TECHNICAL REPORT 03

Updated flooding and hydrology assessment

Appendix P TUFLOW Fine Grid Modelling Report

NARROMINE TO NARRABRI PROJECT

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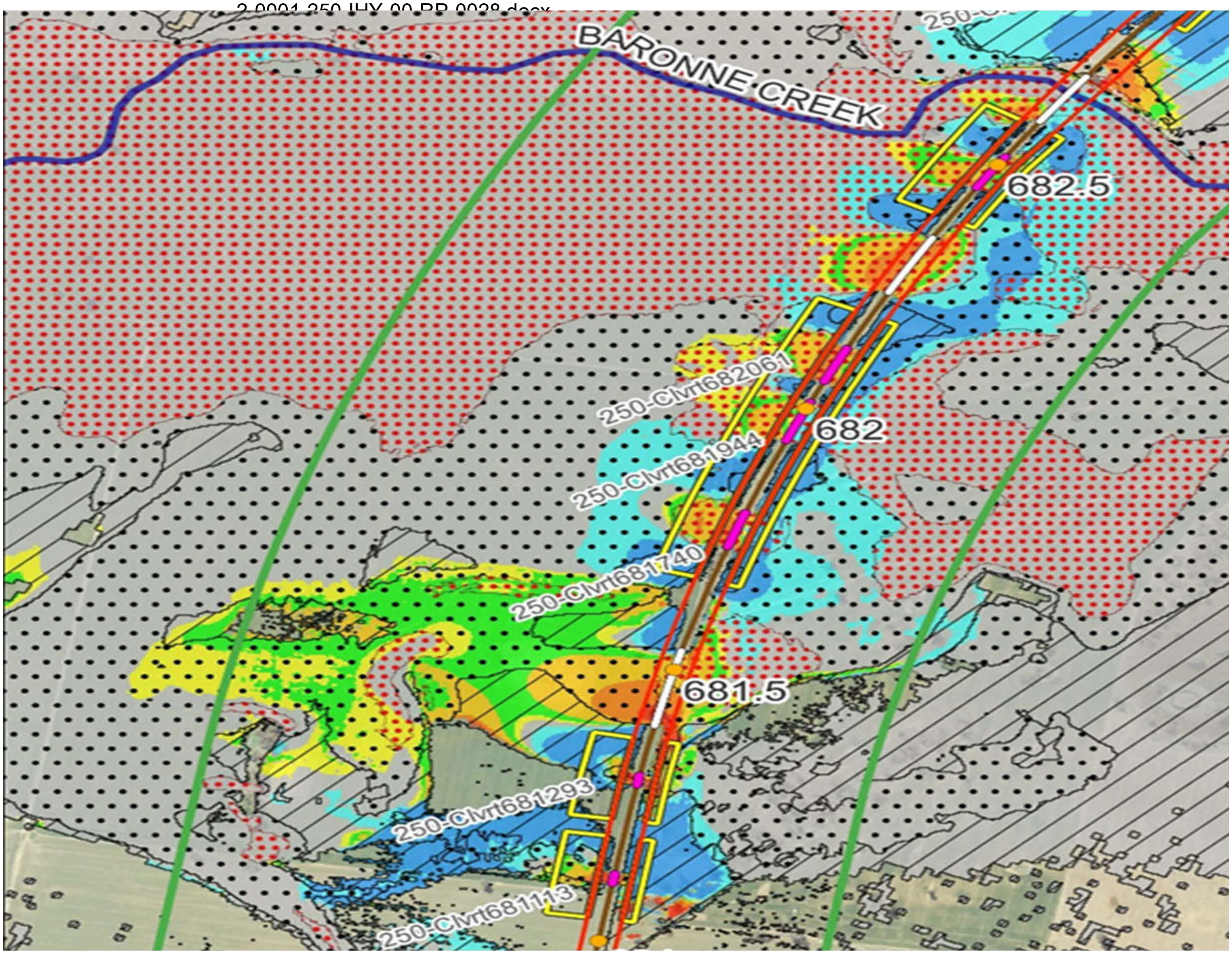

ARTC Inland Rail

Narromine to Narrabri (N2N)

Flooding and Hydrology - Technical Note 16 – Fine Grid Modelling, Velocity QDL Compliance and Geomorphological Assessment for Selected Culvert Locations

Revision 0

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References

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1. Introduction

1.1 Background

ARTC is seeking planning approval to construct the Narromine to Narrabri (N2N) section of Inland Rail. The project has been declared Critical State Infrastructure, and an Environmental Impact Statement (EIS) was submitted to the NSW Department of Planning and Environment (DPE, formerly the NSW Department of Planning, Industry and Environment (DPIE)) in September 2020.

The EIS has been placed on public exhibition, and comments have been received relating to the assessment of flooding impacts. DPE has also provided comments on Technical Report 3 – Flooding and Hydrology Assessment Report in the letter from Bewsher dated 18 March 2021. Given the close proximity of the culvert inlets and outlets to the corridor boundary it has been recognised that the 10 m grid TUFLOW model may not be reliably representing the change in velocity caused by the proposal at the corridor boundary. In addition, DPE has requested that predicted peak velocities associated with the project comply with the flow velocity Quantitative Design Limits (QDLs) outside of the rail corridor and drainage control areas (DCAs).

Fine grid modelling for selected culvert locations using TUFLOW 2.5m quadtree mesh has been completed to provide examples that demonstrate the ability of the project to reduce QDL departures.

Fine grid TUFLOW modelling for Wallaby Creek and Baronne Creek has been undertaken to provide higher resolution definition of flow velocity patterns and impacts to velocities and scour/erosion risk. Assessment of compliance with the velocity QDLs is undertaken with respect to the fine grid modelling results.

1.2 Purpose

The purpose of this Technical Note is to present results from TUFLOW fine grid modelling at selected locations and to assess compliance with velocity QDLs. Assessed Erosion Threshold Velocities (AETVs) are defined for the fine grid modelling locations based on outcomes of site specific fluvial geomorphological and geotechnical assessment of erosion potential, in accordance with the velocity QDLs. The technical note also outlines other management and mitigation measures available for consideration during detailed design to manage/mitigate residual QDL noncompliance.

1.3 Outline methodology

The methodology adopted was to:

- Select representative culvert locations and flood events for fine grid modelling.
- Develop 2.5m quadtree mesh fine grid models for the selected culvert locations.
- Assess impacts of the project on peak flow velocities in the 1% AEP flood event for the selected culvert locations using fine grid modelling.
- Assess velocity QDL compliance based on 1%AEP peak flow model outputs using AETVs based on site-specific geotechnical and geomorphological conditions at structures within the fine grid modelling sites.
- In addition to assessing velocity QDL compliance also assess the erosion potential of watercourses and overland flows within the fine grid modelling areas.
- Assess feasibility of potentially increasing proposed culvert crossing sizing to attenuate culvert entry and exit transition flow velocities.
- Provide information and results on the additional engineering options/scenarios assessed for the selected culvert locations.

1.4 Limitations

This report has been prepared by JacobsGHD IR Joint Venture (JacobsGHD) for ARTC and may only be used and relied on by ARTC for the purpose agreed between JacobsGHD and the ARTC as set out in section 1.2 of this report.

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The opinions, conclusions and any recommendations in this report are based on assumptions made by JacobsGHD described in this report. JacobsGHD disclaims liability arising from any of the assumptions being incorrect.

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The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this Report. JacobsGHD does not accept responsibility arising from, or in connection with, any change to the site conditions. JacobsGHD is also not responsible for updating this report if the site conditions change.

2. Selection of Locations for Fine Grid Modelling

2.1 Overview

Following discussions between DPE and ARTC through the Hydrology Working Group, it was suggested that a finer resolution TUFLOW grid would provide more detailed predictions of changes in velocities between the existing and the design conditions.

TUFLOW models to fine-grid resolutions and validation of modelling results for the entire project constitute significant undertakings during development of the Reference Design. Therefore, as agreed with DPE, fine grid modelling of the Reference Design has been undertaken at representative locations to assess velocity QDL non-compliances and potential mitigation solutions. a

As part of the Flooding and Hydrology Assessment Report (FHAR), drainage control areas have been provisioned at approximately 200 culvert locations to provide additional space in which to implement mitigation measures as part of detailed design, e.g. through consideration of erosion protection or velocity reduction measures to limit associated scour. The drainage control areas (DCAs) extend 50m downstream and 15m upstream from the rail corridor.

2.2 Location selection criteria

Culverts, or groups of culverts, were selected for the fine grid modelling based on velocity threshold exceedances, combined with a risk rating based on the design case velocity exceeding 1m/s. The nominated velocity threshold used for the culvert selection was where design case velocity = existing case velocity + 10%. Refer to the following sections for further details.

2.3 Culvert Locations for the Project

There are a total of 606 drainage culvert locations under the proposed Inland Rail embankment between Narromine and Narrabri. Some of these locations cross well-defined rivers and creeks that generally have flowing water. Others cross ephemeral channels that would only flow during wetter periods. On larger flood plains, flood relief culverts have also been included to allow overland floodwaters to flow under the rail embankment. These would only be active during flood events when overbank flows from rivers and creeks inundate the flood plain.

Section 7.2.4 of the FHAR, Revision 7, provides further information on the velocities downstream of culverts, sampled at the project boundary (including DCAs) for the 1% AEP flood event in the 10m grid TUFLOW modelling.

– A total of 129 culverts have maximum design velocities exceeding the 10% threshold test. but less than 1m/s. These were nominally categorised as “low risk” on the basis that there would be a reasonable likelihood the velocity would be below an assessed erosion threshold velocity, or a drainage solution would be conventionally achieved as part of the detailed design.
– A total of 16 culverts have design velocities exceeding the 10% threshold test and1m/s. These were nominally categorised as “medium risk” on the basis that a drainage solution would be determined as part of the detailed design within the nominated drainage control area, but more extensive treatments could be expected to reduce velocities or provide erosion protection.

2.4 Selection of TUFLOW Models

Fourteen TUFLOW hydraulics models with 10 metres grid resolution were developed to define flood behaviour along the project. The extent of the project covered by each TUFLOW model is shown in

Table 2-1. Each model covers a portion of the project site and an area of the floodplain upslope and downslope sufficient to capture any potential upstream breakouts, changes in flood behaviour due to the project and backwater influences.

Table 2-1 Extent of the project represented in each hydraulics model

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

TUFLOW models N2N9 and N2N13 were selected as containing culvert examples that are representative of the overall project and small enough in size to run efficiently for results to be provided in a reasonable timeframe.

TUFLOW models N2N9 and N2N13 were selected to be transferred to TUFLOW - 2020-10-AD (current at time of analysis). This is capable of more detailed local analysis using quadtree mesh with a grid resolution of 2.5m.

2.5 Selection of Culvert Locations

The N2N9 10m grid TUFLOW model includes 33 culvert locations along the N2N rail corridor. These culverts cross floodplains of Baronne Creek; the main channel of Tenandra Creek and its floodplain; and several unnamed watercourses and their associated floodplains. Seventeen culvert locations (refer to Figure 3-1) within the N2N9 TUFLOW model have been selected for fine grid modelling. Ten of the selected culvert locations are located between chainage 680,800m and 683,800m and the remaining seven culvert locations are located between chainage 693,900m and 695,700m. The number of culvert cells in the Reference Design at the 17 locations varies between 3 and 28, and the width of each culvert cell is 2.4 metres. DCAs have been defined at 15 culvert locations and there are two culvert locations without DCAs.

All 7 culvert locations across the N2N corridor represented in N2N13 10m grid TUFLOW were selected for fine grid modelling. These culverts cross the main channel of Goulburn Creek and its floodplain, and other minor tributaries and their floodplains. The number of culvert cells at the seven locations varies between 20 and 30 and the width of each culvert cell is 2.4 metres. DCAs have been defined at six culvert locations and there is one culvert location without DCA (refer to Figure 3-2).

2.6 Representative Nature of Culvert Locations

The distribution of culverts selected for quadtree mesh modelling versus the total number of culverts is shown graphically in Figure 2-1 and in Table 2-2. Further details for each culvert are provided in **Appendix A**.

Table 2-2 and Figure 2-1 illustrate that the selected culverts cover a range of scenarios from examples that comply with the earlier considered 10% increase from existing velocity condition criteria used for selection of culverts for fine grid modelling to those with minor departures (i.e. design velocities < earlier considered 1m/s limit) and larger departures (design velocities >earlier considered 1m/s limit).

The distribution is skewed with a lower number of culverts selected that comply with the earlier considered 10% increase from existing velocity condition criteria and a higher number of locations exhibiting a larger velocity departure that do not comply with the earlier considered 10% increase from existing velocity condition criteria. This is intentional, as if QDL assessment and design development using quadtree mesh can demonstrate compliance with the velocity QDLs (refer section 3.2 for velocity QDL definition) in areas of larger departures, then it would be expected that it would be a simpler task to achieve velocity QDL compliance in areas with minor departures.

The fine grid modelling results also confirm a skew where 75% of locations have maximum design velocities above the default Erosion Threshold Velocity (ETV) of 0.5m/s.

Figure 2-1 Illustration of representative nature of culverts to be analysed in quadtree mesh

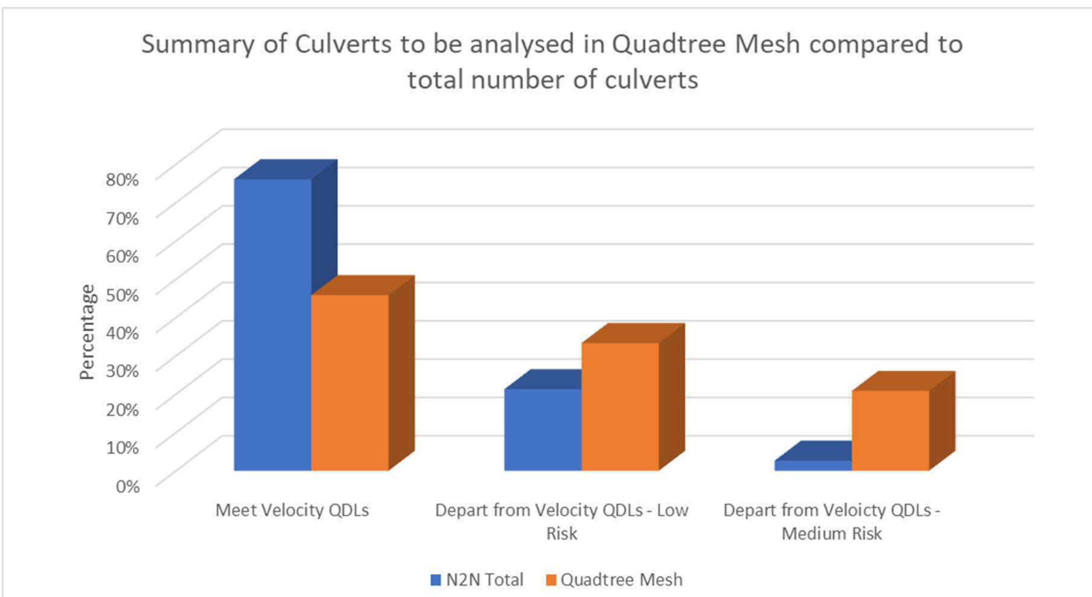


Table 2-2 Summary of number of culverts in quadtree mesh compared to N2N total

item	N2N Total	quadtree Mesh	N2N Total	quadtree Mesh
Meet 10% increase from existing velocity*	461	11	76%	46%

Above 10% increase from existing velocity – Minor departure	129	8	21%	33%
Above 10% increase from existing velocity – Larger departure	16	5	3%	21%
	606	24	100%	100%

* 10% increase from existing velocity in the 10m grid modelling was used as a criterion for selection of culverts for fine grid modelling.

Velocities provided in **Appendix A** are derived from TUFLOW 10m grid models and have been measured at the project boundary, including the drainage control areas nominated within the Preferred Infrastructure Report.

3. Methodology

3.1 Fine Grid Modelling Overview

As discussed in Section 2.4, N2N9 and N2N13 10m grid TUFLOW models were selected for conversion from version 2018-03-AE to 2020-10-AD to utilise 2.5m quadtree mesh for the selected culvert locations.

3.1.1 N2N9 TUFLOW model

N2N9 10m grid TUFLOW model includes 33 culvert locations across the N2N rail corridor as shown in Figure 3-1. These culverts cross Baronne Creek, Tenandra Creek and several unnamed watercourse and their associated floodplains. In total, 17 culvert locations were selected for representation in 2.5m quadtree mesh.

3.1.2 N2N13 TUFLOW model

N2N13 10m grid TUFLOW model includes seven culvert locations across the N2N rail corridor as shown in Figure 3-2. These culverts cross Goulburn Creek and other minor tributaries. All culvert locations were selected for representation in 2.5m quadtree mesh.

3.1.3 Extent of quadtree mesh

A conservative approach was adopted at this stage in the selection of the widths of the 2.5m quadtree mesh upstream and downstream of the N2N corridor for both N2N9 and N2N13 TUFLOW models to understand the model performance and impact pattern, with a view to informing on more suitable widths of the quadtree mesh for future modelling. The adopted width of the 2.5m quadtree mesh was for this exercise only. It is expected that the 750m width (250m upstream and 500m downstream) of the 2.5m quadtree mesh would be narrowed down appreciably for the detailed design.

Two 2.5m quadtree mesh extents were defined for the N2N9 TUFLOW model (refer Figure 3-1). Figure 3-2 shows the extent of the 2.5m quadtree mesh in the N2N13 TUFLOW model. Selected culverts located within the extent of the quadtree mesh were represented in two-dimensions (2D) for a higher detail representation of flow contraction and expansion at each culvert location.


Legend
Rail Alignment
Culverts
Bridges
Quadtree extent
Model Domain
0 1 2 3 km

Figure 3-1 N2N9 TUFLOW model and the extent of 2.5m quadtree mesh

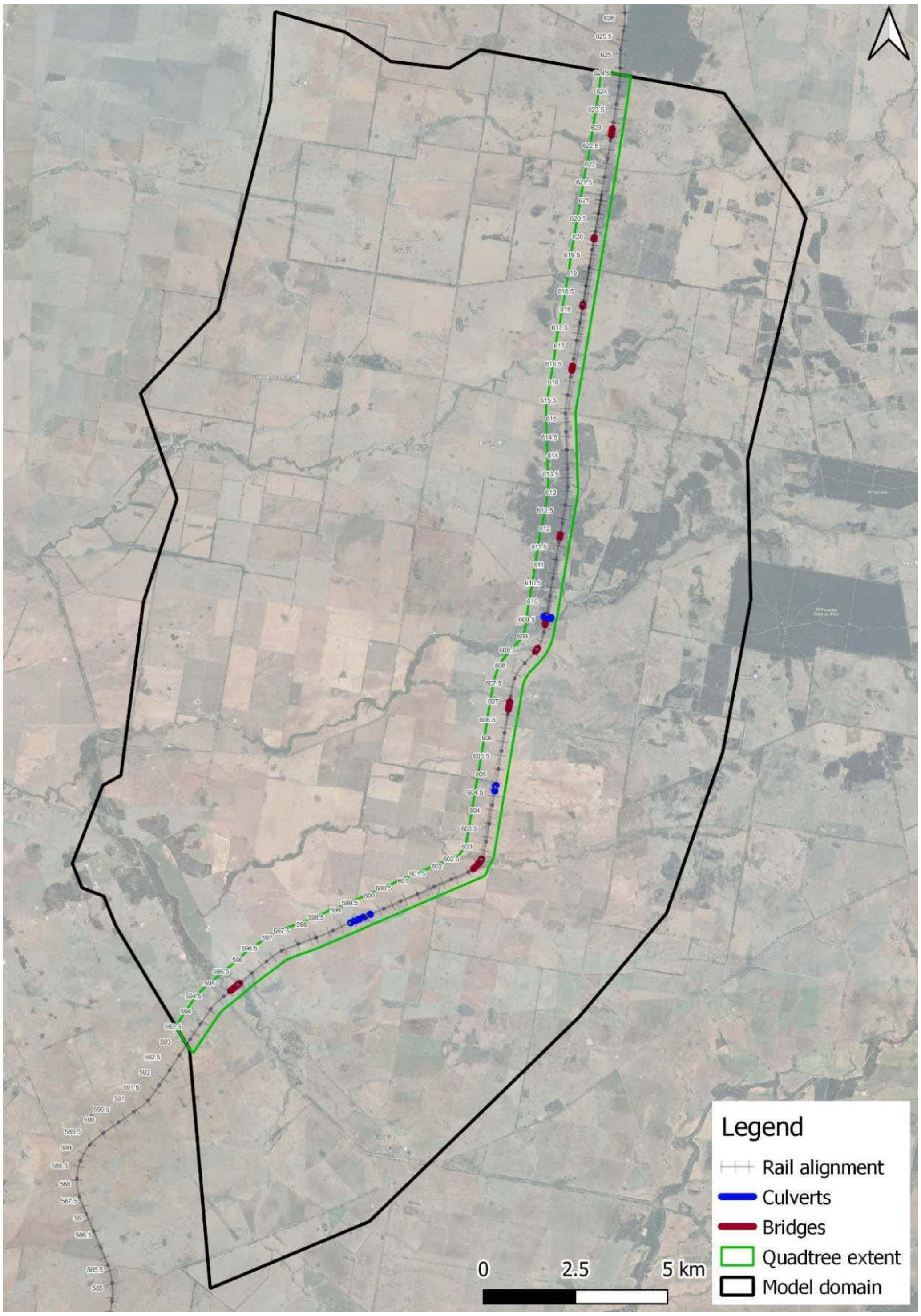


Figure 3-2 N2N13 TUFLOW model and the extent of 2.5m quadtree mesh

3.1.4 Representation of culverts

Selected culverts included in Reference Design with 3 or more 2.4m wide cells were represented in 2D in the 2.5 quadtree mesh models. Adopted parameter values for the 2D culverts are provided in Table 3-1. It is to be noted that the value of L1_FLC (TUFLOW form loss coefficient for structure Layer 1 i.e. between invert and obvert) adopted for the 2D culverts was 1.5 as used in the 1D representation of culverts that were replaced with 2D structures. Further investigations would be undertaken during detailed design to check appropriateness of this conservative assumption on the adopted value of L1_FLC.

Table 3-1 Adopted TUFLOW parameter values for culverts represented in 2D

TUFLOW Parameter	Adopted Parameter Values
TUFLOW Build	2020-10-AD
Layered FLC Default Approach	Method C
Invert (m AHD)	Average of upstream and downstream invert levels adopted for 1D culverts
dZ (m)	0
Shape_Width (m)	7.5
Shape_Option	Null
L1_Obvert (m AHD)	Top of Rail (ToR) - depth to obvert
L1_pBlockage (%)	Total width of culvert / (Number of grid cells *2.5) *100 + debris blockage (minimum 25% else ARR 2019 calculated debris blockage)
L1_FLC	1.5
L2_Depth (m)	ToR - L1_Obvert
L2_pBlockage (%)	100
L2_FLC	1.56
L3_Depth (m)	1.2
L3_pBlockage (%)	10
L3_FLC	0

3.1.5 Debris blockage

Calculations were initially based on ARR 2019 to provide a debris blockage of 0% at the majority of the culvert locations selected for fine grid modelling. However, DPE's reviewer has expressed a view that a minimum blockage of 25% be applied to all culverts for this project and for demonstrative purposes has therefore been adopted for this exercise.

For the purposes of this report, the more conservative value of a minimum 25% blockage has been adopted with no adjustments to cater for debris blockage at multiple culvert cells. The assessment is based on the with-blockage scenario. Comparison of blockage and all-clear scenarios indicated negligible differences in upstream and downstream flow velocities in the majority of culvert locations.

Further investigations would be undertaken during detailed design to validate the ARR 2019 blockage calculation input data and confirm the blockage factor to be adopted for detailed design of culverts.

3.1.6 Selection of flood event

A review of peak flow velocities at the selected culvert locations based on 1D representation of culverts in 10m grid TUFLOW models for the 20% AEP, 5% AEP, 2% AEP and 1% AEP events indicates that the peak flow velocity at the majority of culvert locations occur in the 1% AEP event. Hence, the 1% AEP event was selected for fine grid modelling. In addition, earlier fine grid modelling undertaken for both Wallaby Creek and Baronne Creek (refer to report 2-0001-250-IHY-00-RP-0025) demonstrated peak velocities in the 1%AEP event where critical and therefore also supports selection of the 1% AEP event for the current fine grid modelling.

3.2 Velocity QDL definition

As advised by the Department of Planning and Environment, the velocity QDLs to be adopted are outlined below:

Protected surfaces - 20% increase in velocity where existing velocity already exceeds 1m/s. Local variations in velocity can exceed a 20% change provided that when assessed over a 30m wide flowpath, the velocity change on average does not exceed 20%

Other areas including watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas - An erosion threshold velocity (ETV) of 0.5m/s is to be adopted unless otherwise determined through a site-specific assessment(s) conducted by an experienced geotechnical or scour/erosion specialist to establish an assessed ETV (AETV).

1. Where existing velocity exceeds AETV, velocity is limited to a 0.025m/s increase.
2. Where existing velocity is less than AETV, velocity is limited to the lesser of:
    - Assessed ETV (AETV), or
    - 20% increase or 0.5m/s, whichever is greater. Local variations in velocity can exceed a 20% change provided that when assessed over a 30m wide flowpath, the velocity change on average does not exceed 20%

The floodplain areas assessed in the fine grid modelling are characterised entirely as unprotected surfaces/other areas.

From here on in this report, "default velocity QDL" refers to the situation where no AETV is defined, and the default ETV of 0.5m/s is to be adopted and design velocity is to be limited to 0.025m/s when existing velocity >0.5m/s.

Mapping of the fine grid modelling using the Reference Design is provided in **Appendix B**. Changes in velocity and QDL exceedances using the default ETV are mapped. The exceedances using the default ETV (i.e. 0.5m/s where no site specific ETV has been assessed) are used to inform the further detailed QDL compliance assessment for each of the selected culvert.

3.3 Velocity QDL compliance assessment methodology

The modelling results from the fine grid modelling were used to map areas where the maximum design velocity did not comply with the default velocity QDLs. An assessment of QDL compliance, site-specific Assessed Erosion Threshold Velocities (AETVs), geotechnical soil characteristics and fluvial geomorphology, was then conducted to assess the erosion potential at each culvert location.

Assessment steps are as follows:

Step 1 – does the velocity increase?

- No – Complies, no further assessment required.
- Yes – Use QDLs as stipulated below & proceed to **Step 2**.

Protected surfaces - 20% increase in velocity where existing velocity already exceeds 1m/s. Local variations in velocity can exceed a 20% change provided that when assessed over a 30m wide flowpath, the velocity change on average does not exceed 20%

Other areas including watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas - An erosion threshold velocity (ETV) of 0.5m/s is to be adopted unless otherwise determined through a site-specific assessment(s) conducted by an experienced geotechnical or scour/erosion specialist leading to an assessed ETV (AETV).

1. Where existing velocity exceeds AETV, velocity is limited to a 0.025m/s increase.
2. Where existing velocity is less than AETV, velocity is limited to the lesser of:
   - Assessed ETV (AETV), or
   - 20% increase or 0.5m/s, whichever is greater. Local variations in velocity can exceed a 20% change provided that when assessed over a 30m wide flowpath, the velocity change on average does not exceed 20%.

Step 2 – is velocity increase > 0.025m/s?

- No – Complies
- Yes – go to **Step 3**

Step 3 – Is there an assessed ETV (AETV)?

- No – (not relevant in this assessment as all sites have been assessed)
- Yes – check parameters used to assess site-specific AETV against available N2N geotechnical data. Go to **Step 4**

Step 4 – Where existing velocity > AETV, is design velocity < existing velocity + 0.025m/s?

- Yes – Complies
- No – Exceedance. Go to **Step 7**

Step 5 – Where existing velocity < AETV:

a. Is the design velocity < 0.5? – Yes – Complies; No – Go to **Step 5b**
b. is the max design velocity < existing velocity + 20% – Record and Go to **Step 5c**
c. Is the design velocity < AETV?

- If either a or (b + c) = Yes, Complies
- No, Exceedance, go to **Step 6**

Step 6 – Is design velocity < 20% across a flowpath of up to 30m? Assuming this means across the width of flow (up to 30m wide), at the point of max. velocity within 1km of structure.

- Yes – Complies (not used in this study as maximum velocities adopted for conservative assessment).
- No – Exceedance, go to **Step 7**

Step 7 – check site-specific factors, including vegetation cover, the presence of existing erosion and geomorphology for potential erosion and degree of likely management required to reduce adverse impacts from erosion

A full explanation of the methodology used is presented in a separate report (full reference yet to be determined).

3.4 Assessed Erosion Threshold Velocities (AETVs)

The crucial component in the QDL compliance assessment is establishment of site-specific AETVs. These have been established along the proposal alignment, including in the fine grid modelling extent, based on the following:

- Where available, site-specific calculations of AETV from the Erosion Potential and Fluvial Geomorphology Assessment (2022b) were used.
- The Project alignment was split into sections with similar soil and geomorphological characteristics (Geomorphological Units, as defined in the FHAR, 2022a).
- Further checks were carried out to validate the AETV's in terms of the identified Geomorphological units. These checks were based on the method proposed by Hewlett *et al*. (1987), which is based on (1) flow velocity, (2) type/condition of cover; and (3) duration of flow, refer to Figure 3-3. The maximum velocity flow duration used in this assessment was based on modelled duration values or a qualitative assessment of rainfall / runoff lag time, based on catchment size, soil / vegetation properties and watercourse geomorphology. This assesses the length of time that peak flows are anticipated to act on the channel. Hewlett *et al*.'s findings are similar to those of Fischenish (2001), applied to Australian watercourses by Gippel (2020). These results are based on steady state flows, rather than a peaked hydrograph.

Other information used for determination of the AETVs included:

- Borehole data near watercourses at CH588194, CH599110, CH623146, CH686235, CH591345, CH693966 and CH694184.
- A further borehole and test pit near to CH602663.
- Test pit data near watercourses at CH598994, CH605002, CH616680, CH620300, CH623146, CH679273, CH685522, CH694184, CH984568 and CH700017.
- Flow duration information and assessment of catchment characteristics.

Table 3-2 summarises the AETVs and rationale for their definition for the area covered by the fine grid modelling.

Table 3-2 Site-specific AETVs used in the fine grid modelling areas

Site Specific Information	Geomorphological Unit	Chainage	AETV (m/s)	Rationale for AETV
Ewenmar Creek	Keelindi Alluvial Plains	595239	2	Soil found on site is Silty Clay which is consistent with BH2007, but samples of Sand were extracted from TP2022. Assessment based on the soil being a Silty Clay indicates Very Low to Low erodibility. However, it can be increased to Moderate to High if more Sand is found at the site. Average to good vegetation cover, with moderately long duration flows.
Goulburn Creek	Keelindi Alluvial Plains	599110	2	Soil observed on site is medium to high plasticity Clay and consistent with BH2067. Erodibility is assessed as Very Low considering the erosion resistance of the Clay is high. Average to good vegetation cover, with moderately long duration flows.
Emogandry Creek	Keelindi Alluvial Plains	602663	1.4	Soil observed on site appears slightly plastic. is medium to high plasticity Clay and consistent with BH2067. Erodibility is assessed as Low to Very Low considering the design velocity is relatively high, and the creek has poor grass cover at some spots. Moderate flow duration.
Kickabil Creek	Keelindi Alluvial Plains	609715	2	BH2010 shows both stiff Clay layer and dense sand layer. Coarse sand and gravels were observed both upstream and downstream of the culvert. If the soil is predominantly Sand/Gravel, erodibility is Medium to High. If, however, the soil is predominantly Clay, erodibility is assessed as Low. Average to good grass cover within the creek and floodplain with moderate flow duration.
Milpulling Creek	Keelindi Alluvial Plains	616680	1.4	Coarse Sand was observed on river banks. Erodibility assessed as Medium to High. Average design flow velocity is expected to exceed threshold velocity for soil with poor grass cover.

Site Specific Information	Geomorphological Unit	Chainage	AETV (m/s)	Rationale for AETV
Overland Flow	Basalt Colluvial Plains	686020	2	BH2058 shows both Sand and Clay layers, but TP2132 and TP2133 both show Hard Clay. Land has good vegetation cover. Erodibility is assessed as Very Low to Low considering the low stream power.
Unnamed Creek	Basalt Mesa Plains	697901	4.5	EP2011 and TP2074 show Clayey Sand and Sandy Clay. Samples collected on site are medium to high plasticity clay with good erosion resistance. Erodibility assessed as Very Low based on samples collected on site and considering the short duration of the design flow. Note that a more conservative value of 3m/s was adopted for this section of the alignment, based on information at nearby sites.

The AETVs established for the Erosion Potential and Fluvial Geomorphology Assessment (2022b) used a reach-averaged flow velocity. In this assessment, peak flow velocities have been used. It is noted that the duration of peak flows is lower than the average flow duration and as such represents a conservative basis of assessment. Notwithstanding this, a further velocity QDL compliance sensitivity assessment has been applied using the AETV less 20% (i.e. 80% AETV).

In all cases, poor vegetation cover has been assumed.

In dispersive soils, clay particles can spontaneously disperse into water without any hydraulic shear drag caused by the flow. However, dispersive behaviour is affected by impurities in water. Even a low percentage of dissolved solids in water can suppress dispersive behaviour of clay (Wan, 2005). Good vegetation cover can also bind the soil particles together and increase the erosion resistance of a clayey soil even if the clay fraction of the soil is dispersive. Dispersive soils are present within the study area. However, true dispersion was not observed at the majority of assessed sites, largely due to the presence of stabilising vegetation and turbid flows. Dispersive-type features were observed, but these tended to be associated with silty, sandy or fissured clay soils.

At sites where dispersive soils have been identified through laboratory testing, it would be impractical to attempt to restrict dispersion through imposition of velocity limits, as dispersive erosion is most likely to occur in bare soils exposed to intense rain (i.e. clear water), e.g. during construction, following a drought or flows with a low suspended sediment load. This would, instead, be mitigated by successful construction management measures and post-construction rehabilitation, which would be an integral part of any modern project.

While on site, the performance of existing in-channel structures associated with existing roads and tracks was assessed in terms of the geomorphological functioning of the observed watercourses. Sedimentation was found to be a greater problem than erosion at existing in-channel structures. The high mobile bedload of the watercourses requires sufficient sediment throughput to avoid blockage and disruption of the natural sediment transport mechanisms.

Figure 3-3 Potential for initiation of scour erosion based on flow velocity, duration of flow and type of ground surface protection (Figure 9, CIRIA Report 116, Hewlett et al., 1987)

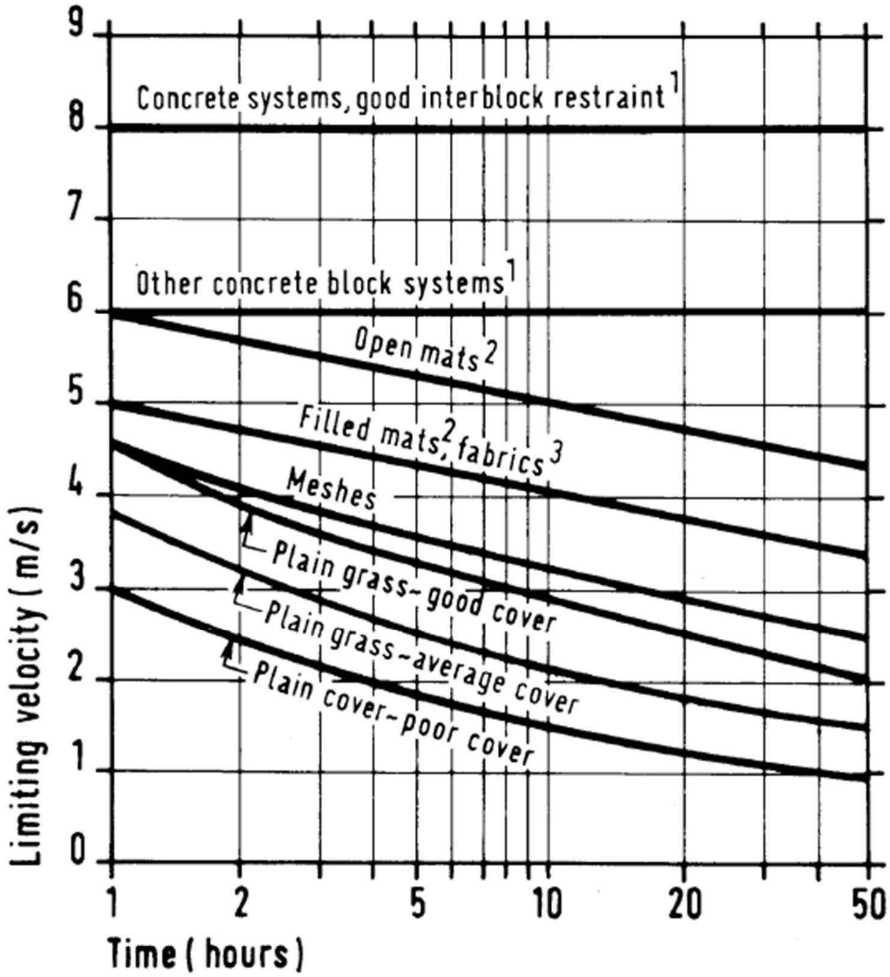


Figure 9 *Recommended limiting values for erosion resistance of plain and reinforced grass*

Notes:
1. Minimum superficial mass 135 kg/m^2, see Section 4.3.3 for other criteria.
2. Minimum nominal thickness 20 mm.
3. Installed within 20 mm of soil surface, or in conjunction with a surface mesh.
4. See Section 4.3.2 for other criteria for geotextile reinforcement.
5. These graphs should only be used for erosion resistance to unidirectional flow. Values are based on available experience and information at date of this report.
6. All reinforced grass values assume well-established, good grass cover.
7. Other criteria (such as short-term protection, ease of installation and management, susceptibility to vandalism, etc) must be considered in choice of reinforcement.

4. Assessment Outcomes

4.1 QDL compliance assessment with AETVs

Table 4-2 provides a summary of the velocity QDL compliance calculations for the Reference Design using the site-specific AETVs. The table also presents a sensitivity assessment with AETVs reduced by 20% to indicate compliance with an additional Factor of Safety.

Of the 24 culverts selected for the fine grid modelling, velocity QDL exceedance is calculated at one culvert location with the Reference Design and one additional and adjacent exceedance location using the AETV reduced by 20%.

4.2 Erosion potential assessment

While the Erosion Potential and Fluvial Geomorphology Assessment (2022b) acknowledged the importance of velocity in erosion potential assessment, it also concluded that other factors should be considered. An understanding of soil erodibility, presence of existing erosion, vegetation and geomorphology are key factors that would be considered during detailed design and development of successful erosion management and mitigation measures.

The fine grid modelling culvert locations, therefore, assessed these factors to determine site-specific erosion potential to inform detailed design. This assessment built on the assessment conducted for the FHAR and draws on learnings of the recent Erosion Potential and Fluvial Geomorphology Assessment (2022b). This information would be taken forward to inform the detailed design process, giving an indication of site-specific factors other than velocity that would be helpful to consider. This aligns with the findings of the Erosion Potential and Fluvial Geomorphology Assessment (2022b).

Table 4-1 outlines the criteria used to assess the site-specific erosion potential.

Table 4-1 Erosion Potential Assessment Criteria for selected culvert locations

Watercourse	Vegetation Cover	Existing Erosion	Geomorphology and Notes
Either Hydroline exists: – Named – Unnamed or – Overland flow	In-Channel or Riparian Vegetation, where applicable, based on criteria used for FHAR. – L = Sparse trees / understorey, cropping – M = Moderately dense trees and / or dense grasses – H = Dense trees and understorey	Assessment of available ground / aerial photography and based on criteria used for FHAR. – L = No visible evidence of erosion on available photographs – M = Sheet wash, incised channel but no recent erosion – H = Rilling and gullying, active channel erosion	Notes on geomorphological functioning of river. Judgement-based assessment of erosion potential

The site-specific assessment for the fine grid modelling culvert locations is provided in Table 4-3.

Table 4-2 Reference Design velocity QDL compliance adopting AETVs

Structure	Watercourse	Assessment based on AETV										Sensitivity assessment with 20% reduction in AETV						
		AETV	Existing Max Velocity (m/s)	Design Max Velocity (m/s)	Change in Max Velocity (%)	Design Vel > Existing Velocity + 20%	Existing Vel > AETV	Design Vel > AETV	Design Vel > Existing Vel + 0.025m/s	Ex Vel < AETV, Des Vel >AETV	QDL Compliance	80% AETV	Design Vel > Existing Velocity + 20%	Existing Vel > AETV	Design Vel > AETV	Design Vel > Existing Vel + 0.025m/s	Ex Vel < AETV, Des Vel >AETV	80% AETV QDL Compliance
250-Clvrt598994	Goulburn Creek	2	1.3	1.3	2	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.6	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt599110	Goulburn Creek	2	0.8	0.8	3	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.6	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt599226	Goulburn Creek	2	1.0	1.0	2	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.6	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt599366	Gouburn Ck Fp	2	0.7	0.7	4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.6	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt599573	Gouburn Ck Fp	2	1.0	1.0	5	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.6	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt604862	Unnamed Creek	1.4	1.1	1.1	2	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.1	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt605002	Unnamed Creek	1.4	1.7	1.7	1	FALSE	TRUE	TRUE	FALSE	FALSE	Complies	1.1	FALSE	TRUE	TRUE	FALSE	FALSE	Complies
250-Clvrt680830	Overland Flow	1.8	0.5	0.6	7	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt681113	Baronne Ck Fp	1.8	0.6	0.6	6	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt681293	Baronne Ck Fp	1.8	0.9	1.0	11	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt681740	Baronne Ck Fp	1.8	1.0	1.1	11	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt681944	Baronne Ck Fp	1.8	1.9	1.9	2	FALSE	TRUE	TRUE	TRUE	FALSE	Exceedance	1.4	FALSE	TRUE	TRUE	TRUE	FALSE	Exceedance
250-Clvrt682061	Baronne Ck Fp	1.8	1.6	1.7	3	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	TRUE	TRUE	TRUE	FALSE	Exceedance
250-Clvrt682460	Baronne Ck Fp	1.8	N/A	N/A	N/A	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt682903	Overland Flow	1.8	0.5	0.5	7	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt683563	Overland Flow	1.8	N/A	N/A	N/A	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt683698	Overland Flow	1.8	N/A	N/A	N/A	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	1.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt693966	Tenandra Ck Fp	3	1.9	2.0	2	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	2.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt694032	Tenandra Ck Fp	3	1.6	1.7	2	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	2.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt694184	Tenandra Creek	3	2.0	2.1	2	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	2.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt694568	Tenandra Ck Trib	3	1.0	1.1	14	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	2.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt694625	Tenandra Ck Trib	3	1.0	1.1	14	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	2.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies
250-Clvrt695558	Overland Flow	3	1.4	1.4	-	FALSE	FALSE	FALSE	FALSE	FALSE	Complies	2.4	FALSE	FALSE	FALSE	FALSE	FALSE	Complies

NOTES:

- 80% AETV refers to AETV reduced by 20% for sensitivity assessment calculations.
- Velocity of N/A is where there are no default velocity QDL exceedances associated with the structure and no further velocity calculations were made.

Table 4-3 Erosion potential sssessment at selected culvert locations

Culvert Name	Watercourse	QDL Exceedance Reason	Vegetation Cover	Existing Erosion	Geomorphology	Soil Type[1]	Assessed Erodibility[2]	Considerations for Detailed Design
250-Clvrt598994	Goulburn Creek	Complies	M/H, but low in gullying area	H	Geomorphological functioning significantly impacted by diversion and deposition along Old Mill Road which is likely to have contributed to broadening of the floodplain and gullying downstream. Slightly incised, anastomosing, variable sinuosity within a narrow riparian corridor. High erosion potential.	TP2023, BH2008 CH, Hard Sandy Clay, EDT=2.2 Sodosol	VL	– Possible opportunity to realign creek to a more sympathetic course and restore a more natural geomorphological functioning. It may then be more hydraulically effective to bridge the creek, rather than install culverts. This option was discounted during the Erosion Potential Assessment, but additional observations have indicated that this may be feasible. However, this would require works within the road corridor as well as the rail corridor. – Consultation with landowner should be considered to stabilise gully network e.g. through construction of earth berms to retard flood flows and encourage sediment deposition and facilitating vegetation establishment in denuded areas. – Conventional measures for management of dispersive soils should be implemented e.g. suitable compaction, use of reinforced soil cover and rapid revegetation (including use of surface protection during revegetation, if required).
250-Clvrt599110	Goulburn Creek	Complies	M/H, but low in gullying area	H	As above. Culverts facilitate passage of flows from same source area.	Sodosol	VL	As above
250-Clvrt599226	Goulburn Creek	Complies	M/H, but low in gullying area	H	As above. Culverts facilitate passage of flows from same source area.	Sodosol	VL	As above
250-Clvrt599366	Gouburn Creek Floodplain	Complies			Overbank flood flows.	Sodosol	VL	Improvement to geomorphological and hydraulic functioning would further reduce flood extents and velocities. Conventional measures for management of dispersive soils would be considered.
250-Clvrt599573	Gouburn Creek Floodplain	Complies			As above. Culverts facilitate passage of flows from same source area.	Sodosol	VL	As above.
250-Clvrt604862	Unnamed Creek	Complies	L	L	Flows channelised into farm dam and disturbed at road crossing.	CI-CH, Hard sandy clay. Chromosol	L	Conventional culvert treatments required.
250-Clvrt605002	Unnamed Creek	Complies	L	L	As above	TP2025 CH, Hard clay. EDT = 2.1 Sodosol	L	Conventional culvert treatments required.
250-Clvrt680830	Overland Flow	Complies	L	L	Overland flows with no sign of existing erosion.	Vertosol	L	Conventional culvert treatments required.
250-Clvrt681113	Baronne Creek Floodplain	Complies	L	L	Overbank flood flows with no sign of existing erosion	Vertosol	L	Conventional culvert treatments required.
250-Clvrt681293	Baronne Creek Floodplain	Complies	L	L	Overbank flood flows with no sign of existing erosion	Chromosol	L	Conventional culvert treatments required.
250-Clvrt681740	Baronne Creek Floodplain	Complies	L	L	Overbank flood flows with no sign of existing erosion	Chromosol	L	Conventional culvert treatments required.
250-Clvrt681944	Baronne Creek Floodplain	Existing Vel > AETV and Design Vel > Existing Vel + 0.025m/s	L	L	Modelled increase in maximum velocity is 0.044m/s. This area has no evidence of existing erosion and existing flood flows are disrupted by the strip of woodland between crop fields. Therefore, it is considered that the reference design is unlikely to result in adverse additional erosion at this location	Chromosol	L	– Refer mapping of residual exceedance area (adopting AETV) in Appendix C – Assess flowpath over 30m per velocity QDLs for compliance with QDL. – Assess impact of track and vegetation modification during detailed design. – Implement velocity attenuation measures within the rail corridor and associated DCA to achieve compliance, e.g. increase surface roughness through placement of coarse material and/or keyed-in apron riprap. – Landowner agreement – Consider extending Baronne Creek Bridge
250-Clvrt682061	Baronne Creek Floodplain	Complies	L	L	Overbank flood flows with no sign of existing erosion	Chromosol	L	As above
250-Clvrt682460	Baronne Creek Floodplain	Complies	L	L	Overbank flood flows with no sign of existing erosion	Chromosol	L	As above
250-Clvrt682903	Baronne Creek Floodplain	Complies	L	L	Minor overbank flooding	Vertosol	L	Conventional culvert treatments required, with consideration of reactive and potentially fissured clay soils.
250-Clvrt683563	Overland Flow	Complies	L	L	Minor overland flows	Vertosol	L	As above

[1] Other geotechnical testing was used for the AETV assessment associated with bridges and structures not included in the fine grid modelling assessment.
[2] Erodibility assessed as per methods used in the Erosion Potential and Fluvial Geomorphology Assessment (2022b).

Culvert Name	Watercourse	QDL Exceedance Reason	Vegetation Cover	Existing Erosion	Geomorphology	Soil Type[1]	Assessed Erodibility[2]	Considerations for Detailed Design
250-Clvrt683698	Overland Flow	Complies	L	L	Minor overland flows	Vertosol	L	As above
250-Clvrt693966	Tenandra Creek Floodplain	Complies	L	L	FGM modelling shows an anomalous response to the embankment, which could be corrected in detailed design.	BH2061 CI-CH, Hard sandy clay. EDT=2.2. Vertosol	L	As above
250-Clvrt694032	Tenandra Creek Floodplain	Complies	L	L	As above	Vertosol	L	As above
250-Clvrt694184	Tenandra Creek	Complies	L	H	Slightly incised, sinuous creek with artificial levees and point bar chute cutoff. Tenandra Creek channel has been realigned and constrained within levees. These have altered the natural functioning of the channel, possibly leading to exacerbation of flooding in the area. The levees could also prevent overland flooding entering the main channel. Outer banks eroding. Flooding is a significant issue. The landowner report that they lose fences due to floodwater depth and velocity.	BH 2069, TP2068: CL-CI hard sandy clay and dense clayey sand, EDT=2.1. On interfluve above creek and floodplain. Vertosol	Clay L Sand M/H	Consider consultation with landowner regarding flood extents and impacts.
250-Clvrt694568	Tenandra Creek Tributary	Complies	L	M	As above but shows signs of recovery	TP2072 CI, Hard sandy clay with gravel, EDT-2.2. On interfluve between creeks. Vertosol	L	As above
250-Clvrt694625	Tenandra Creek Tributary	Complies	L	M	As above but shows signs of recovery	Vertosol	L	As above
250-Clvrt695558	Overland Flow	Complies	L	L	Area of overland flows with small catchment area. Flows along Goorianawa Road are not associated with the project.	Chromosol	L	As above
250-Clvrt695641	Overland Flow	Complies	L	L	As above	Chromosol	L	Consider additional culvert at CH696.4 during detailed design to accommodate additional area of modelled overland flows.

5. Notional culvert augmentation

5.1 Modelled Scenarios

5.1.1 Reference design

Both N2N9 and N2N13 2.5m quadtree mesh TUFLOW models were initially run for the 1% AEP event for existing conditions and using the Reference Design.

5.1.2 Notional culvert augmentation scenario

One of the purposes of the fine grid modelling was to assess notional culvert augmentation scenarios relating the selected reference design culvert locations exhibiting velocity QDL exceedance to potentially limit increases in culvert entry and exit flow velocities.

Two culvert locations which are adjacent to each other on the Baronne Creek floodplain (culverts 250-Culv681944 and 250-Culv682061) were identified in the QDL assessment adopting the sensitivity reduced AETV (i.e. 20% reduced AETV) as being noncompliant to the QDLs (refer Section 4.1). A further test was undertaken in the fine grid modelling of these culvert locations to assess the effect of the notional culvert augmentation on velocity QDL compliance adopting the default ETV.

5.2 Change in velocity and velocity QDL mapping

As introduced at section 3.2, mapping of the fine grid modelling using the Reference Design is provided in **Appendix B**. Changes in velocity and QDL exceedances using the default ETV are mapped. The exceedances using the default ETV (i.e. 0.5m/s where no site specific ETV has been assessed) are used to inform the further detailed velocity QDL compliance assessment.

The fine grid modelling results using the notional culvert augmentation scenario is provided in **Appendix C.** This mapping also reflects minor residual QDL exceedance (adopting AETV) areas associated with the notional culvert augmentation.

Mapping at **Appendix C** also highlights velocity QDL exceedances (adopting AETV) associated with the selected culvert location Reference Design for comparison purposes.

5.3 Velocity QDL compliance assessment with culvert augmentation adopting AETV

The augmentation scenario relating to the two closely located culverts (culverts 250-Culv681944 and 250-Culv682061) includes a combined significant increase in culvert cells from 52 to 76 cells. Compliance assessment (adopting the AETV criteria) of the augmented structures as outlined in Table 5.1 has indicated that the augmentation almost eliminates the velocity QDL exceedance (adopting AETV criteria). This is expected to be eliminated through consideration of the 30m wide flowpath criteria as would be assessed as part of detailed design.

This outcome also highlights that the expansion of culvert waterway area can assist in reducing velocity QDL exceedances within reduced distances of the structures.

In consideration of the minor velocity QDL exceedance demonstrated when assessed in terms of the AETV for the location, elimination or accommodation of the exceedance will be achieved through conventional design approaches and measures during detailed design including:

- Assessing flowpath over 30m per velocity QDLs.
- Assessing impact of track and vegetation modification during detailed design.
- Implementing velocity attenuation measures within the rail corridor and associated DCA to achieve compliance, e.g. increase surface roughness through placement of coarse material and/or keyed-in apron riprap.
- Landowner agreement
- Consider extending Baronne Creek Bridge

In this location, further expansion of the culverts would also result in limited space between the culvert and the Baronne Creek floodplain bridge. In consideration of the high flood depth at this location, a more efficient solution may involve integrating all structures in this area (two bridges and three culvert banks) into one bridge structure. This would be considered during detailed design.

Table 5-1 Reference Design and Culvert Augmentation – compliance to velocity QDL adopting AETV

Culvert ID	Reference design				Notional culvert augmentation				Remark
	No. of Cells	Height (m)	Width (m)	Compliant? Design Vel > Existing Vel + 0.025m/s AND Existing Vel > AETV	No. of Cells	Height (m)	Width (m)	Compliant?	
N2N9 TUFLOW Model									
250-Clvrt681944	28	2.7	2.4	No	52	2.7	2.4	No	Assessed in combination in notional culvert augmentation scenario due to proximity to each other. While compliance is not achieved it is noted that residual velocity QDL exceedance areas are extremely small (refer Appendix C mapping)
250-Clvrt682061	24	2.4	2.4	Yes	24	2.4	2.4		

5.4 Drainage Control Areas

The DCAs currently defined for the reference design are based on the 10m grid hydraulic modelling and earlier considered 10% increase velocity criteria. Outcomes of the fine grid modelling for the Reference Design have highlighted that adjustment through reduction or elimination of the DCA boundaries may be possible during detail design.

5.5 Potential assessment refinement and management measures

In view of the selection process for the sample culvert locations assessed for velocity QDL compliance and the very high level of compliance demonstrated it is expected that the majority of other locations throughout the reference design will also demonstrate compliance with velocity QDLs. It is also therefore acknowledged that noncompliance's of the Reference Design with velocity QDL's will be identified in detailed design that will be required to be addressed during future phases of the project including detailed design.

Assessment refinement and management measures to be considered in future phases of the project to assist in achieving compliance with the velocity QDLs or management of residual noncompliance are summarised in Table 5-2.

Table 5-2 Potential assessment refinement and management measures

Action for consideration	Details
Site-specific geomorphology and erosion potential assessments	Carry out detailed site-specific desktop and field assessments of soil characteristics and fluvial geomorphology at sites identified as susceptible to erosion or where site conditions require further investigation to inform detailed design. Further evaluate AETVs in terms of opportunity to remove conservatism. Assess flowpaths in areas of identified exceedance over 30m per velocity QDL's.
Hydraulic Modelling	Assessment of TUFLOW modelling parameters (e.g. L1_FLC for culverts represented in 2D to remove conservatism)
Structural	Consider watercourse crossing sizing. Where applicable, consider extending the length of adjacent proposed bridges as an alternative to augmentation of proposed culverts. Consider opportunities for improved flow distribution.
	Install velocity attenuation measures such as "rough" culvert exit aprons, other energy dissipation devices.

	Selection of structure sizes to achieve velocity QDLs should be considered in conjunction with other QDLs (e.g. afflux) and hydraulic functioning targets (e.g. sedimentation). Suitability of alternative integrated design amendments (e.g. rail vertical alignment, embankment cut/fill, longitudinal drainage, drainage arrangement modifications) should also be considered.
Erosion protection works	Consider incorporating engineered erosion protection works or ground stabilisation into detailed design, particularly revegetation and surface protection during the revegetation process.
Rehabilitation of existing disturbance of natural geomorphological functioning of watercourses	Locations exist where watercourses are modified from their natural state and where channel rehabilitation could restore some of the natural geomorphological functioning. Where such an opportunity exists, consultation with the landowner or stakeholders may be beneficial to explore the possibility of rehabilitation.
Drainage Control Area adjustments	DCAs should be retained where required. Reduce or eliminate DCAs where velocity QDL compliance is achieved without DCA's being required. Further fine grid modelling and erosion potential assessments at selected locations to inform DCA adjustments (reduction or elimination).
Landowner / stakeholder consultation	Undertake consultation to provide property owners with information on existing and future erosion / flood risks and discuss options for sympathetic management measures.
Monitoring of adverse impacts	As indicated in the FHAR, it would be necessary to establish a regular programme of erosion monitoring with defined triggers for proactive / reactive maintenance and mitigation.
Maintenance and adverse impact remediation	Proactive / reactive maintenance intervention and remedial works as identified by monitoring.

6. Conclusions

There are a total of 606 drainage culvert locations under the proposed Inland Rail embankment between Narromine and Narrabri within the Reference Design.

TUFLOW models N2N9 and N2N13 were updated to quadtree mesh to provide a higher resolution for modelling flow velocities. Twenty-four culvert locations located within the two models were selected to be modelled with a finer model grid (2.5m cell size). The results were used for assessment of compliance against velocity QDLs based on site-specific Assessed Erosion Threshold Velocities (AETVs).

Sites were selected to be representative of locations that were more challenging in terms of achieving velocity QDL compliance. Compliance checking of the selected culvert locations has demonstrated a very high level of compliance (23 out of 24 locations).

As a result of the nature of the selected culvert locations included in this assessment, the high degree of velocity QDL compliance demonstrated by the analysis and the findings of the geomorphological assessments, it is likely that the majority of other locations throughout the reference design will also demonstrate compliance with velocity QDLs. It is acknowledged that noncompliance of some locations within the Reference Design with velocity QDL’s will however continue to be identified during detailed design and will be required to be managed/mitigated during future phases of the project including detailed design.

Assessment refinement and management measures including mitigation opportunities have been identified for consideration during detailed design to address residual velocity QDL exceedances.

APPENDICES

NARROMINE TO NARRABRI PROJECT

TECHNICAL REPORT 03

Updated flooding and hydrology assessment

Appendix A Flow velocities at project boundary based on 10 m grid TUFLOW model results

NARROMINE TO NARRABRI PROJECT

Table A1 Flow velocities (based on 1D representation of culverts in 10m grid TUFLOW models) at project boundary in the 1% AEP event

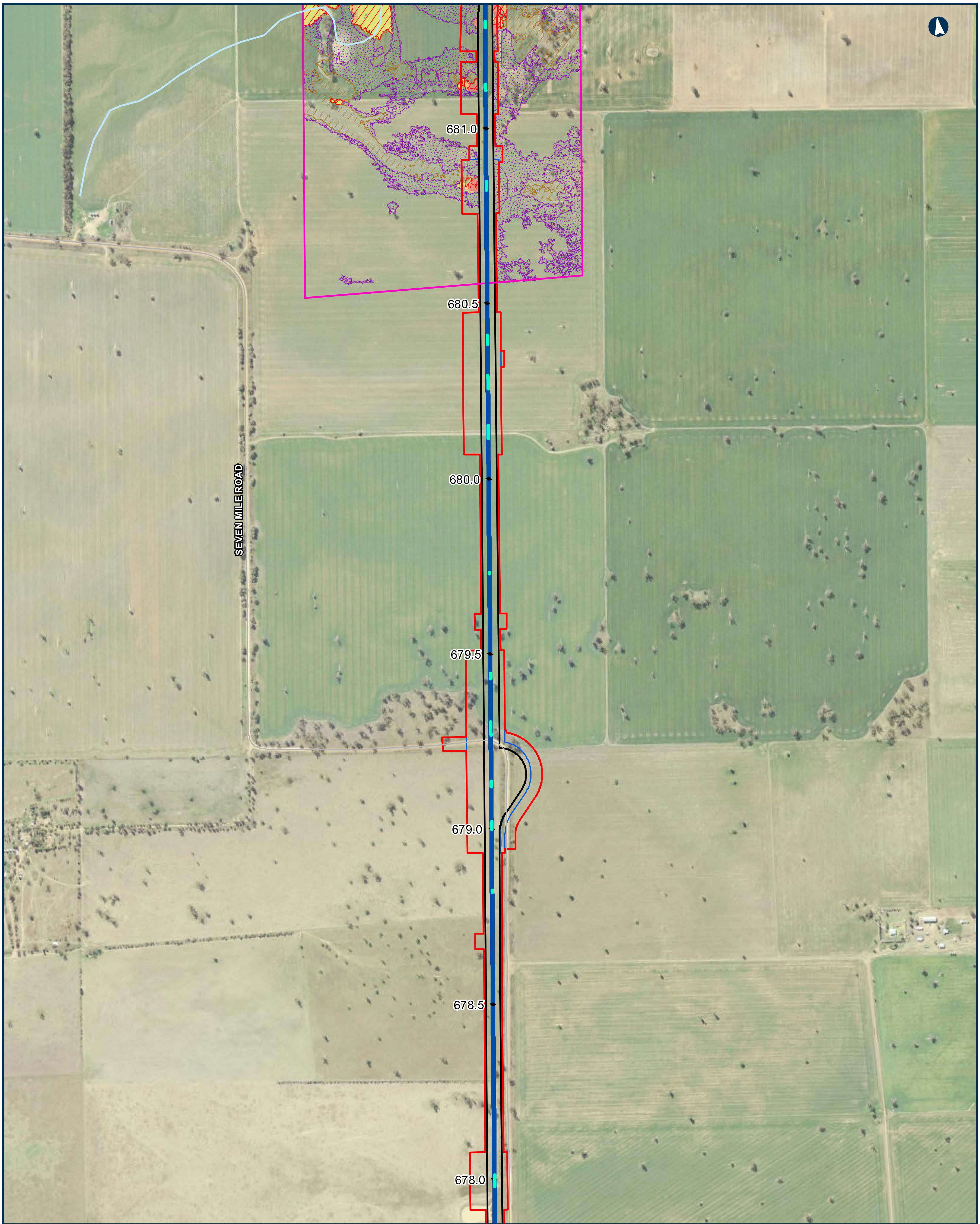
Culvert details				TUFLOW 10m grid velocity at project boundary, including DCAs (Culverts "all clear")				DCA Defined
Culvert ID	No. of Cells	Height (m)	Width (m)	Existing Upstream	Design Upstream	Existing Downstream	Design Downstream	
N2N9 TUFLOW Model								
250-Clvrt680830	8	2.1	2.4	0.57	0.52	0.50	0.56	Yes
250-Clvrt681113	6	1.8	2.4	0.35	0.22	0.52	0.59	Yes
250-Clvrt681293	6	1.8	2.4	0.56	0.61	0.24	0.09	Yes
250-Clvrt681740	24	2.7	2.4	1.43	1.08	0.95	0.96	Yes
250-Clvrt681944	28	2.7	2.4	1.92	1.52	1.43	1.44	Yes
250-Clvrt682061	24	2.4	2.4	1.26	0.82	1.25	1.34	Yes
250-Clvrt682460	24	2.7	2.4	1.25	1.51	1.27	1.24	Yes
250-Clvrt682903	12	0.6	2.4	0.43	0.37	0.45	0.50	Yes
250-Clvrt683563	3	0.9	2.4	-	-	-	-	No
250-Clvrt683698	8	1.5	2.4	0.18	0.29	0.23	0.25	No
250-Clvrt693966	20	0.6	2.4	0.49	0.59	0.62	0.73	Yes
250-Clvrt694032	4	0.6	2.4	0.34	0.34	0.44	0.60	Yes
250-Clvrt694184	10	1.8	2.4	1.81	1.37	0.64	0.83	Yes
250-Clvrt694568	5	1.5	2.4	0.91	0.66	1.37	1.06	Yes
250-Clvrt694625	5	1.5	2.4	0.82	0.84	0.54	0.47	Yes
250-Clvrt695558	5	1.2	2.4	0.59	0.43	0.60	0.75	Yes
N2N13 TUFLOW Model								
250-Clvrt598994	20	0.6	2.4	0.73	0.84	0.62	0.72	Yes
250-Clvrt599110	30	0.9	2.4	0.99	1.23	0.81	0.81	Yes
250-Clvrt599226	30	0.6	2.4	1.25	1.44	0.71	0.80	Yes
250-Clvrt599366	30	0.9	2.4	1.59	1.70	0.67	0.74	Yes
250-Clvrt599573	20	1.2	2.4	0.83	0.95	0.68	0.90	No
250-Clvrt604862	28	1.2	2.4	0.61	0.64	0.96	1.28	Yes
250-Clvrt605002	28	0.9	2.4	0.63	0.38	1.28	1.30	Yes
250-Clvrt695641	5	1.5	2.4	0.63	0.49	0.53	0.75	Yes

TECHNICAL REPORT
03

Updated flooding and hydrology assessment

Appendix B Fine grid modelling velocity QDL exceedance mapping for reference design adopting default ETV

NARROMINE TO NARRABRI PROJECT



NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.1

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

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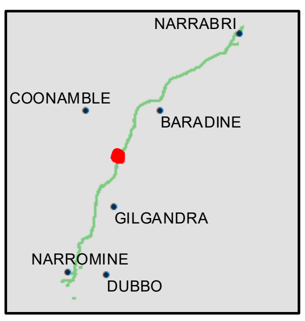
Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

Unprotected Surfaces

- Existing velocity > 0.5m/s, design velocity increased by more than 0.025m/s. DPE QDL exceeded
- Design Velocity < 0.5m/s
- Design Velocity > 0.5m/s, Velocity increase limited to 0.025m/s
- <10% Increase
- 10% to 20% increase
- Greater than 20% increase
- Model Boundary



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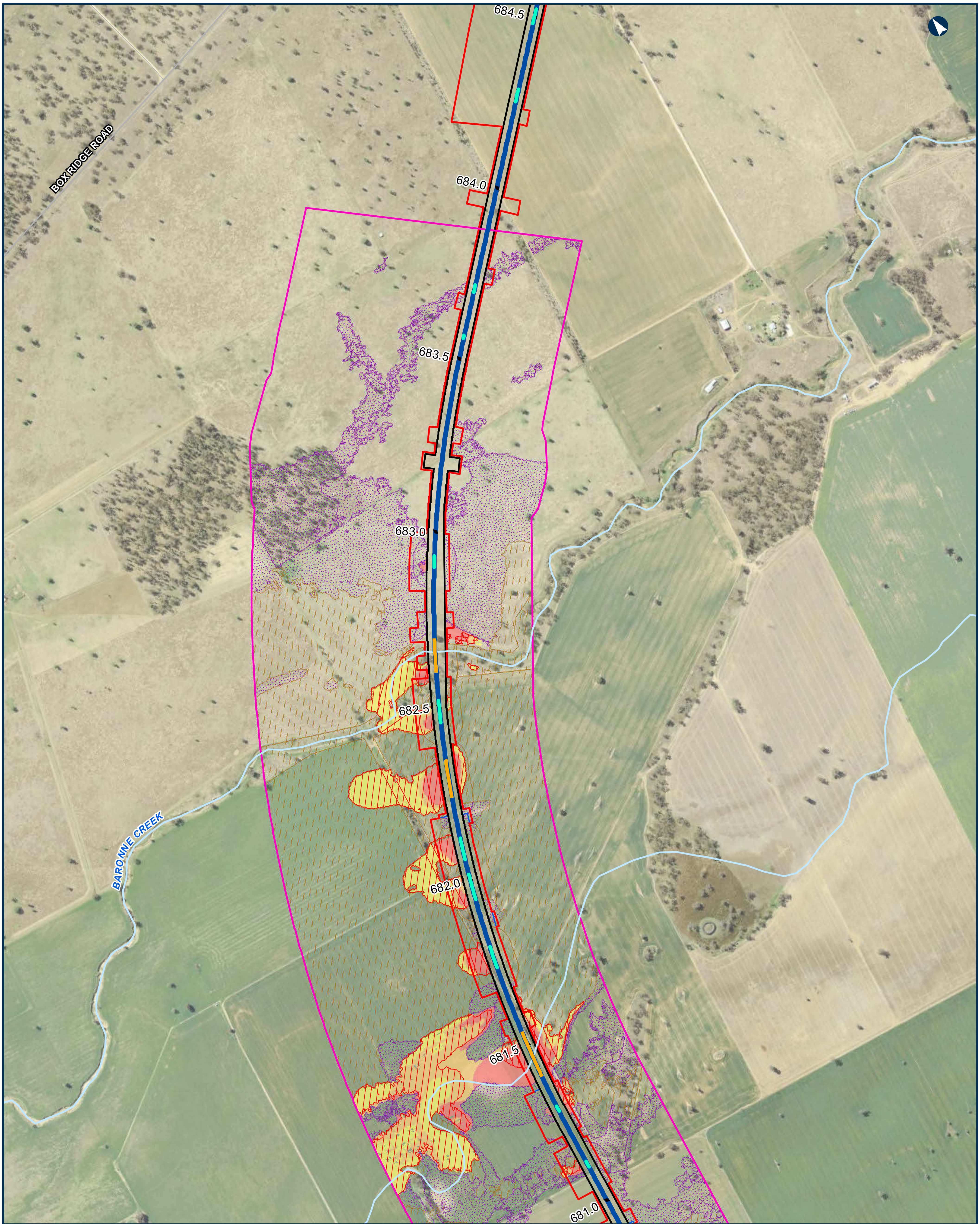

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.2

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

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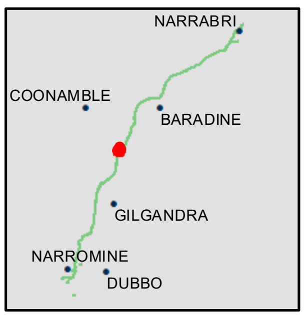

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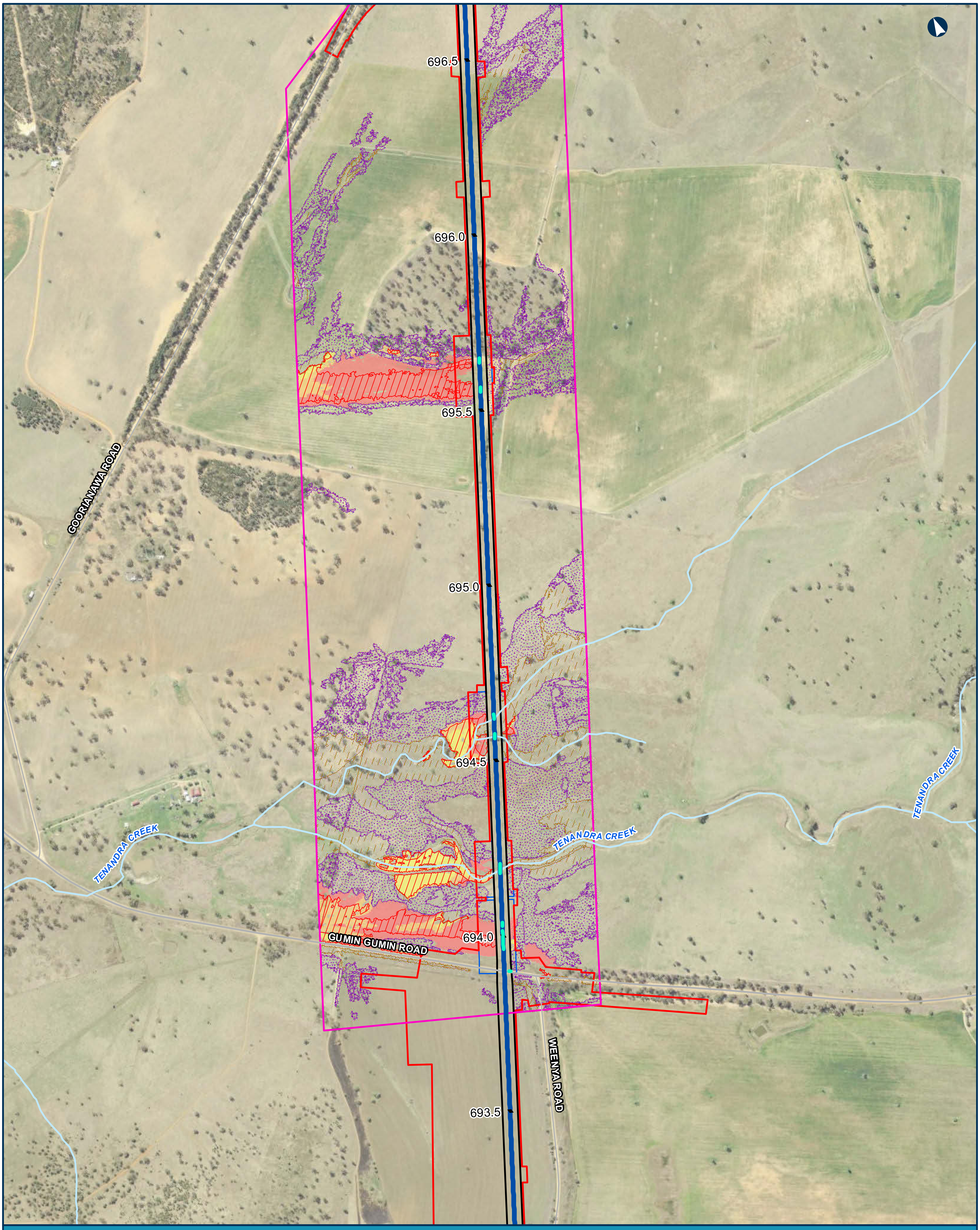

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.3

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022
Paper: A3
Author: JacobsGHD
Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

Unprotected Surfaces

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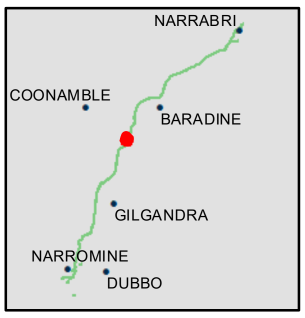

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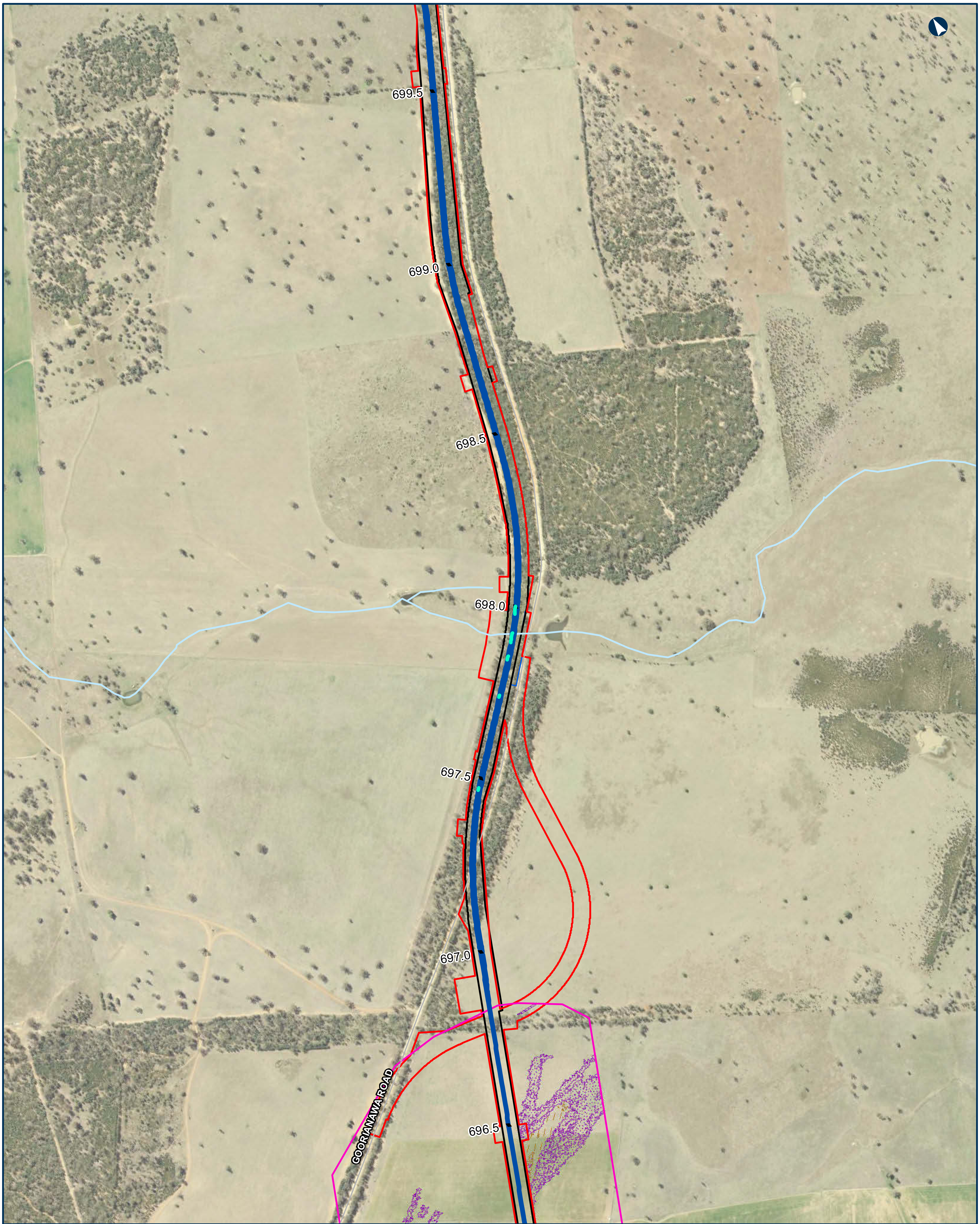


NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

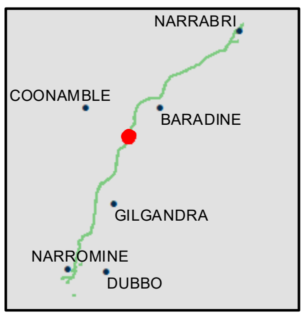
Appendix I - Figure 2.4.4

0 200 400
Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022
Paper: A3
Author: JacobsGHD
Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area
- Design Velocity < 0.5m/s
- Design Velocity > 0.5m/s, Velocity increase limited to 0.025m/s
- Model Boundary



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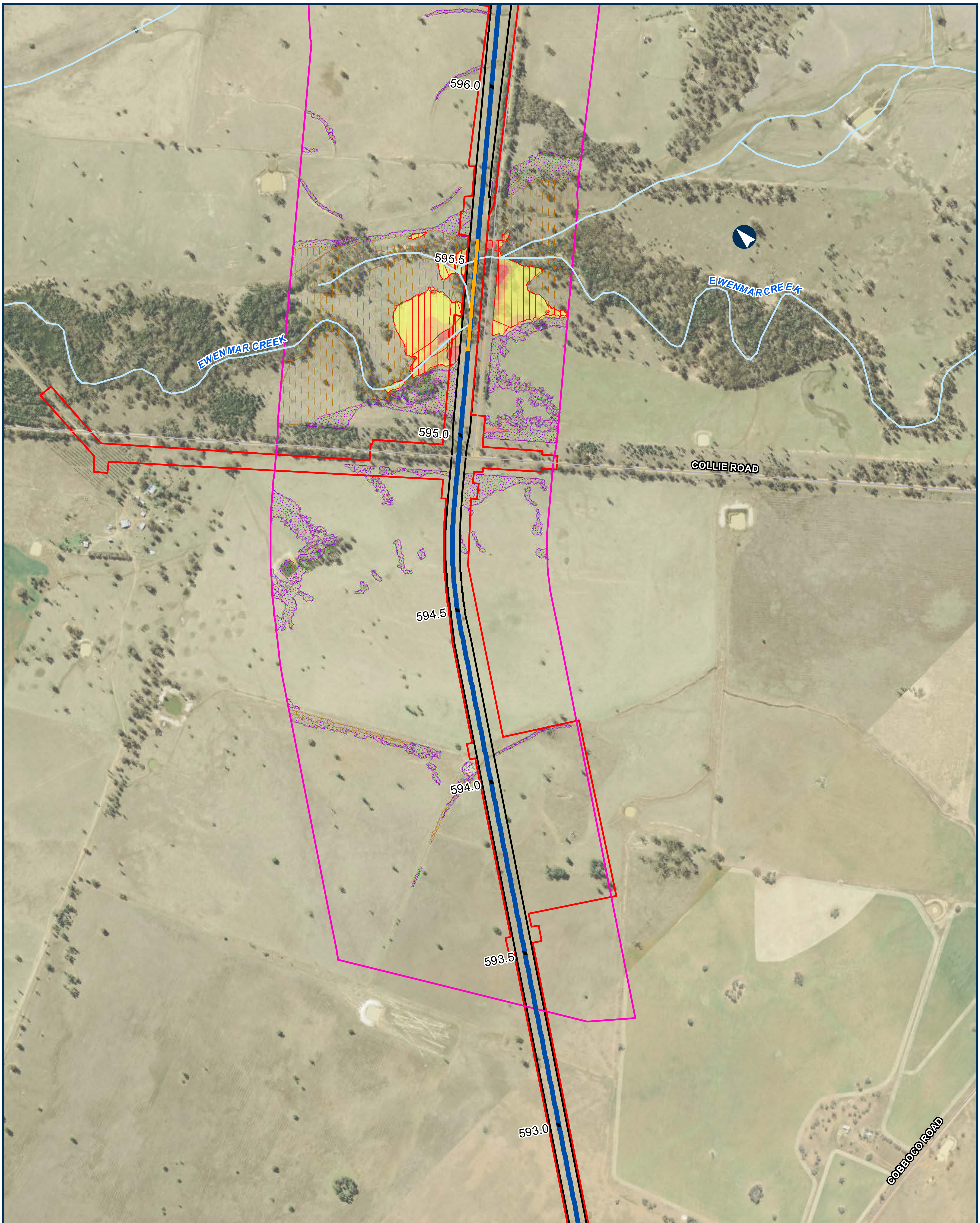

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.1

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Alignment
- The proposal
- Rail Corridor

Unprotected Surfaces

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- Design Velocity > 0.5m/s, Velocity increase limited to 0.025m/s
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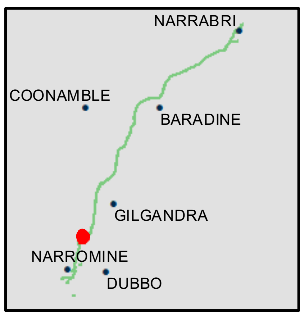
- Greater than 20% increase
- Model Boundary



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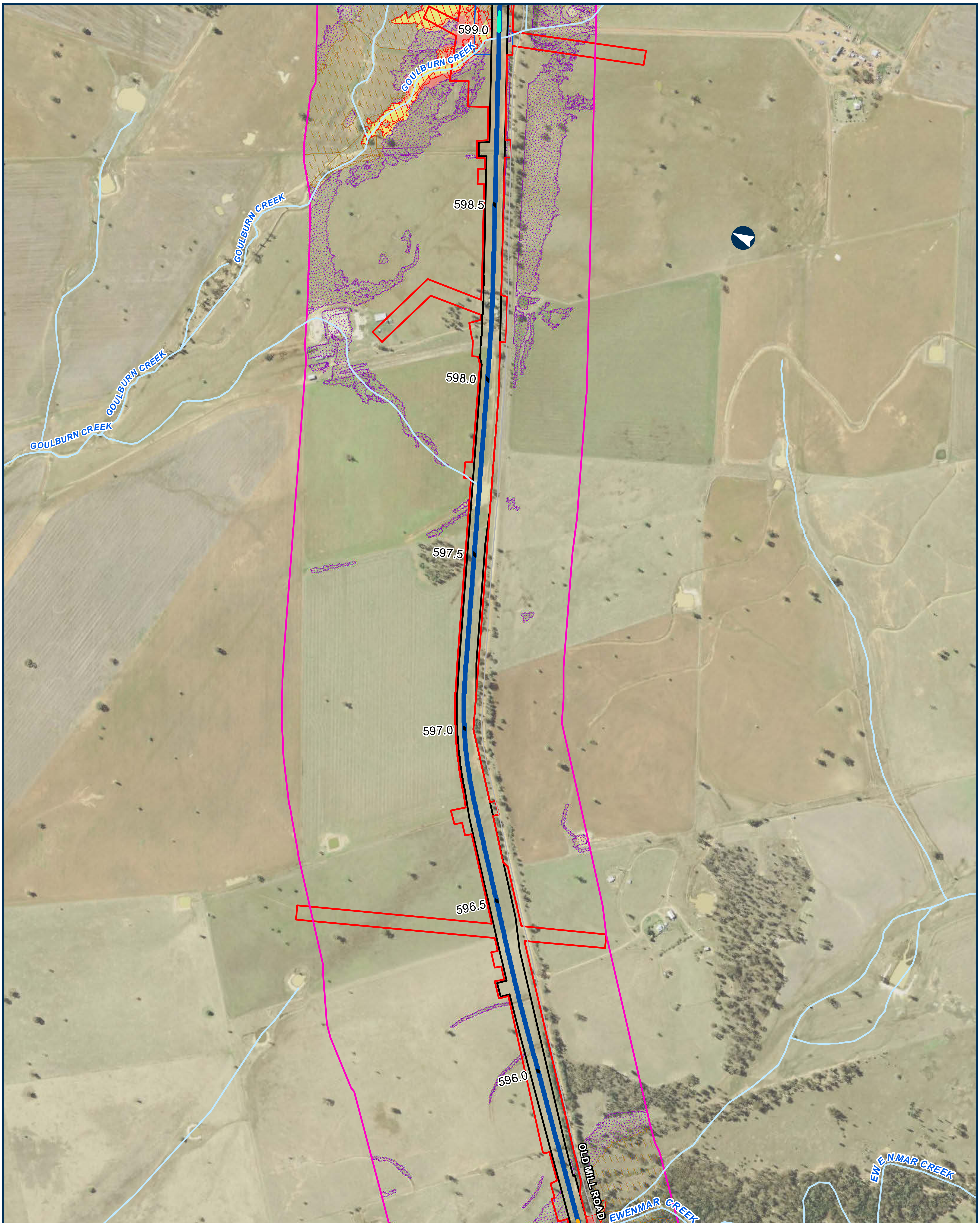

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.2

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

Unprotected Surfaces

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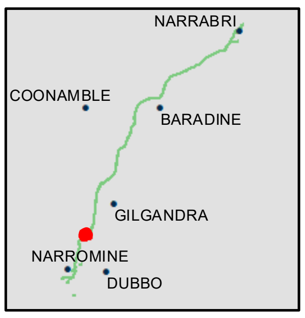

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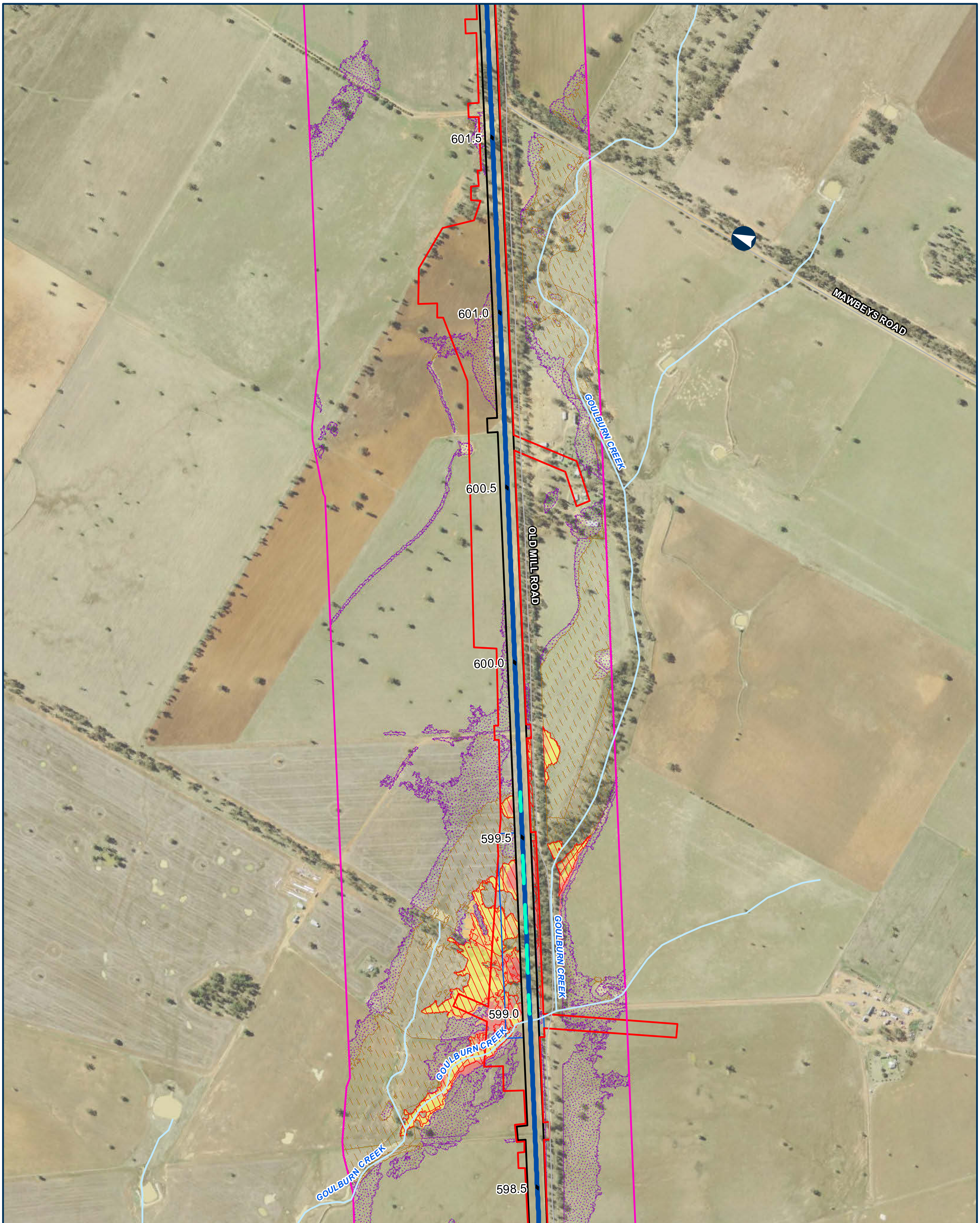
NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.3



0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

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Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

Unprotected Surfaces

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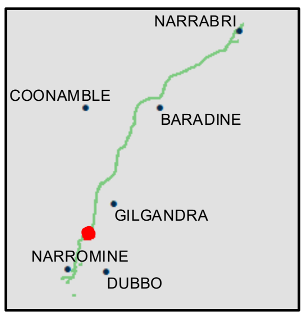
- Design Velocity > 0.5m/s, Velocity increase limited to 0.025m/s
- <10% Increase
- 10% to 20% increase
- Greater than 20% increase
- Model Boundary



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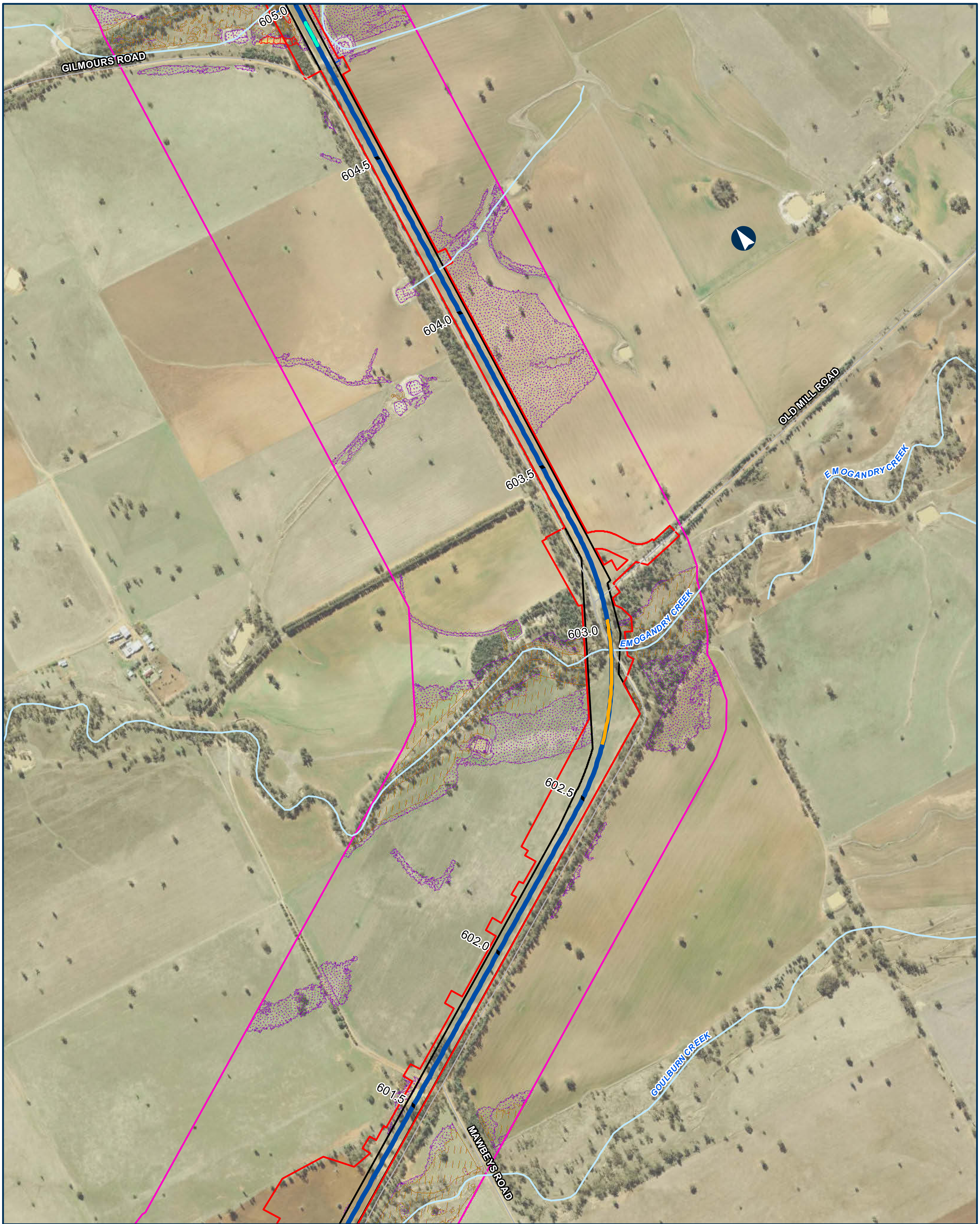

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.4

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

Unprotected Surfaces

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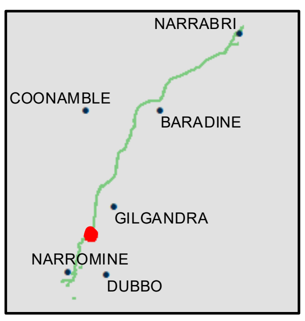

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NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.5

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

Unprotected Surfaces

- Existing velocity > 0.5m/s, design velocity increased by more than 0.025m/s. DPE QDL exceeded
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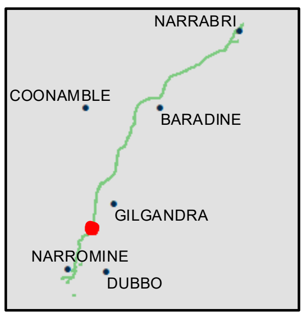
- Design Velocity > 0.5m/s, Velocity increase limited to 0.025m/s
- <10% Increase
- 10% to 20% increase
- Greater than 20% increase
- Model Boundary



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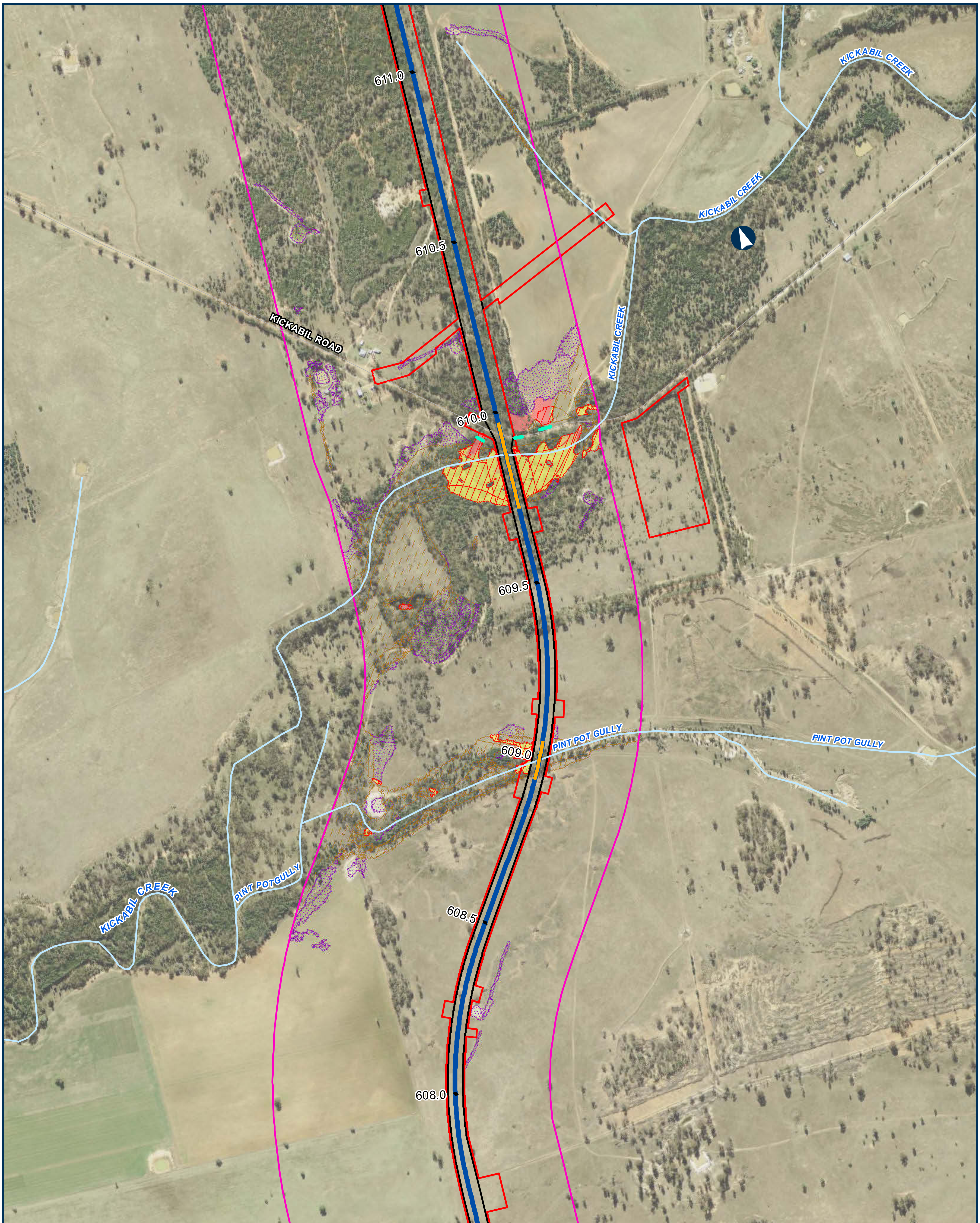

NARROMINE TO NARRABRI   QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.6

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

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Date: 6/07/2022   Paper: A3
Author: JacobsGHD   Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Culvert
- Alignment
- The proposal
- Rail Corridor

Unprotected Surfaces

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- <10% Increase
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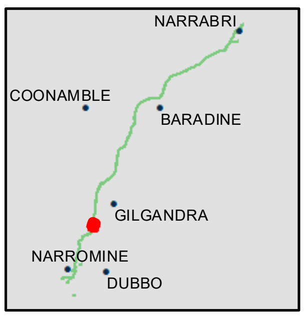
- Model Boundary



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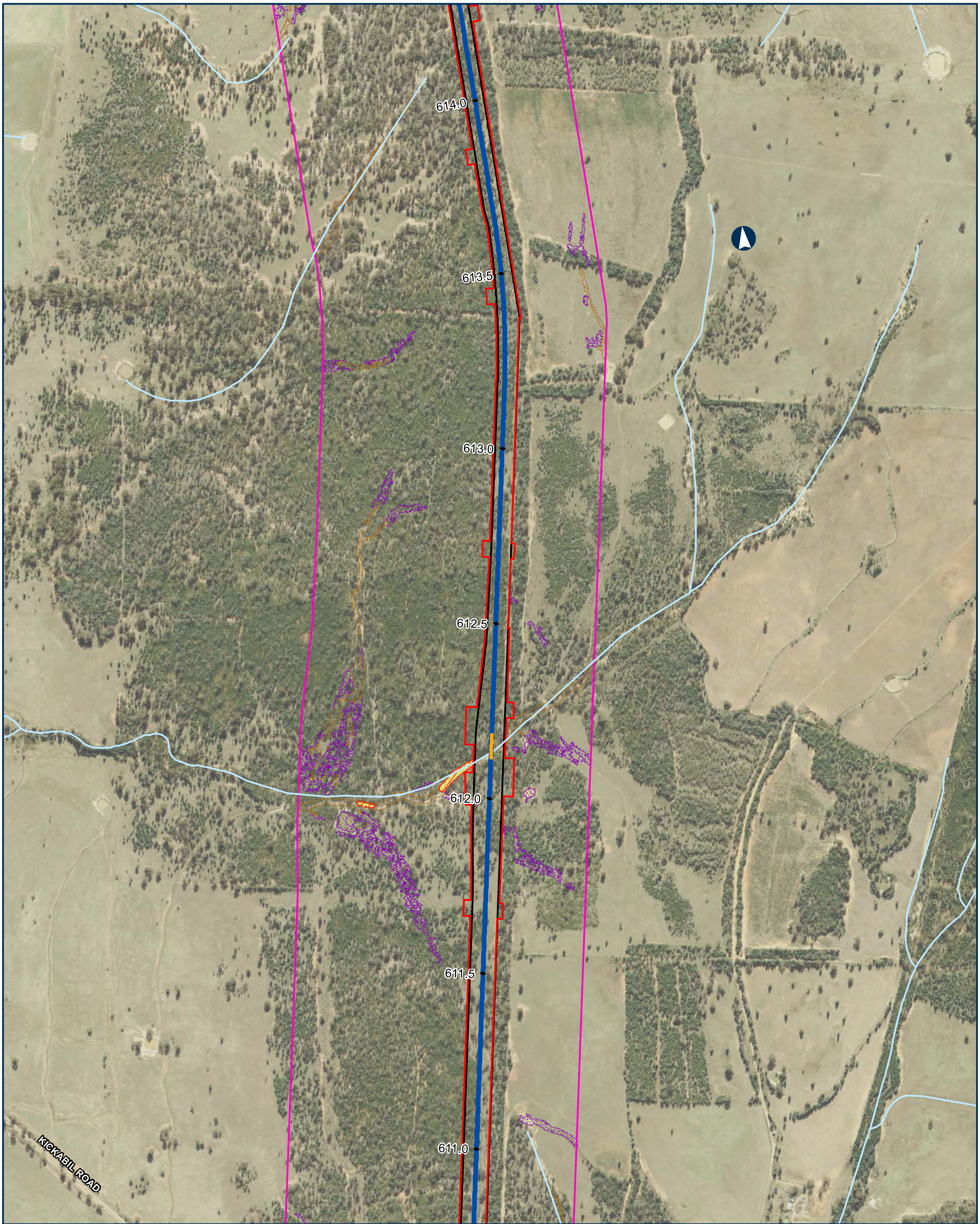

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.7

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Alignment
- The proposal
- Rail Corridor

Unprotected Surfaces

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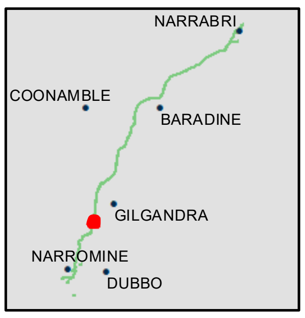
- <10% Increase
- Model Boundary



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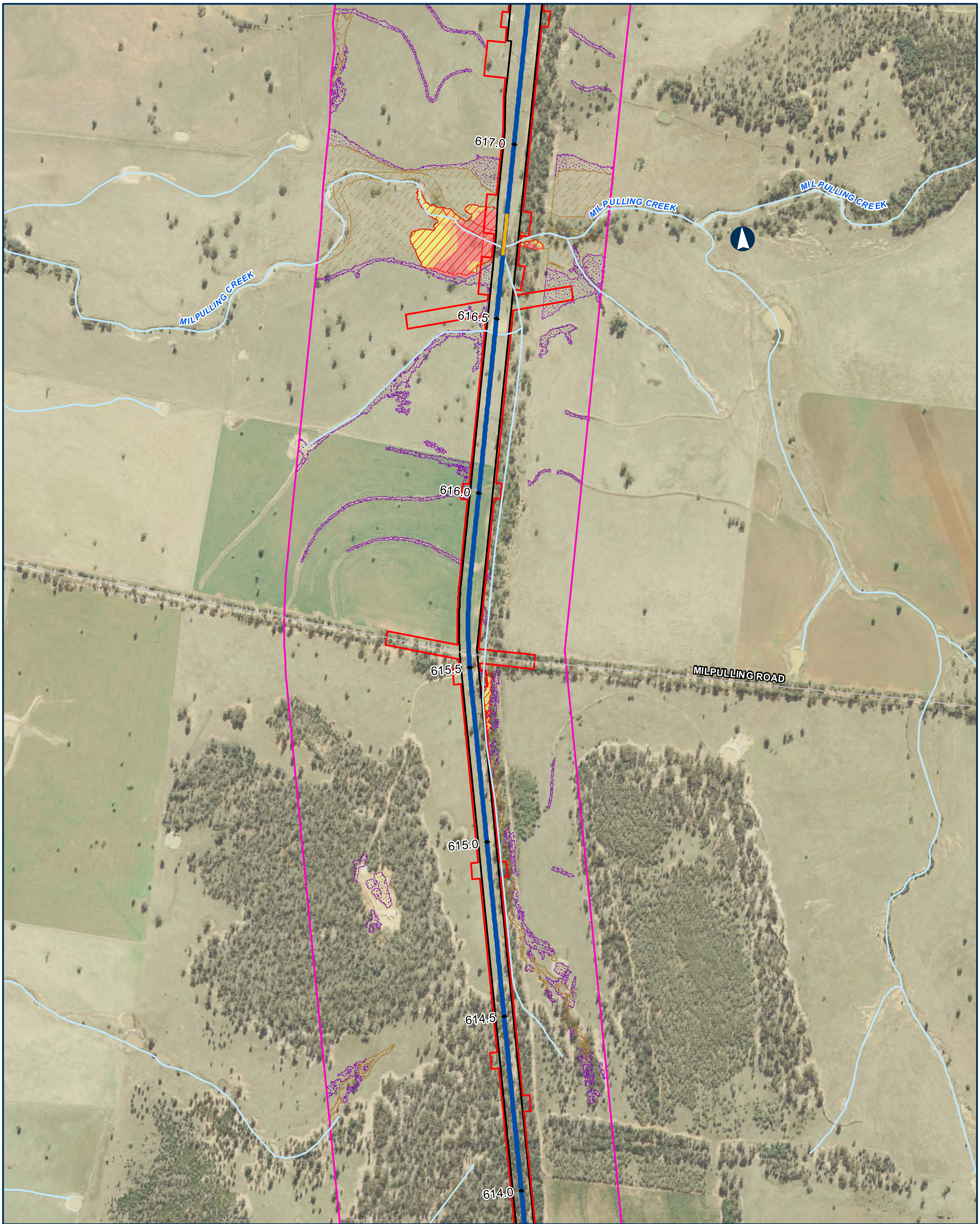

NARROMINE TO NARRABRI

QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.8

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Alignment
- The proposal
- Rail Corridor

Unprotected Surfaces

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- Design Velocity > 0.5m/s, Velocity increase limited to 0.025m/s
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- Greater than 20% increase
- Model Boundary

NARRABRI
COONAMBLE
BARADINE
GILGANDRA
NARROMINE
DUBBO

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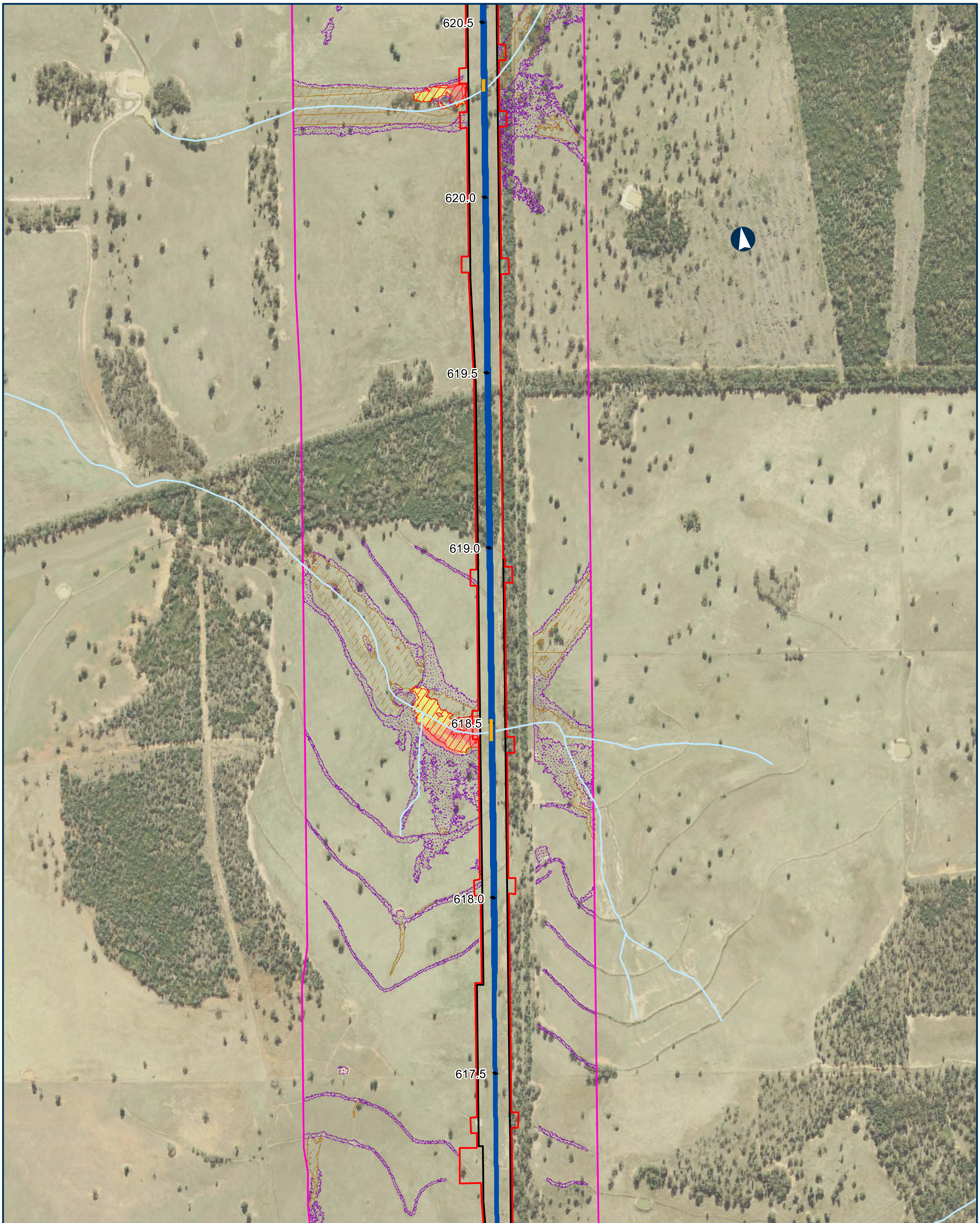

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.9

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

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Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Alignment
- The proposal
- Rail Corridor

Unprotected Surfaces

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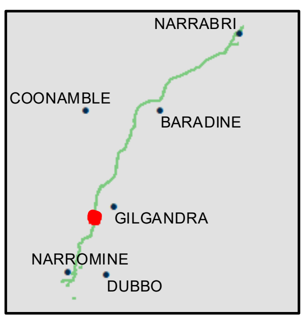
- Greater than 20% increase
- Model Boundary



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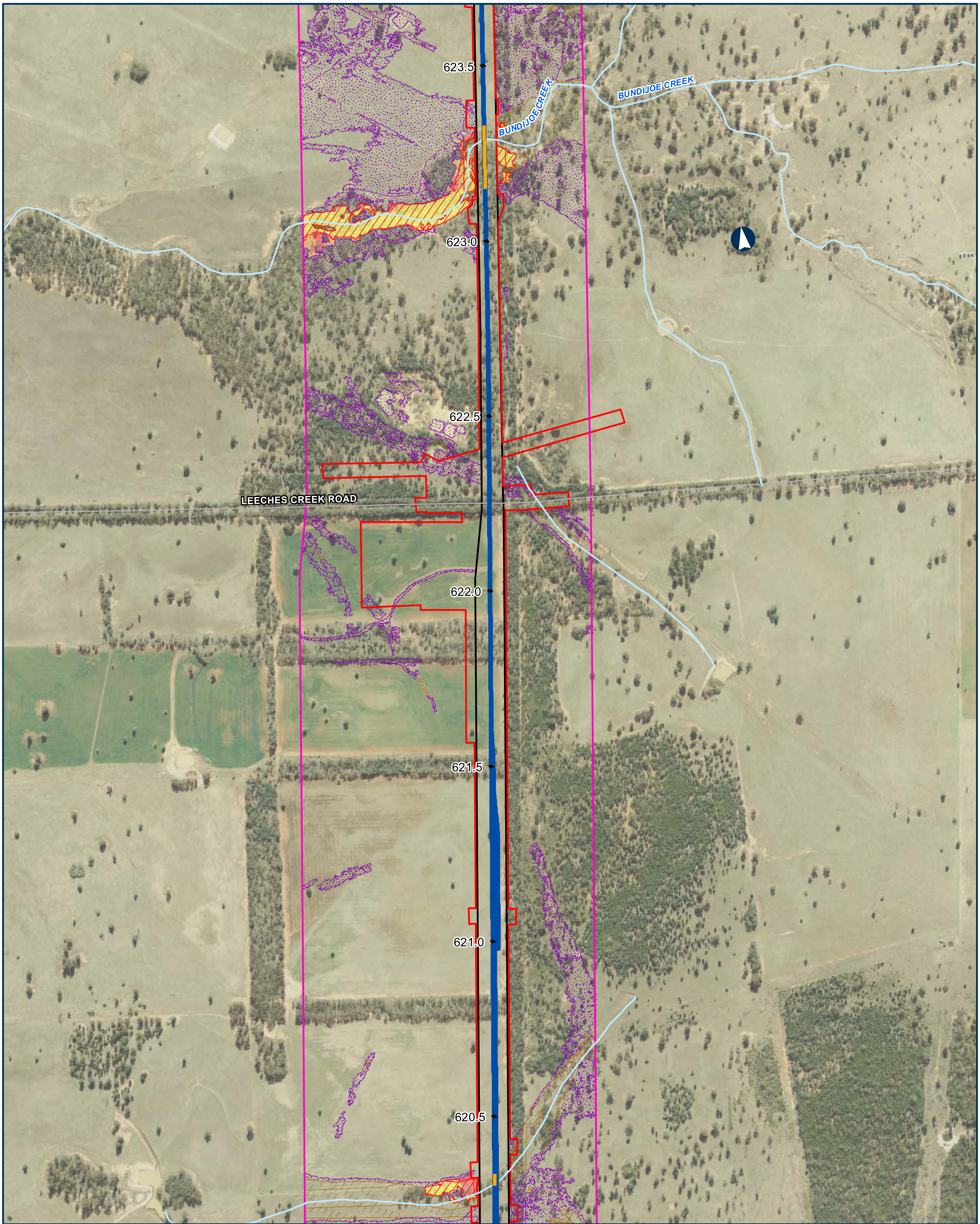

NARROMINE TO NARRABRI QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.10

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

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Paper: A3
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Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Alignment
- The proposal
- Rail Corridor

Unprotected Surfaces

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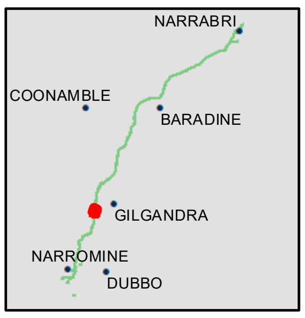
- 10% to 20% increase
- Greater than 20% increase
- Model Boundary



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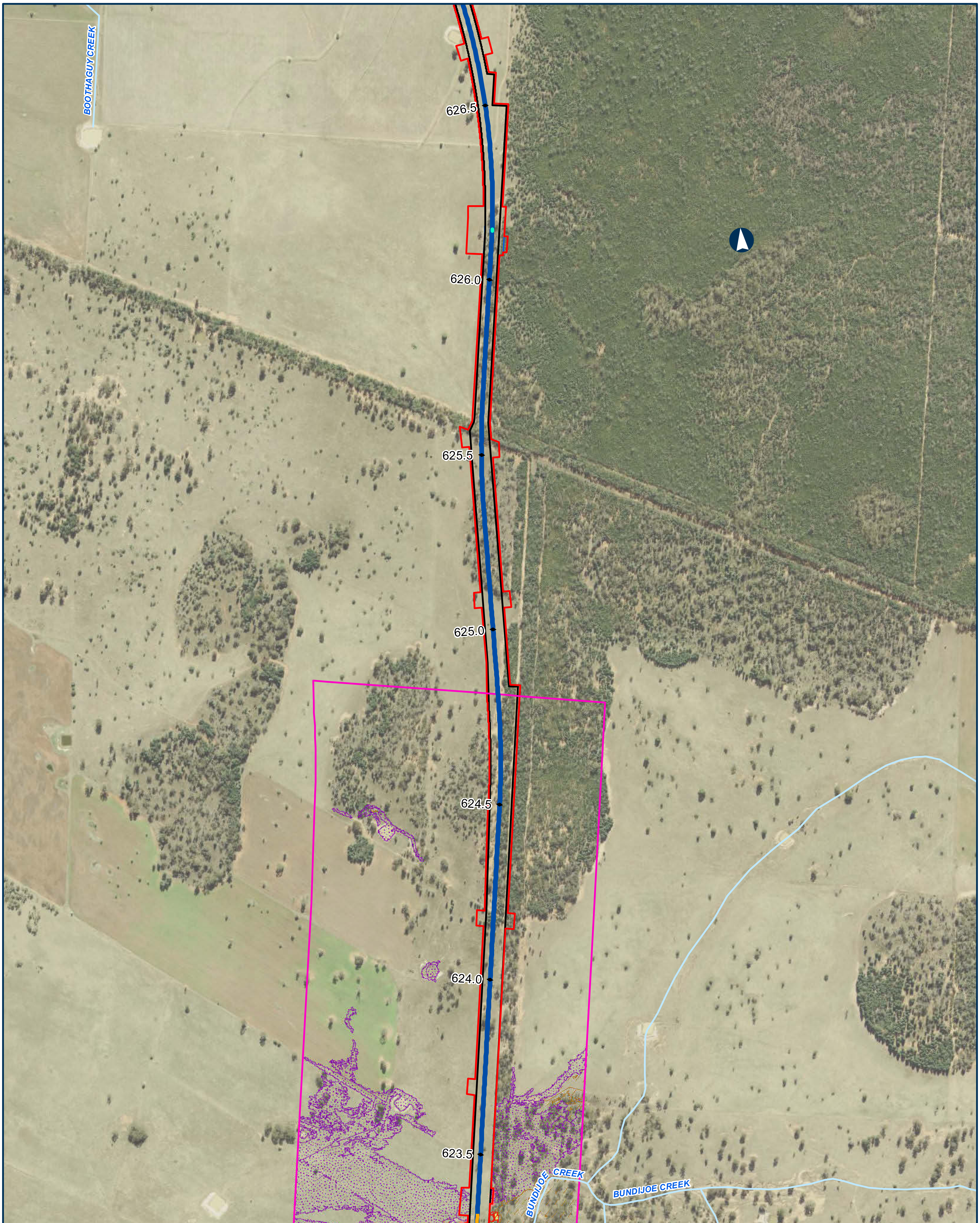

NARROMINE TO NARRABRI

QDL departures - Scour / Erosion - 1% AEP with blockage – Reference Design

Appendix I - Figure 2.4.11

0 200 400 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 6/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:10,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

- Bridge
- Culvert
- Alignment
- The proposal
- Rail Corridor
- Drainage Control Area

Unprotected Surfaces

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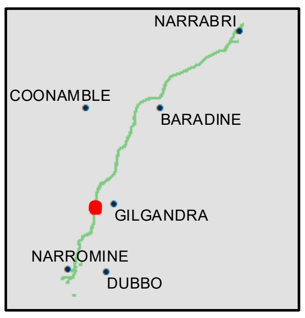
- Greater than 20% increase
- Model Boundary



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TECHNICAL REPORT 03

Updated flooding and hydrology assessment

Appendix C Fine grid modelling velocity QDL exceedance mapping for culvert augmentation scenario adopting AETV

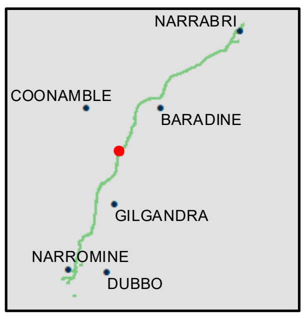
NARROMINE TO NARRABRI PROJECT

NARROMINE TO NARRABRI QDL departures - 1% AEP with blockage – Culvert Augmentation Scenario

Figure C1

Coordinate System: GDA 1994 MGA Zone 55

Date: 8/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:1,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD



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NARROMINE TO NARRABRI Residual QDL departures - 1% AEP with blockage – Reference Design Scenario

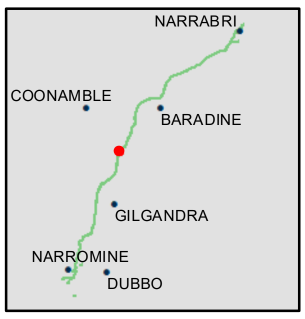
Figure C2

0 20 40 Metres

Coordinate System: GDA 1994 MGA Zone 55

Date: 11/07/2022 Paper: A3
Author: JacobsGHD Scale: 1:1,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

Culvert
Alignment
The proposal
Rail Corridor
Drainage Control Area
QDL Departure
QDL Departure



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