event (SIX Maps)

6 Impact assessment

Throughout this impact assessment section some locations are referred to by rail kilometrage or chainage. Refer to Figure 5-8 for mapped locations of kilometrage / chainage values.

6.1 Proposed Flood Planning Levels and rail flood immunity

A key design objective of the proposal is to deliver a more resilient and reliable rail corridor which can continue to operate in moderate flood events and resist damage in major floods. Based on ARTC's assessment of reliability and resilience requirements for this section of Inland Rail and the wider network, the following FPLs have been adopted:

- FPL for TOF: Minimum of 5% AEP
- FPL for TOR: Minimum of 1% AEP.

The design currently achieves these FPLs through raising the level of the rail by approximately 500 mm above the existing rail levels, with a reconstructed rail formation, and provision of a large number of additional cross drainage structures, primarily flood relief culverts to allow passage of overland flow on the floodplain between the Mehi and Gwydir Rivers.

For events between the 5% and 1% AEP, floodwaters will rise above the TOF and inundate the ballast and sub-layers. This has been accepted by ARTC following a technical review of flood depths, velocities and durations at the formation to confirm that the risk of damage to the rail assets is acceptable for all events up to and including the 1% AEP. Increasing the flood immunity of the TOF and TOR above the FPLs noted above was ruled out due to the difficulties further track raising would present at level crossings and connections to Phase 1.

6.2 Proposed cross drainage infrastructure

Raising the rail level has the potential to considerably worsen flooding on the upstream (eastern) side of the rail corridor due to obstruction of the floodwater that previously overtopped the rail. To avoid this impact significant numbers of additional cross drainage structures have been provided in the design to allow equivalent volumes of floodwater to pass under the rail in a more controlled manner.

These new cross drainage structures replace the overtopping mechanism and have been carefully sized and located to ensure that they do not pass flow too efficiently through the rail corridor and adversely impact flooding on the downstream (western) side of the rail corridor. One of the key objectives of the cross drainage design is to preserve existing flooding patterns as closely as possible as development and farming practices upstream and downstream of the rail corridor have adapted to the existing flood behaviour and are sensitive to any change to the existing behaviour.

The new and upgraded cross drainage infrastructure consists of large clusters of Reinforced Concrete Box Culverts (RCBCs), with some structures set higher in the rail embankment than the surrounding ground levels to replicate the previous rail overtopping behaviour. All existing culverts within the rail corridor will be removed and upgraded. In addition, all existing bridges will be upgraded to support the higher train loads. The lists of new/upgraded bridges and culverts adopted in the design case are provided in Table 6-1 and Table 6-2.

Table 6-1 List of new and upgraded bridges

NO.	KILOMETRAGE	BRIDGE NAME	NUMBER OF PIERS	OPENING WIDTH	NOTES
1	666.340	BR09	11	149.6	Mehi River Bridge – replace existing
2	666.645	BR10	8	80.6	Replace existing
3	666.945	BR11	5	53.6	Replace existing
4	667.210	BR12	6	62.6	Duffys Creek – replace existing
5	667.370	BR13	8	80.6	Duffys Creek – replace existing
6	667.625	BR14	1	17.6	Replace existing
7	667.945	BR15	11	107.6	Skinners Creek Bridge – replace existing
8	676.220	BR16	8	122.6	Gwydir River Bridge – new bridge to be constructed approximately 30 metres upstream of old bridge

Table 6-2 List of new and upgraded culverts

NO.	KILOMETRAGE	NUMBER OF CELLS	SIZE	TYPE	NOTES
1	668.200	30	3000x1200	RCBC	High level flood relief culvert
2	668.700	60	1800x600	RCBC	High level flood relief culvert
3	668.830	2	2400x2400	RCBC	Replace existing 3x1850x1100 RCBC
4	669.000	60	1800x600	RCBC	High level flood relief culvert
5	669.200	60	1800x600	RCBC	High level flood relief culvert
6	669.305	1	1800x1800	RCBC	Replace existing 2x750 RCP
7	669.450	60	1800x600	RCBC	High level flood relief culvert
8	669.650	60	1800x600	RCBC	High level flood relief culvert
9	669.850	60	1800x600	RCBC	High level flood relief culvert
10	670.100A	60	1800x600	RCBC	High level flood relief culvert
11	670.100B	60	1800x600	RCBC	High level flood relief culvert
12	670.500A	50	1800x600	RCBC	High level flood relief culvert
13	670.500B	50	1800x600	RCBC	High level flood relief culvert
14	670.500C	50	1800x600	RCBC	High level flood relief culvert
15	670.500D	40	1800x600	RCBC	High level flood relief culvert
16	670.790A	30	1800x600	RCBC	High level flood relief culvert
17	670.790B	1	3000x1200	RCBC	Replace existing 4x600 RCP
18	671.000A	50	1800x600	RCBC	High level flood relief culvert
19	671.000B	50	1800x600	RCBC	High level flood relief culvert
20	671.200	50	1800x600	RCBC	High level flood relief culvert
21	671.400	50	1800x600	RCBC	High level flood relief culvert
22	671.520	7	3000x2100	RCBC	Replace existing 13x1250 RCP
23	672.000A	50	1800x600	RCBC	High level flood relief culvert
24	672.000B	70	1800x600	RCBC	High level flood relief culvert

NO.	KILOMETRAGE	NUMBER OF CELLS	SIZE	TYPE	NOTES
25	672.000C	70	1800x600	RCBC	High level flood relief culvert
26	672.000D	70	1800x600	RCBC	High level flood relief culvert
27	672.450A	60	1800x600	RCBC	High level flood relief culvert
28	672.450B	20	3600x3600	RCBC	Replace existing 17x4000 x variable height RCBC
29	672.700	20	3000x1200	RCBC	
30	673.050	15	3000x1100	RCBC	
31	673.270	15	3000x1100	RCBC	
32	675.380	2	3000x1100	RCBC	Replace existing 5x900 RCP
33	675.720	2	3000x1100	RCBC	Replace existing 5x750 RCP
34	676.730	20	2400x800	RCBC	
35	676.850	13	2400x800	RCBC	
36	677.350	5	3000x1200	RCBC	
37	677.600	5	3000x1200	RCBC	
38	677.770	3	3000x1800	RCBC	
39	677.875	5	3000x1200	RCBC	
40	678.615A	20	2400x800	RCBC	High level flood relief culvert
41	678.615B	4	3000x1800	RCBC	Replace existing 2x900x600 RCBC
42	680.500A	50	2400x800	RCBC	High level flood relief culvert
43	680.500B	5	3000x2100	RCBC	Replace existing 3x3000 span bridge
44	CM677.300	3	3000x1800	RCBC	

6.3 Flood impact assessment

The flooding impacts of the proposal have been assessed against the criteria set out in Table 4-8. The results are presented in the following sections and appendices:

- Impacts on adjacent land and assets for the primary design case are discussed in Section 6.3.1. Flood impact maps for the design case are provided in Appendix B.
- The effects of climate change on design rail flood immunity and adjacent land impacts are discussed in Section 6.3.2. Flood impact maps for the 1% AEP with climate change scenario are provided in Appendix B.
- Impacts under extreme events are discussed in Section 6.3.3. The flood impact maps for the extreme event (PMF) are provided in Appendix B.
- The cumulative impact assessment of the combined effects of the proposal, N2NS Phase 1 and the future upgrade of the Newell Highway is presented in Section 6.3.4. The flood impact maps for the cumulative impact assessment are provided in Appendix C.

6.3.1 Design case impacts on adjacent land and assets

6.3.1.1 Afflux

Exceedances of the afflux criteria are identified in Table 6-3. Where these impacts affect non-sensitive land use (such as general agricultural land rather than property accesses) they may be accepted as minor low risk impacts subject to agreement from ARTC and consultation with the affected landowners.

Table 6-3 Overview and locations of afflux criteria exceedances for general land uses (excluding buildings and Newell Highway)

LOCATION	20% AEP EVENT AFFLUX CRITERIA EXCEEDANCES	10% AEP EVENT AFFLUX CRITERIA EXCEEDANCES	5% AEP EVENT AFFLUX CRITERIA EXCEEDANCES	2% AEP EVENT AFFLUX CRITERIA EXCEEDANCES	1% AEP EVENT AFFLUX CRITERIA EXCEEDANCES
Main urban area of Moree	No change to flood levels	Afflux of 10 to 20 mm around northern edge of town near sewage treatment works but no exceedances for general land uses	No exceedances (decreased flood level)	No exceedances (decreased flood level)	No exceedances for general land uses Impacts on Moree town due to Phase 1 works – discussed in Section 6.3.4 Afflux of 10 to 20 mm east of rail corridor south of Gwydir Highway
Main central floodplain flow path between Mehi and Gwydir Rivers	East of rail: No exceedances, afflux <200 mm on cropping land West of rail: No exceedances, decreased flood level or no change to flood levels on cropping land	East of rail: No exceedances (decreased flood level) West of rail: No exceedances. Afflux 10 to 50 mm with some localised areas of 50 to 100 mm. All afflux <200 mm objective for cropping land	East of rail: No exceedances (decreased flood level) West of rail: Afflux 10 to 100 mm with some localised areas of 100 to 300 mm. Localised exceedance of 200 mm limit for cropping land west of Newell Highway	East of rail: No exceedances (decreased flood level) West of rail: Reduced area of afflux from 5% AEP event. Afflux 10 to 100 mm with some localised areas of 100 to 300 mm. Localised exceedance of 200 mm limit for cropping land west of Newell Highway	East of rail: No exceedances, afflux <200 mm on cropping land West of rail: No exceedances, decreased flood level or afflux <100 mm on cropping land
Area north of Gwydir River and south of rail alignment (around Back Pally Road and new greenfield rail section)	No exceedances (decreased flood level)	No exceedances (decreased flood level)	No exceedances (decreased flood level)	No exceedances (decreased flood level)	Impact exceeds 100 mm on local road but no exceedances for general land use
Area north of old hairpin and new greenfield rail section	No exceedances, afflux <200 mm on cropping land Impact exceeds 50 mm on Newell Highway	Impact exceeds 200 mm on cropping land Impact also exceeds 50 mm on Newell Highway	Impact exceeds 200 mm on cropping land Impact also exceeds 50 mm on Newell Highway	Impact exceeds 200 mm on cropping land Impact also exceeds 50 mm on Newell Highway	Impact exceeds 200 mm on cropping land Impact also exceeds 50 mm on Newell Highway

In the 20% AEP event (Appendix B Maps DES_AFF_020_1 to 3), the general pattern of flood level change is an increase in flood levels upstream of the rail corridor in the floodplain between the Gwydir River and Duffy Creek and a reduction in flood level downstream. There are no areas of flood level increase that exceed 20 millimetres in urban areas. While not exceeding the impact limit of 200 mm, afflux of up to 200 mm occurs on agricultural land at approximately chainage 680.25 kilometres as noted in Table 6-3.

In the 10% AEP event (Appendix B Maps DES_AFF_010_1 to 3), the general pattern of flood level change is an increase in flood levels downstream of the rail corridor and a reduction in flood level upstream. There are no areas of flood level increase that exceed 20 millimetres in urban areas. There is one area of impact greater than 200 millimetres on agricultural land at approximately chainage 680.25 kilometres as noted in Table 6-3.

Flood levels in the 5% AEP event (Appendix B Maps DES_AFF_005_1 to 3) are generally decreased upstream of the rail corridor and downstream to the south through the main urban area of Moree. Downstream of the corridor to the west and north, flood levels are increased by generally less than 100 millimetres. There is a localised impact that exceeds 200 millimetres on agricultural land at approximately chainage 670.70 kilometres as noted in Table 6-3. Impacts on the cropping land at chainage 680.25 kilometres are also present for this event.

In the 2% AEP event (Appendix B Maps DES_AFF_002_1 to 3), flood levels follow a similar pattern to the 5% AEP event with a general decrease upstream of the corridor and localised increases in flood level downstream. Impacts on the cropping land at chainage 680.25 kilometres are also present for this event.

Flood levels in the 1% AEP event (Appendix B Maps DES_AFF_001_1 to 3) are generally increased upstream of the rail corridor with impacts generally less than 100 millimetres. Impacts local to the rail loop exceed 100 millimetres and impact the local road in this area as noted in Table 6-1. At the southern end of the proposal, flood level increases occur in the urban area of Moree south and are generally less than 20 millimetres. The impacts noted within the centre of Moree west of the rail corridor are due to the Phase 1 works and are discussed further in Section 6.3.4. Impacts on the cropping land at chainage 680.25 kilometres are also present for this event.

6.3.1.2 Velocity

Velocity impacts generally do not exceed the adopted criteria (refer to Appendix B Map sets DES_CHV_020 to DES_CHV_001). A number of exceedances occur around the inlets and outlets of some culverts and in some locations these exceedances propagate downstream or upstream into the adjacent land beyond the rail corridor. These areas were subject to soil testing and detailed assessment of the scour and erosion risk as reported in Section 6.3.1.12. Outside of these relatively localised areas the velocity regime across the majority of the floodplain is unchanged. Some exceedances are noted within the floodplain well away from the rail corridor as a result of minor changes to the velocity regime around the rail corridor that propagate into the floodplain over some distance upstream and downstream and are evident when adopting the very low impact limit of 0.025 m/s as specified in the velocity QDL for areas including watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas. These are also discussed further in Section 6.3.1.9.

The velocity QDL exceedances have been discussed with the affected landowners and the landowners generally accepted that the exceedances would be investigated further and resolved where possible through refinement of the design at the detailed stage, with any remaining impacts that require mitigation to be addressed through ongoing engagement with the landowners. The outcomes of the consultation process are presented in Section 6.4 and commitments to mitigating velocity exceedances are provided in Section 6.6.

6.3.1.3 Duration

Duration impacts generally do not exceed the adopted criteria (refer to Appendix B Map sets DES_CHDUR_020 to DES_CHDUR_001). Some exceedances occur but these are confined to the rail corridor or localised within well-defined channels and/or overland flow areas within rural land.

Changes in flood duration occur primarily because of the elimination of the rail overtopping mechanism and replacement of the mechanism with flow under the rail via the new/upgraded cross drainage structures. Increases in flood duration can occur both upstream and downstream of the corridor depending on the capacity of the new/upgraded structures relative to the overtopping capacity of the existing rail at each location. Some changes in flood duration also occur due to the new under-rail flow mechanism causing localised changes in distribution of flow and timing of peak flood flows occurring within the drainage sub-catchments.

In the instances where duration impacts occur away from the rail corridor, they are confined to agricultural land use, are isolated in nature and the increases occur when the depths are below 200 millimetres. The impacts are not expected to significantly affect agricultural activity or the productivity of the land. Therefore, the locations that duration impacts that exceed the criteria are considered to be low risk.

Duration changes are more significant on the area of affected cropping land at chainage 680.25 kilometres where afflux exceedances and newly flooded areas of land occur.

6.3.1.4 Hazard

Impacts on flood hazard (the product of flood depth and flood velocity) generally do not exceed the adopted criteria (refer to Appendix B Map sets DES_CHHAZ_020 to DES_CHHAZ_001). Similar to the impacts on velocity, increases in hazard greater than 20% are generally localised to the inlets and outlets of culverts and do not extent more than approximately 50 metres from the structure.

In some instances, and most notably in the 5% AEP event, impacts occur over a larger area downstream (west) of the rail corridor. These impacts occur primarily on agricultural land but also extend to the Newell Highway, property accesses and around some properties. These more widespread hazard impacts relate to increases in flood level rather than velocity (refer to Appendix B Map sets DES_AFF and DES_CHV) and require further investigation at the detailed design stage as part of design refinements to achieve a better balance of impacts from east to west across the rail corridor for this event.

Another impacted area of note is the cropping land and floodway at chainage 680.25 kilometres where afflux and duration impacts also occur. The combined impacts on this area require further design refinements at the detailed design stage to achieve a better balance of impact around the old hairpin and new greenfield rail section.

6.3.1.5 Impacts on residential receivers (buildings)

An assessment of afflux at individual buildings has been undertaken to identify buildings experiencing flood level increase greater than 10 millimetres in events ranging from the 20% AEP to 1% AEP. Where possible, the impacts have been checked against Council floor level survey data. A summary of the impact assessment is provided in Table 6-4.

Table 6-4 Summary of impacts at residential receivers (i.e. proposal only impacts)

RESIDENTIAL BUILDING IMPACT SUMMARY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Total buildings assessed	1893	1893	1893	1893	1893
Buildings flooded in existing conditions	0	11	481	745	805
Buildings flooded in design case	0	9	460	740	804
Buildings newly flooded	0	0	0	0	0
Buildings no longer flooded	0	2	21	5	1
QDL exceedance: buildings with flood level increase >10 mm	0	4	3	2	4
QDL exceedance: buildings with flow velocity increase >20%	0	0	0	0	0
QDL exceedance: buildings with duration of flooding increase >5%	0	0	12	5	4
QDL exceedance: buildings with flood hazard (V*D) increase >10%	0	0	0	1	1

The key findings are as follows:

- There is an overall net decrease of 26 in the number of buildings flooded, with 29 buildings no longer flooded and no buildings newly flooded.
- Exceedances of the 10 mm afflux objective for buildings are as follows:
  - 20% AEP event: No exceedances.
  - 10% AEP event: 4 buildings with afflux values exceeding 10 mm, as follows:
    - Building 1: afflux is 14 mm, Council floor level survey data indicates that the flood level remains 97 mm below the floor level for this event.
    - Building 2: afflux is 19 mm, Council floor level survey data indicates that the flood level is 637 mm above the floor level for this event.
    - Building 3: afflux is 26 mm, this property is not included in Council's floor level survey data.
    - Building 4: afflux is 46 mm, this property is not included in Council's floor level survey data.
  - 5% AEP event: 3 buildings with afflux values exceeding 10 mm, as follows:
    - Building 2 (as above): afflux is 45 mm, Council floor level survey data indicates that the flood level is 1207 mm above the floor level for this event.
    - Building 3 (as above): afflux is 59 mm, this property is not included in Council's floor level survey data.
    - Building 4 (as above): afflux is 15 mm, this property is not included in Council's floor level survey data.
  - 2% AEP event: 2 buildings with afflux values exceeding 10 mm, as follows:
    - Building 5: afflux is 14 mm, this property is not included in Council's floor level survey data.
    - Building 6: afflux is 36 mm, this property is not included in Council's floor level survey data.

- 1% AEP event: 4 buildings with afflux values exceeding 10 mm, as follows:
  - Building 7: afflux is 11 mm, Council floor level survey data indicates that the flood level remains 543 mm below the floor level for this event.
  - Building 8: afflux is 13 mm, Council floor level survey data indicates that the flood level remains 483mm below the floor level for this event.
  - Building 9: afflux is 15 mm, Council floor level survey data indicates that the flood level remains 147 mm below the floor level for this event.
  - Building 10: afflux is 66 mm, this property is not included in Council's floor level survey data.
- Exceedances of the 10% hazard (velocity x depth) increase objective for buildings are as follows:
  - 20% AEP event: No exceedances.
  - 10% AEP event: No exceedances.
  - 5% AEP event: No exceedances.
  - 2% AEP event: 1 building with an increase of 32%.
  - 1% AEP event: 1 building with an increase of 19%.

All of the above impacts will be subject to further investigation at detailed design, including collection of additional building floor level survey where required. Consultation with affected property owners will be undertaken to determine whether the impacts adversely affect flood damage at the properties. Where floor level survey data indicates a residual impact, at property mitigation will be consulted on with the property owners.

6.3.1.6 Impacts on other sensitive receivers

A separate assessment of afflux at locations identified as sensitive receivers has been undertaken to identify sensitive locations experiencing flood level increase greater than 10 millimetres in events ranging from the 20% AEP to 1% AEP. A sensitive receivers list of 32 locations were assessed and this includes locations such as hospitals, aged care facilities, schools and parks amongst others. A summary of the impact assessment is provided in Table 6-5.

Table 6-5 Summary of impacts at other sensitive receivers (i.e. proposal only impacts)

OTHER SENSITIVE RECEIVERS IMPACT SUMMARY	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Total receivers assessed	32	32	32	32	32
Receivers flooded in existing conditions	1	1	6	13	15
Receivers flooded in design case	1	1	5	13	15
Receivers newly flooded	0	0	0	0	0
Receivers no longer flooded	0	0	1	0	0
QDL exceedance: receivers with flood level increase >10 mm	0	0	0	1	1
QDL exceedance: receivers with flow velocity increase >20%	0	0	0	0	0
QDL exceedance: receivers with duration of flooding increase >5%	0	0	0	1	1
QDL exceedance: receivers with flood hazard (V*D) increase >10%	0	0	0	0	0

The table shows that exceedances of the impact limits occur at 2 receivers, with further details as follows:

- Moree TAFE Agricultural Skills Centre:
  - 2% AEP event: afflux of 36 mm and flood duration increase of 28%.
- Moree Gun Club:
  - 1% AEP event: afflux of 66 mm with no increase in flood duration.

6.3.1.7 Impacts on Newell Highway

6.3.1.8 Overview of impacts

The rail corridor is located immediately upstream of the Newell Highway for approximately 6 kilometres. Parts of the highway and land immediately adjacent to the highway experience flood impacts from the proposal. The highway is considered critical infrastructure that is sensitive to changes in flood risk and hazard.

The information presented in this section for the Newell Highway and for other roads in the following sections provides summaries of the impacts and QDL exceedances on the affected roads. Consultation with TfNSW is ongoing and more detailed information on the impacts will be provided as required by TfNSW. It is anticipated that the current QDL exceedances will be resolved or reduced through the detailed design process and any remaining exceedances or impacts of concern to TfNSW would be subject to further investigation and mitigation where required.

The flood model results for the existing conditions and design case were sampled at 10 metre intervals for the section of the Newell Highway adjacent to the proposal. Table 6-6 provides a summary of impacts assessed against the criteria set out in Section 4.6 at each sampled location.

Table 6-6 Summary of impacts along the Newell Highway (i.e. proposal only impacts)

NEWELL HIGHWAY IMPACT SUMMARY (AT 10 m INTERVALS)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Total points assessed (10 m intervals)	2174	2174	2174	2174	2174
Points flooded in existing conditions	91	561	872	1083	1204
Points flooded in design case	110	547	835	1080	1167
Points newly flooded	28	63	41	48	4
Points no longer flooded	9	77	78	51	41
QDL exceedance: points with flood level increase >50 mm	65	114	427	260	148
QDL exceedance: points with flow velocity increase >10%	0	0	0	0	2
QDL exceedance: points with duration of flooding increase >10%	34	129	186	263	318
QDL exceedance: points with flood hazard (V*D) increase >10%	0	32	234	244	226

Localised increases in all flood parameters occur as a result of removal of the rail overtopping mechanism and passage of flow under the rail via new and upgraded culverts in a more controlled manner. The results also demonstrate that portions of the highway are no longer flooded for the 10%, 5%, 2% and 1% AEP events, with an increase in flooded portions predicted for the 20% AEP event.

6.3.1.9 Impacts on highway flood hazards

Flood hazard is the product of flood depth and flood velocity and is used to define safe uses of land based on the flood risk. Figure 6-1 is taken from ARR2019 Chapter 7 Section 7.2.7 and provides flood hazard curves and definitions.

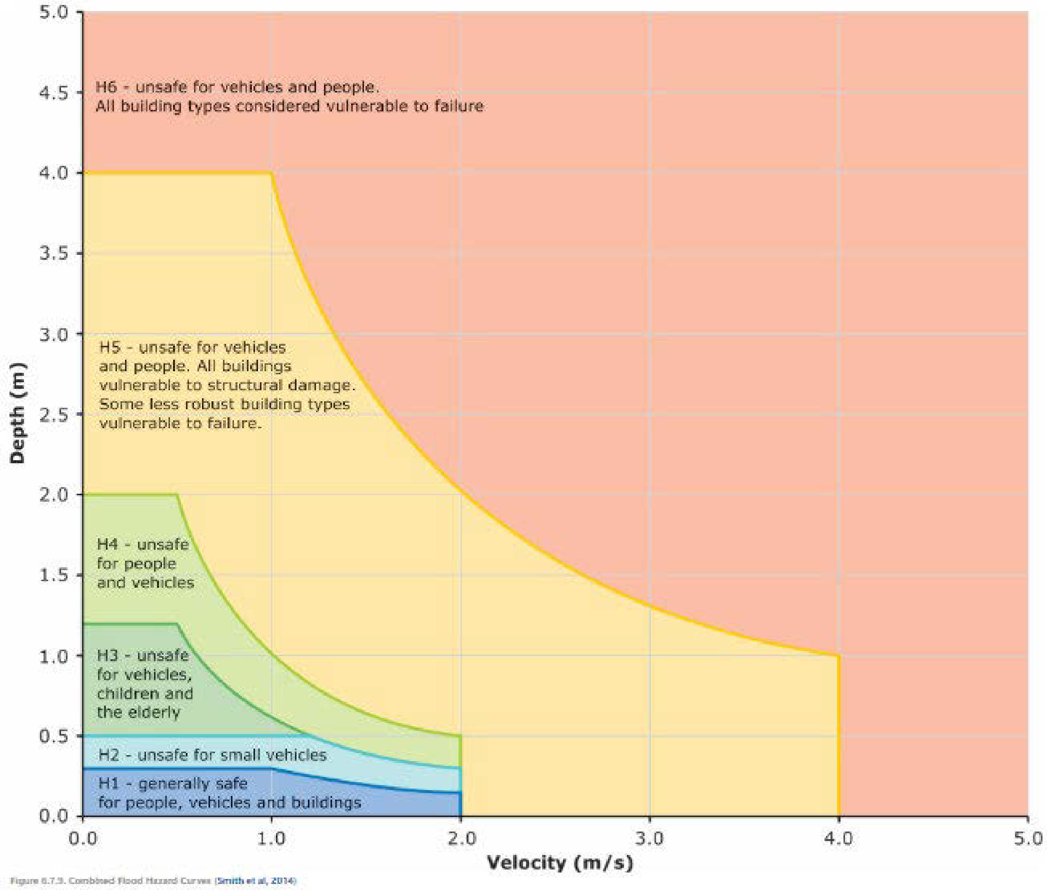

Figure 6-1 Flood hazard curves and definitions (ARR2019, Chapter 7, Section 7.2.7)

An assessment of the hazard under both existing conditions and the design case has been undertaken for the section of the Newell Highway adjacent to the proposal. This assessment has assumed the Newell Highway is as per present day conditions in advance of the proposed Newell Highway upgrade works assessed separately in this report. The impacts on hazard are presented in Table 6-7 and Figure 6-2.

Table 6-7 Flood hazard categorisation assessment for the Newell Highway (i.e. proposal only impacts)

DESIGN EVENT & SCENARIO		H1	H2	H3	H4	H5	H6
20% AEP	Existing Conditions	81	2	5	0	3	0
	Design Case	81	21	5	0	3	0
	Hazard Category Change	0.0%	950.0%	0.0%	0.0%	0.0%	0.0%
10% AEP	Existing Conditions	391	154	5	4	7	0
	Design Case	395	134	7	5	6	0
	Hazard Category Change	1.0%	-13.0%	40.0%	25.0%	-14.3%	0.0%
5% AEP	Existing Conditions	336	322	201	5	8	0
	Design Case	248	295	280	4	8	0
	Hazard Category Impact	-26.2%	-8.4%	39.3%	-20.0%	0.0%	0.0%

DESIGN EVENT & SCENARIO		H1	H2	H3	H4	H5	H6
2% AEP	Existing Conditions	267	173	289	339	14	1
	Design Case	277	157	308	323	14	1
	Hazard Category Impact	3.7%	-9.2%	6.6%	-4.7%	0.0%	0.0%
1% AEP	Existing Conditions	232	224	296	419	31	2
	Design Case	182	226	309	406	43	1
	Hazard Category Impact	-21.6%	0.9%	4.4%	-3.1%	38.7%	-50.0%

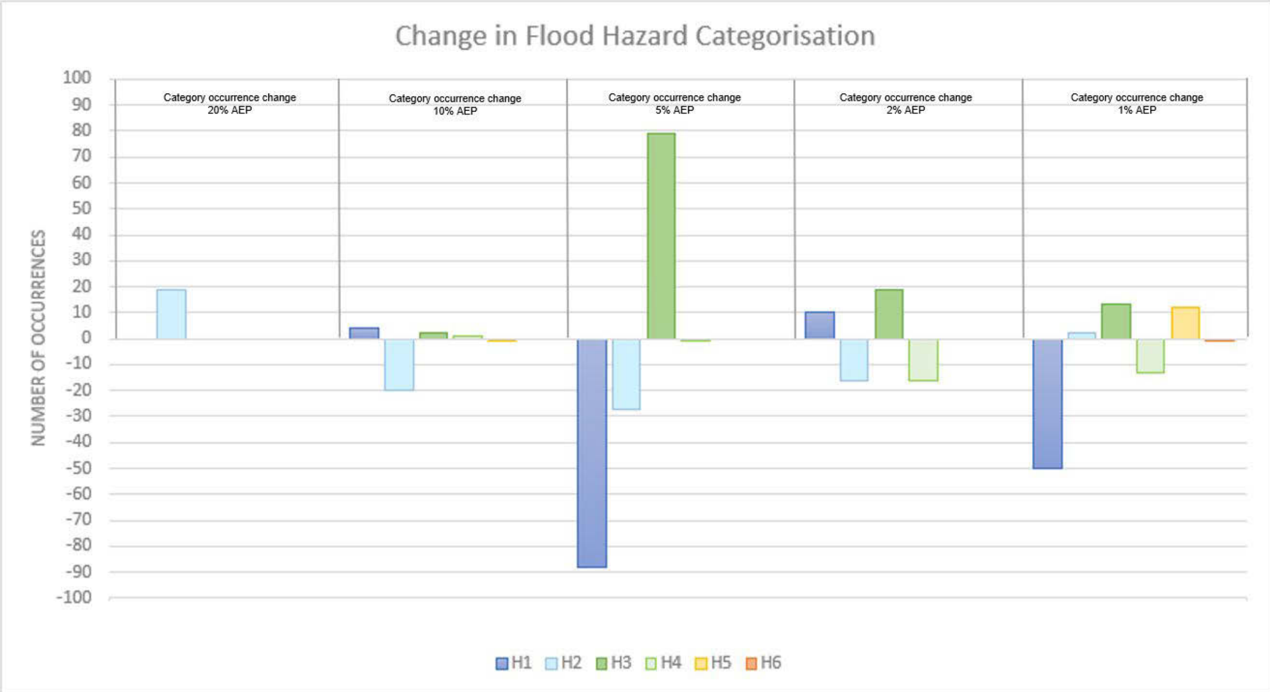

Figure 6-2 Change in flood hazard categorisation for Newell Highway

Table 6-7 and Figure 6-2 demonstrate the overall change in hazard categorisation across the 4 events assessed. The results show the following:

- An overall net decrease in hazard category at 72 locations, made up as follows:
  - net decrease in H1 category at 124 locations
  - net decrease in H2 category at 42 locations
  - net increase in H3 category at 113 locations
  - net decrease in H4 category at 29 locations
  - net increase in H5 category at 11 locations; and
  - net decrease in H6 category at 1 location.
- The overall net decrease in hazard category is distributed across the flood events as follows:
  - net increase for the 20% AEP event at 19 locations
  - net decrease for the 10% AEP event at 14 locations
  - net decrease for the 5% AEP event at 37 locations
  - net decrease for the 2% AEP event at 3 locations; and
  - net decrease for the 1% AEP event at 37 locations.

Overall, the impact on hazard on the Newell Highway is considered to be positive due to the net decrease in hazard categories, particularly in the H1 and H2 categories where vehicles may be using the highway prior to closure due to flooding. Most impact on the highway hazard category occurs for the 5% AEP event which will be subject to further investigation at the detailed design stage to refine the design to better balance impacts east and west of the rail corridor and reduce impacts on the Newell Highway and land to the west of the proposal for this event.

6.3.1.10 Impacts on highway closure times

Impacts on flood duration on the highway and associated times of highway closure during flood events are also key considerations in the highway impact assessment. Time of closure impacts were assessed at the following three locations (see also Figure 6-3):

- lowest point along the highway in the area of influence of the proposal, which occurs just north of the Stirton Road intersection
- point of highest impact of the proposal on the highway south of the Gwydir River, which occurs just south of Moree TAFE
- point of highest impact of the proposal on the highway north of the Gwydir River, which occurs just approximately 2.7 km along the highway north of the Camurra Hairpin.

Figures 6-4 to 6-6 show the flood level hydrographs for existing conditions and the design case at these 3 locations for the 5% and 1% AEP events. The hydrographs also show the level at which the hazard on the highway reaches the H2 category, which would close the highway to traffic. The hydrographs show the following:

- Highway low point north of Stirton Road intersection:
  - 5% AEP event time of closure is decreased by 1 hour from 25 hours to 24 hours (4% decrease).
  - 1% AEP event time of closure is decreased by 2 hours from 51.5 hours to 49.5 hours (4% decrease).
- Point of impact just south of Moree TAFE:
  - 5% AEP event time of closure is increased by 14 hours from 3 hours to 17 hours (467% increase).
  - 1% AEP event time of closure is increased by 7 hours from 37 hours to 44 hours (19% increase).
- Point of impact north of Camurra Hairpin:
  - The highway does not close for the 5% AEP event under existing conditions. In the design case the time of closure is 28.5 hours.
  - 1% AEP event time of closure is increased by 36.5 hours from 33.5 hours to 70 hours (109% increase).

The results show that the project has a positive impact on closure times at the lowest point of the highway in the area of the proposal but extends the closure times significantly in the areas where the proposal has highest impact. As noted in the hazard impact assessment, these areas will be subject to further investigation at the detailed design stage to refine the design to better balance impacts east and west of the rail corridor and reduce impacts on the Newell Highway and land to the west of the proposal.

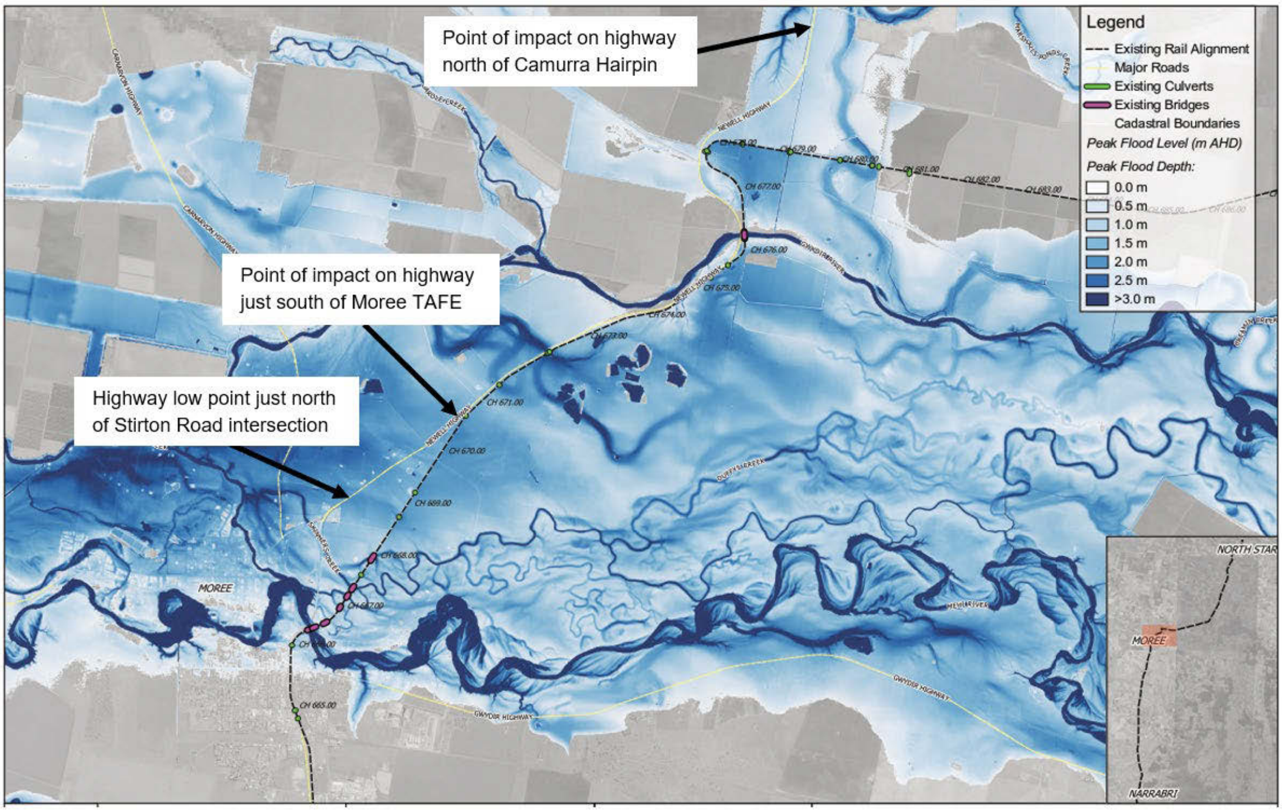

Figure 6-3 Locations along Newell Highway for time of highway closure assessment

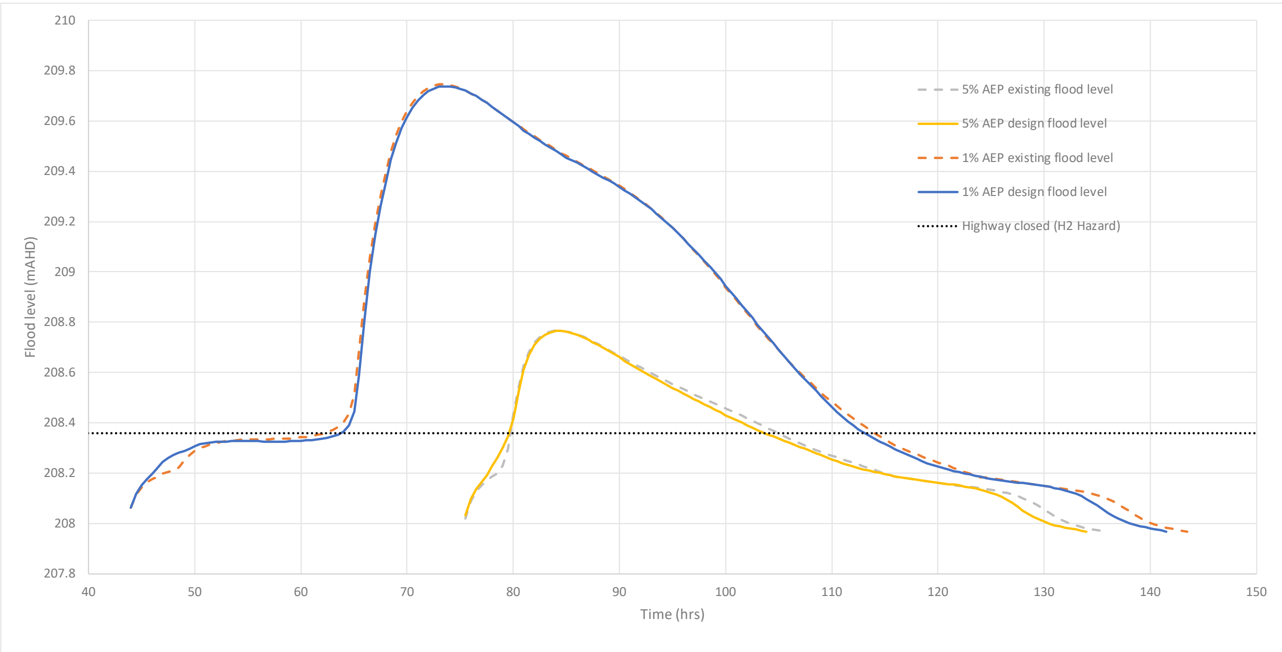

Figure 6-4 5% and 1% AEP event flood level hydrographs at Newell Highway low point just north of Stirton Road intersection

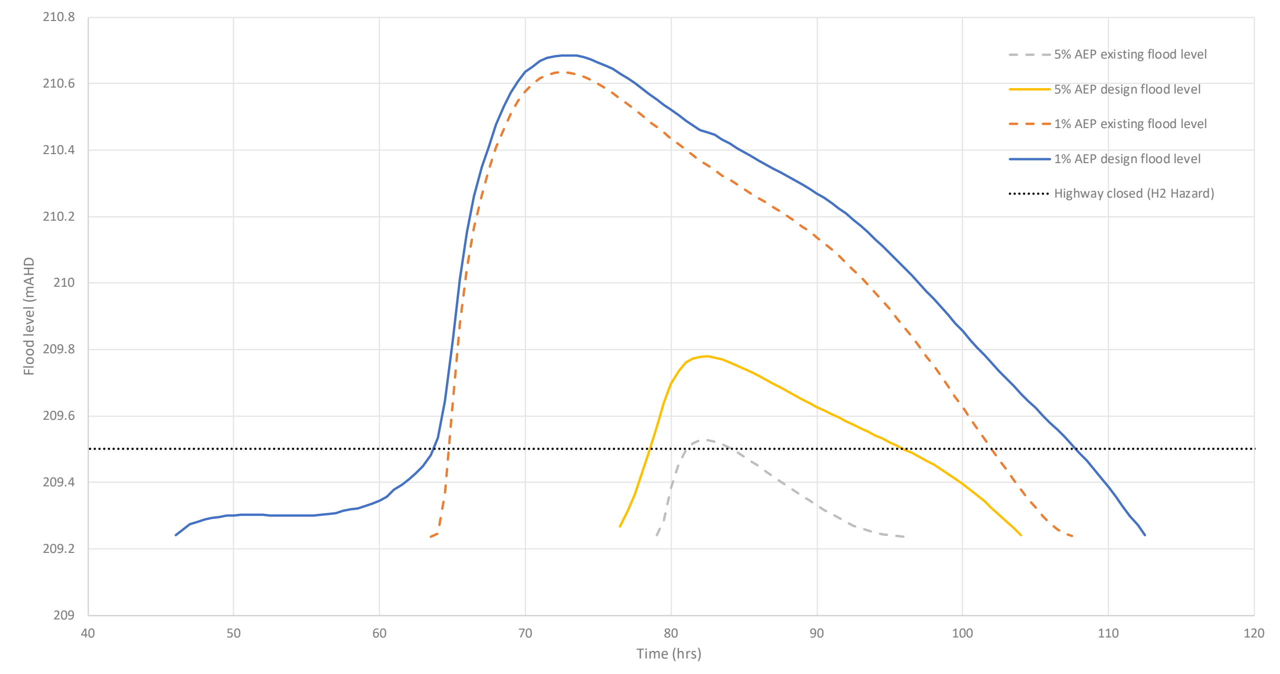

Figure 6-5 5% and 1% AEP flood level hydrographs at Newell Highway just south of Moree TAFE

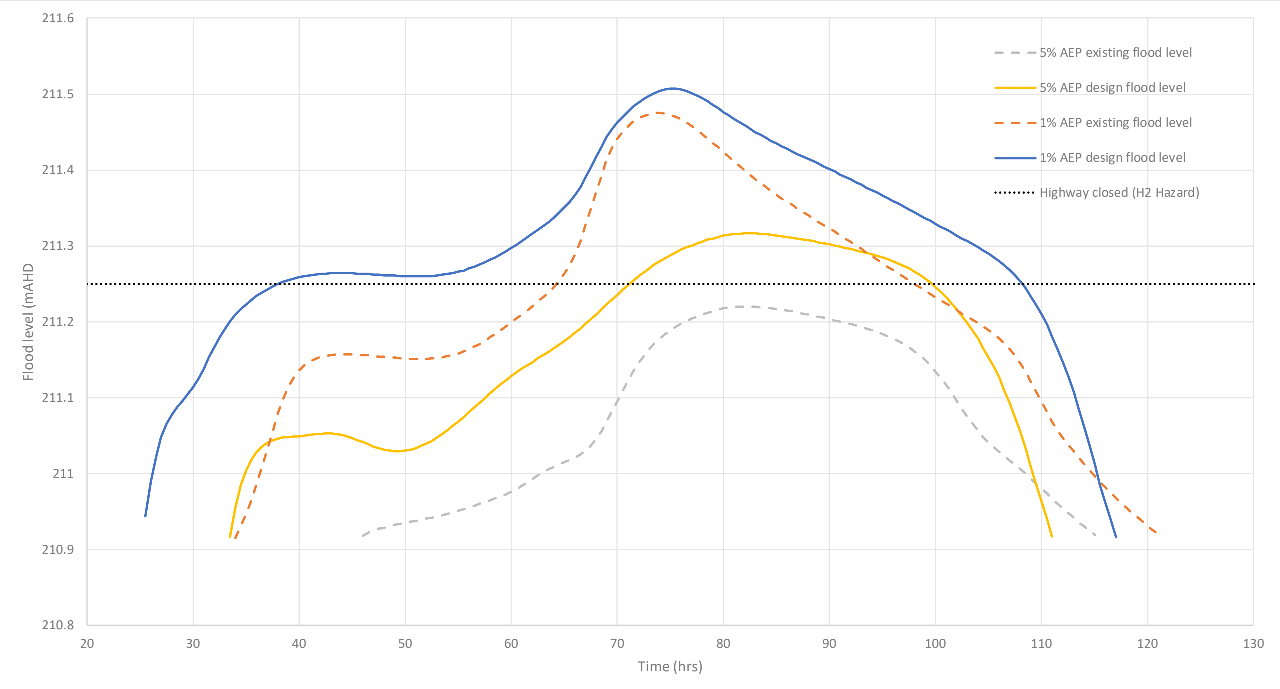

Figure 6-6 5% and 1% AEP flood level hydrographs at Newell Highway north of Camurra Hairpin

As previously noted, impacts on the Newell Highway will be subject to further investigation at the detailed design stage to refine the design to better balance impacts east and west of the rail corridor and reduce impacts on the highway across the full range of events. At the concept design stage it is not possible to undertake exhaustive investigation of all types of culvert structure and flow control options, however, at the detailed design stage these aspects of the cross drainage design can be fully investigated to achieve a better balance of impacts east and west of the rail corridor.

6.3.1.11 Impacts on other roads

Impacts on Carnarvon Highway

The flood model results for the existing conditions and design case were sampled at 10 metre intervals for the section of the Carnarvon Highway extending 8.3 km north of the intersection with Boggabilla Road, located west of the proposal. Table 6-8 provides a summary of impacts assessed against the criteria set out in Section 4.6 at each sampled location. For this and other roads less affected by the proposal, a simpler hazard category impact assessment has been undertaken and reported in the summary tables.

Table 6-8 Summary of impacts along the Carnarvon Highway (i.e. proposal only impacts)

CARNARVON HIGHWAY IMPACT SUMMARY (AT 10 m INTERVALS)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Total points assessed (10 m intervals)	832	832	832	832	832
Points flooded in existing conditions	171	342	561	773	780
Points flooded in design case	167	346	575	773	779
Points newly flooded	0	4	15	0	0
Points no longer flooded	4	0	1	0	1
QDL exceedance: points with flood level increase >50 mm	0	3	99	0	0
QDL exceedance: points with flow velocity increase >10%	0	0	0	0	0
QDL exceedance: points with duration of flooding increase >10%	0	8	43	0	1
QDL exceedance: points with flood hazard (V*D) increase >10%	0	24	134	4	0
Points with flood hazard category increase (H1 to H6)	0	3	30	12	1
Points with flood hazard category decrease (H1 to H6)	0	0	0	2	6

The table shows that hazard impacts are minor or positive for the 20%, 10% and 1% AEP events with minimal change in the number of flooded locations and hazard categories. More significant impacts occur for the 5% and 2% AEP events with increases in the number of flood locations and/or increases in hazard categories. Similar to the Newell Highway impacts noted in the previous section, impacts for the 5% AEP event which will be subject to further investigation at the detailed design stage to refine the design to better balance impacts east and west of the rail corridor and reduce impacts on the Carnarvon Highway for this event. Better balancing to reduce impact for the 5% AEP event should also resolve the lesser impacts at the 2% AEP event.

Impacts on Gwydirfield Road

The flood model results for the existing conditions and design case were sampled at 10 metre intervals for Gwydirfield Road, located east of the proposal. Table 6-9 provides a summary of impacts assessed against the criteria set out in Section 4.6 at each sampled location.

Table 6-9 Summary of impacts along Gwydirfield Road (i.e. proposal only impacts)

GWYDIRFIELD ROAD IMPACT SUMMARY (AT 10 m INTERVALS)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Total points assessed (10 m intervals)	602	602	602	602	602
Points flooded in existing conditions	6	151	536	602	602
Points flooded in design case	6	138	462	584	588
Points newly flooded	0	3	0	0	0
Points no longer flooded	0	16	74	18	14
QDL exceedance: points with flood level increase >50 mm	0	8	3	0	0
QDL exceedance: points with flow velocity increase >10%	0	0	0	0	0
QDL exceedance: points with duration of flooding increase >10%	0	5	7	1	0
QDL exceedance: points with flood hazard (V*D) increase >10%	0	4	8	42	78
Points with flood hazard category increase (H1 to H6)	0	0	0	0	2
Points with flood hazard category decrease (H1 to H6)	0	1	100	39	16

The table shows that impacts on Gwydirfield Road are positive, with significant net reductions in the number of locations flooded and hazard categories across all events assessed.

Impacts on Back Pally Road

The flood model results for the existing conditions and design case were sampled at 10 metre intervals for the section of Back Pally Road extending 8.3 km east of the intersection with the Newell Highway, located predominantly east of the proposal. Table 6-10 provides a summary of impacts assessed against the criteria set out in Section 4.6 at each sampled location.

Table 6-10 Summary of impacts along Back Pally Road (i.e. proposal only impacts)

BACK PALLY ROAD IMPACT SUMMARY (AT 10 m INTERVALS)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Total points assessed (10 m intervals)	833	833	833	833	833
Points flooded in existing conditions	333	468	578	674	732
Points flooded in design case	304	451	563	668	726
Points newly flooded	0	0	0	0	0
Points no longer flooded	29	17	15	6	6
QDL exceedance: points with flood level increase >50 mm	0	0	0	0	151
QDL exceedance: points with flow velocity increase >10%	0	0	0	0	0
QDL exceedance: points with duration of flooding increase >10%	3	1	3	1	2

BACK PALLY ROAD IMPACT SUMMARY (AT 10 m INTERVALS)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
QDL exceedance: points with flood hazard (V*D) increase >10%	0	3	7	28	53
Points with flood hazard category increase (H1 to H6)	2	0	3	0	31
Points with flood hazard category decrease (H1 to H6)	3	71	65	23	21

For the 20%, 10%, 5% and 2% AEP events the table shows that impacts on Back Pally Road are positive, with significant net reductions in the number of locations flooded and hazard categories. For the 1% AEP event, the food hazard is increased over a distance of approximately 1.3 km east of the new greenfield section of the alignment. As noted in previous sections, the impacts on this area require further design refinements at the detailed design stage to achieve a better balance of impact around the old hairpin and new greenfield rail section.

6.3.1.12 Scour and erosion impacts

All bridge abutments and culvert inlets and outlets include scour protection to protect the structures from undermining due to scour during large flood events and progressive erosion over time. The scour protection measures have been designed in accordance with industry standards, as described in Section 4.4.2.

The culvert design includes relatively short barrels (<5 metres long) with 4 metre long inlet and outlet concrete aprons. Additional rock scour protection is provided beyond the concrete aprons, with the rock size and extent determined by the velocity regime and dimensions of the culvert. In most cases, the culvert rock aprons do not extend beyond the rail corridor but in some cases it is necessary to extend the rock apron beyond the rail corridor to achieve the required level of scour protection. Figure 6-7 shows an example of a culvert where the outlet scour protection extends approximately 4 metres beyond the rail corridor. In such cases, consultation with the adjacent landowner will be required at the detailed design stage to gain acceptance of the scour protection design and allow the rock apron to be installed beyond the rail corridor. Out of a total of 33 culvert banks in the design, 6 of these banks require outlet rock aprons to extend beyond the corridor at the following locations:

- Chainage 668.830 km: 2x2400x2400 RCBC, apron extends approximately 13 metres into downstream drainage channel.
- Chainage 669.305 km: 1x1800x1800 RCBC, apron extends approximately 7 metres into downstream drainage channel.
- Chainage 671.520 km: 7x3000x2100 RCBC, apron extends approximately 7 metres into downstream overland flow path.
- Chainage 672.450 km: 60x1800x600 + 20x3600x3600 RCBC, apron extends approximately 4 metres into downstream overland flow path.
- Chainage 677.770 km: 3x3000x1800 RCBC, apron extends approximately 2 metres into downstream irrigation channel.
- Chainage 680.500 km: 50x2400x800 + 5x3000x2100 RCBC, apron extends approximately 5 metres into downstream overland flow path and drainage channel.

In all cases the current apron design is at the level of concept design and will be refined and confirmed at the detailed design stage, at which time the landowners will be further engaged on the potential impact of this encroachment and, where necessary, the project boundary will be adjusted to incorporate such encroachments.

The scour protection prevents scour and erosion of the landscape immediately upstream and downstream of the culverts. The purpose of the extended rock aprons is to provide scour resistant material for some distance upstream and downstream of culverts to protect the material local to the culverts from scouring. Velocity impacts can occur beyond the extent of the rock aprons and these are dealt with through the impact assessment process.

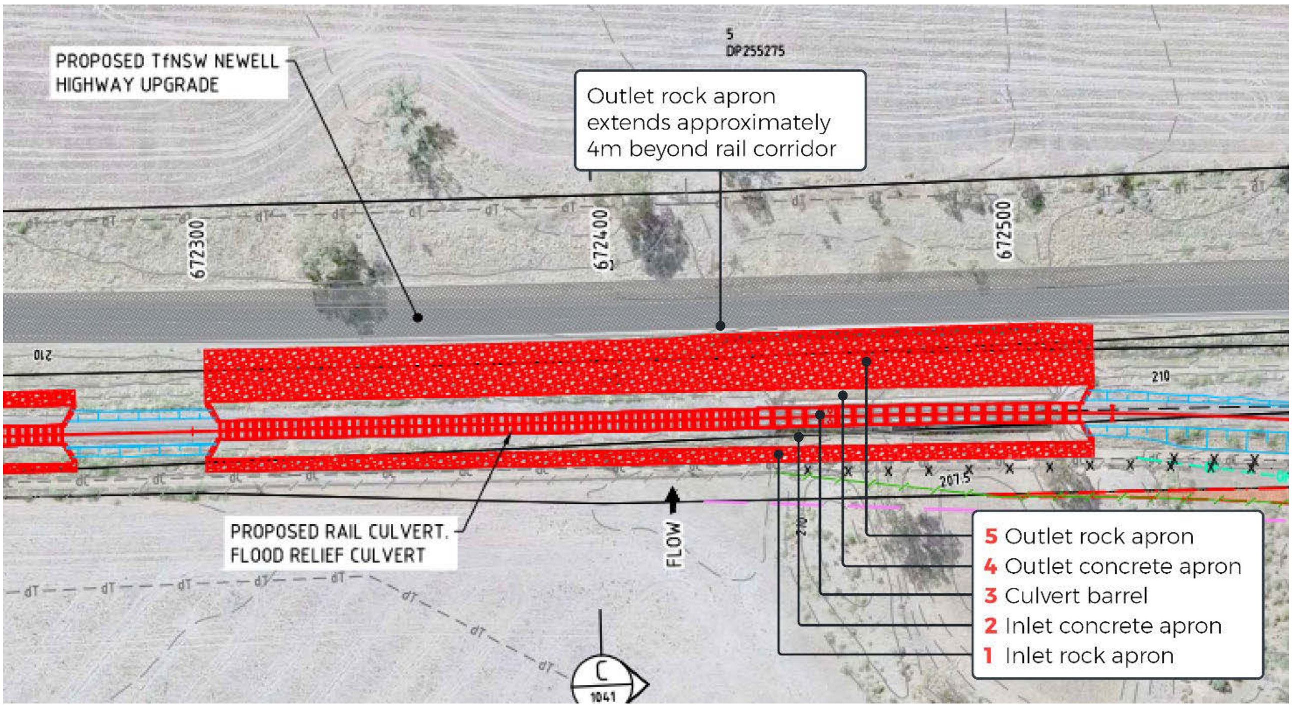

Figure 6-7 **Example of rock apron for culvert scour protection extending beyond the rail corridor**

The potential for scour and erosion impacts on the landscape beyond the limits of the scour protection are assessed by examining the change in peak velocity around the rail corridor and within the wider floodplain. Section 6.3.1.2 provides an overview of the changes in the velocity regime within the floodplain surrounding the proposal and demonstrates that changes are generally localised around the culverts, however, some exceedances of the QDLs are indicated in the flood modelling results local to the culverts and in other areas away from the rail corridor, as discussed in detail below.

Within and around the rail corridor, exceedances were noted at 10 locations around culvert inlets and outlets. These 10 locations were the subject of soil sampling and laboratory testing to establish the erosive velocity thresholds of the in-situ soils, as described in Appendix F. Table 6-11 presents the 1% AEP event existing conditions and design case velocity values and erosive velocity thresholds for the 10 sampled sites.

Table 6-11 **Soil erodibility assessment at sampling sites**

SITE	EXISTING CONDITIONS 1% AEP VELOCITY (M/S)	DESIGN CASE 1% AEP VELOCITY (M/S)	BARE SOIL EROSIVE VELOCITY (M/S)	50% WEED COVER EROSIVE VELOCITY (M/S)	50% CROP COVER EROSIVE VELOCITY M/S)
1	0.3	0.6	0.7	1.0 to 1.4	1.4 to 2.2
2	0.4	0.6	0.7	1.0 to 1.4	1.4 to 2.2
3	0.5	0.9	0.7	1.0 to 1.4	1.4 to 2.2
4	0.3	0.7	0.3	0.7 to 1.0	0.7 to 1.2
5	0.7	0.7	0.7	1.0 to 1.4	1.4 to 2.2
6	0.5	1.1	0.7	1.0 to 1.4	1.4 to 2.2
7	0.5	0.8	0.7	1.0 to 1.4	1.4 to 2.2
8	0.5	0.8	0.7	1.0 to 1.4	1.4 to 2.2
9	0.7	0.9	0.7	1.0 to 1.4	1.4 to 2.2
10	0.1	0.9	0.7	1.0 to 1.4	1.4 to 2.2

The table shows that for most sites the design case velocities are close to the erosive velocities for the bare soil condition and less than the lower bound of the erosive velocities for 50% weed cover. The exceptions are Site 4 where the design case velocity is significantly higher than the bare soil erosive velocity and just exceeds the lower bound of the 50% weed cover erosive velocity range, and Site 6 where the design case velocity is significantly higher than the bare soil erosive velocity and just exceeds the lower bound of the 50% weed cover erosive velocity range. Specific velocity impact mitigation measures are likely to be required at these sites, particularly Site 4 which is located in an area of hardstand constructed from imported fill for farm operations that is vulnerable to erosion. Potential mitigation measures have been consulted on with the impacted landholder and site specific mitigation measures will be developed through further engagement with the landholder at the detailed design stage – refer to Section 6.4 and Section 6.6 for information on the consultation outcomes and commitments to impact mitigation.

The velocity impact maps in Appendix B have used the velocity QDL criteria as set out in Table 4-8, which require design case velocities to remain below 0.5 m/s where existing velocities are below this value, and not to increase by more than 0.025 m/s where above this value. An alternative set of 1% AEP velocity impact maps is provided in Appendix G which use alternative threshold values of 0.7 m/s and 1.0 m/s corresponding to the predominant bare soil and 50% weed cover erosive velocities determined from the soil sampling. These maps show significantly reduced areas of impact when compared to the maps in Appendix B that use the 0.5 m/s threshold, demonstrating that erosion risk in the adjacent land is minimal when using erosive thresholds established from the soil testing.

Figure 6-8 shows the area around Skinners Creek which experiences the most extensive changes to the velocity regime in the adjacent land. The figure shows that velocities remain below the impact criteria limit (refer to Table 4-8) of 0.5 m/s for the 10% AEP event, with the exception of a small area within Skinners Creek upstream of the upgraded bridge where velocities of between 0.5 and 1.0 m/s occur. More widespread velocity changes occur for the 1% AEP event, where velocities of between 1.7 and 2.0 m/s are experienced around the abutments of the upgraded bridge and where velocities of between 0.5 and 1.0 m/s occur in the wider floodplain upstream and downstream of the bridge. Existing conditions and design case velocities for the three locations indicated on Figure 6-8 are provided in Table 6-12. Non-compliant impacts occur at locations 1 and 2 and the impact at location 3 is compliant. For the non-compliant locations the percentage change in velocity is significant but the absolute values of increased velocity remain low at <0.6 m/s, and below the bare soil erosive velocity of 0.7 m/s determined from the soil testing.

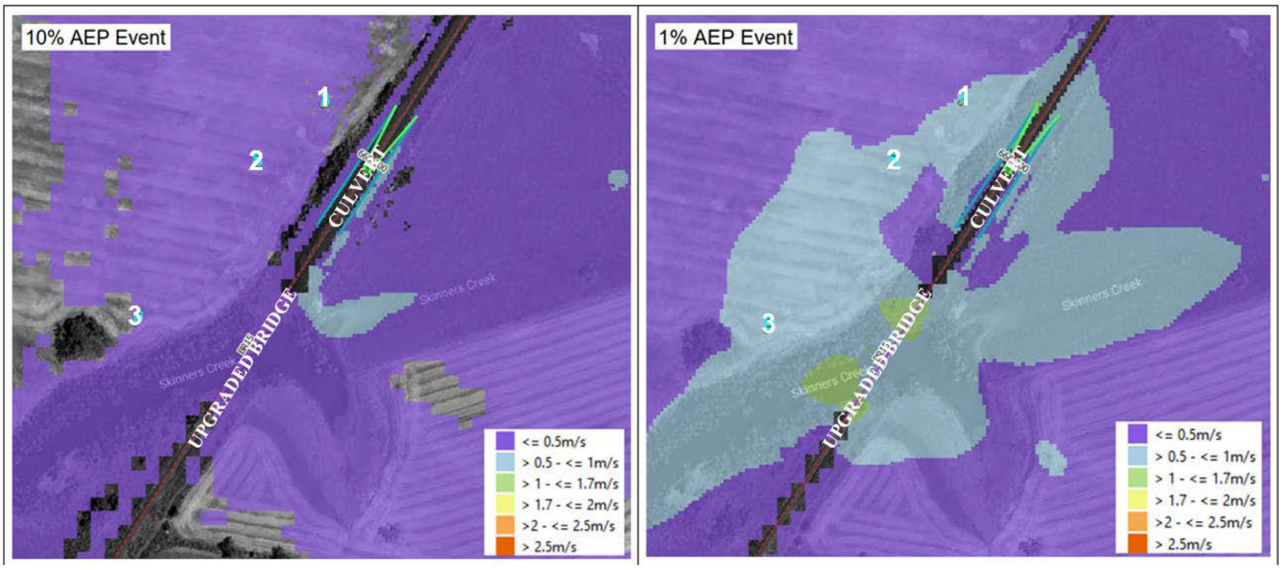

Figure 6-8 Design case velocities in the vicinity of the bridge and culverts at Skinners Creek

Table 6-12 Selected locations for 1% AEP velocity impacts on floodplain near Skinners Creek

LOCATION	EXISTING CONDITIONS 1% AEP VELOCITY (M/S)	DESIGN CASE 1% AEP VELOCITY (M/S)	CHANGE IN 1% AEP VELOCITY (%)	COMPLIANCE WITH VELOCITY IMPACT CRITERIA IN TABLE 4-8
1	0.35	0.52	+50%	Not compliant: Baseline velocity is <0.5 m/s and design case velocity is >0.5 m/s, change in velocity is >20%.
2	0.43	0.51	+20%	Not compliant: Baseline velocity is <0.5 m/s and design case velocity is >0.5 m/s.
3	0.59	0.56	-4%	Compliant: Baseline and design case velocities are >0.5 m/s and velocity is reduced in design case.

Other exceedances were found to occur remote from the corridor within the floodplain and creek systems upstream and downstream of the corridor. Figures 6-9 and 6-10 below show a sample of these areas with the typical 1% AEP design case velocities in these areas and the percentage increase above the existing velocities.

The design case velocities within the creek systems are less than 0.8 m/s, which is just above the erosive velocity for bare soil identified from the soil testing within the rail corridor. The creek channels and overbank areas where these exceedances occur are vegetated which provides protection against erosion at velocities of this magnitude. Other exceedances occur along roadways, such as Gwydirfield Road as indicated in Figure 6-9, where design case velocities are less than 1.0 m/s which will not cause erosion of sealed roads and vegetated road verges.

Figures 6-11 and 6-12 show these same areas with a velocity threshold of 0.7m/s applied, which is the bare soil erosive velocity established from the soil testing undertaken within the rail corridor – see Table 6-11. These figures show that applying this alternative threshold would remove or significantly reduce the QDL exceedances shown in Figures 6-9 and 6-10.

As noted in Section 6.3.1.2, the exceedances occurring remote from the corridor are due to minor changes in the velocity regime around the rail corridor that propagate into the floodplain over some distance upstream and downstream and are evident when adopting the very low impact limit of 0.025 m/s as specified in the velocity QDL.

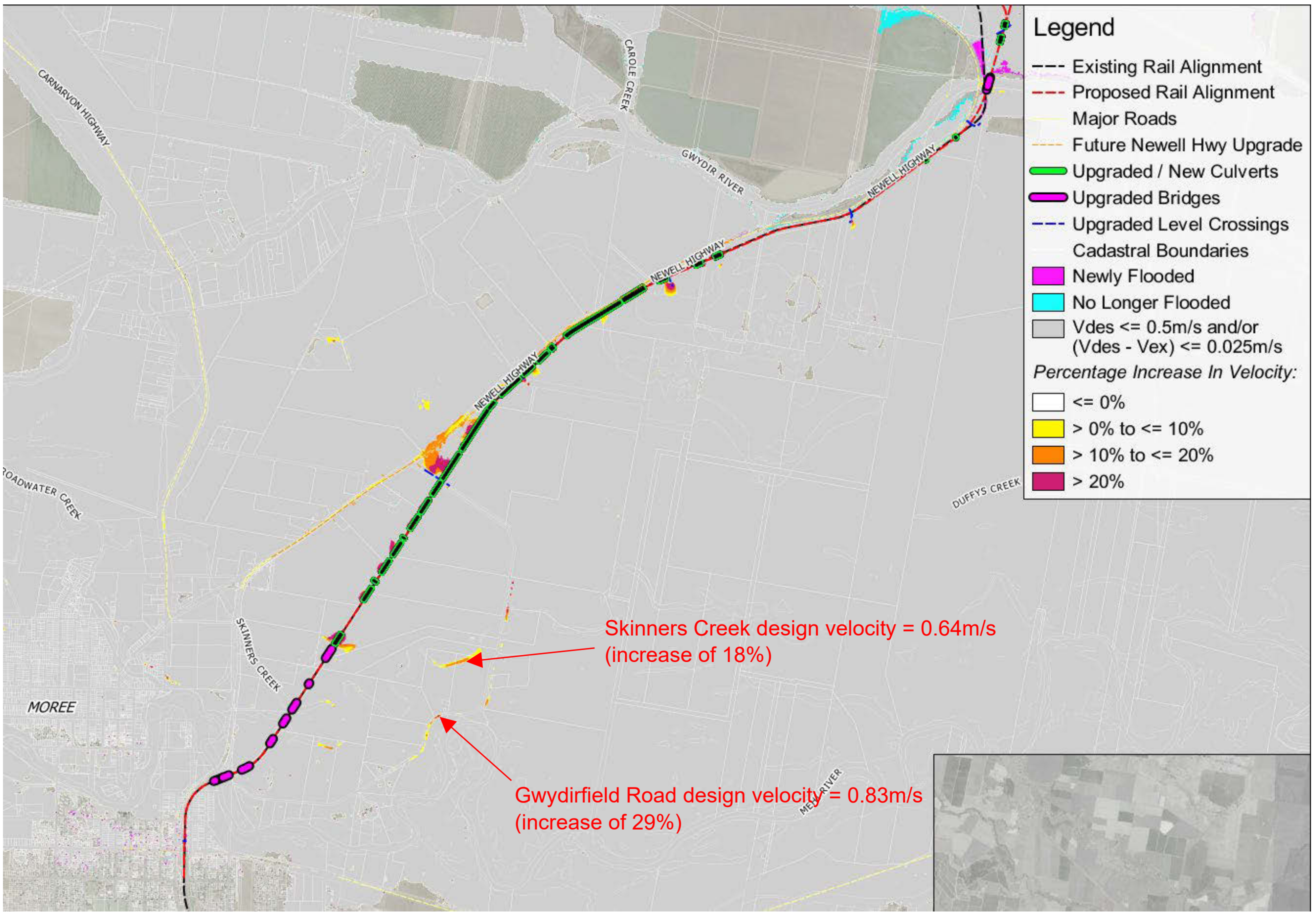

Figure 6-9 Locations of selected 1% AEP velocity QDL exceedances remote from rail corridor in Skinners Creek and around Gwydirfield Road with 0.5 m/s impact threshold applied

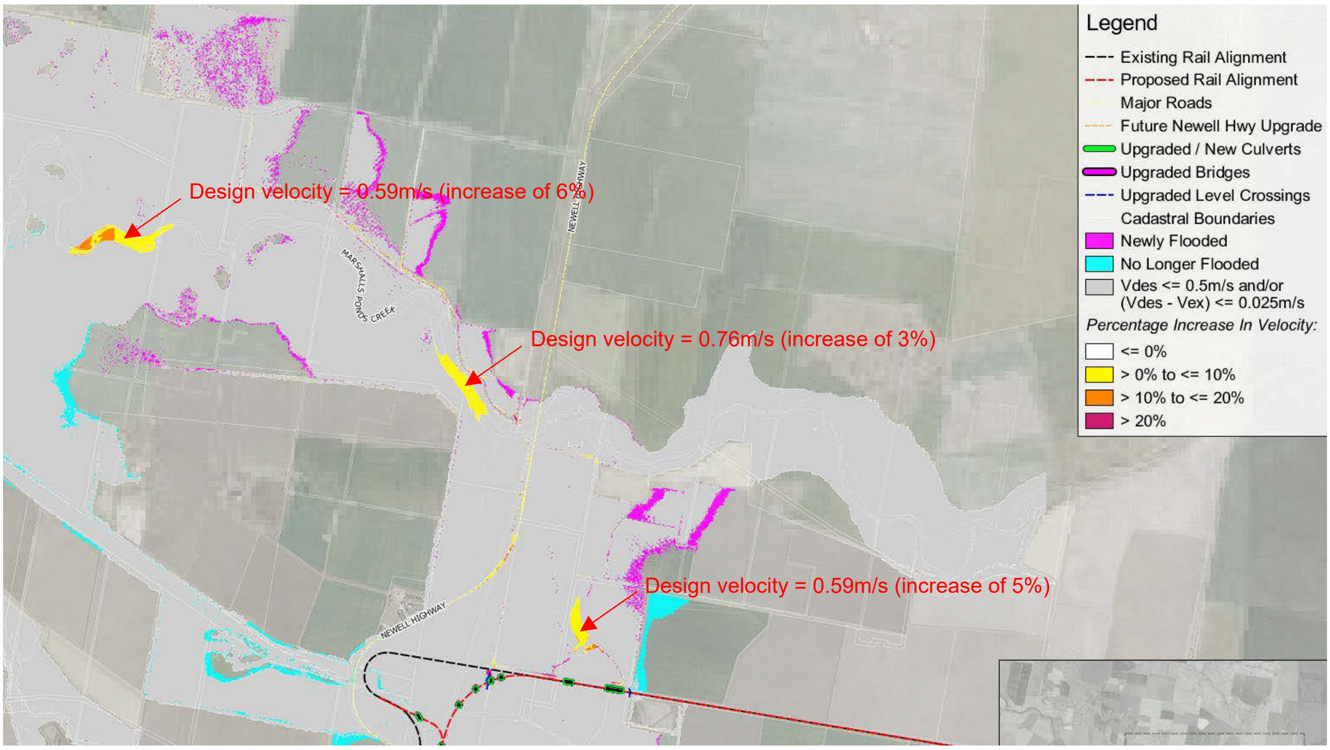

Figure 6-10 Locations of selected 1% AEP velocity QDL exceedances remote from rail corridor in Marshalls Ponds Creek with 0.5 m/s impact threshold applied

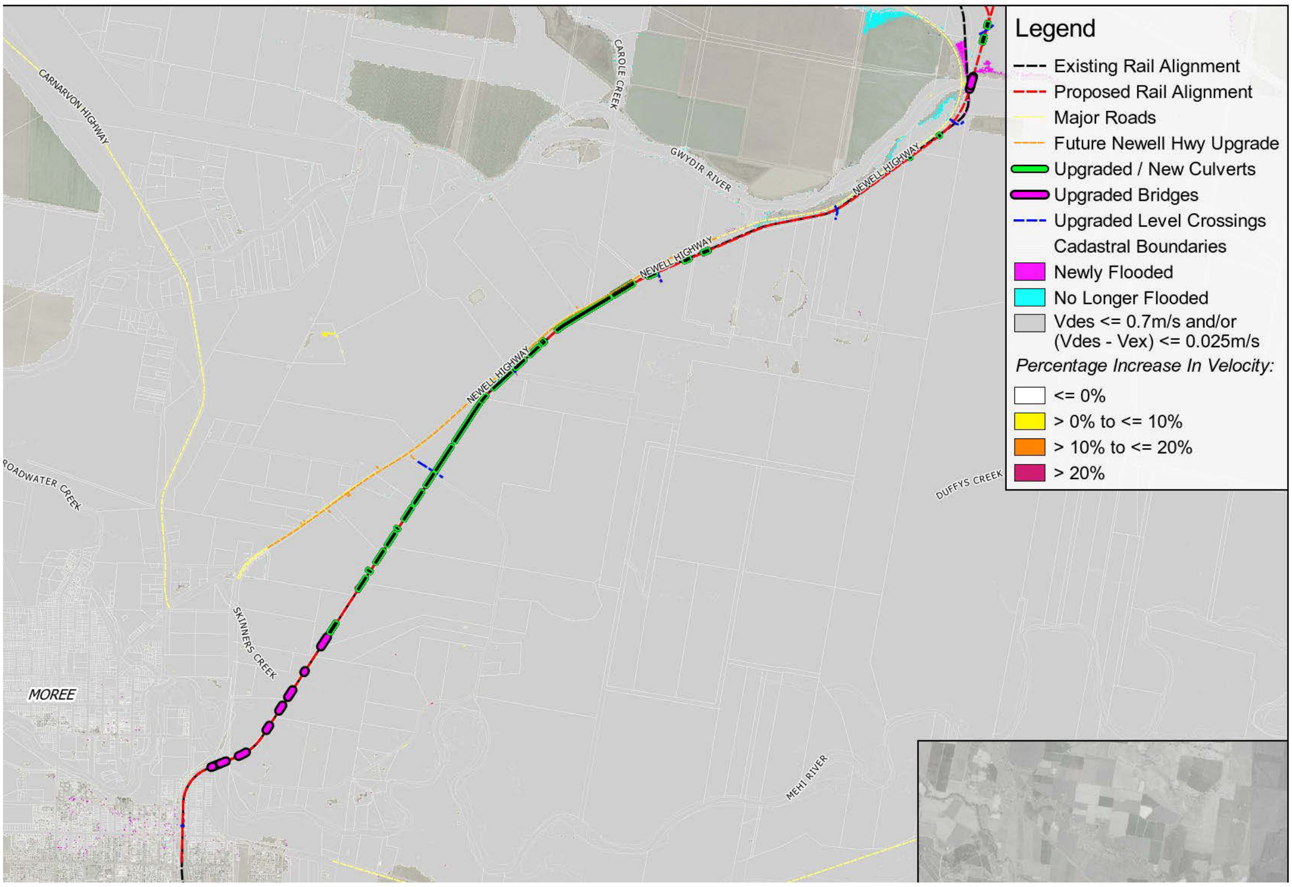

Figure 6-11 Locations of selected 1% AEP velocity QDL exceedances remote from rail corridor in Skinners Creek and around Gwydirfield Road with 0.7 m/s impact threshold applied

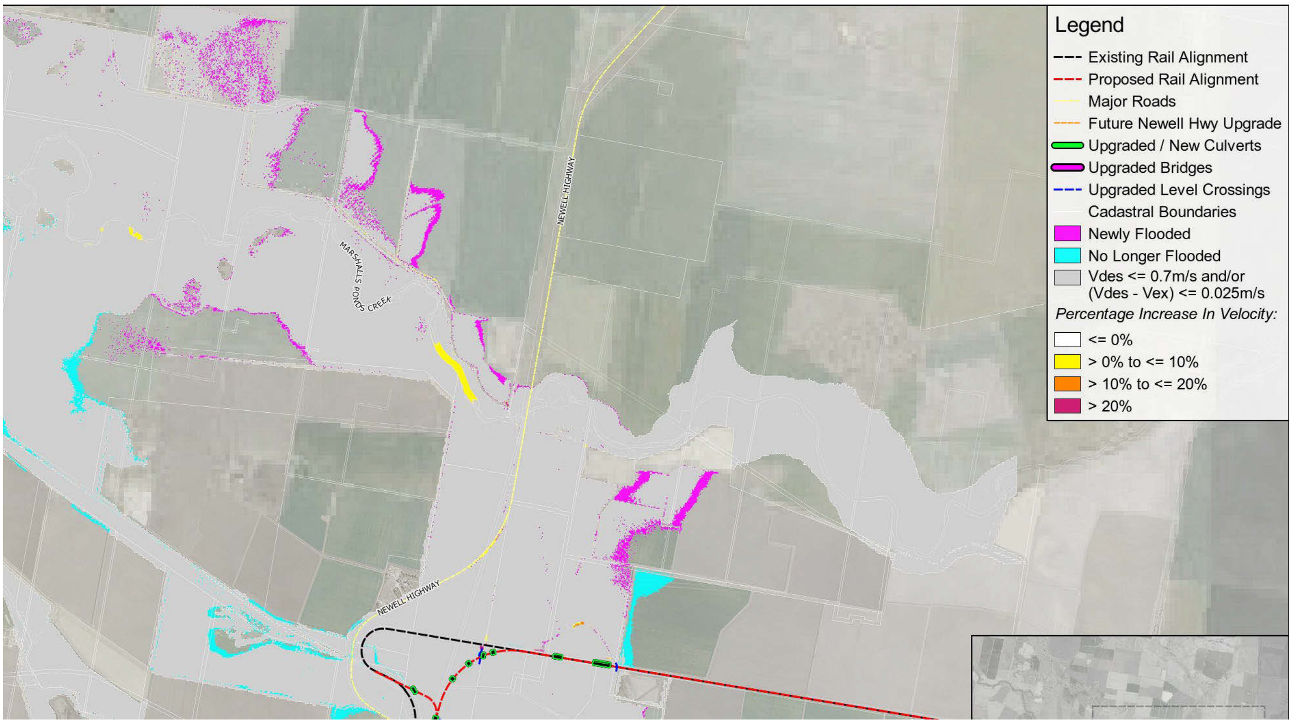

Figure 6-12 Locations of selected 1% AEP velocity QDL exceedances remote from rail corridor in Marshalls Ponds Creek with 0.7 m/s impact threshold applied

The results demonstrate that changes in the velocity regimes beyond the rail corridor only occur in the rare events and, while significant increases in the peak velocity occur downstream of some of the new flood relief culverts, the absolute values of peak velocity generally remain close to the erosive velocities for the bare soil condition and less than the lower bound of the erosive velocities for 50% weed cover. Therefore, the proposal is not expected to cause more widespread or more frequent occurrences of soil erosion during flood events than currently occurs. Discussions with landowners will continue into the detailed design phase to agree on suitable mitigation of impacts in some locations where erosion risks are predicted.

6.3.1.13 Impacts on flow paths and geomorphology

In addition to the assessment of changes in the key flood parameters described in the previous sections, the potential for the proposal to divert or change flow paths and change flow and geomorphological conditions in waterways was assessed.

The existing rail line intercepts and diverts overland and floodplain flow on the upstream side of the rail corridor and directs flow to the existing cross drainage structures. The existing rail is overtopped in some localised areas at the 10% AEP event, with widespread overtopping over approximately 6.7 km of the line predicted at the 1% AEP event. The design replicates this existing influence of the rail line on flooding by replacing the overtopping regime with controlled flow under the rail line via the large number of new flood relief culverts. The design culverts have been carefully located and use different culvert floor levels to match as closely as possibly the combination of underflow through culverts and overtopping flow that occurs in the existing situation. Figure 6-13 shows a visualisation of a typical bank of flood relief/floodplain culverts. The variable floor levels are used to control the event at which the culverts act to pass flow, with low floor culverts passing all flow that reaches the culvert bank and high floor culverts passing larger event flows only.

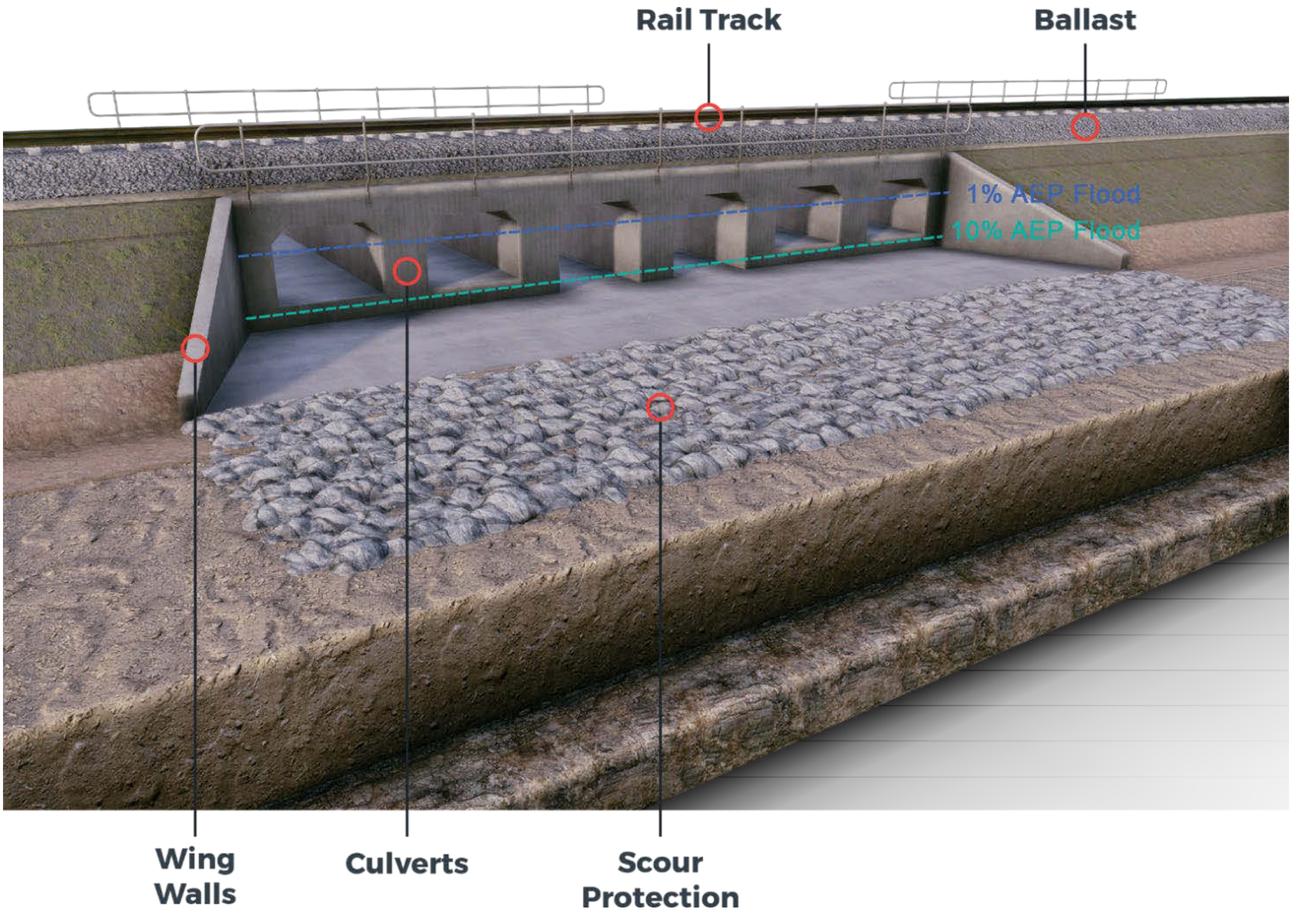

Figure 6-13 Visualisation of typical floodplain culvert bank showing variable culvert floor levels

This cross drainage design approach maintains the existing flow paths across the majority of the rail corridor. Towards the northern extent of the proposal near the existing Camurra Hairpin, some changes to flow paths occur – these changes are shown in the flood impact maps contained in Appendix B which identify areas that are newly flooded or no longer flooded by the proposal. The flow path that runs to the west just south of the existing hairpin is significantly reduced by the proposal in the 20%, 10% and 5% AEP events as the proposal diverts these flood flows to the north – this is demonstrated in Figure 6-14 which contains an excerpt from the afflux map for the 10% AEP event (Map DES_AFF_010_3 in Appendix B). Consultation with local landowners with operating farms in the area did not identify any concerns with this reduction in floodway flow to the west.

The flow path diversion is caused by the new greenfield section of rail embankment that replaces the old hairpin. The new embankment obstructs the westerly floodplain flow path and diverts it to the north through an existing floodway and adjacent agricultural land, causing afflux within the floodway, agricultural land and sections of the Newell Highway. Maps DES_AFF_002_3 and DES_AFF_001_3 in Appendix B show that the flow path impacts are lessened in the 2% and 1% AEP events, however, with lower flood levels occurring within the flow path as floodwater is also diverted to the north for these events.

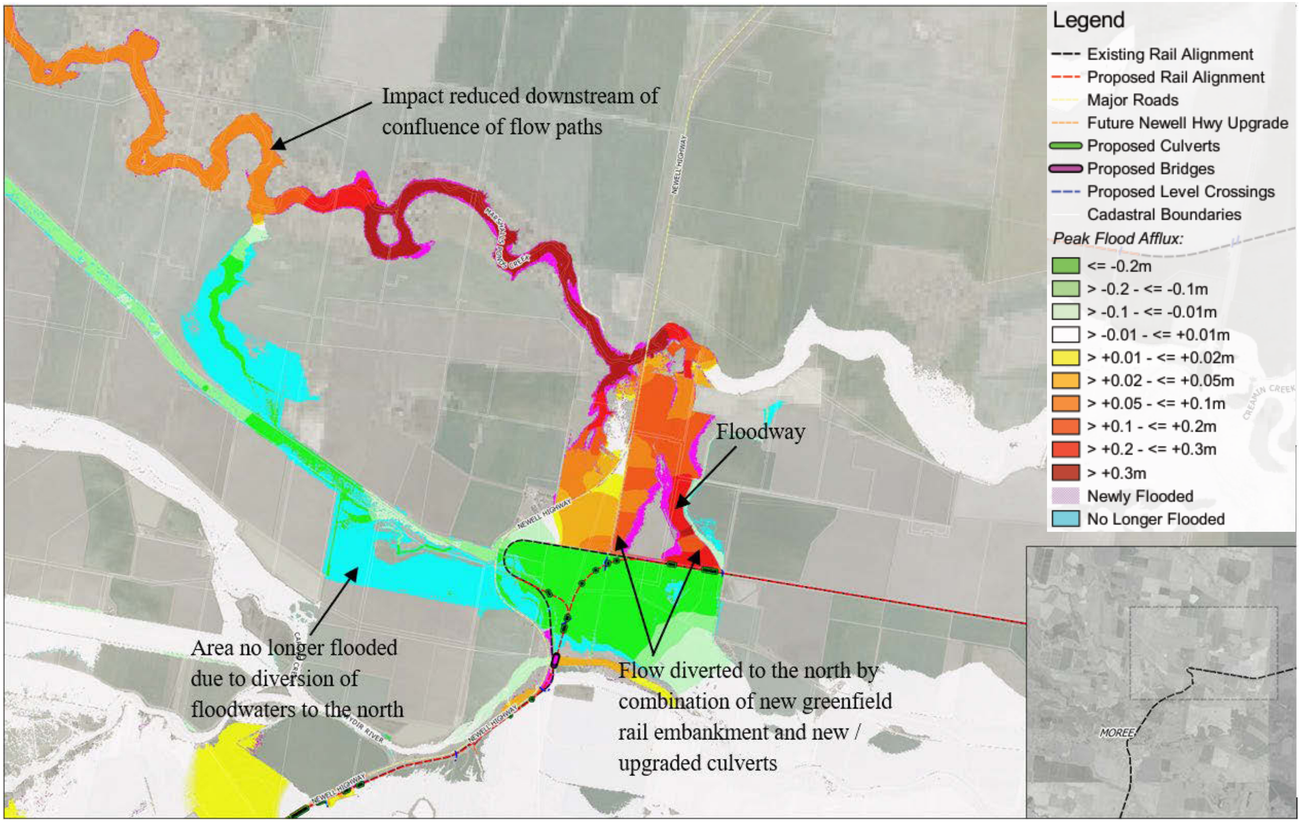

Figure 6-14 Excerpt from 10% AEP afflux map showing flow path diversion in the Camurra Hairpin area

This flow diversion impact is shown in the flow hydrographs in Figures 6-15 and 6-16 below.

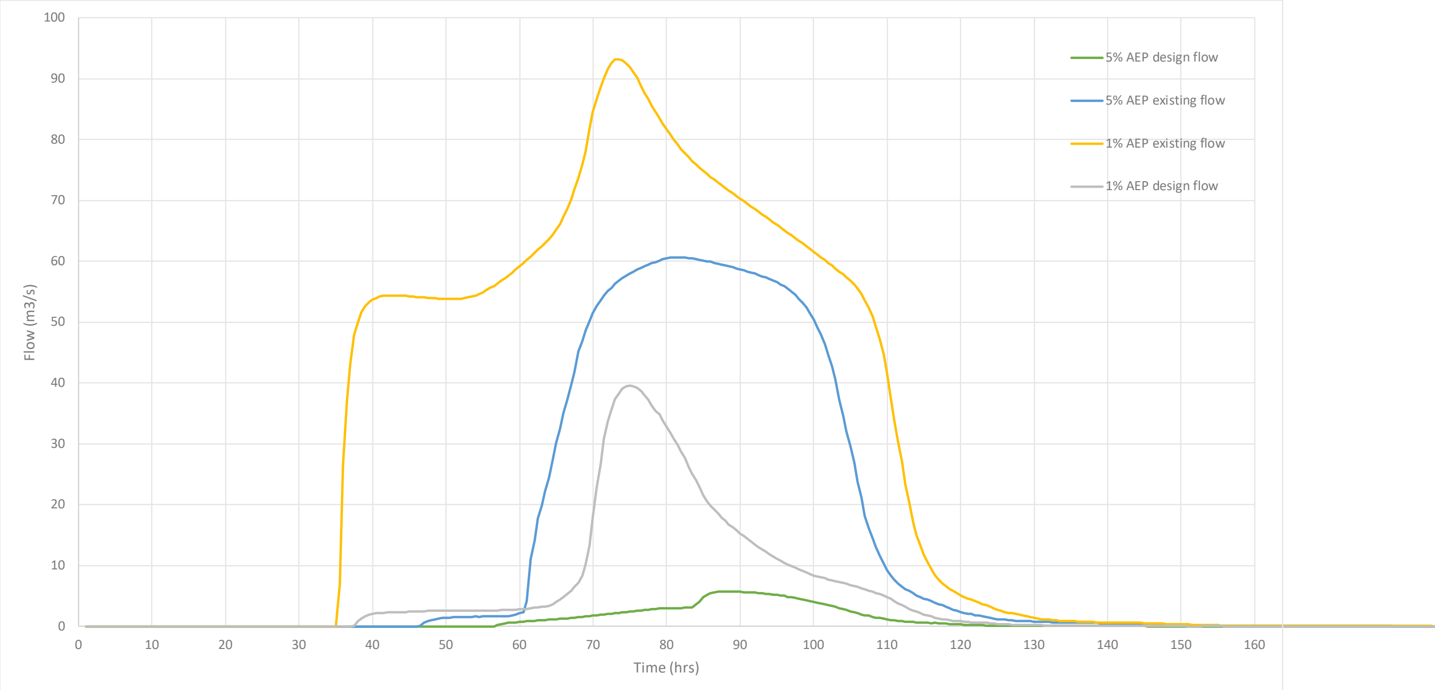

Figure 6-15 5% and 1% AEP flow hydrographs in overland flow path south and west of Camurra Hairpin

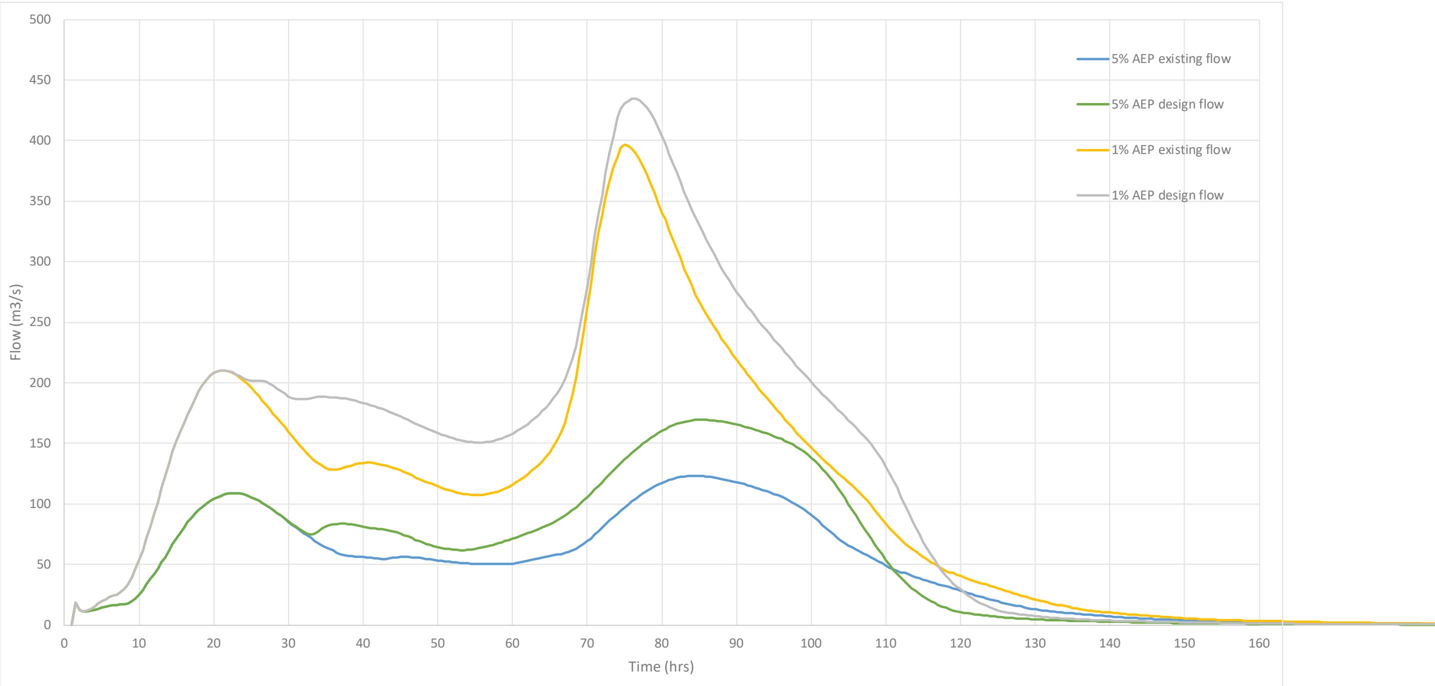

Figure 6-16 5% and 1% AEP flow hydrographs in Marshall Ponds Creek flow path north of Camurra Hairpin

The flow paths in this area are complex and the current results represent a balanced impact that seeks to minimise afflux impacts on the Newell Highway and adjacent properties, with the highest afflux directed towards the agricultural land. The obstructed flow path is not a defined waterway but a narrow overland flow path that runs alongside Camurra Lane between large irrigation storages that terminates and joins Marshalls Pond Creek near Ashley approximately 13.5 km to the north west of the Camurra Hairpin.

Further testing of design options in this area is required at the detailed design stage to better replicate the current flow paths, reduce impacts on the agricultural land that receives any resulting diverted flow and avoids impacts on the Newell Highway and adjacent properties.

The proposal does not cause any other flow diversions or significantly changed flow conditions within the main waterways and overland flow paths crossing the proposal, as demonstrated by the flood impact maps that show no other significant areas of newly flooded or no longer flooded land for all events, and the hydrographs in Figure 6-17 below which show flows from the main Gwydir and Mehi floodplain south of the Camurra Hairpin and downstream of the proposal.

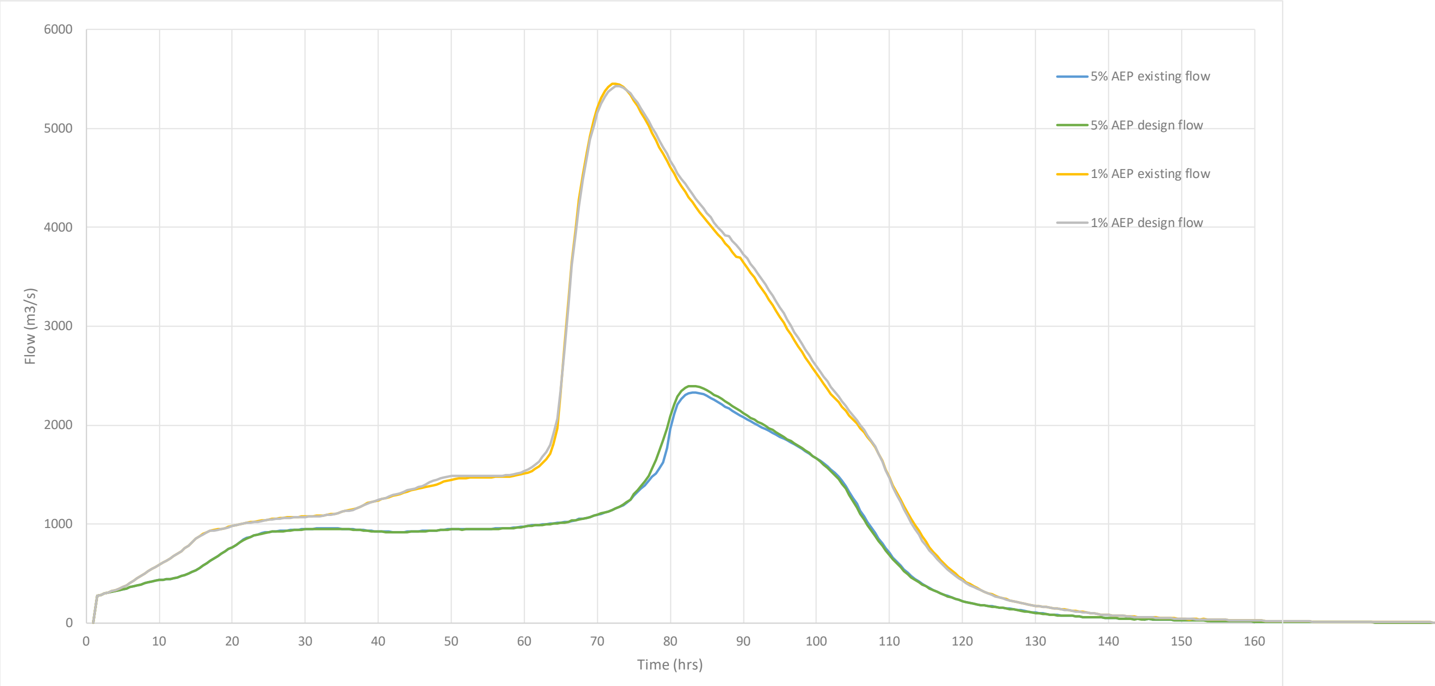

Figure 6-17 5% and 1% AEP flow hydrographs in main Gwdyir-Mehi floodplain downstream of the proposal

As described in the previous sections, the velocity impacts of the proposal within the main waterways and overland flow paths are insignificant, with velocity regimes generally remaining unaltered apart from some localised changes around new flood relief culverts. The proposal is therefore considered to have no impact on the geomorphological regime of the main waterways and floodplain flow paths around the proposal site.

6.3.1.14 Impacts on agricultural properties and infrastructure

North of Moree extensive areas of agricultural land are located either side of the proposal site. The agricultural land is used for cropping and numerous large water storages are located on the properties in the vicinity of the proposal. These storages are excluded from the flood model domain as they are assumed to be full of stored water during a flood event and do not store or convey floodwaters – this can be seen on the flood maps in Appendix A and B which show extensive regularly-shaped areas in the floodplain that are not flooded.

The proposal has the potential to impact on agricultural properties and infrastructure by diverting floodplain flows away from established storage areas, increasing flood levels and durations on cropping land and increasing floodplain velocities and potential for soil and levee erosion. The previous section demonstrates that only one minor flow path in the floodplain around the Camurra Hairpin is subject to diversion (with the loss of flow to the west identified as not a concern to the local farming landowners) and the predominant floodplain flow paths are unaffected by the proposal. Sections 6.3.1.2 and 6.3.1.3 demonstrate that the velocity and duration regimes are generally unaffected by the proposal. The proposal causes some changes in flood level on the floodplain but these changes are generally limited to less than 200 mm in areas that experience flood depths of 1 metre or higher. Afflux around water storages may cause minor additional inundation of the storages where the levee banks are lower than the flood level, however, additional inflow of floodplain water into storages that are intended to store water pumped from the local rivers will not impair the function of these storages.

Areas of exceedance of the 200 mm limit for afflux on agricultural land area as follows:

- 20% AEP event: None, afflux exceeding 200 mm is confined to floodways and creek channels
- 10% AEP event: 14 hectares
- 5% AEP event: 32 hectares
- 2% AEP event: 15 hectares
- 1% AEP event: 28 hectares.

The proposal is not considered to have adverse impacts on agricultural properties and infrastructure, with the exception of the agricultural property to the north of the Camurra Hairpin that receives floodwaters diverted from the south (refer to Section 6.3.1.13). This property has an afflux impact in all events which could affect the productivity of the cropping land on the property. Further assessment of this impact will be undertaken at the detailed design stage to attempt to reduce the afflux impacts and achieve a better balance of afflux impact across the property and adjacent land.

6.3.1.15 Social and economic Impacts related to flooding

The previous sections demonstrate that the proposal does not have widespread significant impacts on residences, highways and local roads, and agricultural properties and infrastructure. The proposal will therefore not cause flooding impacts that will adversely impact social and economic activities in the local community. Where the proposal has isolated flooding impacts on residences, roads and agricultural properties, further assessment will be undertaken at the detailed design stage to reduce the impact and/or agree appropriate mitigation measures with the affected resident/landowner.

6.3.1.16 Impacts on Flood Planning Levels

Council sets Flood Planning Levels for other development within the floodplain which includes urban development, local roads, flood protection infrastructure and agricultural infrastructure. TfNSW also sets Flood Planning Levels for current highways and roads and their future upgrades. Changes in flood levels caused by the proposal may require changes to the Flood Planning Levels set by these agencies. The flood level impacts on adjacent infrastructure owned or managed by other agencies that set FPLs are discussed in the sections above. The flood level impact outcomes achieved at detailed design will be consulted on with these agencies to determine whether any adjustments to their Flood Planning Levels or the design of the project are required.

6.3.2 Effects of climate change

The 1% AEP climate change scenario was used to assess the potential impacts of climate change (RCP 8.5 scenario) on the rail formation flood immunity and the flooding impacts of the proposal on adjacent land to determine if the design has capacity to deal with future climate changes. The results are discussed in the following sections.

6.3.2.1 Impact on rail formation flood immunity

The increase in flood level for the 1% AEP event under the climate change scenario was checked to determine the impact on the rail formation flood immunity. The climate change scenario results in variable increases in flood level at the rail corridor as summarised in Table 6-13 below, with an average increase of 250 millimetres and a maximum increase of 360 millimetres.

Table 6-13 Impact of climate change on 1% AEP flood levels at rail corridor

FLOOD LEVEL INCREASE	EXTENT OF RAIL CORRIDOR AFFECTED
0 to 100 mm	0.4%
100 to 200 mm	13.4%
200 to 300 mm	62.5%
300 to 400 mm	22.3%
400 to 500 mm	0.0%
>500 mm	N/A

The increased flood levels under the climate change scenario reduce the TOF flood immunity and result in the 1% AEP flood level overtopping of the rail at 3 separate locations. The combined length of rail impacted by flood overtopping is 1700 metres.

6.3.2.2 Impacts on adjacent land

The 1% AEP with climate change flood impact maps are provided in Appendix B. The impacts shown on the maps can be summarised as the follows:

- Map set DES_AFF_001CC demonstrates afflux upstream of the rail corridor is increased when compared to the 1% AEP impacts without climate change, with the occurrence of new areas of exceedance of the afflux criteria. Generally upstream impacts are less than 200 millimetres with localised increases up to 400 millimetres. There are localised increases between 50 millimetres and 100 millimetres in the urban areas of Moree upstream and downstream of the rail corridor as a result of the higher rail embankment diverting more flow through the southern part of the proposal where the Mehi river and floodplain bridges are located. Most of the afflux criteria exceedances are confined to rural or agricultural land areas.
- Map set DES_AFF_001CC demonstrates new impacts on more sensitive urban/settlement areas with increased impacts noted through the Moree urban area that result in new exceedances of the afflux criteria. Generally the impacts are less than 100 millimetres with localised increases up to 115 millimetres.
- Velocity impacts remain very similar to the 1% AEP event impacts without climate change (compare map set DES_CHV_001CC with map set DES_CHV_001 in Appendix B).
- Duration impacts remain very similar to the 1% AEP event impacts without climate change (compare map set DES_CHDUR_001CC with map set DES_CHDUR_001 in Appendix B).
- The pattern of hazard impact changes similar to afflux under the climate change scenario (compare map set DES_CHHAZ_001CC with map set DES_CHHAZ_001 in Appendix B), with higher hazard increases occurring upstream and downstream of the rail around the Mehi river and floodplain bridges. The increased hazard impacts also extend into the northern parts of the Moree urban area.

For impacts on adjacent land, the most affected parameter is afflux with the highest increases occurring upstream of the corridor within agricultural land, with lesser increases in flood level occurring around urban areas and buildings through the Moree urban area. These increased afflux impacts are accompanied by increased hazard impacts, although the increased hazard impact is less widespread. Velocity and duration impacts are similar and demonstrate these criteria are not particularly sensitive to climate change conditions.

6.3.3 Impacts under extreme events

The PMF event was simulated to assess the potential impacts of the proposal under an extreme flood event. For this event, the rail embankment, ballast and rail infrastructure was modelled as fully intact. This assumption will exaggerate the predicted flood level impacts of the proposal under this event as the ballast layers, and possibly some sections of the formation earthworks, may wash away under such conditions, which would act to equalise water levels across the rail corridor at the peak of the event.

The PMF event flood maps for existing conditions are provided in Appendix A and the flood impact maps for the design case are provided in Appendix B. Impact map sets DES_AFF_PMF, DES_CHV_PMF, DES_CHDUR_PMF and DES_CHHAZ_PMF demonstrate that the pattern of flooding in the PMF remains similar to other events assessed across afflux, velocity, duration and hazard. The impact on flood levels can be summarised as follows:

- There is an increase in flood level upstream of the rail corridor of generally less than 200 millimetres with localised increases up to 250 millimetres on agricultural land use.
- Flood level increases also occur in the urban area of Moree. Upstream of the rail, flood level increases greater than 100 millimetres occur up to a maximum of 125 millimetres. These increases occur in areas that experience PMF depths of greater than 1 metre under existing conditions.
- Downstream of the rail in the Moree south area, flood level increases are generally less than 100 millimetres.

In cases where high affluxes are predicted, the flood depths are significant under existing conditions and the afflux caused by the rail line would generally be added to flood depths that are in excess of 1 metre under existing conditions.

PMF velocity impacts are minimal. Increased flood durations occur along the fringe of the southern floodplain and through southern areas of Moree. Increased hazard also occurs through Moree south of the Mehi River. These duration and hazard impacts are caused by the higher rail embankment diverting more flow through the Mehi River and floodplain bridges as a result of less overtopping of the rail in the central part of the floodplain.

In general, it is considered that the impacts under the extreme event are acceptable given the low impacts and the likelihood that localised failure of the rail embankment, or at least the ballast layers, would occur under such events which would reduce the afflux upstream of the rail line. The widespread washout of ballast and rail embankment in some areas during significant events that has occurred historically, for example during the February 2012 flood event, will be considerably lessened in future as a result of the proposal due to the provision of numerous additional cross drainage structures that will relieve water pressure on the upstream side of the rail corridor. As noted in Section 4.2.4, observations of rail washouts and embankment failures during previous events indicate that these failures are not sudden and do not produce damaging flood surges that propagate over significant distances downstream, which is supported by the model predictions of relatively low velocities for all events up to the PMF. In addition, large floods rise and recede over a long duration, generally in the order of 5 or more days, and conditions that would cause rapid rise and drawdown of floodwater around the formation, which has the potential to destabilise the formation, are not expected in this floodplain. Table 6-14 below provides PMF water levels and velocities at key locations along the rail corridor where the water level difference across the rail line is at its highest. The table demonstrates that peak water level differences and velocities across the rail embankment are relatively low indicating a low risk of sudden failure of the rail embankment and associated damaging flood surges through the rail corridor.

Table 6-14 PMF parameters at key locations

LOCATION	PMF LEVEL UPSTREAM OF RAIL (mAHD)	PMF LEVEL DOWNSTREAM OF RAIL (mAHD)	PMF WATER LEVEL DIFFERENCE ACROSS RAIL (mm)	PMF VELOCITY UPSTREAM OF RAIL (m/s)
Moree Station	211.67	211.23	440	0.6
Skinners Creek	211.76	211.43	330	1.1
600 m south of Gwydirfield Road level crossing	211.90	211.72	180	0.6
Just south of main Gwydir River channel	215.36	215.04	320	0.4

The low risk is further demonstrated by the water level hydrographs shown in the figure below for the location 600 m south of the Gwydirfield Road level crossing. The figure shows that large water level differences occur during the rise and recession of the floodwaters in the 1% AEP event with climate change allowance, with up to 800 mm difference in water level. However, these peak differences occur well below the top of rail. For the PMF event the rail line is overtopped but the peak water level differences across the rail are lower at 300 to 400 mm.

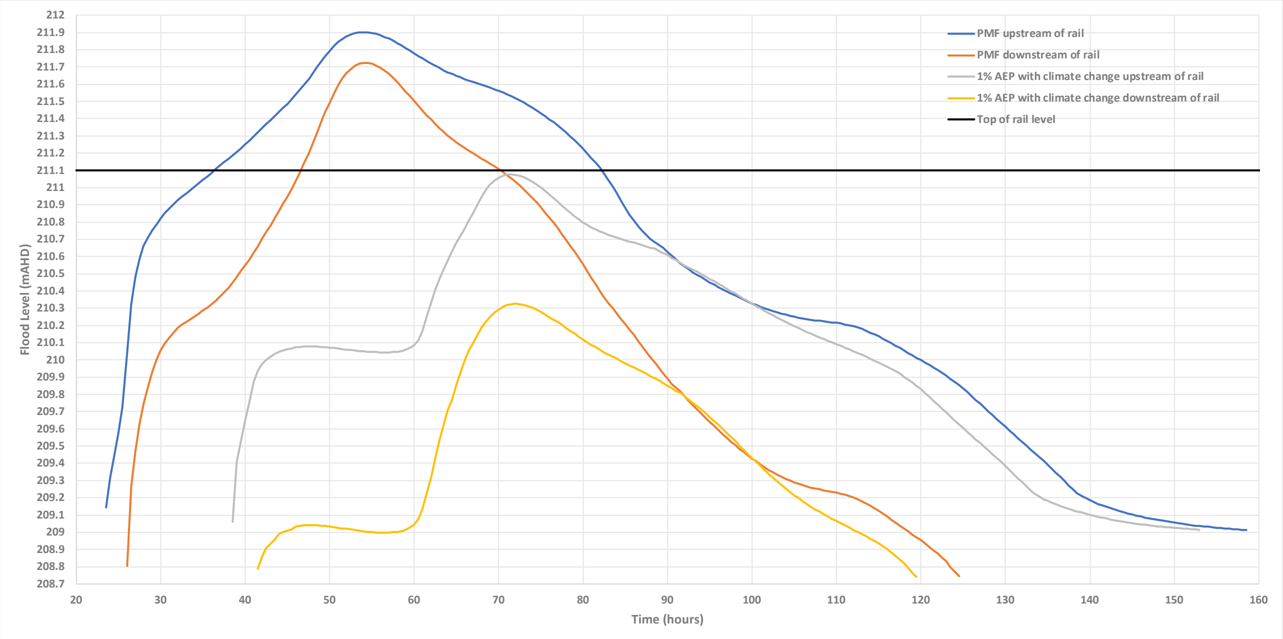

Figure 6-18 1% AEP with climate change and PMF water level hydrographs upstream and downstream of rail at a location 600m south of Gwydirfield Road level crossing

A more detailed failure analysis of the rail embankment under extreme overtopping events will be undertaken at the detailed design stage when the geotechnical design of the embankment is further developed.

6.3.4 Cumulative impact assessment

N2NS Phases 1 and 2 have combined effects on flooding processes on the southern Mehi River floodplain around Moree near the southern interface of both projects. Specifically, these combined effects occur south of the Alice Street level crossing around Moree station. N2NS Phase 1 and the proposed Newell Highway upgrade do not produce combined effects on flooding due to the distance between the projects, with the Newell Highway upgrade located approximately 2.3 km to the north of N2NS Phase 1. The cumulative effects of N2NS Phase 2 with N2NS Phase 1 and the Newell Highway upgrade are described separately in the following sections.

6.3.4.1 Cumulative impacts of N2NS Phases 1 and 2

Flood impact maps for the cumulative impact assessment that considers the combined effects of N2NS Phases 1 and 2 are provided in Appendix B. The impacts can be summarised as the follows:

- Up to the 2% AEP event, there are no adverse impacts on flooding as a result of the combined effects of both projects. The 2% AEP afflux map DES_AFF_002_1 shows that flood levels around the southern Mehi floodplain in Moree are reduced by between 10 and 100 mm.
- However, the 1% AEP afflux map DES_AFF_001_1 shows that the combined effects of both projects produce adverse flood impacts in Moree west of Moree Station, with afflux values of between 10 and 40 mm occurring at 86 residential properties. The cause of this impact is an increase in the 1% AEP flood level east of Moree Station of up to 10 mm which is sufficient to divert significant quantities of additional floodwater around the Station and into the centre of Moree.

- The 1% AEP impact in Moree is mainly an increase in flood level. There are no widespread or significant changes in velocity, duration and hazard for the 1% AEP event – refer to maps DES_CHV_001_1, DES_CHDUR_001_1 and DES_CHHAZ001_1.

Mitigation measures to prevent this cumulative impact both N2NS phases are discussed in Section 6.6.1.

6.3.4.2 Cumulative impacts of N2NS Phase 2 and Newell Highway upgrade

Flood impact maps for the cumulative impact assessment that considers the combined effects of the proposal and the planned Newell Highway upgrade are provided in Appendix C. It should be noted that the impacts of both projects only combine around the 4.5 km section of the Newell Highway Upgrade north of Stirton Road.

Table 6-15 below provides a summary of impacts on the Newell Highway with the proposal and the highway upgrade in place and can be compared to the equivalent Table 6-6 in Section 6.3.1.7 which presents the same results without the highway upgrade in place. For clarity and ease of reference Table 6-16 is provided below which identifies the quantum of change in impacts between the proposal only and the cumulative assessment (i.e. the combined impacts of the proposal and highway upgrade).

The impacts on the highway in this 4.5 km section can be summarised as follows for the cumulative assessment in reference to the flood impact criteria (i.e. the QDLs) adopted under this report:

- The upgraded section of the highway has greater than 20% AEP flood immunity and impacts of the proposal on this section of the highway are significantly reduced for all events up to the 1% AEP event.
- The number of points no longer flooded increases particularly for the low to medium events due to the raised pavement level of the highway (which improves its flood immunity).
- There are more hazard impacts on the highway in the upgrade case. This is due to localised increases in water level and velocity (i.e. water flowing across the lower areas of the highway) generated by the raised highway embankment for events that overtop the upgraded section of the highway (i.e. the 5%, 2% and 1% AEP events)

The impacts occurring around the highway and rail corridor in this 4.5 km section can be summarised as the following in reference to the flood impact criteria (i.e. the QDLs) adopted under this report:

- For the 1% and 2% AEP events, map sets DESNH_AFF_001 and DESNH_AFF_002 demonstrate that the cumulative impact results are in general consistent with the design scenario results with some minor increases in afflux around the rail corridor.
- Afflux map sets DESNH_AFF_005 and DESNH_AFF_010 demonstrate a change in afflux due to the cumulative impact of the projects. In both events, the properties located in the area between the road and rail corridor are subject to new impacts from increased flood levels. Extracts from the 10% AEP (Afflux) flood impact maps are presented in Figure 6-19 and Figure 6-20 below to identify the general area of cumulative afflux discussed and to demonstrate the cumulative afflux impacts as modelled under this report. Key conclusions regarding cumulative afflux in this area can be summarised as:
  - The increase in flood level is generally less than 100 millimetres with some localised increases up to 200 millimetres. There are also impacts noted immediately downstream of new cross drainage structures under the highway.
  - No exceedances of the afflux QDLs for buildings located in this area occur due to the cumulative impacts of both projects. This is primarily due to those building being protected from the additional afflux via existing flood mitigation infrastructure (i.e. mounds, bunds).
  - The unprotected areas surrounding these buildings including property accesses (i.e. driveways) are affected by the additional cumulative afflux. It should be noted that this additional cumulative afflux is most pronounced in the 10% and 5% AEP events as this cumulative impact reduces once flood waters rise above the upgraded Newell Highway pavement levels.

- It is considered that the proposal does not generally alter the materiality of the impacts of cumulative afflux regarding either the reduction of freeboard of buildings or constrained access to residential properties during flooding events. This is due to the proportionately lower contribution of the proposal to the cumulative afflux in this area and the existing conditions which indicate flooding occurring in the area for the 10%, 5%, 2% and 1% AEP events.
- The Newell Highway Upgrade Review of Environmental Factors sets flood impact criteria for the highway upgrade and where these criteria are exceeded, TfNSW has undertaken consultation with affected landholders as part of the REF approval process. In areas where the cumulative impacts of both projects occur, ARTC will undertake further consultation with TfNSW and affected landholders to determine the potential for design modifications or other mitigation measures to address the cumulative impacts attributable to the rail project scope. This will be undertaken during the detailed design phase of the proposal.
- Velocity impacts are similar to the non-cumulative design case impacts (compare map sets DESNH_CHV_001 to DESNH_CHV_010 in Appendix C with map sets DES_CHV_001 to DES_CHV_010 in Appendix B).
- Map sets DESNH_CHDUR_001 to DESNH_CHDUR_010 demonstrate that the Newell Highway upgrade results in an increase to the duration of flooding. The figures demonstrate exceedances of the duration criteria (duration increase >10%) across all events both upstream and downstream of the proposed highway changes.
- Hazard impacts are similar to the non-cumulative design case impacts (compare map sets DESNH_CHHAZ_001 to DESNH_CHHAZ_010 in Appendix C with map sets DES_CHHAZ_001 to DES_CHHAZ_010 in Appendix B), with some increased hazard impact upstream of the highway and rail corridor in the cumulative case.

Table 6-15 Summary of impacts along the Newell Highway with both the Proposal and Newell Highway Upgrade in place (i.e. cumulative impacts of both projects)

NEWELL HIGHWAY IMPACT SUMMARY (AT 10 m INTERVALS)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Total points assessed (10 m intervals)	2174	2174	2174	2174	2174
Points flooded in existing conditions	91	561	872	1083	1204
Points flooded in design case	108	401	802	1074	1166
Points newly flooded	28	63	77	48	3
Points no longer flooded	11	229	146	57	41
QDL exceedance: points with flood level increase >50 mm	65	152	394	284	184
QDL exceedance: points with flow velocity increase >10%	0	0	0	3	4
QDL exceedance: points with duration of flooding increase >10%	34	193	262	291	314
QDL exceedance: points with flood hazard (V*D) increase >10%	6	81	283	424	473

Table 6-16 Comparison of change of impacts along the Newell Highway – cumulative impacts of the Proposal and Newel Highway Upgrade vs Proposal only impacts

NEWELL HIGHWAY IMPACT SUMMARY (AT 10 m INTERVALS)	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Change to Total points assessed (10 m intervals)	0	0	0	0	0
Change to Points flooded in existing conditions	0	0	0	0	0
Change to Points flooded in design case	-2	-146	-33	-6	-1
Change to Points newly flooded	0	0	+36	0	-1
Change to Points no longer flooded	+2	+152	+68	+6	0
Change to QDL exceedance: points with flood level increase >50 mm	0	+38	-33	+24	+36
Change to QDL exceedance: points with flow velocity increase >10%	0	0	0	+3	+2
Change to QDL exceedance: points with duration of flooding increase >10%	0	+64	+76	+28	-4
Change to QDL exceedance: points with flood hazard (V*D) increase >10%	+6	+49	+49	+180	+247

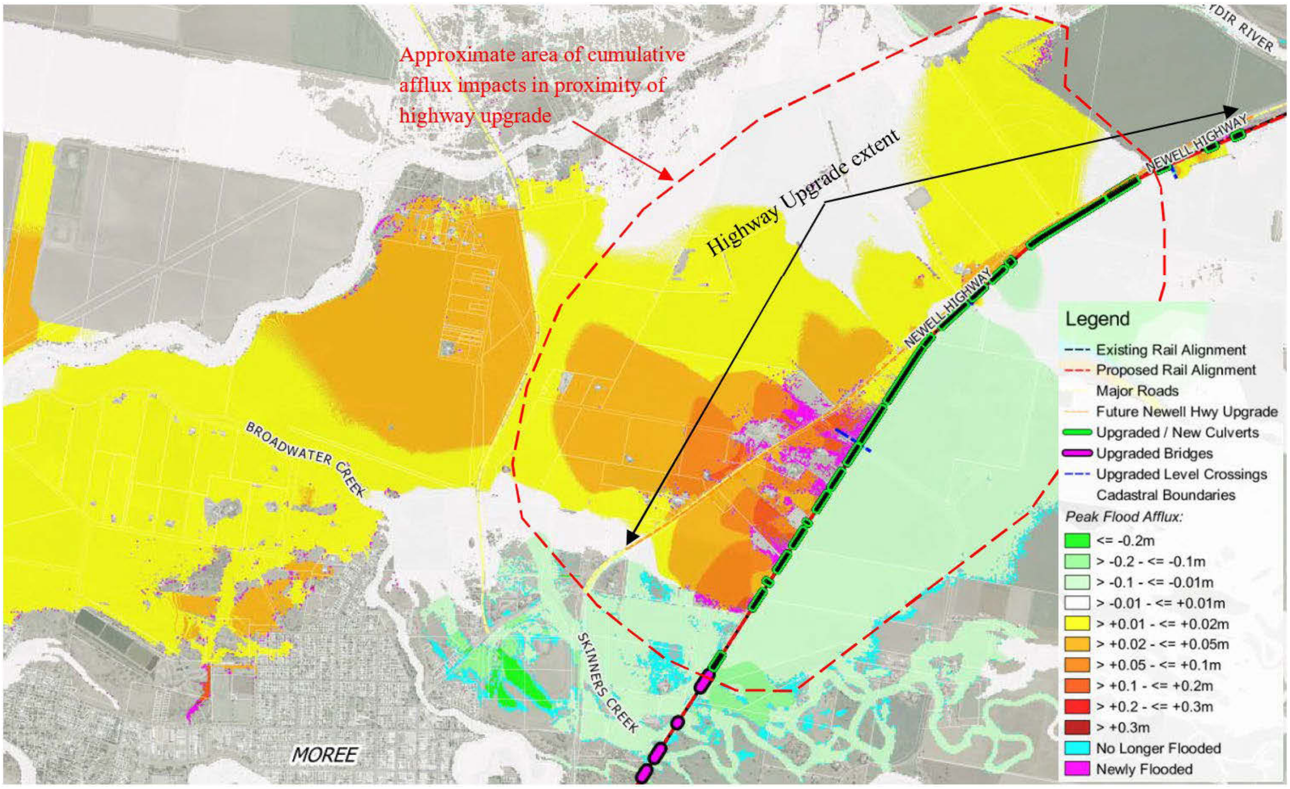

Figure 6-19 Design only afflux changes in proximity of Newell Highway Pavement Upgrade – 10% AEP event

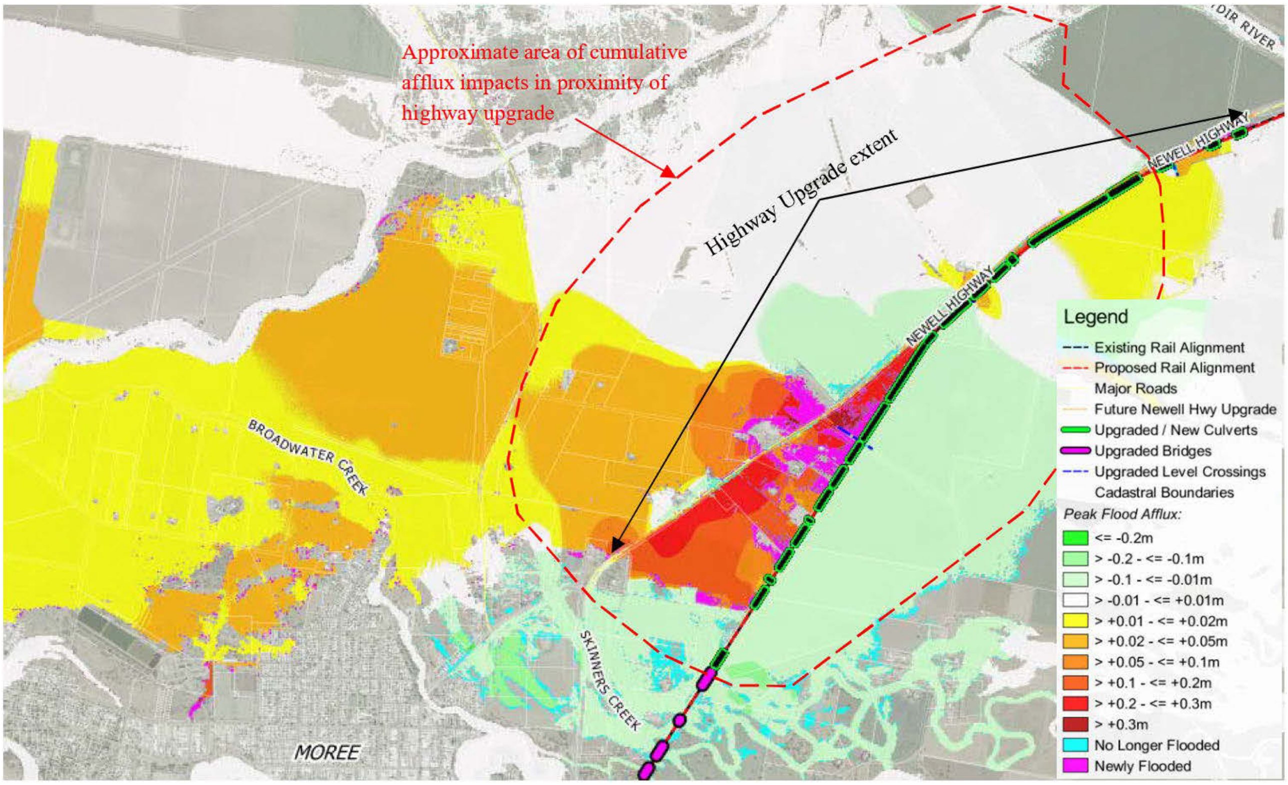

Figure 6-20 Cumulative afflux changes in proximity of Newell Highway Pavement Upgrade – 10% AEP event

6.3.5 Culvert blockage factor sensitivity tests

As described in Section 4.3.2.10, sensitivity tests were undertaken on culvert blockage to determine how flood impacts may vary with culvert blockage. Afflux maps for the 1% AEP event for blockage factors of 0%, 25% and 50% are provided in Appendix I. The results show the following:

- For the 0% blockage case afflux is decreased upstream by up to 200 mm in the southern and central areas of the floodplain, including around Moree. Afflux is generally unaffected downstream, with some increases in localised areas.
- For the 25% blockage case the upstream afflux is increased by up to 200 mm and afflux is more widespread. There are decreases in afflux downstream but these are not widespread. The urban area of Moree experiences higher affluxes upstream and downstream of the rail as a result of the increased blockage of the culverts diverting more flow through the southern part of the floodplain where the Mehi River and floodplain bridges are located.
- For the 50% blockage case the pattern of afflux variation is similar to the 25% blockage case, but with higher afflux values occurring upstream (up to 400 mm) and lower values occurring downstream. Afflux is worsened significantly through Moree upstream and downstream of the rail with afflux values of up to 200 mm occurring in the most affected areas upstream and downstream of the Mehi floodplain bridges.

Given the critical influence of blockage factors on the predicted flood impacts, further testing at the detailed design stage is required to develop a refined set of blockage factors that best represents the conditions and blockage risks at each individual culvert group. To safeguard against excessive blockages occurring at sensitive locations, the detailed design will also consider blockage management measures such as debris deflectors.

6.4 Stakeholder consultation

Consultation with relevant stakeholders on flooding was undertaken with the following objectives:

- to present results of the baseline flood modelling to landowners to verify that the model predictions of flood extent and depth were consistent with landowners' observations during historic floods
- to determine stakeholder sensitivities to changes in drainage and flooding patterns, focussing on property/building vulnerabilities to flooding, function and performance of irrigation infrastructure, access to/from properties during flood events and vulnerability of farmland to changes in flow paths and flood regimes
- to present initial findings of the flood impact assessment to landowners who are predicted to experience changes in flood parameters to obtain initial feedback on the acceptability of the changes.

The consultation was undertaken using a combination of Community information sessions, face-to-face meetings and video conference meetings and included the following stakeholders:

- individual landowners or local groups of landowners
- irrigator organisations
- Moree Plains Shire Council
- the local Floodplain Management Committee
- the local Emergency Management Committee
- local representatives from TfNSW; and
- local representatives from the State Emergency Service (SES).

Key outcomes of the consultation were as follows:

- Landowners reviewed the baseline flood maps and confirmed that the various design event flood extents and levels were consistent with observed flood behaviour during historic floods. For example, the 5% and 2% AEP event predictions of flood levels and durations were consistent with landowner recollections of the most recent significant floods that occurred in November 2011 and February 2012.
- Landowners and other stakeholders were supportive of the proposed cross drainage design that would remove the rail overtopping/washout mechanism with more controlled flow through large numbers of additional culverts.
- Landowners in the floodplain were generally accepting of the predictions of minor increases in flood height at their properties, particularly for low order events (such as the 10% and 5% AEP events), provided that their properties remained protected against above floor level flooding in high order events (such as the 2% and 1% AEP events).
- Landowners engaged in farming activities adjacent to the proposal were generally accepting of the requirement to provide large numbers of additional culverts in the rail corridor to replace the existing overtopping/washout mechanism, based on the key findings from the flood modelling analyses that these culverts would not create newly flooded/no longer flooded areas and no significant increases in flood velocity or duration across land used for cropping.
- Landowners affected by changes to the velocity regime around new culverts were consulted on the impacts and presented with the findings of the soil erodibility assessment and the velocity impact mapping. The landowners were advised that areas where the velocity QDLs were exceeded would be subject to further investigation at the detailed design stage and mitigation measures would be negotiated with the landowners as required. The majority of landowners were comfortable with the level of change predicted and agreed these impacts could be addressed during the detailed design phase via the potential mitigation measures previously mentioned. One landowner did, however, express concern at the predicted velocity and afflux impacts due to the potential impact on the value of the land. This landowner was however agreeable to working through these issues in the detailed design phase when the final impact will be refined/determined and mitigation measures can be collaboratively tailored to the specific use of the land.

- Further consultation with landowners affected by minor flood level increases at properties will be required at the detailed design stage to confirm any reductions in impact achieved at the detailed design stage and if at-property mitigation measures are required to manage residual impacts.
- Consultation with the Local Emergency Management Committee, the State Emergency Services (SES) Planning Coordinator (Southern and Western Zone), the Rural Fire Service and the Moree Police Service was undertaken to provide an overview of the potential hydrology impacts of the project. It was identified that ongoing engagement with emergency services should be maintained during the detailed design phase, as well as later phases to ensure adequate planning in the event of any emergency.
- Further flood modelling and design iterations are required at the northern end of the proposal to attempt to balance the impacts around the old hairpin and greenfield section to reduce impacts on the cropping land north of the rail corridor and the Newell Highway.
- Details of new culvert scour protection measures that need to extend some distance beyond the rail corridor into neighbouring land will need to be confirmed and agreed with the adjacent landowners at the detailed design stage.
- Further consultation TfNSW on the combined effects of the proposal and the Newell Highway upgrade will be required to achieve a better flood impact outcome on properties between the rail corridor and the upgraded highway section, and in the area downstream of the highway upgrade. This may require some repositioning and reconfiguration of the cross drainage structures in the current rail design adjacent to the highway upgrade.
- Ongoing consultation with Moree Plains Shire Council will be required through the detailed design stage to ensure that the flooding analysis for the proposal remains consistent with Council's ongoing floodplain risk management activities.
- Further consultation with DPE Water will be undertaken to discuss the Gwydir Valley Floodplain Management Plan.
- Ongoing engagement with the relevant SES representatives throughout the future phases of the project as well consultation with the Local Emergency Management Committee.

A detailed account of consultation is provided in Chapter 4 of the EIS: Consultation and Appendix D to the EIS: Consultation Technical Paper. Impact mitigation and management.

6.5 Construction phase mitigation and management measures

The proposal is located within a highly sensitive floodplain and the construction phase has the potential to significantly impact flooding of sensitive assets and property if not appropriately managed. Table 6-17 provides a list of construction activities that could affect flooding during the construction phase and proposed mitigation and management measures to reduce or avoid these impacts.

Table 6-17 Construction activities, impacts and management measures

REF	ACTIVITY	POTENTIAL IMPACT OF ACTIVITY	PROPOSED MANAGEMENT AND MITIGATION MEASURES

HF-1	Flood modelling analysis and flood impact assessment for construction phase	▸ Temporary embankment opening during demolition/reconstruction may pass additional flow downstream;
		▸ Location and level of long term construction facilities (such as compounds, access tracks and stockpiles) may obstruct and divert flows; and
		▸ Location and level of temporary works in waterways and overland flow paths during bridge and culvert construction may obstruct and divert flows.
			▸ Following development of the construction methodology, critical stages of the works should be identified and tested in the flood model to identify potential construction phase flooding impacts. The tests should simulate the following in the model for a number of construction phase scenarios as required:
			  ▸ key stages of temporary embankment opening during demolition/reconstruction that could pass additional flow downstream
			  ▸ location and level of long term construction facilities (such as compounds, access tracks and stockpiles) that could obstruct and divert flows; and
			  ▸ location and level of temporary works in waterways and overland flow paths during bridge and culvert construction that could obstruct and divert flows.
			▸ The construction phase flood modelling should be iterated through sufficient scenarios to inform planning of the works such that construction phase flood impacts are identified and managed accordingly.
			▸ The outcomes of the modelling should be used to inform the construction phase flood emergency response plan.

HF-2	Location of construction facilities (compounds, stockpiles, equipment, access tracks) within the floodplain	▸ Displacement and diversion of floodwater and overland flow causing increased flood level, velocity and duration in adjacent land. ▸ Scour and erosion of sensitive land causing crop damage and other damages due to changed flooding conditions.	▸ Use flood model results to identify areas free from flooding in a 10% AEP event and locate construction facilities in these areas where possible. ▸ Where locating construction facilities within the floodplain is unavoidable, use flood model results to identify areas where flood depth and velocity are low to ensure that facilities are located in areas of lowest flood risk.

REF	ACTIVITY	POTENTIAL IMPACT OF ACTIVITY	PROPOSED MANAGEMENT AND MITIGATION MEASURES
HF-3	Progressive demolition and reconstruction of existing rail embankment	- Temporary openings in rail embankment cause new flow paths to occur during flood events, increasing flooding downstream of the corridor. - Associated increase in flood level, velocity and duration, associated damage to land, crops and other assets.	- Key stages of embankment works to be analysed using the flood model to determine most sensitive embankment sections and appropriate limits on extents of temporary embankment openings. - Identify likely flood warning times between rainfall forecast and onset of flooding and, where required, stage works so that demolished sections of the embankment can be sufficiently reinstated and stabilised prior to onset of flooding.
HF-4	Temporary works obstruction of waterways and overland flow paths	- Temporary works such as cofferdams, working platforms and access tracks in waterways and overland flow paths obstruct flow and displace/divert floodwater. - Associated increase in flood level, velocity and duration, associated damage to land, crops and other assets.	- Key stages of temporary works to be analysed using the flood model to determine appropriate limits on extents of temporary works in waterways and flow paths. - Identify likely flood warning times between rainfall forecast and onset of flooding and, where required, design the temporary works to allow partial removal of key flow obstructions prior to onset of flooding.

HF-5	Establishment of construction phase flood warning system and flood emergency response plan	- Displacement and diversion of floodwater and overland flow causing increased flood level, velocity and duration in adjacent land.
		- Damage or loss of equipment and/or machinery.
		- Injury or death of personnel.
		- Damage or loss of adjacent infrastructure including private buildings.
			Prior to construction, a flood warning system should be established that monitors real time and forecast rainfall data and real time streamflow gauge data. The rainfall and streamflow data should be used to set a number of trigger levels and associated actions in a flood emergency response plan to manage works areas appropriately prior to and during, and after flood events. Typical actions would include the following:
			- Prior to flood events:
			  - stabilise and protect disturbed areas and stockpiles
			  - where required, remove flow obstructions from waterways and flow paths and reinstate open sections of embankment
			  - secure/evacuate equipment and machinery
			  - evacuate personnel
			  - issue flood warnings to potentially affected agencies and landowners.
			- During flood events:
			  - monitor flood data to anticipate damage
			  - collate reports of damage.

REF	ACTIVITY	POTENTIAL IMPACT OF ACTIVITY	PROPOSED MANAGEMENT AND MITIGATION MEASURES
			▸ After flood events: ▸ confirm flooding has receded and access to works areas is safe ▸ inspect works areas for flood damage ▸ undertake inspections of temporary works to assess stability before undertaking repairs or recommencing work ▸ respond to reports of flood damage by neighbouring landowners ▸ where necessary, prepare flood event reports assessing damages to adjacent land, causes and any required compensation and future mitigation works.

6.6 Operational phase mitigation and management measures

Table 6-18 provides a list of impacts that could affect flooding during the operation phase and proposed mitigation and management measures to reduce or avoid these impacts.

Table 6-18 Detailed design and operational impacts and management measures

REF	ACTIVITY	POTENTIAL IMPACT OF ACTIVITY	PROPOSED MANAGEMENT AND MITIGATION MEASURES
HF-6	Detailed Design	▸ Formation of new flow paths or changes to existing modelled flows during detailed design. ▸ Confirmation of velocity QDL exceedances in land adjacent to the rail corridor. ▸ Confirmation of impact on Flood Planning Levels set by other agencies, including Council and TfNSW.	▸ Further refinement of the cross drainage design is recommended at the detailed design stage to reduce exceedances of the impact criteria. This may involve some repositioning and reconfiguration of the cross drainage structures in the current design and provision of additional structures. As part of this refinement confirm the most appropriate blockage factors to assume in design and consider adoption of debris deflectors or other similar measures to manage blockage risks at sensitive locations. Sensitivity testing to alternative representations of large culvert banks within the flood model using a two-dimensional modelling approach rather than the current one-dimensional approach should also be undertaken to confirm the best approach to modelling the proposed drainage infrastructure (noting that the current one-dimensional modelling approach is consistent with the current industry standard). ▸ Following refinement of the cross drainage design, where velocity QDL exceedances occur in land adjacent to the corridor that cannot be resolved through infrastructure measures within the corridor, negotiate mitigation measures with the affected landowners for the affected land areas.

REF	ACTIVITY	POTENTIAL IMPACT OF ACTIVITY	PROPOSED MANAGEMENT AND MITIGATION MEASURES
			▶ Undertake consultation and collaboration with Transport for NSW on the combined effects of the proposal and the Newell Highway upgrade is recommended to gain a better flood impact outcome on properties between the rail corridor and the upgraded highway section, and in the area downstream of the highway upgrade. This may require some repositioning and reconfiguration of the cross drainage structures in the current rail design adjacent to the highway upgrade. ▶ Source additional topographic data and update the topographic grid in the hydraulic model to ensure that the best available data is incorporated into the modelling analysis. ▶ Calibrate the detailed design flood model to recent flood events, including the events that occurred in 2011, 2012 and 2021, to increase confidence in the model's accuracy. ▶ Following calibration, the design event model should be updated to adopt ARR2019 rainfall runoff modelling methodologies for the local catchments around Moree and the flood frequency analysis updated as required to include the latest flow records at the Gravesend stream gauge. ▶ The updated model will be used to assess the proposal's impacts against all aspects of the QDLs, including those that allow minor or negligible impacts to be filtered out (e.g. those attributable to model noise) so that material impacts are focussed on for mitigation. The detailed design will identify and quantify QDL exceedances to a high level of detail, and where these cannot be designed out or mitigated, they will be justified by a thorough examination of each exceedance to demonstrate that the associated flood risk does not adversely affect the land use or asset that is subject to the QDL exceedance. ▶ The final afflux outcomes achieved at detailed design will be advised to Council, TfNSW and other agencies so that any required adjustments to their Flood Planning Levels can be made.

REF	ACTIVITY	POTENTIAL IMPACT OF ACTIVITY	PROPOSED MANAGEMENT AND MITIGATION MEASURES
HF-7	Appropriate design of infrastructure	▸ Obstruction of floodwater that previously overtopped the rail causing increased flooding on the upstream (eastern) side of the rail corridor. ▸ Passing of floodwater too efficiently through the rail corridor resulting in increased flooding on the downstream (western) side of the rail corridor. ▸ Location of permanent spoil mounds within the floodplain may cause obstruction and diversion of flows with associated adverse impacts on adjacent land and property.	▸ The design of the proposal has aimed to improve the flood immunity and resilience of the rail corridor while preserving existing flood patterns and characteristics as far as possible. The design includes significant numbers of additional cross drainage structures to allow equivalent volumes of floodwater that overtop the existing rail to pass under the rail in a more controlled manner. ▸ All new and upgraded culverts and bridges have been carefully sized and located to ensure that they do not obstruct flow upstream (east) of the rail corridor or pass flow too efficiently through the rail corridor and adversely impact flooding on the downstream (western) side of the rail corridor. The impacts of the proposal on flooding have been balanced upstream and downstream of the rail corridor across the range of events from the 20% AEP to the 1% AEP. Further refinements of the design are required at the detailed design stage to achieve a better balance in areas that are predicted to have most impact from the current design. These include the area around the Camurra Hairpin and land west of the rail corridor in the central floodplain, including the Newell and Carnarvon Highways. ▸ The design approach maintains existing drainage characteristics and minimises impacts on drainage and flooding patterns around the proposal site. This prevents the formation of new flow paths or changes to existing flow paths and therefore reduces potential for erosion and scour during flood events. The culvert designs incorporate long concrete aprons at inlets and outlets, flared wingwalls and extended rock aprons where velocities are high to reduce flow velocity across the culvert and reduce potential scour and disturbance of bed sediments. The bridge designs incorporate abutment scour protection and piers aligned with the main river flow directions to avoid scouring and disturbance of river banks and beds around the bridges. ▸ No spoil mounds are proposed as part of the proposal's permanent works.

REF	ACTIVITY	POTENTIAL IMPACT OF ACTIVITY	PROPOSED MANAGEMENT AND MITIGATION MEASURES
HF-8	Operation: Adaptation of infrastructure for climate change effects	▸ Climate change has the potential to reduce flood immunity and resilience of the proposal, and increase the flooding impacts of the proposal on adjacent land and assets	▸ When and if required, potential future impacts can be addressed by additional works to restore the intended design flood immunity and resilience and offset the impacts by a combination of future upgrade works, including: ▸ increase in rail level ▸ provision of additional scour protection on rail embankments and cross drainage structures ▸ provision of additional cross drainage structures to provide more flow capacity in flood events.
HF-9	Operation	▸ Progressive deterioration of cross drainage structure condition and capacity over time due to siltation, debris build-up and flood damage	▸ Inspections will be carried out of cross-drainage structures in accordance with ARTC's Structures Inspection Engineering Code of Practice (ETE-09-01) to identify defects and conditions that may affect waterway and drainage system capacity or indicate increased risk of flooding such as: ▸ scour ▸ blockages due to debris build up ▸ indication of floods overtopping a structure ▸ culvert or drain damage or collapse.

6.6.1 Mitigation of cumulative impact of N2NS Phases 1 and 2 on Moree

Section 6.3.4.1 describes the cumulative impact of both N2NS phases on Moree, which causes afflux of up to 40 mm on 86 residential properties within Moree for the 1% AEP event, with no impact predicted for the 2% AEP and lower events.

The cause of the impact is a minor increase of approximately 10 mm in the 1% AEP flood level east of Moree Station which is sufficient to divert significant additional volume of floodwater around the station and into the centre of town. Flood model testing has shown that this impact can be mitigated by a combination of the following measures:

- increase in design rail level of approximately 50 mm immediately north of Moree Station, and gradual reduction in rail level to tie in to existing rail level at the Alice Street level crossing; and
- provision of a low bund within the rail corridor south of the Alice Street level crossing to provide a secondary low level barrier to flood flow through the corridor where the rail level drops to tie in to the Alice Street level crossing. Preferably this bund will be formed of hard material such as concrete to avoid settlement and erosion over time.

Figure 6-21 shows the effect of such mitigation measures, with a significantly reduced impact within Moree.

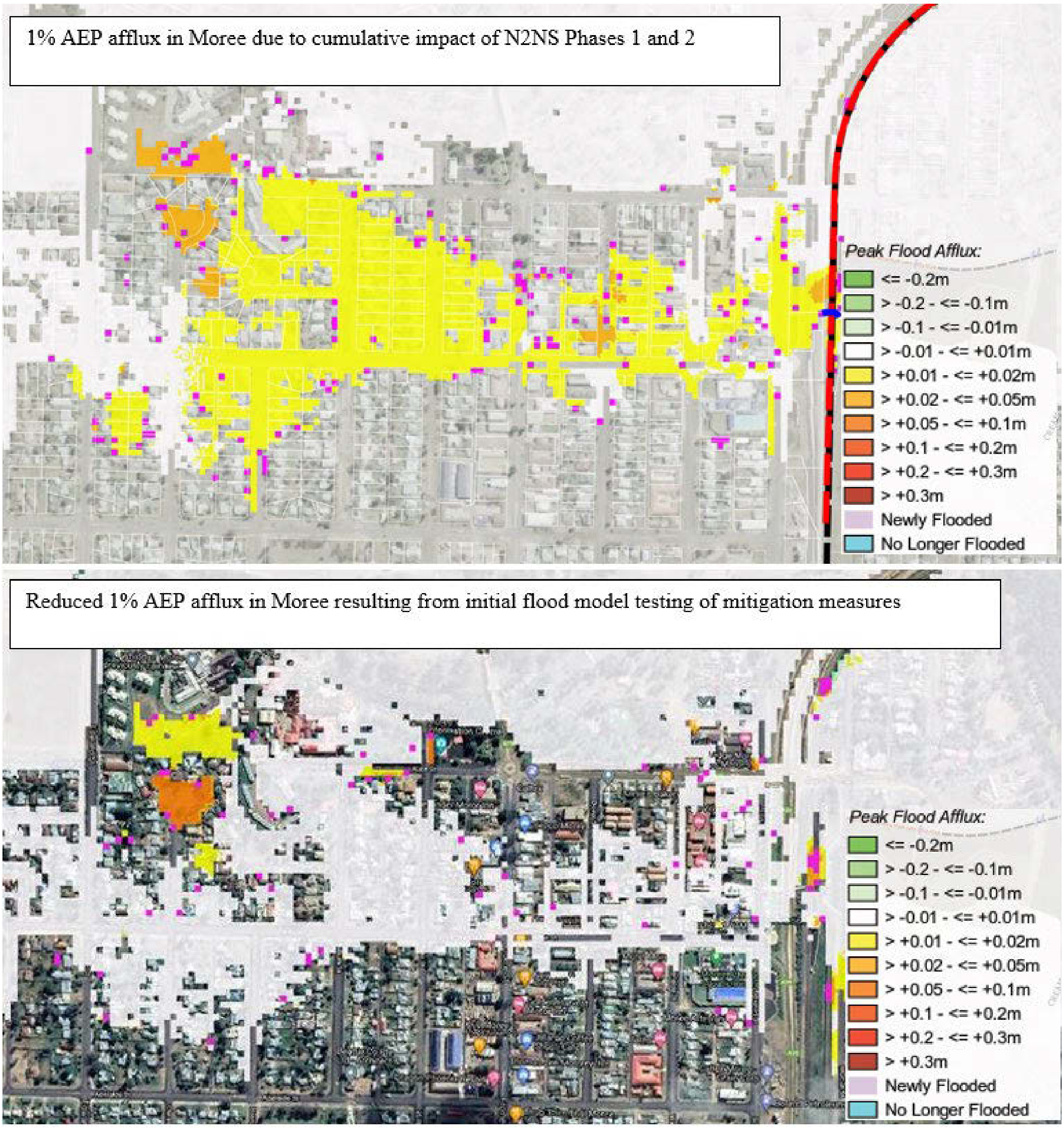

Figure 6-21 Effect of initial flood model testing of mitigation measures to remove 1% AEP afflux impact on Moree

The mitigation measures and resolution of the impacts will be delivered either through the N2NS Phase 1 construction works or through the design process for the upgrade of Moree Station in collaboration with Trains NSW, depending on the timeframes of these projects in relation to the subsequent design stages of N2NS Phase 2.

7 Conclusions and recommendations

7.1 Conclusions

- The proposal is located within a large floodplain where the existing rail corridor and adjacent sensitive assets, such as residences, highways, local roads and valuable agricultural lands, are susceptible to extensive and damaging flooding.
- The existing rail corridor does not have sufficient flood immunity and resilience to meet the requirements of Inland Rail and requires a significant upgrade to meet these requirements. The upgrade entails raising the rail level by approximately 500 millimetres, upgrade of all existing bridges and culverts and provision of large numbers of new cross drainage infrastructure.
- The design of the proposal has sought to maintain the existing flood behaviour as far as possible. No diversions of existing flow paths are proposed and the design attempts to replicate the current rail overtopping mechanism with new cross drainage structures that will pass flood flow through the rail corridor in a more controlled manner.
- The complexity of the floodplain requires that flood impacts need to be balanced across the rail corridor and for a range of flood events so that changes and impacts are not concentrated upstream or downstream of the corridor.
- The design of the proposal has been iterated to meet a set of flood impact criteria as far as possible. The criteria currently developed by ARTC in consultation with DPE have been adopted for this assessment. The key outcomes of the impact assessment are as follows:
  - Design case impacts:
    - Impact limits on agricultural land are generally met, with the exception of the agricultural land located north of the proposal near the greenfield section at 680.25 km where flood level and duration exceedances occur for all events. The impacts on this area require further design refinements at the detailed design stage to achieve a better balance of impact around the old hairpin and new greenfield rail section.
    - Impact limits are generally met at buildings and other sensitive receivers. There is a net reduction in the number of buildings flooded, but afflux exceedances occur at 10 buildings with afflux values ranging from 11 to 66 mm. Afflux and duration exceedances also occur at the TAFE Agricultural Skills Centre and the Moree Gun Club. Most of the impacts on buildings and sensitive receivers occur at the higher events assessed (2% and 1% AEP). These impacts will be subject to further investigation at detailed design, including collection of additional building floor level survey where required. Consultation with affected property owners will be undertaken to determine whether the impacts adversely affect flood damage at the properties. Where floor level survey data indicates a residual impact, at property mitigation will be consulted on with the property owners.
    - Overall, the impact on the Newell Highway is considered to be positive due to a net reduction in flood hazard along the highway. Most impacts on the highway occur for the 5% and 2% AEP events which will be subject to further investigation at the detailed design stage to refine the design to better balance impacts east and west of the rail corridor and reduce impacts on the Newell Highway and land to the west of the proposal for these events.
    - For the Carnarvon Highway, impacts are minor or positive for the 20%, 10% and 1% AEP events with minimal change in the number of flooded locations and hazard categories. Hazard impacts occur for the 5% and 2% AEP events with increases in the number of flood locations and/or increases in hazard categories. Similar to the Newell Highway impacts noted above, impacts for the 5% AEP event which will be subject to further investigation at the detailed design stage to refine the design to better balance impacts east and west of the rail corridor and reduce impacts on the Carnarvon Highway for this event. Better balancing to reduce impact for the 5% AEP event should also resolve the lesser impacts at the 2% AEP event.

  - Impacts on Gwydirfield Road are positive, with significant net reductions in the number of locations flooded and hazard categories across all events assessed.
  - Impacts on Back Pally Road are positive for the 20%, 10%, 5% and 2% AEP events, with significant net reductions in the number of locations flooded and hazard categories. For the 1% AEP event, the food hazard is increased over a distance of approximately 1.3 km east of the new greenfield section of the alignment. As noted above, the impacts on this area require further design refinements at the detailed design stage to achieve a better balance of impact around the old hairpin and new greenfield rail section.
  - Exceedances of the velocity QDLs occur beyond the rail corridor around some culvert locations. If these exceedances persist following refinement of the cross drainage design, mitigation measures will be negotiated with the affected landowners. It is noted that the velocity QDL exceedances are predicted to occur when applying the default 0.5 m/s erosive threshold, however, soil testing undertaken to date indicate that the in-situ soils have higher erosive thresholds which would significantly reduce the number of QDL exceedances if applied. Based on these results and feedback received from the affected landowners during the consultation process, it is anticipated that the impacts associated with these exceedances can be mitigated through property specific solutions through further engagement and agreement with affected landholders.
- Climate change effects:
  - Climate change is predicted to reduce the flood immunity of the rail and cause extensive overtopping to occur at the 1% AEP event.
  - Impacts of the proposal on flooding in adjacent land are increased under the climate change scenario, with higher impacts on sensitive receivers and more receivers affected. Most of the increased impact under the climate change scenario is seen on the upstream (east) side of the rail corridor. Increased impacts also occur through Moree as a result of more flow conveyed through the Mehi River and floodplain bridges in the south of the proposal.
- Extreme event impacts:
  - Under the extreme event (PMF) impacts are predicted to occur particularly upstream of the rail corridor and within Moree. Generally the impacts occur in areas that would experience considerable damage under this event and the additional impact caused by the proposal is likely to be minimal when compared against the existing flood risk profile for this event.
  - Damaging flood surges as a result of sudden embankment failure under extreme events is considered unlikely given the relatively low water level differences across the rail line and relatively low velocities across the floodplain upstream and downstream of the rail corridor. A more detailed analysis of rail embankment failure will be undertaken at the detailed design stage when the geotechnical design of the embankment is developed.
- Assessment of cumulative impacts:
  - The combined effects of N2NS Phases 1 and 2 increase flood levels at up 86 properties within Moree due to diversion of additional floodwater around Moree Station and towards the centre of town. These impacts only occur for the 1% AEP event, with no impact predicted at the 2% AEP and lower events.
  - The combined effects of the proposal and the Newell Highway upgrade include increased flood levels on properties located in the area between the road and rail corridor. There are also impacts noted immediately downstream of new cross drainage structures under the highway. The Newell Highway Upgrade Review of Environmental Factors sets flood impact criteria for the highway upgrade and where these criteria are exceeded, TfNSW has undertaken consultation with affected landowners. In areas where the cumulative impacts of both projects occur, ARTC will undertake further consultation with TfNSW and affected landowners to determine acceptability of impacts and the potential for design modifications or other mitigation measures to address the cumulative impacts attributable to the rail project scope.

  - Assessment of sensitivity of flood impacts to culvert blockage assumptions:
    - Sensitivity testing shows that the impacts of the proposal are sensitive to the culvert blockage factors adopted in the flood model. Significantly higher impacts occur in and around Moree for blockage factors higher than currently assumed in the design.
- Specific flood management and mitigation measures will be necessary for the construction phase and should include:
    - Location of construction facilities out of the floodplain or within shallow low velocity areas of the floodplain where possible.
    - Flood modelling analyses of critical construction stages to determine impacts and inform the construction planning and staging to avoid or minimise impacts.
    - Development of a flood warning system and flood emergency response plan for the construction phase to protect construction staff and adjacent land from flood damage.
- The design has sought to achieve minimal change to flood patterns through the design of the permanent cross drainage infrastructure. To manage the potential effects of climate change, future upgrade works can be planned to restore the intended flood immunity and resilience of the rail and introduce additional cross drainage structures in the rail corridor to manage impacts on adjacent land under the higher flow climate change scenario.

7.2 Recommendations

The following recommendations are made for future stages of design:

- Source additional topographic data and update the topographic grid in the hydraulic model to ensure that the best available data is incorporated into the modelling analysis.
- Calibrate the detailed design flood model to recent flood events that occurred in 2011, 2012 and 2021. Obtain Council’s flood model calibration database for the 2011 and 2012 event to facilitate this process.
- Further refinement of the cross drainage design is recommended at the detailed design stage to reduce exceedances of the currently adopted impact criteria. This may involve some repositioning and reconfiguration of the cross drainage structures in the current design and provision of additional structures. As part of this refinement confirm the most appropriate blockage factors to assume in design and consider adoption of debris deflectors or other similar measures to manage blockage risks at sensitive locations. Alternative two-dimensional modelling representations of large culvert banks should also be investigated to determine the most accurate modelling methodology for these structures.
- Mitigation measures to prevent the cumulative impact of N2NS Phases 1 and 2 in Moree town will be implemented as part of the Phase 1 works. Measures that will remove the impact will involve a combination of minor raising of the design rail level north of Moree Station and minor raising of ground levels within the rail corridor south of the Alice Street level crossing. Initial flood model testing has shown that these measures will prevent the diversion of additional floodwater around the station and towards the centre of town in the 1% AEP event. The mitigation measures and resolution of the impacts will be delivered either through the N2NS Phase 1 construction works or through the design process for the upgrade of Moree Station in collaboration with Trains NSW, depending on the timeframes of these projects in relation to the subsequent design stages of N2NS Phase 2.
- Further model testing to reduce/remove property impacts and further consultation with affected land and property owners is to be undertaken at detailed design to determine the implications of any residual flooding impacts on the properties and to agree appropriate mitigation measures where necessary. The assessment of property impacts may need to be informed by additional building floor level survey data to supplement the data already provided by Council.
- Further flood modelling and design iterations are required to better balance impacts east and west of the rail corridor, particularly for the 5% and 2% AEP events, with a focus on reducing impacts on the Newell and Carnarvon Highways and land to the west of the proposal for these events.

- Further flood modelling and design iterations are required to resolve velocity QDL exceedances in adjacent land outside the rail corridor and confirm any mitigation measures required to be negotiated with affected landowners to manage these exceedances if they remain following detailed design.
- Further flood modelling and design iterations are required at the northern end of the proposal to attempt to balance the impacts around the old hairpin and greenfield section to reduce impacts on the cropping land north of the rail corridor, the Newell Highway and Back Pally Road.
- Consultation and collaboration with Transport for NSW on the combined effects of the proposal and the Newell Highway upgrade is recommended to gain a better flood impact outcome on properties between the rail corridor and the upgraded highway section, and in the area downstream of the highway upgrade. This may require some repositioning and reconfiguration of the cross drainage structures in the current rail design adjacent to the highway upgrade.
- Testing of rail embankment failure scenarios under extreme overtopping events should be undertaken at the detailed design stage to determine the potential for damage in land downstream of the proposal during a failure scenario.
- Flood modelling of critical construction stages is recommended to facilitate construction planning, design of temporary works and management of flooding impacts during construction.
- Development of a flood warning system and flood emergency response plan for the construction phase is recommended as part of the construction planning process.

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