Technical and Approvals Consultancy Services: Parkes to Narromine

Flood Study Report

July 2019

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Prepared for

Australian Rail Track Corporation

Prepared by

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Glossary

1D	One dimensional
2D	Two dimensional
AEP	Annual Exceedance Probability
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ARTC	Australian Rail Track Corporation
ARR 2016	Australian Rainfall and Runoff 2016
BoD	Basis of Design
BoQ	Bill of Quantities
BX	Storage coefficient multiplication factor – a RAFTS model parameter
CL	Continuing loss (rainfall) – a RAFTS model parameter
CoA	Conditions of Approval
DD	Detailed Design
DEM	Digital Elevation Model
DIRD	Department of Infrastructure and Regional Development
Down	‘Down’ direction is towards Narromine. The ‘down’ side of the track is on the left when facing Narromine.
DPE	NSW Department of Planning and Environment
DRAINS	An industry standard hydrology / hydraulics modelling software program
EIS	Environmental Impact Statement
EY	Exceedances per Year
FFA	Flood Frequency Analysis
FMO	Flood Management Objectives
GIS	Geographic Information System
HHIP	Hydrology and Hydraulics Investigation Plan
HPC	Heavily Parallelised Computations
IFC	Issued for Construction
IFD	Intensity-Frequency-Duration

IL	Initial loss (rainfall) – a RAFTS model parameter
IR	Inland Rail
IRDJV	Inland Rail Design Joint Venture – A joint venture of WSP Australia and Mott MacDonald set up to deliver the detailed design for the project
LX	Level Crossing
LiDAR	Light Detection and Ranging
m AHD	Metres above Australian Height Datum
MCA	Multi-Criteria Analysis
P2N	Parkes to Narromine
P1	Priority 1 (part of P2N)
P2	Priority 2 (part of P2N)
RAFTS	Water Resource Engineering Software (www.wateronline.com)
RFFE	Regional Flood Frequency Estimation
RCBC	Reinforced Concrete Box Culvert
RCP	Reinforced Concrete Pipe
RFI	Request for Information
RAATM	Requirements Analysis, Allocation and Traceability Matrix
R&O	Risk & Opportunity
RMS	Roads and Maritime Services
SRTM	Shuttle Radar Topography Mission
TA	Technical Adviser
TIN	Triangular Irregular Network
TOF	Top of Formation
TUFLOW	Water Flow Modelling Software (www.tuflow.com)
Up	‘Up’ direction is towards Parkes. The ‘up’ side of the track is on the left when facing Parkes.
VE	Value Engineering

1 Introduction

1.1 Background

The Australian Government has committed to deliver the Melbourne to Brisbane Inland Rail (Inland Rail), as a vital piece of infrastructure to complete the National Freight Network and to provide for a significant modal shift of freight from road to rail. On behalf of the Department of Infrastructure and Regional Development (DIRD), the Australian Rail Track Corporation (ARTC) has been tasked with preparing a 10-year delivery strategy for Inland Rail.

The Parkes to Narromine (P2N) section of Inland Rail is a brownfield site, extending from 449.200km to 547.550km, on the existing Goobang Junction to Narromine line within the ARTC network between Parkes and Narromine. The P2N section also includes the North-West Connection, a 5.6km greenfield connection, including a fork at Southern Junction. The rail line is a single bi-directional track, running a variety of freight and grain.

This report addresses the flood modelling undertaken to support the detailed design process, for the P2N section.

1.2 Scope

This report summarises the flood behaviour for the catchments within the Macquarie, Bogan and Lachlan River floodplains, including estimates of flood levels, duration of inundation and velocities for existing and design conditions (including the future permanent works) for the 39%, 18%, 10%, 5%, 2%, 1% and 0.05% Annual Exceedance Probability (AEP) events.

The report documents the flood modelling analyses undertaken at the Issue for Construction (IFC) detailed design stage, the hydraulic design of cross drainage structures based on the flood modelling and the assessment of the compliance of the design with the Requirements Analysis, Allocation and Traceability Matrix (RAATM) and flood management objectives (or flood impact limits) currently assumed for the project, which are consistent with the Conditions of Approval (CoA) provided by the Department of Planning & Environment (DPE) in June 2018.

This report has been updated primarily to address the changes that have been requested by ARTC following submission of the IFC design, to amend culvert designs and the alignment at Peak Hill. The associated design updates have been incorporated into the flood models, the results of which are presented in this document.

1.3 Objectives

The objectives of the flooding analyses undertaken for the project are as follows:

- Establish a set of hydrological and hydraulic models for the project area, that make best use of all available data and are sufficiently accurate to inform the detailed design of the project;
- Define the baseline or existing flooding conditions within the catchments, adjacent to the project area and predict the impact of the project on these flood conditions;
- Set the required minimum flood immunity of the upgraded rail formation by providing input to ARTC’s Flooding Multi-Criteria Analysis (MCA) process, that informs ARTC’s business decision on rail flood immunity; and
- Design the cross drainage systems for the upgraded rail corridor to achieve the required minimum rail flood immunity and meet flood management objectives (or impact limits) for land adjacent to the rail corridor.

1.4 Related Documents

This report should be read in conjunction with the following additional project documentation:

- Hydrological and Hydraulic Investigation Plan (3-0001-240-IHY-00-PL-0001): This plan set out the methodology adopted for the hydrological and hydraulic modelling analyses and introduced the flood management objectives (or flood impact limits) that were later refined on receipt of the CoA;
- Hydrological Calibration Report (3-0001-240-IHY-00-RP-0001): This report provides an update of the hydrological modelling methodology, a summary of the review of hydrological data used to build and calibrate the hydrological models, a description of the hydrological model calibration process and the results achieved, and a description of additional verification checks on the results of the hydrological and hydraulic modelling of the existing flooding conditions within the project area. This is a key document that is required to give ARTC and the Technical Advisor (TA) (the SMEC-Arup Joint Venture providing technical experts to assist ARTC in delivering the Inland Rail Program) confidence in the hydrological modelling and design flow estimates before proceeding to adopt the hydrological model for the detailed design;
- Flood Study Report Volume 2 (3-0001-240-IHY-00-RP-0004): This volume provides supplementary flood mapping information for additional events not presented in this report; and
- Critical State Significant Infrastructure, Inland Rail – Parkes to Narromine Conditions of Approval, NSW Department of Planning & Environment, June 2018: This document (referred to as ‘CoA’ throughout this report) provides the Minister’s conditions of approval for the project and includes requirements for management of flood risks associated with the project. Conditions E21 to E25 relate to flooding and are specifically relevant to this Flood Study Report.

1.5 Status of Report

The report is currently at IFC Detailed Design stage. This report has addressed, where appropriate, all significant comments received from ARTC and the TA on the 100% Detailed Design Flood Study Report.

Any future design updates or changes affecting flooding will be documented in an addendum to this report that will present key findings and selected results that are affected by the updates / changes.

1.6 Updates Since Last Revision

Revision 0 of this report was submitted in December 2018 to reflect the IFC design at that time.

Revision 1 of this report was prepared in May 2019 to incorporate changes to some cross drainage culvert sizes to facilitate procurement and future maintenance of the cross drainage infrastructure.

Revision 2 of this report was prepared in July 2019 to address ARTC comments on Revision 1. These comments required further information be included in the report on compliance of the design with the CoA.

2 Project Description and Study Area

2.1 Project Description

The project consists of approximately 98.5km of upgraded rail track, 5.6km of new rail track and associated infrastructure and is generally located along the existing rail corridor between the towns of Parkes and Narromine, via the town of Peak Hill. A new connection to the Broken Hill line is proposed outside the existing rail corridor at the southern end of the project near Parkes. The section of the proposed Inland Rail corridor between Parkes and Narromine is located within the major catchments of the Lachlan River Basin and the Macquarie-Bogan River Basin.

2.2 Study Area

2.2.1 Catchment Overview

While the corridor lies within these two major river catchments, it does not directly cross a major river or tributary but instead the following minor (and predominantly ephemeral) watercourses and their tributaries, that feed into the larger, regional scale rivers:

- Lachlan River Catchment:
  - Headwaters of Ridgey Creek;
- Bogan River Catchment:
  - Headwaters of Cookopie Creek;
  - Burrill Creek;
  - Hallinans Creek;
  - Stanfords Creek;
  - Ten Mile Creek;
  - Barrabadeen Creek;
  - Bulldog Creek;
  - Gundong Creek;
  - Tomingley Creek;
  - Bradys Cowal; and
- Macquarie River Catchment:
  - Yellow Creek.

Beyond the rail corridor, the project area and surrounding land is mostly cleared for agricultural purposes, particularly cotton, wheat and livestock. Small pockets of uncleared native vegetation have been retained in the form of National Park or State Forest, within the contributing catchments. Other small and localised pockets of urban areas are centred around the regional townships of Parkes, Peak Hill and Narromine, with the occasional mine and quarry, within the contributing catchments. Areas with these land use types are generally well cleared.

Further information on the study area, can be found in the Environmental Impact Statement (EIS) Technical Report 6: Hydrology and Flooding Assessment (GHD, 2017).

2.2.2 Study Area Breakdown

For the purpose of this flood study, the project has been broken into five portions:

- Lachlan River Catchment:
  - Covered by the hydraulic model LAC01 from 449.2km to 464.0km;
- Bogan River Catchment: Covered by the following three separate hydraulic models:
  - BOG01 from 464.0km to 485.0km;
  - BOG03 from 485.0km to 505.8km;
  - BOG05 from 505.8km to 540.88km; and
- Macquarie River Catchment:
  - Covered by the hydraulic model MAC01 from 540.7km to 547.55km. It should be noted that the northern extent of the project is outside the regional influence of the Macquarie River which extends to the Backwater Cowal system at 552km, approximately 5km north of the P2N rail corridor.

Refer to Figure 2.1 and Figure 2.2 below, for details of the study area breakdown.

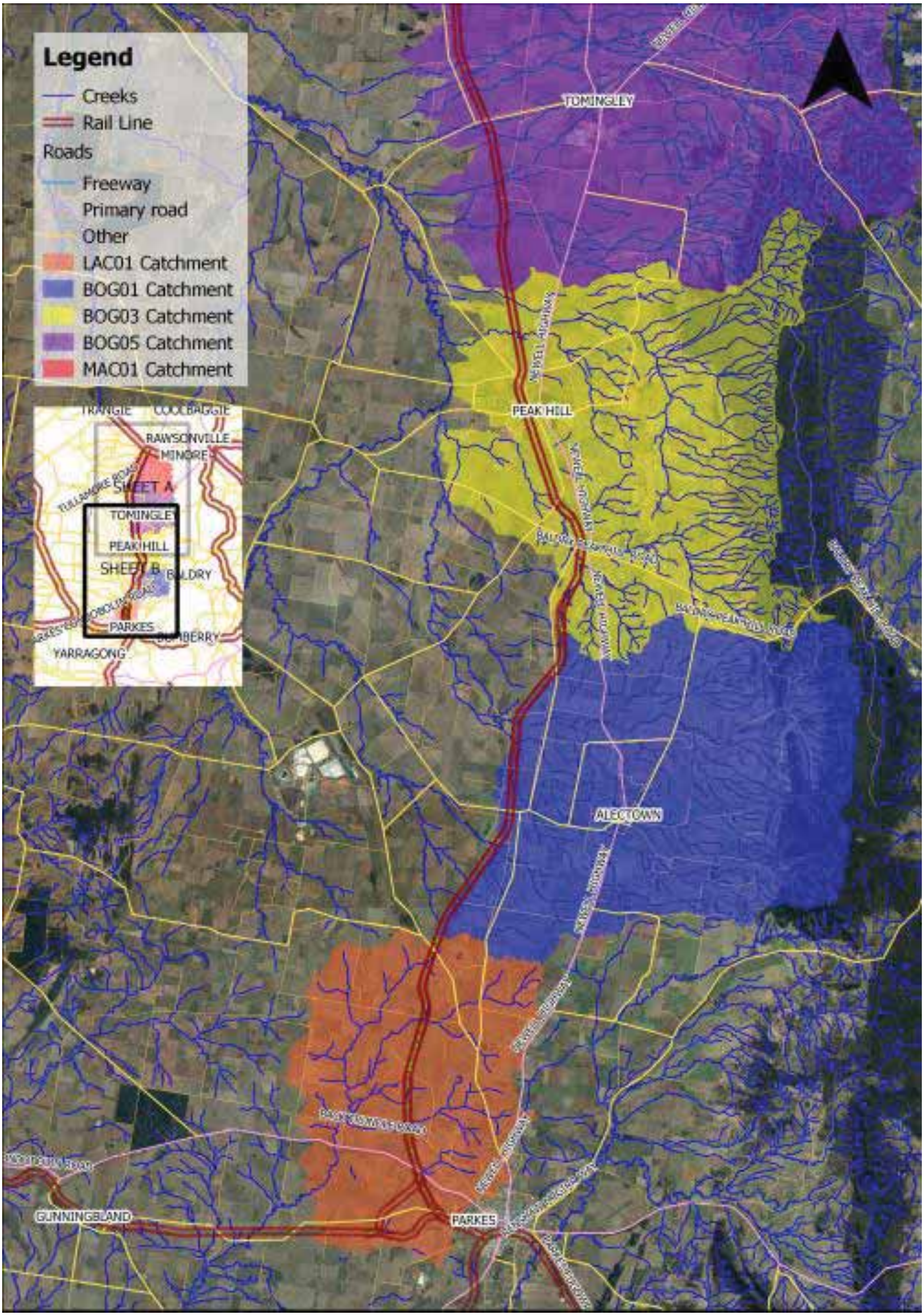


Figure 2.1 P2N Study area breakdown: LAC01, BOG01 and BOG03 hydraulic model extents

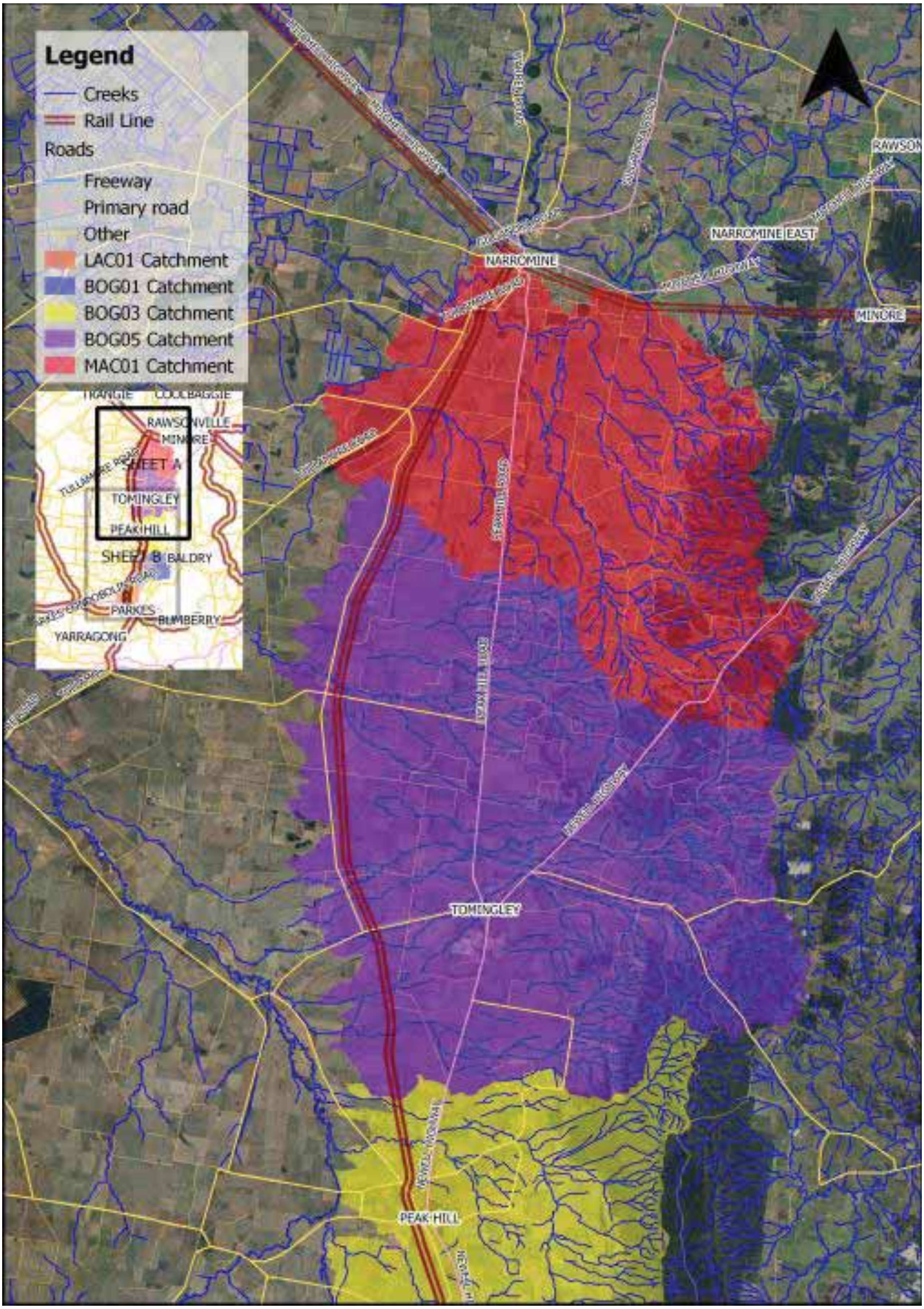


Figure 2.2 P2N Study area breakdown: BOG05 and MAC01 hydraulic model extents

2.2.3 Catchment Descriptions

The project area is located within the Lachlan, Bogan and Macquarie River catchments. The project area is located outside of the regional floodplains of the Lachlan and Macquarie Rivers and crosses local upland catchments of the Lachlan, Bogan and Macquarie River systems.

2.2.3.1 Lachlan River Local Catchments

At the southern end of the project, there is no direct interaction with the Lachlan River regional floodplain and the project is not impacted by regional scale flooding. The rail alignment is located within the upper portion of the Lachlan River catchment. The rail in this location generally runs in a northern direction from Parkes towards Bogan Road, Goonumbla. Most of the alignment in this section is a brownfield site upgrade of the existing rail; however, this section also includes the North-West Connection greenfield sub-section that connects the main alignment at approximately 452.32km to the Orange – Broken Hill Line, west of Parkes.

The flood behaviour in this area is predominantly local overland flow, with majority of the upstream catchments taken up by farmland. The urban area of Parkes generally drains in a southerly direction east of the project area. The flood immunity for the existing rail formation within the LAC01 hydraulic model area is estimated to be less than the 10% AEP event in some localised low points and greater than the 1% AEP event in other areas, where shallow overland flow is the predominant flood behaviour.

2.2.3.2 Bogan River Local Catchments

The rail alignment is located within the upper portions of the Bogan River catchment and crosses the tributaries of the Bogan for approximately 75km of the alignment. The rail generally runs in a north-south direction, passing near Peak Hill and near the Newell Highway. The design rail alignment within the Bogan River Catchment is predominantly a brownfield development with no significant deviations from the existing rail alignment.

The flood behaviour in this area is predominantly local overland flow, with majority of the upstream catchments taken up by farmland. Peak Hill is the only major urban area in the catchment upstream of the rail alignment. The flood immunity of the existing rail formation within the Bogan River catchment ranges from less than the 10% AEP event in some areas and to greater than the 1% AEP event in other areas.

2.2.3.3 Macquarie River Local Catchments

The rail alignment in this location generally runs in a north-easterly direction towards Narromine, with the northern extent of the project located approximately 7.5km south of Narromine. The project is outside the regional Macquarie River floodplain and therefore not impacted by regional scale flooding in this catchment.

The flood behaviour in this area is predominantly local overland flow, with majority of the upstream catchments taken up by farmland. As for the other sections of the project, the flood immunity of the existing rail formation ranges from less than the 10% AEP event to greater than the 1% AEP event.

2.3 Previous Studies and Data

Refer to the Hydrological and Hydraulic Investigation Plan (HHIP) (3-0001-240-IHY-00-PL-0001) and the Hydrological Calibration Report (3-0001-240-IHY-00-RP-0001) for details of the previous studies and data that was used to inform this flood study.

3 Design Criteria, Assumptions and Inputs

3.1 Design Criteria

The design has been undertaken in accordance with ARTC Basis of Design (BoD) and RAATM for the Inland Rail Program. A summary of the key design requirements with respect to flooding are documented in this section.

3.1.1 Flood Management Objectives

The HHIP proposed a set of Flood Management Objectives (FMOs), or impact criteria, for the following parameters:

- Flood level change (afflux);
- Flood velocity change;
- Flood duration change; and
- Flood hazard change.

These FMOs were reviewed against flood impact criteria contained within the CoA received from the DPE in June 2018 and were found to be generally consistent. A key objective of the design is to meet the FMOs at most locations and, where the FMOs are not met and cannot be achieved at a reasonable cost, these will be proposed as non-compliances for approval by ARTC, DPE and the affected landowners, provided the non-compliances can be demonstrated to have no significant impact on the use of the land.

The following sections define the FMOs in detail. The HHIP also provided FMOs for flood hazard; however, as the hazard classification throughout the project area is predominantly low due to low depths and velocities within the local catchment floodplains, this parameter is not a key consideration for design and impact assessment.

3.1.1.1 Flood Management Objectives for Afflux

The FMOs for afflux proposed in the HHIP were as set out in Table 3-1 below.

Table 3-1 Flood management objectives for afflux

Land use	Maximum allowable afflux
Residential and commercial buildings	50mm (10mm limit for above floor level flooding)
Cropping paddocks	200mm
Stock paddocks	200mm
Newell Highway	50mm
Other roads	100mm
Public infrastructure (pump stations, sewage treatment plants, health services etc.)	50mm (10mm limit for above floor level flooding)

These are consistent with the CoA, which state the following:

E22 The CSSI must be designed with the objective of not exceeding, by reason of the SSI, the following flooding characteristics on adjacent lands / properties during any flood event up to the 100 year ARI:

(a) a maximum increase in inundation time of five per cent for houses, commercial premises and urban areas and 10 per cent for roads, agricultural (grazing and cropping) areas and public infrastructure (e.g. water and sewage pump stations and sewage treatment plants);
(b) a maximum increase of 10 mm in inundation at properties where floor levels are currently exceeded;
(c) a maximum increase in 50 mm in inundation at properties where floor levels are currently not exceeded;
(d) no inundation of floor levels which are currently not inundated;
(e) a maximum increase of 50 mm along the Newell Highway and 100 mm on all other roads; and
(f) a maximum increase of 200 mm on agricultural areas.

Figure 3.1 Excerpt from the Conditions of Approval

3.1.1.2 Flood Management Objectives (FMOs) for Velocity Change

The FMOs for flood velocity proposed in the HHIP were as set out in Table 3-2 below.

Table 3-2 Flood management objectives for flood velocity

General criteria	Applicable land uses and other specific criteria
Velocities to remain below 1.0m/s where currently below this figure and an increase on no more than 20% where existing velocities are above 1.0m/s	Residential and commercial buildings – no change to the flood hazard regime
	Cropping paddocks
	Stock paddocks
	Newell Highway – no change to the flood hazard regime
	Other roads – no change to the flood hazard regime
	Public infrastructure (pump stations, sewage treatment plants, health services etc.)

These are consistent with the CoA provided by DPE, which states the following.

E29 Replacement culverts must be designed with the objective that the exit flow velocity is no greater than the exit flow velocity through the existing culvert. Where this cannot be achieved due to engineering considerations, a higher exit flow velocity is permitted provided that it does not result in impacts on soil structure or condition, or cause scouring and erosion either outside the rail corridor, or beyond the area of scour protection works where an adjacent landowner has agreed to the installation of such works on their property in accordance with **Condition E32.**

Where areas outside of the rail corridor currently show scour or erosion and this is directly attributable to a culvert that is to be replaced, mitigation measures be implemented to ensure stable downstream conditions, and further scouring or erosion resulting from flows exiting the replacement culvert are mitigated.

E30 Where it is proposed to construct new culverts along the length of the CSSI, the new culverts must be designed with the objective that:

(a) flows through the new culvert must not increase the downstream lateral flood extent by more than five percent for each magnitude flood event; and
(b) flow velocities exiting the rail corridor must not exceed velocities that will result in impacts on soil structure or condition, or cause scouring and erosion outside the rail corridor, or beyond scour protection works where an adjacent landowner has agreed to the installation of such works on their property in accordance with **Condition E32**; and
(c) if existing flow velocities at the boundary of the rail corridor are less that one metre per second, then design flow velocities must not exceed one metre per second, and where they are greater than one metre per second, then they must not increase by more than 20 percent.

Figure 3.2 Excerpt from the Conditions of Approval

3.1.1.3 Flood Management Objectives for Duration Change

The FMOs for flood duration proposed in the HHIP were as set out in Table 3-3 below.

Table 3-3 Flood management objectives for flood duration

Design criteria	Applicable land uses
Total flood duration to remain less than 6 hours where currently less than this figure; and an increase of no more than 10% in flood duration where existing flooded durations are above 6 hours	Residential and commercial buildings – No increase in above floor flooded duration.
	Newell Highway
	Public infrastructure (pump stations, sewage treatment plants, health services etc.)
Total flood duration to remain less than 12 hours where currently less than this figure; and an increase of no more than 10% in flood duration where existing flooded durations are above 12 hours.	Cropping paddocks
	Stock paddocks
No more than a 10% increase in flood duration	Other roads

These are similar to the CoA, which states the following.

E22 The CSSI must be designed with the objective of not exceeding, by reason of the SSI, the following flooding characteristics on adjacent lands / properties during any flood event up to the 100 year ARI:

(a) a maximum increase in inundation time of five per cent for houses, commercial premises and urban areas and 10 per cent for roads, agricultural (grazing and cropping) areas and public infrastructure (e.g. water and sewage pump stations and sewage treatment plants);
(b) a maximum increase of 10 mm in inundation at properties where floor levels are currently exceeded;
(c) a maximum increase in 50 mm in inundation at properties where floor levels are currently not exceeded;
(d) no inundation of floor levels which are currently not inundated;
(e) a maximum increase of 50 mm along the Newell Highway and 100 mm on all other roads; and
(f) a maximum increase of 200 mm on agricultural areas.

Figure 3.3 Excerpt from the Conditions of Approval

It is noted that the CoA introduced a more stringent limit of no greater than a 5% increase in flood duration for houses, commercial premises and urban areas.

3.1.2 Project Specific Criteria and General Guidelines and Standards

A RAATM has been compiled against the various requirements of the project and incorporates the specific BoD developed for the project. The BoD and RAATM contain the primary design criteria and objectives for the flooding analysis and cross drainage design.

In addition to the RAATM, the design has also been developed based on the following guidelines and standards:

- 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;
- Australian Rainfall and Runoff 2016 (ARR2016); and
- Austroads Guide to Road Design, Part 5: Drainage – General and Hydrology Considerations, Austroads 2013.

The RAATM and BoD also provide impact criteria for afflux and flood velocity. These are generally consistent with the FMOs discussed in the previous section and are described in the following sections.

3.1.2.1 RAATM Requirements for Afflux

The RAATM provides the following key requirements for afflux:

- Where there are existing flood prone buildings (habitable and non-habitable), the afflux should be close to zero, with an afflux of 0.01 metre allowed above floor levels of existing buildings;
- The allowable afflux for neighbouring infrastructure such as roads, should generally also be no more than 0.01 metre unless specific permission is obtained; and
- In other land use areas, the allowable afflux should be determined based on specific assessments, with a higher afflux possible in certain situations.

3.1.2.2 RAATM Requirements for Flood Velocity

The RAATM provides the following key requirements for flood velocity:

- In the absence of soil data, the outlet velocity for all culverts should be less than 2.5m/s;
- The design should attempt to maintain a safe flow velocity through the structures from local soil test and environmental assessments; and
- Where soil data is not available, and the flow velocity is higher than 2.5m/s at the culvert or bridge outlet velocities, appropriate scour protection must be designed.

3.1.3 ARTC Flooding Multi Criteria Analysis

The ARTC MCA process, as defined in the ARTC document *Flood Risk Assessment Procedure – Upgraded Sections of Inland Rail* is a key input to the design. This process aims to provide a continuous assessment of flood risk along the project corridor and use this assessment to identify a variable minimum required Top of Formation (TOF) flood immunity and concept drainage sizing. The process is described further in Section 4.5.

3.2 Assumptions

The following key assumptions were made for the IFC Detailed Design:

- The EIS, site investigation photos and existing bridge drawings have been used to supplement any missing information/ discrepancies in the detailed ground survey relating to existing structures (bridges and culverts) within the project extents;
- The formation is to have 1% AEP flood immunity, except in areas nominated for a lesser standard of immunity identified from ARTC's MCA process;
- The project works are to meet the FMOs and RAATM requirements described above in Section 3.1;
- Reinforced concrete box culverts (RCBCs) have been used in preference to bridge structures for larger waterway crossings; and
- Blockage factors have been applied to structures in accordance with the latest guidelines in Australian Rainfall & Runoff 2016 (ARR2016).

3.3 Inputs

The IFC Detailed Design has been based on the following site investigations and base information:

- Light Detection and Ranging (LiDAR) provided by ARTC supplemented by detailed ground surveys prepared by Bennett and Bennet on behalf of Inland Rail Design Joint Venture (WSP Australia | Mott MacDonald Design Joint Venture trading as (IRDJV));
- Previous site investigation data provided by ARTC; and
- Site assessments completed for culverts and bridges.

4 Methodology

4.1 Hydrology

Hydrological models have been used to simulate rainfall generation and flow routing through the catchments upstream of the alignment. The hydrological modelling has provided critical runoff hydrographs for input into the five hydraulic models covering the project area.

A brief overview of the process involved in establishing the hydrological models for the project, is as follows:

- Develop a surface elevation model and identify broad hydrological catchment divides;
- Delineate the sub-catchments to an appropriate level of detail for hydrological estimation and hydraulic design;
- Use the catchment delineations and aerial photos to define the hydrological sub-catchment nodes in a hydrological model;
- Build and calibrate the hydrological model to available streamflow gauge data;
- Use the calibrated hydrological model to estimate design flows for a range of events at the gauges and compare these to Flood Frequency Analysis (FFA) and Regional Flood Frequency Estimation (RFFE) method flow estimates at the gauges, to confirm that the model produces credible design peak flow estimates; and
- Run design rainfall events in the calibrated hydrological model to develop design flows at each cross drainage location.

4.1.1 Model Construction

The hydrological models were constructed in the DRAINS modelling software using RAFTS storage routing methodology, with the kinematic wave method. The project area was divided into five sections, each of which was modelled as a separate DRAINS model.

Refer to Appendix A1 for schematics of the DRAINS models.

4.1.2 Catchment and Climate Parameters and Characteristics

4.1.2.1 Topography and Survey Data

The following topographic datasets were used to generate a surface elevation model representing the study area:

- LiDAR survey (2015) – 0.2m resolution covering approximately a 10km wide strip along the project corridor;
- LiDAR survey (2017) – 0.2m resolution covering approximately a 1km wide strip along the project corridor;
- Site survey – survey of local features and structures; and
- Shuttle Radar Topographic Mission (SRTM) data – elevation grid data with 30m resolution – adopted to supplement the surface model outside of the LiDAR extent. This relatively coarse dataset was used for hydrological model catchment delineation only and not for hydraulic model topographic input data.

The LiDAR to ground survey comparison report (3-0001-240-ESV-00-RP-0003) documents the comparison of the high-resolution LiDAR acquired for the project corridor in 2017 with ground survey. This report demonstrates the LiDAR to have sufficient agreement with the ground survey to allow for combination of the datasets for the purposes of detailed design.

Catchment delineation and physical parameters for hydrological modelling, such as slope, were determined based on the combined surface elevation model generated from the LiDAR survey (2015) and the Shuttle Radar Topographic Mission (SRTM) elevation model.

4.1.2.2 Rainfall Depths and Temporal Patterns

The design rainfall was specified as per the ARR 2016 design guidelines (Chapter 3, Book 2, ARR 2016). Rainfall depths for the range of design storms, were generated from the Bureau of Meteorology 2016 Intensity-Frequency-Duration (IFD) dataset and applied to temporal patterns sourced from the ARR 2016 datahub. The data was extracted for each of the five hydrological models separately, giving area specific rainfall parameters for each of the sections.

Pre-burst rainfall was generated from the ARR 2016 datahub for each section and applied to the hydrological models.

4.1.2.3 Catchment Loss and Storage Factors

Section specific rainfall losses were generated from the ARR 2016 datahub website, for the sections of the project area. The rainfall losses generated from the ARR 2016 datahub were calibrated against historical rainfall and gauged flows in accordance with the ARR 2016 guidelines (Chapter 3, Book 5, ARR 2016). During this process, a BX factor was selected in line with the historical data calibration. Refer to Table 4-1 for adopted loss factors and refer to the Hydrological Model Calibration Report (3-0001-240-IHY-00-RP-0001) for details of the calibration process.

Table 4-1 Catchment loss and storage factors used in the hydrological models

Hydrological model	Initial Loss (mm)	Continuing Loss (mm/h)	BX Factor
LAC01(1)	25	1.0	0.5
BOG01(2)	25	1.4	0.7
BOG03	28	0.6	0.7
BOG05	26	0.4	0.7
MACQ01	27	0.6	0.7

Note:

(1) LAC01 model calibrated to flow gauge 412138

(2) BOG01 model calibrated to flow gauges 50119 and 421076

4.1.2.4 Areal Reduction Factor

An Areal Reduction Factor (ARF) is a reduction factor applied to rainfall depth in larger catchments to allow for the fact that larger catchments are less likely to experience the high intensity rainfall depth, estimated at a point location, simultaneously across the entire area as per ARR 2016 design guidelines (Chapter 4, Book 2, ARR 2016).

The ARR 2016 guideline estimates the ARF factor to the point of interest (e.g. to an individual cross drainage structure) with the factor varying based on AEP, storm duration and catchment area. ARR 2016 also states that "*There has been limited research on ARF applicable to catchments that are less than 10 km^2. The recommended procedure is to adopt an ARF of unity for catchments that are less than 1 km^2, with an interpolation to the empirically derived equations for catchments that are between 1 and 10 km^2*".

The application of a unique ARF per catchment / AEP / area combination was not readily applicable in the DRAINS software adopted for this project and the approach implemented and described below is a slight simplification of the guidance.

ARF Estimation Process for P2N Hydrology

- Catchment area <1km^2 – no ARF applied consistent with ARR 2016 advice;
- Catchment area between 1km^2 and 10km^2 – no ARF applied, based on the following:
  - ARR advice is to calculate the ARF for a 10km^2 catchment and then factor using a second equation based on the catchment area;
  - Figure 4.1 demonstrates the range of ARF for catchments <10km^2. For more frequent AEP, the ARF range trends towards 1. For expected catchment area vs duration combinations (i.e. lower critical duration and smaller area, higher critical duration to larger area) – the values trend towards > 0.95;
  - This suggests that the ARF factor, is in the region of 5% reduction of rainfall depth for most catchments <10km^2; and
  - Given the uncertainty and minor influence on the design, no ARF has been applied to catchments less than 10km^2.

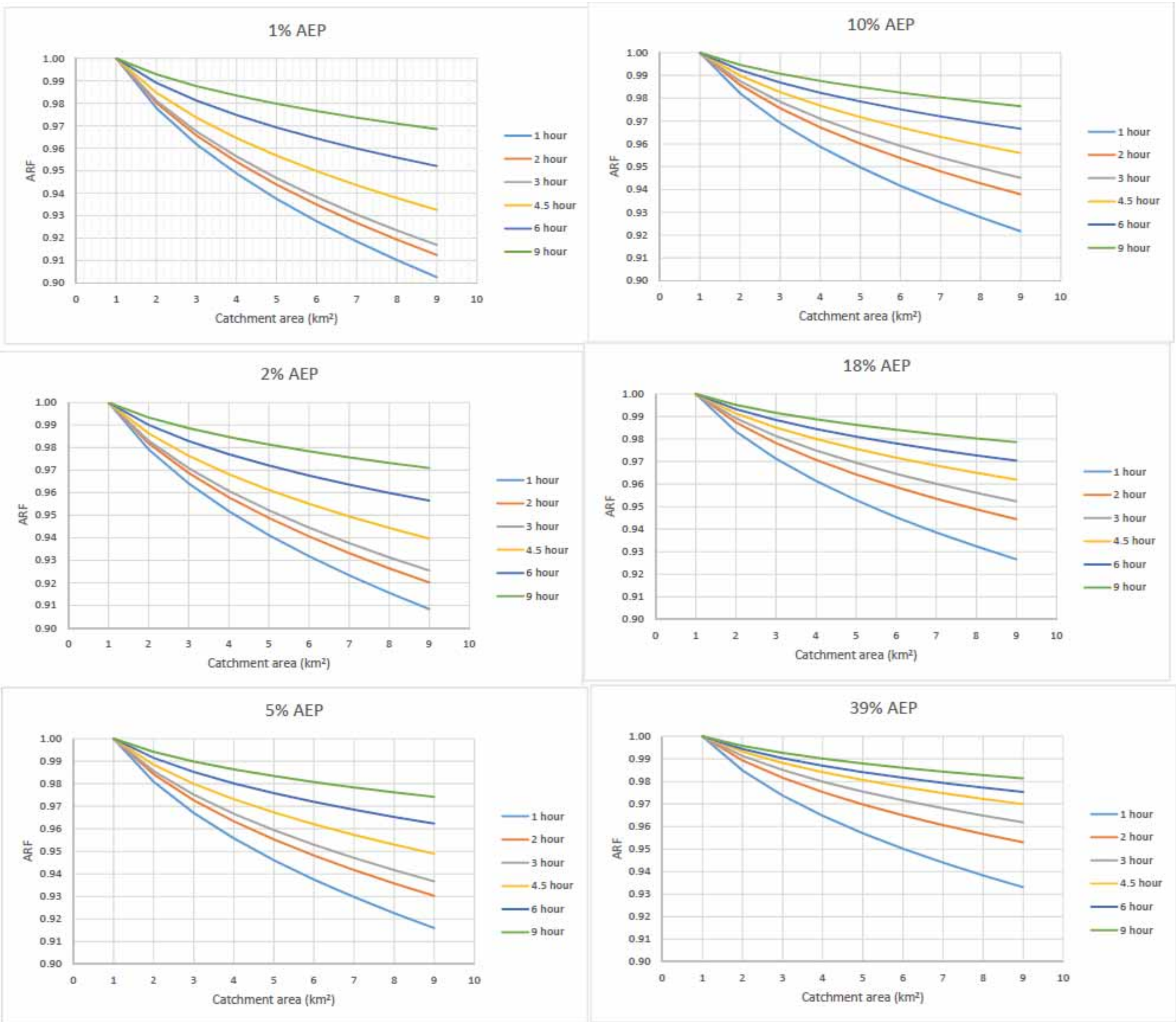


Figure 4.1 ARF range for P2N catchment area < 10km^2

- Catchments >10km^2 and <1000km^2 – adopt a single ARF per AEP event, based on the maximum value from a subset range of 5 most likely critical durations, as per the process outlined below:
  - Process is limited to the largest catchments in the study and therefore those most impacted by ARF (19 in total);

- Estimate an ARF per AEP event for these catchments only;
- Estimate critical duration for catchment based on a Probabilistic Rational Method time of concentration method factored by 2. It is acknowledged that the Rational Method approach is no longer recommended in ARR 2016. The Tc calculation has been used to provide a starting point for the method and is similar to the assumptions on critical duration made in the ARR Revision Project 5 (ARR Project 5 Regional Flood Methods Stage 3 Report, 2015);
- Estimate the ARF for this duration and for the nearest 4 storm event durations (2 longer and 2 shorter - 5 in total); and
- Assume the highest ARF from this sub-set for each AEP – result is a slight overestimation of rainfall depths. Given the uncertainty limits of other parameters such as losses, this overestimation is not thought to be significant.

Table 4-2 demonstrates the range of catchment areas in the P2N project area and a summary of where ARF have been applied.

Table 4-2 Summary of ARF methodology

Catchment Area	Estimated ARF range	ARF adopted
<1km^2	1	1
1km^2 - 10km^2	0.9 - 1	1
>10km^2	0.7 - 1	Assessed per catchment

Table 4-3 provides a summary of the ARF adopted in the hydrology at each catchment location with an area greater than 10km^2 and for each AEP event.

Table 4-3 Summary of ARF adopted for catchments >10km^2

Catchment	Area (km^2)	1% AEP	2% AEP	5% AEP	10% AEP
455.228	20.41	0.95	0.96	0.96	0.96
461.15	33.61	0.95	0.95	0.95	0.96
468.565	12.66	0.96	0.96	0.97	0.97
472.03	18.90	0.95	0.96	0.96	0.96
478.262	30.03	0.95	0.95	0.96	0.96
479.3	245.04	0.92	0.92	0.93	0.93
489.844	25.34	0.95	0.95	0.95	0.96
490.553	55.51	0.93	0.93	0.94	0.94
491.834	10.55	0.97	0.97	0.97	0.97
503.599	168.10	0.89	0.90	0.90	0.91
509.64	81.37	0.92	0.92	0.93	0.93
512.108	134.51	0.90	0.90	0.91	0.92
519.224	94.14	0.91	0.92	0.92	0.93
528.371	80.91	0.92	0.92	0.93	0.93

Catchment	Area (km^2)	1% AEP	2% AEP	5% AEP	10% AEP
529.768	60.18	0.93	0.93	0.93	0.94
531.906	25.90	0.95	0.95	0.95	0.96
533.611	34.54	0.94	0.94	0.95	0.95
546.542	50.12	0.93	0.93	0.94	0.94
552.631	279.17	0.87	0.88	0.88	0.89

4.1.3 Calibration

A detailed calibration of the hydrological parameters and models has been undertaken and this process is documented in detail in the Hydrological Model Calibration Report (3-0001-240-IHY-00-RP-0001).

4.1.4 Design Event Modelling

Table 4-4 provides the list of design events required for simulation.

Table 4-4 Hydrological design events

Design event	Approximate equivalent Average Recurrence Interval (ARI)	Purpose of event analysis
39% AEP	2.5 year ARI	Low order event for impact assessment
18% AEP	5 year ARI	Low order event for impact assessment
10% AEP	10 year ARI	Medium event for flood impact assessment and potential lower standard adopted for hydraulic design
5% AEP	20 year ARI	Medium event for flood impact assessment and potential lower standard adopted for hydraulic design
2% AEP	50 year ARI	Medium event for flood impact assessment and potential lower standard adopted for hydraulic design
1% AEP	100 year ARI	Typical standard for hydraulic design
1% AEP with climate change	100 year ARI with climate change	Climate change scenario simulated to inform the project sustainability assessment
0.05% AEP	2000 year ARI	Extreme event for impact assessment

The hydrological modelling has been undertaken using the ensemble method of flow estimation, as detailed within the ARR 2016 design guidelines (Chapter 3, Book 4, ARR 2016) and shown in Figure 4.2. Each flood event (AEP) was run for a range of standard durations and for an ensemble of 10 temporal patterns within each duration. Results were extracted for the critical flow at each culvert crossing separately and the median of these flows was selected as the design flow for each AEP event.

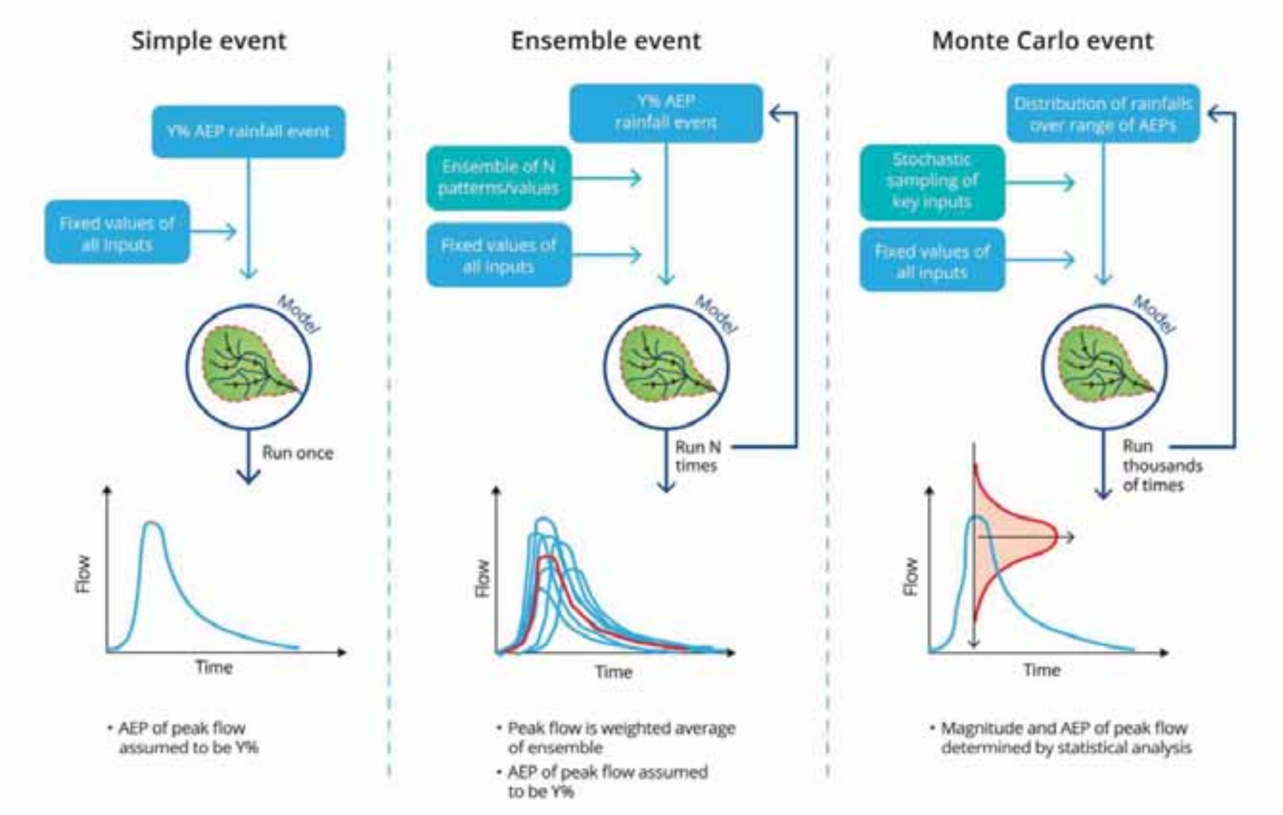


Figure 4.2 ARR 2016 approaches to estimation of peak flow

Source: ARR design guidelines Book 4 Chapter 3 (ARR 2016) http://book.arr.org.au.s3-website-ap-southeast-2.amazonaws.com/

An example of the results generated per catchment in the hydrological models is provided in Figure 4.3. The model indicates that the largest median flow from the ensemble of events is the 12-hour duration Temporal Pattern 1 highlighted in red. This event has then been adopted as the critical event for this catchment for the design and the associated hydrograph applied in the hydraulic model.

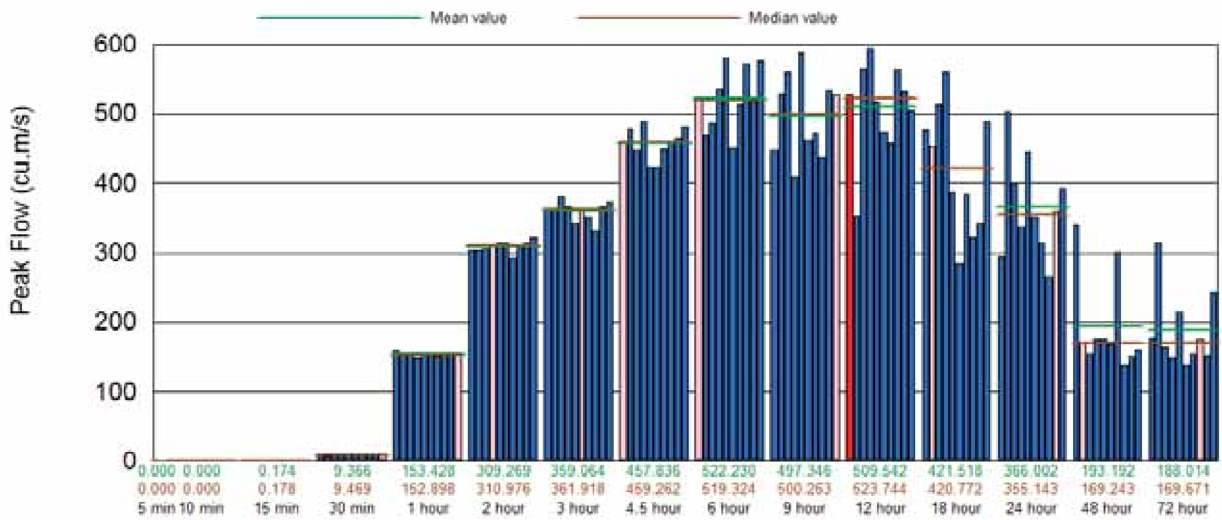


Figure 4.3 Median flow results for the 1% AEP event from a sample catchment (479.3km)

A summary of the critical duration and temporal pattern storm combination generating the median flow at each cross drainage location is provided in Table 4-5.

Table 4-5 Catchment critical duration and temporal pattern combination

Catchment ID	1% AEP		2% AEP		5% AEP		10% AEP	
	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern
449.765	1.5	1	1.5	1	2	1	2	5
449.852	1.5	1	1.5	1	2	1	1.5	7
451.332	3	1	3	1	2	1	3	1
452.721	3	10	3	9	3	9	6	6
453.405	3	9	3	9	12	9	6	6
453.642	2	8	2	6	2	6	3	5
454.353	2	6	2	5	2	5	3	5
454.844	2	8	3	9	3	9	3	2
455.228	6	2	6	7	9	7	6	6
457.486	1	1	2	6	2	6	3	2
456.184	3	1	3	9	3	9	6	7
458.323	3	8	2	7	2	7	3	4
458.648	2	3	1	5	2	5	3	1
460.127	2	6	2	6	2	6	3	5
460.698 & 461.157	6	7	6	3	6	3	1	2
464.694	3	9	3	9	3	9	6	6
466.824	3	6	3	6	3	8	9	4
468.176	3	9	3	6	3	6	9	9
468.366	4.5	1	9	10	9	8	9	3
469.524	3	9	4.5	8	4.5	5	6	5
470.467	2	5	3	9	4.5	5	6	5
472.03	4.5	1	4.5	8	9	8	9	3
473.905	4.5	8	4.5	9	4.5	6	9	4
476.771	4.5	8	4.5	8	9	4	9	3
477.703	4.5	9	4.5	8	9	4	9	1
478.262	6	1	9	10	9	8	12	5
478.796	4.5	8	4.5	1	9	4	9	3

Catchment ID	1% AEP		2% AEP		5% AEP		10% AEP	
	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern
479.3	12	1	12	9	12	7	12	1
480.35	4.5	9	9	10	9	3	12	7
481.921	3	6	4.5	9	9	4	9	1
482.824	2	4	3	6	3	6	3	7
482.947	2	8	2	4	2	1	3	4
483.549	2	5	2	5	3	8	6	7
483.94	2	5	4.5	1	3	8	6	7
484.581	2	4	2	5	2	6	3	9
484.829	2	4	2	5	2	6	3	9
487.96	3	6	3	6	3	1	9	9
488.694	3	9	4.5	8	4.5	5	6	7
488.908	2	4	2	7	2	1	3	4
489.844	4.5	1	9	10	9	3	12	5
490.553	9	2	9	2	12	7	12	7
491.834	4.5	1	4.5	1	9	8	9	9
492.947	4.5	9	4.5	9	9	4	9	9
493.293	2	4	2	4	1	7	6	3
493.749	2	8	2	8	2	6	3	4
494.815	4.5	1	4.5	8	9	4	9	3
495.535	4.5	8	4.5	9	4.5	6	9	3
496.067	2	5	2	8	3	6	6	3
496.885	4.5	8	9	10	9	8	9	9
497.613	2	4	2	5	2	6	3	4
497.78	2	4	1	7	2	1	2	1
498.061	2	7	2	4	2	6	2	6
498.625	2	4	2	4	2	6	3	9
498.87	4.5	2	4.5	2	9	1	6	4
499.545	4.5	1	4.5	2	6	5	6	4
499.577	9	10	9	10	12	5	12	5
500.138	9	10	9	10	12	5	12	5

Catchment ID	1% AEP		2% AEP		5% AEP		10% AEP	
	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern
500.482	9	10	9	10	12	5	12	9
500.558	9	2	9	2	9	3	12	9
500.663	9	2	9	2	12	1	12	5
501.167	9	2	9	2	9	8	12	7
502.456	9	2	9	2	12	7	12	1
502.974	9	2	9	10	12	7	12	7
503.599	9	2	9	2	12	7	12	7
503.72	4.5	8	4.5	8	9	3	9	9
504.707	9	10	9	10	9	8	12	7
504.798	4.5	8	4.5	8	6	8	9	9
505.502	9	10	18	2	12	7	12	7
506.676	3	9	4.5	8	4.5	6	9	9
506.799	2	8	3	9	3	8	3	8
507.025	3	9	3	9	3	8	6	8
508.164	4.5	9	4.5	9	9	4	9	3
509.64	12	10	18	2	12	7	12	7
510.815	9	10	9	10	6	8	9	3
512.108	12	10	12	9	12	10	12	10
513.671	4.5	9	9	10	9	8	9	3
514.218	4.5	8	6	7	9	8	9	3
515.001	9	10	9	10	12	7	12	7
515.084	4.5	8	4.5	9	9	4	9	3
515.601	9	10	9	10	9	8	12	7
516.313	9	10	9	10	12	7	12	5
516.484	4.5	8	4.5	8	6	8	9	4
516.98	9	10	9	10	12	7	12	7
517.428	9	10	9	10	12	7	12	7
518.556	9	10	9	10	12	7	12	7
519.224	18	2	18	2	12	10	24	9
520.339	9	10	9	10	12	7	12	7

Catchment ID	1% AEP		2% AEP		5% AEP		10% AEP	
	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern
521.918	4.5	1	9	10	9	8	9	3
523.223	9	10	9	10	12	7	12	7
524.18	9	10	9	10	12	7	12	7
524.984	9	10	9	10	12	7	12	7
525.984	9	10	9	2	9	5	12	7
528.371	12	10	12	9	12	10	12	7
528.668	4.5	1	4.5	8	9	1	9	1
528.741	2	5	2	5	3	8	3	6
529.274	9	10	9	10	12	7	12	7
529.768	12	10	18	2	12	7	12	7
530.705	9	10	9	10	12	7	12	7
531.132	9	10	9	10	12	5	12	5
531.543	4.5	1	4.5	1	9	8	9	3
531.757	4.5	9	4.5	9	9	4	9	3
531.906	12	10	12	10	12	7	12	7
532.351	6	4	9	10	9	8	12	7
533.149	9	10	18	2	12	7	12	7
533.611	12	10	18	2	12	7	12	7
534.776	9	10	9	10	12	7	12	7
535.106	9	10	9	10	9	8	12	7
536.243	9	10	9	10	12	7	12	7
536.539	4.5	1	4.5	1	9	8	9	3
536.891	2	5	2	5	3	8	3	6
537.571	9	10	9	10	9	8	12	7
537.993	3	9	3	9	4.5	6	6	8
538.563	2	5	2	5	3	8	3	9
539.013	2	8	3	9	3	6	6	8
539.707	4.5	8	4.5	9	4.5	5	9	4
542.605	9	2	9	2	12	7	12	7
543.766	4.5	8	9	10	9	8	9	3

Catchment ID	1% AEP		2% AEP		5% AEP		10% AEP	
	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern	Critical Duration (hrs)	Temporal Pattern
544.452	3	9	3	9	3	8	6	8
545.968	9	10	9	10	9	8	9	8
546.542	9	10	12	1	12	7	12	7
547.282	9	2	9	2	12	7	12	7
547.559	9	10	9	10	12	7	12	7
547.739	9	2	9	2	9	8	9	8
547.841	4.5	8	4.5	8	9	8	9	3
548.064	9	10	9	10	12	5	12	5
548.581	4.5	9	4.5	9	9	8	9	3
549.027	4.5	8	4.5	8	9	4	9	3
549.09	9	10	9	10	12	7	12	7
550.835	9	5	12	10	12	5	12	5
551.146	12	1	12	1	12	6	12	5
551.571	9	10	12	1	12	7	12	7
552.631	12	9	12	10	12	7	12	5
554.243	12	1	12	10	12	6	12	7

At several locations, equivalent storms that were similar in duration and magnitude to the median flow critical storm were adopted to reduce the number of unique duration / storm event iterations, required to be run in the hydraulic model.

Table G1 in Appendix F provides a table of design flows generated by the hydrological models at each rail cross drainage sub-catchment location for existing conditions. This information was provided with the Hydrological Calibration Report and is repeated here for ease of reference. The table compares the peak flow estimates generated by the RAFTS design models, the RFFE method and the EIS assessment. Table G2 in the appendix provides a summary of the average peak flows estimated by each method for a range of sub-catchment sizes.

4.1.5 Climate Change Event Modelling

The 1% AEP event was selected for a climate change scenario assessment. This scenario involved simulation of a 12% increase in rainfall intensity for the 1% AEP event, based on the ARR2016 recommendation to adopt the CSIRO Representative Concentration Pathway 4.5 as an appropriate climate change scenario. This scenario was used to determine the potential impacts on rail formation flood immunity and impacts on adjacent land under climate change.

4.1.6 Extreme Event Modelling

The 0.05% AEP event was also run to assess the impact of flooding on the rail corridor and the impacts of the project on adjacent land under an extreme flooding scenario.

4.1.7 Sensitivity Tests

Given that the hydraulic performance of the cross drainage and the flood impacts of the project have been tested for a large number and range of flow scenarios (see Table 4-4), no further sensitivity testing of the flood models was considered necessary.

4.1.8 Model Review

The hydrological models have been subject to internal IRDJV independent verification which reviewed the following:

- Model conceptualisation and assumptions;
- Model input parameters;
- Hydraulic representations of the existing and future rail infrastructure and other adjacent infrastructure that affects the flood behaviour;
- The methodology for combining multiple models results for the ensemble storm events; and
- Model results and numerical stability.

The technical review comments from the Independent Verifier and demonstration that these comments have been addressed and closed out are provided in Appendix I.

4.2 Hydraulics

Hydraulic models have been used to simulate the interaction between runoff hydrographs generated by the hydrological models, site topography and hydraulic structures along the rail alignment. Two dimensional (2D) hydraulic models have been developed using the TUFLOW hydraulic modelling software program. The models have been built using the 2017 version of TUFLOW and adopt the HPC (Heavily Parallelised Computations) solver. The TUFLOW models were used to simulate the scenarios and events listed in Table 4.4.

4.2.1 Model Construction

Refer to Appendix A2 for schematics of the TUFLOW models.

4.2.1.1 Topography and Survey Data

LiDAR datasets (refer to Section 4.1.2.1) were used to build surface elevation models of the rail corridor and adjacent land. The surface elevation model is based on the LiDAR survey (2015) which provides a consistent catchment scale elevation model. This data was supplemented with key local features such as top of rail crest level from the corridor LiDAR survey (2017) and detailed site survey of the existing structures.

4.2.1.2 Culverts

As the proposed rail alignment is generally raised, cutting off existing flow paths, culvert structures along the existing rail alignment have been replaced and upgraded in the design case to provide adequate conveyance of the flood flows through the alignment and to meet the design requirements for the project. The existing flood immunity of the rail formation is lower than 10% AEP in many locations, which has been upgraded to generally 1% AEP flood immunity in the design case.

Culvert structures have been represented in the hydraulic model using a one-dimensional (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 two-dimensional (2D) mesh. 1D / 2D connectivity has been represented with a ‘*2d_bc*’ layer, defining connection between the culvert network and the 2D mesh.

Refer to Table 4-6 for 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

4.2.1.3 Newell Highway Upgrade

Roads and Maritime Services (RMS) has recently completed works to realign a 6.5km section of the Newell Highway at Trewilga. The works extend from 36.7km to 43.1km north of Parkes and have provided another northbound overtaking lane, widening the road and construction of a truck parking area. About 3.2km of the works involved a new road alignment. The realigned section moved the highway closer to the existing rail line and were completed in 2018. Thus, the proposed Newell Highway Upgrade works have been adopted in both the existing conditions and the design case flood models of the Bogan floodplain area. Cross drainage structures required as part of the works have been represented based on IFC design drawings.

4.2.1.4 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.

Bridge structures along the existing rail alignment have been replaced with culverts in the design case. 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 FLC values adopted for layer one represents the 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;
- 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 provided or site images in lieu of detailed survey. Some of the existing bridges are low level timber structures that are not hydraulically efficient, which has resulted in the specification of higher FLC values than would be expected for a more traditional structure. Whilst it is difficult to validate the impact of the FLC assumption at these locations, the flood level and flow predictions are likely to be insensitive to the FLC value as the velocities are low in almost all events.

Table 4-7 lists the FLC values and blockages specified at the existing bridges in the TUFLOW models.

Table 4-7 FLC and blockage values adopted in the TUFLOW models for existing bridges

Existing bridge ID	Flood model	FLC value	Blockage (%)
453.403 BR	LAC01	0.065	0.53
454.844 BR	LAC01	0.390	0.34
460.698 BR	LAC01	0.730	0.51
461.157 BR	LAC01	0.222	0.31
468.565 BR	BOG01	0.500	0.29
472.030 BR	BOG01	0.445	0.19
478.262 BR	BOG01	0.400	0.23
484.829 BR	BOG01	0.450	0.24
503.600 BR	BOG03	0.580	0.26
505.502 BR	BOG03	0.580	0.25
509.640 BR	BOG05	0.200	0.19
513.671 BR	BOG05	0.200	0.30
515.011 BR	BOG05	0.200	0.30
515.601 BR	BOG05	0.200	0.30
519.224 BR	BOG05	0.200	0.30
528.540 BR	BOG05	0.200	0.30
529.768 BR	BOG05	0.200	0.45

4.2.1.5 Boundary Conditions

Hydrographs for incoming flows were imported from the hydrological model for the 10%, 5%, 2% and 1% AEP storm events for both the existing and design cases. 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.

A water level versus flow (HQ) boundary condition with a slope matching the channel bed, has been used as the downstream boundary of the TUFLOW model.

4.2.1.6 Manning's n Values for Floodplain Areas

The Manning's 'n' values used in the hydraulic models for floodplain areas are consistent with ARR 2016 guidance and were estimated from land use mapping and aerial photography. 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 4-8.

Table 4-8 Manning's 'n' values adopted for floodplain areas

Land use	Manning's 'n' value
Pasture	0.05
Roads/Rail	0.02
Buildings	3
Ponds and other water	0.03
Urbanised Areas	0.1
Industrial Areas	0.1
Low Density Urbanised Areas	0.08
Heavily Vegetated Creek	0.08
Maintained Grass	0.04

4.2.1.7 Grid Size and Timestep

A 10m grid size was adopted for the five hydraulic models. The grid size was selected following initial testing of several model grid resolutions (5m, 10m and 20m grid). 10m grid resolution was adopted, as it achieved a balance between sufficient resolution to model the catchment features and reduced model run times to allow for multiple design iterations within the project program.

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.

4.2.1.8 Blockage

Blockage of hydraulic structures in both existing and design scenarios has been assessed as per the recommendations of ARR 2016 (Chapter 6, Book 6, ARR2016). 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; and
- Random Chance - An unquantifiable but significant factor.

The process and assumptions adopted for the assessment are documented in detail in Appendix E. A full list of results from the blockage assessment is provided in Appendix E, with the resultant blockage values ranging from 0% to 25%. For the IFC design a single blockage factor of 15% has been adopted at all locations. This uniform assumption has been adopted to allow for a consistent approach to blockage of structures across the project based on the range of potential blockage factors determined from the project specific assessment provided in Appendix E. The uniform blockage approach has been adopted as there is an element of subjectivity involved in the determination of the parameters used to assess the potential for blockage and this method provides consistency in the design approach at each cross-drainage structure location.

4.2.2 Design Flood Level Selection

As detailed in Section 4.1.4, the hydrological modelling has been undertaken using the ensemble method of flow estimation from the ARR2016 design guidelines (Chapter 3, Book 4, ARR 2016). The selected critical duration median storm design flow for each AEP event for each individual catchment has been run through the hydraulic models for all catchments within that hydraulic model.

In the hydraulic modelling, the flood level results have been taken as the combined maximum flood level from the selected range of flood events, which are the critical duration median storm design flows, for each AEP. Table 4-9 below, documents the variance between the maximum flood level of the sub-set of median flows and the flood level obtained from the critical duration storm median flow to demonstrate that there is minimal difference in the flood level selected. This method ensures that where flood levels are governed by hydraulic connectivity between catchments the peak flood level from the dominant catchment is adopted in the design process.

For example, the largest difference between the critical storm and maximum flood levels occurs at 528.741km. The catchment draining to the culvert at 528.741km has an area of 0.013km^2 and the critical median storm for the 1% AEP is the 2-hour Storm 5 event. However, the neighbouring catchment draining to 529.768km has an area of 60.2km^2 and has a critical median storm of 12-hour Storm 10. The critical storm for the larger catchment dominates the flood level for both the catchments and the flood level adopted for design purposes represents this hydraulic connectivity between the catchments.

Table 4-9 Catchment critical duration and maximum flood level comparison

Catchment ID	Critical Storm Flood Level			Maximum Flood Level			Difference (m)	Comment
	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)		
449.765	1.5	1	322.73	2	8	322.736	0.006	
450.204	1.5	1	318.257	3	1	318.276	0.019	
451.332	3	1	308.438	2	8	308.498	0.06	
452.721	2	8	301.769	6	2	301.917	0.148	Minor catchment – flood level driven by surrounding major catchment.
453.405	3	9	301.267	6	2	301.294	0.027	
453.642	2	8	301.51	3	8	301.531	0.021	
454.353	2	6	300.31	2	8	300.311	0.001	
454.871	2	8	298.314	6	2	298.441	0.127	Minor catchment - flood level driven by surrounding major catchment.
455.228	6	2	299.233	6	2	299.233	0	

Catchment ID	Critical Storm Flood Level			Maximum Flood Level			Difference (m)	Comment
	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)		
456.184	2	8	303.102	6	2	303.156	0.054	
458.323	3	8	310.718	2	8	310.753	0.035	
460.127	2	6	309.972	3	1	309.985	0.013	
461.14	6	7	308.541	6	2	308.587	0.046	
464.694	3	9	309.397	6	2	309.477	0.08	
466.824	3	6	312.634	12	1	312.769	0.135	
468.176	3	9	314.622	12	1	314.701	0.079	
468.366	4.5	1	314.898	12	1	314.931	0.033	
469.524	3	9	317.921	12	1	318.099	0.178	
470.467	2	5	321.623	12	1	321.75	0.127	
472.03	4.5	1	313.908	12	1	314.111	0.203	
473.905	4.5	8	314.428	12	1	314.465	0.037	
476.771	4.5	8	296.997	12	1	297.016	0.019	
477.703	4.5	9	294.59	12	1	294.597	0.007	
478.262	6	1	292.62	6	1	292.62	0	
478.796	4.5	8	292.813	6	1	292.851	0.038	
479.3	12	1	293.244	6	1	293.245	0.001	
480.35	4.5	9	293.838	6	1	293.885	0.047	
481.921	3	6	299.475	12	1	299.546	0.071	
482.824	2	4	305.343	2	4	305.343	0	
482.947	2	8	0	2	4	0	0	
483.549	2	5	311.22	12	1	311.239	0.019	
483.94	2	5	315.244	12	1	315.353	0.109	
484.581	2	4	318.067	12	1	318.23	0.163	
484.829	2	4	317.36	12	1	317.432	0.072	
487.96	3	9	296.281	3	9	296.281	0	
488.694	3	9	291.937	4.5	8	291.938	0.001	
488.908	2	4	290.856	4.5	8	290.872	0.016	
489.844	4.5	8	286.832	9	10	286.877	0.045	

Catchment ID	Critical Storm Flood Level			Maximum Flood Level			Difference (m)	Comment
	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)		
490.553	9	10	287.132	9	10	287.132	0	
491.834	4.5	8	281.711	4.5	8	281.711	0	
492.947	4.5	8	278.164	9	10	278.165	0.001	
493.293	2	4	277.653	2	4	277.653	0	
493.749	2	8	276.88	2	4	276.899	0.019	
494.815	4.5	8	272.36	4.5	8	272.36	0	
495.535	4.5	8	269.308	4.5	8	269.308	0	
496.067	2	8	268.367	4.5	8	268.433	0.066	
496.885	4.5	8	267.091	4.5	8	267.091	0	
497.613	2	4	264.935	2	4	264.935	0	
497.78	2	4	265.142	2	4	265.142	0	
498.061	2	4	265.715	2	4	265.715	0	
498.625	2	4	265.49	2	4	265.49	0	
498.87	4.5	8	264.776	2	4	264.821	0.045	
499.545	4.5	8	261.438	2	4	261.55	0.112	Minor catchment - flood level driven by surrounding major catchment.
499.577	9	10	261.121	2	4	261.256	0.135	Minor catchment - flood level driven by surrounding major catchment.
500.138	9	10	258.85	2	4	258.99	0.14	Minor catchment - flood level driven by surrounding major catchment.
500.482	9	10	258.494	4.5	8	258.511	0.017	
500.558	9	10	258.467	4.5	8	258.485	0.018	
500.663	9	10	258.492	4.5	8	258.508	0.016	
501.167	9	10	258.701	4.5	8	258.722	0.021	

Catchment ID	Critical Storm Flood Level			Maximum Flood Level			Difference (m)	Comment
	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)		
502.456	9	10	256.301	9	10	256.301	0	
502.974	9	10	256.121	9	10	256.121	0	
503.599	9	10	255.977	9	10	255.977	0	
503.72	4.5	8	256.155	9	10	256.179	0.024	
504.707	9	10	255.616	9	10	255.616	0	
504.798	4.5	8	255.55	9	10	255.563	0.013	
505.502	9	10	255.17	9	10	255.17	0	
515.084	4.5	8	254.375	9	10	254.385	0.01	
515.601	9	10	253.734	12	10	253.735	0.001	
516.313	9	10	254.048	18	2	254.073	0.025	
516.484	4.5	8	253.992	18	2	254.079	0.087	
516.98	9	10	254.275	18	2	254.275	0	
517.428	9	10	254.275	9	10	254.275	0	
518.556	9	10	254.339	18	2	254.353	0.014	
519.224	18	2	254.246	18	2	254.246	0	
520.339	9	10	253.742	18	2	253.757	0.015	
521.918	4.5	8	253.574	9	10	253.579	0.005	
523.223	9	10	252.812	18	2	252.844	0.032	
524.18	9	10	251.312	9	10	251.312	0	
524.984	9	10	250.389	9	10	250.389	0	
525.984	9	10	248.088	9	10	248.088	0	
528.371	18	2	243.148	12	10	243.151	0.003	
528.668	4.5	8	242.949	12	10	243.009	0.06	
528.741	2	5	242.526	12	10	243.004	0.478	Minor catchment - flood level driven by surrounding major catchment.
529.274	9	10	242.328	9	10	242.328	0	
529.768	12	10	241.945	12	10	241.948	0	

Catchment ID	Critical Storm Flood Level			Maximum Flood Level			Difference (m)	Comment
	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)	Critical Duration (Hrs)	Temporal Pattern	Flood Level (m AHD)		
530.705	9	10	241.694	9	10	241.694	0	
530.705	9	10	241.684	9	10	241.684	0	
531.132	9	10	241.689	9	10	241.689	0	
531.543	4.5	8	241.67	9	10	241.692	0.022	
531.757	4.5	8	241.742	9	10	241.77	0.028	
531.906	18	2	241.897	9	10	241.913	0.016	
532.351	4.5	8	242.122	9	10	242.185	0.063	
533.149	9	10	243.26	9	10	243.26	0	
533.611	18	2	243.351	9	10	243.363	0.012	
534.776	9	10	243.548	9	10	243.548	0	
535.106	9	10	243.55	9	10	243.55	0	
536.243	9	10	243.356	4.5	8	243.359	0.003	
536.539	4.5	8	243.358	4.5	8	243.358	0	
536.891	2	5	243.332	4.5	8	243.406	0.074	
537.571	9	10	245.038	4.5	8	245.069	0.031	
537.993	4.5	8	246.085	4.5	8	246.085	0	
538.563	2	5	249.419	4.5	8	249.423	0.004	
539.013	2	5	252.318	4.5	8	252.335	0.017	
542.605	9	2	253.601	12	1	253.617	0.016	
543.766	4.5	8	247.825	9	5	247.845	0.02	
544.452	3	9	245.12	12	1	245.152	0.032	
545.968	9	10	240.477	9	5	240.552	0.075	
546.542	9	10	239.842	9	5	239.862	0.02	
546.812	9	10	239.749	9	5	239.768	0.019	
547.282	9	2	239.416	9	5	239.445	0.029	
547.559	9	10	239.355	9	5	239.389	0.034	

4.2.3 Sensitivity Tests

As noted in Section 4.1.3, given that the hydraulic performance of the cross drainage and the flood impacts of the project have been tested for a large number and range of flow scenarios (see Table 4-4), no further sensitivity testing of the flood models was considered necessary.

4.3 Flood Impact Assessment

The results of the hydraulic model outputs for the existing conditions and design case were compared using GIS software to determine change in the following flood parameters in land adjacent to the corridor:

- Flood level;
- Flood velocity; and
- Flood duration.

The changes in these parameters were then compared to the FMOs (refer to Section 3.1.1) which propose different impact limits depending on the land use, with lower limits set for sensitive land uses (e.g. buildings, roads) than for less sensitive land uses (e.g. forested and agricultural land).

4.4 Cross Drainage Hydraulic Design

The cross drainage culverts were sized using the hydraulic models. In general, the design has adopted a strategy to replace existing culverts with structures that provide an equivalent waterway opening and hydraulic performance. In some locations, a track lift was required to provide the required minimum flood immunity to the top of rail formation. Additional cross drainage culverts have been provided at these locations to replicate the existing overtopping flow hydraulic behaviour.

The cross drainage for the IFC Detailed Design stage has been designed in accordance with the Inland Rail RAATM and to meet the FMOs set out in Section 3.1.1. The design approach to sizing the structures was broadly as follows:

- Where overtopping of the rail occurs for the 1% AEP event under existing conditions, the waterway area corresponding to the overtopping flow was calculated and used as a first pass to size the new cross drainage structures required at that location;
- This first pass cross drainage upgrade estimate was trialled in the model for the 1% AEP event and was typically found to be too conservative (allowing too much flow through the structure). The structure was then optimised by reducing size / number of cells until the following two criteria were met:
  - The required minimum formation flood immunity was achieved;
  - The upstream afflux impact was at or close to the upper limit of compliance based on the adjacent land use;
- The next step was to test the structure performance under the 39% and 10% AEP events to determine if a similar afflux impact was achieved. Typically, the upstream afflux was low or negative for these lower events and increased flood levels occurred on the downstream side of the corridor. The structure was further optimised to balance the afflux compliance upstream and downstream across all three of the key events (39%, 10% and 1% AEP events);
- Once the afflux was balanced, the velocity was then checked through the structure and downstream. If the structure was found to generate high velocities (typically in excess of 3 m/s) then additional cells were added to increase the waterway area and reduce the velocity;
- The flood duration impacts were then checked and impacts across all parameters were checked for the intermediate design events (18%, 5% and 2% AEP events) to check if any anomalous impacts occurred that were not observed in the trends for the key events. If any anomalies were found, the structure was further investigated and optimised; and

- Overlaying the above process was the need to coordinate the cross drainage design with the other disciplines of rail, road, longitudinal drainage and utilities. In some areas, the other infrastructure posed constraints on the cross drainage design and optimising the structure following the procedure above was not possible. In these cases, a compromise was necessary in the cross drainage design that resulted in a non-compliant flood impact or a non-compliant rail formation flood immunity. Such non-compliances were then further assessed and justified as required.

4.5 ARTC Flooding Multi-Criteria Analysis and Rail Formation Flood Immunity

ARTC have undertaken a flood risk assessment using the MCA process for each catchment, to provide a continuous assessment of flood risk along the project length for the flood immunity at the TOF. To facilitate this process, IRDJV provided MCA Criteria Input reporting tables that summarise key flood risk parameters at cross drainage locations (grouped together where the structures are hydraulically connected). This data was reviewed by ARTC and locations identified where a TOF flood immunity of less than the 1% AEP may be acceptable to achieve cost savings. The process is described in detail in the ARTC document *Flood Risk Assessment Procedure – Upgraded Sections of Inland Rail* and is summarised below:

1. Undertake initial existing conditions flood modelling and extract key parameters (flood levels, velocities, times of formation submergence and rail overtopping lengths) for a range of flood events (1% to 39% AEP) to populate MCA Criteria Input reporting tables.

2. ARTC review the MCA Criteria Input reporting tables and identify where a TOF flood immunity of less than 1% AEP may be acceptable and alternative TOF flood immunities for further investigation.

3. The identified options are then assessed in the design case flood models and further parameters extracted from the results (including cross drainage structure sizings, flood impact parameters and flood risk parameters) to populate Concept Drainage Sizing reporting tables.

4. ARTC review the Concept Drainage Sizing reporting tables and select the preferred option for design.

Stages 1 and 2 were undertaken and applied in the 70% design. Stages 3 and 4, which involve investigation of alternative cross drainage sizing, were trialled at the 70% design stage and were not progressed as the cross drainage design was found to be driven primarily by the need to prevent overtopping of the rail up to the 1% AEP event and to meet the FMOs for all events up to the 1% AEP event, which did not allow significant flexibility in the design.

4.6 Model Verification

The hydrological and hydraulic models have been subject to internal IRDJV independent verification which included but was not limited to the following:

- Model conceptualisation and assumptions;
- Model input parameters;
- Hydraulic representations of the existing and future rail infrastructure and other adjacent infrastructure that affects the flood behaviour;
- The methodology for combining multiple models results for the ensemble storm events; and
- Model results and numerical stability.

The technical review comments from the Independent Verifier and demonstration that these comments have been addressed and closed out are provided in Appendix I.

5 Results

5.1 Existing Conditions Flood Behaviour

For existing conditions 39, 10 and 1% AEP event results for flood level/depth, velocity and duration refer to the maps provided in Appendix B. The existing conditions map sets for the 18, 5, 2 and 0.05% AEP events are provided in the Flood Study Report Volume 2 (3-0001-240-IHY-00-RP-0004).

5.1.1 Overview of Existing Conditions Results for the LAC01 Model Area (445 to 466km)

Flooding in this section of the project is generally constrained to the creeks and the cross drainage structures tend to be independent of each other. Flood flow behaviour is heavily influenced by the existing rail embankment with flows diverted to existing structures until overtopping of the rail formation occurs. In the 1% AEP flood event, the existing rail alignment is overtopped in several locations. The most significant overtopping occurs at chainage 461.16km over a length of approximately 0.5km. It is noted that the existing rail formation has a flood immunity of less than the 10% AEP event in some locations.

The velocity maps show that floodplain flow velocities are generally less than 1 m/s and in-channel velocities are generally less than 2m/s.

5.1.2 Overview of Existing Conditions Results for the BOG01 Model Area (466 to 485km)

Flooding in the sections between chainages 466.0 to 474.0km and 483.0 to 485.0km is generally constrained local to the creeks and cross drainage structures tend to be independent of each other. Flood flow behaviour is heavily influenced by the existing rail embankment with flows diverted to existing structures until overtopping of the rail formation occurs. From chainage 474.0km to 483.0km significant flooding occurs from Burrill Creek and connected catchments resulting in over 1.8km of rail overtopped in the 1% AEP flood event. It is noted the existing rail formation has a flood immunity of less than the 10% AEP event in some locations.

The velocity maps show that floodplain flow velocities are generally less than 1m/s. Higher velocities occur locally to the existing structures and in-channel, but the velocities are generally less than 2m/s.

5.1.3 Overview of Existing Conditions Results for the BOG03 Model Area (485 to 506km)

Flood flow behaviour is heavily influenced by the existing rail embankment with flows diverted to existing structures until overtopping of the rail formation occurs. Flood flows in the section between chainages 488.0 to 501.0km, including at Peak Hill, flow along the alignment before joining with the Bogan River, to the west. North of Peak Hill, flood flows are generally in an east to west direction with widespread flooding at chainage 503.6km. In the 1% AEP flood event the existing rail alignment is overtopped over a distance of 1.5km. It is noted the existing rail formation has a flood immunity of less than the 10% AEP event at some locations.

The velocity maps show that the floodplain flow velocities are generally less than 1 m/s and in-channel velocities are generally less than 2m/s.

5.1.4 Overview of Existing Conditions Results for the MAC01 Model Area (541 to 547.55km)

The flood extent maps for this section of the project demonstrate widespread and relatively shallow flooding with significant hydraulic connectivity occurring between several catchments draining to the existing rail alignment. Flood flow behaviour is heavily influenced by the existing rail embankment with flows diverted to existing structures until overtopping of the rail formation occurs. It is noted the existing rail formation has a flood immunity of less than the 10% AEP event at some locations.

The velocity maps show that floodplain flow velocities are generally less than 1m/s and in-channel velocities are generally less than 2m/s.

5.2 Design Case

5.2.1 Cross Drainage Structure Upgrades

All existing cross drainage locations have maintained connectivity with capacity equivalent or greater than existing in the upgraded rail alignment design. The upgrades to the existing cross drainage culverts and bridges were designed using the process outlined in Section 4.4. A culvert only strategy was adopted for the project, with RCBC structures used for all rail cross drainage culverts and most level crossing cross drainage culverts. The details of the upgraded culverts and associated scour protection are provided in the Design Report (3-0001-240-PEN-00-RP-0008) and associated IFC detailed design drawings. Refer to Appendix H for details of the culvert design.

5.2.2 Formation Flood Immunity

During the 70% design phase, the results of the existing conditions flood modelling were reviewed by ARTC as part of the ARTC Flood MCA process and the potential to adopt alternative lower levels of flood immunity was assessed for the locations listed below in Table 5-1. At all other locations, the 1% AEP was chosen for the formation flood immunity. The results in Table 5-1 were provided as an input into the rail vertical alignment design.

Table 5-1 Minimum required formation flood immunities identified from the Flooding MCA process

No.	Catchment / Kilometrage	Start Kilometrage for Assessment	End Kilometrage for Assessment	Minimum Top of Formation Flood Immunity
1	456.184	455840	456960	5% AEP
2	460.127	459800	460320	10% AEP
3	465.310	465260	465840	10% AEP
4	468.366	467440	469000	5% AEP
5	478.262	477440	478570	5% AEP
6	479.300	479240	480120	5% AEP
7	481.920	481580	482800	10% AEP
8	493.749	493380	493920	5% AEP
9	497.613	497000	498040	5% AEP
10	498.061	498040	498400	10% AEP
11	498.625	498400	499100	5% AEP
12	499.577	499100	499572	5% AEP
13	500.138	499572	500180	As existing
14	500.482	500180	501060	5% AEP
15	501.167	501060	501520	10% AEP

No.	Catchment / Kilometrage	Start Kilometrage for Assessment	End Kilometrage for Assessment	Minimum Top of Formation Flood Immunity
16	504.707	503800	504600	5% AEP
17	512.108	511220	513500	10% AEP
18	516.313	515780	516400	As existing
19	517.428	516800	518100	As existing
20	521.918	521400	522300	10% AEP
21	523.223	522300	523520	As existing
22	524.180	523520	524260	As existing
23	524.984	524260	524920	As existing
24	525.984	524920	526060	As existing
25	528.540	528400	528700	10% AEP
26	529.274	528700	529285	As existing
27	529.770	528780	529800	5% AEP
28	530.705	529800	531540	10% AEP
29	531.132	529800	531600	10% AEP
30	531.906	531600	532220	10% AEP
31	533.611	533100	534100	5% AEP
32	534.776	534100	535060	5% AEP
33	536.243	535060	536320	5% AEP
34	545.968	544460	546320	10% AEP
35	546.542	546320	546840	10% AEP
36	547.282	546840	547300	5% AEP
37	547.559	547300	547560	5% AEP
38	547.841	547760	547900	5% AEP
39	548.064	547900	548440	5% AEP
40	548.581	548440	548800	5% AEP
41	549.072	548800	549060	5% AEP

5.2.3 Design Case Flood Behaviour

For design case 39, 10, 1% AEP event and 1% AEP event with climate change results for afflux, velocity change and duration change refer to the maps provided in Appendix C. The design case map sets for the 18, 5, 2 and 0.05% AEP events are provided in the Flood Study Report Volume 2 (3-0001-240-IHY-00-RP-0004).

Flood afflux maps present the difference in flood level between the existing conditions and the design case flood levels in gridded increments of between 50mm and 100mm as required to demonstrate compliance to the design criteria. Areas no longer inundated with flooding in the design case conditions are specifically shown in black. Areas that are newly inundated with flooding in the design conditions are included in the afflux impact grid increments.

Flood velocity maps present the percentage difference in flow velocity between the existing conditions and the design case flow velocity in gridded increments of between -20% to +20%. A dark grey shading is applied where the design flow velocity remains less than 1 m/s.

Flood duration maps present the percentage difference in duration of flood inundation between the existing conditions and the design case flood durations in gridded increments of between -5% to +10%. A depth cut-off limit of 0.2m has been applied in defining flood inundation with areas that experience a maximum flood depth less than 0.2m excluded from the assessment. A dark grey shading is applied where the total flooded duration remains less than 6 hours in the design event.

5.2.3.1 Overview of Design Case Results for the LAC01 Model Area (445 to 466km)

The afflux maps demonstrate that in general the afflux is compliant with the FMOs set out in Section 3.1.1, with impacts occurring local to the rail alignment. The largest increase in flood levels in this section occur at the southern end of the project, around the North-West Connection, where flood level increases of greater than 0.2m occur. In general, flow behaviour closely replicates the existing flow behaviour with no significant diversion of existing flow paths occurring as demonstrated by the limited areas shown as “no longer inundated” in the mapping.

The velocity change maps demonstrate that floodplain flow velocities for the design case generally remain less than 1 m/s, as indicated by the dark grey shading. For areas where the peak velocity is greater than 1 m/s, there is minimal change in velocity, with increases in velocity of greater than 20% occurring local to cross drainage culvert inlets and outlets.

The duration change maps demonstrate most significant change from existing conditions, with generally a reduction in flood duration upstream of the alignment and an increase downstream, particularly between 455 and 459km. Duration change mostly occurs in shallow flow areas where depths are less than 0.5m.

5.2.3.2 Overview of Design Case Results for the BOG01 Model Area (466 to 485km)

The afflux maps demonstrate that in general the afflux is compliant with the FMOs set out in Section 3.1.1, with impacts occurring local to the rail alignment. Afflux is most significant around the Burrill Creek crossing at 479.5km. In general, flow behaviour closely replicates the existing flow behaviour with no significant diversion of existing flow paths occurring as demonstrated by the limited areas shown as “no longer inundated” in the mapping.

The velocity change maps demonstrate that floodplain flow velocities for the design case generally remain less than 1 m/s, as indicated by the dark grey shading. For areas where the peak velocity is greater than 1 m/s, there is minimal change in velocity, with increases in velocity of greater than 20% occurring local to a small number of the cross drainage culvert inlets and outlets.

The duration change maps demonstrate little significant change from existing conditions, with some increases and decreases in duration in the Burrill Creek catchment.

5.2.3.3 Overview of Design Case Results for the BOG03 Model Area (485 to 506km)

The afflux maps demonstrate that in general the afflux is compliant with the FMOs set out in Section 3.1.1, with impacts occurring local to the rail alignment. The largest increase in flood levels in this section occur south of Trewilga and north of Peak Hill. In general, flow behaviour closely replicates the existing flow behaviour with no significant diversion of existing flow paths occurring as demonstrated by the limited areas shown as “no longer inundated” in the mapping.

The velocity change maps demonstrate that floodplain flow velocities for the design case generally remain less than 1 m/s, as indicated by the dark grey shading. For areas where the peak velocity is greater than 1 m/s, there is minimal change in velocity, with increases in velocity of greater than 20% occurring local to a small number of the cross drainage culvert inlets and outlets.

The duration change maps demonstrate most significant change from existing conditions, with generally a reduction in flood duration upstream of the alignment and an increase downstream. Most significant change occurs west and north of Peak Hill. Duration change mostly occurs in shallow flow areas where depths are less than 0.5m.

5.2.3.4 Overview of Design Case Results for the BOG05 Model Area (506 to 541km)

The afflux maps demonstrate that in general the afflux is compliant with the FMOs set out in Section 3.1.1. Afflux is most pronounced in this section with increases of up to 200mm in several areas, however, there are only two areas of localised non-compliant afflux at 509.5km and 510.5km. In general, flow behaviour closely replicates the existing flow behaviour with no significant diversion of existing flow paths occurring as demonstrated by the limited areas shown as “no longer inundated” in the mapping.

The velocity change maps demonstrate that floodplain flow velocities for the design case generally remain less than 1 m/s, as indicated by the dark grey shading. For areas where the peak velocity is greater than 1 m/s, there is minimal change in velocity, with increases in velocity of greater than 20% occurring local to cross drainage culvert inlets and outlets.

The duration change maps demonstrate most significant change from existing conditions, with generally a reduction in flood duration upstream of the alignment and an increase downstream. Most significant change occurs downstream of the alignment at 509 to 514km, 520 to 522km and 524 to 533km. Duration change mostly occurs in shallow flow areas where depths are less than 0.5m.

5.2.3.5 Overview of Design Case Results for the MAC01 Model Area (541 to 547.55km)

The afflux maps demonstrate that in general the afflux is compliant with the FMOs set out in Section 3.1.1, with impacts occurring local to the rail alignment. In general, flow behaviour closely replicates the existing flow behaviour with no significant diversion of existing flow paths occurring as demonstrated by the limited areas shown as “no longer inundated” in the mapping.

The velocity change maps demonstrate that floodplain flow velocities for the design case generally remain less than 1 m/s, as indicated by the dark grey shading. For areas where the peak velocity is greater than 1 m/s, there is minimal change in velocity, with increases in velocity of greater than 20% occurring local to a small number of cross drainage culvert inlets and outlets.

The duration change maps demonstrate most significant change from existing conditions, with generally a reduction in flood duration upstream of the alignment and an increase downstream. Most significant change occurs at the northern extent of the model area. Duration change mostly occurs in shallow flow areas where depths are less than 0.5m.

5.3 Design Compliance

5.3.1 RAATM and BoD Compliance

5.3.1.1 Afflux

Refer to Section 3.1.2.1 for the RAATM requirements for afflux. Afflux that potentially affects buildings was found at a total of 4 properties for the 1% AEP event. At these locations, only 1 building appears to experience above floor level flooding. The design case increases flood levels at this building by 24mm, exceeding the 10mm limit nominated by the RAATM. The details of the assessment at these 4 properties is provided below in Table 5-2.

Table 5-2 Assessment of afflux impacts at buildings

Property ID	Existing conditions flood level (mAHD)	Design case flood level (mAHD)	Afflux (mm)	Floor level* (mHAD)	Above floor flooding in existing and/or design case?
12DP7070	240.629	240.651	22	240.756	No for both cases
14DP7070	240.496	240.534	38	240.598	No for both cases
156DP755113	259.992	260.003	11	260.249	No for both cases
76DP754001	291.341	291.365	24	291.309	Yes for both cases

The afflux impact at the affected building at Lot 76 DP754001 exceeds the 10mm limit, however, this building has been identified to be a shed not a dwelling and the property owner has confirmed that it is not sensitive to minor increases in flood level.

Some non-compliances to the RAATM criteria also occur for local roads, however, these occur in areas where the roads are already flood prone and there is no significant increase in flood hazard on the road; therefore, the impacts can be considered minor or low risk. This is discussed further in Section 5.3.2.4 below.

5.3.1.2 Flood Velocity

Refer to Section 3.1.2.2 for the RAATM requirements for velocity. Out of a total of 191 rail culverts the velocity exceeds 2.5m/s at 49 locations (26%). Controlling velocity has not been a governing factor in the design. Instead, culverts have been designed to meet the flood impact criteria as far as possible and scour protection measures have been designed based on the resulting design velocities. Where velocities exceed 1.6 m/s, scour protection measures have been provided in the design (refer to the Design Report 3-0001-240-PEN-00-RP-0008 for details). Given that the design has broadly met the flood impact criteria and provided scour protection based on an assessment of the in-situ soil conditions and a lower velocity threshold, it is considered that the design complies with the RAATM velocity requirements.

5.3.1.3 Rail Formation Flood Immunity

As discussed in Section 5.2.2, ARTC have identified 41 locations where the minimum flood immunity of the formation may be less than the 1% AEP event. The rail vertical design has been based on these requirements and the design case flood levels. The design has attempted to meet the minimum immunity requirements as far as practical, but some non-compliances remain due to constraints on the rail design. These are presented in the table below. Note that at four out of the five locations, the non-compliances occur, a result of tying in to the existing rail at the limits of the P2N works or existing sidings. Detailed analysis and justification of the non-compliance items 2 to 4 in the table below are provided in Appendix E. Items 1 and 5 are a result of tie-ins to the existing rail at the southern and northern extents of the project and are not documented in detail.

Table 5-3 Locations of non-compliance with formation flood immunity requirements

No.	Location	ARTC Minimum Flood Immunity Requirement	Design Formation Flood Immunity Achieved	Maximum submergence depth above formation for required flood immunity event (mm)	Justification for non-compliance
1	NWL 0.000km - 300.000km (Western tie in point to existing rail)	1% AEP	>5% AEP	350	Constraint posed by the tie in to a fixed point of existing rail level.
2	449.355km – 449.585km	1% AEP	>5% AEP	225	Constraint posed by the tie-in to the existing rail level and 2 level crossings.
3	458.740km – 458.930km	1% AEP	>5% AEP	68.5	Constraint posed by the tie-in to the existing rail siding and level crossing.
4	538.870km – 538.900km	1% AEP	>5% AEP	130	Localised impact upstream at a level crossing over a 10m length. Lifting the rail formation will not resolve this issue due to the resultant increase in Level Crossing that would block additional flow and raise flood levels further. Maximum cross drainage capacity provided to fit with cover and existing utility constraints.
5	547.530km (Northern tie in point to existing rail)	5% AEP	<10% AEP	380	Constraint posed by the tie in to a fixed point of existing rail level.

5.3.2 Compliance with Flood Management Objectives

5.3.2.1 Afflux

The FMOs for afflux are presented in Section 3.1.1.1. Afflux maps are provided in Appendix C for the 39, 10 and 1% AEP events. Table 5-4 below provides a list of key impacts that do not comply with the afflux FMOs with references to flood maps contained within Appendix C. It should be noted that non-compliant values that occur within the rail corridor on ARTC owned land, which are generally contained within the rail longitudinal drainage systems or localised around rail culvert inlets and outlets, have not been included in the table below.

Table 5-4 List of non-compliant impacts for afflux

No.	Lot & DP No. / Road Name	Owner	Flood Map Reference	Afflux Value	Land area / road length of non-compliant afflux	Impact risk rating	Justification for impact risk rating
39% AEP Impacts							
1	4DP707543	Robyn Lee Blackstock	DE39A8	>200mm	<0.2 ha	Low	Impact is very localised around rail corridor and within existing floodplain.
2	40DP755093	Warwick John Kopp	DE39A15	>200mm	<0.1 ha	Low	Impact is very localised around rail corridor and within existing floodplain.
3	10DP580332	James Phillip Stanford	DE39A16	>200mm	<0.5 ha	Low	Impact is either located within an existing flow channel or is fragmented areas of an existing shallow overland flow path
4	Peak Hill Railway Road	Narromine Shire Council	DE39A17 to 21	>100mm	Localised sections of 10 to 20m	Low	Exceeds 100mm afflux limit on local road at a number of locations, however road is already flood affected and likely to be cut off in areas to the north and south where there is no impact
10% AEP Impacts							
1	10DP1185173	Roads & Maritime Services	DE10A11	>200mm	<0.2 ha	Low	Impact is very localised around rail corridor and within existing overland flow path.
2	2DP1164491	Garry Kopp	DE10A15	>200mm	<0.2 ha	Low	Impact is very localised around rail corridor and within existing floodplain.
3	40DP755093	Warwick John Kopp	DE10A15	>200mm	<0.1 ha	Low	Impact is very localised around rail corridor and within existing floodplain.
4	10DP580332	James Phillip Stanford	DE10A16	>200mm	<0.5 ha	Low	Impact is either located within an existing flow channel or is fragmented areas of an existing shallow overland flow path
5	Peak Hill Railway Road	Narromine Shire Council	DE10A17 to 21	>100mm	Localised sections of 10 to 20m	Low	Exceeds 100mm afflux limit on local road at a number of locations, however road is already flood affected and likely to be cut off in areas to the north and south where there is no impact
1% AEP Impacts							
1	307DP750179	P S Marine Pty Ltd	D1A1	>200mm	<0.1 ha	Low	Impact is very localised around rail corridor and within an existing overland flow path
2	200DP627302	Kenneth James Keith	D1A1	>200mm	<1 ha	Low	Impact is very localised around rail corridor and within an existing overland flow path
3	10DP753984	Andrew Charles Townsend	D1A4	>200mm	<0.5 ha	Low	Impact is very localised around rail corridor and within an existing overland flow path
4	2DP861741	Alison Narelle Westcott	D1A8	>200mm	<2.5 ha	Low	Impact confined to existing Burrill Creek floodplain. Balanced by reduction in flood risk in same property downstream.

No.	Lot & DP No. / Road Name	Owner	Flood Map Reference	Afflux Value	Land area / road length of non-compliant afflux	Impact risk rating	Justification for impact risk rating
5	Barber Lane near LX1086	Parkes Shire Council	D1A8	>100mm	300 m	Low	Exceeds 100mm afflux limit on local road, however road is already flood affected and likely to be cut off in areas where there is no impact. Balanced by reduction in flood risk on same road downstream.
6	5DP1185173	Ian Wesley Westcott	D1A10	>200mm	<0.5 ha	Low	Impact is very localised around rail corridor and within an existing floodplain
7	40DP755093	Warwick John Kopp	DE1A16	>200mm	<15 ha	Medium	Impact is confined to an existing floodplain, but covers a significant area.
8	10DP580332	James Phillip Stanford	DE1A16	>200mm	<0.5 ha	Low	Impact is either located within an existing flow channel or is fragmented areas of an existing shallow overland flow path
9	Peak Hill Railway Road	Narromine Shire Council	DE1A17 to 21	>100mm	Localised sections of 10 to 20m	Low	Exceeds 100mm afflux limit on local road at a number of locations, however road is already flood affected and likely to be cut off in areas to the north and south where there is no impact

In summary, there are a total of 12 landowners that experience a non-compliant afflux on their land, including Parkes and Narromine Shire Councils as the landowners for the affected local roads. There are no non-compliant impacts on the Newell Highway or public infrastructure. The impact rating assigned to 11 of the affected landowners is low, on the basis that the impact is localised/isolated or in fringe floodplain areas, where water depth is shallow, and the use of the land is unlikely to be affected. One landowner (Warwick Kopp, also owner of Towalba Pty Ltd.) will experience the impact over a significant area of land and this has been identified as a medium risk.

5.3.2.2 Flood Velocity

The FMOs for flood velocity are presented in Section 3.1.1.2. Velocity change maps are provided in Appendix C for the 39, 10 and 1% AEP events.

The maps show that non-compliant velocity impacts occur around the inlets and outlets of numerous culverts, however, these impacts are very localised to the structures and generally do not extend more than approximately 20 metres from the structure, with some of the impacted area extending beyond the rail corridor into the adjacent land. These increases in velocity are managed through scour protection measures (including rock and similar scour resistant materials) at the inlets and outlets that are placed within the zones, where velocities are high enough to erode the existing soils. Designing out these non-compliances would only be possible by including additional numbers of culvert cells at significant extra cost, which is not considered justified given the localised nature of the non-compliances and the scour protection measures provided in the design. In all cases the velocities remain below 2m/s in the non-complying areas outside the extent of the scour protection.

The velocity change impact extends for significant distances beyond the rail corridor at the following two locations:

- At the southern tie in of the North-West Connection to the existing rail line – Refer to map DE1VC1 in Appendix C. At this location, the velocities are increased along the new rail line and the tie in over a distance of approximately 750m. The rail cess drain at this location has low capacity and does not contain the area of velocity change and the non-compliance extends beyond the project boundary into the adjacent land. However, the resulting velocities in the design case remain below 2m/s and therefore do not pose a scour risk; and

- At 512.2km – Refer to map DE39VC16 in Appendix C. At this location, the non-complying velocity change caused by the upgraded cross drainage extends into a channel over a distance of approximately 750m. However, as in the above case, the resulting velocities in the design case remain below 2m/s and therefore do not pose a scour risk.

The velocity non-compliances are therefore all considered to be low risk impacts as the scour risk is mitigated in the design and the non-compliances will not affect the use of the land.

5.3.2.3 Flood Duration

The FMOs for flood duration are presented in Section 3.1.1.3. Duration change maps are provided in Appendix C for the 39, 10 and 1% AEP events.

The mapping indicates a high number of potential non-compliances with the impact criteria for all events, as shown in the example below:

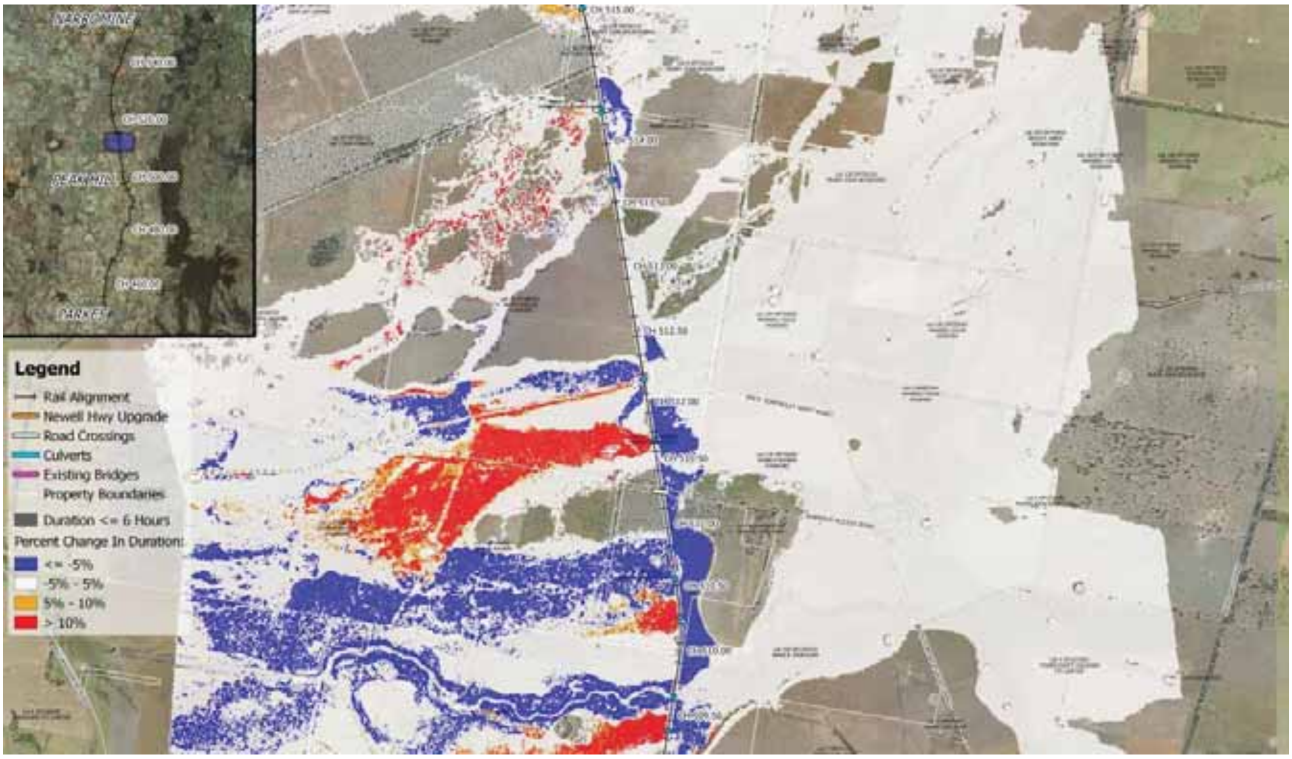


Figure 5.1 Example of 1% AEP duration impact mapping showing significant areas of non-compliance (red zones)

The DPE has proposed more stringent impact criteria than the HHIP, by introducing a 5% impact limit for houses, commercial areas and urban areas. The exceedances of the 10% duration increase limit shown in the mapping occur in the agricultural / rural land away from the commercial and urban areas.

The increases in flood duration are due to the elimination of the rail overtopping mechanism which passes flow more quickly and efficiently downstream and increases flood durations downstream while reducing upstream flood durations. This is evident in areas as shown above in Figure 5.1 where reductions in flood duration are experienced upstream of the rail corridor. Some reductions also occur downstream as the upgraded cross drainage infrastructure redistribute flows around the floodplain, particularly in areas where the floodplain is extensive and characterised by generally shallow flow depth.

To assess the true impact of the duration increases, flood depth hydrographs have been extracted at a selection of locations where non-compliances occur for the 1% AEP event. These locations and the extracted hydrographs are shown below in Figures 5.2 to 5.5.

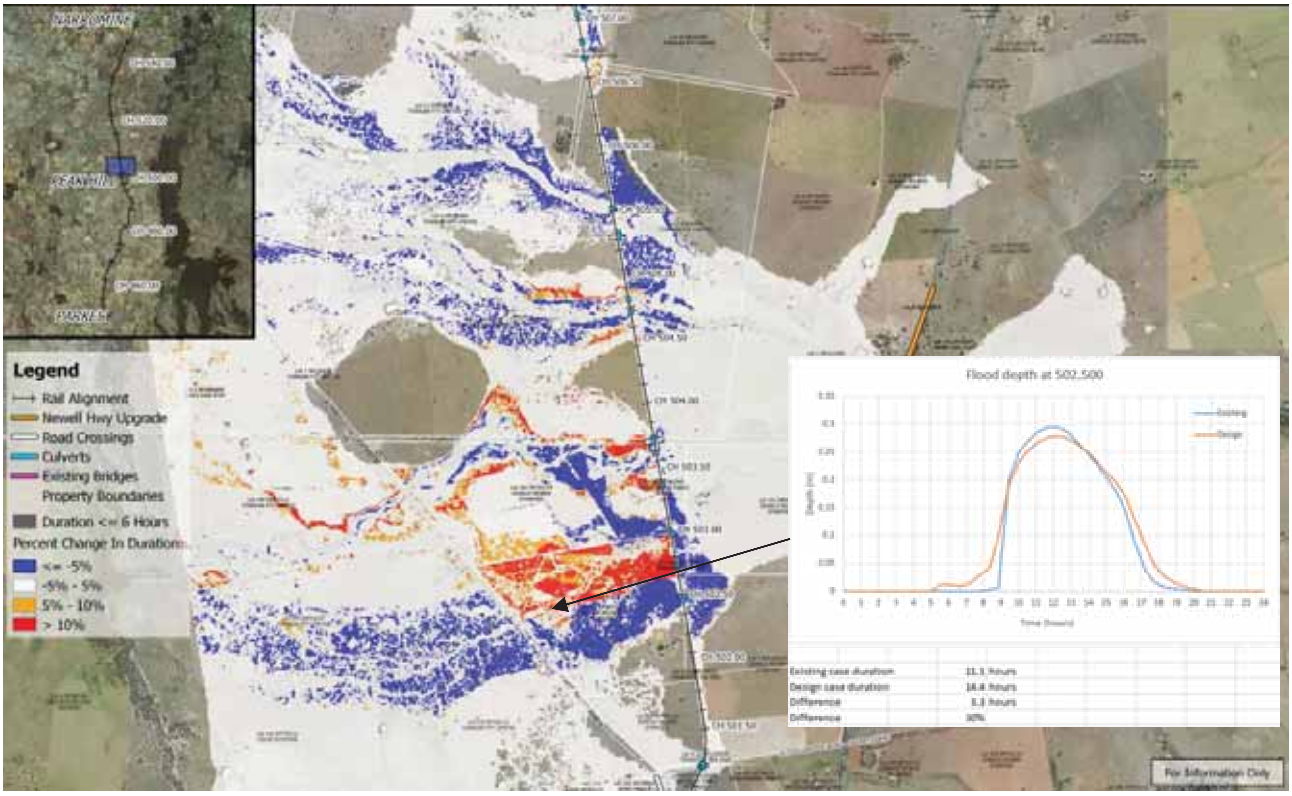


Figure 5.2 Example of 1% AEP duration impact mapping with extracted hydrograph at 502.5km

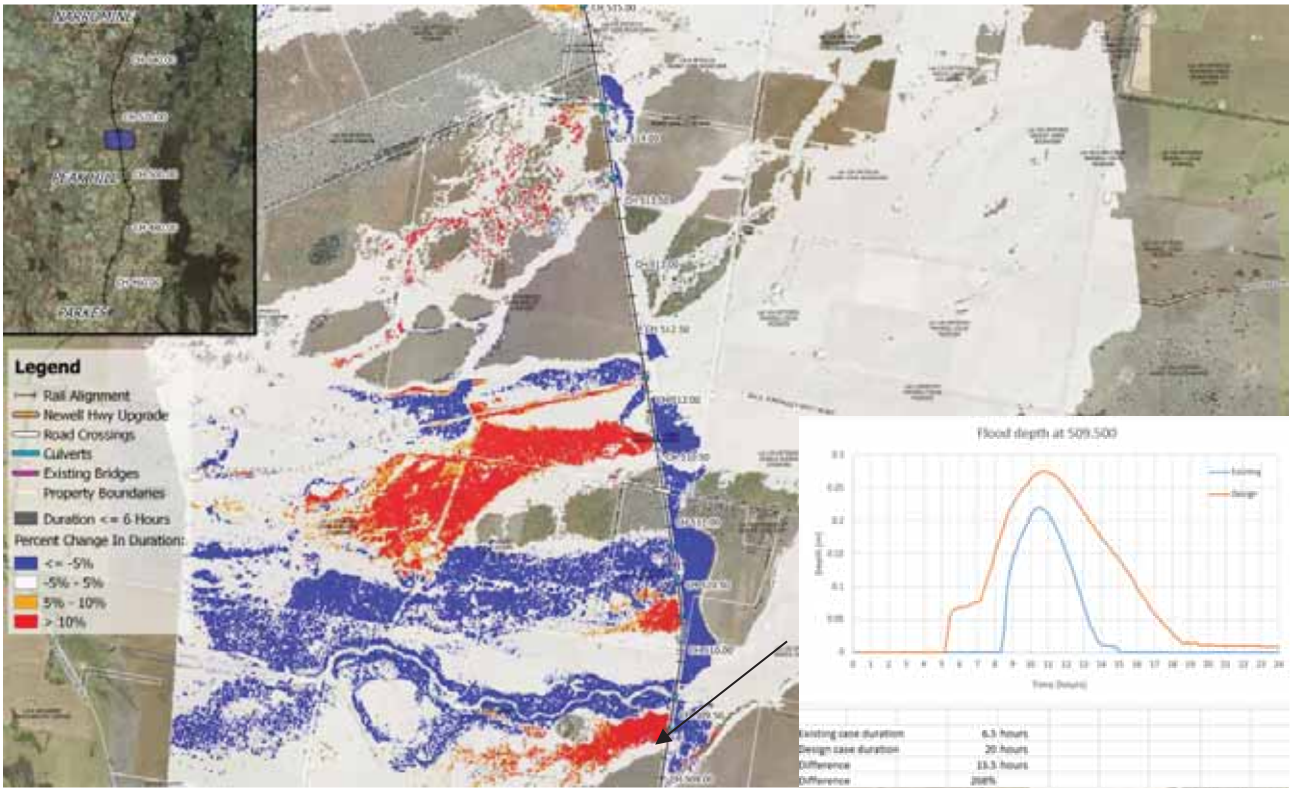


Figure 5.3 Example of 1% AEP duration impact mapping with extracted hydrographs at 509.5km

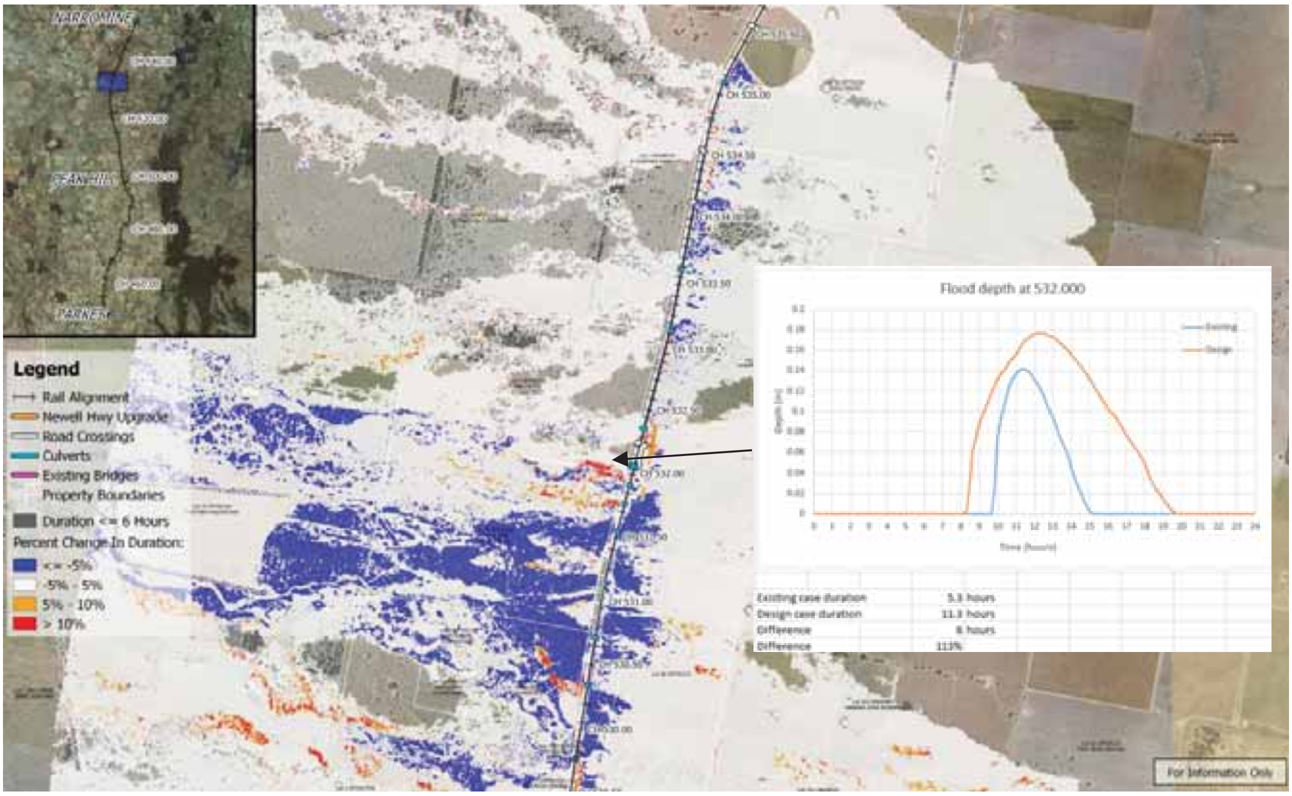


Figure 5.4 Example of 1% AEP duration impact mapping with extracted hydrograph at 532km

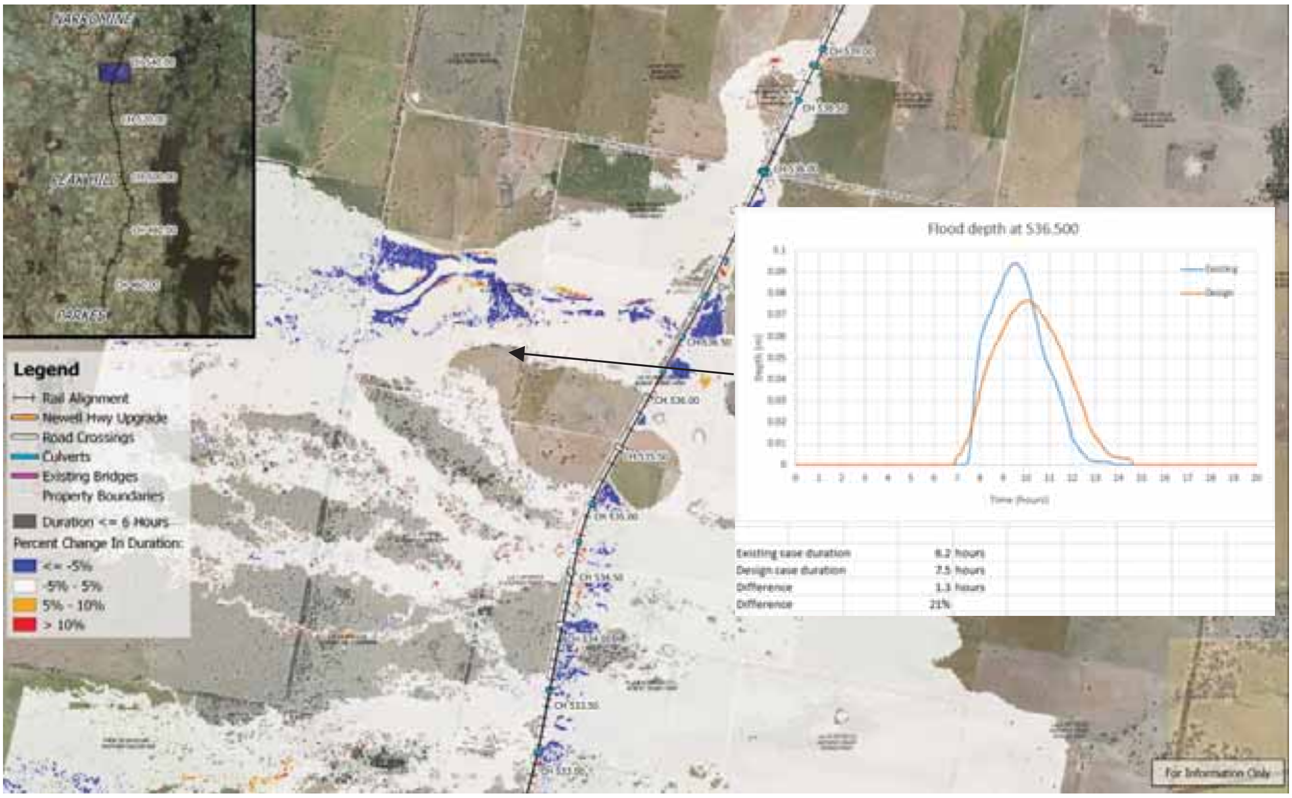


Figure 5.5 Example of 1% AEP duration impact mapping with extracted hydrograph at 536.5km

The following is observed from the results shown in the figures above:

- The non-compliances occur in shallow depth areas, with peak depths less than 300mm;
- Exceedances of the 10% increase limit range between 20% and 200% approximately; and
- The duration increases range between 3 and 14 hours approximately.

Based on these results, the duration impacts that do not comply with the CoA and FMOs are considered to be low risk due to the following:

- The impacts are confined to agricultural / rural land and do not extend to urban or commercial areas;
- The impacts are confined to shallow depth areas on the floodplain;
- The non-compliant impacts are considerably more widespread for the 1% AEP than for the 10% and 39% AEP events, with the lower order event non-compliances distributed over less catchments and highly scattered and isolated in nature; and
- The extended durations are limited to less than 20 hours for the 1% AEP event. This relatively short and infrequent occurrence should not significantly affect agricultural activity and the productivity of the land.

Notwithstanding the above, focussed consultation has been undertaken with the landowners most affected by duration impacts to assess the sensitivity of their land and activities to the impacts. The list of significant areas of duration non-compliance and landowners consulted is provided in Table 5-5.

Table 5-5 List of non-compliant impacts for duration

No.	Lot & DP No.	Owner	Map Reference	1% AEP Duration Impact	Impact risk rating	Justification for impact risk rating
1	2DP623370	Christopher Paul Rohrlach	DE1DC2	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
2	81DP750161	Geoffrey Boger Wyatt	DE1DC3	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
3	85DP704737	Joel Philip Howard Jelbart	DE1DC8	>10%	Low	Impact will occur very infrequently and in existing floodplain.
4	2DP737128	Ian Wesley Westcott	DE1DC10	>10%	Low	Impact will occur very infrequently and in existing floodplain.
5	320DP755113 321DP755113	Westy's Ag Pty Ltd	DE1DC12	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
6	102DP755113 114DP755113	Donald Reuben Stanford	DE1DC13	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
7	1DP110288	Towalba Pty Limited	DE1DC14	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
8	2DP1164491	Garry Kopp	DE1DC15	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
9	4112DP1208586	Warwick John Kopp	DE1DC16	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
10	10DP580332	James Phillip Stanford	DE1DC16	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
11	53DP755123	Stafford Richard Julian Job	DE1DC18	>10%	Low	Impact will occur very infrequently and in shallow depth areas only.
12	52DP755123	Lynne Maree Sharkey	DE1DC18	>10%	Low	Impact will occur very infrequently and in existing floodplain.
13	2DP1067496	Lorraine Catharina Skinner	DE1DC20	>10%	Low	Impact will occur very infrequently and in existing floodplain.
14	1DP1067496 10DP755109	Matthew Walter Rae	DE1DC20	>10%	Low	Impact will occur very infrequently and in existing floodplain.
15	1DP755123 5DP755123	Ann Louise Stonestreet	DE1DC20	>10%	Low	Impact will occur very infrequently and in existing floodplain.

5.3.2.4 Flood Hazard

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 5.6 is taken from ARR2016 Chapter 7 Section 7.2.7 and provides flood hazard curves and definitions.

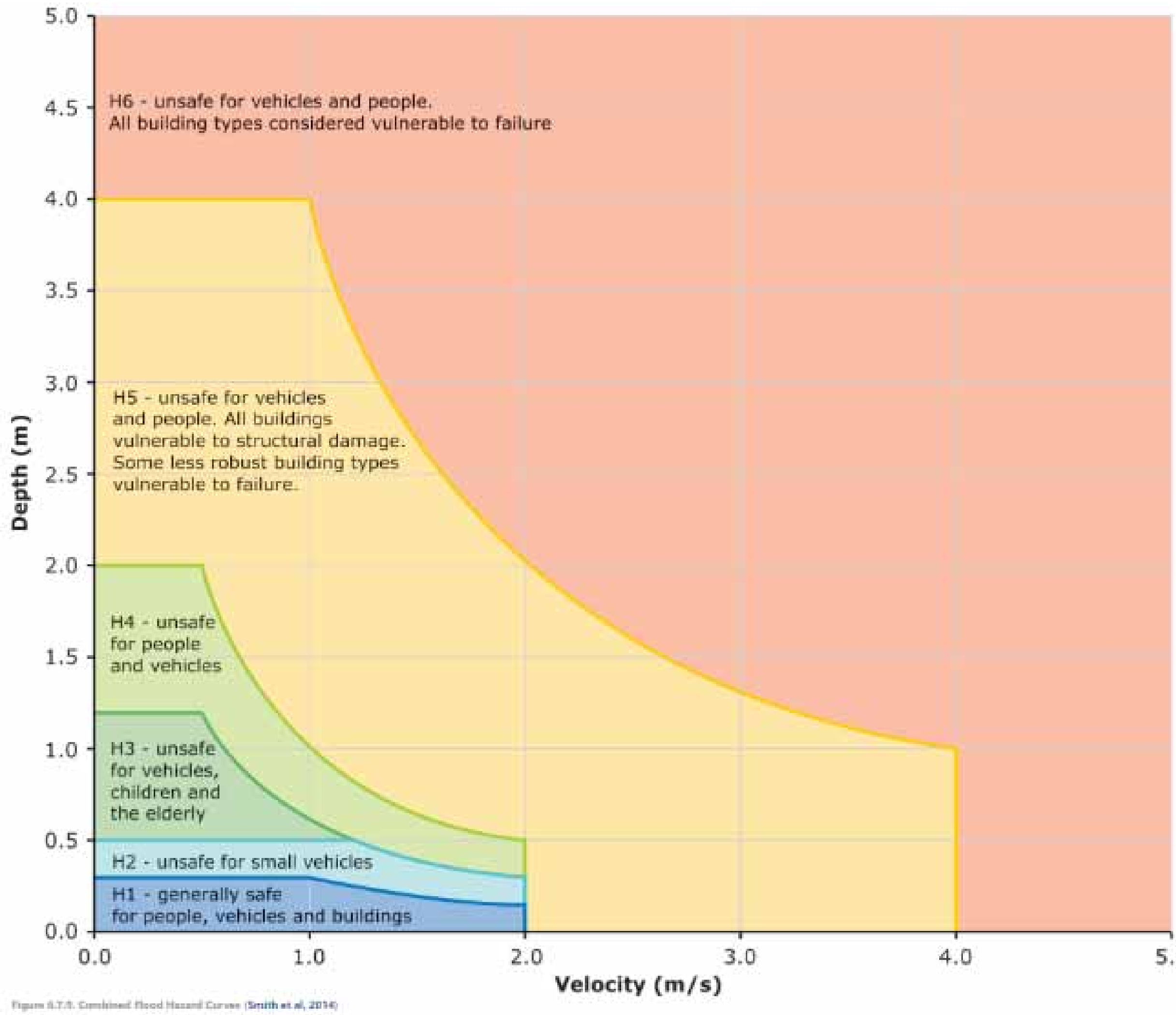
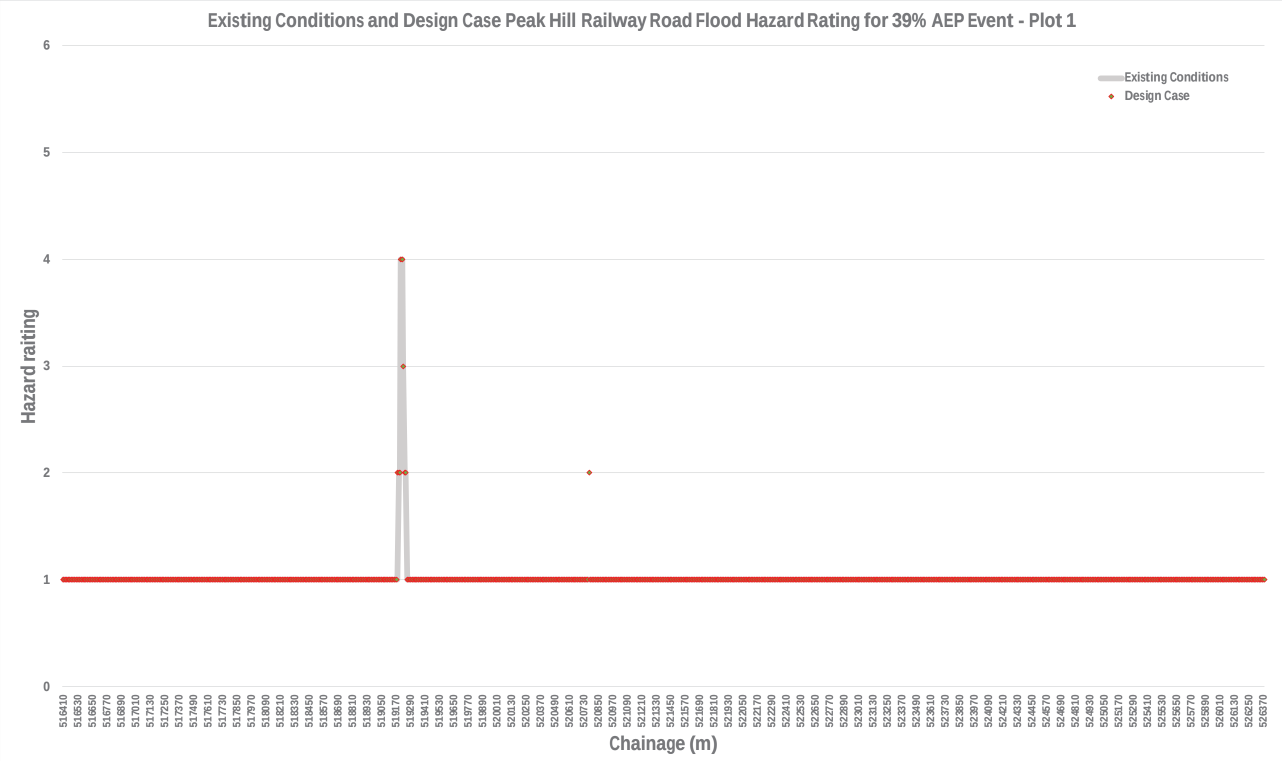


Figure 5.6 Flood hazard curves and definitions (ARR2016, Chapter 7, Section 7.2.7)

Flood risk throughout the project area is generally characterised by low velocity and shallow depth flow, resulting in a low hazard categorisation throughout most of the area. Peak Hill Railway Road is an exception to this trend and is subject to higher depths and velocities than other areas. This road also experiences both afflux and velocity impacts from the project localised around culvert outlets, which could also locally increase the hazard categorisation.

An assessment of the hazard under both existing conditions and the design case has been undertaken for key locations of impact along Peak Hill Railway Road. The results are presented below in Figures 5.7 to 5.9 for the entire length of road adjacent to the project and in Table 5-6 and Table 5-7 for a selection of the larger culvert banks associated with the project.



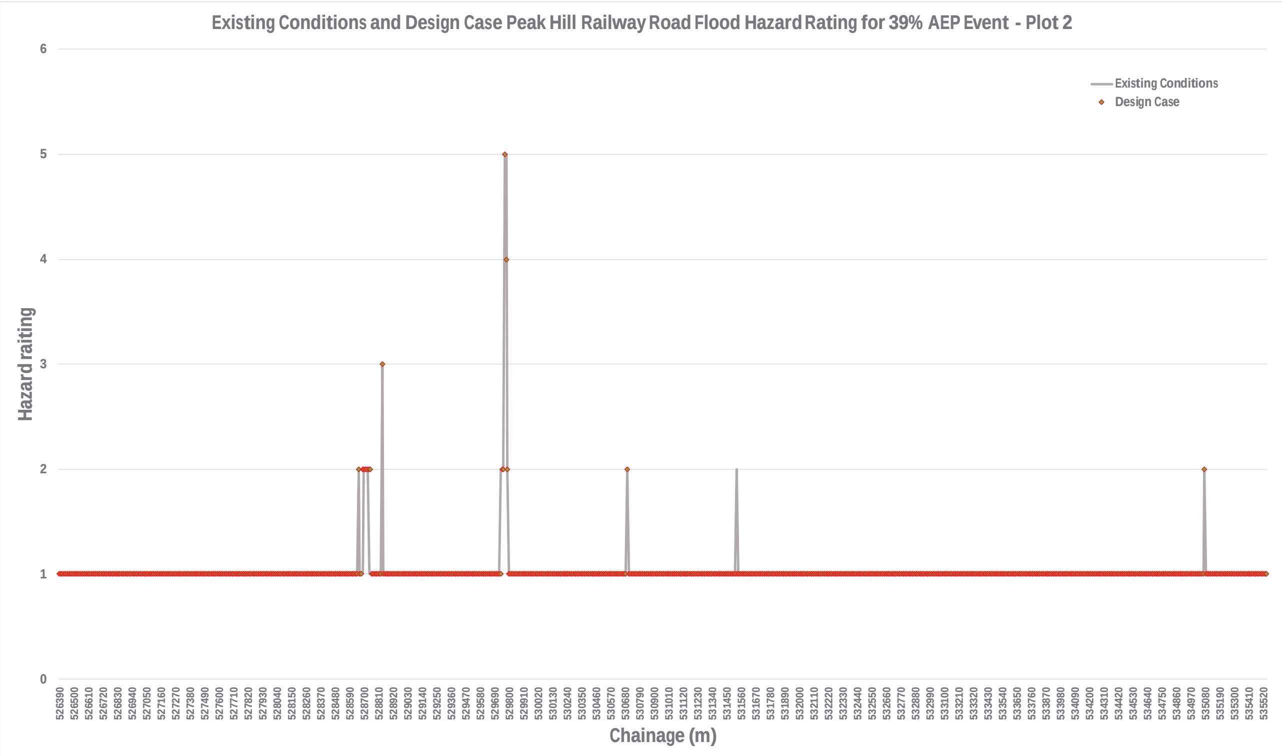
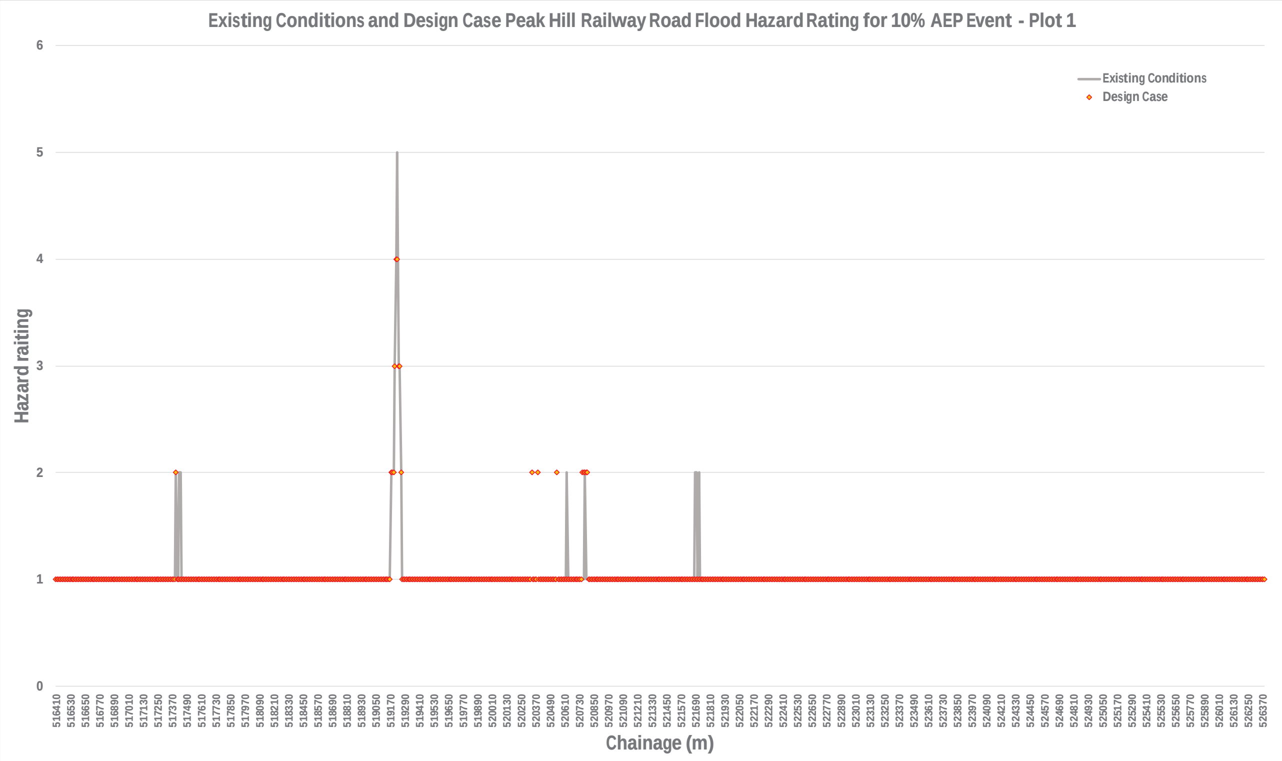


Figure 5.7 Change in flood hazard at Peak Hill Railway Road – 39% AEP Event



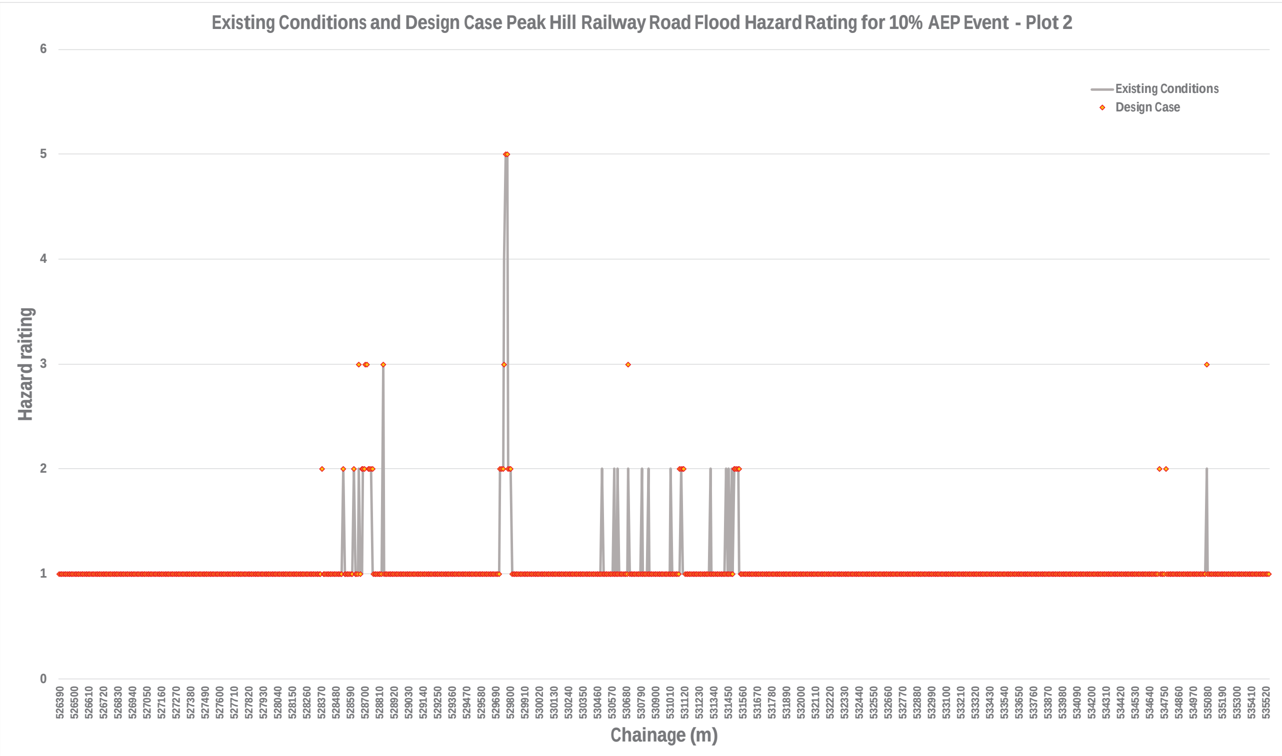
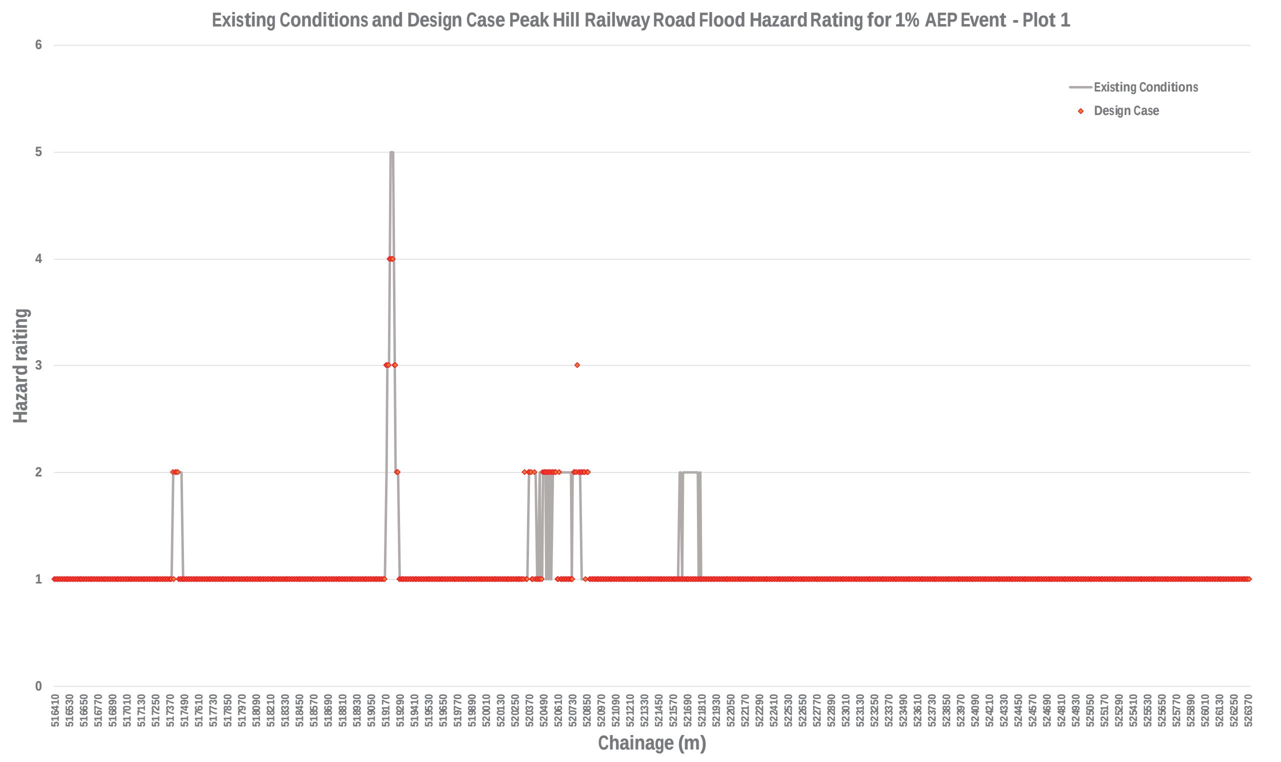


Figure 5.8 Change in flood hazard at Peak Hill Railway Road – 10% AEP Event



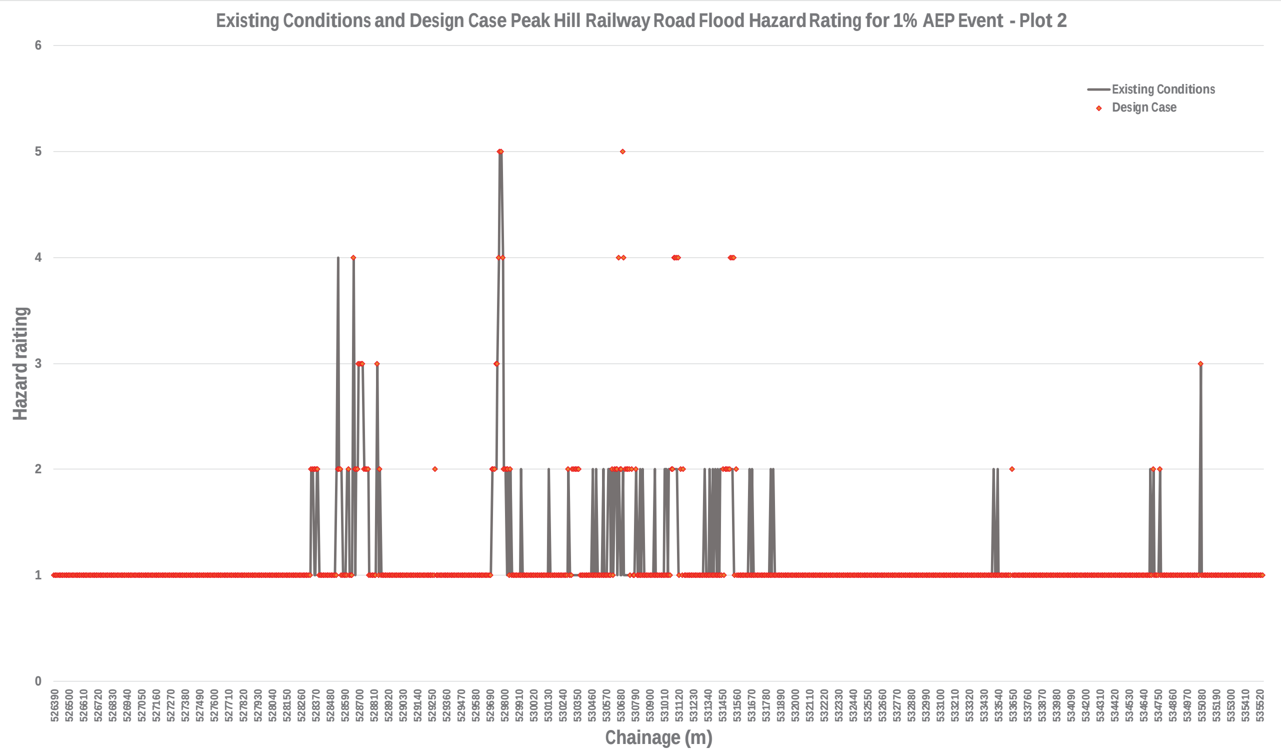


Figure 5.9 Change in flood hazard at Peak Hill Railway Road – 1% AEP Event

Table 5-6 Flood hazard assessment for Peak Hill Railway Road for 1% AEP event

Location (km)	Existing Conditions			Design Case			Hazard Category Impact
	Depth (m)	Velocity (m/s)	Hazard (m^2/s)	Depth (m)	Velocity (m/s)	Hazard (m^2/s)	
529.768	0.83	1.54	1.28 (H5)	0.84	1.25	1.06 (H5)	No change
530.33	0.37	0.62	0.23 (H2)	0.56	1.39	0.77 (H4)	Increase
530.5	0.32	0.67	0.22 (H2)	0.17	0.34	0.06 (H1)	Reduction
530.705	0.47	0.68	0.32 (H2)	0.73	1.41	1.03 (H5)	Increase
531.02	0.18	0.94	0.17 (H1)	0.09	0.67	0.06 (H1)	No change
531.132	0.40	1.26	0.50 (H2)	0.56	1.92	1.07 (H4)	Increase

Table 5-7 Flood hazard assessment for Peak Hill Railway Road for 10% AEP event

Location (km)	Existing Conditions			Design Case			Hazard Category Impact
	Depth (m)	Velocity (m/s)	Hazard (m^2/s)	Depth (m)	Velocity (m/s)	Hazard (m^2/s)	
529.768	0.75	1.36	1.02 (H4)	0.71	0.98	0.70 (H3)	Reduction
530.33	0.27	0.41	0.11 (H1)	0.41	0.87	0.36 (H2)	Increase
530.5	0.24	0.51	0.12 (H1)	0.08	0.09	0.01 (H1)	No change
530.705	0.42	0.50	0.21 (H2)	0.51	0.81	0.41 (H2)	No change
531.02	0.12	0.76	0.09 (H1)	0.07	0.58	0.04 (H1)	No change
531.132	0.33	1.16	0.38 (H2)	0.41	1.42	0.57 (H2)	No change

The assessment generally shows some localised increases in hazard for the 39% and 10% AEP events, with the increases low in number and located in areas where there is significant existing hazard. There are more significant increases in hazard for the 1% AEP event, but these increases are restricted to areas where the existing hazard is significant and where the road is unlikely to be trafficable under existing conditions.

It should also be noted that the improvements in the rail infrastructure delivered by the project will remove the current rail overtopping mechanism that causes washout of the rail and ballast and deposition of this material on the land downstream with associated hazards. It is also noted that the velocities in the design case remain relatively low (below 2m/s), and this road would be subject to high hazards over long distances where the project has no impact. Taking these other aspects of the flood risk into account, the localised increases in flood hazard are considered to constitute low risk impacts.

5.3.1 Compliance with Conditions of Approval

The status of compliance with the CoA is summarised in the following table.

Table 5-8 Summary of compliance with Conditions of Approval

CoA number	CoA	Compliance	Where addressed
E21	Further flood modelling based on the detailed design of the CSSI must be undertaken for flood impacts (including downstream impacts of the CSSI). The results of the modelling must be detailed in a Flood Design Report. The Flood Design Report must be prepared in consultation with OEH and relevant councils and include	Compliant – This report meets this part of CoA E21. Consultation with Parkes and Narromine Shire Councils has been undertaken during the preparation of this report. The report will be provided to OEH for review and comment.	This report Refer to Section 6 for consultation with councils
	(a) the results of the downstream flood assessment for the 5 year ARI event, 20 year ARI event, 100 year ARI event;	Compliant – The flood study identifies downstream impacts and for all events specified.	Sections 5.1 to 5.3
	(b) provide consideration of the consequences of extreme flood events greater than the 100 year ARI event;	Compliant – The flood study assesses the 1% AEP with climate change and the 0.05% AEP events.	Section 5.4 and Volume 2 of the Flood Study Report (3-0001-240-IHY-00-RP-0004)
	(c) flood height changes to a resolution no coarser than one (1) centimetre;	Compliant – Flood depth and extent maps and afflux maps have been prepared to the required resolution.	Appendices B and C and flood mapping contained in Volume 2 of the Flood Study Report (3-0001-240-IHY-00-RP-0004)
	(d) a comparison of the results with the requirements of Condition E22;	Compliant – Refer to response to E22 below	Response to E22 below
	(e) the mitigation and management measures that will be undertaken in the event that the assessment indicates that the flooding characteristics exceed the design objectives specified in Condition E22;	Compliant – All exceedances of the objectives have been classified as low risk impacts that do not affect ongoing use of the land.	Response to E22 below
	(f) changes in the depths of inundation including locations where previously there would have been no inundation;	Compliant – Afflux maps identify areas of new inundation.	Afflux maps contained in Appendix C and Volume 2 of the Flood Study Report (3-0001-240-IHY-00-RP-0004)
	(g) flow changes in all watercourses and overland paths;	Compliant – Flood modelling demonstrates that no changes to flow patterns or flow diversions will occur as a result of the project.	Flood impact mapping contained in Appendix C and Volume 2 of the Flood Study Report (3-0001-240-IHY-00-RP-0004)

CoA number	CoA	Compliance	Where addressed
	(h) an assessment of the impacts of the CSSI including impacts on sedimentation, erosion, scouring and bank and stream stability;	Compliant – Scour and erosion risks identified and mitigated through design of scour protection upstream and downstream of culverts and within channels where required.	Sections 4.4, 5.3.1.2 and 5.3.2.2
	(i) mitigation measures to minimise potential adverse impacts and respond to actual impacts in accordance with DPI's Guidelines for Controlled Activities on Waterfront Land; and	Compliant – Design incorporates scour protection measures and avoids diversion of flows to maintain hydraulic conditions as close to existing as possible.	Sections 4.4, 5.3.1.2 and 5.3.2.2
	(j) a description of the cross-sectional dimensions and location of all proposed spoil mounds associated with the CSSI.	Compliant – Spoil mounds to have been located outside of main flow paths.	Section 8 of Project Design Report (3-0001-240-PEN-00-RP-0012)
	The Flood Design Report must be reviewed and endorsed by a suitably qualified and experienced hydrologist who is independent of the person who prepared the Flood Design Report and whose appointment must be approved by the Secretary. The hydrologist's endorsement must include a statement verifying that new and replacement culverts have been designed in accordance with the requirements of Conditions E29 and E30.	Compliant – This report has been provided to the Department of Planning & Environment for review by their appointed Independent Hydrologist.	N/A
	The Flood Design Report must be submitted to the Secretary and OEH for information at least one (1) month prior to the commencement of construction of permanent works that may impact on flooding.	Compliant – Previous versions of this report have been provided to the Department of Planning & Environment for review.	N/A
E22	The CSSI must be designed with the objective of not exceeding, by reason of the SSI, the following flooding characteristics on adjacent lands / properties during any flood event up to the 100 year ARI:	Compliant – The study has assessed impacts under numerous events up to and including the 1% AEP event	Sections 5.2 and 5.3
	(a) a maximum increase in inundation time of five per cent for houses, commercial premises and urban areas and 10 per cent for roads, agricultural (grazing and cropping) areas and public infrastructure (e.g. water and sewage pump stations and sewage treatment plants);	Generally compliant – Instances where the criteria have not been met have been identified as low risk impacts that do not affect the ongoing use of the land.	Section 5.3.2.3
	(b) a maximum increase of 10mm in inundation at properties where flood levels are currently exceeded;	Compliant	Section 5.3.1.1
	(c) a maximum increase of 50mm in inundation at properties where flood levels are currently not exceeded;	Compliant	Section 5.3.1.1
	(d) no inundation of floor levels which are currently not inundated;	Compliant	Section 5.3.1.1

CoA number	CoA	Compliance	Where addressed
	(e) a maximum increase of 50mm along the Newell Highway and 100mm on all other roads; and	Generally compliant – Some localised exceedances occur on roads that are already subject to widespread flooding and not trafficable under the event for which the exceedances occur.	Sections 5.3.2.1 and 5.3.2.4
	(f) a maximum increase of 200mm on agricultural areas.	Generally compliant – Instances where the criteria have not been met have been identified as low risk impacts that do not affect the ongoing use of the land.	Section 5.3.2.1
	Where the flooding characteristics cannot be met, the Proponent must achieve compliance through modified design of the CSSI, or achieve an acceptable level of mitigation of impacts through at-property design measures (e.g. raised access tracks, flood refuge, house raising) in consultation with affected landowners / infrastructure owners. The mitigation measures must be detailed in the Flood Design Report required by Condition E21 and implemented within the timeframes specified in the Flood Design Report.	Compliant – Exceedances of the flood management objectives are minor, localised and do not affect ongoing use of the land. Consultation has been undertaken with affected landowners relating to these exceedances. Mitigation works in the form of minor land drainage modifications may be required by a small number of landowners subject to agreement with ARTC during the construction phase.	Sections 5.3.2 and 6
E23	For the first 15 years of operation, the Proponent must prepare a Flood Review Report(s) after the first defined flood event for any of the following flood magnitudes that occur – the 5 to 10 year ARI event, 10 to 20 year ARI event, 20 to 100 year ARI event. The Flood Review Report(s) must be prepared by a suitably qualified and experienced hydrologist(s) and include:	To be undertaken following future flood events	N/A
	(a) a comparison of the observed extent, level and duration of the flooding event against the impacts predicted in (or inferred from) the EIS, the Flood Design Report required by Condition E21 and the requirements specified in Condition E22; and	To be undertaken following future flood events	N/A
	(b) identification of the properties and infrastructure affected by flooding during the reportable event;	To be undertaken following future flood events	N/A
	(c) where the observed extent and level of flooding or other flooding or erosion impacts exceed the predicted impacts due to the CSSI with the consequent effect of adversely impacting on property(ies), structures and infrastructure, and/or exceed the requirements specified in Condition E22, identification of the measures that would be implemented to reduce future impacts of flooding related to the CSSI works, including the timing and responsibilities for implementation.	To be undertaken following future flood events	N/A
	A copy of the Flood Review Report(s) must be submitted to the Secretary for information and OEH and relevant council(s) within three (3) months of finalising the report(s).	To be undertaken following future flood events	N/A

CoA number	CoA	Compliance	Where addressed
	Additional flood mitigation measures must be developed in consultation with the affected property / structure / infrastructure owners, OEH and the relevant council(s), as relevant, and implemented within the timeframes specified in the Flood Review Report(s).	To be determined following review of flood behaviour during future flood events	N/A
E24	The Proponent must develop a methodology for spatially defining how the length(s) of the rail corridor impacted by a flood event will be determined for the purposes of Condition E23. The methodology must be developed in consultation with OEH and submitted to the Secretary for approval prior to commencement of operation of the CSSI.	To be confirmed with OEH	N/A
E25	Flood information including flood reports, models and geographic information system outputs, and work as executed information from a registered surveyor certifying finished ground levels and the dimensions and finished levels of all structures within flood prone land, must be made available to the relevant council(s), OEH and the SES upon request. The relevant councils, OEH and the SES must be notified in writing that the information is available no later than one (1) month following the completion of construction. Information requested by a relevant council, OEH or the SES must be provided within three (3) months.	This report and associated flood models and outputs will be provided to agencies upon request. A works as executed version of the report, model and model outputs to be provided following completion of construciton.	N/A

5.4 Other Results

5.4.1 Impacts of Climate Change

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

5.4.1.1 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 predicted significant increases in flood level (defined as greater than a 200mm increase) at 11 locations. The impact at these locations is summarised in the table below.

Table 5-9 Impact of climate change on rail formation flood immunity

Chainage Start (km)	Chainage End (km)	Length (m)	Max 1% AEP Increase in flood level (mm)	Formation Level overtopped (Y/N)	Max Ballast Inundation depth (mm)	Rail Overtopped (Y/N)
454530	454850	320	205	No	N/A	No
460510	460905	395	250	Yes	199	No
465380	465685	304	250	Yes (10% AEP flood immunity required)	150	No
477935	479060	1125	245	Yes (5% AEP flood immunity required between CH477440 to 478570)	250	No
489505	489995	490	225	Yes	251	No
492850	493280	430	245	Yes	197	No
510220	511060	840	260	Yes	230	No
515400	515720	320	200	Yes	15	No
520775	522485	1710	410	Yes (10% AEP flood immunity required between CH521400 to 522300, rail levels as existing rail between CH522300 to 526060)	360	No
522820	523000	180	Newly inundated in the 1AEPCC scenario.	No	N/A	No
529950	531850	1900	225	Yes (10% AEP flood immunity required between CH529800 to 531600)	535	No

The results are considered to demonstrate resilience in the design and capacity to accommodate climate change for the following reasons:

- The impact of climate change is concentrated at 11 locations totalling only 8.0km (or 8.2%) of the project length;
- For the areas most affected, the depth of submergence of the formation remains less than 300mm on average; and
- The rail is not overtopped at any location.

5.4.1.2 Impacts on Adjacent Land

The 1% AEP with climate change flood impact maps for afflux, velocity and duration are provided in Appendix C. The maps demonstrate the following:

- Afflux impacts remain similar to the 1% AEP impacts without climate change at most locations. Afflux is more pronounced but non-compliances are generally confined to the same areas where land use is not sensitive. Some new areas of non-compliance are introduced – refer to 502.5km to 506km on map DE1CCA14; 509km to 512km on map DE1CCA16; 520km to 522km on map DE1CCA18; 530km to 532km and 534km to 535km on map DE1CCA21. These new non-compliances are confined to agricultural land upstream of the alignment;
- Velocity impacts remain similar to the 1% AEP impacts without climate change at all locations; and
- Duration impacts remain similar to the 1% AEP impacts without climate change at all locations.

Given that the flood impacts remain similar under the climate change scenario, with no marked increase in flood risk, the design is considered to have capacity to accommodate future climate change.

5.4.2 Extreme Event Impacts

The 0.05% AEP event was simulated to determine the potential impacts of the project under an extreme flooding scenario. For this event, the rail line was modelled as fully intact. This exaggerates the likely impacts of the project under this event as the embankment is likely to wash away in a number of locations under such conditions, which would equalise water levels across the rail corridor at the peak of the event.

The 0.05% AEP flood maps for existing conditions and the design case are provided in the Flood Study Report Volume 2 (3-0001-240-IHY-00-RP-0004). This section summarises the 0.05% AEP afflux impacts of the project at key sensitive locations.

Figure 5.10 below shows the 0.05% AEP afflux around Peak Hill where significant urban areas are located close to the rail corridor. The figure shows that afflux remains contained within the non-sensitive land areas. The maximum afflux value in this area remains below 500mm.


Grey area: Afflux < 100mm
Orange areas: Afflux up to 200mm
Red areas: Afflux > 200mm
CH 501.50
CH 501.00
CH 500.50
CH 500.00
CH 499.50
CH 499.00
CH 498.50
CH 498.00
CH 497.50
CH 497.00
CH 496.50
CH 496.00
CH 495.50

Figure 5.10 0.05% AEP event afflux near Peak Hill

Figure 5.11 below shows the 0.05% AEP afflux in the Burrill Creek catchment which experiences widespread high afflux for this event. The figure shows that afflux remains contained within the non-sensitive land areas. The maximum afflux value in this area remains below 500mm. Buildings / residences in the area remain outside the afflux impact.

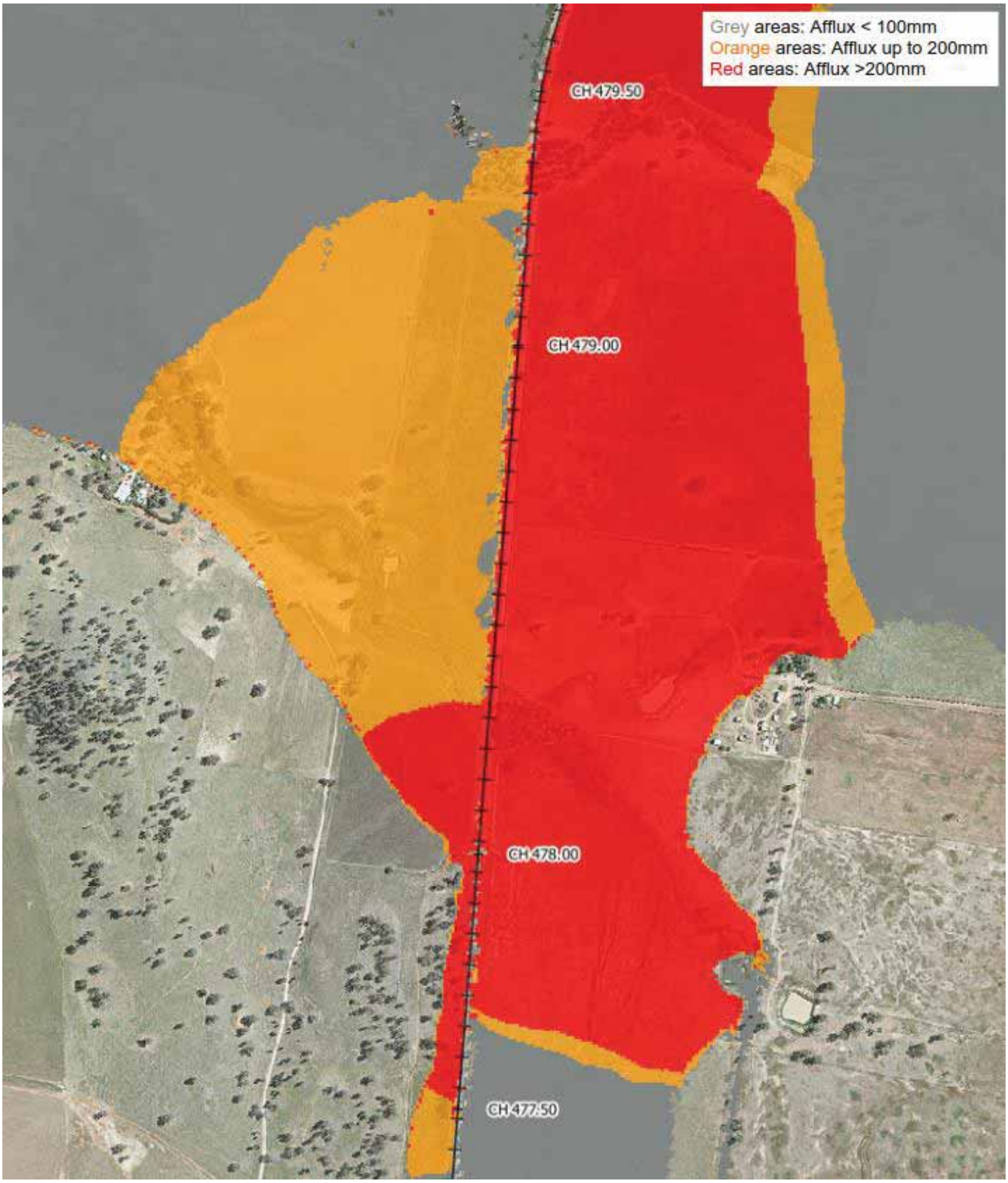


Figure 5.11 0.05% AEP event afflux in Burrill Creek catchment

5.4.3 Cross Drainage Design Justification

The design process followed for the cross drainage is described in Section 4.4. The design was developed to balance impacts across the range of flood events and upstream and downstream of the rail corridor. To demonstrate the reasonable balance achieved in the design and give confidence that a cost effective outcome was achieved (i.e. that the cross drainage was not overdesigned), the following figures show how the afflux impact was balanced at key locations.

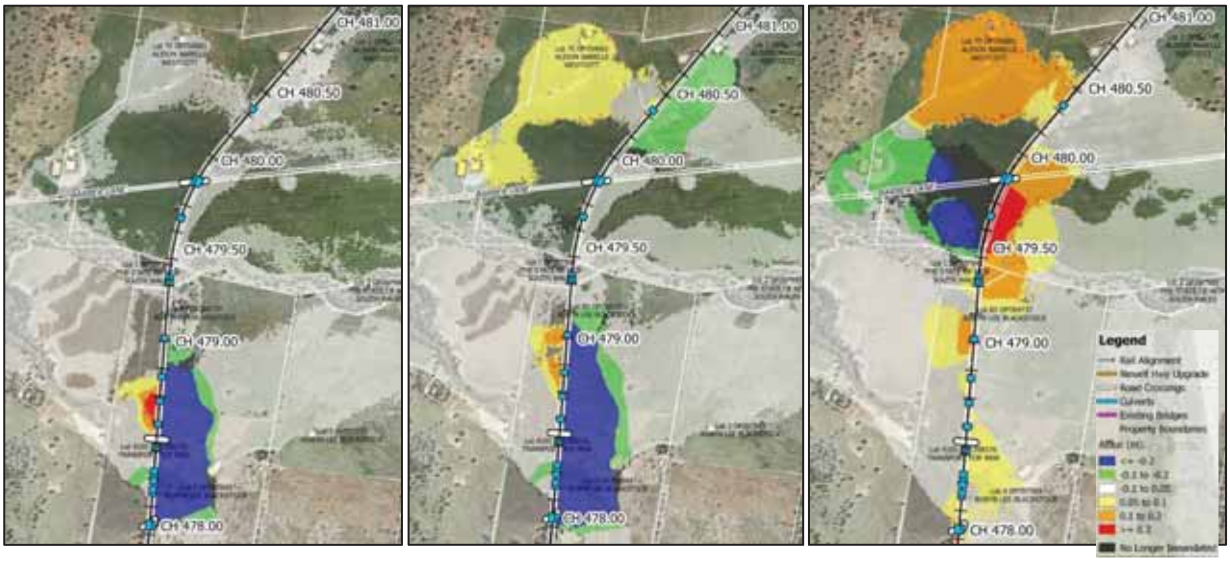


Figure 5.12 Balancing of afflux impact at Burrill Creek for 39, 10 and 1% AEP events

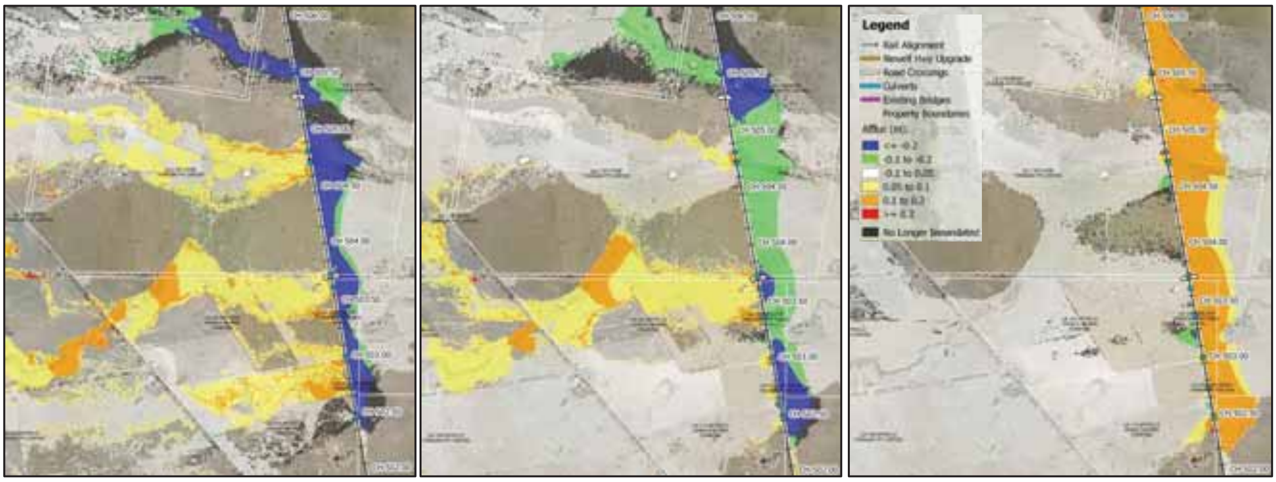


Figure 5.13 Balancing of afflux impact at 502 to 506km for 39, 10 and 1% AEP events