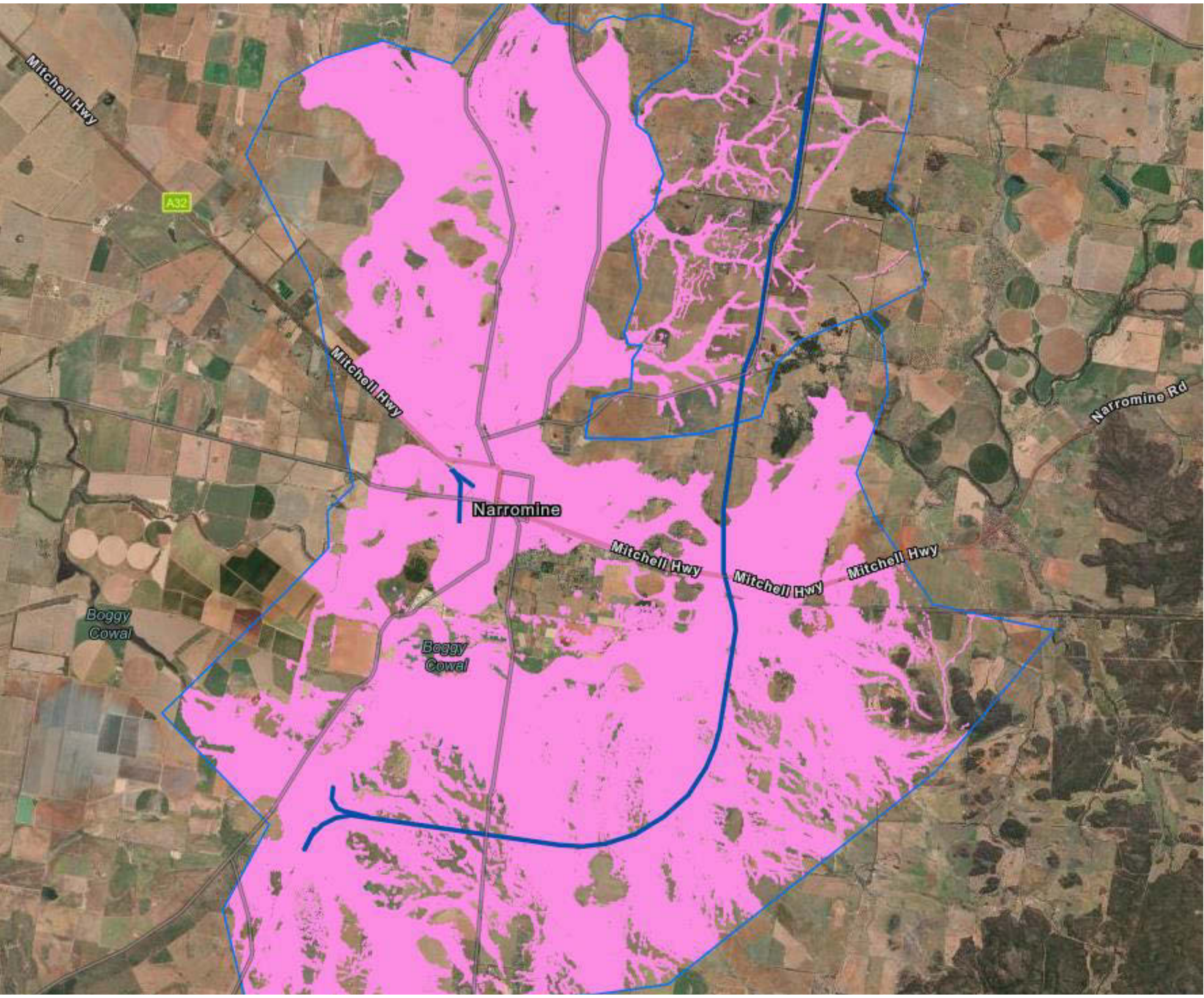
TECHNICAL REPORT 03

Updated flooding and hydrology assessment

Appendix J Hydrology and Hydraulic Models Calibration Report

NARROMINE TO NARRABRI PROJECT



ARTC Inland Rail

Narromine to Narrabri (N2N)

Hydrology and Hydraulic Models Calibration Report

Revision 4

2-0001-250-IHY-00-RP-0002.docx

Executive summary

The proposal

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

The proposal would involve the construction of a new rail line between Narromine and Narrabri, including new crossing loops, river crossings and rail bridges.

Ancillary work would include works to roads, level crossings, signalling and communications, signage, fencing, services and utilities.

This report

The proposed works are located within the major regional water catchments of the Macquarie River Basin, Castlereagh River Basin, and Namoi River Basin. Hydrology and hydraulic computer models are required to define flood behaviour along the proposal for the full range of flood events both for the existing conditions and the proposed developed conditions.

The report presents details on the available data, adopted approach, assumptions, limitations and results of calibration and validation of hydrology and hydraulic models. Consultation with the community was undertaken to collect available information on observed flood behaviour.

The available stream gauge and rainfall data was utilised to calibrate RORB hydrology and TUFLOW hydraulic models. Data for two stream gauges were used to calibrate two RORB models for the catchment areas of Baradine Creek and Bohena Creek.

At-site flood frequency analyses were undertaken for the relevant stream gauges for the Macquarie River, Castlereagh River and Baradine Creek. At-site flood frequency analysis for the Namoi River/ Narrabri Creek adopted in the Narrabri Flood Study (WRM, 2016) was reviewed and adopted in this study. Results obtained from at-site flood frequency analyses and regional flood frequency estimates were made to reconcile estimated peak runoff for two calibrated catchments for design flood events up to and including the 1% AEP event.

It was recommended that the RORB hydrology models for modelling design flood events should be parameterised as follows:

- For gauged catchments – calibrated rainfall losses and RORB parameter values should be adopted.
- For ungauged catchments – RORB models for ungauged catchments should adopt parameter values, k_c and m, based on Australian Rainfall and Runoff (*Ball et al*, 2019). The lower value of the initial rainfall loss obtained from calibration results from adjacent catchment (where available) and ARR 2019 Data Hub should be adopted for each ungauged catchment. The lower value of the continuing rainfall loss rate obtained from calibration results from adjacent catchment (where available) and the default ARR Data Hub continuing loss rate with a multiplication factor of 0.4 should be adopted for each ungauged catchment.

A TUFLOW hydraulic model for Narromine (Lyall & Associates, 2013) was available to this study. Following a review, the TUFLOW model for Narromine was updated to satisfy the objectives of the Reference Design. The updated TUFLOW model was calibrated against the same historic flood events of 1990 and 2010 which were used by Lyall & Associates (2013). In addition, the updated TUFLOW model was calibrated against two additional historic flood events of 1998 and 2000. The flood behaviour simulated by the TUFLOW model for Narromine for a range of design flood events was validated against available independent estimates. Both calibration and validation results were satisfactory.

A MIKE Flood hydraulic model (WRM, 2016) for Narrabri was available to this study. The MIKE Flood model was reviewed and a new TUFLOW hydraulic model for Narrabri was developed utilising the available topographic data to ensure a better representation of the entire model domain in 10 m grids and to expedite assessment of the various route options and optimisation of hydraulic structures for the proposal for the full range of flood events for the Reference Design. The TUFLOW model for Narrabri was calibrated against the same five historic flood events which were used to calibrate the MIKE Flood hydraulic model (WRM, 2016) for Narrabri. TUFLOW calibration results were satisfactory and comparable to calibration results obtained using the MIKE Flood model for Narrabri. The TUFLOW model was validated against flood behaviour simulated by the MIKE Flood model for a range of design flood events up to and including the 1% annual exceedance probability (AEP) event.

Two new hydraulic models were developed for Baradine Creek (N2N7) and Bohena Creek (N2N1) . Each TUFLOW model covers a portion of the project area and an area of the floodplain sufficient to capture potential upstream breakouts, changes in flood behaviour due to proposed works and be relatively free from tailwater influences. The adopted grid size for all TUFLOW models was 10 m.

TUFLOW models for Baradine Creek (N2N7) and Bohena Creek (N2N1) were calibrated against recorded stream data for two flood events.

The predicted flood behaviour simulated by TUFLOW models was presented to landowners by ARTC in meetings held between July 2019 and March 2020. In general, the feedback received was that the flood models provided a reasonable prediction of the expected 1% AEP flood extents. Models were also checked against surveyed flood levels and historical flooding photographs, where available.

Glossary

Acronym	Definition
AEP	Annual exceedance probability
AHD	Australian Height Datum
ARR	Australian Rainfall and Runoff, 2019
ARTC	Australian Rail Track Corporation
BoM	Bureau of Meteorology
DECC	Department of Environment and Climate Change
DEM	Digital Elevation Model
DIPNR	Department of Infrastructure, Planning and Natural Resources
DPI	Department of Primary Industries
DPIE	Department of Planning, Industry and Environment
EIA	Environmental impact assessment
EIS	Environmental Impact Statement
ELVIS	Elevation visualisation data
ENSO	El Nino – Southern Oscillation
FFA	Flood frequency analysis
GEV	General extreme value probability distribution
GIS	Geographical Information System
IFD	Intensity frequency and duration
LP3	Log Pearson Type III probability distribution
LiDAR	Light Detection and Ranging
LPI	Land and Property Information
MDB	Murray Darling Basin
NSW	New South Wales
OEH	Office of Environment and Heritage
PMF	Probable maximum flood
RFFE	Regional Flood Frequency Estimation
RORB	A rainfall-runoff routing computer program used for estimating the hydrological response of catchments
SEAR	Secretary Environmental Assessment Requirements
SEPP	State Environmental Planning Policy
SES	State Emergency Service
SRTM	Shuttle Radar Topography Mission
TUFLOW	A computer program for simulating depth-averaged, one and two-dimensional free-surface flows resulting from floods and tides

Table of contents

Table index

Figure index

Appendices

1. Introduction

1.1 Overview

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

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

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

The Inland Rail program has been divided into 13 sections, seven of which are located in NSW. Australian Rail Track Corporation Ltd (ARTC) ('the proponent') is seeking approval to construct and operate the Narromine to Narrabri section of Inland Rail ('the proposal').

1.2 The proposal

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

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

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

1.2.1 Location

The proposal would be located within a new section of rail corridor between the towns of Narromine and Narrabri in western NSW. The proposal would link the Narrabri to North Star section of Inland Rail located in northwest NSW, with the Parkes to Narromine section located in central west NSW.

The location of the proposal is shown in Figure 1-1.

1.2.2 Key features

The key design features of the proposal include:

Rail infrastructure

- A new 306 kilometre long rail corridor between Narromine and Narrabri
- A single-track standard gauge railway and track formation within the new rail corridor

- Seven crossing loops
- Bridges over rivers and other watercourses (including the Macquarie River, Castlereagh River and the Namoi River/Narrabri Creek system), floodplains and roads
- Connections with existing rail lines
- A new rail junction between the Inland Rail Parkes to Narromine and Narromine to Cobar lines (‘the Narromine West connection’)

Road infrastructure

- Road realignments at various locations
- Provision of an operational rail maintenance access road along (within) the rail corridor
- Provision of new access roads to various properties

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

The key features of the proposal are shown in Figure 1-2.

Figure 1.1 **Location of the proposal**

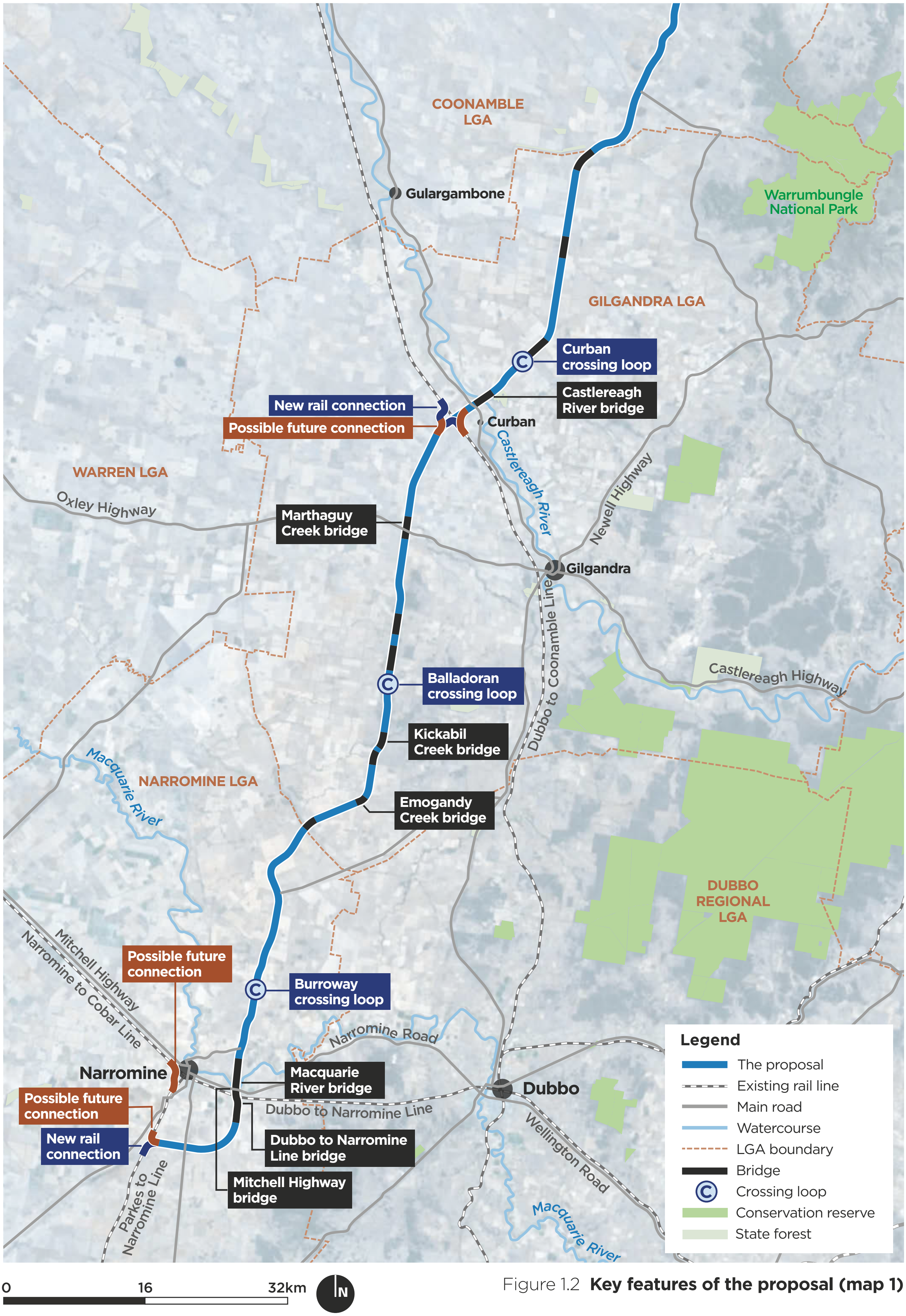


Figure 1.2 **Key features of the proposal (map 1)**

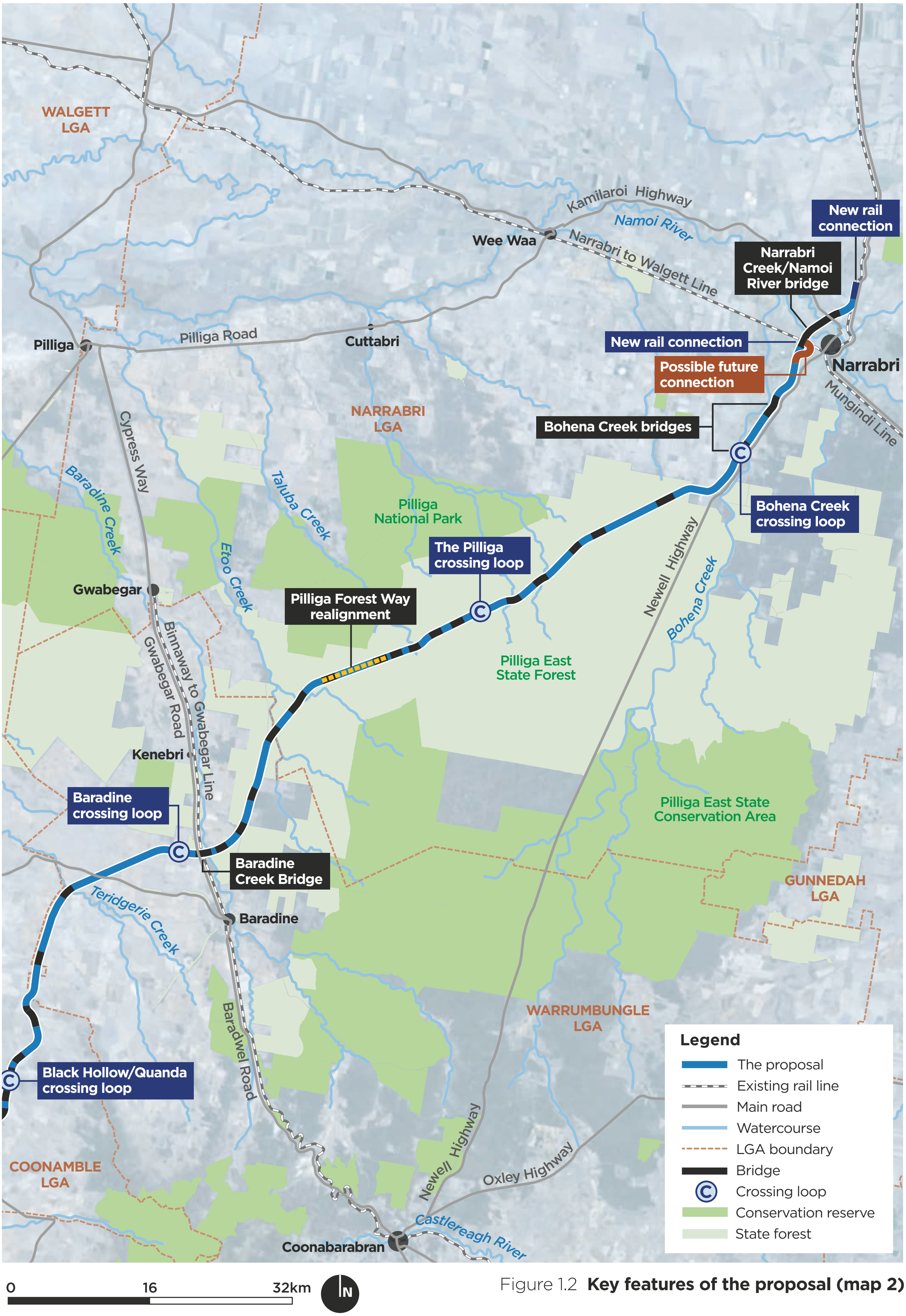


Figure 1.2 **Key features of the proposal (map 2)**

1.2.3 Construction overview

An indicative construction strategy has been developed, based on the reference design. Detailed construction planning, including programming, work methodologies, staging and work sequencing would be undertaken once construction contractor(s) have been engaged and during detailed design.

The following key infrastructure is proposed to support construction of (see Figure 1-3):

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

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

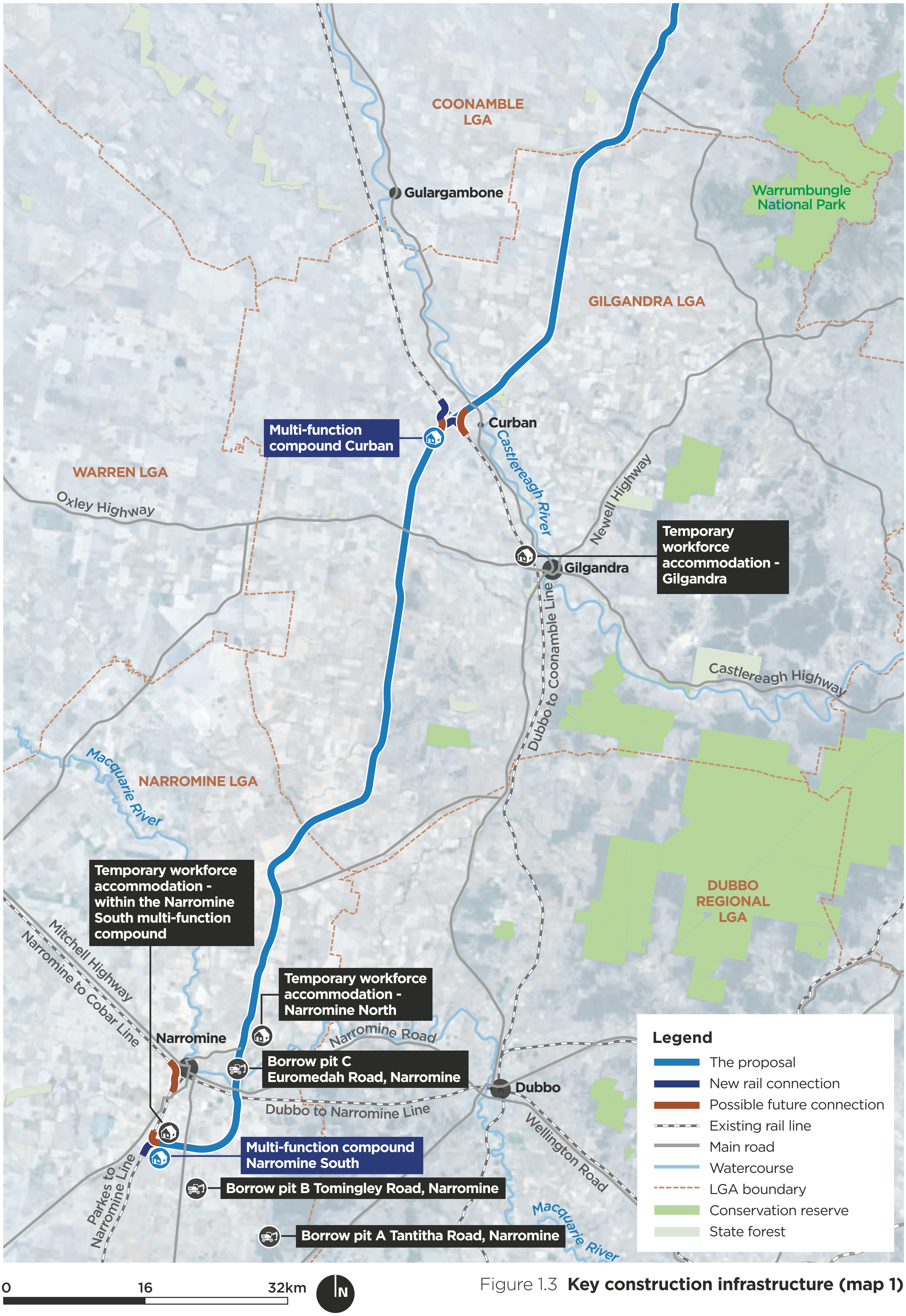


Figure 1.3 **Key construction infrastructure (map 1)**

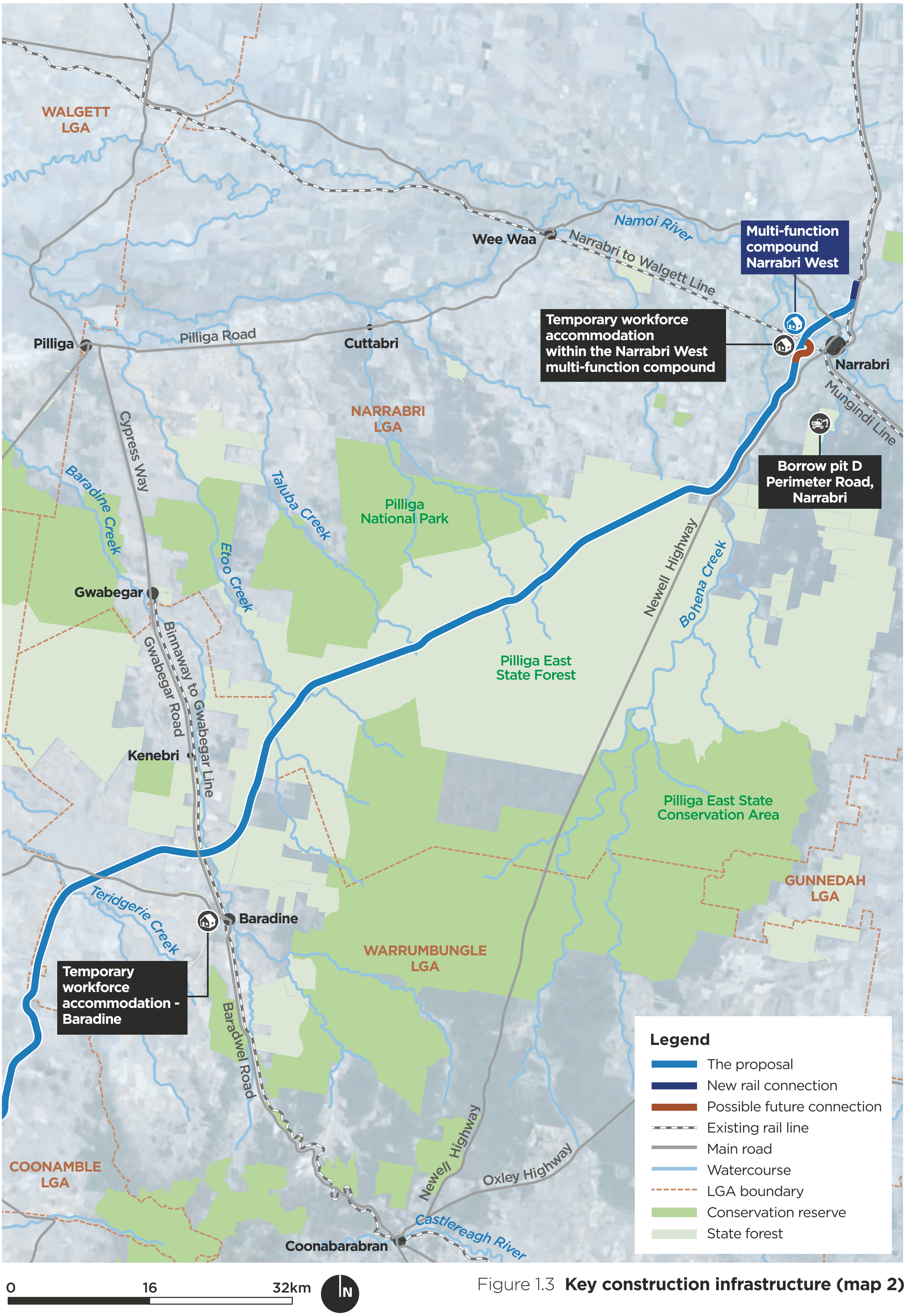


Figure 1.3 **Key construction infrastructure (map 2)**

1.3 Purpose and scope of this report

The purpose of this report is to outline the model selection and development and to present calibration and validation results of hydrology and hydraulic models developed for the Phase 2 Reference Design on the Narromine to Narrabri section of Inland Rail. The report summarises the adopted approach, data collection and reporting of calibration and validation of hydrology and hydraulic models for the existing conditions at the Reference Design stage. The report utilised available recorded stream data and reports which were available up to 2018. This report has been developed to assist in the technical review of the hydrology models, with the intended audience being technically experienced people. This report has not been written for interpretation by the general public.

1.4 Structure of this report

The structure of the report is outlined below:

- Section 1 – introduces the report
- Section 2 – provides a summary of the existing flooding and hydrological conditions
- Section 3 – describes the adopted methodology for calibration of flood models
- Section 4 – describes the available data used in the calibration of flood models
- Section 5 – provides a summary of calibration results of hydrological models
- Section 6 – presents a summary of calibration results of hydraulic models
- Section 7 – concludes the key findings and recommendations from the investigation

1.5 Limitations and exclusions

This report has been prepared by 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 1.3 of this report.

JacobsGHD otherwise disclaims responsibility to any person other than ARTC arising in connection with this report. JacobsGHD also excludes implied warranties and conditions, to the extent legally permissible.

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The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. JacobsGHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

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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2. Catchment hydrology

2.1 Major river and basin systems

The proposed works are located within the major regional water catchments of the Macquarie River Basin, Castlereagh River Basin, and Namoi River Basin.

The Macquarie River starts south of Bathurst, fed by Campbells River and Fish River. It flows roughly north to Lake Burrendong, which regulate downstream flows by way of the Burrendong Dam, meeting the Barwon River at Walgett. The Barwon River is a tributary of the Murray Darling Basin (MDB), meeting the Darling River near Bourke.

The Castlereagh River starts west of Coonabarabran, flowing generally southwards to Mendooran, before meandering generally west through Gilgandra and Coonamble. At Warrington, the river becomes less defined, becoming a series of pools and meandering, braided flow pathways, before becoming more defined around Youendah before meeting the Macquarie River west of Walgett.

The Namoi River (including the adjacent Narrabri Creek) starts in the western slopes of the Great Dividing Range flowing westwards through Lake Keepit towards Boggabri, Narrabri (and the proposed alignment) and Wee Waa, before meeting the Barwon River at Walgett. The Barwon River is a tributary of the Murray – Darling Basin (MDB), meeting the Darling River near Bourke.

2.2 Watercourses

Surface water within the Study Area is predominately comprised of ephemeral waterways, excluding the regulated Macquarie and Namoi River systems. Table 2-1 presents a list of the catchments, sub-catchments and named watercourses, including their respective flow type and hierarchy (derived through BoM Geofabric Surface Hydrology dataset), which are mapped as intersecting the proposal.

The catchments areas associated with sections of the alignment were delineated based on the SRTM DEM (Section 4.3.3). Catchment areas presented in Table 2-1 are shown in Figure 2-1. Each of these catchments was further divided into sub-catchments for the purpose of modelling.

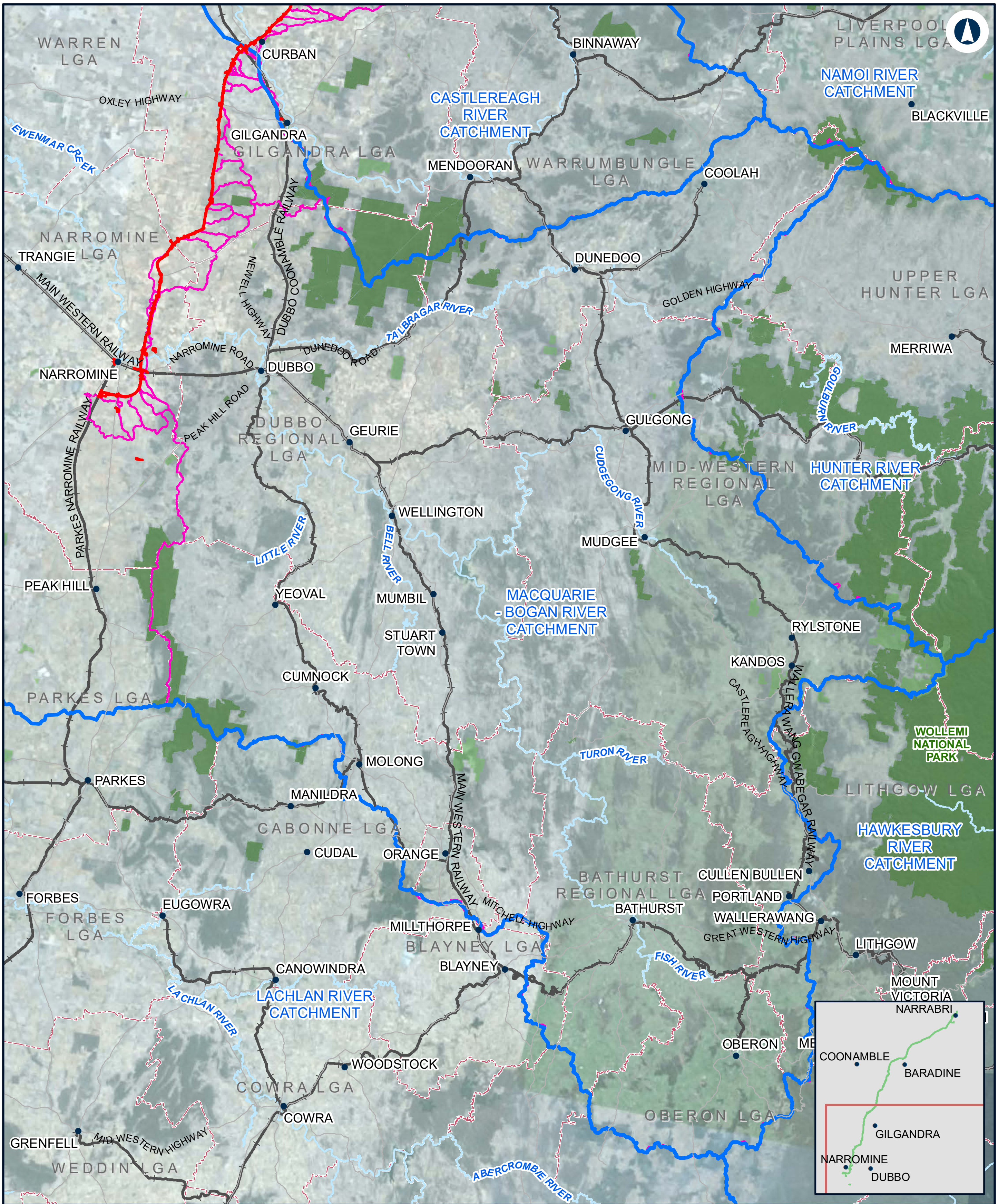
Table 2-1 shows that the majority of watercourses comprise minor watercourses with non-perennial (ephemeral / intermittent) flow conditions. Only two major perennial watercourses (Macquarie River and Namoi River) are intersected.

Table 2-1 Catchments and watercourses intersecting the proposal

Basin	Catchments/ Watercourses	N2N Chainage (km)	Upstream catchment area (km^2)	Flow type/ hierarchy
Macquarie River basin	Yellow Creek	-	60	Non-Perennial - Minor
	Wallaby Creek	553.99	133	Non-perennial - Major
	Unnamed tributary of Backwater Cowal (South)	556.19	65	Non-Perennial - Minor
	Unnamed tributary of Backwater Cowal (North)	557.85	34	Non-Perennial - Minor

Basin	Catchments/ Watercourses	N2N Chainage (km)	Upstream catchment area (km^2)	Flow type/ hierarchy
	Macquarie River	562.35	25,900	Perennial - Major
	Ewenmar Creek	595.24	151	Non-Perennial - Minor
	Goulburn Creek	599.20	25	Non-Perennial - Minor
	Emogandy Creek	602.66	79	Non-Perennial - Minor
	Native Dog Creek	607.15	15	Non-Perennial - Minor
	Pint Pot Gully	608.93	5	Non-Perennial - Minor
	Kickabil Creek	609.72	109	Non-perennial - Major
	Milpulling Creek	616.68	71	Non-perennial - Major
	Bundijoe Creek	623.23	19	Non-Perennial - Minor
	Marthaguy Creek	633.68	416	Non-Perennial - Major
Castlereagh River basin	Castlereagh River	651.73	6,722	Non-perennial - Major
	Judes Creek	659.20	30	Non-Perennial - Minor
	Gulargambone Creek	673.08	243	Non-Perennial - Minor
	Baronne Creek	682.60	389	Non-Perennial - Major
	Tenandra Creek	694.20	42	Non-Perennial - Minor
	Mungery Creek	700.02	25	Non-Perennial - Minor
	Caleriwi Creek	702.34	28	Non-Perennial - Major
	Quanda Quanda Creek	704.59	28	Non-Perennial - Minor
	Black Gutter	708.47	< 5	Non-Perennial - Minor
	Salty Springs Creek	709.27	17	Non-Perennial - Minor
	Calga Creek	714.59	34	Non-Perennial - Minor
	Noonbar Creek	718.17	5	Non-Perennial - Minor
	Bucklanbah Creek	722.29	114	Non-Perennial - Minor
	Small Creek	728.11	5	Non-Perennial - Minor
	Teridgerie Creek	730.50	160	Non-Perennial - Major
	Ironbark Creek	737.89	35	Non-Perennial - Minor
Namoi River basin	Baradine Creek	747.77	933	Non-Perennial - Major
	Coolangla Creek	752.71	15	Non-Perennial - Minor
	Cumbil Forest Creek	758.97	10	Non-Perennial - Minor

Basin	Catchments/ Watercourses	N2N Chainage (km)	Upstream catchment area (km^2)	Flow type/ hierarchy
	Etoo Creek	763.46	122	Non-Perennial - Major
	Stockyard Creek	767.94	15	Non-Perennial - Minor
	Rocky Creek	769.14	127	Non-Perennial - Minor
	Tinegie Creek	773.37	<5	Non-Perennial - Minor
	Talluba Creek	779.64	29	Non-Perennial - Minor
	Cubbo Creek	783.65	59	Non-Perennial - Minor
	Rocky Creek	789.38	20	Non-Perennial - Minor
	Coghill Creek	796.41	48	Non-Perennial - Major
	Mollieroi Creek	800.45	92	Non-Perennial - Major
	Black Creek	803.65	20	Non-Perennial - Minor
	Goona Creek	809.11	45	Non-Perennial - Minor
	Bundock Creek	817.65	34	Non-Perennial - Minor
	Bohena Creek	828.22	2,038	Non-Perennial - Major
	Namoi River	844.12	25,073	Perennial - Major
	Breakout of Mulgate Creek	852.57	85	Non-Perennial - Minor



NARROMINE TO NARRABRI Waterways and catchments - Macquarie River Catchment Figure 2.1a

0 25 50 Km

Coordinate System: GDA 1994 MGA Zone 55

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

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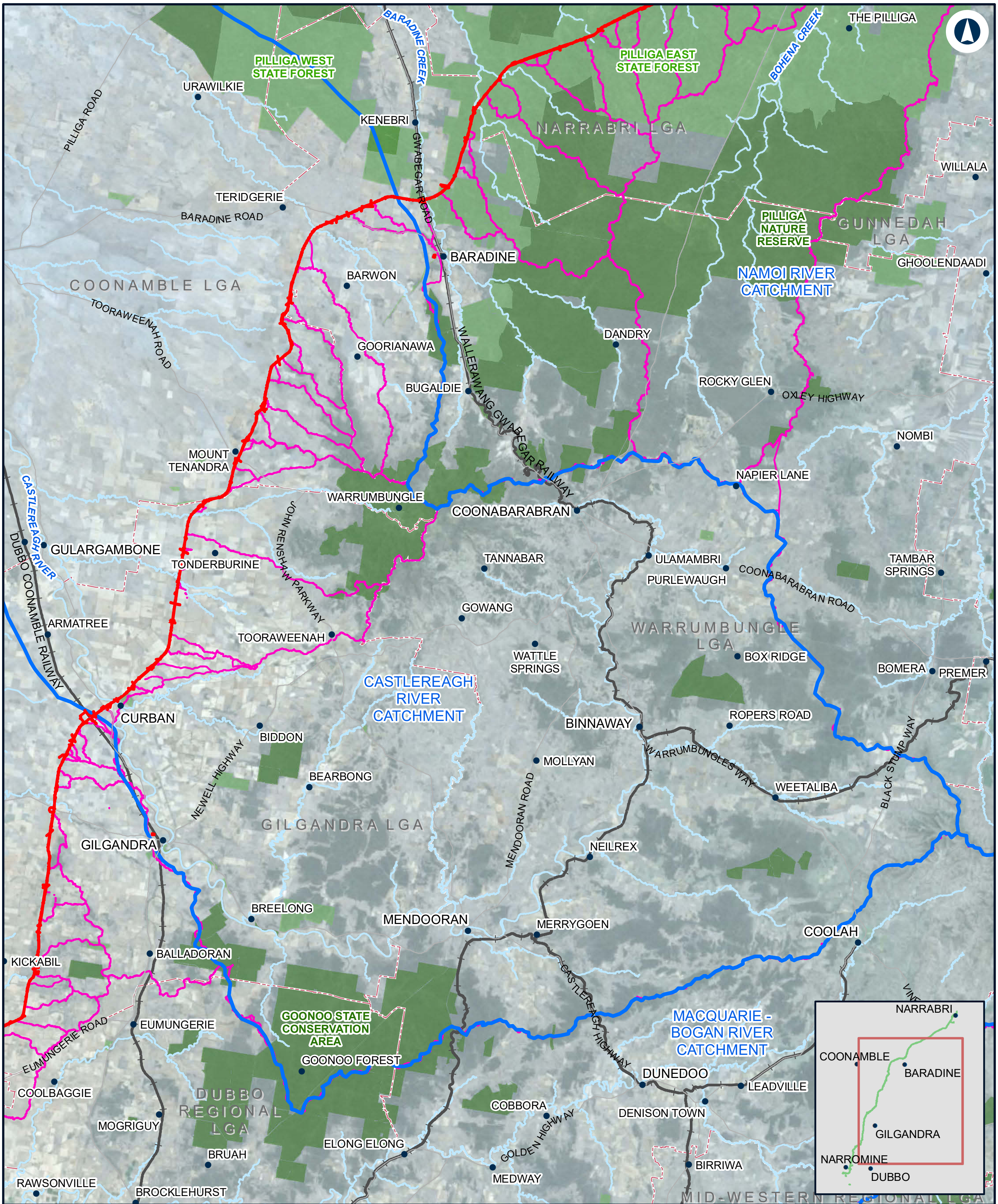

NARROMINE TO NARRABRI Waterways and catchments - Castlereagh River Catchment Figure 2.1b

0 10 20 Km

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LEGEND

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

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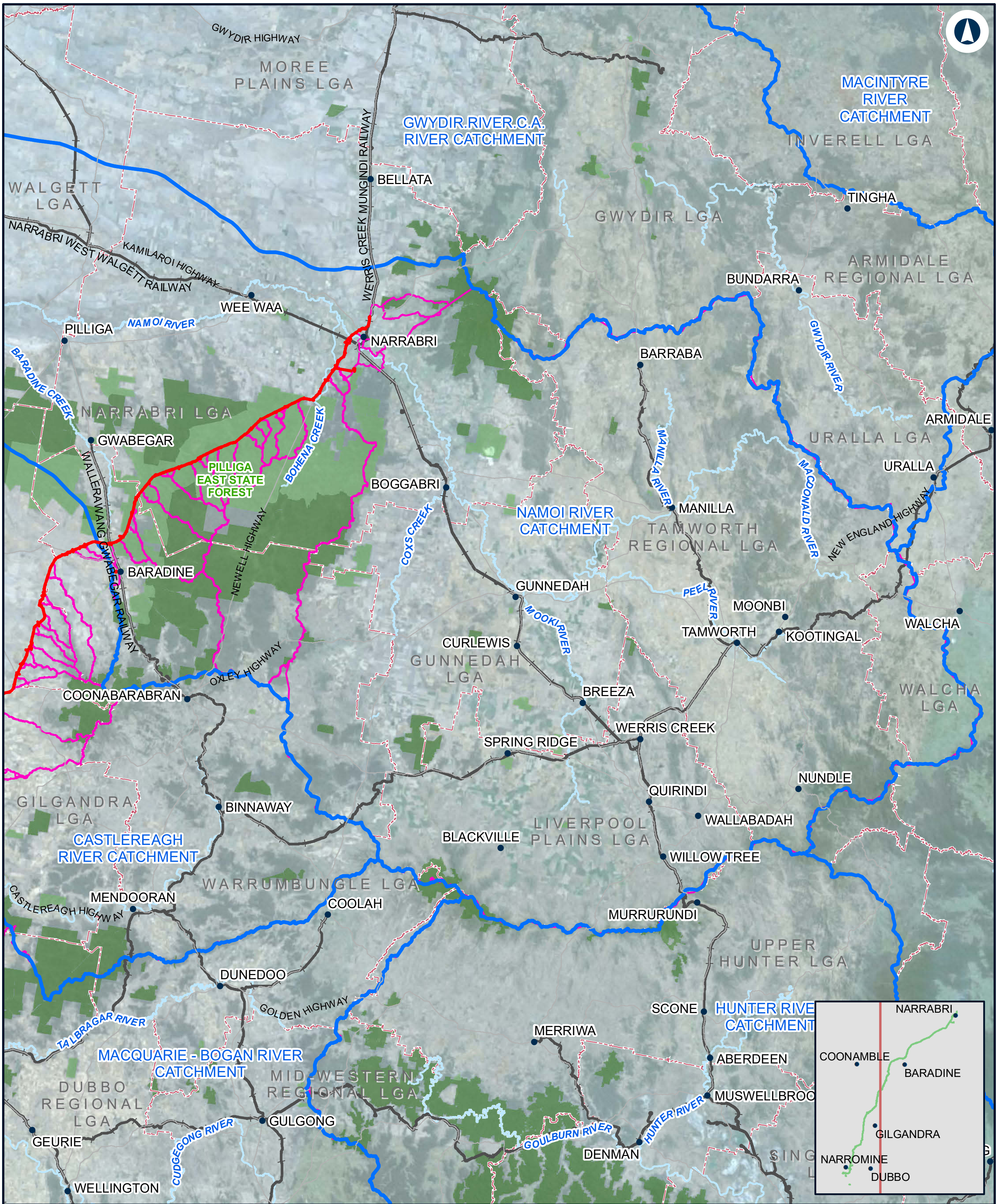

NARROMINE TO NARRABRI Waterways and catchments - Namoi River Catchment Figure 2.1c

0 30 60 Km

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LEGEND

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2.3 Land use

The Study Area is characterised by relatively flat catchments (gradient of up to five per cent) with some locally steeper proportions. Floodplain slopes are generally about one-half to one per cent gradient.

The land surrounding the Study Area is dominated by agricultural uses, particularly cotton, wheat, and livestock. These industries have resulted in significant clearing when compared to native bushland. This clearing has an impact on the resulting storm flows by lowering the catchment roughness (a measure by which surface flow in impaired by the surface type), which quickens the catchment's response time to rainfall and results in shorter, more intense catchment flows.

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

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

The flatter portions of the catchments are generally used for agricultural uses.

2.4 Flooding

2.4.1 Source

Flooding in the Study Area may be influenced by floods from two sources (or a combination of these sources):

- Flooding caused by high flows in the major rivers (Macquarie, Castlereagh and Namoi) and their tributaries.
- Flooding because of rainfall over local catchments draining through the Study Area.

2.4.2 History

2.4.2.1 Macquarie River

The Macquarie River rises in the Great Dividing Range near Oberon, Lithgow and the Mid-Western Regional local government areas. Boggy Cowal, also known as Backwater Cowal, and Brady's Cowal, located south of Narromine, rise in the Sappa Bulga Range. Backwater Cowal is reported as an old abandoned channel of the Macquarie River.

The most severe flooding near Narromine has been generated by rainfalls over the headwaters of the Macquarie River. The worst floods experienced in the township of Narromine are reported as those of 1867, 1892, 1926, 1950, 1955 and 1956 (SES 2014). The 1955 flood was reported as being the worst with floodwaters breaking the banks of the Macquarie River upstream of Narromine and flowing south to Backwater Cowal and the Bogan River. The more recent floods were reportedly less severe.

The largest recorded flood at the Narromine gauge (which was operational from 1913 to 1978) was about 251.5 m AHD in 1955 (SES 2014), which is understood to be about a 0.9 per cent AEP magnitude event.

The hydrology within the Macquarie River catchment at Narromine has been impacted by the construction of significant water storages since the floods of the 1950s. The storages include Burrendong Dam (catchment area approximately 13,900 km^2) and Windamere Dam (catchment area approximately 1,070 km^2) (http://waterinfo.nsw.gov.au/).

At the Baroona gauge, located about 12 km upstream of Narromine, the Macquarie River was recorded as reaching 244.69 m AHD in 2010 along with a similar level in 1990. Floodwaters are generally reported as being relatively shallow (less than 1 m deep) and relatively slow moving in the area near Narromine.

Flooding occurs in the Macquarie River in all seasons (SES 2014). Typical flood-producing conditions are as follows:

- In summer, heavy rainfalls can occur because of cyclonic low-pressure systems from northern Australia creating relatively short intense rainfalls.
- In winter, flooding frequently results from troughs associated with southern depressions from the western areas of Australia and these can produce significant rainfalls over extended periods of days.
- From November to March, convective thunderstorms can produce intense short duration rainfalls that may be very localised and create flash flooding in local watercourses.

Upstream of Narromine the Macquarie River flooding is generally confined to the relatively narrow and well-confined floodplain.

2.4.2.2 Castlereagh River

The headwaters of the Castlereagh River are within the eastern slopes of the Warrumbungle Ranges, west of Coonabarabran. It meanders generally eastwards, then southwards through Coonabarabran, Binnaway, Mendooran, Gilgandra, as a generally well- defined watercourse, with relatively confined floodplains, resulting in flood events that typically rise and fall relatively quickly (SES 2008).

Below Gilgandra, the Castlereagh River meanders generally northwest, through Gulargambone and Coonamble, before meeting the Macquarie River about 40 km west of Walgett. The lower reaches of the Castlereagh River are generally broad and flat, with numerous areas where the river channel is poorly defined whilst within other areas the river is perched (SES 2008).

Flooding occurs in the Castlereagh River in all seasons (SES 2008). Typical flood-producing conditions are as follows:

- In summer, heavy rainfalls can occur because of cyclonic low- pressure systems from northern Australia creating relatively short intense rainfalls.
- In winter, flooding frequently results from troughs associated with southern depressions from the western areas of Australia and these can produce significant rainfalls over extended periods of days.
- From November to March, convective thunderstorms can produce intense short duration rainfalls that may be very localised and create flash flooding in local watercourses.

Major flooding has occurred on a number of occasions, with the largest recorded flood event occurring in 1955, reaching a height of 10.05 m at the Gilgandra River gauge (*Lyall & Associates,1996)* estimate that this event was approximately equivalent to the one per cent AEP flood event. The 1955 flood resulted in significant flooding of the township, damaging commercial and residential properties.

2.4.2.3 Namoi River

The headwaters of the Namoi River are the western slopes of the Great Dividing Range. The Namoi River flows generally westwards across the broad, flat floodplain of the Liverpool Plains, passing Boggabri, Narrabri and Wee Waa before meeting the Barwon River near Walgett. Three major dams are located within the Namoi River Basin upstream of Narrabri. These dams include Keepit Dam (catchment area 5,700 km^2 and storage capacity 425,000 megalitres) Split Rock Dam (catchment area 1,650 km^2 and storage capacity 397,370 megalitres) and Chaffey Dam (catchment area 420 km^2 and storage capacity 100,500 megalitres) (http://waterinfo.nsw.gov.au/).

About 2.5 km upstream of the Narrabri town centre, the Namoi River divides into two branches: the Namoi River and Narrabri Creek. The two branches join back together about 10 km downstream of Narrabri. Under low flow conditions, all flow is carried by Narrabri Creek. A large sand and gravel bar in the Namoi River at its offtake from Narrabri Creek prevents water from entering the Namoi River until local low-level flooding from Narrabri Creek starts to occur. Each of these major flow paths has a gauge. These two gauges do not give the same level for a particular flood nor do they have the same gauge zero. After the winter floods of July-August 1998, it was decided that all future warnings would be made for the Narrabri Creek gauge. SES flood intelligence for Narrabri is also based on the height at the Narrabri Creek gauge. (SES 2015).

Narrabri has experienced several very large flood events in 1955, 1910, 1920, 1971 and 1998 (WRM, 2016) due to regional flooding in the Namoi River. Narrabri experienced flooding from local catchments in December 2004 and February 2012 (WRM, 2016).

3. Methodology

3.1 Background

Hydrology computer models are required to estimate rainfall runoff for the full range of design flood events which would be generated from catchments located upstream of the proposal. Hydraulic computer models would route the runoff hydrographs simulated by hydrology models to define flood behaviour in channels and on the floodplains traversed by the proposal.

The purpose of the calibration of the hydrology and hydraulic models is to:

- Estimate robust hydrologic and hydraulic parameter values for gauged catchments.
- Extrapolate hydrologic and hydraulic model parameter values for the full range of design flood events.
- Assist in the selection of model parameter values for ungauged catchments for the full range of design flood events.

This section provides an overview of the methodology for model calibration. Details specific to the calibration of each hydrology and hydraulic model are provided in Section 5 and 6, respectively.

3.2 Data collection and review

The following data was collected and reviewed to identify relevant information which could be used in the calibration of hydrology and hydraulic models for the Study Area:

- Background information and documents provided by ARTC referenced in Section 4.1
- Previous studies and flood models identified in Section 4.2
- Topographic data including aerial imagery
- Rainfall data
- Stream gauge data

3.3 Selection of hydrology and hydraulic models

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

TUFLOW (BMT, 2018) is a combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model which was used for developing new hydraulic computer models. TUFLOW is an industry-standard flood modelling platform identified in ARR 2019 (*Ball et al, 2019*), which has:

- Capability in representing complex flow patterns on the floodplain, including dispersed overland flows, flows in flow paths and watercourses and flows around buildings

- Capability in accurately modelling flow behaviour in 1D channel, bridge and culvert structures and interflows with adjacent 2D floodplain areas
- Capability with 2D modelling of complex bridge structures including bridge hydraulic energy losses Topographic data including aerial imagery
- Flexibility in representation and modelling of future mitigation works
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs

3.4 Selection of calibration events

The available information was reviewed to identify flood events which could be selected to calibrate hydrology and hydraulic models against data recorded at stream gauges, observations made during site inspections, information provided by the community, available flood imagery and flood behaviour reported in the relevant reports cited in Section 4.2.

3.5 Formulation of hydrology models

RORB hydrology models were developed as part of the Reference Design for the gauged catchment areas of Baradine Creek and Bohena Creek. Location of stream gauges for the two creeks and other waterways are shown in Figure 4-3.

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

Sufficient historical streamflow data is available for the major rivers including the Macquarie River, Castlereagh River and Namoi River to undertake at-site flood frequency analysis based on the methods outlined in ARR 2019 (Ball et al, 2019). Due to the large catchment areas upstream of the proposal and the presence of major water storages in the Macquarie and Namoi basins, RORB models for the three major catchments were configured to simulate runoff hydrographs for rare to extreme flood events.

3.6 Spatial and temporal distribution of rainfall

The available rainfall data was utilised to define the spatial and temporal distribution of rainfall for the selected flood events. Recorded rainfall data was used to define the spatial distribution of rainfall over the catchment area at the gauge for each event. Sub-daily rainfall recorded at the nearest rain gauges were used to define temporal distribution of rainfall for each calibration event.

3.7 Baseflow separation

The RORB model transforms the rainfall excess for a given storm event into a flood hydrograph. RORB does not incorporate the attenuated baseflow component originating from groundwater stores, replenished by a prior (and current) storm event. In order to compare the routed storm excess estimated by RORB to the actual observed storm hydrographs, it is necessary to remove the baseflow component from the recorded hydrograph of total streamflow.

There are many methods for separating baseflow response of a stream hydrograph without recourse to rainfall or other hydrologic information, though while most procedures are based on physical reasoning, the quantitative elements of separation techniques are essentially arbitrary.

The approach undertaken to separate the baseflow was based on ARR 2019 (*Ball et al, 2019*) and the overall approach is summarised below:

- The streamflow hydrograph on either side of the event is examined in order to provide confirmation on the general magnitude of the groundwater contribution in the absence of rainfall.
- The streamflow at the beginning of the hydrograph rise is assumed to be comprised solely of baseflow.
- A baseflow separation line is drawn by extending the recession curve prior to the stream rise to a point under the peak of the hydrograph.
- The baseflow hydrograph is assumed to peak after the total hydrograph peak due to the storage-routing effect of the sub-surface stores.
- The falling limb of the baseflow recession curve is assumed to follow an exponential decay function so as to re-join the total hydrograph at the cessation of surface runoff.

3.8 Runoff-routing parameters

Calibration of model parameters was undertaken by trial and error to obtain the best agreement between observed and estimated hydrographs. The approach to the fitting procedure was to determine loss parameter values which resulted in an acceptable reproduction of the initial rise and volume of the observed hydrograph, and then to determine the optimum combination of routing parameters that yielded the best fit to the observed hydrograph. A fixed value of m of 0.8 was adopted for all RORB models and a value of k_c was obtained based on trial and error after adjusting initial and continuing rainfall losses.

3.9 Simulation of hydrographs for calibration events

In the case of gauged catchments (refer to Table 5-1 and Table 5-2), several model simulations were undertaken to obtain a reasonable agreement between modelled and observed flow hydrographs for each calibration event. Generally, the value k_c and rainfall losses were varied to obtain the best fit.

3.10 Calibration results

A comparison was made between modelled and recorded peak flow, the rising limb of the hydrograph, the falling limb of the hydrograph, flow volume and time to peak for all calibration events. Calibration results are shown in Appendix B.

3.11 Validation of peak flows for design flood events

The calibrated RORB models were used to simulate peak flows for 20% annual exceedance probability (AEP), 10% AEP, 5% AEP, 2% AEP and 1% AEP events using the recommended procedures in ARR 2019 (*Ball et al, 2019*). The median value of k_c and rainfall losses were adopted from calibration results. Modelled peak flows for design flood events at the stream gauges were compared against at-site flood frequency results and the regional flood frequency estimation (RFFE) tool, provided by ARR 2019 (*Ball et al, 2019*).

3.11.1 At-site flood frequency analysis

The primary objective of at-site flood frequency analysis is to establish a relationship between magnitude of flood events and their frequency of occurrence at a stream gauge. At-site flood frequency analysis (FFA) is a statistical technique which fits a probability distribution to streamflow data series. The streamflow data are assumed to be stochastic in nature and assumed to be space and time independent.

A sanity check of channel cross section, gauged flows and rating curves was undertaken for each stream gauge, where sufficient historical streamflow data was available for FFA. FFA for each site was undertaken on annual peak flows recorded between 1 January and 31 December of each year. FFA for each site was undertaken based on the methods outlined in ARR 2019 (*Ball et al, 2019*) using TUFLOW FLIKE software. A General Extreme Value (GEV) and a Log Pearson Type III (LP3) probability distributions were fitted to the annual peak flow series with and without inclusion of the Multiple Grubbs Beck Test. The Multiple Grubbs Beck Test aims to remove potentially influential low flows from the flood frequency analysis.

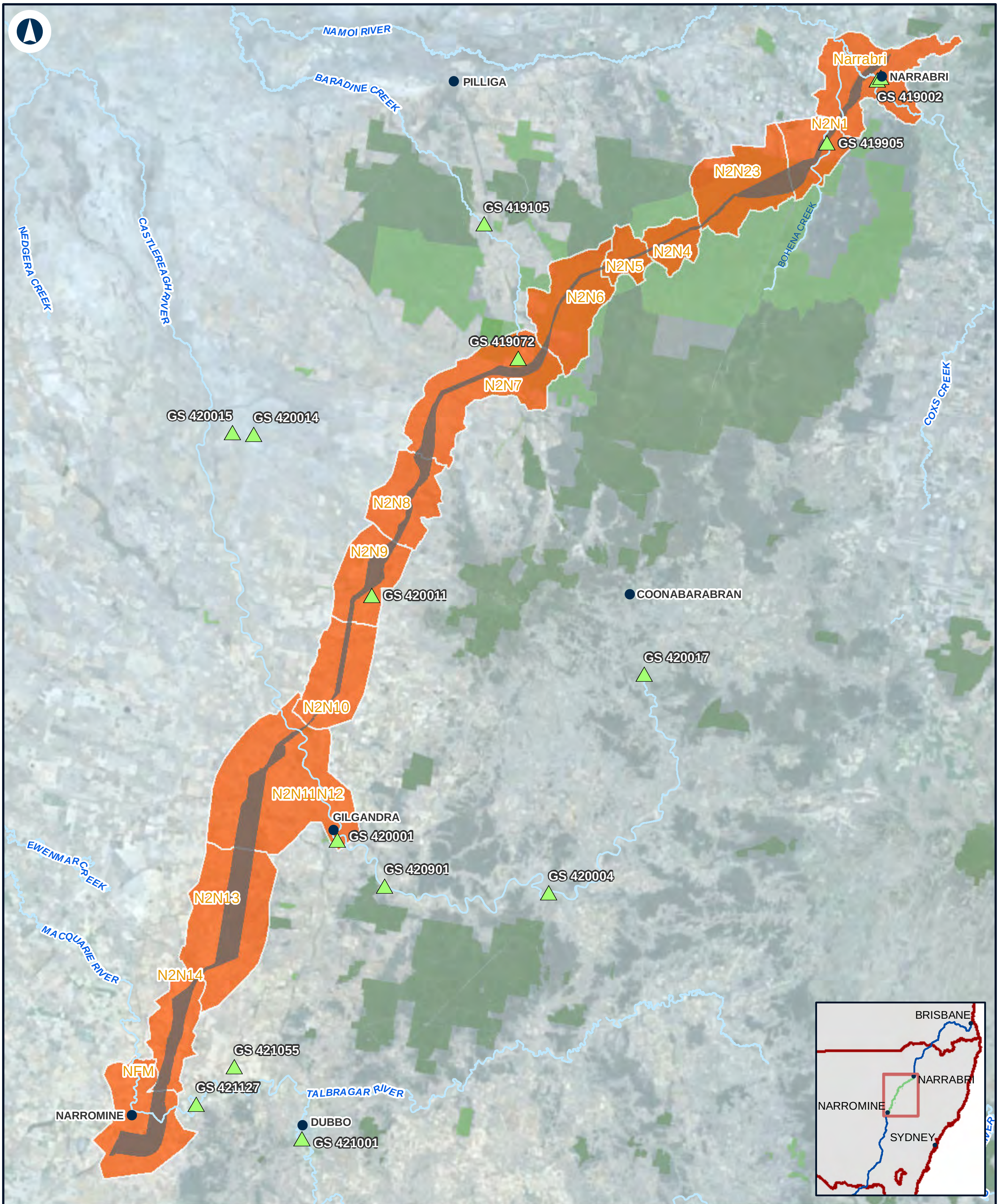
Stream gauges for which FFA analyses were undertaken as part of previous flood studies were reviewed and updated where required. Outcomes from FFA were utilised in the validation of design peak flows for tributary catchments for which hydrology models were developed as part of this study or previous flood studies.

3.11.2 Regional flood frequency

RFFE tool from ARR 2019 (*Ball et al, 2019*) was used to estimate peak flows for the selected design flood events.

3.12 Formulation of hydraulic models

The available topographic data and land use data were reviewed and it was identified that fourteen TUFLOW hydraulic models would be required to define flood behaviour along the proposal. Preliminary extents of the hydraulic models are shown in Figure 3-1 and the extent of the proposal covered by each hydraulic model is shown in Table 3-1. Each hydraulic model covers a portion of the proposal site and an area of the floodplain upslope and downslope sufficient to capture any potential upstream breakouts, changes in flood behaviour due to the proposal and relatively free from backwater influences.



NARROMINE TO NARRABRI

Hydraulic model extents and stream gauging stations

Figure 3.1

0 20 40 Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 18/08/2020 Paper: A4
Author: JACOBS Scale: 1:30,000,000
Data Sources: Phase 2 study area, hydraulic data: GHDJACOBS; Imagery: ARTC; all other layers IR ARTC

LEGEND

- Study area
- Stream gauge
- Watercourse
- TUFLOW model extents

INLAND RAIL ARTC

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

G:\22\19593\GIS\GIS_2500_N2N_v2\Maps\Deliverables_100percentUpdate\EIS\FloodCalibration\2500_EISFLOCAL_023_ModelExtents_StreamGauges.mxd

Table 3-1 Extent of the proposal represented in each hydraulic model

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

The adopted grid size for the new TUFLOW (2018 03 AB HPC GPU) (BMT, 2018) hydraulic models is 10 metres. A 10 metres grid size was considered reasonable for the models in terms of the size of the Study Area, model run time, potential depth of flooding, flood events and scenarios to be assessed. The hydraulic model topography was defined from DEMs provided by ARTC (refer Section 4.3.1) and DEMs extracted from ELVIS (refer Section 4.3.2). Surface roughness was based on typical industry standard values for different land use types identified from GIS layers (e.g. land use and planning layers for NSW) and aerial photography, and was adjusted through the model calibration process. The adopted surface roughness values are shown in Table 3-2.

Existing road and railway embankments and levees were represented in the TUFLOW models as ‘Z’ lines. Narrow creeks were defined as ‘GULLY’ lines in the models. Bridges were generally modelled in two dimensions as flow constrictions. Typically, culverts were modelled as one-dimensional elements to capture the hydraulic response of each culvert and to allow for the simple modification of the number of culverts and dimensions. Details on the existing culverts and bridges were sourced from the hydraulics models for Narrabri and Narromine provided by councils, topographic survey undertaken for the proposal, information from Transport for NSW and identified based on a review of terrain data and aerial imagery.

Generally, a slope boundary (HQ) was defined where the waterway is defined adequately and a water boundary (HT) was adopted for the floodplain. The downstream boundaries are typically located several kilometres (approximately 6 to 8 kilometres) downstream of the proposal and the difference in elevation between the proposal and the HQ/HT boundary is typically more than 10 metres. Hence, flood behaviour along the proposal is unlikely to be influenced by the adopted HQ/HT boundaries.

Table 3-2 Adopted surface roughness values

Land use	Manning's n
River/Creek	0.035 (0.07 for dense vegetation)
Dam	0.020
Swamp	0.060
Grazing	0.050
Pasture	0.040
Non-irrigated Cropping	0.045
Irrigated Cropping	0.060
Cotton Cropping	0.080
Horticulture	0.060
Residential	0.150
Developed areas	0.100
Paved Road	0.020
Dirt Road	0.025
Transport Corridor	0.030 (0.100 for forest)
Forest	0.100
Mining	0.100

The flood study models provided by Narromine and Narrabri Shire Councils were reviewed and, where necessary, extended to cover additional sections of the Study Area. The updated and extended council models were re-run for the existing conditions, and the resulting flood extents and depths compared to those reported in the council flood studies to validate consistency between council models and those used for the proposal.

3.13 Calibration of hydraulic models

Recorded stream flow data was used in the hydraulic models and the models were run for the calibration events. Water level and discharge simulated by the models were compared against stream gauge (water level and discharge) data and surveyed flood marks. Where necessary, adopted hydraulic roughness values were adjusted to improve the model performance. A comparison between modelled and the latest rating curve was also undertaken.

3.14 Validation of hydraulic models

The available data for stream gauges and surveyed flood marks for historic flood events were utilised in the calibration of hydraulic models and consequently, it was not possible to verify hydraulic models against other historic flood events. Hence, the performance of the hydraulic models was verified by modelling design flood events and comparing the modelled flood behaviour to that adopted in recent council flood studies for Narromine and Narrabri.

4. Available data

This chapter identifies the data available to undertake a flood study for the proposal.

4.1 Standards, guidelines and relevant documents

The following standards and guidelines were used, as appropriate:

- Australian Rainfall and Runoff (AR&R) (2019) Reference - Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I (Editors), 2019, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia
- Austroads (2013) Guide to Road Design Part 5: Drainage – General and Hydrology Considerations, Sydney
- NSW Department of Infrastructure, Planning and Natural Resources (2005) Floodplain Development Manual, the management of flood liable land
- Draft Floodplain Management Plan for the Macquarie Valley Floodplain 2018 (Department of Industry, 2018)
- The *Narromine Floodplain Risk Management Study and Plan* (Lyall & Associates, 2009) which is currently under review (https://www.narrominenewsonline.com.au/story/6313404/flood-risk-management-plan-under-review/ accessed 28/02/2020)
- Floodplain Management Plan for the Upper Namoi Valley Floodplain 2019 (NSW Government, 2019)
- Floodplain Management Plan for the Lower Namoi Valley Floodplain 2020 (NSW Government, 2020)
- *Narromine Shire Flood Emergency Sub Plan* (SES, 2014)
- *Gilgandra Shire Local Flood Plan* (SES, 2008)
- *Warrumbungle Shire Flood Emergency Sub Plan* (SES, 2013)
- *Narrabri Shire Flood Emergency Sub Plan* (SES, 2015)

4.2 Previous studies and flood models

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

Below is a summary of available flood studies for the major river systems.

4.2.1 Narromine

Narromine has an existing levee that provides protection against flood events smaller than the 1% AEP event (*Lyall & Associates, 2013*). The 800m long existing levee was constructed after the flood event of 1950. The Floodplain Risk Management Study prepared for the town of Narromine by Lyall & Associates in 2009 recommended the feasibility study for a river bank levee as a high priority measure for inclusion in the Floodplain Risk Management Plan for Narromine. Narromine Shire Council engaged Lyall & Associates to undertake a flooding and drainage investigation of seven possible levee routes along the southern bank of the Macquarie River at Narromine. Lyall & Associates (2013) developed a flood model for the feasibility study of the proposed river bank levee. The flood model developed by Lyall & Associates (2013) was provided by Narromine Shire Council for use in the Reference Design by JacobsGHD. The feasibility study for the proposed river bank levee adopted peak design discharges in the Macquarie River at Narromine based on a post-Burrendong Dam flood frequency analysis presented in Table 4-1.

Table 4-1 Peak design discharges in the Macquarie River at Narromine (Lyall & Associates, 2013)

AEP	Macquarie River at Narromine (m^3/s)
5%	1,610
2%	2,720
1%	4,000
0.5%	5,800

Lyall & Associates (2013) developed a TUFLOW hydraulic model and the key features of the model are:

- A two-dimensional model domain comprised of 10 m rectangular grids and elevation data for the grids were sourced from a LiDAR survey.
- The main channel of the Macquarie River was represented as a one- dimensional element.
- A 7.5 km long reach of the river and the associated floodplains downstream of the two-dimensional model domain was represented as one-dimensional element.
- Backwater Cowal and the southern overbank areas were represented as one- dimensional elements.
- A discharge hydrograph was used to define the upstream inflow and conceptual weirs were used to represent free draining outlets in the model.
- The model was calibrated against flood events of August 1990 and December 2010 using different Manning's n values for the main channel of the Macquarie River. This due to the fact that whilst peak flows in the Macquarie River for two flood events are approximately similar, the December 2010 event is 0.59 m higher than the August 1990 flood levels at the Narromine Flood gauge. For both flood events, a Manning's n value of 0.06 was adopted for the main channel of the Macquarie River upstream of Eumungerie Road Bridge. Lower Manning's n values of 0.044 and 0.055 for the flood events of 1990 and 2010 respectively were adopted for the main channel of the river downstream of Eumungerie Road Bridge to obtain a reasonable agreement between modelled and recorded peak flood levels for both flood events.
- The TUFLOW model was used to simulate flood behaviour for the 1% and 0.5% AEP events.

4.2.2 Macquarie River Floodplain Management Plan

The draft Floodplain Management Plan (FMP) for the Macquarie Valley Floodplain 2018 (Department of Industry, 2018) assessed flood behaviour in the Macquarie River at Narromine, in the lower reaches of Ewenmar Creek and Marthaguy Creek. The Study Area for the proposal is located at the eastern extremity of the designated floodplain for the plan. The proposal intersects Management Zone CU which represents the urban area of Narromine where there is a separate floodplain risk management study and plan in place.

For the draft Macquarie Valley FMP, a RORB hydrology model was used to simulate rainfall runoff from the ungauged tributary catchments. Hydrology modelling was undertaken for the nearby Coolbaggie Creek to estimate RORB model parameter values for the ungauged catchments. The RORB model for Coolbaggie Creek was calibrated against flood events of July 1998, November 2010 and March 2012. Except for the initial rainfall loss, the same values of k_c (26.5), m (0.8) and a continuing rainfall loss rate (1.2 mm/hour) were adopted for all three calibration events. The adopted initial losses for the three events were 0 mm (July 1998), 20 mm (November 2010) and 48 mm (March 2012).

RORB model parameter values k_c, m, initial loss and continuing loss rate adopted for ungauged catchments were 26.5, 0.8, 30 mm and 1.2 mm/hour, respectively. The simulated flow hydrographs from the RORB models for ungauged catchments were used as inputs to the hydraulic models. A comparison of modelled flood extent for the 2010 flood event and the available satellite imagery indicated an over estimation of flood extent by the hydraulic model and hence inflows were scaled down to match the flood patterns of the 2010 flood. The likely reason for this over-estimation identified in the draft FMP is that Coolbaggie Creek has a higher average slope than the ungauged tributaries.

4.2.3 Compilation of Flood Studies Addendum for the Macquarie River, Dubbo

Dubbo Regional Council engaged Cardno to update the Dubbo Flood Study and in March 2012, Version 3 of the report titled “Macquarie River, Dubbo – Compilation of Flood Studies” was delivered to council. Additional investigations and peer reviews were subsequently undertaken prior to release of the draft final report titled “Macquarie River, Dubbo – Compilation of Flood Studies” in January 2019 (Cardno, 2019).

The Dubbo Flood Study is complex due to the junction of the Macquarie River (catchment area approximately 20,000 km^2) and the Talbragar River (catchment area approximately 5,000 km^2) being located immediately downstream of Dubbo and the upstream presence of Burrendong Dam (catchment area approximately 13,900 km^2).

Streamflow records for the Macquarie River at the Dubbo gauge (GS 421001) are analysed in detail in the Dubbo Flood Study (Cardno, 2019) and the study was peer reviewed. Peak design inflows for the Macquarie River adopted in the study are provided in Table 4-2.

Table 4-2 Peak design inflows (m^3/s) for the Macquarie River (Cardno, 2019)

AEP	Macquarie River (Dubbo)
10%	790
5%	1,343
2%	2,557
1%	4,037
0.5%	5,300

It is to be noted that peak design inflows shown in Table 4-2 for the Macquarie River are based on a flood frequency analysis of streamflow data post-Burrendong Dam. It is also to be noted that the peak flow shown in Table 4-2 for the 1% AEP event is slightly higher than the corresponding peak flow in the Macquarie River at Narromine shown in Table 4-1.

4.2.4 Gilgandra

The Gilgandra Floodplain Management Study (*Lyall & Associates 1996*) provides a summary of the flood behaviour of the Castlereagh River at Gilgandra.

The largest historical flood occurred in 1955, reaching a height of 10.05 m at the local river gauge. Lyall & Associates (1996) estimated that this event was approximately equivalent to the 1% AEP flood event. The 1955 flood resulted in significant flooding of the township, damaging commercial and residential properties.

The floodplain management study presents several options for the management of future flood events, ranging from the installation of a flood warning system to the construction of a levee. These options were reviewed by URS (2014), who recommended a scoping study to investigate the feasibility of various levee options, including temporary flood levees, and adoption of flood planning levels within the township.

4.2.5 Gulargambone

A flood study (*Jacobs 2016*) for Gulargambone defines flood behaviour for the township of Gulargambone due to flooding from the Castlereagh River and Gulargambone Creek. The proposal is located outside the Study Area for the flood study.

4.2.6 Baradine

Warrumbungle Shire Council prepared a floodplain risk management study and plan for Teridgerie Creek at Baradine. The Study Area includes the upper reach of Teridgerie Creek and includes the western parts of Baradine township. The study does not include the Study Area for the proposal.

4.2.7 Narrabri Flood Study Namoi River, Mulgate Creek and Long Gully (WRM, 2016)

Narrabri Shire Council engaged WRM Water & Environment Pty Ltd (WRM) to prepare a flood study to address regional flooding from the Namoi River (catchment area 25,400 km^2) and local catchment flooding from catchment areas of Mulgate Creek (catchment area 202 km^2) and Long Gully (catchment area 28 km^2) at Narrabri.

WRM reviewed the stage discharge rating curve for Narrabri and the rating curve was updated through hydraulic modelling. The regional design discharges at Narrabri were estimated from an annual series flood frequency analysis of the combined recorded flows at the two stream gauges (Namoi River at Narrabri (GS 419002) and Narrabri Creek at Narrabri (GS 419003)). Available flood information for Narrabri dating back to 1890 (126 years from 1890 to 2015) was included in the analysis. A Log-Pearson Type III distribution was fitted to the annual series of recorded (and inferred) peak flood discharges at Narrabri using the Bayesian inference methodology recommended in ARR 2019 (*Ball et al, 2019*) using the TUFLOW FLIKE software. The 1% AEP design discharge at Narrabri was estimated at 4,860 m^3/s, which was slightly lower than the historical 1955 flood of the Namoi River. The estimated AEP of the 1955 flood is between 1% and 0.5%.

The design discharges from the catchment areas of Mulgate Creek and Long Gully were estimated using an XP-RAFTS hydrology model developed for this study. XP-RAFTS design discharge estimates for the local catchments based on ARR 1987 (*Institution of Engineers, 1987*) were validated against results from Regional Flood Frequency Estimate (RFFE) program (Ball et al, 2019).

A ground surface digital elevation model (DEM) of the floodplain around Narrabri was provided by NSW Government Land and Property Information (LPI). The DEM was based on Light Detection and Ranging (LiDAR) data captured in January 2014. The DEM and surveyed topographic data were used to develop a computer based MIKE-Flood FM (flexible mesh) hydraulic model to simulate the flow behaviour of the Namoi River, Narrabri Creek and local creeks within the Study Area. The flexible mesh in MIKE Flood FM allows the user to define the topography according to local needs. Six (6) regions are defined in the MKE Flood FM model for Narrabri for important flow path, developed area, secondary flow path, general floodplain/ rural land, intensive cropping and non-floodplain. The maximum element area for each region varies between 75 m^2 for important flow paths and 1200 m^2 for non- floodplain. The maximum element area for rural land assigned in the MIKE Flood FM model is 400 m^2.

The MIKE-Flood FM model was calibrated against three regional flood events of February 1955, February 1971 and July 1998 and two local flood events of December 2004 and February 2012.

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

4.3 Topographic data

Four sets of topographical data covering the Study Area were obtained:

- Survey model obtained through LiDAR survey and aerial imaging.
- ELVIS.
- Digital Elevation Model (DEM) obtained through Shuttle Radar Topography Mission (SRTM).
- Localised site survey undertaken by JacobsGHD.

4.3.1 LiDAR

A topographic survey model obtained through LiDAR imaging was provided by ARTC. The LiDAR data provided by ARTC was captured by AAM Pty Ltd in 2015, 2017 and 2018. Figure 4-2 shows extents of LiDAR data captured by AAM Pty Ltd on three occasions. Data validation showed a vertical accuracy (root mean square error) of 0.079 m and a standard deviation of 0.078 m.

4.3.2 ELVIS

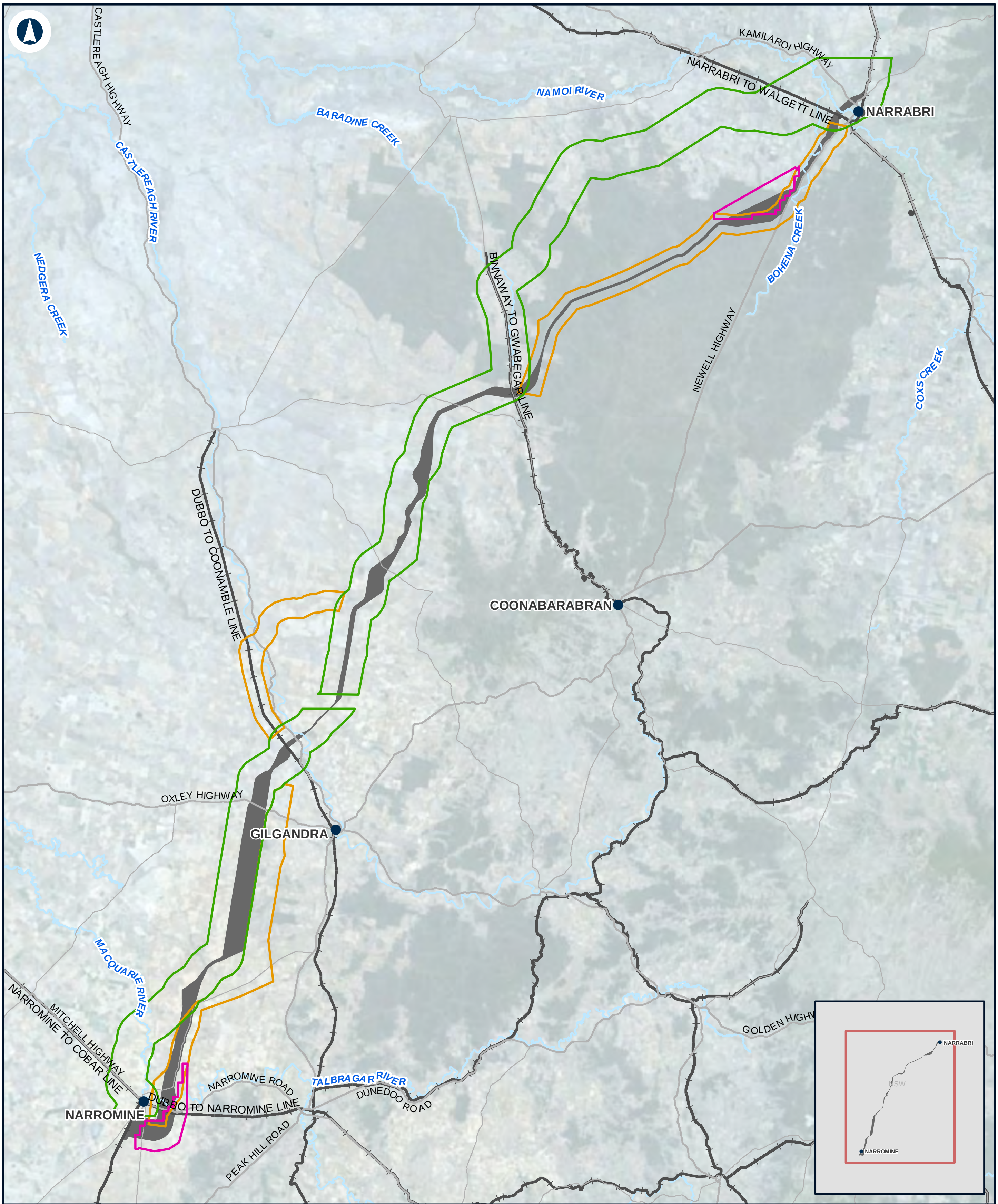
Geoscience Australia provides processed 1 m and 5 m DEMs for most of NSW through *ELVIS* (www.elevation.fsdf.org.au). These DEMs are based on LiDAR and other surveys undertaken on behalf of state and federal governments.

4.3.3 Shuttle radar

Topographic data generated by the SRTM program was used for terrain outside the LiDAR corridor where necessary to define catchment boundaries that extend beyond the supplied information. The horizontal resolution of the DEM is about 30 m. The reported vertical accuracy of the data is plus or minus 10 m. However, the accuracy is expected to exceed this figure given the generally flat landscape. The SRTM data was used to form the terrain model outside the LiDAR corridor.

4.3.4 Site survey

As part of investigations for the proposal, existing culverts, bridges, channel cross sections and historic flood marks identified by land owners were surveyed in May 2019. The surveyed features are located in the vicinity of the proposal on crown land, road reserves and private properties with authorised land access. In total, 46 culverts were surveyed and geographical coordinates, basic dimensions, field notes and photographs were captured for each culvert. Geographical coordinates, basic dimensions, field notes and photographs were also collected for eight (8) bridges. Twenty (20) channel cross sections were surveyed. Landowners provided information on historic flood levels for two locations. One historic flood mark is located in Narromine and the other historic flood mark is located in Narrabri. Location of the surveyed features are shown in Figure 4-3. It is to be noted that the topographic survey was based on the NSW CORS / SmartNet network, where the typical expected horizontal accuracy is plus or minus 100 mm.



NARROMINE TO NARRABRI Extent of LiDAR data captured by AAM

Figure 4.1

0 20 40 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 18/08/2020 Paper: A4
Author: JACOBS Scale: 1:1,100,000
Data Sources: Alignment: GHDJACOBS: Imagery, base layers: NSW Spatial Services: all other layers: IR ARTC

LEGEND

- Study area
- Road
- Existing railway
- Watercourse

LiDAR capture date

- 2015
- 2017
- 2018

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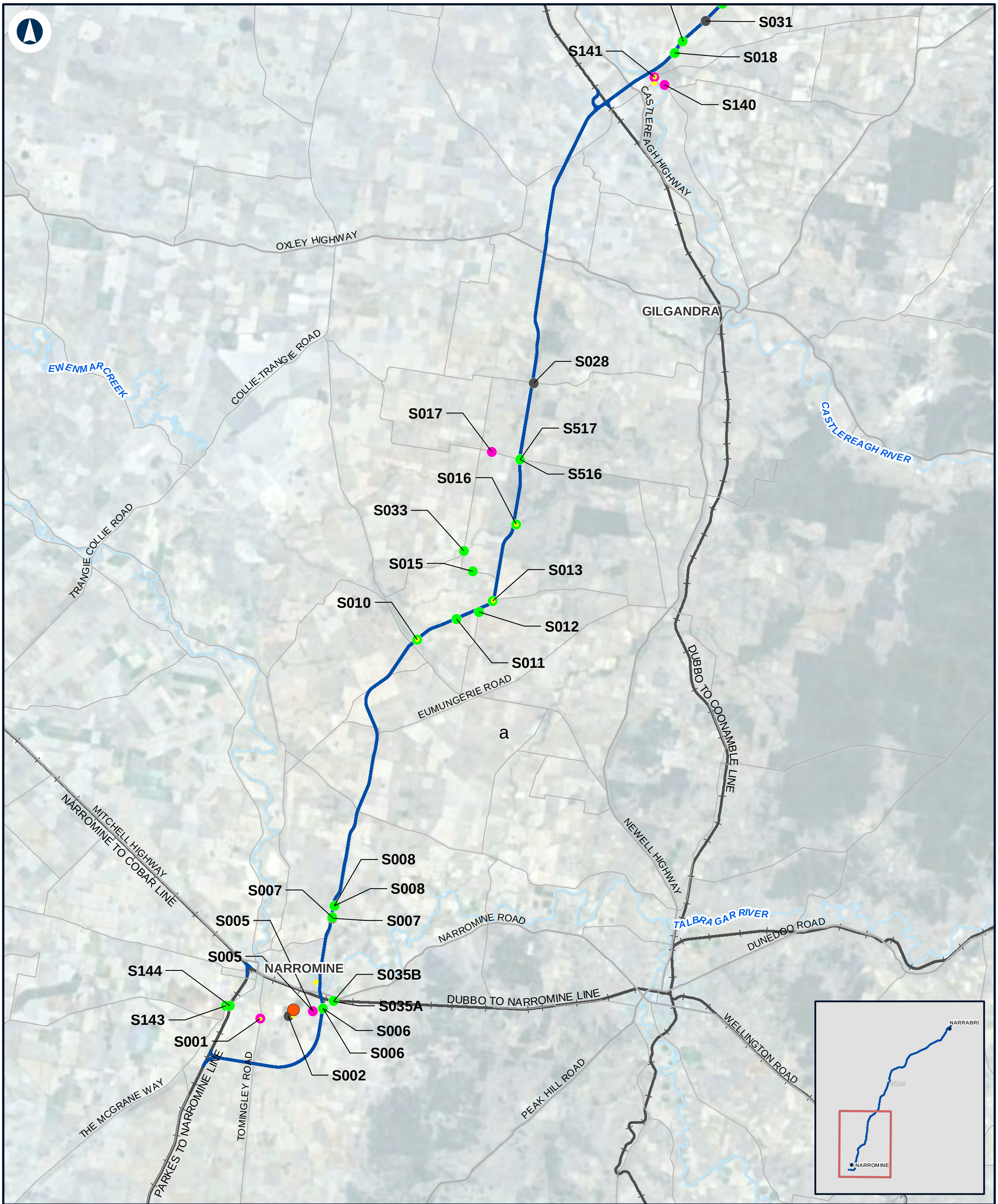

NARROMINE TO NARRABRI Surveyed features

Figure 4.2a

0 10 20 Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 18/08/2020 Paper: A4
Author: JACOBS Scale: 1:450,000
Data Sources: Alignment: GHDJACOBS: Imagery, base layers: NSW Spatial Services: all other layers: IR ARTC

LEGEND

- Preferred preliminary alignment
- Cross sections
- Flood marks
- Road
- Existing railway
- Watercourse

Structure type

- Bridge
- Culvert
- No structure

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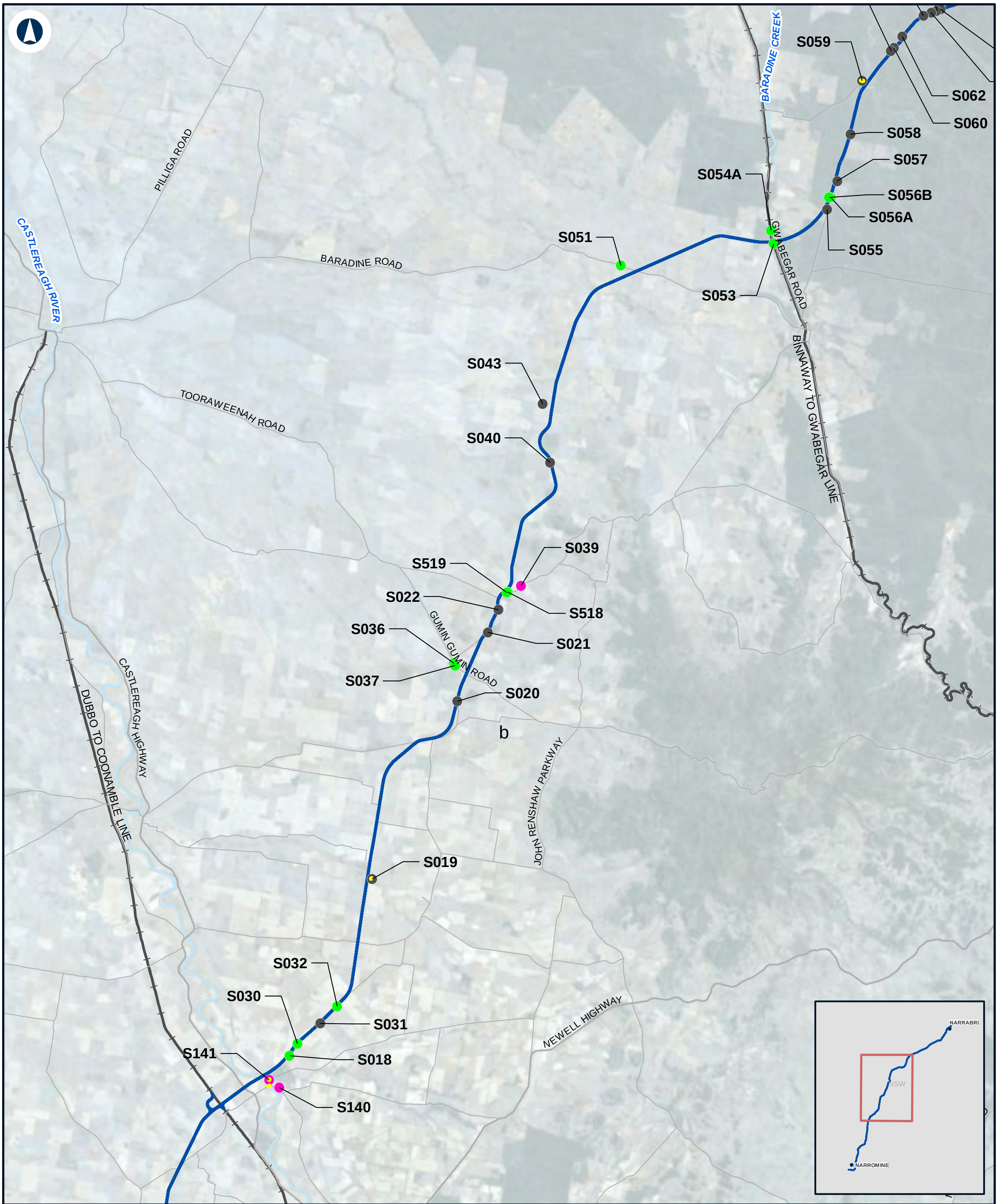

NARROMINE TO NARRABRI

Surveyed features

Figure 4.2b

0 10 20 Km

Coordinate System: GDA 1994 MGA Zone 55

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Data Sources: Alignment: GHDJACOBS: Imagery, base layers: NSW Spatial Services: all other layers: IR ARTC

LEGEND

- Preferred preliminary alignment
- Cross sections
- Flood marks
- Road
- Existing railway
- Watercourse

Structure type

- Bridge
- Culvert
- No structure

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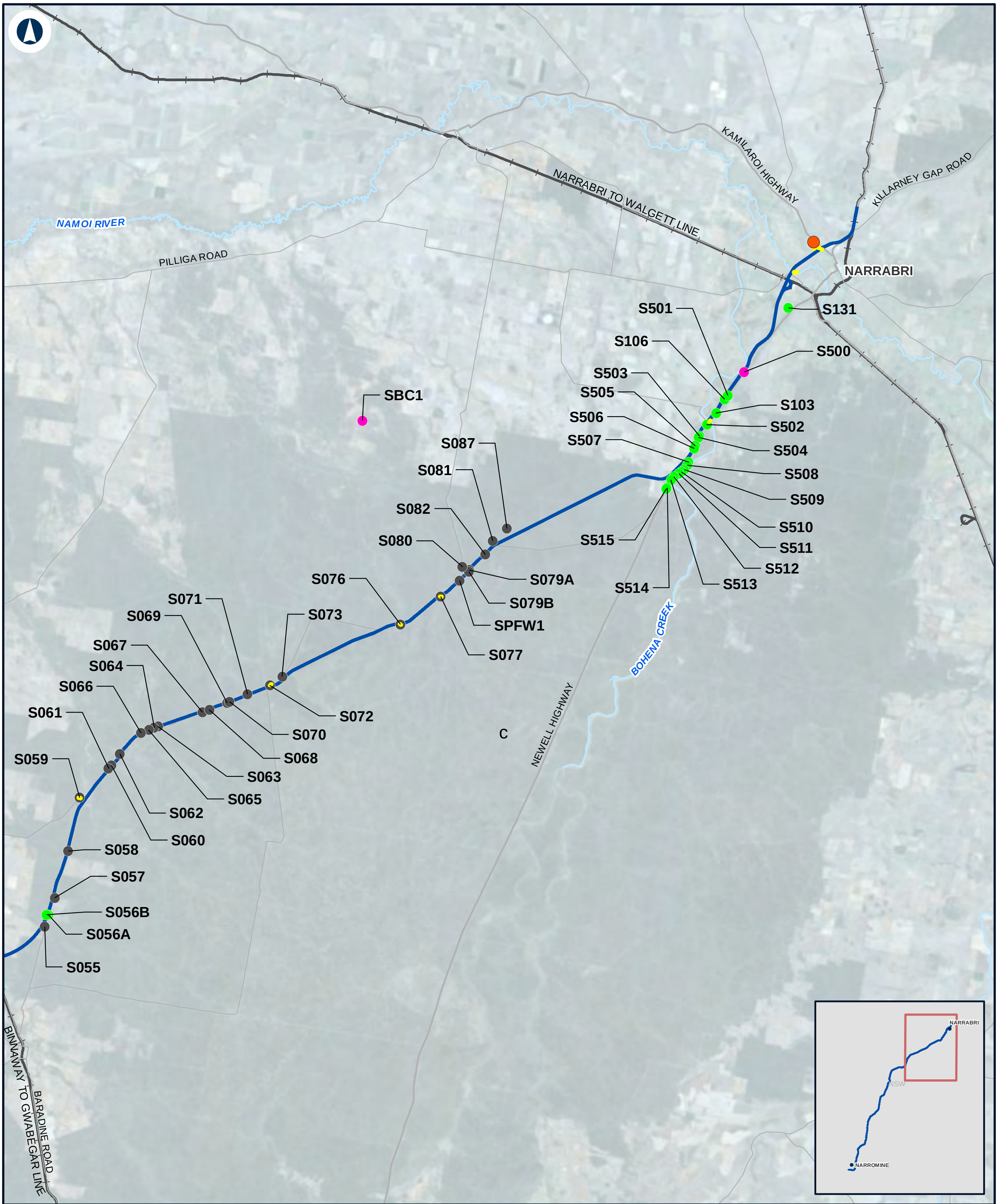

NARROMINE TO NARRABRI

Surveyed features

Figure 4.2c

0 10 20 Km

LEGEND

Preferred preliminary alignment
Cross sections
Flood marks
Road
Existing railway
Watercourse

Structure type
Bridge
Culvert
No structure

Coordinate System: GDA 1994 MGA Zone 55

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Date: 18/08/2020 Paper: A4
Author: JACOBS Scale: 1:450,000
Data Sources: Alignment: GHDJACOBS: Imagery, base layers: NSW Spatial Services: all other layers: IR ARTC

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An attempt was made by surveyors from JacobsGHD in February 2019 to connect gauge zeros for two discontinued stream gauges (Baradine Creek at Kienbri No. 2 (GS 419072) and Baronne Creek near Gulargambone (GS 420011)) to m AHD. However, surveyors were unable to locate both discontinued gauges and their bench marks.

4.4 Rainfall data

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

A number of long-term Bureau of Meteorology (BoM) meteorological recording stations are located within or adjacent to the Study Area (Figure 4-4), as listed in Table 4-3.

Table 4-3 Meteorological recording stations

Station ID	Station name	Elevation	Resolution	Historical reporting period
50031	Peak Hill Post Office	285	3 hour depth	October 1967 to November 2018
51010	Coonamble Comparison	180	3 hour depth	November 1976 to October 2010
51018	Gilgandra (Chelmsford Ave)	282	3 hour depth	January 1966 to December 1975
51049	Trangie Research Station Aws	215	1 minute depth	March 2011 to November 2018
			1 minute intensity	August 1968 to May 2013
			30 minute depth	October 1997 to November 2018
			3 hour depth	January 1970 to November 2018
51115	Narromine Airport	236.5	3 hour depth	March 1970 to June 1974
51124	Warren (Auscott)	198	3 hour depth	December 1968 to December 1975
51161	Coonamble Airport Aws	181.3	1 minute depth	November 2011 to November 2018
			30 minute depth	September 1997 to November 2018
			3 hour depth	September 1997 to November 2018
52060	Burren Junction (Plain View)	-	1 minute intensity	September 1966 to December 1970
52069	Pilliga (Riverview)	-	1 minute intensity	December 1970 to July 1983
52082	Burren Junction (Lochmohr)	-	1 minute intensity	August 1988 to July 1989
53002	Baradine Forestry	302	3 hour depth	January 1986 to July 2012
53030	Narrabri West Post Office	212	3 hour depth	January 1962 to July 2002
54003	Barraba Post Office	500	3 hour depth	January 1969 to November 2018
54038	Narrabri Airport Aws	229	1 minute depth	November 2011 to November 2018
			30 minute depth	August 2001 to November 2018

Station ID	Station name	Elevation	Resolution	Historical reporting period
			3 hour depth	August 2001 to November 2018
54102	Barraba (Rosevale)	620	1 minute intensity	January 1971 to May 2013
54151	Narrabri (Mt Kaputar National Park)	1450	1 minute intensity	May 1981 to August 1983
55023	Gunnedah Pool	306	3 hour depth	January 1965 to December 2011
55024	Gunnedah Resource Centre	307	1 minute intensity	April 1946 to May 2013
			3 hour depth	January 1965 to November 2018
55031	Manilla Post Office	373	1 minute intensity	January 1953 to December 1969
55049	Quirindi Post Office	390	3 hour depth	January 1986 to November 2018
55054	Tamworth Airport	404	1 minute intensity	August 1958 to December 1992
			3 hour depth	January 1960 to December 1992
55081	Blackville (Glasston)	505	1 minute intensity	December 1964 to May 1968
55194	Gowrie North	518	1 minute intensity	January 1971 to February 2013
55202	Gunnedah Airport Aws	263	1 minute depth	November 2011 to November 2018
			30 minute depth	September 2001 to November 2018
			3 hour depth	September 2001 to November 2018
55235	Nundle Shire Council	-	1 minute intensity	January 1959 to December 1977
55302	Nundle (Chaffey Dam)	520	1 minute intensity	November 1977 to April 2012
55309	Dungowan	1050	1 minute intensity	April 1981 to June 1983
55325	Tamworth Airport Aws	394.9	1 minute depth	September 2008 to November 2018
			30 minute depth	April 1992 to November 2018
			3 hour depth	February 1992 to November 2018
55327	Tamworth (Oxley Lane)	-	1 minute intensity	January 1993 to April 2012
61051	Murrurundi (Haydon Street)	466	3 hour depth	October 1985 to November 2018
61053	Muswellbrook (Lower Hill St)	180	3 hour depth	January 1969 to June 1972
61069	Scone (Philip Street)	213	3 hour depth	March 1965 to December 1991
61086	Jerrys Plains Post Office	90	3 hour depth	January 1960 to April 2014
61089	Scone Scs	216	1 minute intensity	July 1952 to May 2011

Station ID	Station name	Elevation	Resolution	Historical reporting period
			3 hour depth	January 1965 to November 2018
61186	Merriwa (Rosebank)	-	1 minute intensity	February 1965 to February 1969
61212	Liddell (Power Station)	155	1 minute intensity	August 1964 to April 1995
61287	Merriwa (Roscommon)	375	1 minute depth	June 2011 to November 2018
			1 minute intensity	March 1969 to March 2013
			30 minute depth	August 2007 to November 2018
			3 hour depth	August 2007 to November 2018
61343	Scone Scs.2.	-	1 minute intensity	October 1952 to December 1970
61363	Scone Airport Aws	222.5	1 minute depth	October 2010 to November 2018
			30 minute depth	January 1989 to November 2018
			3 hour depth	January 1990 to November 2018
61392	Murrurundi Gap Aws	729	1 minute depth	October 2010 to November 2018
			30 minute depth	June 2003 to November 2018
			3 hour depth	June 2003 to November 2018
62005	Cassilis Post Office	395	1 minute intensity	May 1967 to January 2004
62009	Cassilis (Dalkeith)	420	1 minute intensity	December 1965 to November 1966
62013	Gulgong Post Office	475	3 hour depth	September 1985 to November 2018
62020	Bylong (Montoro)	400	1 minute intensity	February 1965 to April 1991
62021	Mudgee (George Street)	454	3 hour depth	January 1962 to December 1995
62026	Rylstone (Ilford Rd)	605	1 minute intensity	September 1955 to January 1974
62053	Ulan Power Station	-	1 minute intensity	January 1965 to June 1974
62096	Rylstone (Yoothamurra)	-	1 minute intensity	March 1981 to June 1983
62100	Nullo Mountain Aws	1080	1 minute depth	February 2010 to November 2018
			30 minute depth	January 1989 to November 2018
			3 hour depth	August 1990 to November 2018
62101	Mudgee Airport Aws	471 -	1 minute depth	September 2011 to November 2018
			30 minute depth	January 1989 to November 2018

Station ID	Station name	Elevation	Resolution	Historical reporting period
			3 hour depth	August 1989 to November 2018
62102	Bylong (Bylong Road)		1 minute intensity	May 1991 to May 2013
63035	Hill End Post Office	870	1 minute intensity	September 1959 to February 1975
64008	Coonabarabran (Showgrounds)	505	3 hour depth	January 1960 to November 2018
64009	Dunedoo Post Office	388	1 minute intensity	September 1959 to February 1975
			3 hour depth	January 1986 to November 2018
64017	Coonabarabran Airport Aws	645	1 minute depth	November 2011 to November 2018
			30 minute depth	August 2001 to November 2018
			3 hour depth	August 2001 to November 2018
64033	Coonabarabran (Mirrigundi)	-	1 minute intensity	February 1967 to August 1971
64046	Coonabarabran (Westmount)	860	1 minute intensity	July 1971 to December 2013
65012	Dubbo (Darling Street)	275	3 hour depth	January 1960 to December 1999
65023	Molong (Hill St)	560	3 hour depth	January 1960 to December 1963
65034	Wellington (D&j Rural)	300	1 minute intensity	March 2005 to September 2013
			3 hour depth	January 1965 to November 2018
65035	Wellington Research Centre	390	1 minute intensity	February 1961 to February 2005
			3 hour depth	January 1965 to February 2005
65070	Dubbo Airport Aws	284	1 minute depth	September 2011 to November 2018
			1 minute intensity	April 2000 to August 2013
			30 minute depth	April 1993 to November 2018
			3 hour depth	January 1993 to November 2018
65092	Dubbo (Jaymark Road)	-	1 minute intensity	December 1986 to August 1998

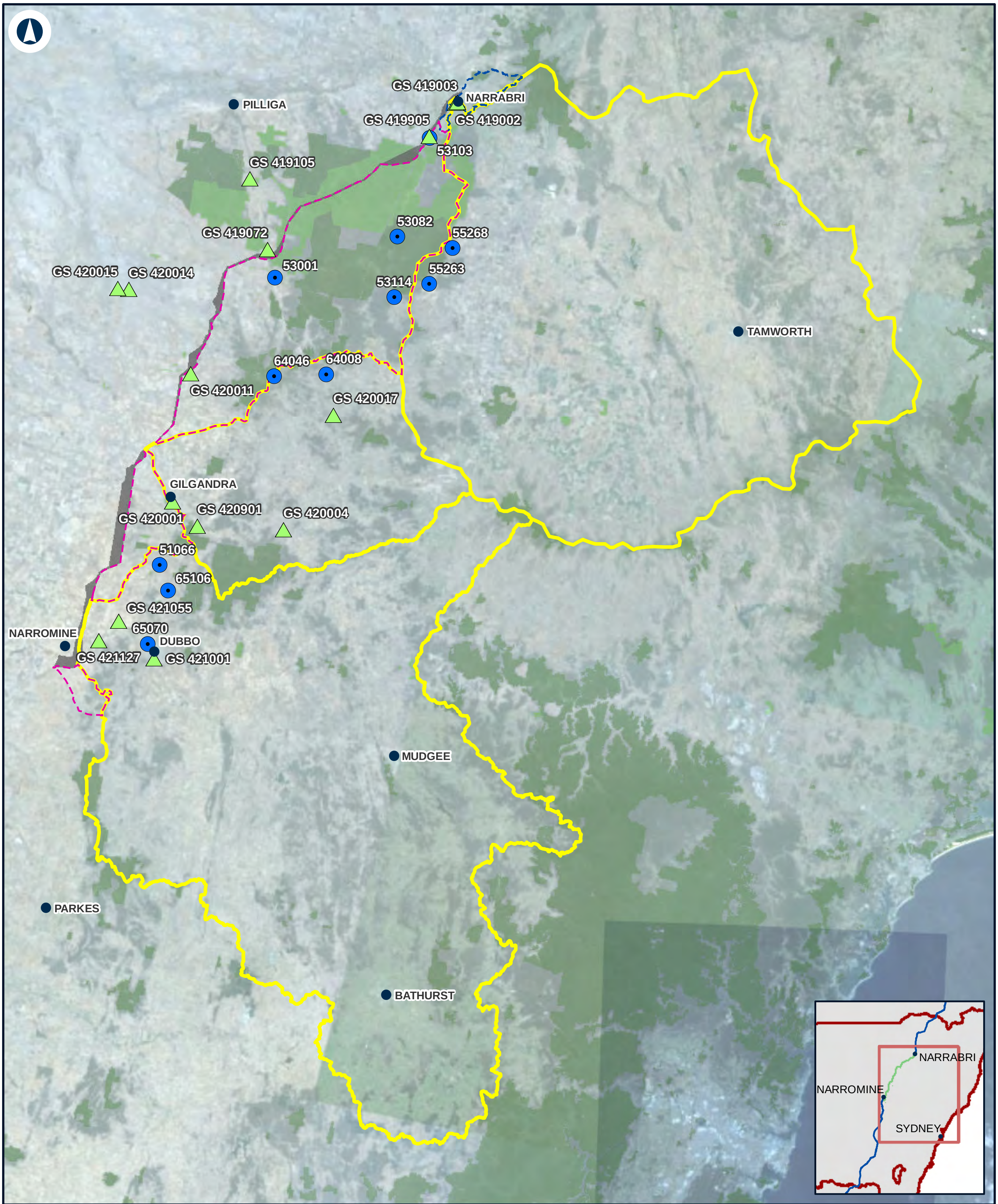
The mean annual rainfall recorded at these stations varies along the alignment. The average annual rainfall is about 640 mm. Rainfall occurs relatively uniformly throughout the year, with higher variability during summer and autumn due, in part, to the influence of the *El Nino Southern Oscillation*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

4.5 Stream gauge data

Stream gauge data was extracted from publicly available databases (waterinfo.nsw.gov.au, realtimedata.waternsw.com.au and PINNEENA, a surface and groundwater monitoring database released by NSW Government). Stream gauging stations (Figure 4-4) of interest to this Study Area are listed in Table 4-4 and further details on the selected stream gauges are provided in Section 5.1.

Table 4-4 Flow gauging stations considered in assessment

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



NARROMINE TO NARRABRI Catchments and gauging stations Figure 4.3

0 20 40 Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 18/08/2020 Paper: A4
Author: JACOBS Scale: 1:25,000,000
Data Sources: Phase 2 study area, hydraulic data: GHDJACOBS; Imagery: ARTC; all other layers IR ARTC

LEGEND

- Study area
- Large gauged catchment (FFA)
- RORB catchment
- XP-Rafts catchment
- Stream gauge
- Rainfall gauge

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4.6 Flood data collection

The collection of historical flood intelligence from adjacent landholders provides additional insight into historical flood patterns which can be considered in the validation of the flood models. Such information is considered important in the development of a robust flood model that is more likely to be trusted by affected landowners.

Historical flood intelligence for Phase 1 Study Area of the proposal was collected in September 2016 (refer to Section 4.6.1) and additional historical flood intelligence along the Phase 2 study area was collected as part of site survey (refer to Section 4.3.4) and meetings with landowners held between July 2019 and March 2020 (refer to Section 4.6.2).

4.6.1 Narromine to Narrabri (N2N) inland rail flood modelling - TC-04602 site visit report

The report presents outcomes from a site inspection and community consultation undertaken by Kellogg Brown & Root Pty Ltd (KBR) as part of Phase 1 investigations undertaken for the proposal after the flood event of September 2016. The site inspection commenced on 21 September 2016 at Narrabri and completed on 23 September 2016 at Narromine. Seven landholder meetings and inspection of a few waterway crossings were completed during the site inspection. It is to be noted that the site inspection was focussed on Phase 1 of the Study Area which is different from the Study Area for Phase 2, therefore the information collected during Phase 1 is of limited use for Phase 2. In addition, flood event of September 2016 was a lesser flood event than the flood event of 2010 in all three basins traversed by the proposal.

4.6.2 Meetings with landowners in 2019-2020

Between July 2019 and March 2020, ARTC carried out meetings with landowners along the proposal to discuss various aspects of the project, including flooding and other associated impacts. In total, land owners of 111 properties (land parcels) were consulted during these meetings and feedback received was used to check the models.

5. Calibration and validation of hydrology models

5.1 Selection of stream gauges

A search of the available rainfall and stream gauge data was undertaken for all but the catchment areas of the Macquarie River, Castlereagh River and Namoi River to select stream gauges for calibration of hydrology models developed as part of this study. The following three stream gauges were identified which are located within the vicinity of the Study Area:

- Baronne Creek at near Gulargambone (GS 420011)
- Baradine Creek at Kienbri No. 2 (GS 419072)
- Bohena Creek at Newell Highway (GS 419905)

The only gauge currently in operation is GS 419905 and the remaining two gauges were discontinued several years ago. In addition, gauge zeros for the discontinued gauges are not connected to the Australian Height Datum and flow gaugings were not undertaken at GS 420011 and consequently no rating curves are available for the gauge. Hence, only two stream gauges are available for a direct calibration of hydrology models.

5.2 Review of stream gauge data

A review of the rating curve and associated data for each analysed gauge was undertaken to identify any concerns with the rating curve. Details on the stream gauging for the relevant gauges were extracted from publicly available databases (waterinfo.nsw.gov.au, realtimedata.waternsw.com.au and PINNEENA).

5.2.1 Macquarie River at Baroona

In total, 253 flow gaugings were undertaken at the gauge between 1981 and 2019 (realtimedata.waternsw.com.au). The current rating curve for the gauge is shown in Figure 5-1. Records held in PINNEENA indicate that the maximum flow (1984 m^3/s) was gauged on 7 December 2010 corresponding to a gauge height of 12.9 m. PINNEENA indicates that the maximum flow includes flows measured in the main channel, break out on the right bank and floodplain on the left bank. The maximum water level recorded at the gauge is also 12.9 m.

A review of cross section data for the gauge available in PINNEENA shows that the lowest bank of the Macquarie River is located at gauge height 9 m. PINNEENA also shows that, in total, 8 flow gaugings were undertaken above gauge height 9 m during flood events of April 1990 (gauge height 10.265 m and gauge heigh 11.75 m), August 1990 (gauge height 12.79 m), November 2000 (gauge height 9.53 m and gauge height 11.088 m) and December 2010 (gauge height 10.889 m, gauge height 11.54 m and gauge height 12.9 m). PINNEENA identifies that flood gaugings on four occasions corresponding to gauge heights of 12.9 m, 12.79 m, 11.088 m and 9.53 m were undertaken between 500 m and 2 km upstream of the gauge and only one flow gauging (gauge height 10.889 m) was undertaken 6 km downstream of the gauge. It is expected that the flood gauging undertaken downstream of the gauge would have a minor influence on the flow rating curve for the gauge.

Both ARTC and JacobsGHD contacted WaterNSW, the current custodian of the gauge, to get further information on the gauge. WaterNSW advised on 12 November 2019 that the current high stage rating for the gauge was based on seven high flow gaugings undertaken between gauge heights 10 and 13 m and no gauging report was available for the gauge.

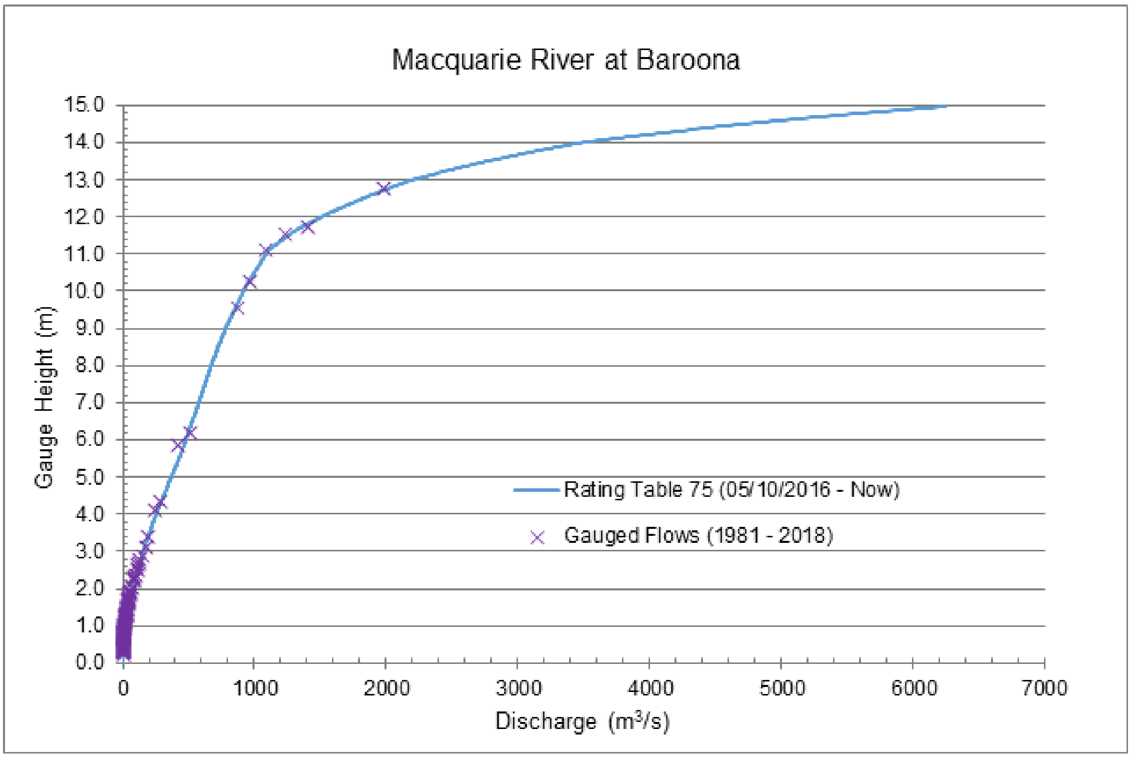


Figure 5-1 Rating curve and gauged flows - Macquarie River at Baroona

5.2.2 Castlereagh River at Mendooran

In total, 238 flow gaugings were undertaken at the gauge between 1970 and 2002 (realtimedata.waternsw.com.au). The flow rating curve for the gauge is shown in Figure 5-2. Records held in PINNEENA indicate that the maximum flow (581 m^3/s) was gauged on 28 July 1998 corresponding to a gauge height of 5.41 m. The maximum gauge height (8.984 m) was recorded on 4 December 2010. A review of cross section data for the gauge available in PINNEENA shows that the lowest bank of the Castlereagh River is located at gauge height 9.5 m.

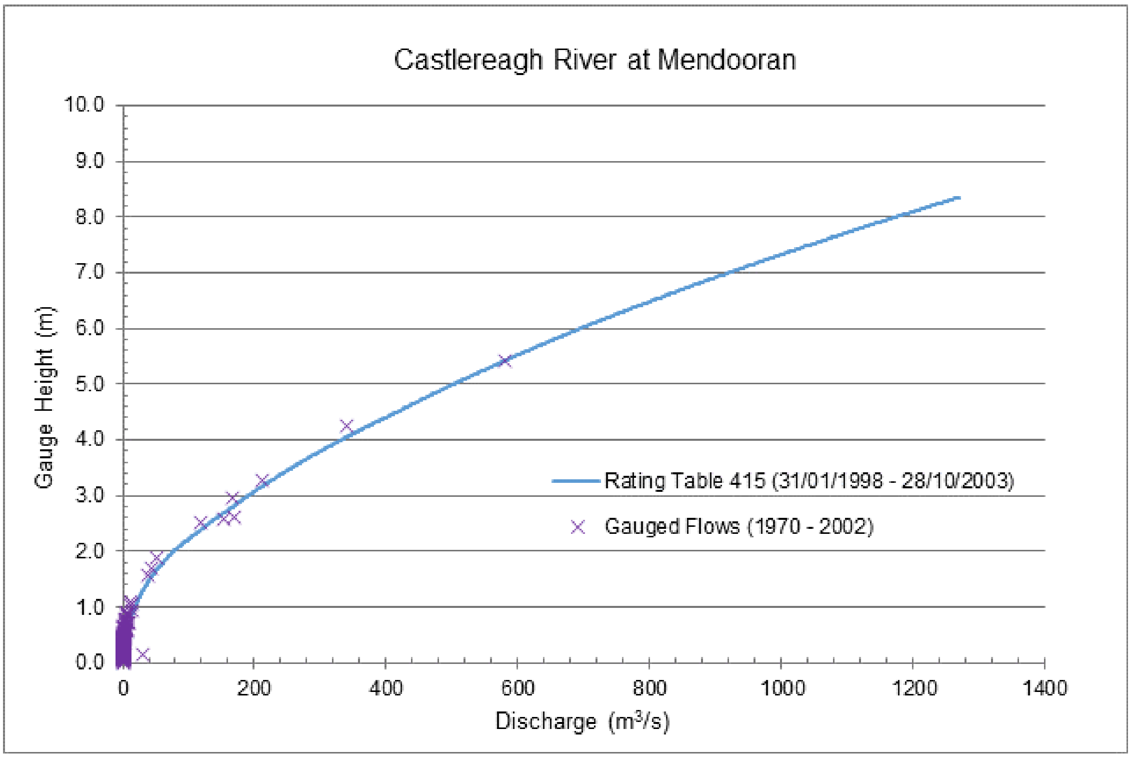


Figure 5-2 Rating curve and gauged flows - Castlereagh River

5.2.3 Baradine Creek at Kienbri No. 2

In total, 59 flow events were recorded at the gauge between 1995 and 2011. The maximum flow (37.4 m^3/s) was measured on 17 January 1984 corresponding to a gauge height of 3.089 m. The maximum height recorded at the gauge was 4.736 m on 22 December 2007. The channel is reasonably well defined, and the top of bank level is located above gauge height 9 m. Hence a reasonable extrapolation of the rating curve is possible up to gauge height 9 m.

A comparison of the gauge rating curve to measured flows (Figure 5-3) indicates that the rating curve is likely to provide a reasonable estimate of flood flows. However, as the gauge zero is not connected to m AHD (Section 4.3.4), it is not possible to compare the published rating curve with rating curves generated from the TUFLOW model outputs.

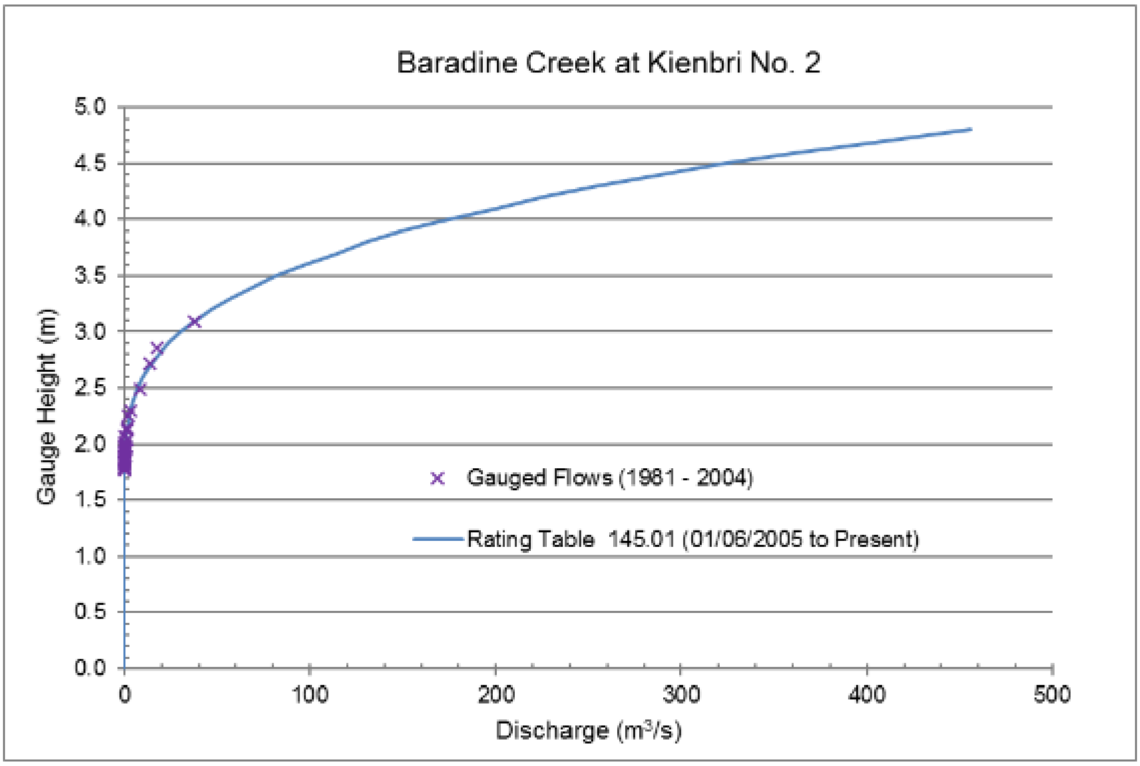


Figure 5-3 Rating curve and gauged flows - Baradine Creek

5.2.4 Bohena Creek at Newell Highway

Only two flow events (https://realtimedata.waternsw.com.au/) were measured at the gauge since commissioning of the gauge in May 1995. The maximum flow measured (408.7 m^3/s) was on 28 July 1998 corresponding to a gauge height of 2.977 m. The maximum water level recorded at the gauge was 3.231 m on 05 September 1998. The top of bank is located at gauge height 5.0 m.

The available recorded data for the stream gauge was collected from WaterNSW in 2018. WaterNSW provided water level and discharge data for the gauge for the period 1 September 1995 to 16 January 2018. The data provided by WaterNSW included both point and mean gauge height and discharge data and quality codes for the recorded data were not provided. The point gauge height and discharge data for the gauge is shown in Figure 5-5. Figure 5-5 shows long gaps in the discharge data for the period between 2005 to 2018 during which the gauge was at or close to cease to flow levels. In the absence of the quality codes for the recorded gauge heights, it is not known whether there were no flows in the creek or the stream gauge was not in operation. The cease to flow level for the gauge is identified as being 0.35 m (https://realtimedata.waternsw.com.au/) however, the lowest height recorded at the gauge since 2005 is about 0.7 m.

Due to the limited flow gaugings and significant gaps in the available data during the period 2005 to 2018, FFA was not considered suitable for this gauge. A comparison of the gauge rating curve to recorded peak flows (Figure 5-4) indicates that the rating curve is likely to provide a reasonable estimate of flood flows. The rating curve was also checked using the TUFLOW model as part of calibration (Section 6.4) and verification (Section 6.5) of the model.

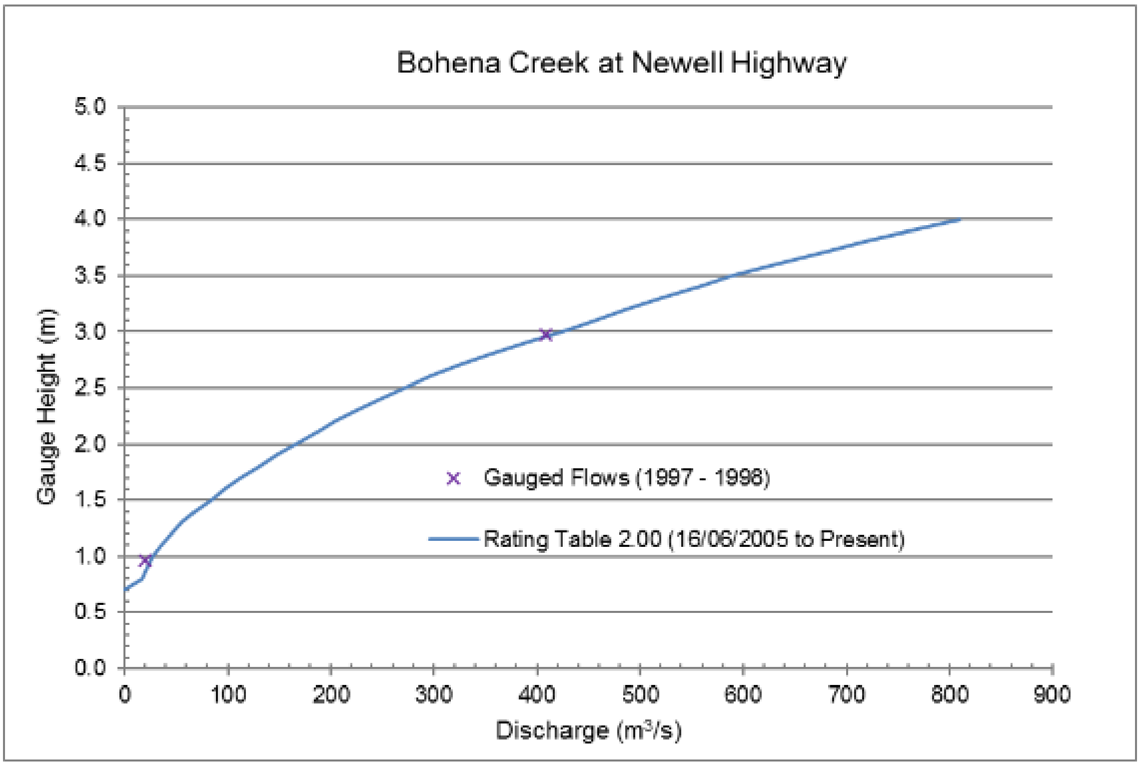


Figure 5-4 Rating curve and gauged flows - Bohena Creek

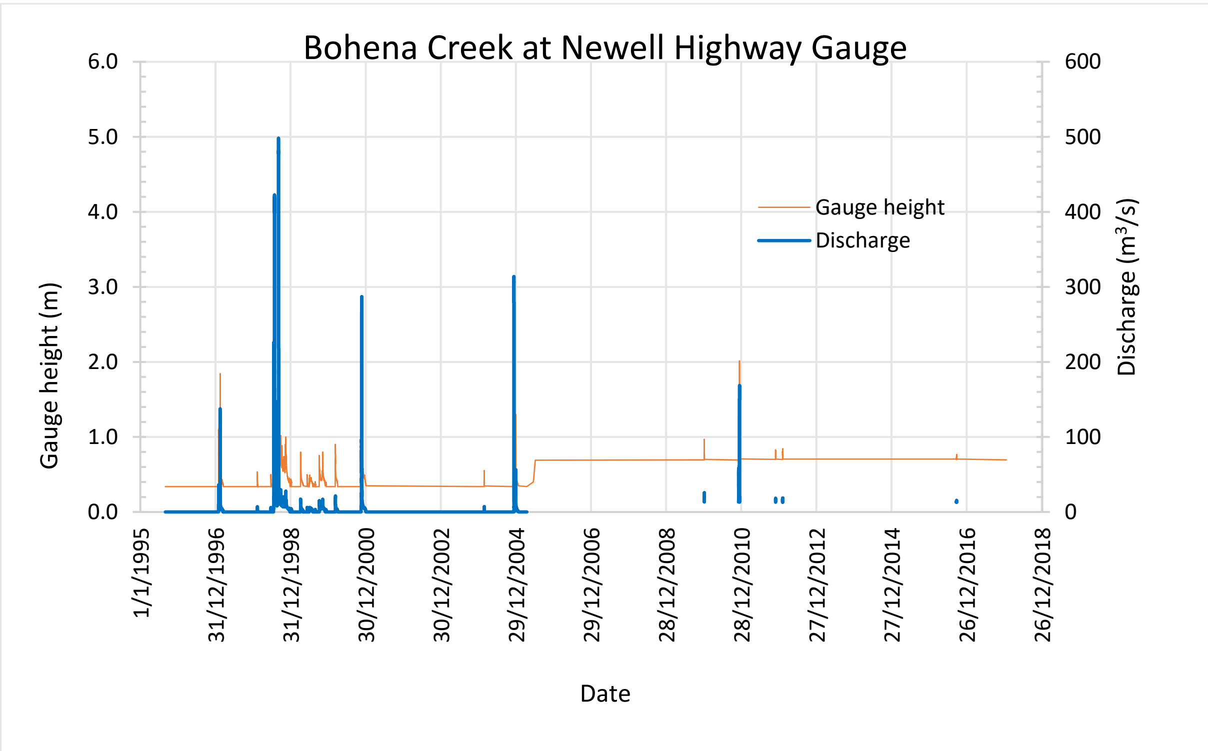


Figure 5-5 Recorded gauge height and flows - Bohena Creek

5.2.5 Namoi River and Narrabri Creek at Narrabri

WRM (2016) undertook a detailed review of flow gauging data for Namoi River at Narrabri gauge (GS 419002) and Narrabri Creek at Narrabri gauge (GS 419003). The combined stage discharge stage rating curve for Narrabri for the Namoi River and Narrabri Creek was updated by WRM (2016) through hydraulic modelling. JacobsGHD reviewed WRM's (2016) analysis and found the analysis of acceptable quality for use in the flooding assessment for the proposal.

5.3 Development of RORB models

The SRTM data was combined with a GIS layer of watercourses and satellite imagery, and sub-areas for the RORB model were delineated based on this data set. The sub-areas within the RORB model were defined to coincide with watershed boundaries and stream junctions. At the catchment scale, the proportion of imperviousness represented by houses and roads are negligible and therefore not included in the models. All links were defined as natural channel type. Sub-areas for the RORB model and channel lengths were measured in GIS. The resulting sub-areas for Baradine Creek and Bohena Creek are shown in Appendix A.

5.4 Calibration of hydrology models

5.4.1 Catchment modelled by council flood studies

An XP-RAFTS hydrology model was provided by Narrabri Shire Council representing catchment areas of Mulgate Creek and Long Gully. No streamflow gauges are available to calibrate the XP-RAFTS model and estimated peak discharges for modelled design flood events were validated against RFFE as part of the Narrabri Flood Study (WRM, 2016). No additional information is available for further validation of the XP-RAFTS model.

The provided XP-RAFTS model was reviewed and considered appropriate for use for this study.

5.4.2 RORB models

RORB models for Baradine Creek and Bohena Creek were calibrated to historical flow events, using sub-daily rainfall series obtained from the Australian Bureau of Meteorology. The routing parameter (k_c) and rainfall losses in the RORB models were adjusted so that the modelled flood hydrograph for a catchment matched, as close as practical, the observed flood hydrograph.

Baradine Creek

The RORB model for Baradine Creek was calibrated to streamflow data for three flood events recorded at Kienbri No. 2 gauge (GS 419072). Rainfall recorded at rain gauges located within the catchment area of Baradine Creek and the adjoining areas were used to define spatial distribution of rainfall and rainfall data recorded at rain gauge 64046 (Coonabarabran (Westmount)) was used to define temporal distribution of rainfall for all calibration events for Baradine Creek. Observed (excluding baseflow) and calculated hydrographs at Kienbri No. 2 gauge for three flood events are presented in Appendix B. Appendix B shows a reasonable agreement between modelled and observed (excluding baseflow) hydrographs for all calibration events. In particular, the RORB model replicates the magnitude of the flood peak, the rising limb and the falling limb for each calibration event. The values of k_c, m, initial loss and continuing loss rate that provided the best fit for each calibration event are presented in Table 5-1. Except for the initial loss, the same values of k_c, m, and continuing loss rate provided the best fit for the calibration events. Table 5-1 shows that the adopted initial loss varies between 48 mm and 84 mm for the calibration events and there is a reasonable agreement between the observed and modelled volume of the flood for each event. Limited additional data is available to verify the model.

Table 5-1 RORB model calibration summary - Baradine Creek at Kienbri No.2 (GS 419072)

Event	Peak flow (m^3/s)		Total volume (m^3)		Parameters			
	Observed*	Modelled	Observed*	Modelled	k_c	m	IL (mm)	CL (mm/hr)
Dec 2007	425	425	1.54×10^7	1.65×10^7	20	0.8	86	2.9
Sep 1998	169	170	6.28×10^6	5.37×10^6	20	0.8	48	2.9
Nov 1998	76	76	3.25×10^6	2.91×10^6	20	0.8	72.7	2.9

*excluding baseflow

Bohena Creek

The RORB model for Bohena Creek was calibrated to streamflow data for three flood events recorded at the Newell Highway stream gauge (GS 419905). Rainfall recorded at rain gauges located within the catchment area of Bohena Creek and the adjoining areas were utilised to define spatial distribution of rainfall and rainfall data recorded at rain gauge 64046 (Coonabarabran (Westmount)) was used to define temporal distribution of rainfall for all calibration events for Bohena Creek.

Observed (excluding baseflow) and calculated hydrographs at the Newell Highway gauge for three flood events are presented in Appendix B. Appendix B shows a reasonable agreement between modelled and observed (excluding baseflow) hydrographs for all calibration events. In particular, the RORB model replicates the magnitude of the flood peak, the rising limb and the falling limb for all calibration events. The values of k_c, m, initial loss and continuing loss rate that provided the best fit for each calibration event are presented in Table 5-2. The same values of m and continuing loss rate provided the best fit for the calibration events. Table 5-2 shows that the value k_c varies between 21 and 22 and initial loss varies between 27 mm and 59 mm for the calibration events. Table 5-2 also shows a reasonable agreement between observed and modelled volume of the flood for each event. Limited additional data is available to verify the model.

Table 5-2 RORB model calibration summary - Bohena Creek at Newell Highway (GS 419905)

Event	Peak flow (m^3/s)		Total volume (m^3)		Parameters			
	Observed*	Modelled	Observed*	Modelled	k_c	m	IL (mm)	CL (mm/hr)
Sep 1998	490.9	489.8	2.10×10^7	1.60×10^7	22	0.8	59	2.50
July 1998	400.1	402.5	1.76×10^7	1.78×10^7	21	0.8	39.8	2.50
Feb 1997	133.9	133.9	4.32×10^6	4.48×10^6	21	0.8	27	2.50

*excluding baseflow

5.5 Validation of peak flows for design flood events

5.5.1 Peak flows estimated by calibrated RORB models

The calibrated RORB models for Bohena and Baradine Creeks were run to simulate peak flows for 20% annual exceedance probability (AEP), 10% AEP, 5% AEP, 2% AEP and 1% AEP events. All data (e.g, rainfall depths, temporal patterns, pre-burst depths, areal reduction factors etc) required to run both RORB models for the selected design flood events were extracted from AR&R Data Hub. The recommended regional loss values for Baradine Creek from the AR&R Data Hub were an initial loss of 49.0 mm (prior to adjustment for preburst rainfall) and a continuing loss rate of 2.9 mm/h. The recommended regional loss values for Bohena Creek from the AR&R Data Hub were an initial loss of 45.0 mm (prior to adjustment for preburst rainfall) and a continuing loss rate of 4.7 mm/h.

Parameter values obtained from calibration results (refer to Table 5-3) were adopted for both Baradine Creek and Bohena Creek RORB models in the estimation peak flows for the selected design flood events based on recommendations in ARR 2019 (*Ball et al, 2019*). Further details on ARR 2019 recommendations are provided in Section 5.6.1. Areal reduction factors and median pre-burst depths extracted from the AR&R Data Hub were applied to both models and both models were run for the selected design flood events. Peak flows predicted by the calibrated RORB models at the two stream gauges are presented in Table 5-4.

Table 5-3 Adopted parameter values for validation of peak flows for design flood events

RORB model	Parameter Values			
	k_c	*m*	IL (mm)	CL (mm/hr)
Baradine Creek	20	0.8	72.7	2.90
Bohena Creek	21	0.8	39.8	2.50

Modelled peak flows presented in Table 5-4 are compared against at-site flood frequency results and the regional flood frequency estimation (RFFE) tool (*Ball et al, 2019*) in Section 5.5.4.

Table 5-4 Peak flows estimated by calibrated RORB models

AEP	Baradine Creek at Kienbri No. 2	Bohena Creek at Newell Highway
20%	84	1,392
10%	426	2,450
5%	694	3,096
2%	1,096	4,377
1%	1,446	4,870

5.5.2 At-site flood frequency analysis

Macquarie River at Baroona (GS 421127)

Flood events of 1870, 1955 and 1956 are considered major flood events for the Macquarie River at Dubbo (SES, 2013). Due to the limited length of stream records for the Baroona gauge, these three flood events were also included in the flood frequency analysis. Both GEV and LP3 probability distributions were fitted to the annual peak flow series. Plots showing annual peak flows and the fitted distribution are shown in Appendix C which shows that the LP3 distribution provides the best fit. Peak flows estimated by the LP3 distribution for the Baroona gauge with and without inclusion of the Multiple Grubbs Beck Test are presented in Table 5-5.

Table 5-5 FFA Results based on LP3

AEP	Macquarie River (Baroona)**		Castlereagh River (Mendooran)*		Baradine Creek*	
	Without	With	Without	With	Without	With
20%	541	480	471	457	111	104
10%	1045	873	706	711	215	202
5%	1,875	1,473	917	933	348	321
2%	3,786	2,742	1,151	1,164	562	499
1%	6,210	4,231	1,294	1,295	747	640

*Multiple Grubbs Beck Test; ** Censoring of three historic flood events

Castlereagh River at Mendooran (GS 420004)

Both GEV and LP3 probability distributions were fitted to the annual peak flow series with and without inclusion of the Multiple Grubbs Beck Test. Plots showing annual peak flows and the fitted distribution are shown in Appendix C which shows that the LP3 distribution fitted provided the best fit. Peak flows estimated by the LP3 distribution for the gauge with and without inclusion of the Multiple Grubbs Beck Test are presented in Table 5-5.

Baradine Creek at Kienbri No. 2 (GS 419072)

A General Extreme Value (GEV) and a Log Pearson Type III (LP3) probability distributions were fitted to the annual peak flow series with and without inclusion of the Multiple Grubbs Beck Test. Plots showing annual peak flows and the fitted distribution are shown in Appendix C which shows that the GEV distribution with inclusion of the Multiple Grubbs Beck does not censor any data and the LP3 distribution fits the annual peak flow series better than the GEV distribution. Appendix C also shows that the LP3 distribution with inclusion of the Multiple Grubbs Beck Test provides a better fit than without the Multiple Grubbs Beck Test. Peak flows estimated by the LP3 distribution for the gauge with and without inclusion of the Multiple Grubbs Beck Test are presented in Table 5-5.

Namoi River and Narrabri Creek at Narrabri

WRM (2016) undertook an annual series flood frequency analysis of the combined recorded flows at the two stream gauges (Namoi River at Narrabri (GS 419002) and Narrabri Creek at Narrabri (GS 419003)). Available flood information for Narrabri dating back to 1890 (126 years from 1890 to 2015) was included in the analysis. WRM (2016) fitted a Log-Pearson Type III distribution to the annual series of recorded (and inferred) peak flood discharges at Narrabri using the Bayesian inference methodology recommended in ARR 2019 (*Ball et al, 2019*) using the TUFLOW FLIKE software. The 1% AEP design discharge at Narrabri was estimated at 4,860 m^3/s, which was slightly lower than the historical 1955 flood of the Namoi River. The estimated AEP of the 1955 flood is between 1% and 0.5%.

The combined flood frequency analysis for the Namoi River and Narrabri Creek undertaken by WRM (2016) was reviewed by JacobsGHD and the analysis was considered appropriate for use in this investigation.

5.5.3 Regional flood frequency

RFFE tool from ARR 2019 (*Ball et al, 2019*) was used to estimate peak flows for the selected design flood events for calibrated catchments of Baradine Creek and Bohena Creek. Peak flows estimated by RFFE for the two catchments are shown in Table 5-6. It is to be noted that the RFFE tool is applicable to catchment areas up to 1,000 km^2 and the catchment area of Bohena Creek at Newell Highway gauge is 2,180 km^2 as shown in Table 4-4.

A comparison between RFFE (refer to Table 5-6) and FFA (refer to) estimates for Baradine Creek shows significant overestimation of peak flows by RFFE for all design flood events up to and including the 1% AEP event.

A comparison between peak flows estimated using RFFE (refer to Table 5-6) and peak flows estimated using the RORB model for Bohena Creek (refer to Table 5-4) shows significantly higher peak flows estimated by the RORB model for all design flood events up to and including the 1% AEP event.

Table 5-6 Peak flows estimated by RFFE

AEP	Baradine Creek at Kienbri No. 2	Bohena Creek at Newell Highway
20%	501	820
10%	803	1,320
5%	1,190	1,970
2%	1,870	3,110
1%	2,530	4,220

5.5.4 Reconciliation of peak flows for design flood events

5.5.4.1 Baradine Creek

An attempt was made to reconcile estimated peak flows for the design flood events estimated by the calibrated RORB model for Baradine Creek against other independent estimates, in particular, FFA. The RORB model was run for 20%, 10%, 5% 2% and 1% AEP events for the following scenarios:

- ARR 2019: m= 0.8; k_c (28.16), initial rainfall loss and continuing rainfall loss rate based on ARR 2019 (Ball et al, 2019).
- Calibration: m= 0.8; median value of k_c(20), initial rainfall loss (39.8 mm) and continuing rainfall loss rate (2.5 mm/hour) obtained from calibration results.

A comparison of peak flows estimated by the RORB model, FFA and RFFE for Baradine Creek is shown in Figure 5-6. Following observations are made from Figure 5-6:

- Adopted values of m= 0.8 and median value of k_c (20), initial rainfall loss (39.8 mm) and continuing rainfall loss rate (2.5 mm/hour) obtained from calibration results provide best agreement between peak flows estimated by the RORB model and FFA.
- Higher initial rainfall losses need to be adopted to get a closer agreement between FFA and RORB model results for flood events between 10% AEP and 1% AEP events.
- Estimated peak flows by the RORB model for flood events smaller than the 10% AEP event are sensitive to the adopted initial rainfall loss.

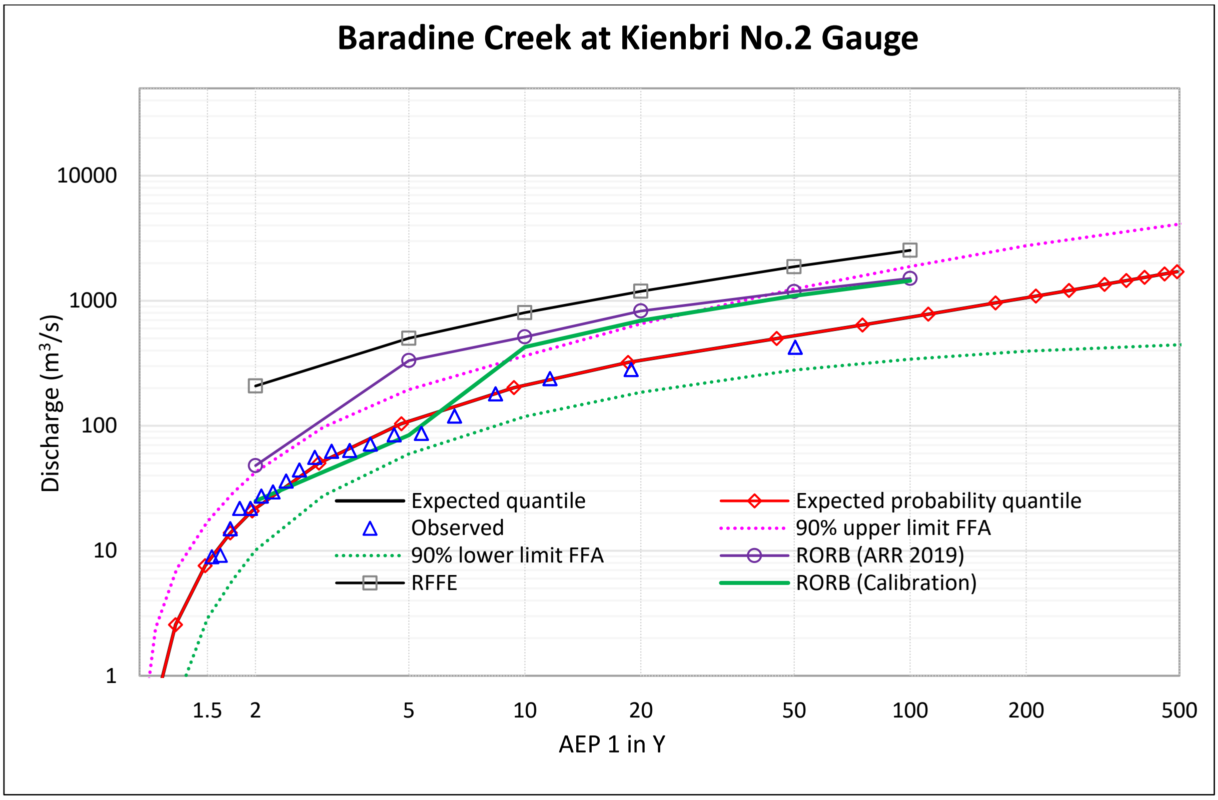


Figure 5-6 Peak flow estimates – Baradine Creek

Median values of k_c (20), initial rainfall loss (39.8 mm) and continuing rainfall loss rate (2.5 mm/hour) obtained from calibration results are recommended in the estimation runoff hydrographs for Baradine Creek for the Reference Design.

5.5.4.2 Bohena Creek

A comparison of peak flows estimated using the RORB model for Bohena Creek and RFFE shows peak flows estimated by the RORB model are significantly higher than RFFE estimates for all design flood events up to and including the 1% AEP event. Further investigations are recommended for reconciling the estimated peak flows during detailed design due to the following:

- Limited stream gauge data of unknown quality is available to undertake FFA.
- The catchment area for Bohena Creek at the Newell Highway gauge is 2,180 km^2 and RFFE is applicable to catchment areas up to 1,000 km^2.
- Further consultation should be held with local landowners and other stakeholders (e.g. TfNSW, rail authorities, NSW SES) to identify historic flood events in Bohena Creek which resulted in flooding of properties, Newell Highway and railways.

5.6 Recommended parameter values for ungauged catchments

5.6.1 Rainfall losses

ARR 2019 (*Ball et al, 2019*) recommends that rainfall losses for ungauged catchments should be estimated using the following methodology (in order of preference):

1. Use the average of calibration losses from the actual study on the catchment if available.
2. Use the average calibration losses from other studies in the catchment, if available and appropriate for the study.
3. Use the average calibration losses from other studies in the similar adjacent catchments, if available and appropriate for the study.

4. Use the NSW FFA-reconciled losses available through the ARR Data Hub, with additional scrutiny of initial loss and pre-burst.
5. Use default ARR Data Hub continuing losses with a multiplication factor of 0.4 (OEH, 2019).

The range of variations in rainfall initial and continuing losses for calibration events within the vicinity of the Study Area are shown in Table 5-7. Initial rainfall losses for the calibrated events vary between 16 mm to 86 mm and continuing loss rates vary between 0.9 to 2.9 mm/hour. Due to the wide variation in rainfall losses for the calibration events, a conservative approach is recommended for selecting rainfall losses for ungauged catchments. The lower value of the initial rainfall loss obtained from calibration results from adjacent catchment (where available) and ARR 2019 Data Hub losses should be adopted for ungauged catchments. It is further recommended that the lower value of the continuing rainfall loss rate obtained from calibration results from adjacent catchment (where available) and the default ARR Data Hub continuing loss rate with a multiplication factor of 0.4 should be adopted for ungauged catchments.

Table 5-7 Range of variation of rainfall losses for calibration events

Gauging Station	Initial rainfall loss (mm)	Continuing rainfall loss rate (mm/hour)
Warrena Creek at Warrana[1]	16 – 30	1.0 – 2.7
Magometon Creek (Site 3) at Near Coonamble[1]	23 – 52	0.9 – 2.6
Baradine Creek at Kienbri No. 2	48 – 86	2.9
Bohena Creek at Newell Highway	27 – 59	2.5

[1] Source: SKM 2009

5.6.2 RORB runoff routing parameter k_c

A comparison between the median value of k_c obtained from calibration of RORB models for Baradine Creek and Bohena Creek catchments and the regional values of k_c estimated based on ARR 2019 (*Ball et al, 2019*) are provided in Table 5-8. Estimated k_c values for Warrena Creek and Magometon Creek which are tributaries of the Castlereagh River are also shown in Table 5-8. Table 5-8 shows a wide range of variations in calibrated values of k_c for similar sized catchment areas of Magometon Creek and Warrena Creek. The correlation between d_{av} values and the median values of k_c for estimated for the four calibrated RORB models was found to be weak. It is recommended that the value of k_c for ungauged catchments should be calculated based on the recommended equation (**$k_c = 1.18\ A^{0.46}$**, where, A is the catchment area in square kilometres) presented in ARR 2019 (Ball et al, 2019) for both eastern and western NSW.

Table 5-8 Comparison of k_c values

Gauging Station	Catchment Area (km^2)	Median Value of k_c	d_{av}	Regional Value of k_c (ARR 2019)
Warrena Creek at Warrana[1]	583	95	34	22
Magometon Creek (Site 3) at Near Coonamble[1]	540	34	39	21
Baradine Creek at Kienbri No. 2	995	20	45	28
Bohena Creek at Newell Highway	2,180	21	66	41

[1] Source: SKM (2009)

5.6.3 Summary

Based on the above analysis, and considering recommendations in ARR 2019 guidelines, the RORB models are parameterised as follows:

- For gauged catchments – calibrated rainfall losses and RORB model parameter values, k_c and m, were adopted.
- For ungauged catchments – the lower value of the initial rainfall loss obtained from calibration results from adjacent catchment (where available) and ARR 2019 Data Hub loss was adopted for each ungauged catchment. The lower value of the continuing rainfall loss rate obtained from calibration results from adjacent catchment (where available) and the default ARR Data Hub continuing loss rate with a multiplication factor of 0.4 was adopted for each ungauged catchment. Adopted RORB model parameter values, k_c and m, were based on ARR 2019.

A comparison of peak flows estimated using the RORB model for Bohena Creek and RFFE shows considerably higher peak flows estimated by the RORB model for all design flood events up to and including the 1% AEP event. At the Reference Design stage, these results are considered to be conservative. Further investigations are recommended for reconciling the estimated peak flows in Bohena Creek during the detailed design stage.

6. Calibration and validation of hydraulic models

6.1 Selection of models

Extents of hydraulic models for the proposal and the available stream gauges along the proposal are shown in Figure 3-1. The available stream gauge data, flood imagery and flood intelligence were reviewed and a list of hydraulic models considered suitable for calibration and verification is provided in Table 6-1. Flood events selected for calibration of the hydraulic models are identified in Section 6.4.

Table 6-1 TUFLOW hydraulic models to be calibrated

Hydraulic Model	Waterway	Stream Gauge
Narromine (Updated Council model)	Macquarie River	Narromine Bridge (GS 421006)
N2N7	Baradine Creek	Baradine Creek at Kienbri No. 2 (GS 419072)
N2N1	Bohena Creek	Bohena Creek at Newell Highway (GS 419905)
Narrabri	Namoi River Narrabri Creek	Namoi River at Narrabri (GS 419002) Narrabri Creek at Narrabri (GS 419003)

6.2 Council hydraulic models

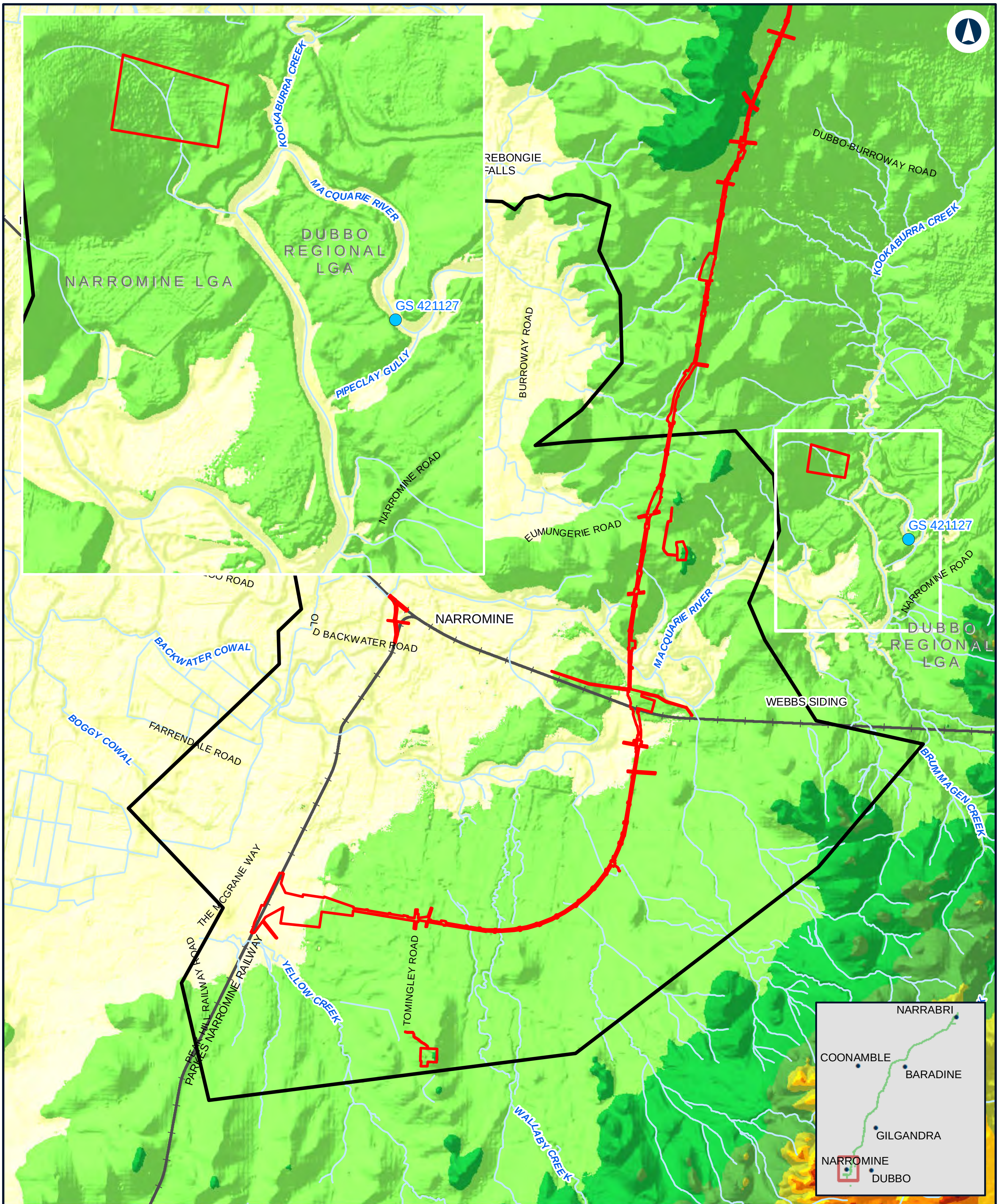
6.2.1 Narromine

The TUFLOW hydraulic model for Narromine developed by Lyall & Associates (2013) was updated (refer to Appendix D) to satisfy the requirements of this study. In particular, the model was extended and the 1D channels and floodplains represented in the TUFLOW model (refer Section 4.2.1) were represented in two-dimensional grids.

A review of the 1 m DEM (refer to Figure 6-1) identified that a high level breakout is located on the left bank of the Macquarie River approximately 200 m upstream of the Baroona gauge. The review also identified that flows escaping though the breakout re-join the Macquarie River approximately 1,200 m downstream of the breakout. Flood gaugings undertaken at the Baroona gauge include flows in the main channel of the Macquarie River and the breakout located approximately 200 m upstream of the gauge (refer to Section 5.2 for further details).

The upstream boundary of the TUFLOW model was defined approximately 6 km (refer to Appendix D) downstream of the location where the breakout flows re-join the Macquarie River. The 1 m DEM shows that no breakouts are present in the 6 km reach of the Macquarie River located upstream of the inflow boundary of the TUFLOW model. Hence the recorded inflows at the Baroona gauge were utilised in the TUFLOW model to represent inflow in the Macquarie River.

The updated TUFLOW model (refer to Appendix D) for Narromine was calibrated using the procedure defined in the following sections.



NARROMINE TO NARRABRI

Terrain in the vicinity of the Baroona gauge

Figure 6.1

0 1.5 3 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 18/08/2020
Author: JacobsGHD
Paper: A4
Scale: 1:50,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- Stream gauge

High : 811.347

Low : 99.389

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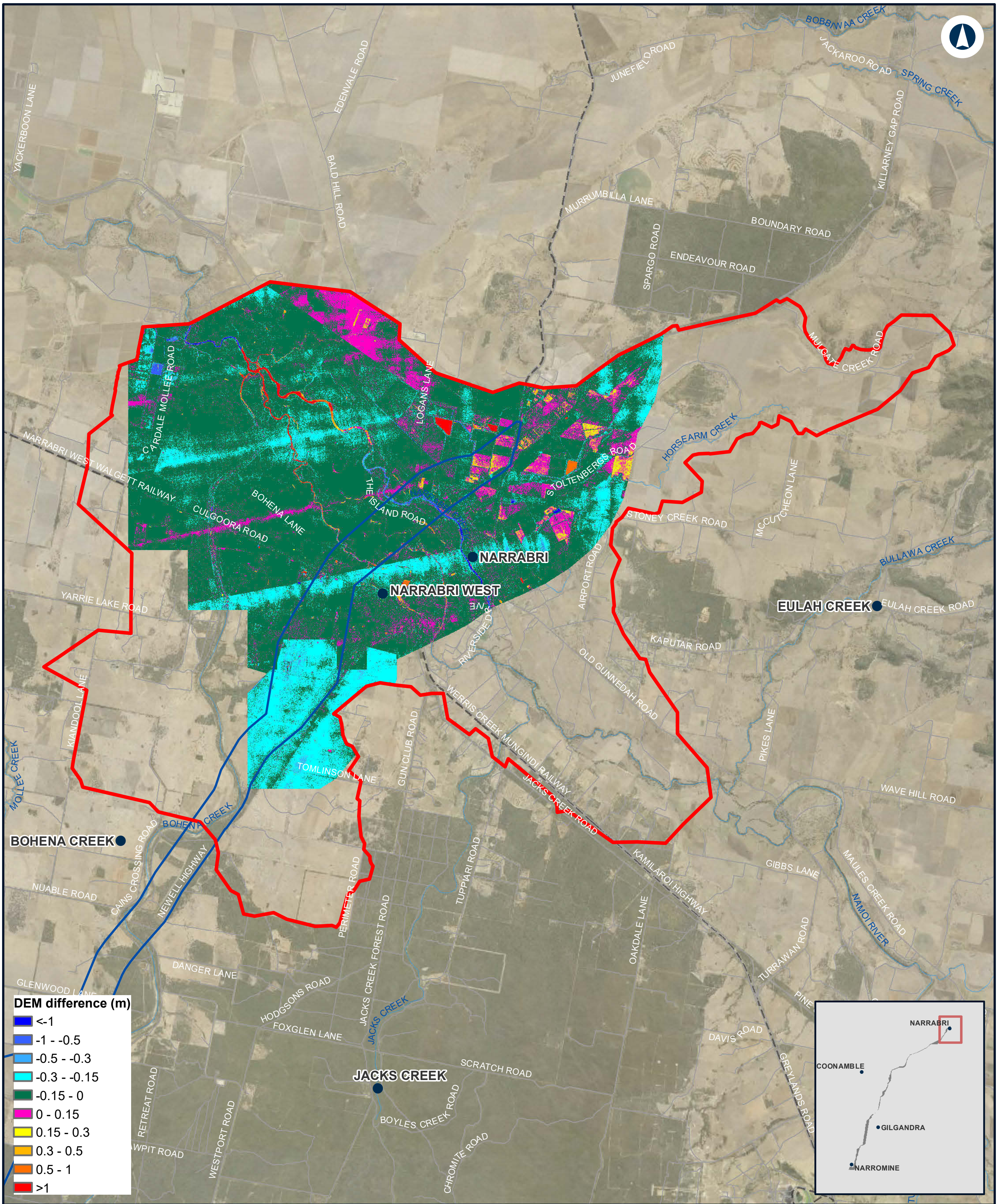
6.2.2 Narrabri

Flood modelling data and the WRM (2016) Flood Study Report were reviewed by JacobsGHD. A comparison between 2014 DEM and 1 m DEM provided by ARTC is presented in Figure 6-2. Figure 6-2 shows a typical difference of 0.15 m in elevation between the two data sets. There are significant areas where 1 m DEM provided by ARTC is 0.15 to 0.30 m lower than the 2014 DEM. Differences in elevation within water courses, farm storages and areas where earthworks were undertaken between 2014 and 2018 are more than 1 m. Therefore, the 1 m DEM provided by ARTC is considered appropriate for this investigation as the DEM represents the most recent terrain data for Narrabri.

An attempt was made to develop the base case hydraulic utilising the MIKE Flood FM model and adopting the 1 m DEM provided by ARTC. JacobsGHD invested significant time and efforts in the development of the base case MIKE Flood FM hydraulic model. However, preliminary results obtained by JacobsGHD for the base case for the 1% AEP event indicated several numerical instabilities in the modelling results and significant changes to flood behaviour adopted by Narrabri Shire Council. Hence, JacobsGHD developed a TUFLOW model for Narrabri based on the following considerations:

- Better representation of the entire model domain in 10 m grids.
- Efficient assessment of various route options and optimisation of hydraulic structures for the proposal for the full range of flood events.
- The same hydraulic modelling software utilised for the entire proposal.

Details on the Narrabri TUFLOW hydraulic model are provided in Appendix D and the model was calibrated using the procedure defined in the following sections.



NARROMINE TO NARRABRI Comparison of DEMs for Narrabri Figure 6.2

0 2 4 Km

Coordinate System: GDA 1994 MGA Zone 55

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LEGEND

- TUFLOW Model Boundary
- Study area
- Road
- Existing railway
- Watercourse

Date: 23/06/2021 Paper: A4
Author: JACOBS Scale: 1:175,000
Data Sources: Phase 2 study area, hydraulic data: GHDJACOBS; Imagery: ARTC; all other layers IR ARTC

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6.3 Development of new hydraulic models

Twelve new hydraulic models covering the remaining length of the proposal between Narromine and Narrabri were developed as a part of the Feasibility Design. Details on the model set up for TUFLOW models for Baradine Creek (N2N7) and Bohena Creek (N2N1) which were calibrated and verified as part of this study are provided in Appendix D. Land use for each model domain is also shown in Appendix D.

6.4 Calibration of models against observed flood events

Limited stream gauging data is available for calibration of TUFLOW hydraulic models for Narromine, Baradine Creek, Bohena Creek and Narrabri. In addition, historic flood levels for Narromine and Narrabri are available for calibration of TUFLOW hydraulic models.

In addition to the available historic flood levels for Narromine and Narrabri, one additional flood mark for Narromine and another flood mark for Narrabri were surveyed by JacobsGHD. These two flood marks were also used to check the performance of the respective flood models. In addition, preliminary flood maps for the 1% AEP event were shown to landowners for the existing development conditions during meetings held between July 2019 and March 2020 and feedback was used to check the model results.

6.4.1 Narromine TUFLOW model

The updated Narromine model (as discussed in Section 6.2) was calibrated using the historical stream flow data in Baroona (GS 421127) for the August 1990, August 1998, November 2000 and November 2010 flood events. Table 6-2 below summarises the adopted peak inflow and flood level at Baroona and the associated recorded flood level at the flood level gauge at Timbrebongie Bridge (located approximately 23 kilometres downstream of Baroona gauge). Location of both gauges are shown in Figure E-1 in Appendix E.

Table 6-2 Summary of model calibration events

Event	Recorded Peak Flow Rate at Baroona (m^3/s)	Recorded Peak Water Level at Baroona (m AHD)	Recorded Peak Water Level at Timbrebongie Bridge (m AHD)
August 1990	2077	244.63	237.5
August 1998	998	242.20	234.2
November 2000	1104	242.70	235.2
November 2010	2185	244.68	238.1

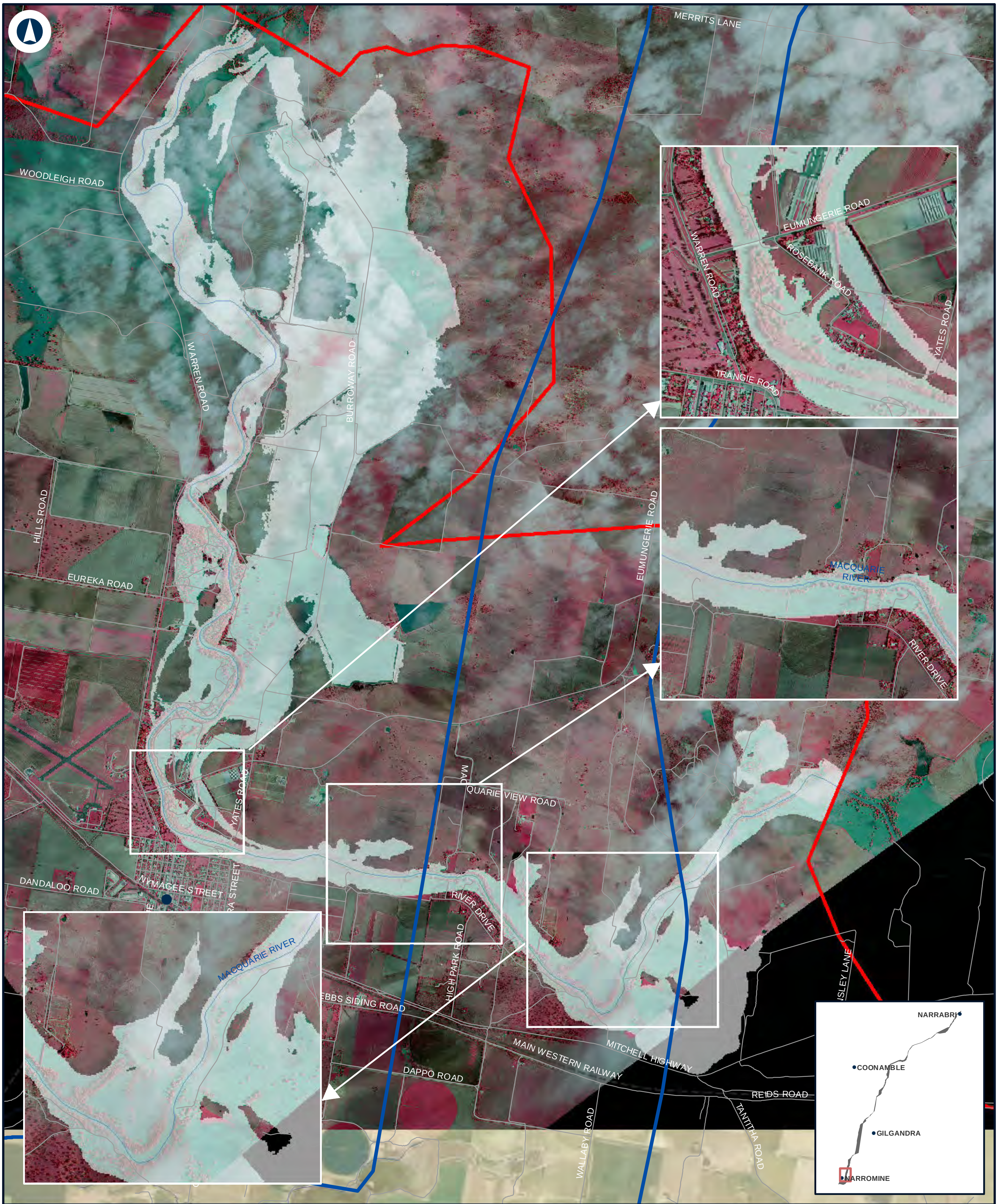
The previous study report provided from Narromine Shire Council (as discussed in Section 4.2) indicates that the peak flood levels in the Macquarie River at Narromine are heavily dependent on the conveyance capacity of the river, with the majority of the discharge being conveyed within the channel and on its immediate overbank area. Hence, the calibration of the hydraulic model has mainly focussed on the Manning's roughness values within the Macquarie River.

Table 6-3 summarises the modelling result at Timbrebongie Bridge and associated adopted Manning's roughness value. Table 6-3 shows a good agreement between modelled and recorded peak flood levels for the flood events of August 1990 and August 1998. The maximum difference between modelled and recorded flood level is 0.04 m for the two flood events using a Manning's roughness value of 0.05 for the main channel of the Macquarie River. In the case of the November 2000 flood event, the TUFLOW model underestimates peak flood level at the bridge by 0.07 m with a Manning's roughness value of 0.06. A Manning's roughness value of 0.065 is adopted in the TUFLOW model for the flood event of November 2010 and the model underestimates peak flood level at the bridge by 0.21 m. The comparison of the modelled and observed flood extent for the 2010 flood event (false colour imagery) is shown in Figure 6-3 which shows a reasonable agreement between observed and modelled flood extent for this event.

Table 6-3 Summary of model calibration results

Flood Event	Recorded Peak Water Level at Timbrebongie Bridge (m AHD)	Modelled Peak Water Level at Timbrebongie Bridge (m AHD)	Difference between Modelled and Recorded Peak Water Level (m)	Adopted Manning's Roughness Value
August 1990	237.50	237.46	-0.04	0.05
August 1998	234.20	234.23	+0.03	0.05
November 2000	235.20	235.13	-0.07	0.06
November 2010	238.10	237.89	-0.21	0.065

The calibration indicates that in order to achieve a good fit between modelling and recorded results, a Manning's roughness value of 0.05 to 0.065 is required. The adopted Manning's roughness values for the main channel of the Macquarie River are in agreement with previous flood studies (Bewsher, 1998 and *Lyall & Associates*, 2013) for Narromine. Although the adopted Manning's roughness values may appear to be high, it is to be noted that the Macquarie River being a regulated river, landowners are not generally permitted to clear floating debris and remove snags from the river. The floating debris and snags have the potential to impede flood flow resulting in higher energy losses.



NARROMINE TO NARRABRI

Modelled vs observed flood extent for the 2010 flood event (false colour imagery)

Figure 6.3

0 1 2 Km

Coordinate System: GDA 1994 MGA Zone 55

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LEGEND

- Phase 2 study area
- Roads
- Existing railway
- Watercourse
- TUFLOW Model Boundary
- 2010 modelled flood extent

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Date: 18/06/2020 Paper: A4
Author: JACOBS Scale: 1:70,000
Data Sources: Phase 2 study area, hydraulic data: GHDJACOBS; Imagery: ARTC; all other layers IR ARTC

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6.4.2 Baradine Creek (N2N7) TUFLOW model

Limited stream gauging data is available for calibration of the N2N7 TUFLOW model at GS 419072. It is to be noted that GS 419072 is a discontinued gauge and the gauge datum is not connected to AHD. Surveyors from JacobsGHD were unable to locate the gauge and its benchmark in February 2019.

The N2N7 TUFLOW model was calibrated against flood events of July 1998 and December 2007. Discharge data from PINNEENA for GS 419072 was used as inflow boundary for the model. For both flood events, simulated discharges at the gauge were compared against discharges extracted from PINNEENA. It is not possible to compare observed and simulated water levels as the gauge zero for GS 419072 is not connected to AHD. Calibration results for both events are presented in Appendix E. Overall, the calibration results are considered satisfactory.

6.4.3 Bohena Creek (N2N1) TUFLOW model

Limited stream gauging data is available for calibration of the N2N1 TUFLOW model at GS 419905 and hence the N2N1 TUFLOW model was calibrated against flood events of July and September 1998. Discharge data provided by WaterNSW for GS 419905 was used as inflow boundary for the model. For both flood events, simulated water levels and discharges were compared against corresponding data provided by WaterNSW. Calibration results for both events are presented in Appendix E. Overall, a satisfactory agreement was achieved for both flood events.

A comparison of the published rating curve and that generated from N2N1 TUFLOW model output is presented in Appendix E. Overall, a satisfactory agreement was achieved.

6.4.4 Narrabri TUFLOW model

The MIKE Flood hydraulic model for Narrabri adopted by Narrabri Shire Council was calibrated against three regional flood events and two local flood events for Mulgate Creek and Long Gully. The regional flood events include flood events of February 1995, February 1971 and July 1998, and the local flood events include flood events of December 2004 and February 2012. It is to be noted that the same terrain and MIKE Flood model set up were used for all calibration events.

Inflow hydrographs utilised in the calibration of council's hydraulic model (WRM, 2016) were utilised for calibration of the TUFLOW model for Narrabri. The same TUFLOW model set up, terrain data, outflow boundaries and Manning's n values were used for calibrating the model for the flood events of February 1995, February 1971, July 1998, December 2004 and February 2012.

Calibration results for regional flood events

A comparison between historic flood levels (WRM, 2016) and flood levels modelled by the TUFLOW model is shown in Figure 6-4. A comparison between historic flood levels (WRM, 2016) and flood levels modelled in the council flood study (WRM, 2016) is also shown in Figure 6-4. Figure 6-4 shows a reasonable agreement between calibration results obtained in this study and the council flood study (WRM, 2016). Further comparison between modelled and recorded flood levels for the 1955 flood event and modelled flood extent are presented in Appendix E. A comparison of rating curves generated from TUFLOW model output and MIKE Flood model output (WRM, 2016) is shown in Figure 6-5. Figure 6-5 shows a reasonable agreement in rating curves between the two studies and modelled water levels are lower in the TUFLOW model for flows less than 200 m^3/s.

The calibration results for both 1955 and 1971 flood events shown in Appendix E indicate a pattern of the TUFLOW model overestimating flood levels on the upstream side of the Newell Highway and underestimating on the downstream side on the western side of the Namoi River within Narrabri. It is to be noted that the existing terrain and floodplain conditions were used for calibration of the TUFLOW model against historic flood events. The same approach including the terrain and floodplain conditions was also adopted in the calibration of the MIKE Flood model (WRM, 2016). The variance from observed flood levels is typically +/- 0.2m which is considered a reasonable fit given the uncertainties about changed floodplain conditions since the calibration events up to the present and a typical difference of 0.15 m in elevation between the two LiDAR data sets captured in 2014 and 2018.

In general, TUFLOW calibration results for the 1955 flood event are considered satisfactory and comparable to calibration results achieved in council's flood study (WRM, 2016). The TUFLOW model simulated a peak flood level of 211.3 m AHD for the 1955 calibration event at the surveyed flood mark in Narrabri (Section 4.3.4). The surveyed 1955 flood level at the flood mark is 211.1 m AHD which agree closely with the flood level simulated by the TUFLOW model for the 1955 flood event.

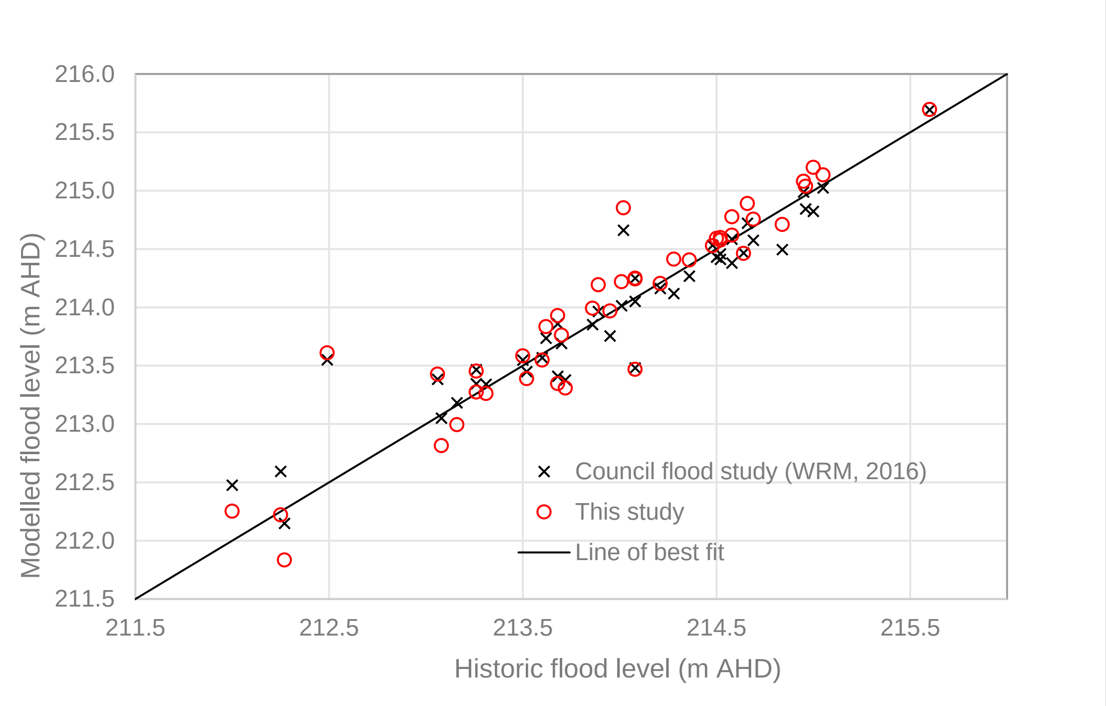


Figure 6-4 Comparison between historic and modelled flood levels – 1955 Flood

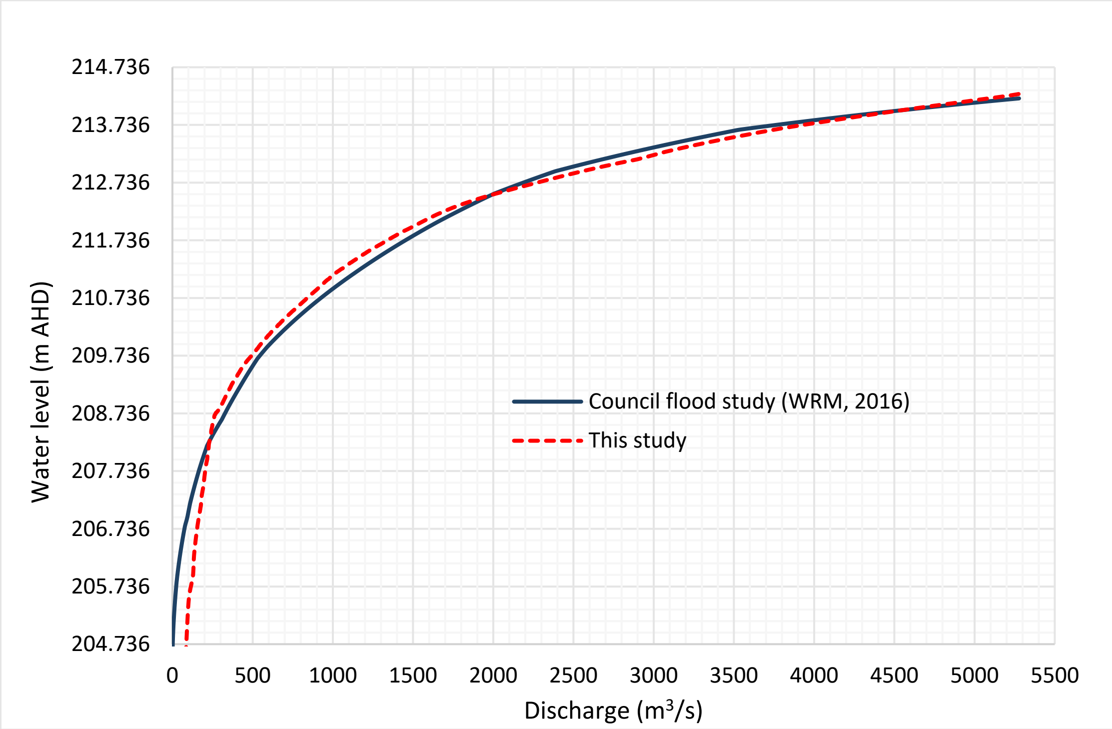


Figure 6-5 Comparison between stage-discharge rating curves

A comparison between 1971 historic flood levels (WRM, 2016) and flood levels predicted by the TUFLOW model is shown in Figure 6-6. A comparison between historic flood levels (WRM, 2016) and flood levels predicted in the council flood study (WRM, 2016) is also shown in Figure 6-6. Figure 6-6 shows a reasonable agreement between calibration results obtained in this study and the council flood study (WRM, 2016). Further comparison between modelled and recorded flood levels for the 1971 flood event and modelled flood extent are presented in Appendix E.

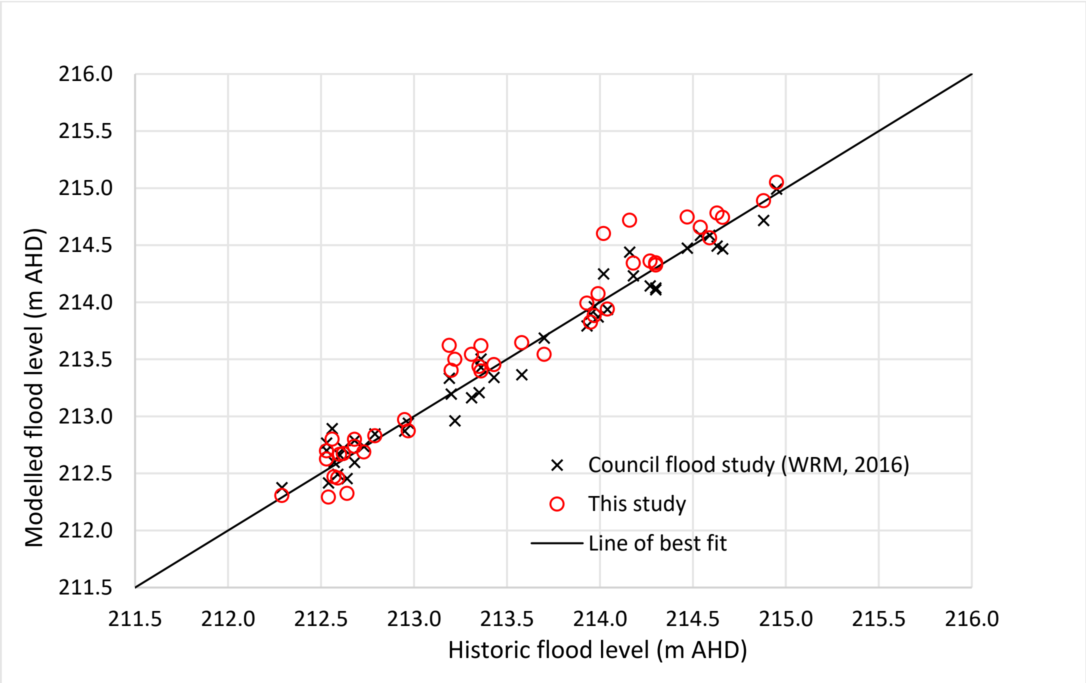


Figure 6-6 Comparison between historic and modelled flood levels – 1971 Flood

In the case of the flood event of 1998, only two recorded peak water levels at two stream gauges (refer Figure in Narrabri are available. Recorded peak water levels and peak water levels simulated by the TUFLOW model and council flood study (WRM, 2016) for the 1998 flood event are shown in Table 6-4. Peak water levels modelled by the TUFLOW model at the two gauges agree closely with recorded levels at the gauge and peak water levels modelled in the council flood study (WRM, 2016).

Table 6-4 Calibration results for the flood event of 1998

Location	Recorded Peak Water Level (m AHD)	This Study - Modelled Peak Water Level (m AHD)	Council Flood Study - Modelled Peak Water Level (m AHD)
Narrabri Creek at Narrabri gauge	212.93	212.80	212.92
Namoi River at Narrabri gauge	212.82	212.76	212.70

Calibration results for local flood events

No recorded stream gauging data are available for both Mulgate Creek and Long Gully for the local flooding events of December 2004 and February 2012. The peak discharge in the Namoi River for the flood event of December 2004 has an AEP of less than 20% and the peak Namoi River flow for the flood event of February 2012 has an AEP between 10% and 20% (WRM 2016). A comparison of modelled and recorded peak water levels at the Narrabri Creek at Narrabri gauge shows that the TUFLOW model overestimates peak water levels at the gauge by 0.2 m and 0.5 m for the flood events of February 2012 and December 2004 respectively. This is probably due to a coarse representation of channel bathymetry and other in-bank features in the TUFLOW model based on the available DEMs.

Modelled flood extents and flood contours for local flooding events of December 2004 and February 2012 are presented in Appendix E which generally agree with flood extents presented in the council flood study (WRM, 2016).

6.5 Validation of models

Flood behaviours for both Narromine and Narrabri were assessed for a range of design flood events as part of recent flood studies undertaken by Narromine Shire Council and Narrabri Shire Council respectively. Calibrated TUFLOW models for Narromine and Narrabri were run for a range of design flood events based on ARR 2019 (*Ball et al, 2019*) and modelled flood behaviour for the selected design flood events were compared with the most recent council flood study to verify flood behaviour for design flood events. In addition, the modelled rating curve for Bohena Creek was compared with measured discharge data and the latest rating curve for the stream gauge located at Newell Highway. Details on the model verification are provided in the following sections.

6.5.1 Narromine TUFLOW model

A RORB hydrology model was developed for the entire catchment area of the Macquarie River at Narromine. Existing dams and water diversion structures were not represented in the RORB model. RORB model parameter values (k_c and m) and other hydrological inputs (rainfall depths, rainfall losses, spatial and temporal distribution of rainfall) for the full range of design flood events were based on ARR 2019 (*Ball et al, 2019*). Runoff hydrographs simulated by the RORB model were scaled on the basis of FFA results adopted (Section 5.5.2) in this study to derive inflow hydrographs for the Macquarie River upstream of Narromine for flood events up to and including the 0.5% AEP event.

The TUFLOW model was run for the full range of design flood events up to and including the PMF event for the existing conditions. A comparison of modelled peak flood levels and adopted peak inflow in the Macquarie River upstream of Narromine between this study and Lyall & Associates (2013) is shown in Table 6-5.

Table 6-5 Comparison of modelled flood levels at Timberbongie Bridge

Flood Event	Lyall & Associates (2013) (m AHD)	This Study (m AHD)
1% AEP	239.12 (adopted peak inflow 4,000 m^3/s)	238.94 (adopted peak inflow 4,216 m^3/s)
0.5% AEP	239.36 (adopted peak inflow 5,800 m^3/s)	239.09 (adopted peak inflow 5,880 m^3/s)

Table 6-5 shows that modelled flood levels at Timberbongie Bridge for both design flood events are slightly lower than flood levels modelled in the council flood study (Lyall & Associates, 2013). A comparison of modelled 1% AEP flood levels along the Macquarie River between Lyall & Associates (2013) and this study is shown in Table 6-6. Table 6-6 shows that 1% AEP flood levels modelled in this study are slightly higher upstream of Crossley Drive and slightly lower downstream of Crossley Drive than Lyall & Associates (2013). It is to be noted that flood levels simulated by Lyall & Associates (2013) are yet to be adopted by council for floodplain risk management for Narromine Shire and the 1% AEP flood levels adopted in the Narromine Floodplain Risk Management Plan (*Lyall & Associates*, 2009) for the same reach of the Macquarie River identified in Table 6-6 are 0.15 to 0.70 m lower than Lyall & Associates (2013).

Table 6-6 Comparison of 1% AEP modelled flood levels

River Chainage (km)	Location	Lyall & Associates (2013) (m AHD)	This Study (m AHD)
0.00	Upstream limit of MIKE11 hydraulic model	243.20	243.22
1.35		243.04	243.08
3.25	Adjacent to eastern end of River Drive	242.24	242.37
5.50		240.81	240.75
6.50	Adjacent to eastern end of Crossley Drive	240.43	240.59
7.30		239.98	239.84
8.15		239.55	239.47
8.75	Narromine-Eumengerie Road Bridge and Narromine Flood Gauge	239.12	238.93
9.40		238.74	238.52

Flood levels simulated by the updated TUFLOW model are consistent with Lyall & Associates (2013) and the updated TUFLOW model is considered appropriate for the flooding impact assessment for the proposal.

The estimated 1% AEP flood level at the surveyed flood mark in Narromine (Section 4.3.4) is 241.3 m AHD and the surveyed 1955 flood level at the flood mark is 240.9 m AHD.

6.5.2 N2N1 TUFLOW model

RORB hydrology models were run for the full range design flood events based on ARR 2019. Modelled results were reviewed to identify critical storm duration and temporal patterns for the Study Area. Inflow hydrographs generated by the RORB models were routed through the calibrated N2N1 TUFLOW model to simulate flood behaviour for the full range of design flood events. Modelled peak discharge and flood levels for all design flood events are compared with measured discharges and the latest rating curve for Bohena Creek at Newell Highway gauge in Figure 6-7. Figure 6-7 shows that peak water levels and discharges modelled by the N2N1 TUFLOW model for the full range of design events are in reasonable agreement with the current rating curve and the measured data.

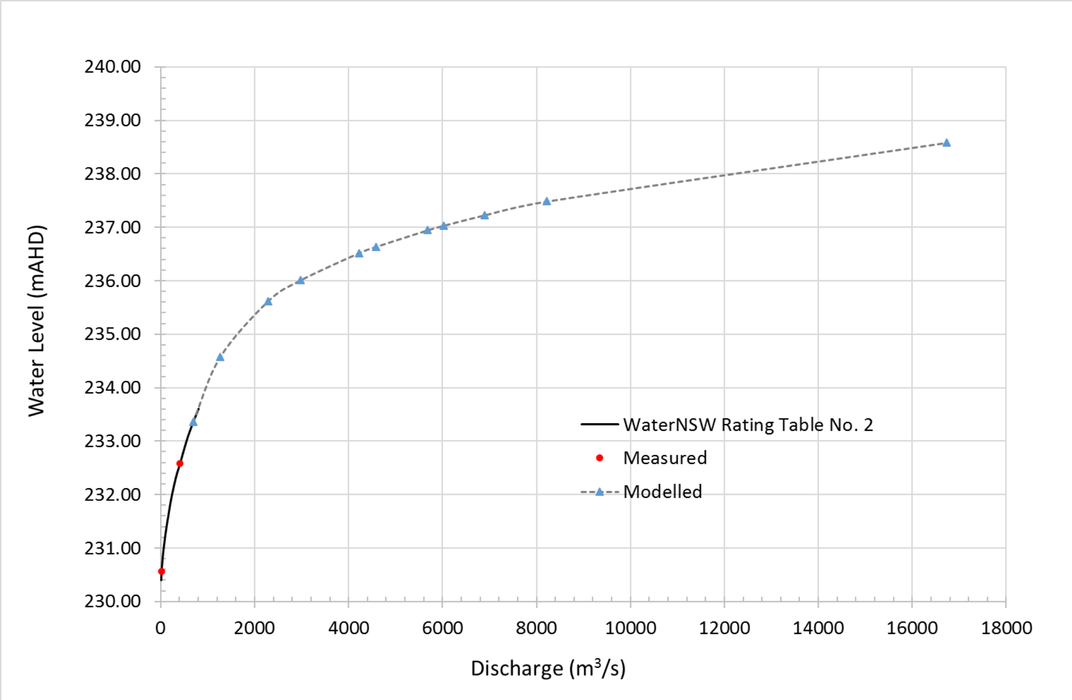


Figure 6-7 Comparison of rating curve – Bohena Creek at Newell Highway

6.5.3 Narrabri TUFLOW model

A RORB hydrology model was developed for the entire catchment area of the Namoi River at Narrabri. Existing dams and water diversion structures are not represented in the RORB model. RORB model parameter values (k_c and m) and other hydrological inputs (rainfall depths, rainfall losses, spatial and temporal distribution of rainfall) for the full range of design flood events were based on ARR 2019 (Ball et al, 2019). Runoff hydrographs simulated by the RORB model were scaled on the basis of FFA results (WRM, 2016) to derive inflow hydrographs for the Namoi River upstream of Narrabri for flood events up to and including the 1% AEP event.

The XP-RAFTS hydrology model for the catchment areas of Mulgate Creek and Long Gully was run for the full range of design flood events based on the guidelines presented in ARR 2019 (Ball et al, 2019). A comparison of 1% AEP design rainfall depths between WRM (2016) and design rainfall depths extracted from ARR Datahub indicates that rainfall depths extracted from ARR Datahub for the 36 hour storm duration adopted in WRM (2016) are generally up to 15% lower. It is to be noted that design rainfall depths adopted in the council flood study (WRM, 2016) are based on ARR 1987. A 10 mm initial rainfall loss is adopted in the council flood study (WRM, 2016) for both 1% and 2% AEP events which is approximately 60% lower than the recommended value in ARR 2019. Initial rainfall losses adopted in the council flood study for flood events smaller than 2% AEP are generally similar to the losses recommended in ARR 2019 (Ball et al, 2019). The same continuing loss rate (2.5 mm/hr) adopted in the council flood study has also been adopted in this study.

Runoff hydrographs simulated by the XP-RAFTS model were reviewed to select the critical storm duration of interest to the Feasibility Design. A 12 hour storm duration was selected as it provides peak discharges for all events between 0.2% AEP and 5% AEP for the catchment area (approximately 95 km^2) of Mulgate Creek at the railway culvert. A critical storm of 18 hour was adopted for flood events smaller than the 5% AEP event.

Inflow hydrographs for the Namoi River and local catchments were defined in the TUFLOW model in such a way so that peak flooding from local catchments do not coincide with peak flooding in the Namoi River and there are moderate flood flows in the Namoi River due to rainfall runoff generated from catchment areas of Bullawa and Jacks Creeks. This approach is consistent with the approach adopted in the council flood study (WRM, 2016).

The TUFLOW model for Narrabri was run for the full range of flood events to assess flood behaviour due to regional flooding in the Namoi River and local catchment flooding. A comparison between modelled peak flood levels at the two stream gauges for the selected design flood events is shown in Figure 6-7. Figure 6-7 shows a reasonable agreement between peak flood levels modelled in this study and the council flood study (WRM, 2016) for all but the 20% AEP event. In the case of the 20% AEP event, the modelled peak flood level in the Namoi River at Narrabri gauge is about 1 m higher than the council flood study. However, a review of the council flood study report shows an anomaly in modelled peak flood levels for the 20% AEP event at the two gauges and observed flood levels at both gauges for flood events similar to the 20% AEP event. It is concluded that the council flood study (WRM, 2016) underestimated flood level at the Namoi River at Narrabri gauge by about 1 m in the 20% AEP event.

Table 6-7 Comparison of modelled flood levels (m AHD) at stream gauges

Event	Namoi River at Narrabri			Narrabri Creek at Narrabri		
	WRM, 2016 Flood Level (m AHD)	This Study, Flood Level (m AHD)	Difference in Flood Level (m)	WRM, 2016 Flood Level (m AHD)	This Study, Flood Level (m AHD)	Difference in Flood Level (m)
1% AEP	213.56	213.76	0.20	214.08	214.08	0.00
2% AEP	213.31	213.47	0.16	213.82	213.77	-0.05
5% AEP	212.91	212.97	0.06	213.29	213.17	-0.12
10% AEP	212.45	212.58	0.13	212.48	212.50	0.02
20% AEP	210.98	211.92	0.94	211.30	211.30	0.00

7. Conclusions

The purpose of this report is to outline the model selection and development and to present calibration and validation results of hydrology and hydraulic models developed for the Phase 2 Reference Design on the Narromine to Narrabri section of Inland Rail.

The following hydrology and hydraulics assessments were undertaken for the Narromine to Narrabri section of Inland Rail proposal:

- Relevant data for the proposal including topographical data, rainfall data, streamflow data, reports, flood modelling data, GIS layers etc. were collected and reviewed.
- The reviewed rainfall and streamflow data were used to identify catchments to calibrate RORB hydrology models. RORB hydrology models for Baradine Creek and Bohena Creek were formulated and each model was satisfactorily calibrated against three observed flood events.
- RORB model parameter values obtained from model calibration and design rainfall data sourced from ARR Data Hub were used to simulate peak flows for Baradine Creek and Bohena Creek for a selected design flood events up to and including the 1% AEP event. An at-site flood frequency analysis and a regional flood frequency analysis using the RFFE tool were undertaken to verify peak flows estimated by the RORB model for Baradine Creek. Peak flows estimated by the RORB model for Baradine Creek were generally higher than at-site flood frequency estimates and lower than RFFE estimates. It was also identified that peak flows simulated by the RORB model for minor flood events were sensitive to the adopted initial rainfall loss. Hence, the adopted initial rainfall loss was not reduced to reconcile peak flows estimated by the RORB model and at-site flood frequency estimates. In the case of Bohena Creek an at-site flood frequency was not undertaken due to the limited length of streamflow data of unknown quality. Hence, peak flows estimated by the RORB model for Bohena Creek were verified against peak flows estimated using the RFFE tool. Peak flows estimated by the RORB model are generally higher than RFFE estimates and it is recommended that additional investigations should be undertaken during detailed design to reconcile peak flows against anecdotal flood behaviour.
- It is recommended that the RORB models for ungauged catchments should adopt parameter values, k_c and m, based on ARR 2019 guidelines. The lower value of the initial rainfall loss obtained from calibration results from adjacent catchment (where available) and ARR 2019 Data Hub should be adopted for each ungauged catchment. The lower value of the continuing rainfall loss rate obtained from calibration results from adjacent catchment (where available) and the default ARR Data Hub continuing loss rate with a multiplication factor of 0.4 should be adopted for each ungauged catchment.
- At-site flood frequency analyses were undertaken for the Macquarie River and the Castlereagh River to estimate peak flows for design flood events. At-site flood frequency results for Narrabri estimated in the Narrabri flood study (WRM, 2016) were adopted.
- The TUFLOW hydraulic model for Narromine provided by Narromine Shire Council was updated and an additional two TUFLOW hydraulic models were formulated utilising the available topographic data to model flood behaviour in Baradine Creek (N2N7) and Bohena Creek (N2N1). Information from Narrabri flood study (WRM, 2016) was used as the basis for developing a new TUFLOW hydraulic model for Narrabri.

- TUFLOW models for Narromine (Macquarie River), N2N7 (Baradine Creek), N2N1 (Bohena Creek) and Narrabri (Namoi River and Narrabri Creek) were calibrated against observed flood events. Calibration results for all TUFLOW models are considered satisfactory. TUFLOW models for Narromine and Narrabri were run for design flood events and modelled results were validated against flood behaviour adopted in council flood studies. Validation results are in reasonable agreement with council flood studies. Satisfactory calibration and verification results were obtained using TUFLOW hydraulic models for the gauged catchments of the Macquarie River at Narromine, Baradine Creek, Bohena Creek and the Namoi River/ Narrabri Creek at Narrabri and these models are considered suitable for a flood impact assessment for the proposal.

8. References

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia.

Bewsher Consulting, 1998, *Narromine Flood Behaviour Study,* report prepared for Narromine Shire Council.

BMT, 2018, *TUFLOW Classic/HPC User Manual, Build 2018-03-AC.*

BOM, 2004, *The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method.*

DECC, 2007, *Floodplain Risk Management Guidelines – Practical Consideration of Climate Change.*

DIPNR, 2005, *Floodplain Development Manual, The Management of Flood Liable Land.*

Institution of Engineers, Australia (1987) Australian Rainfall and Runoff: A Guide to Flood Estimation, Vol. 1, Editor-in-chief D.H. Pilgrim, Revised Edition 1987 (Reprinted edition 1998), Barton, ACT.

Laurenson, E. M., Mein, R. G. and Nathan, R. J., 2010, *RORB version 6 runoff routing program user manual*. Monash University Department of Civil Engineering in conjunction with Hydrology and Risk Consulting Pty Ltd and Melbourne Water Corporation. RORB version 6.31.

Lyall & Associates, 1996, *Gilgandra Floodplain Management Study*, prepared for the town of Gilgandra.

Lyall & Associates, 2009, *Narromine Floodplain Risk Management Study and Plan*, prepared for Narromine Shire Council.

Lyall & Associates, 2013, *Narromine River Bank Levee Feasibility Study*, prepared for Narromine Shire Council.

OEH, 2019, *Floodplain Risk Management Guide, Incorporating 2016 Australian Rainfall and Runoff in studies.*

SES, 2013a, *Gilgandra Shire Local Flood Plan.*

SES, 2013b, *Warrumbungle Shire Flood Emergency Sub Plan.*

SES, 2013c, *Dubbo City Local Flood Plan.*

SES, 2014, *Narromine Shire Flood Emergency Sub Plan.*

SES, 2015, *Narrabri Shire Flood Emergency Sub Plan.*

SKM, 2009, *Coonamble Levee - Flood Gradient Sensitivity Modelling Study,* prepared for NSW Department of Environment and Climate Change - *http://www.coonambleshire.nsw.gov.au/LiteratureRetrieve.aspx?ID=212401&A=SearchResult&SearchID=12191563&ObjectID=212401&ObjectType=6* accessed on 25 February 2019.

URS, 2014, *Narrabri Flood Study Review.*

URS, 2012, *Review of Gilgandra Floodplain Risk Management Study*, prepared for Gilgandra Shire Council.

WRM, 2016, *Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully*, prepared for Narrabri Shire Council.

APPENDICES

NARROMINE TO NARRABRI PROJECT

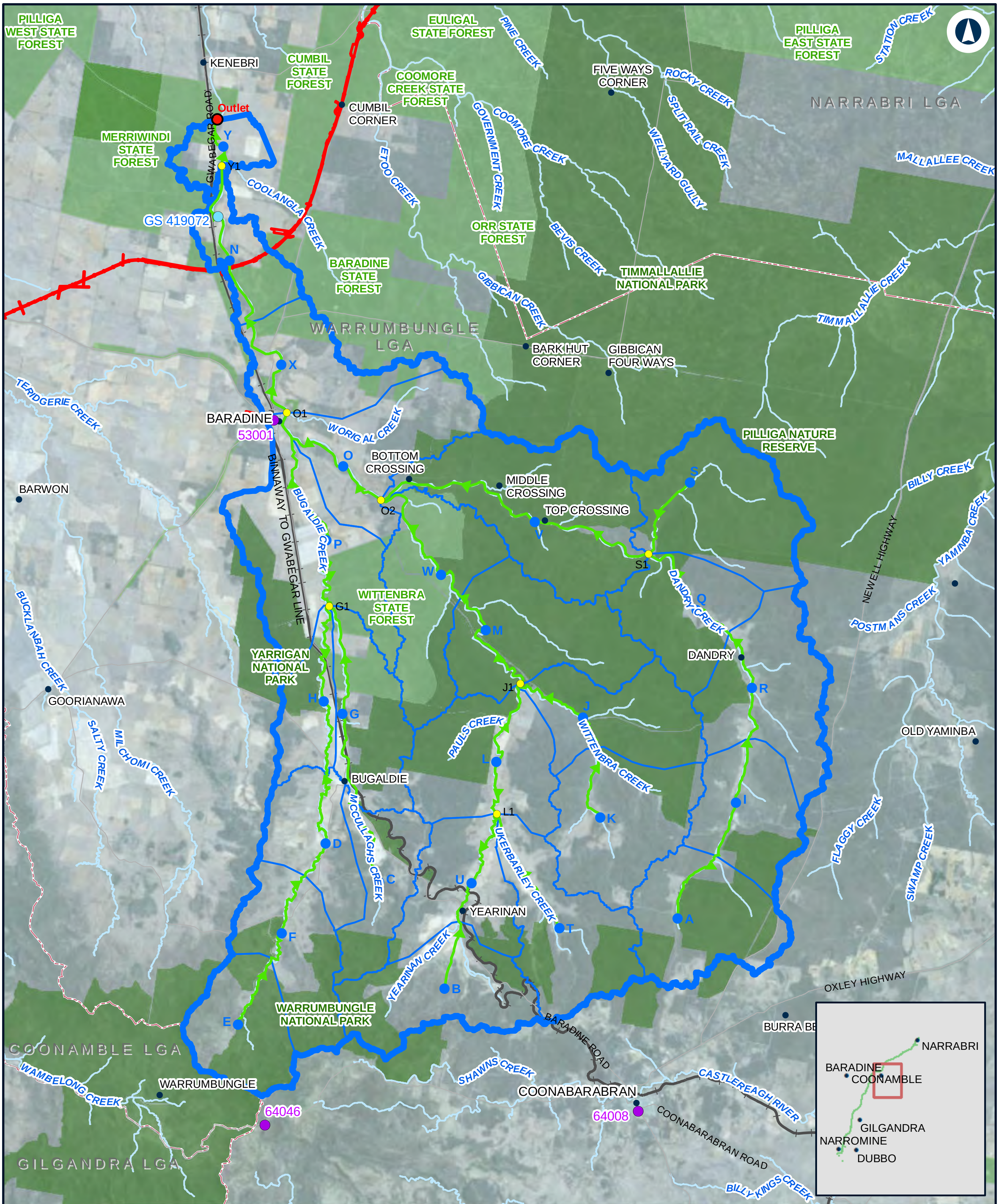
TECHNICAL REPORT

03

Updated flooding and hydrology assessment

Appendix A RORB model set up

NARROMINE TO NARRABRI PROJECT



NARROMINE TO NARRABRI Hydrology model setup - model N2N7_RORB_1 (Baradine Creek) Figure A.1

0 3.5 7 Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 18/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:280,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- Sub-area node
- Junction node
- Outlet
- Reach
- Sub-area
- Catchment boundary
- Rainfall gauge
- Stream gauge

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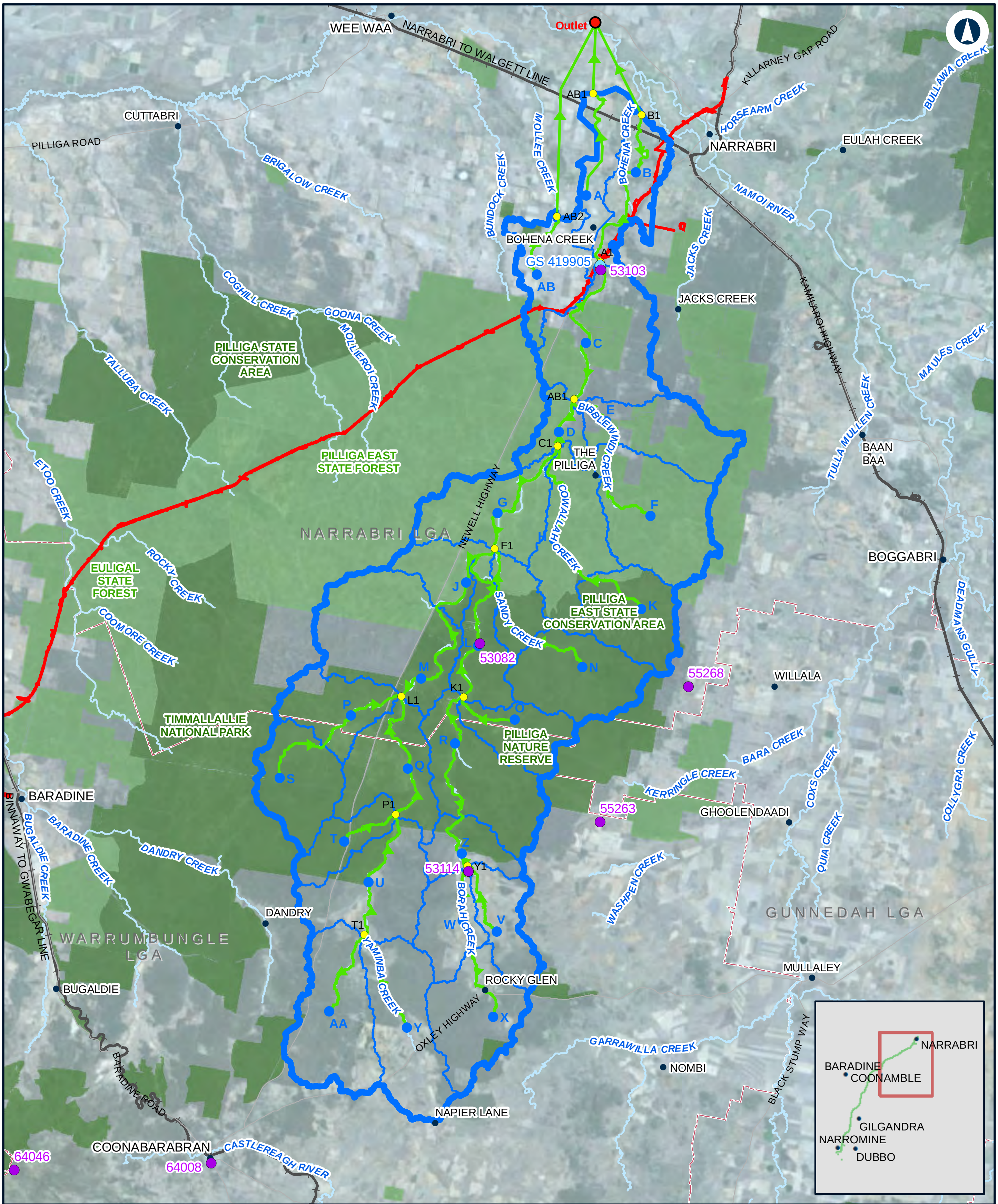

NARROMINE TO NARRABRI

Hydrology model setup - model N2N1_RORB_1 (Bohena Creek)

Figure A.2

0 7.5 15 Km

Coordinate System: GDA 1994 MGA Zone 55

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Author: JacobsGHD Scale: 1:530,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- Sub-area node
- Junction node
- Outlet
- Reach
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- Rainfall gauge
- Stream gauge

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TECHNICAL REPORT 03

Updated flooding and hydrology assessment

Appendix B RORB model calibration results

NARROMINE TO NARRABRI PROJECT

Appendix B – RORB model calibration results

Baradine Creek

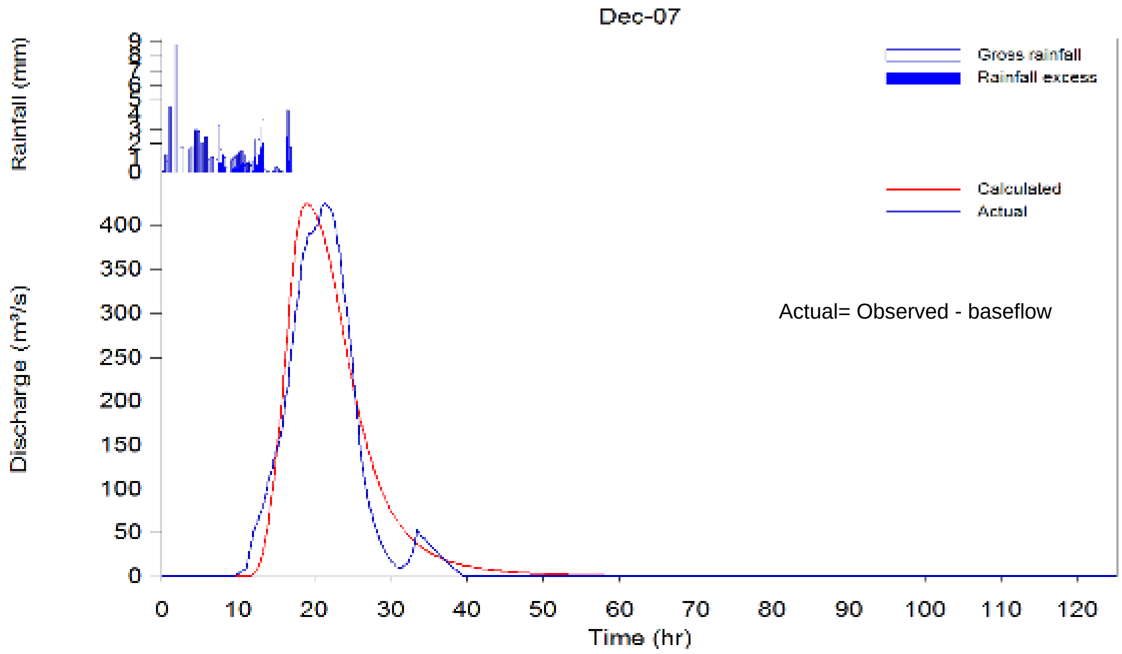


Figure B.1 - RORB calibration summary - Baradine Creek, December 2007

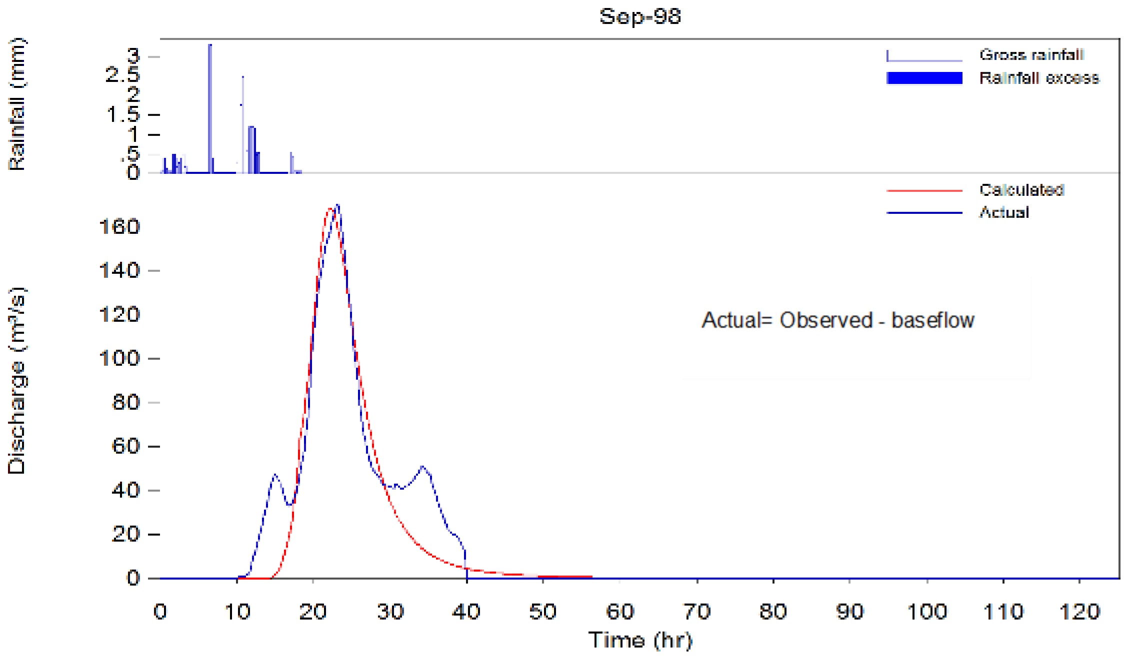


Figure B.2 - RORB calibration summary - Baradine Creek, September 1998

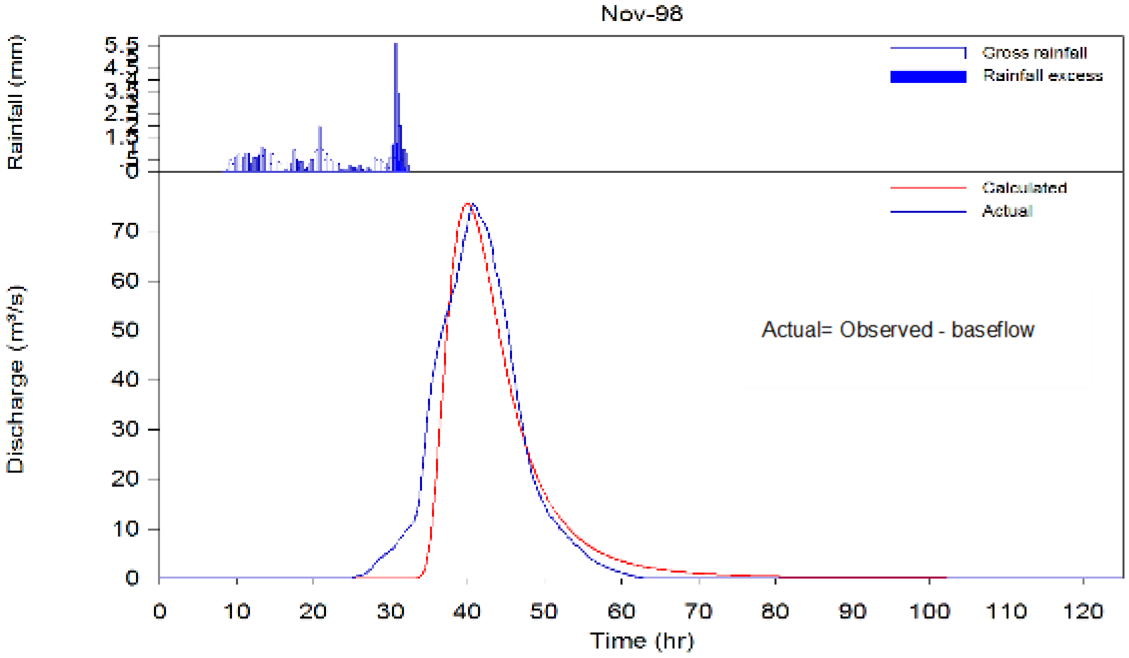


Figure B.3 - RORB calibration summary - Baradine Creek, November 1998

Bohena Creek

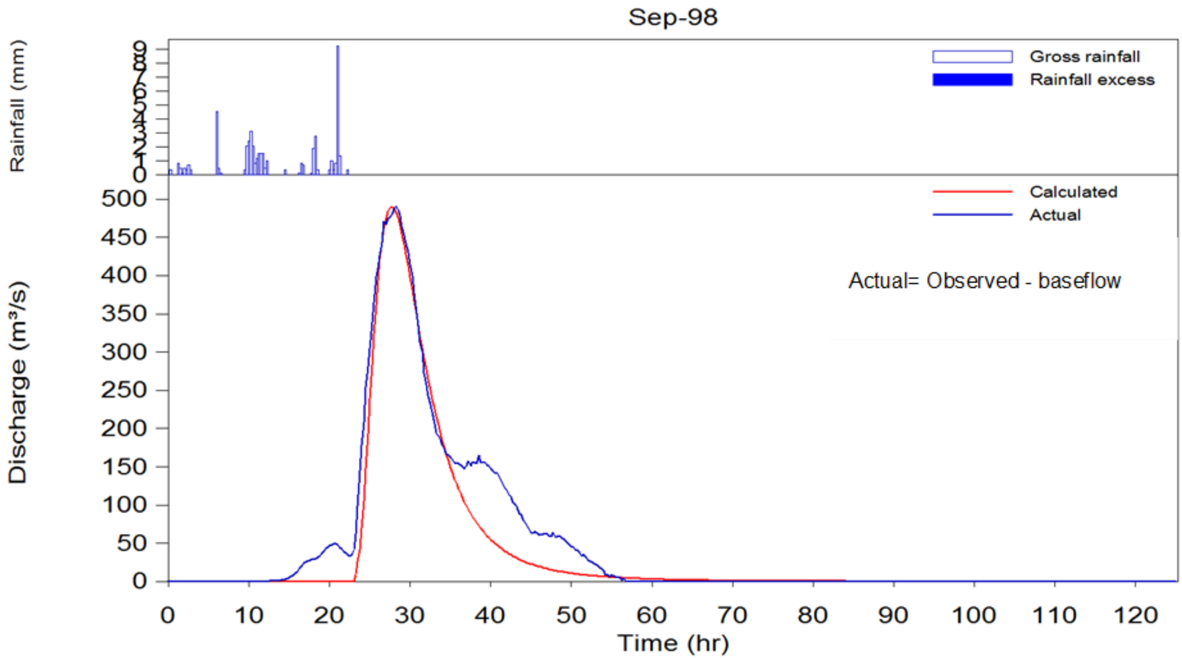


Figure B.4 - RORB calibration summary - Bohena Creek, September 1998

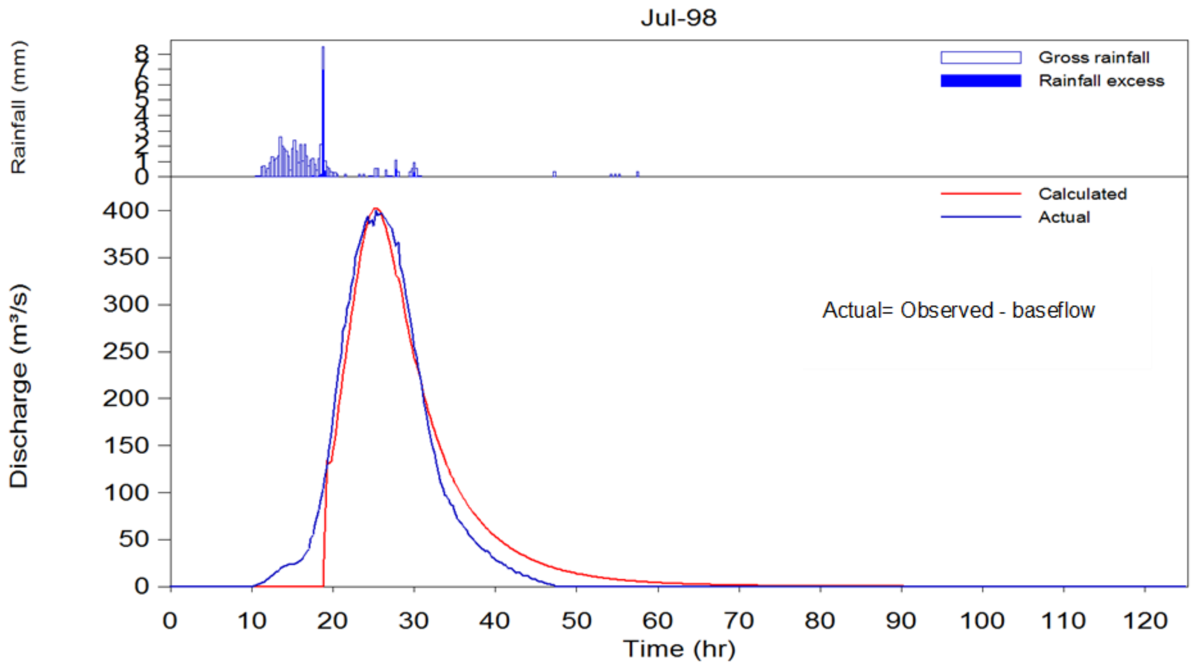


Figure B.5 - RORB calibration summary - Bohena Creek, July 1998

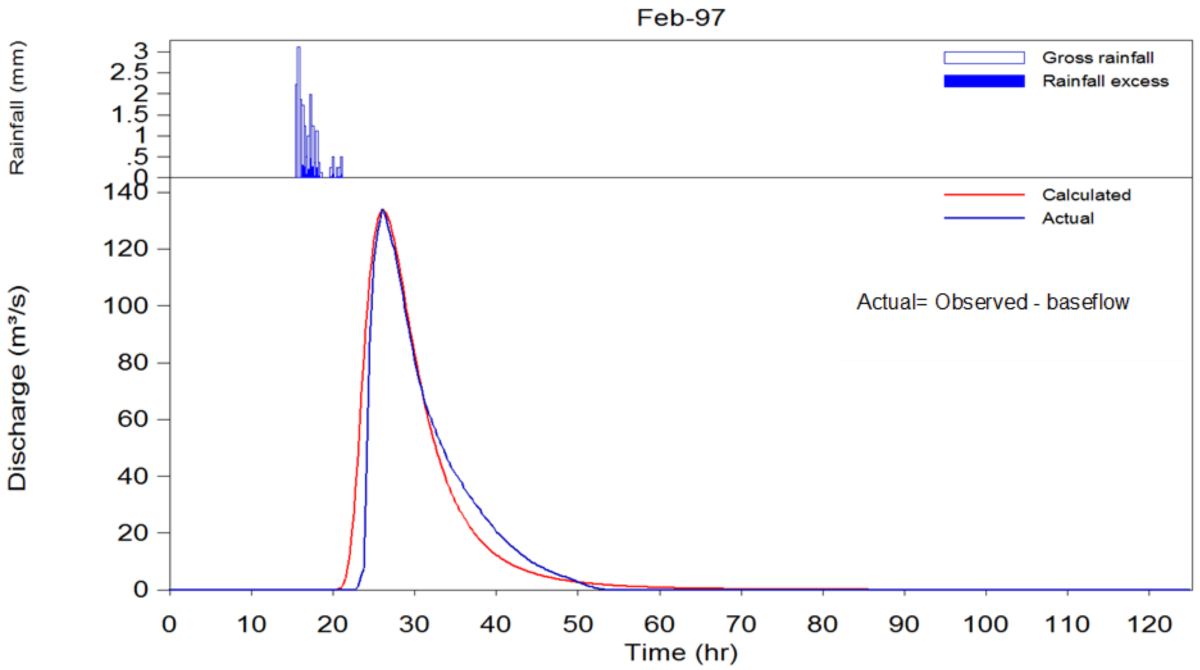


Figure B.6 - RORB calibration summary - Bohena Creek, February 1997

TECHNICAL REPORT

03

Updated flooding and hydrology assessment

Appendix C FFA Results

NARROMINE TO NARRABRI PROJECT

Appendix C – FFA Results

Macquarie River

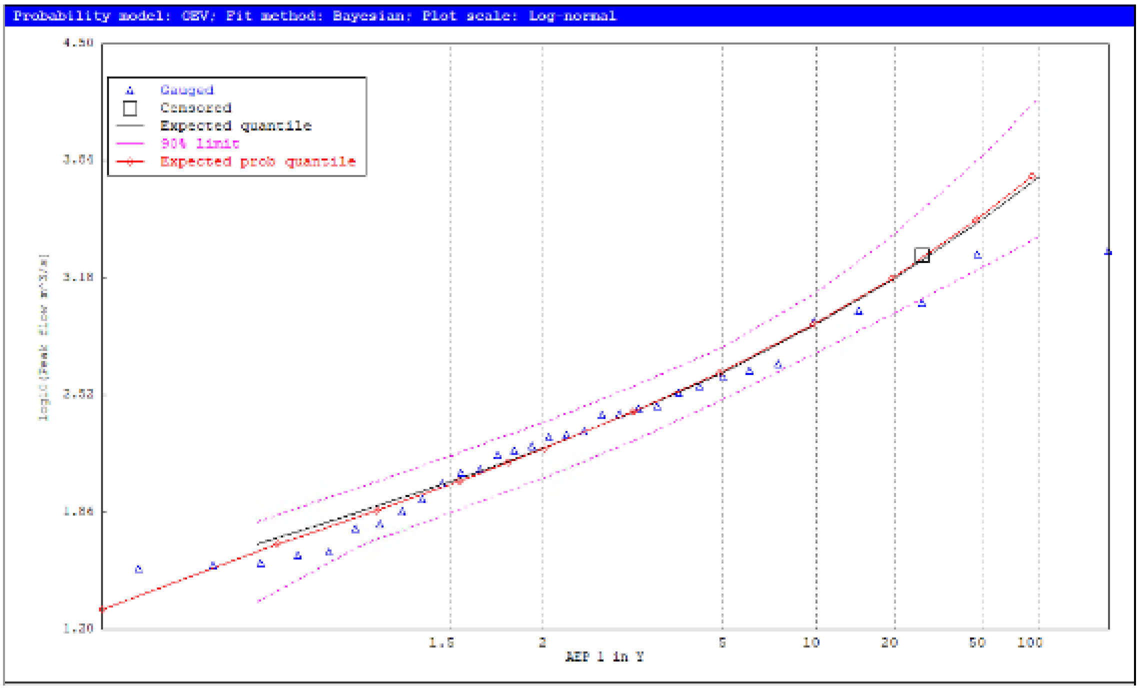


Figure C.1 – FFA (GEV) - Macquarie River at Baroona

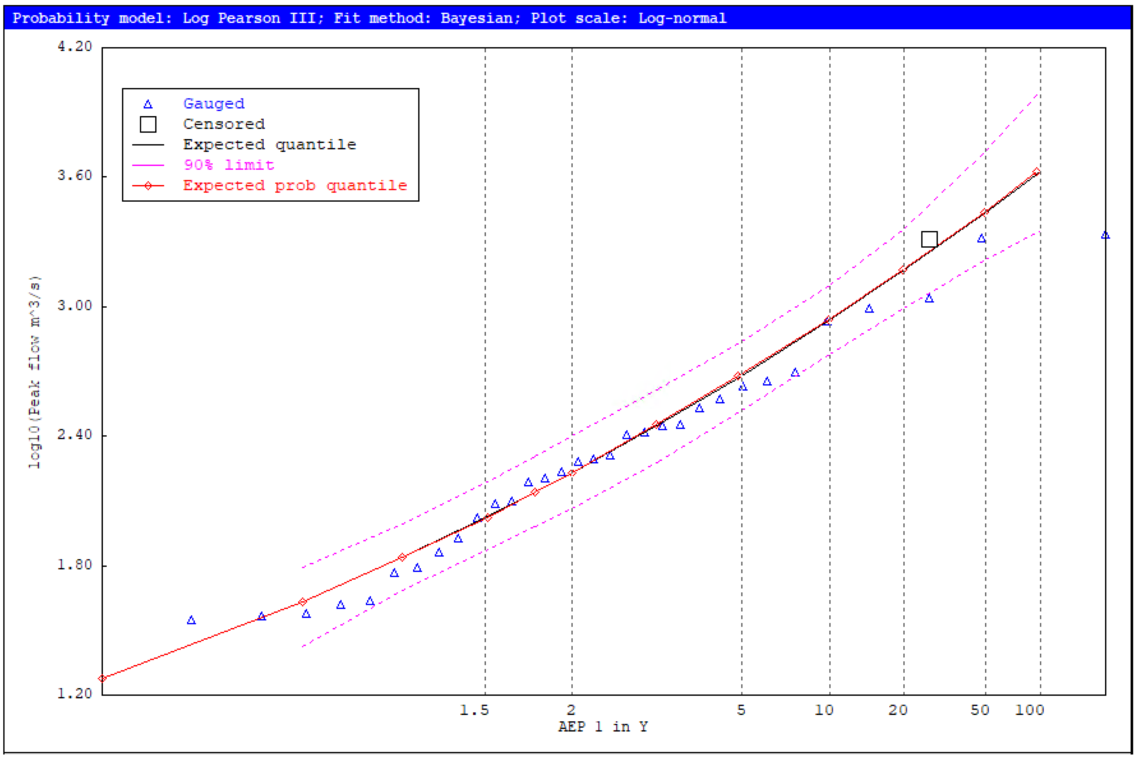


Figure C.2 – FFA (LP3) - Macquarie River at Baroona

Castlereagh River

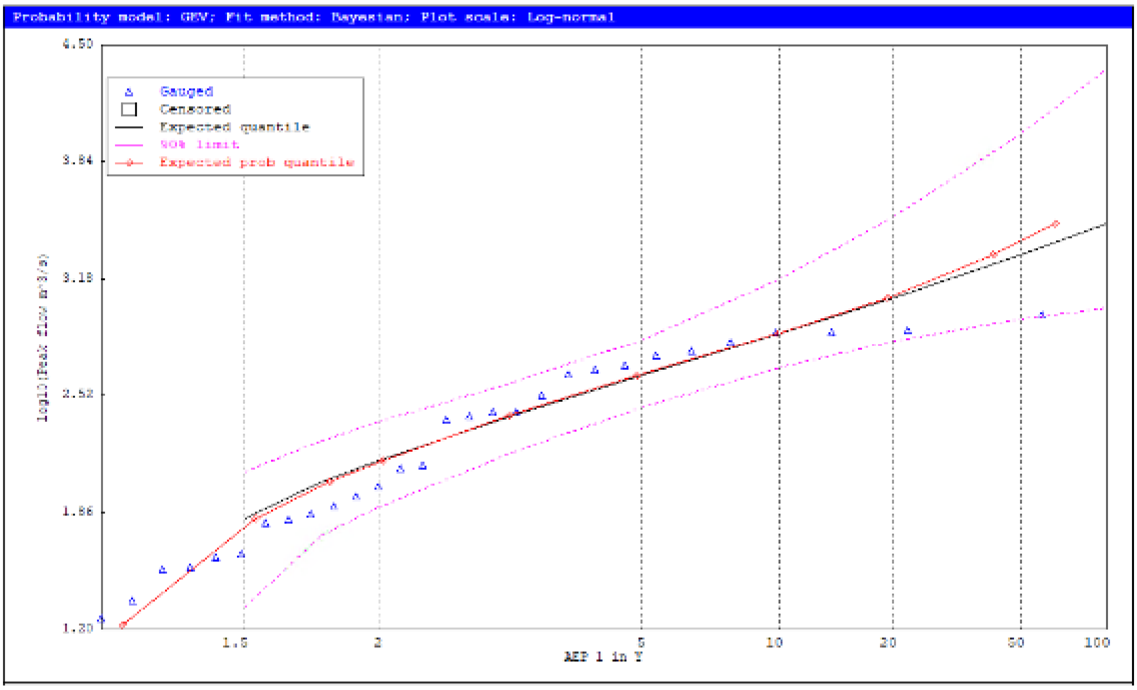


Figure C.3 – FFA (GEV) - Castlereagh River at Mendooran

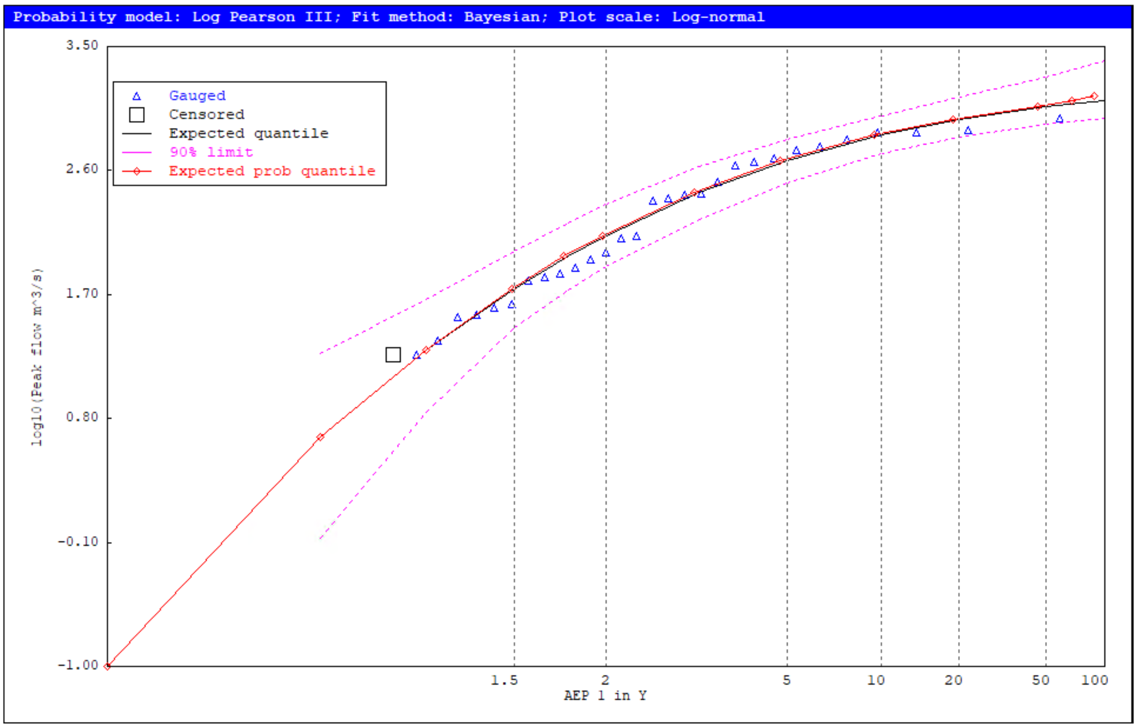


Figure C.4 – FFA (LP3 with multiple Grubbs Beck test) - Castlereagh River at Mendooran

Baradine Creek at Kienbri No. 2 (GS 419072)

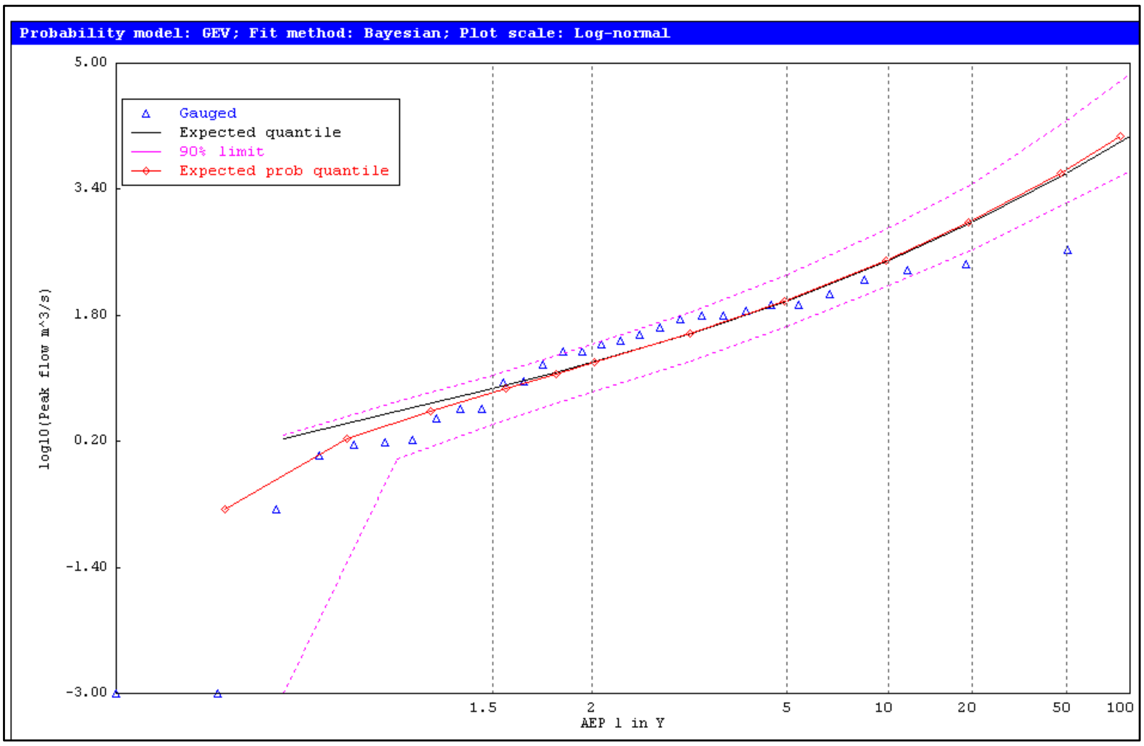


Figure C.5 – FFA (GEV with and without multiple Grubbs Beck test) - Baradine Creek

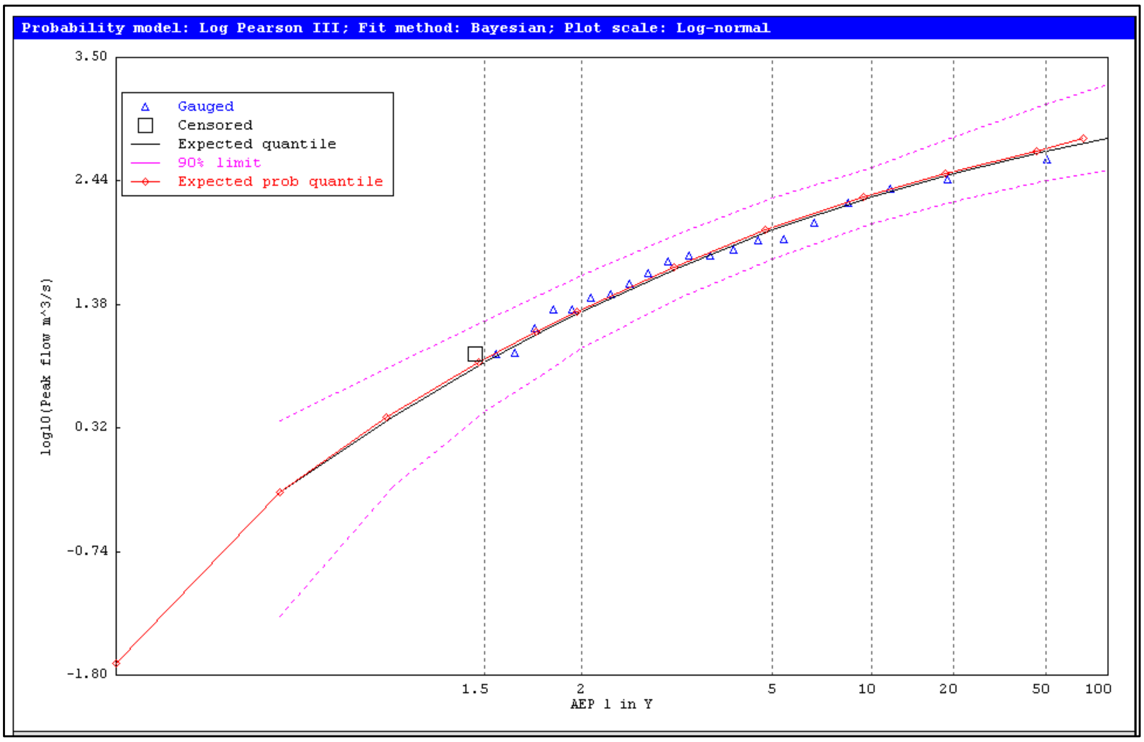


Figure C.6 – FFA (LP3 with multiple Grubbs Beck test) - Baradine Creek

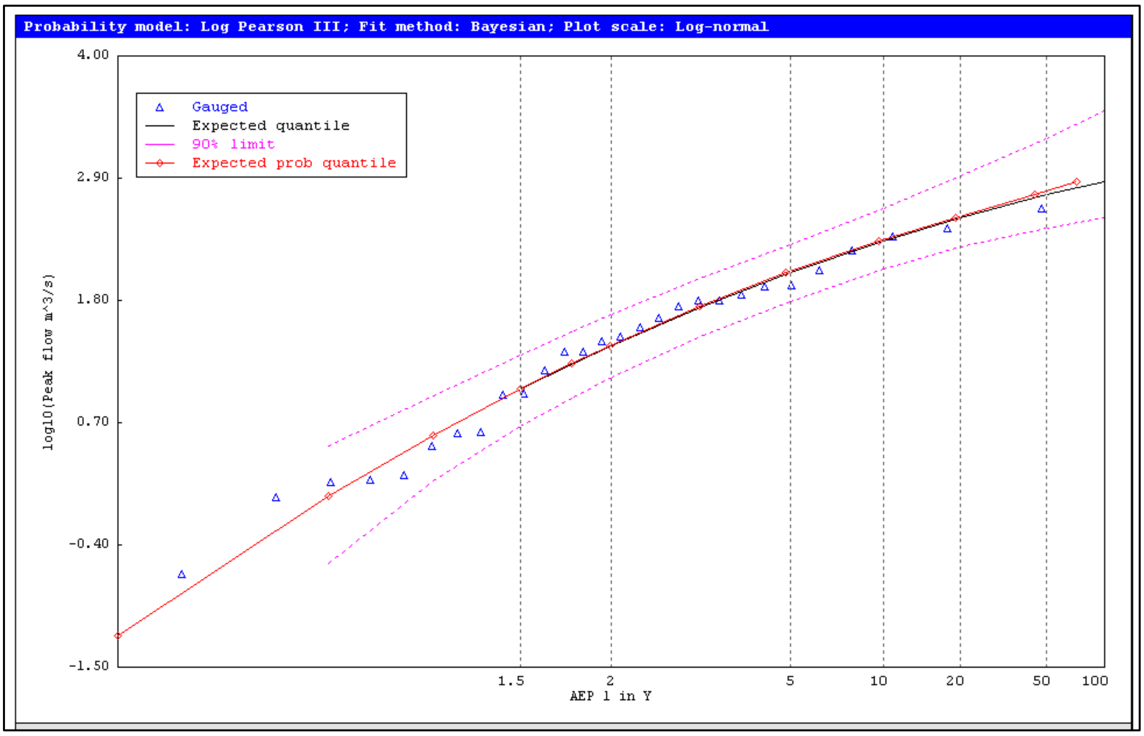


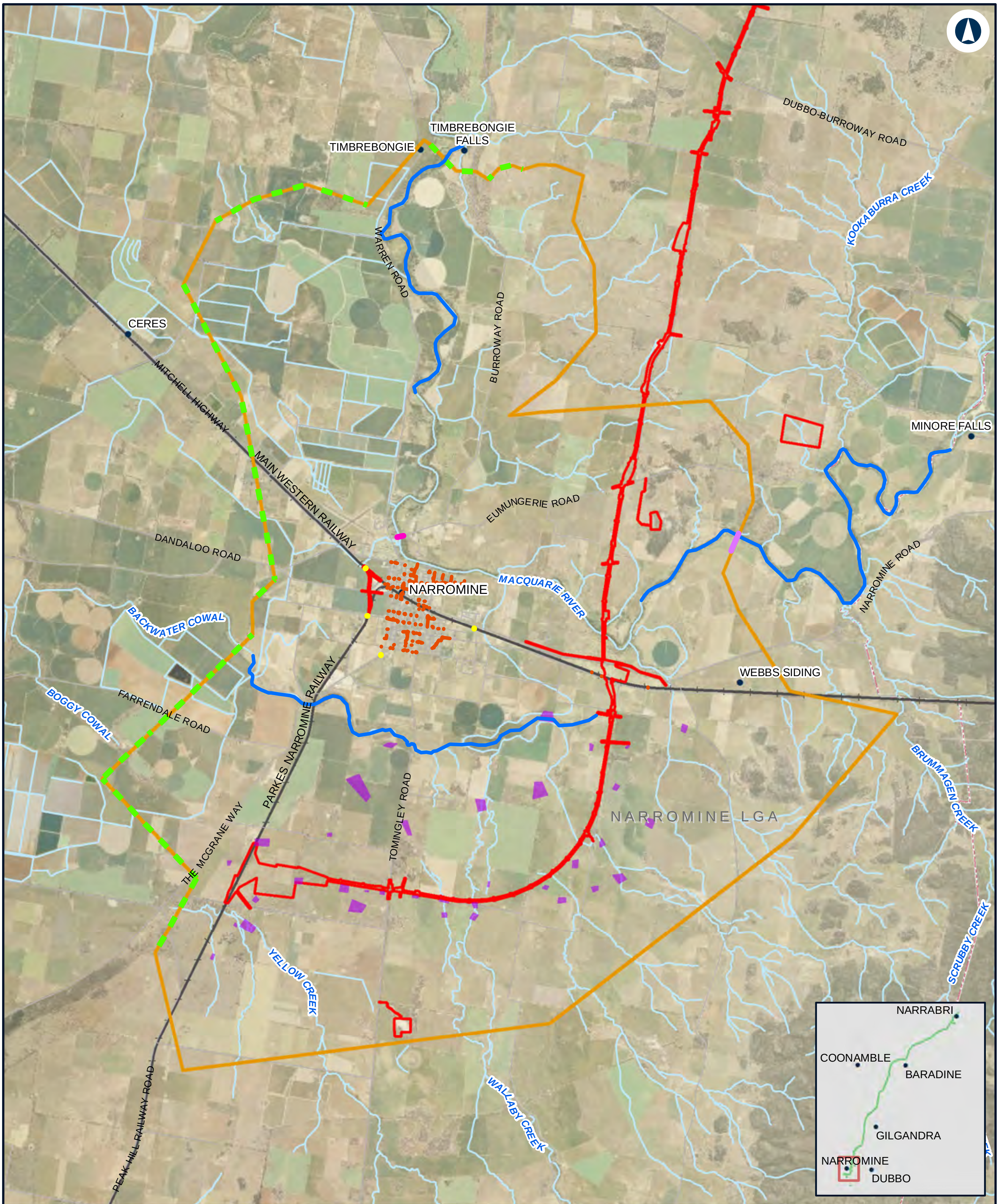
Figure C.7 – FFA (LP3 without multiple Grubbs Beck test) - Baradine Creek

TECHNICAL REPORT 03

Updated flooding and hydrology assessment

Appendix D TUFLOW model set up

NARROMINE TO NARRABRI PROJECT



NARROMINE TO NARRABRI TUFLOW model setup - Narromine Figure D.1

0 1.5 3
Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:140,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- Bridge
- Culvert
- Inflow
- Gully
- Downstream boundary
- Pipe

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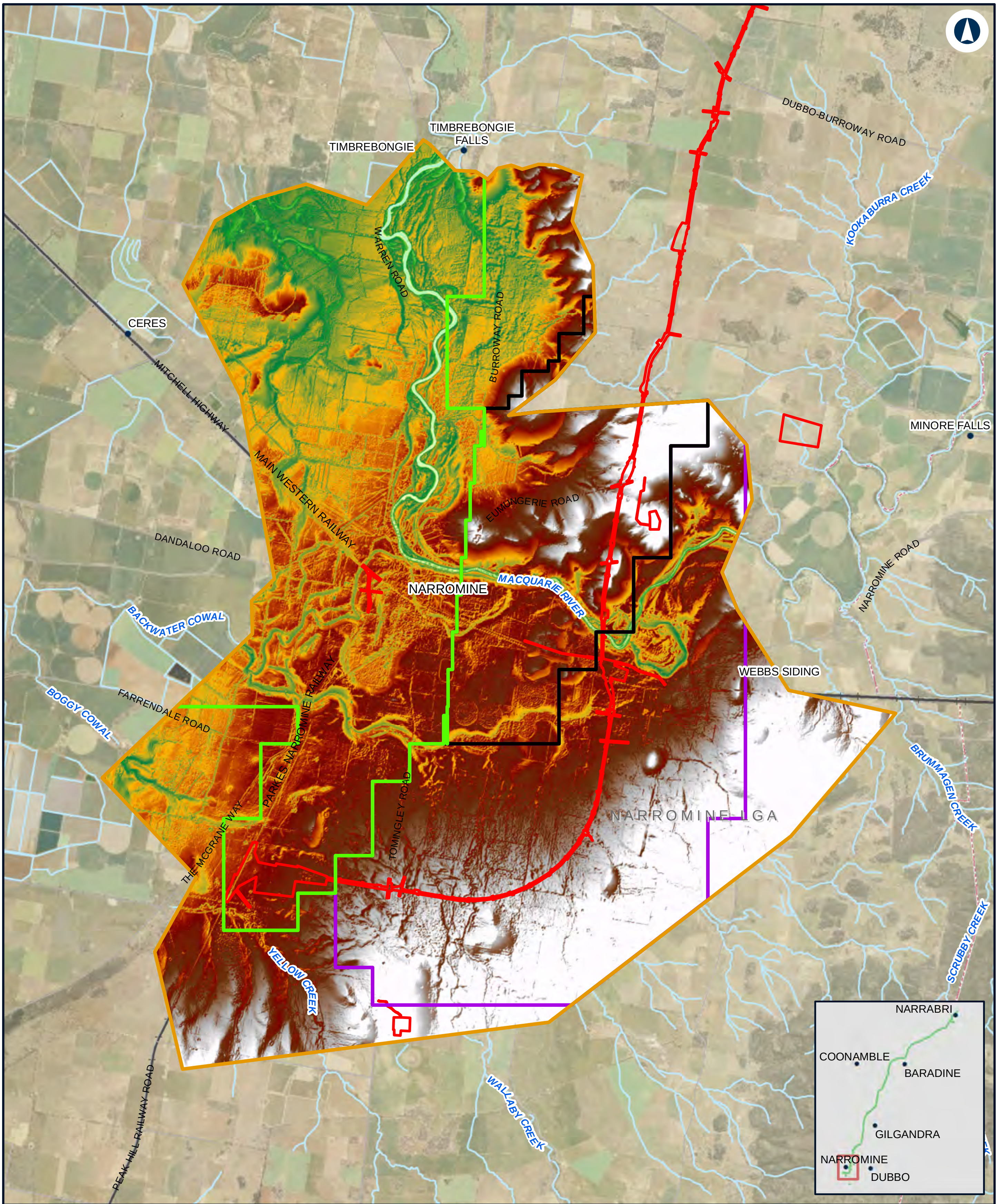

NARROMINE TO NARRABRI TUFLOW model DEM - Narromine Figure D.2

0 1.5 3
Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:140,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- ARTC DEM captured in 2018
- ARTC DEM captured in 2015
- ARTC DEM captured in 2017

Value
High : 330.095
Low : 218.748

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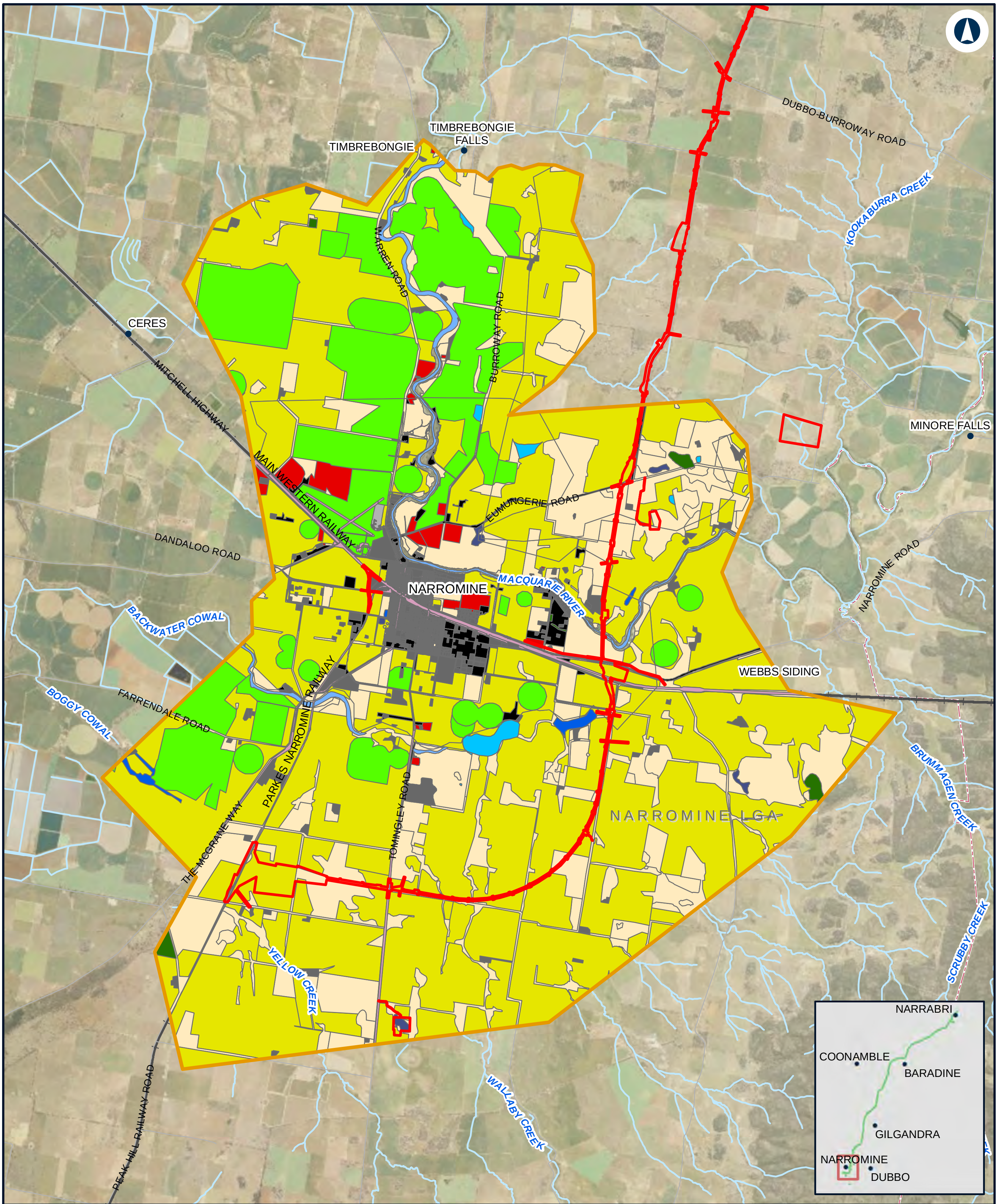
G:\22\19593\GIS\GIS_2500_N2N_v2\Maps\Deliverables_SPIR\EIS\FloodCalibration\2500_EISFLOCAL002_TUFLOWModelDEM.mxd



NARROMINE TO NARRABRI

TUFLOW material layer - Narromine

Figure D.3

0 1.5 3 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:140,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary

Landuse

- River/Creek
- Dam
- Swamp
- Grazing
- Pasture
- Non-irrigated Cropping
- Irrigated Cropping
- Horticulture
- Residential
- Developed areas
- Transport Corridor
- Forest
- Mining
- Paved Road

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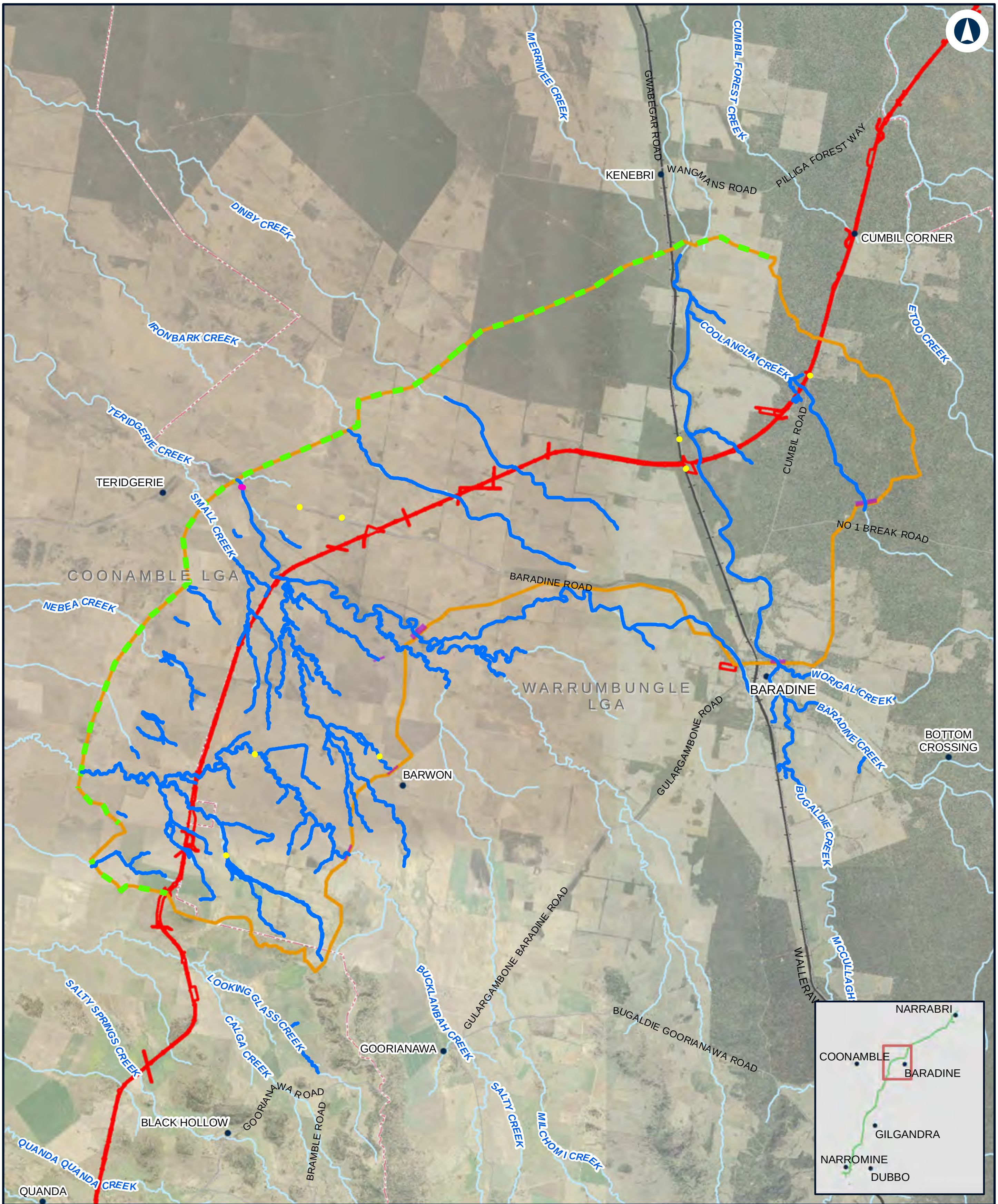

NARROMINE TO NARRABRI TUFLOW model setup - N2N7 Figure D.4

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- Bridge
- Culvert
- Inflow
- Gully
- Downstream boundary

INLAND RAIL ARTC

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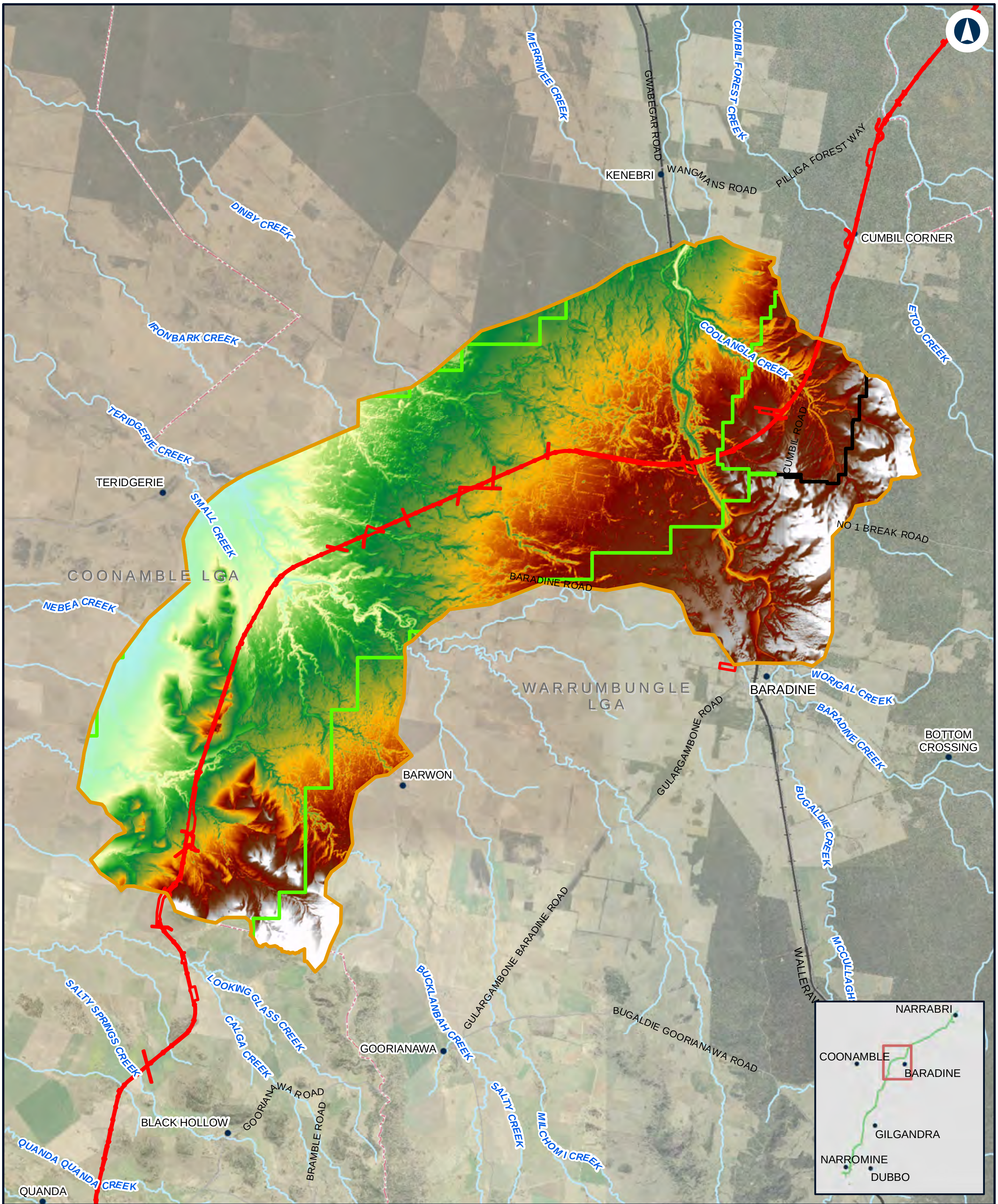
G:\22\19593\GIS\GIS_2500_N2N_v2\Maps\Deliverables_SPIR\EIS\FloodCalibration\2500_EISFLOCAL001_TUFLOWModel.mxd



NARROMINE TO NARRABRI

TUFLOW model DEM - N2N7

Figure D.5

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- ARTC DEM captured in 2015
- ARTC DEM captured in 2017

Value

High : 395.53

Low : 236.295

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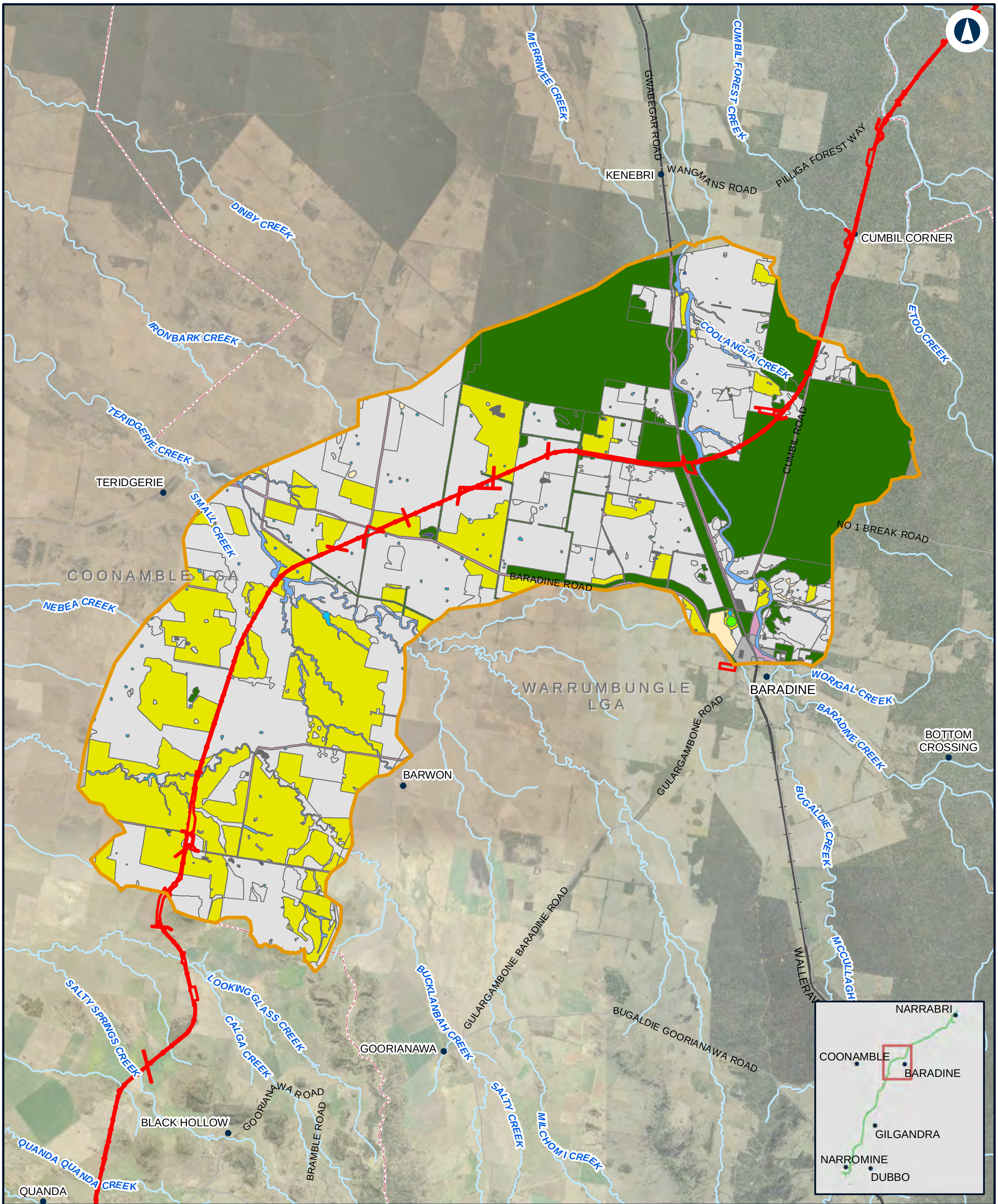

NARROMINE TO NARRABRI

TUFLOW material layer - N2N7

Figure D.6

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary

Landuse

- River/Creek
- Dam
- Swamp
- Grazing
- Pasture
- Non-irrigated Cropping
- Irrigated Cropping
- Residential
- Developed areas
- Transport Corridor
- Forest
- Mining

INLAND RAIL ARTC

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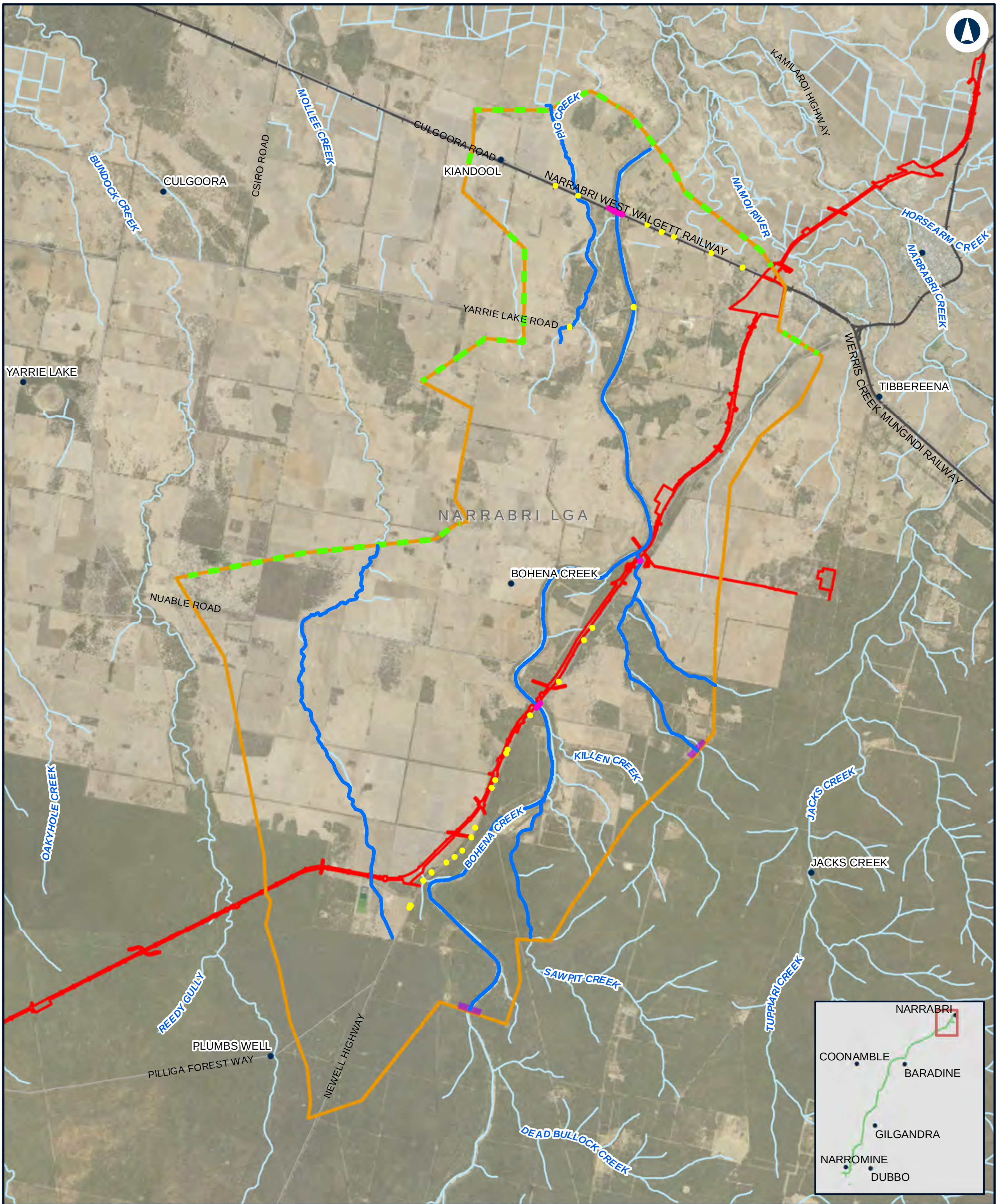

NARROMINE TO NARRABRI TUFLOW model setup - N2N1

Figure D.7

0 2 4 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:150,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- Bridge
- Culvert
- Inflow
- Gully
- Downstream boundary

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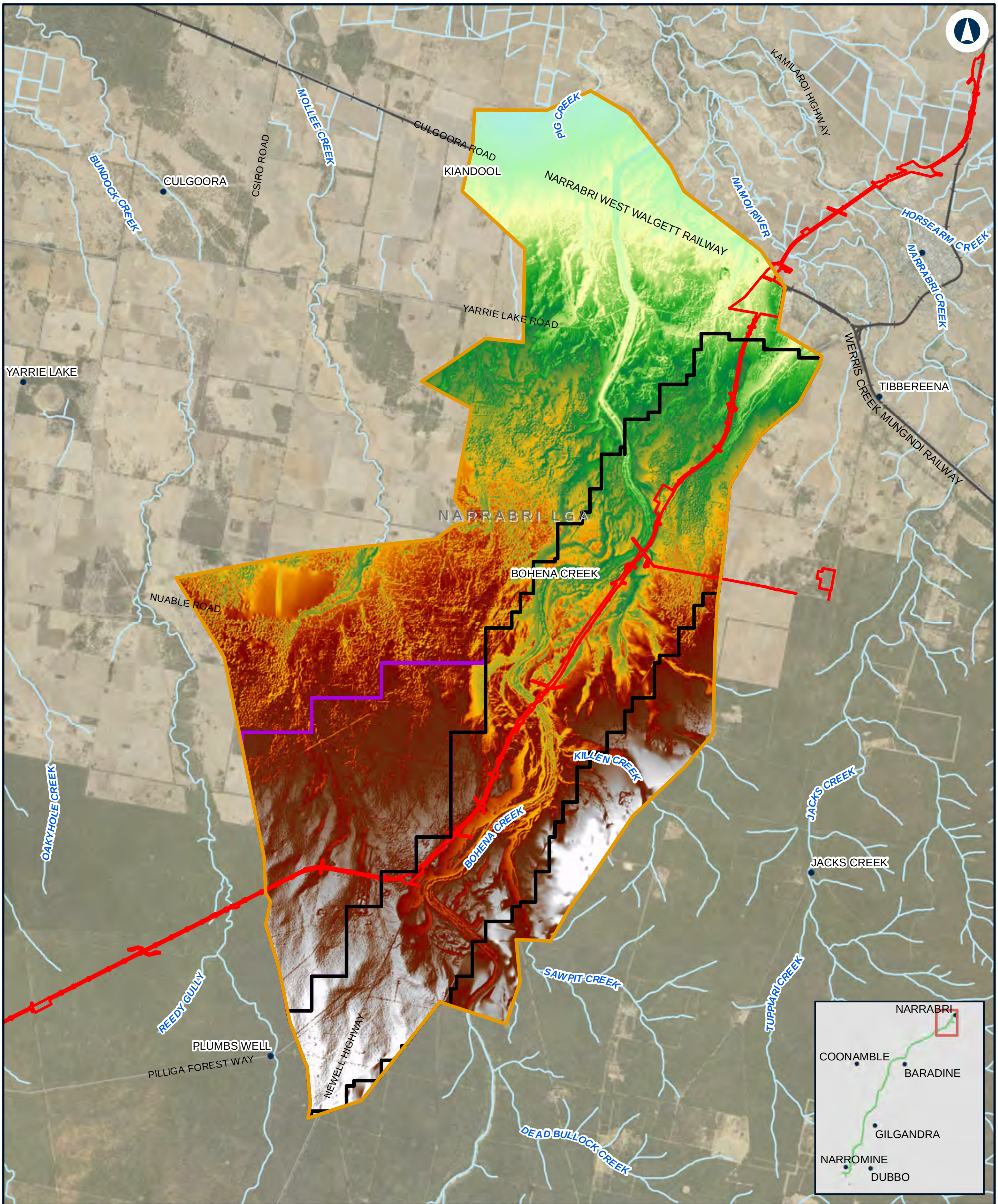

NARROMINE TO NARRABRI TUFLOW model DEM - N2N1 Figure D.8

0 2 4 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:150,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- ARTC DEM captured in 2018
- ARTC DEM captured in 2017

Value

High : 279.208

Low : 205.136

INLAND RAIL ARTC

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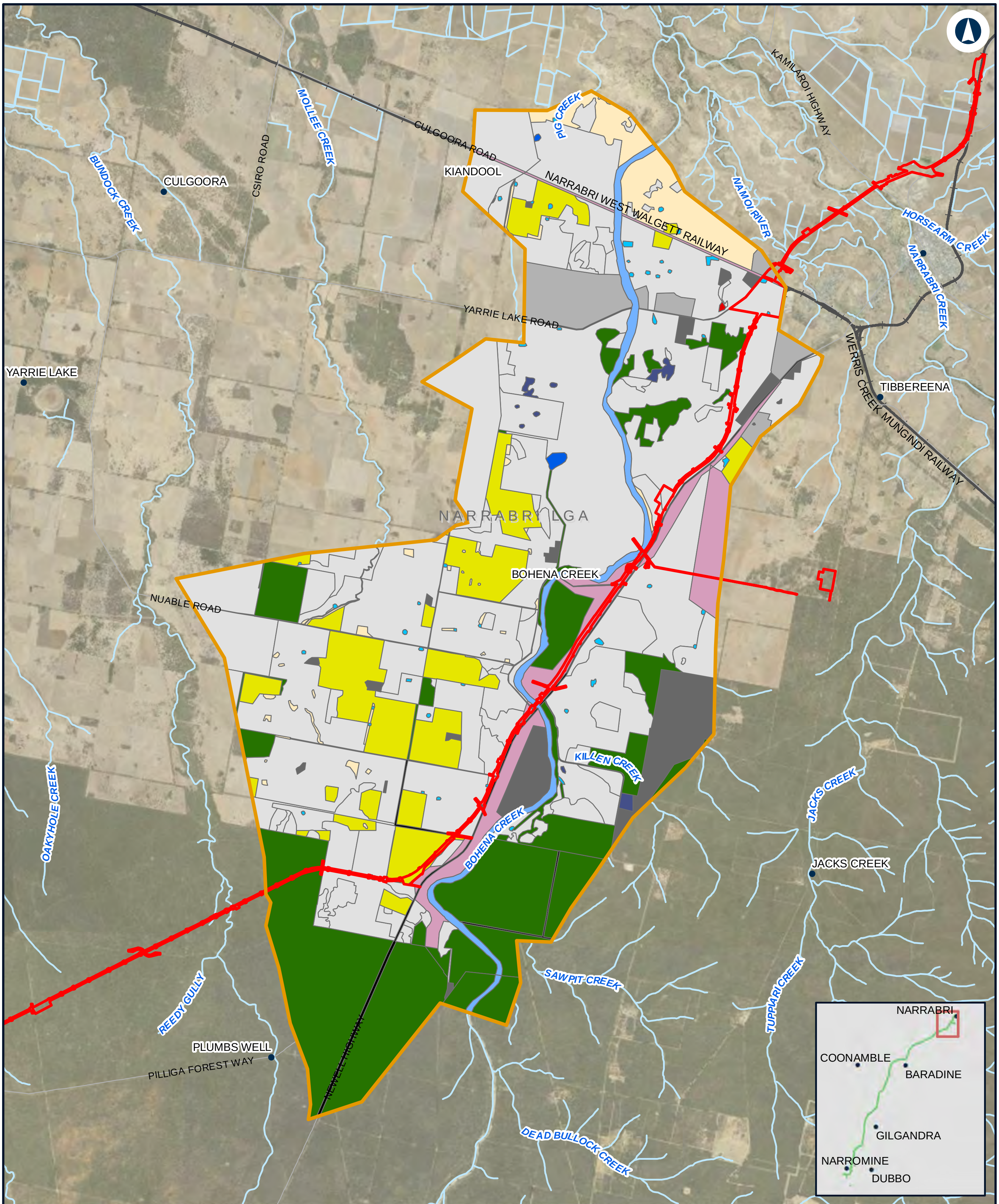

NARROMINE TO NARRABRI TUFLOW material layer - N2N1 Figure D.9

0 2 4 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:150,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary

Landuse

- River/Creek
- Dam
- Swamp
- Grazing
- Pasture
- Non-irrigated Cropping
- Horticulture
- Residential
- Developed areas
- Transport Corridor
- Forest
- Mining
- Paved Road

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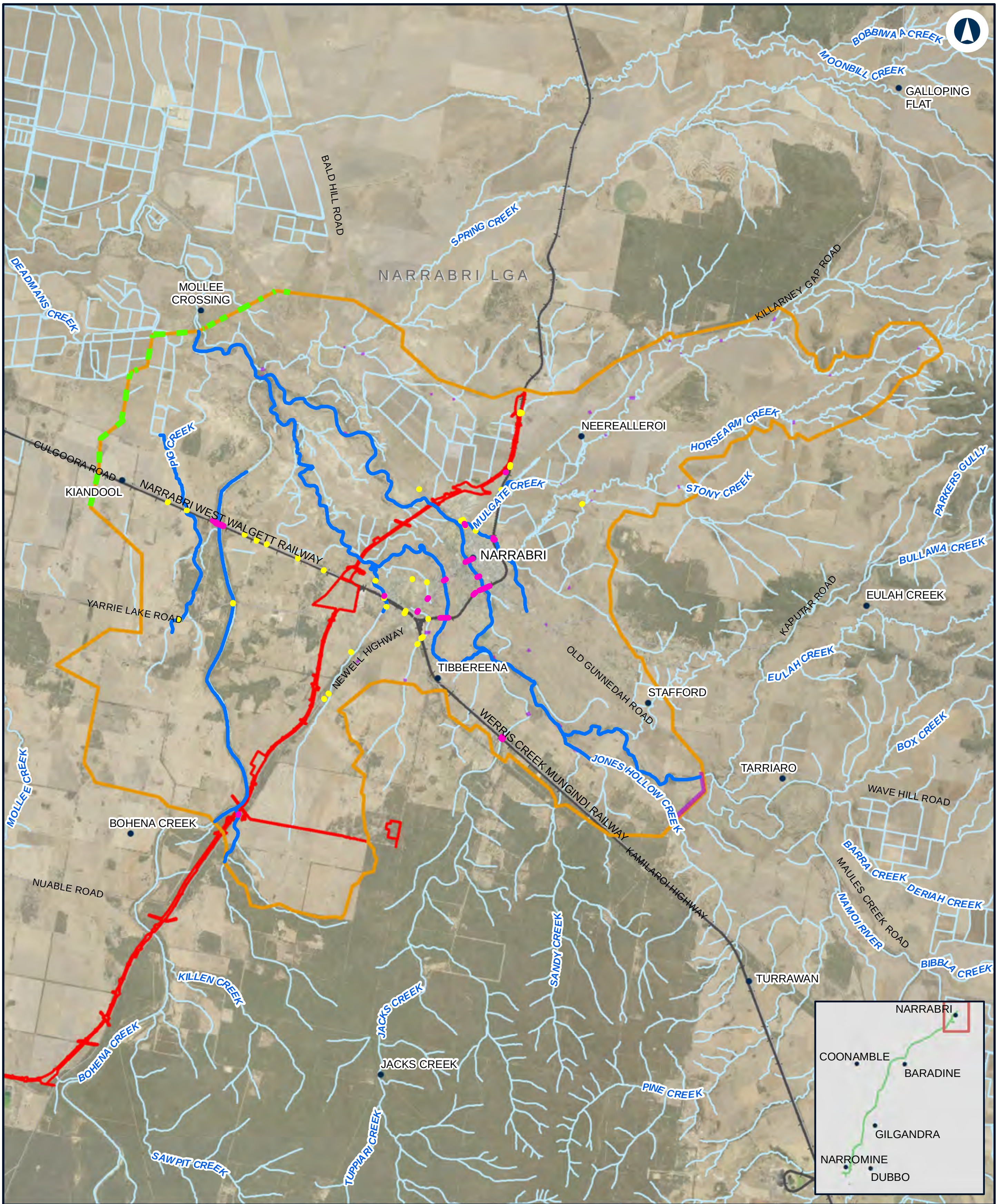

NARROMINE TO NARRABRI

TUFLOW model setup - Narrabri

Figure D.10

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:180,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- Bridge
- Culvert
- Inflow
- Gully
- Downstream boundary

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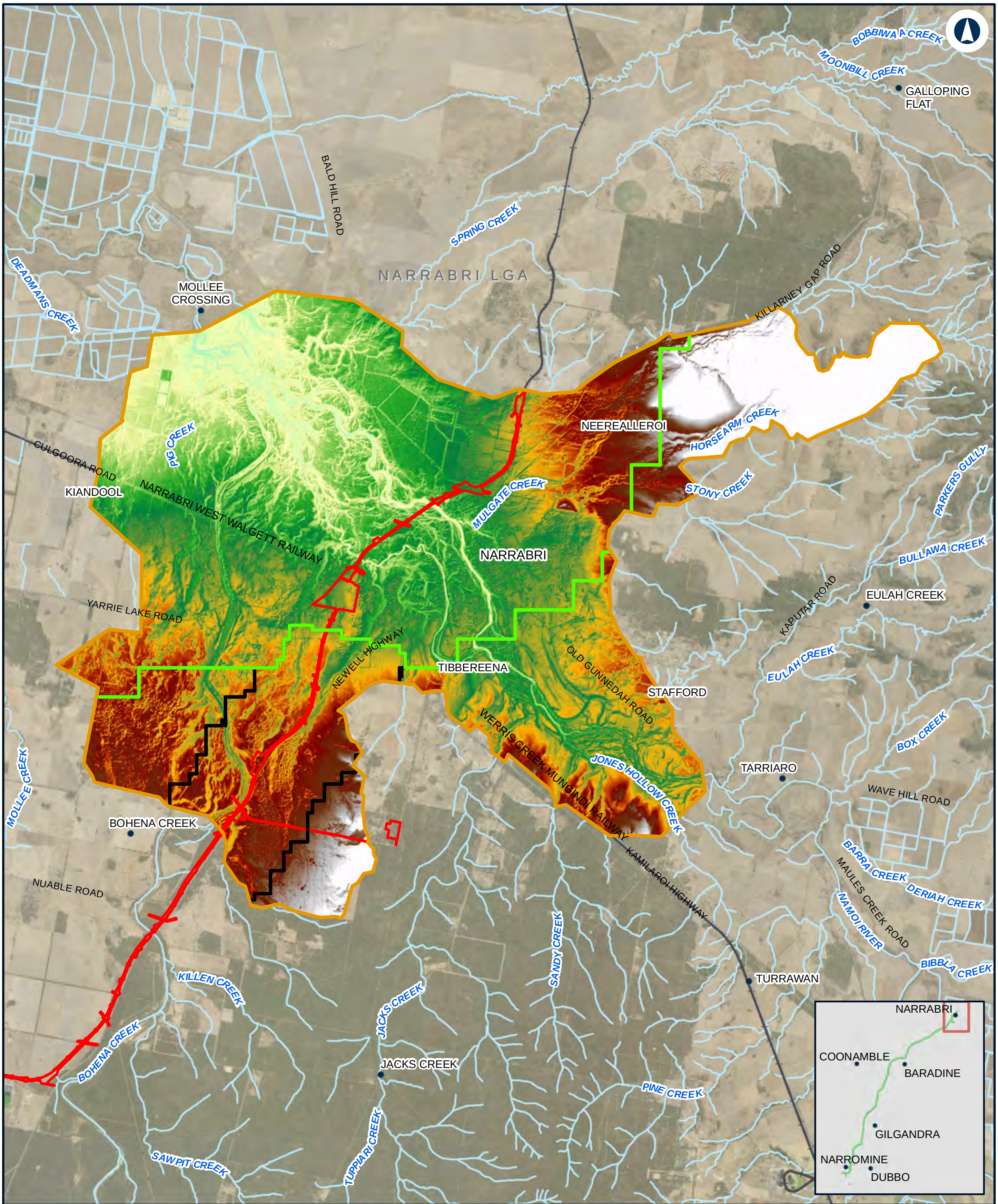

NARROMINE TO NARRABRI TUFLOW model DEM - Narrabri Figure D.11

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021 Paper: A4
Author: JacobsGHD Scale: 1:180,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- ARTC DEM captured in 2015
- ARTC DEM captured in 2017

Value
High : 326.716
Low : 197.544

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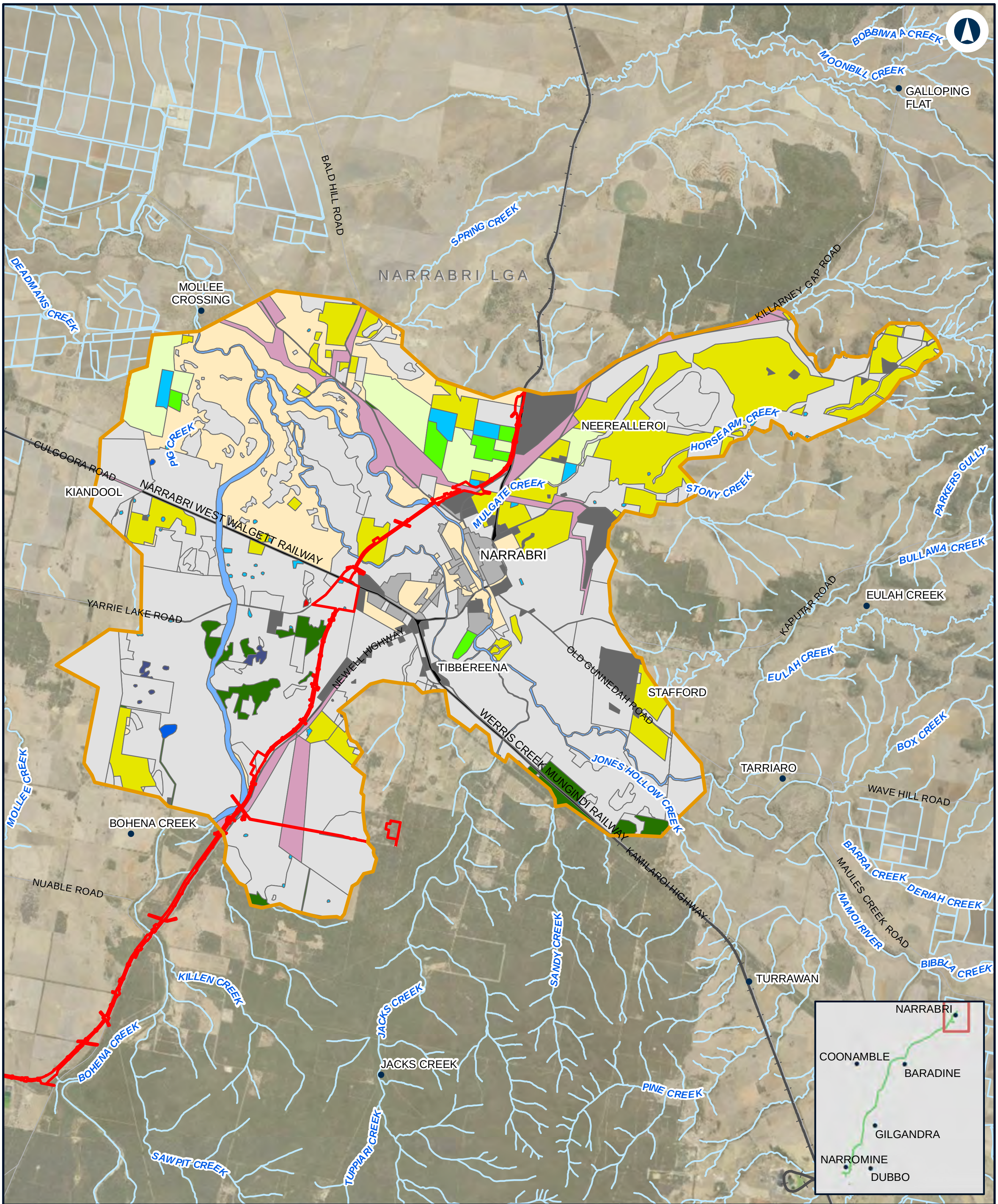

NARROMINE TO NARRABRI

TUFLOW material layer - Narrabri

Figure D.12

0 2.5 5
Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 25/06/2021
Paper: A4
Author: JacobsGHD
Scale: 1:180,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary

Landuse

- River/Creek
- Dam
- Swamp
- Grazing
- Pasture
- Non-irrigated Cropping
- Irrigated Cropping
- Cotton Cropping
- Horticulture
- Residential
- Developed areas
- Transport Corridor
- Forest
- Mining
- Paved Road

INLAND RAIL

ARTC

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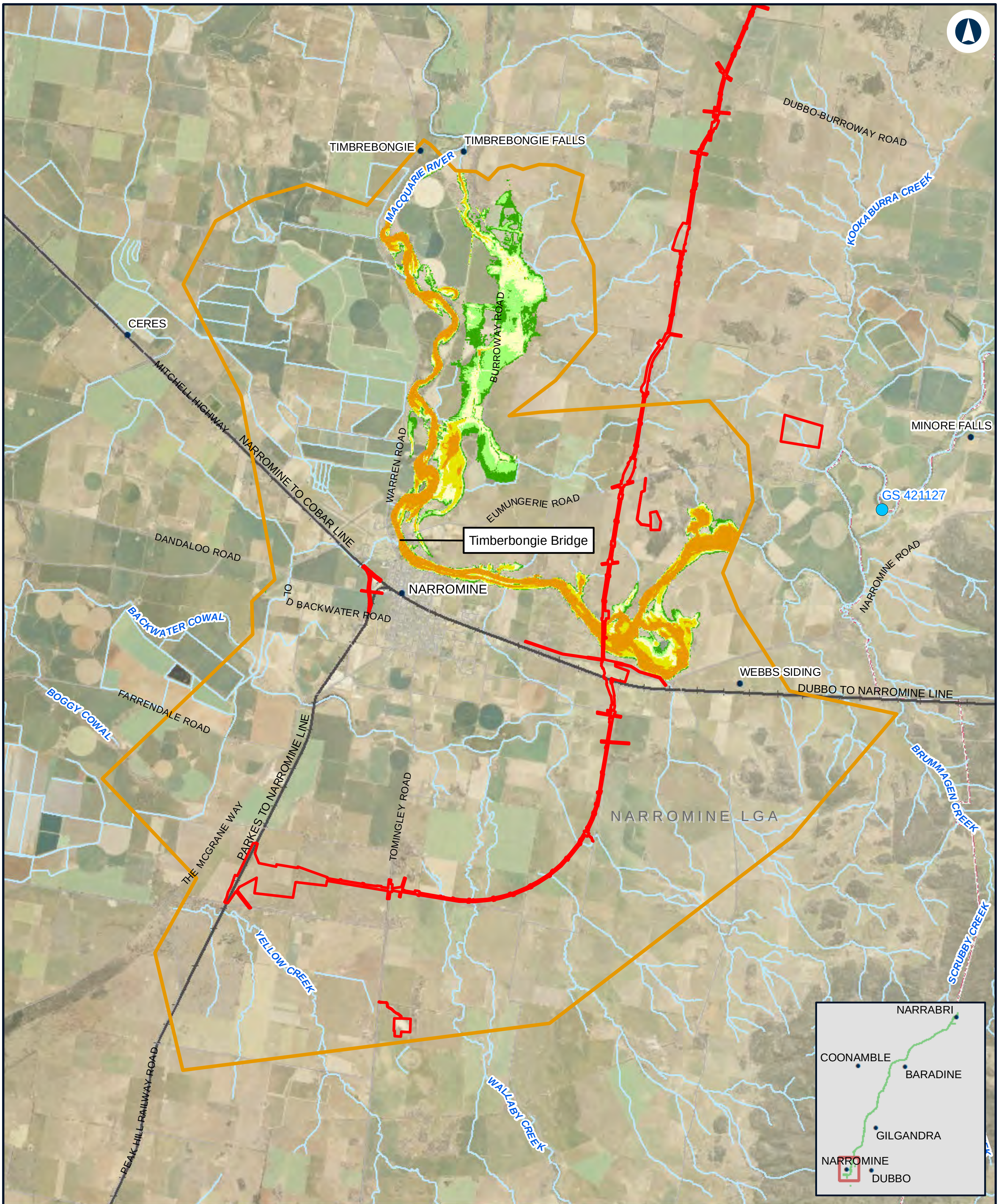
TECHNICAL REPORT 03

Updated flooding and hydrology assessment

Appendix E TUFLOW model calibration results

NARROMINE TO NARRABRI PROJECT



NARROMINE TO NARRABRI Peak flood depth for historical event 08/1990 - Narromine Figure E.1

0 1.5 3 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:140,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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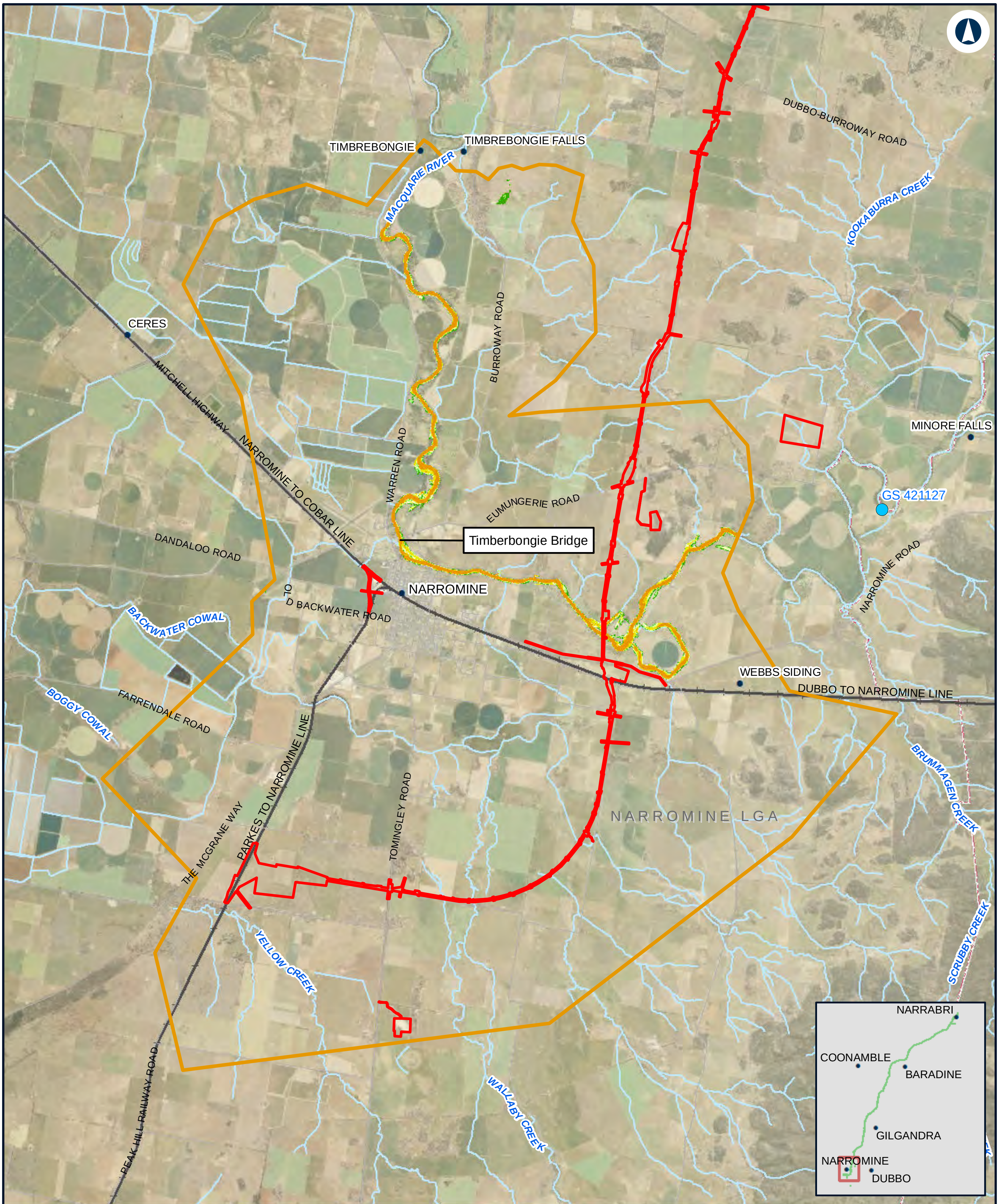
G:\22\19593\GIS\GIS_2500_N2N_v2\Maps\Deliverables_100percent\EIS\FloodCalibration\2500_EISFLOCAL017_PeakFloodDepth_081990_NFM.mxd



NARROMINE TO NARRABRI Peak flood depth for historical event 08/1998 - Narromine Figure E.2

0 1.5 3
Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:140,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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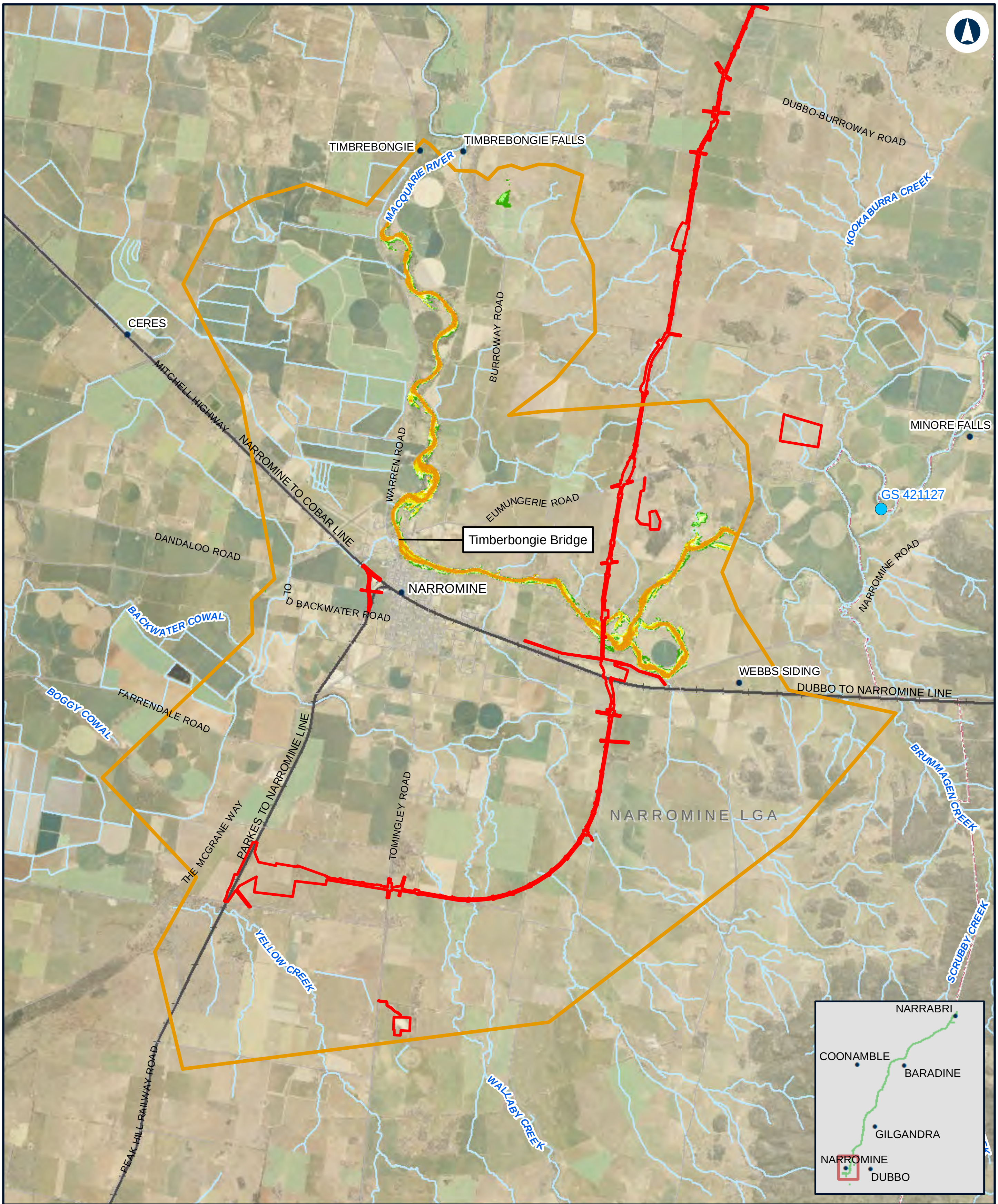

NARROMINE TO NARRABRI Peak flood depth for historical event 11/2000 - Narromine Figure E.3

0 1.5 3 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:140,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

INLAND RAIL ARTC

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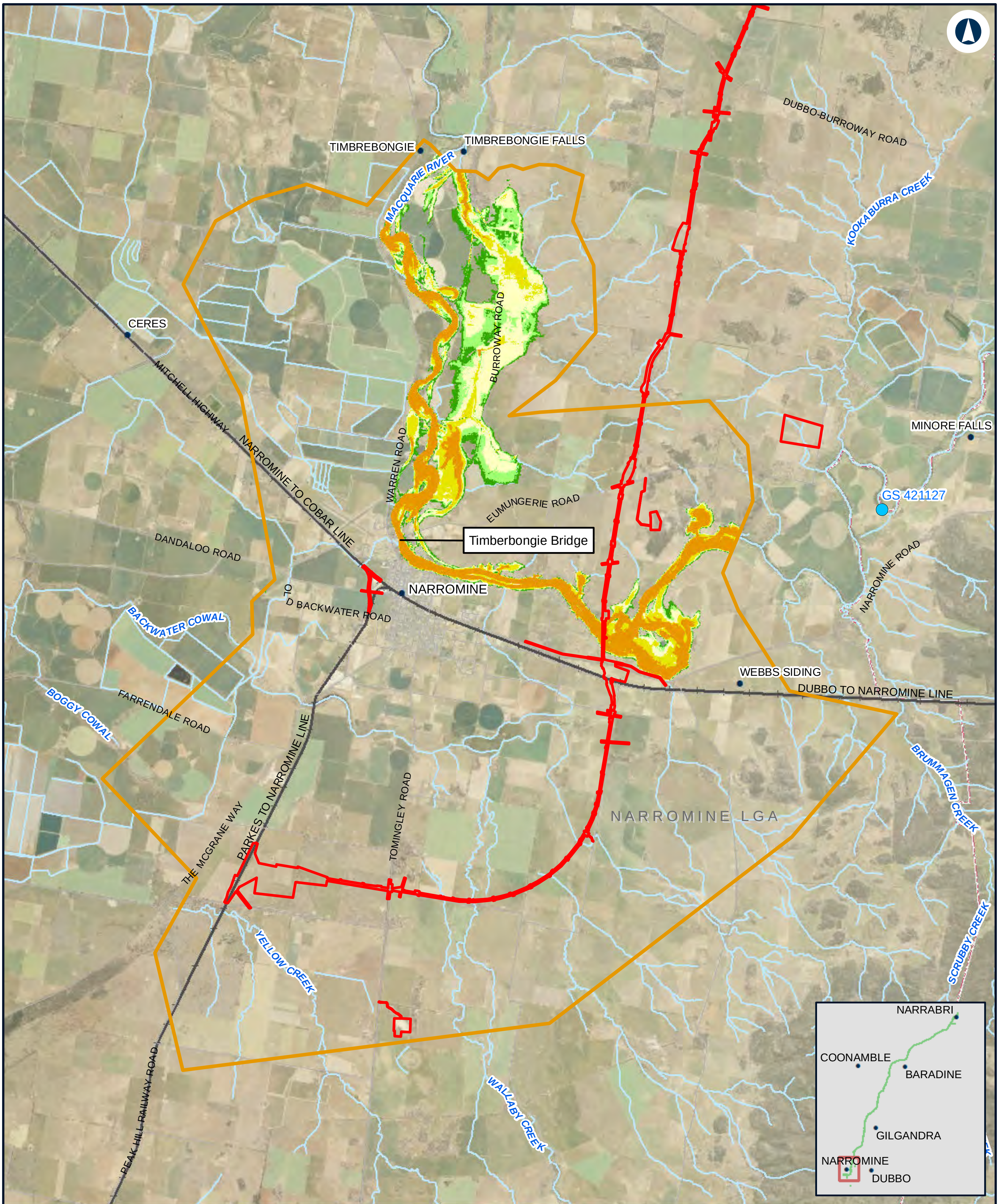

NARROMINE TO NARRABRI Peak flood depth for historical event 11/2010 - Narromine Figure E.4

0 1.5 3 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:140,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood level

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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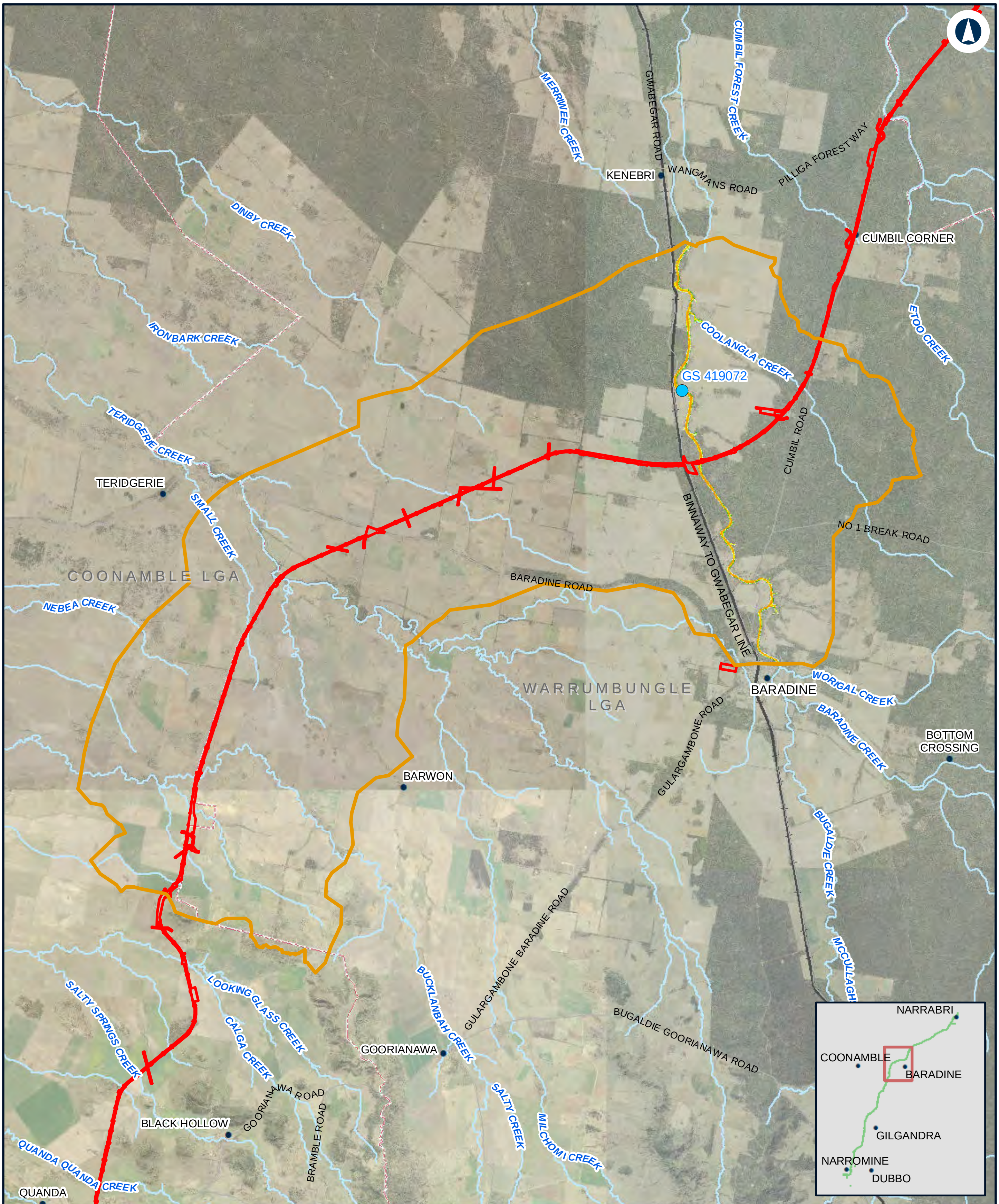

NARROMINE TO NARRABRI Peak flood depth for historical event 07/1998 - N2N7 Figure E.5

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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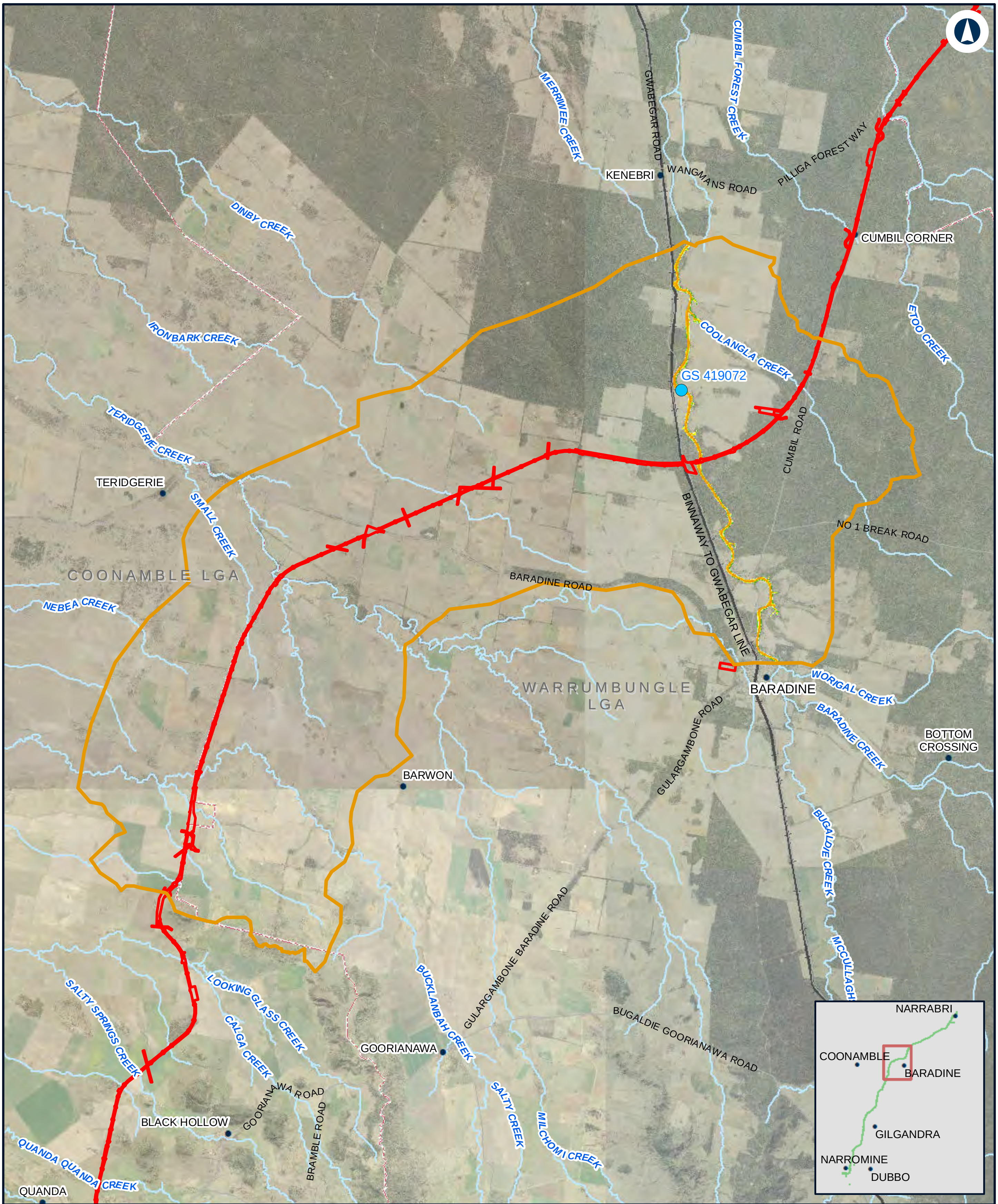

NARROMINE TO NARRABRI Peak flood depth for historical event 12/2007 - N2N7 Figure E.6

0 2.5 5
Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:200,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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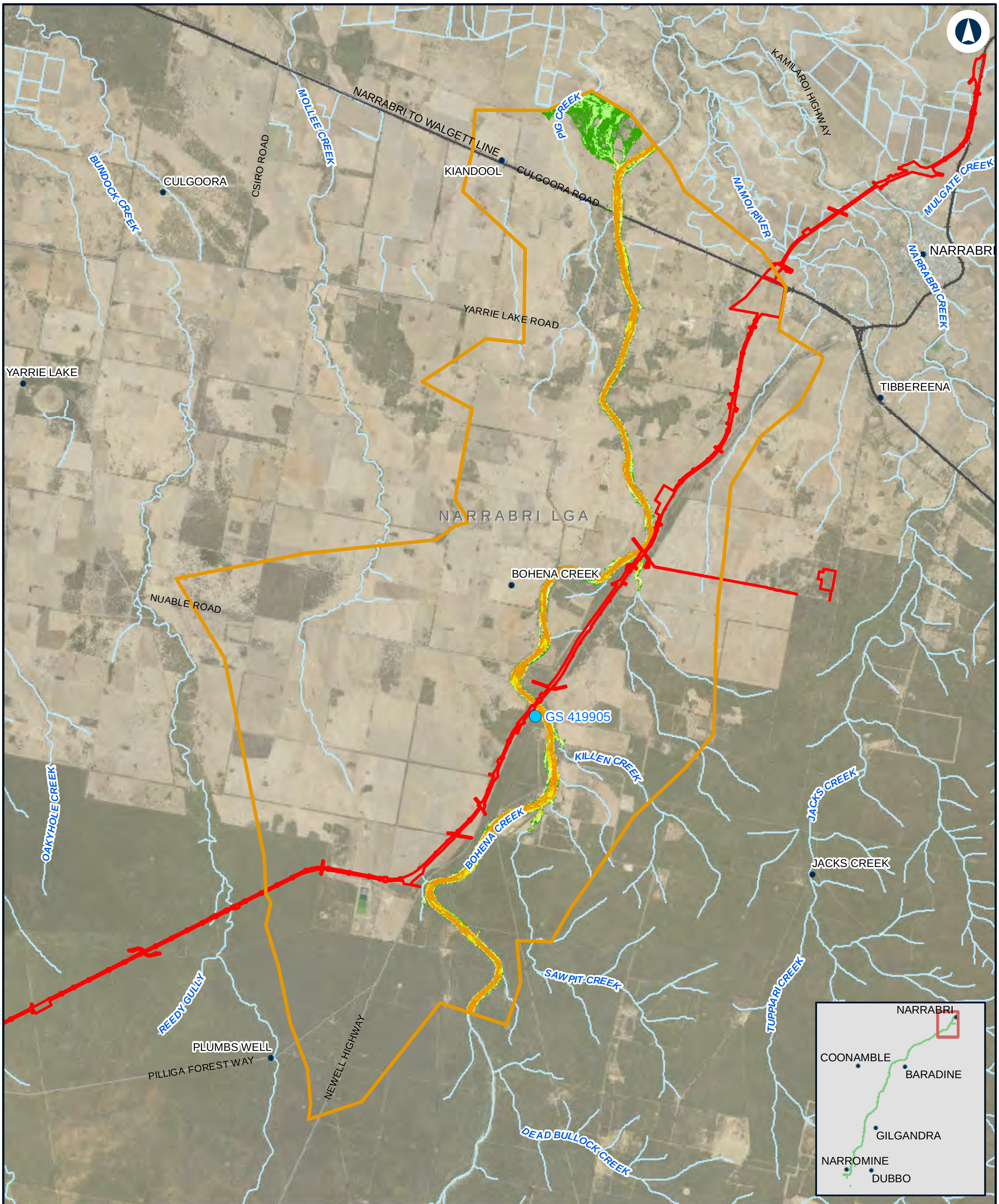

NARROMINE TO NARRABRI

Peak flood depth for historical event 07/1998 - N2N1

Figure E.7

0 2 4 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:150,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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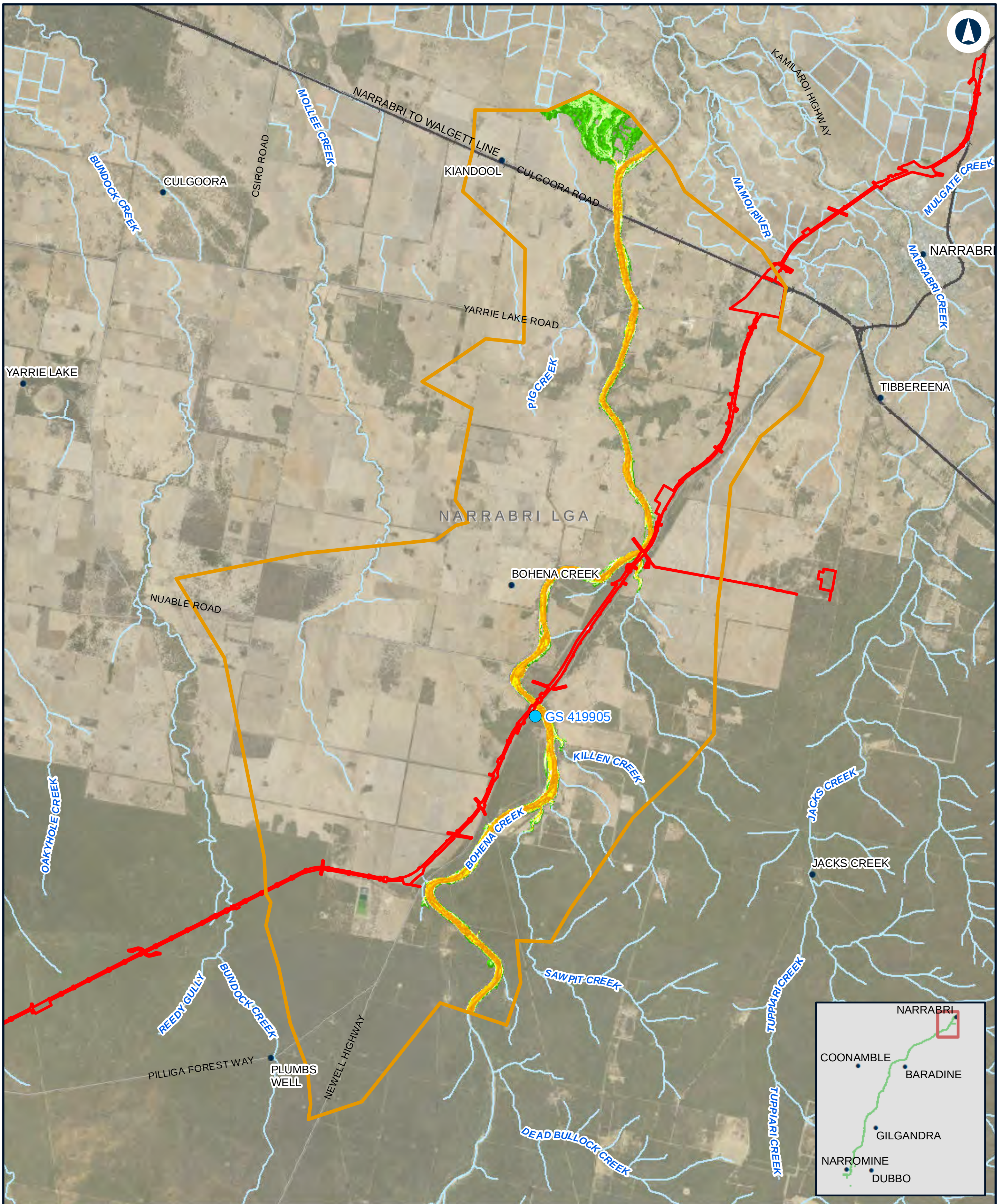

NARROMINE TO NARRABRI Peak flood depth for historical event 09/1998 - N2N1

Figure E.8

0 2 4 Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:150,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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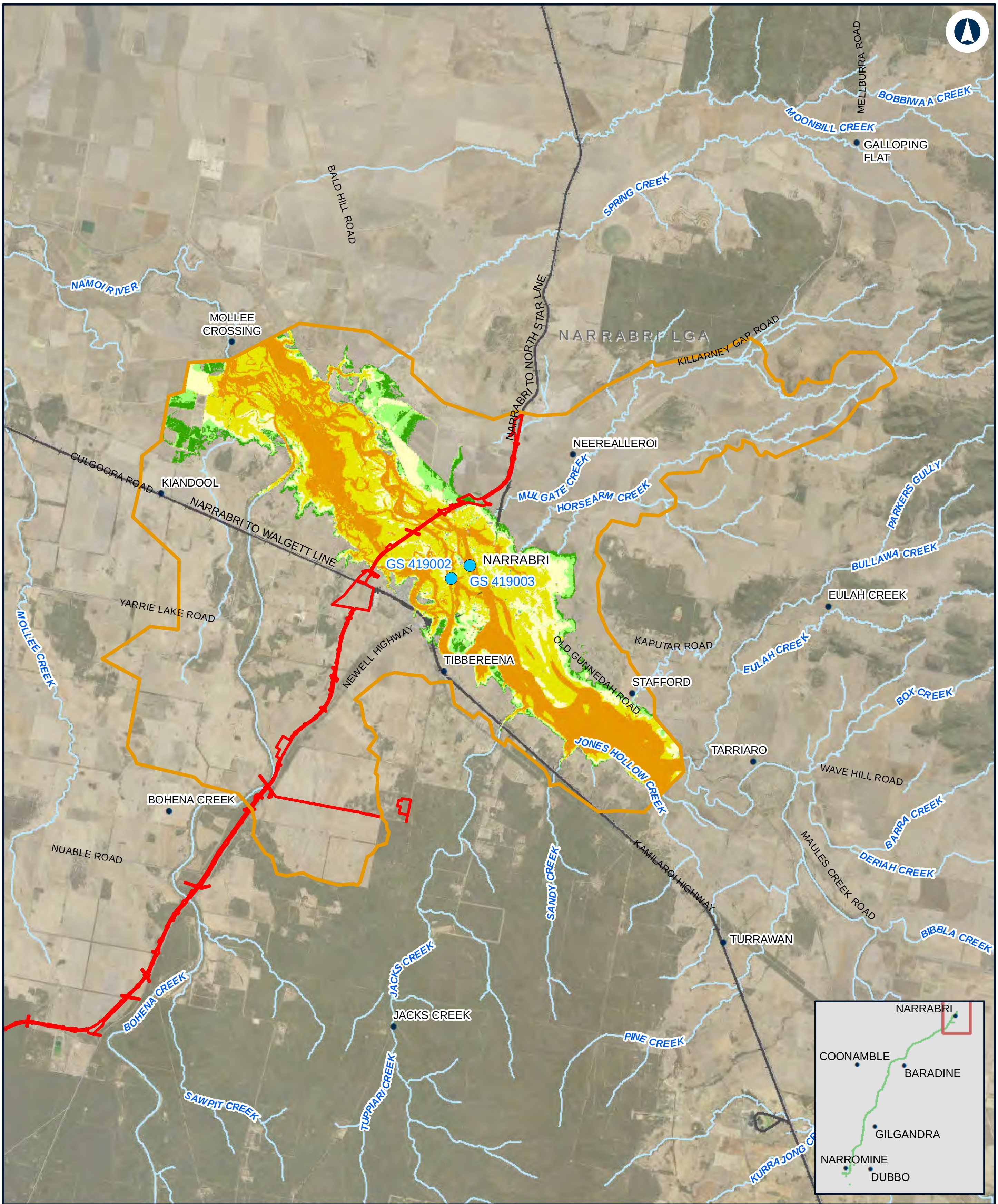

NARROMINE TO NARRABRI Peak flood depth for historical event 02/1955 - Narrabri Figure E.9

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:200,890
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

The proposal site
TUFLOW model boundary
> 2.0m
Stream gauge

Flood depth

0.0m - 0.25m
0.25m - 0.5m
0.5m - 1.0m
1.0m - 2.0m

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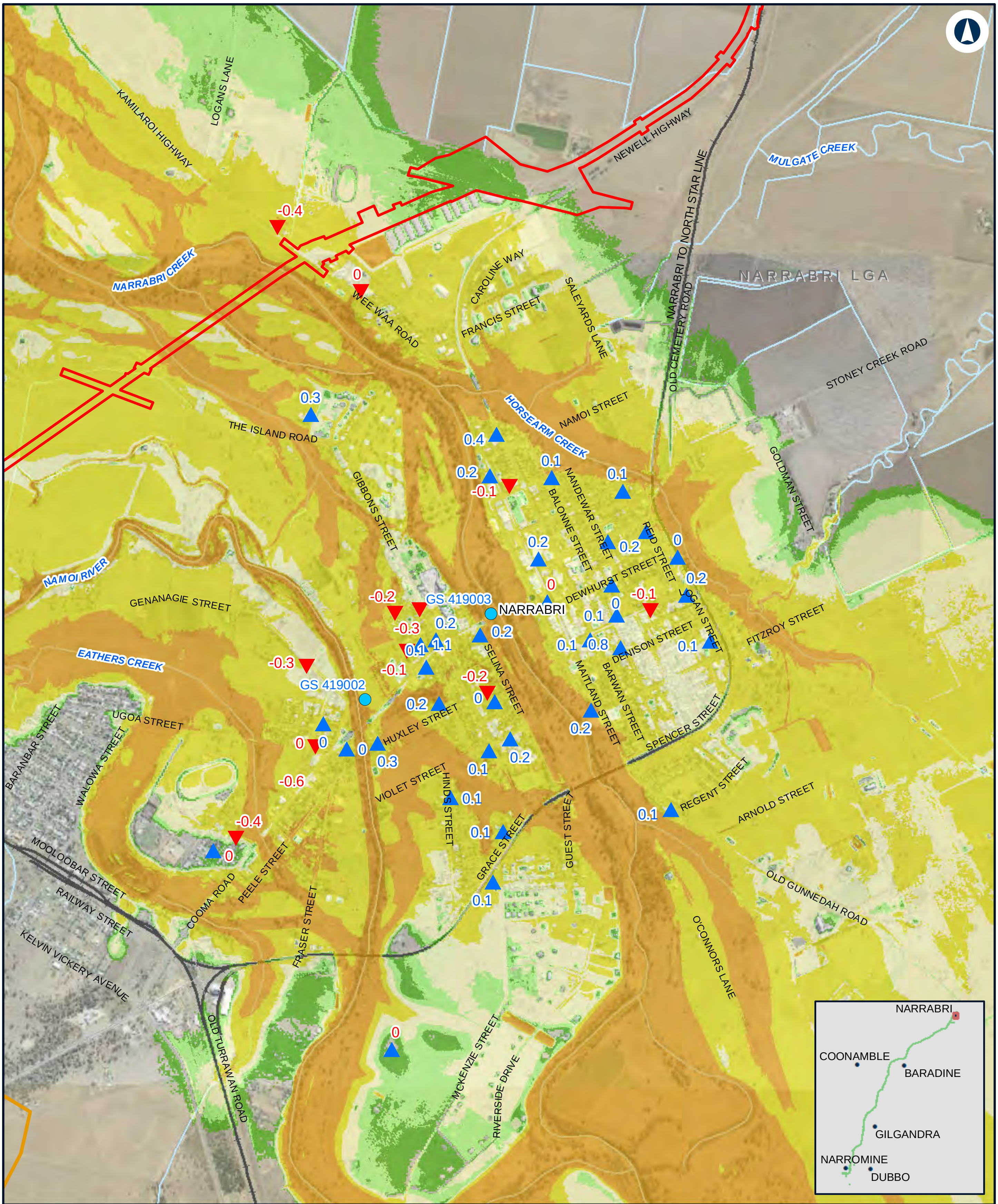

NARROMINE TO NARRABRI

Flood level comparison for historical event 02/1955 - Narrabri

Figure E.10

0 0.4 0.8 Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 23/06/2020 Paper: A4

Author: JacobsGHD Scale: 1:30,000

Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m
- > 2.0m

Recorded flood level

- Predicted flood level lower than recorded
- Predicted flood level higher than recorded
- Stream gauge

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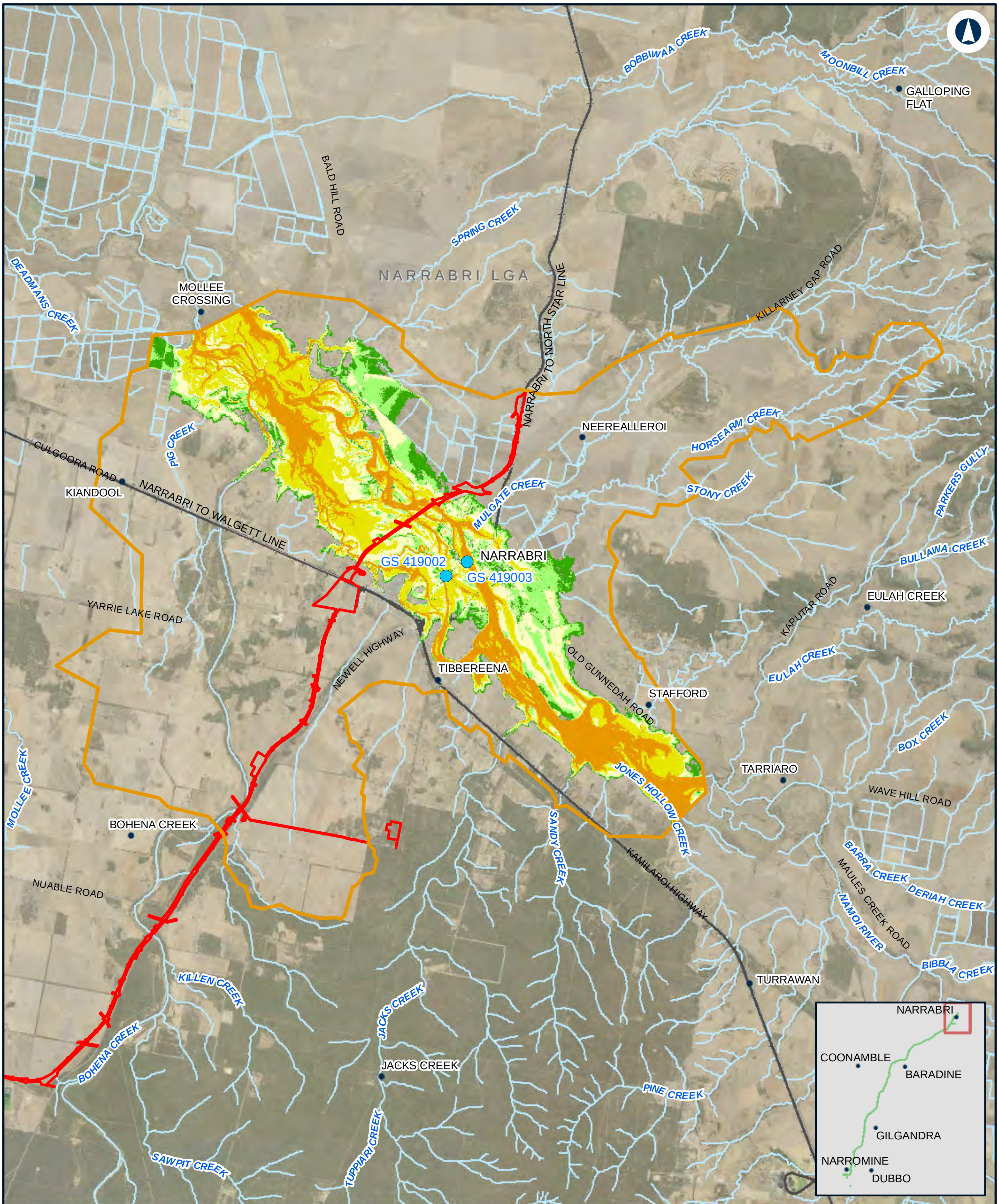

NARROMINE TO NARRABRI Peak flood depth for historical event 02/1971 - Narrabri Figure E.11

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:180,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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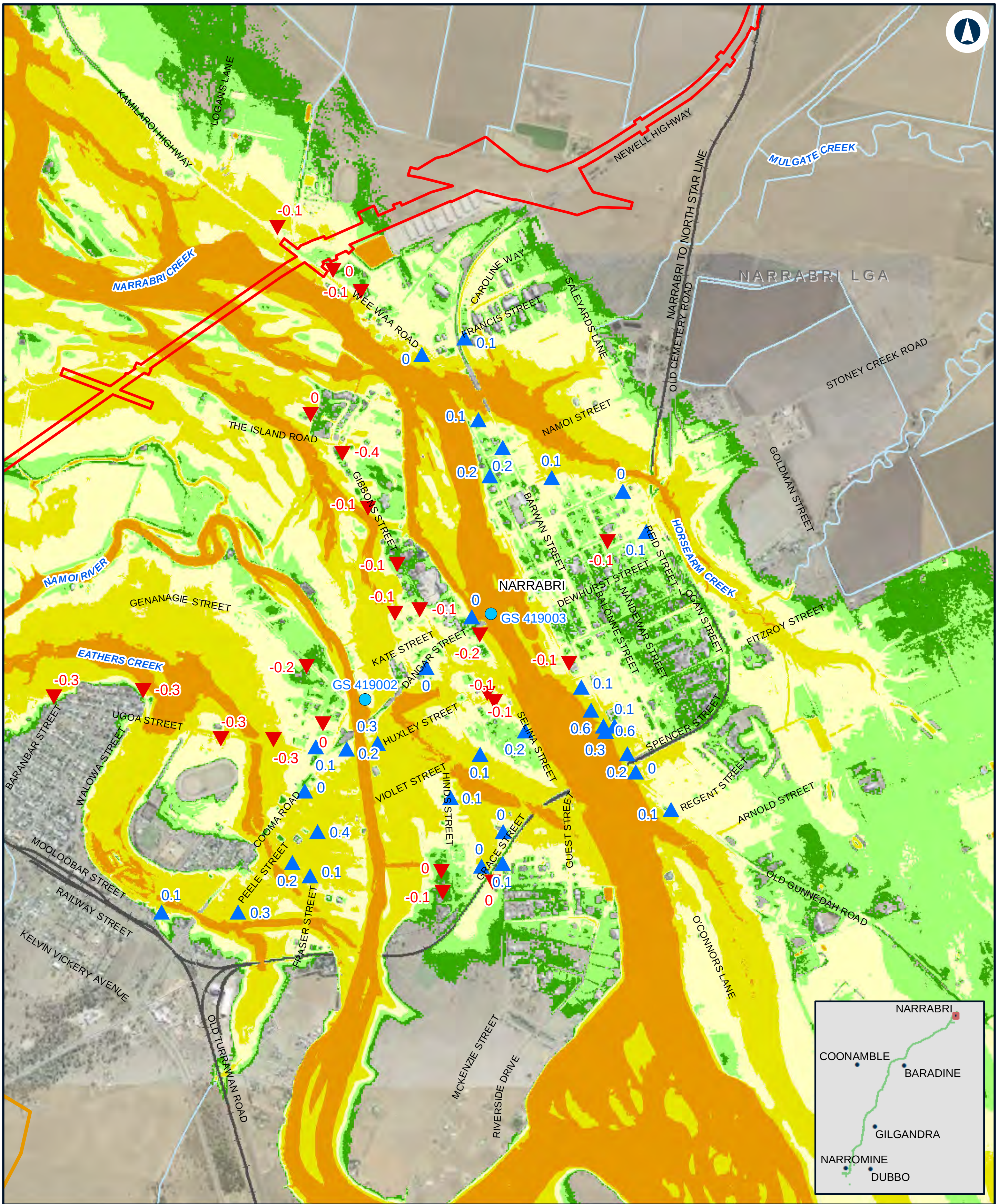

NARROMINE TO NARRABRI Flood level comparison for historical event 02/1971 - Narrabri

Figure E.12

0 0.4 0.8 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:30,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m
- > 2.0m

Recorded flood level

- Predicted flood level lower than Recorded
- Predicted flood level higher than Recorded
- Stream gauge

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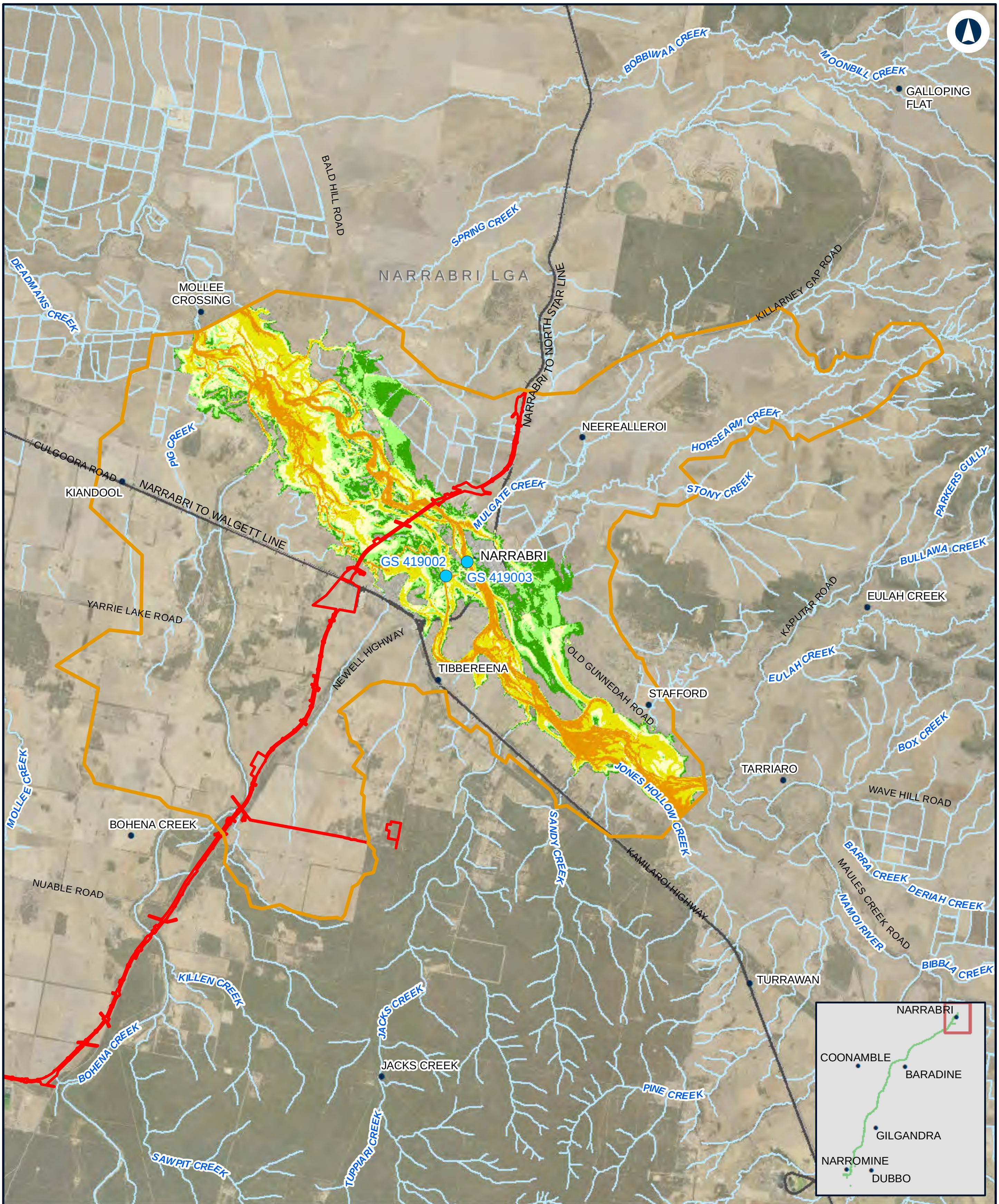

NARROMINE TO NARRABRI

Peak flood depth for historical event 07/1998 - Narrabri

Figure E.13

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:180,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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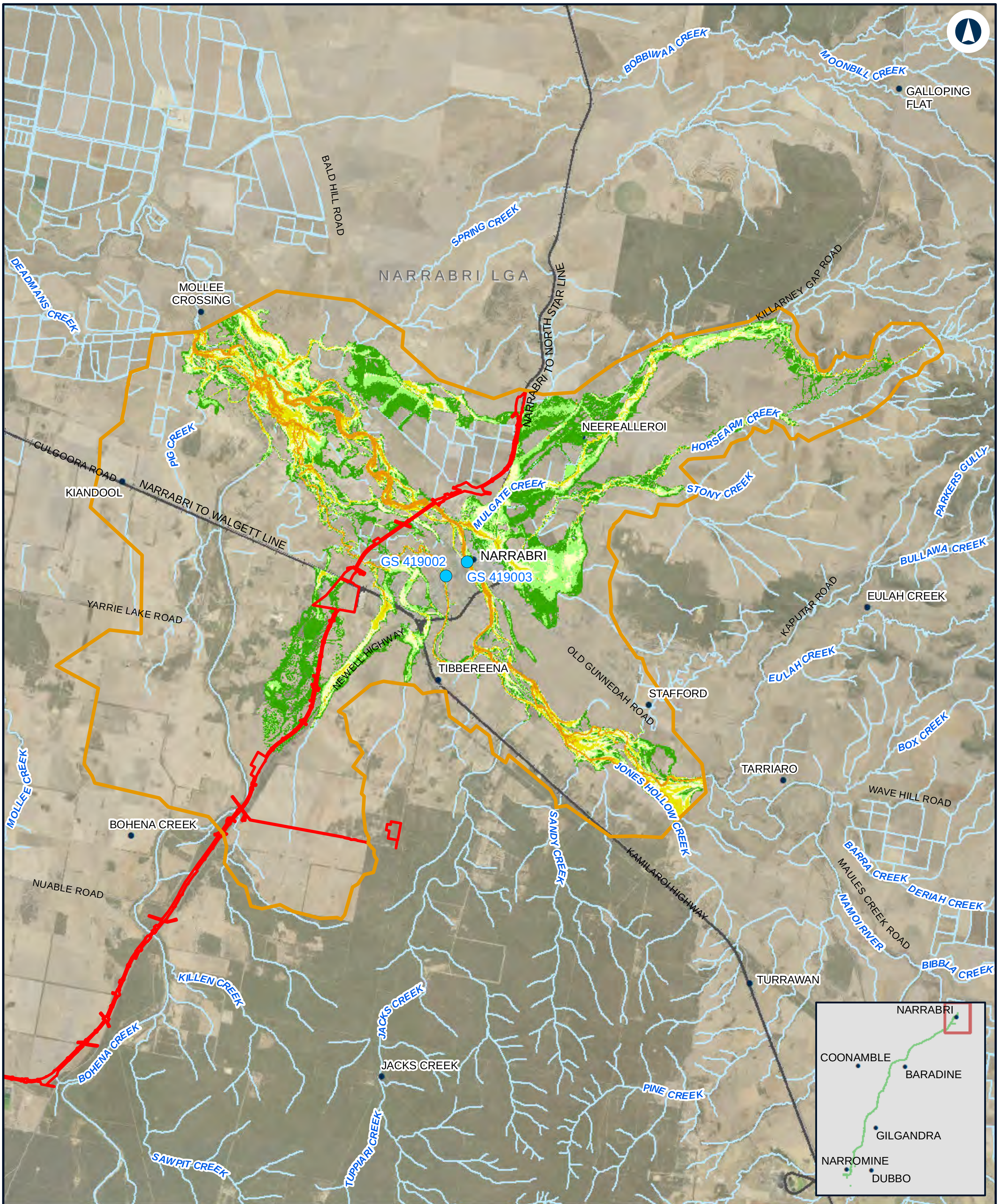

NARROMINE TO NARRABRI

Peak flood depth for historical event 12/2004 - Narrabri

Figure E.14

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:180,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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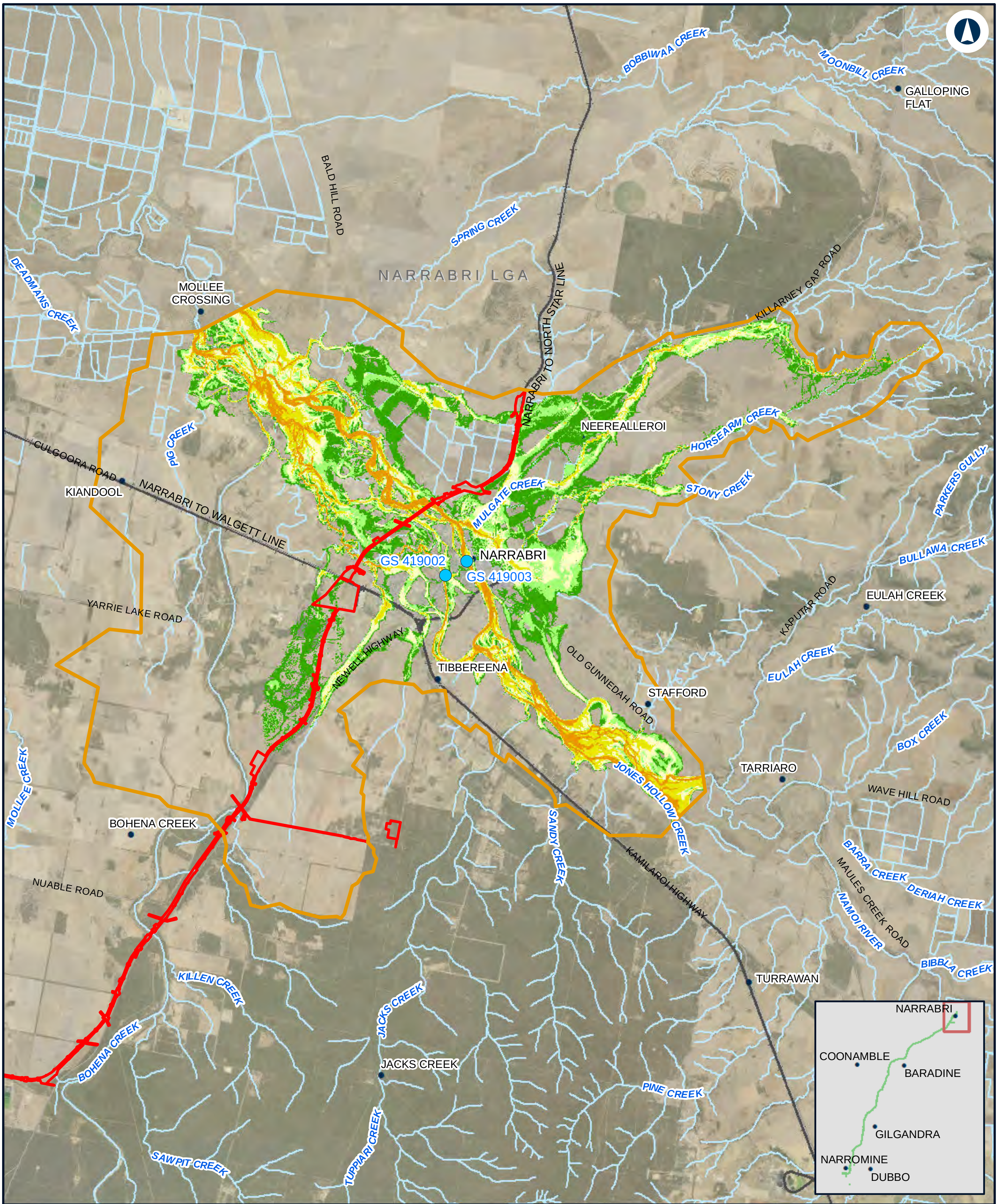

NARROMINE TO NARRABRI Peak flood depth for historical event 12/2012 - Narrabri Figure E.15

0 2.5 5 Km

Coordinate System: GDA 1994 MGA Zone 55

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Date: 23/06/2020 Paper: A4
Author: JacobsGHD Scale: 1:180,000
Data Sources: Basemap layers: NSWSS; all other layers: JacobsGHD

LEGEND

- The proposal site
- TUFLOW model boundary
- > 2.0m
- Stream gauge

Flood depth

- 0.0m - 0.25m
- 0.25m - 0.5m
- 0.5m - 1.0m
- 1.0m - 2.0m

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Flood hydrographs

Narromine

Calibration Results for Narromine TUFLOW model – Macquarie River at Timbrebongie.

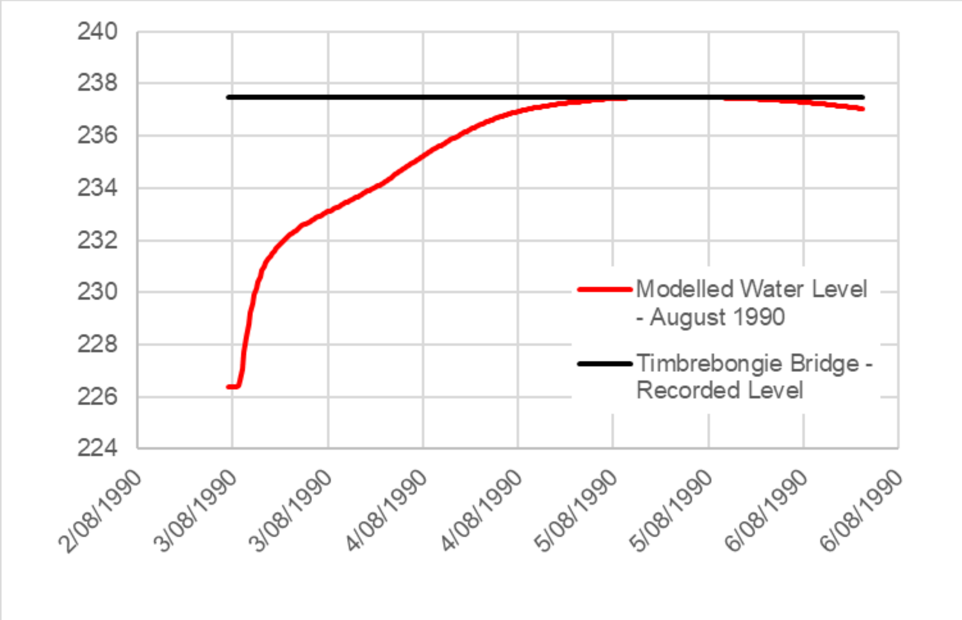

Figure E.16 - August 1990 flood – comparison of flood level

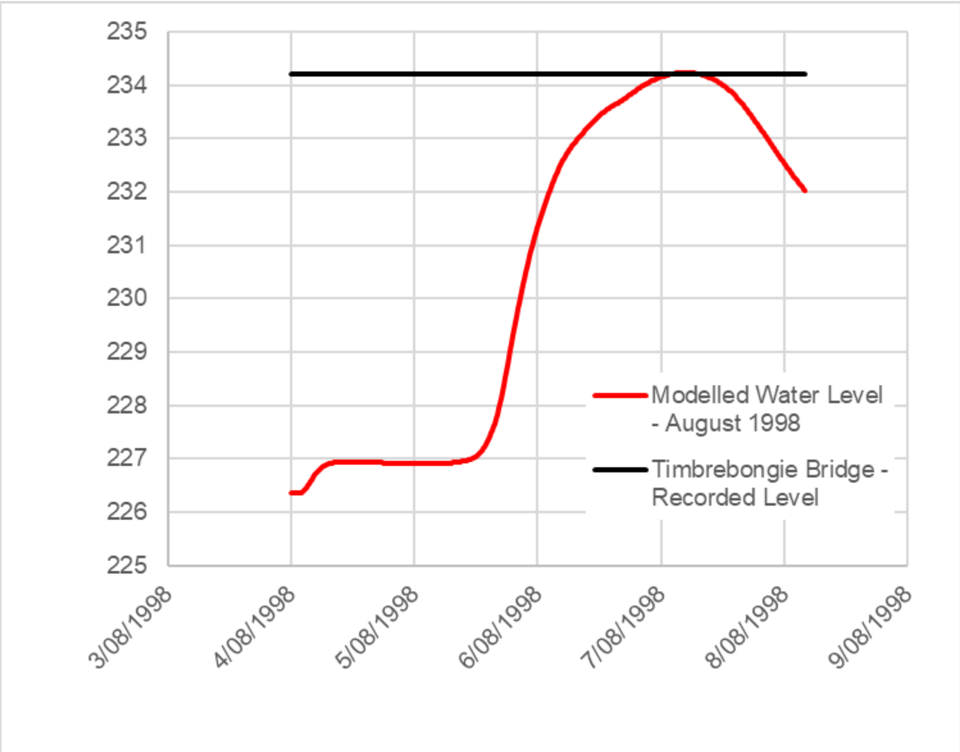

Figure E.17 - August 1998 flood – comparison of flood level

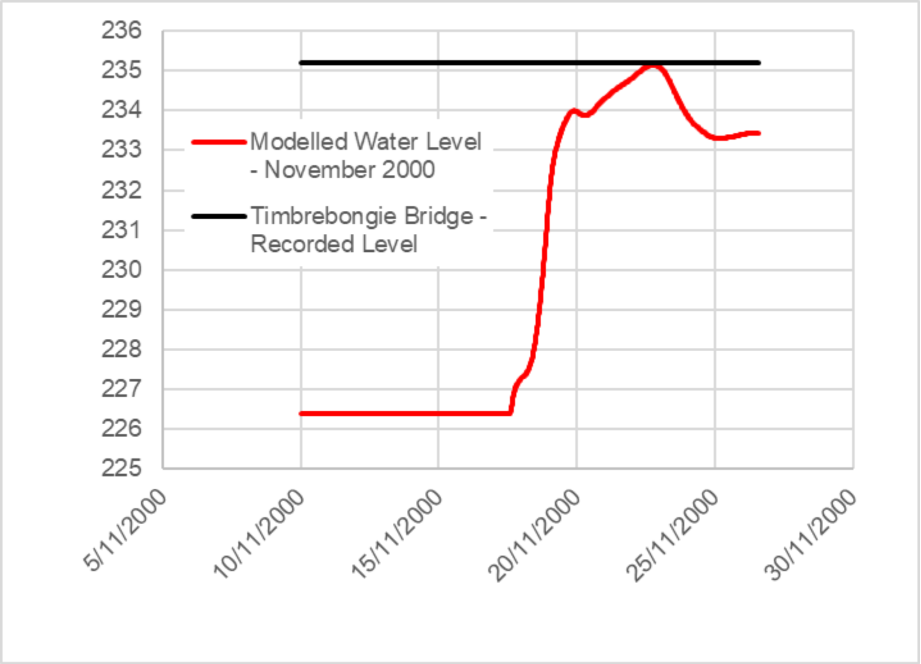

Figure E.18 - November 2000 flood – comparison of flood level

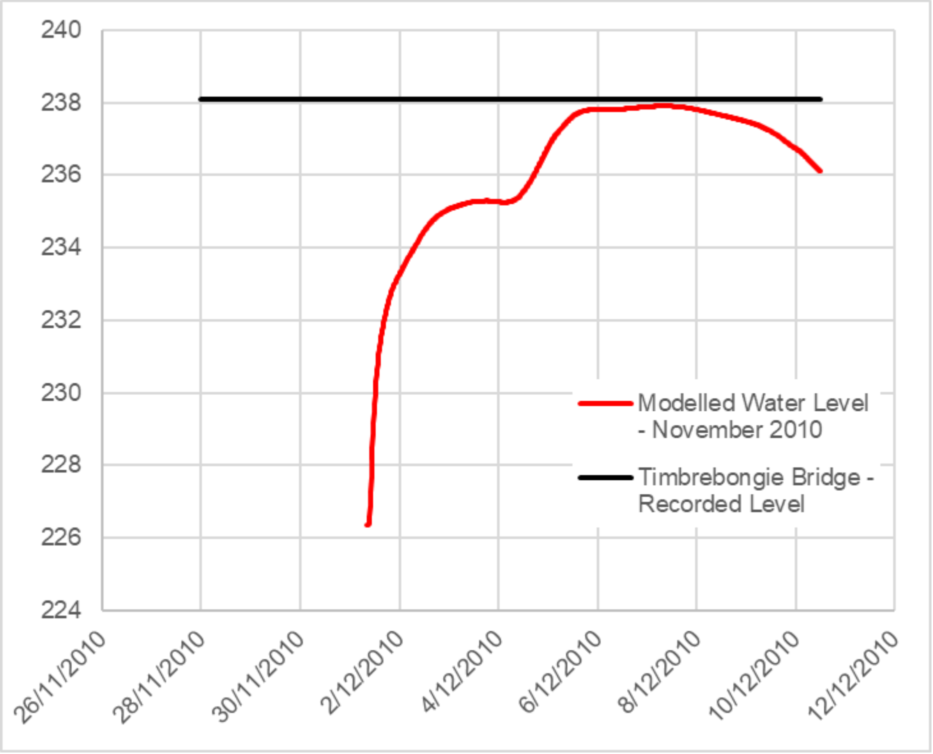

Figure E.19 - November 2010 flood – comparison of flood level

Baradine Creek

Calibration Results for N2N7 TUFLOW model – Baradine Creek at Baradine Creek at Kienbri No. 2 (GS 419072).

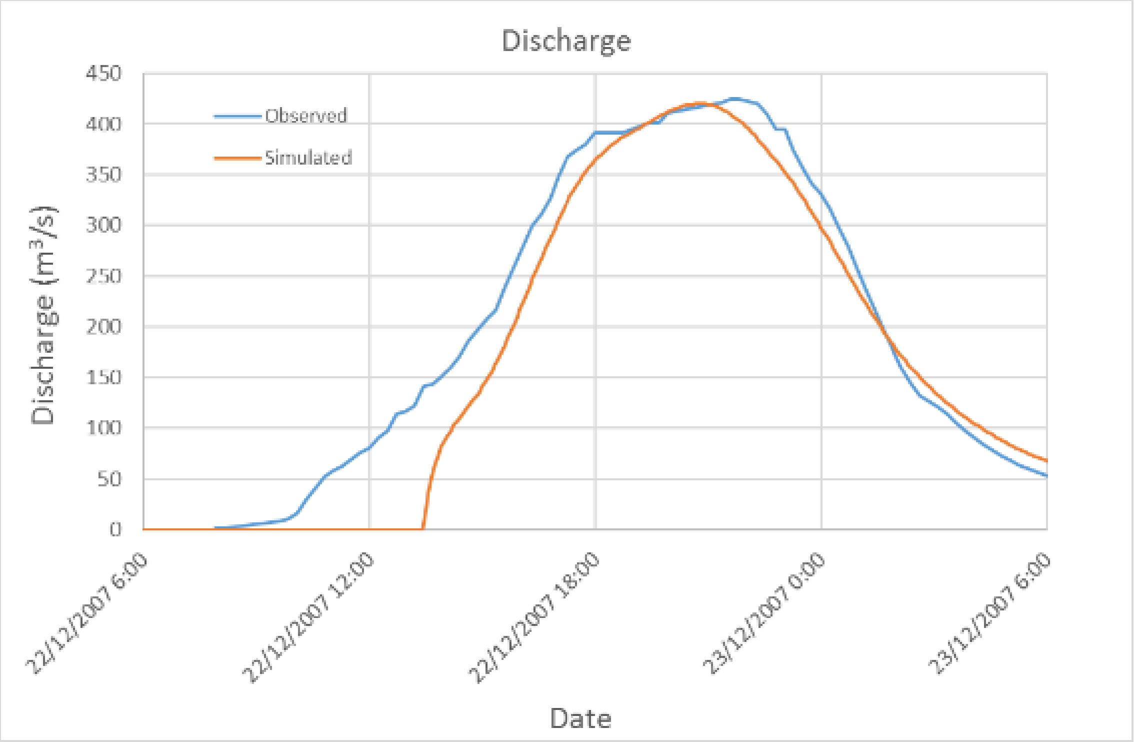

Figure E.20 - December 2007 flood – comparison of discharge

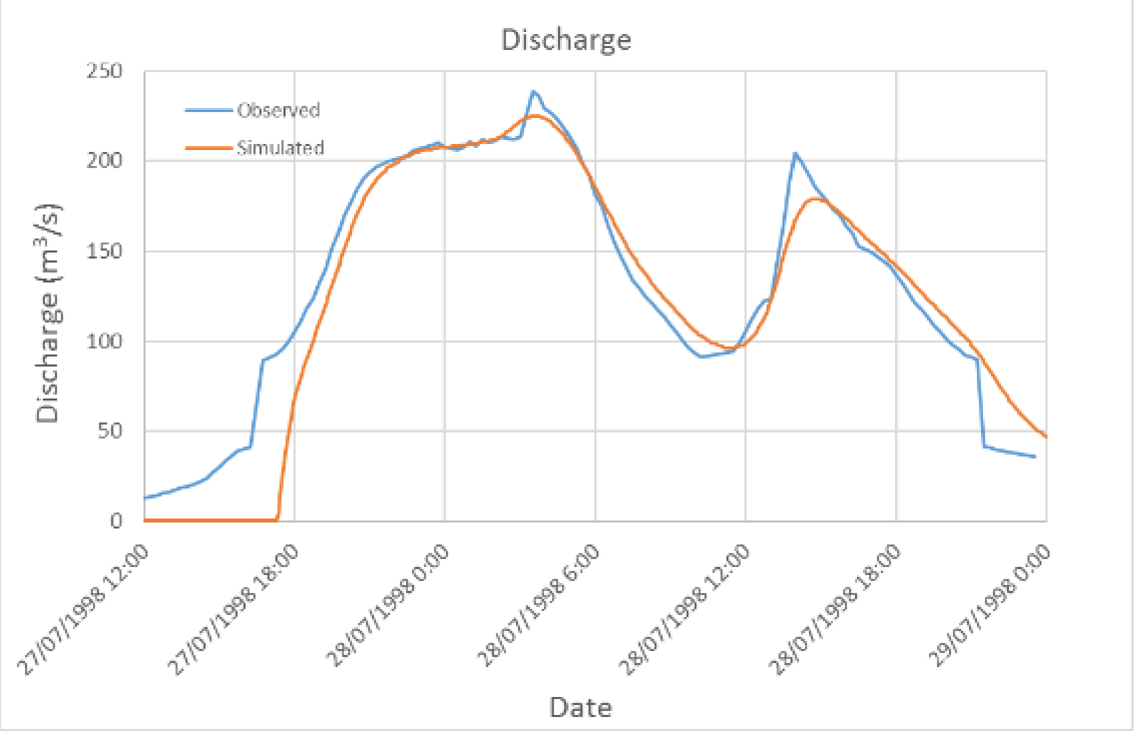

Figure E.21 - July 1998 flood – comparison of discharge

Bohena Creek

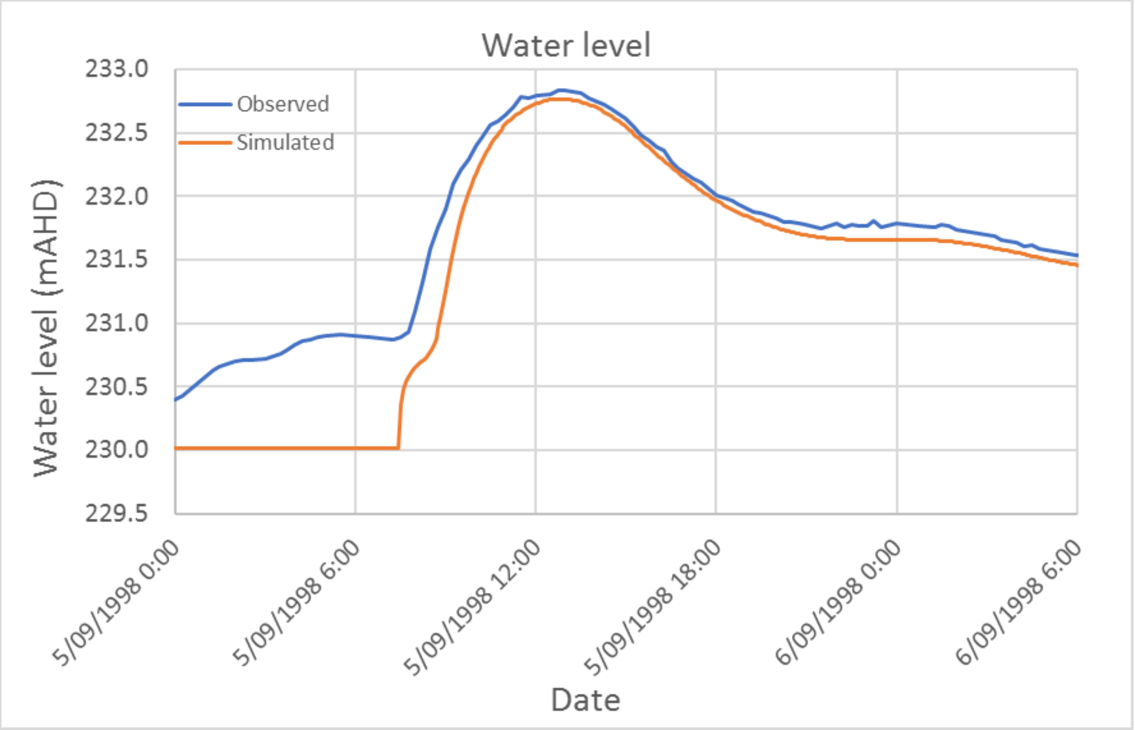

Figure E.22 - September 1998 event – water level calibration result

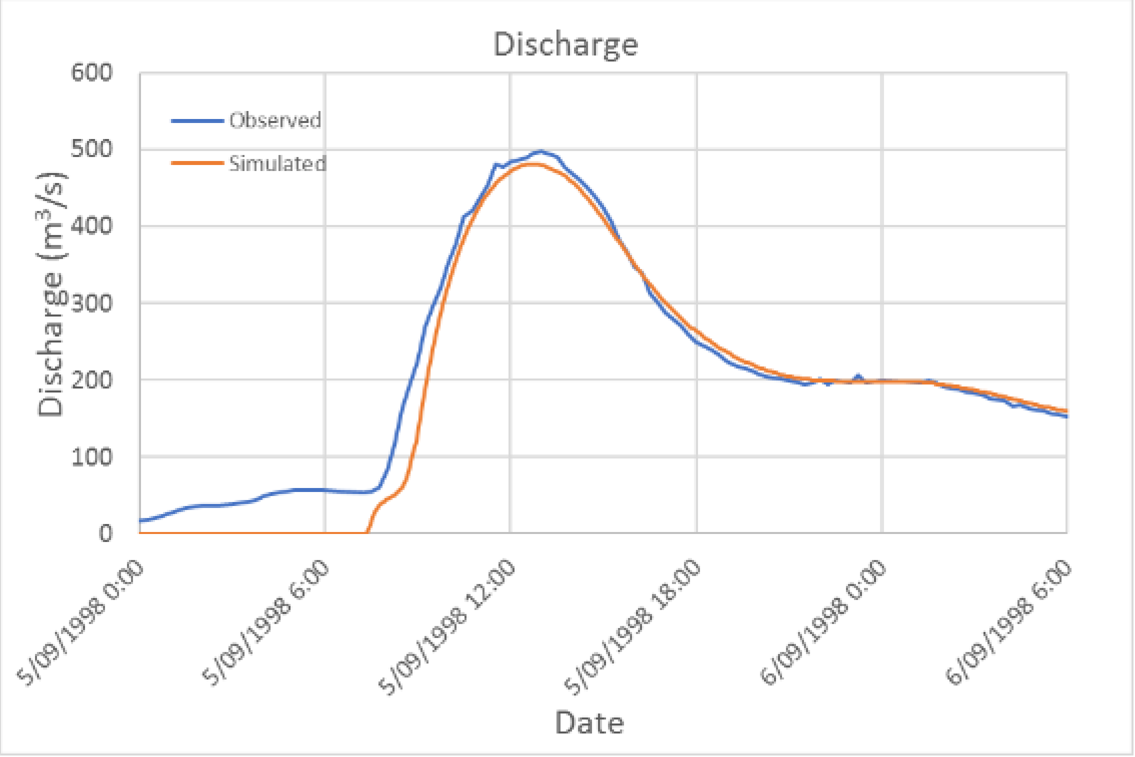

Figure E.23 - September 1998 event – discharge calibration result

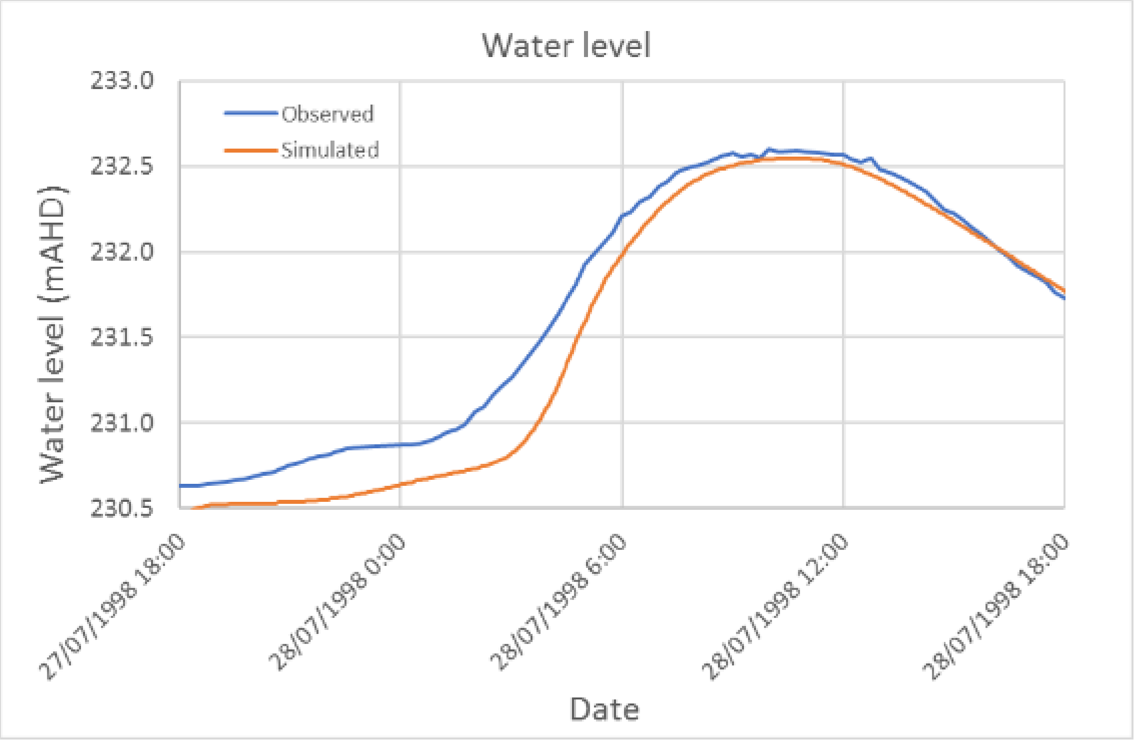

Figure E.24 - July 1998 event – water level calibration result

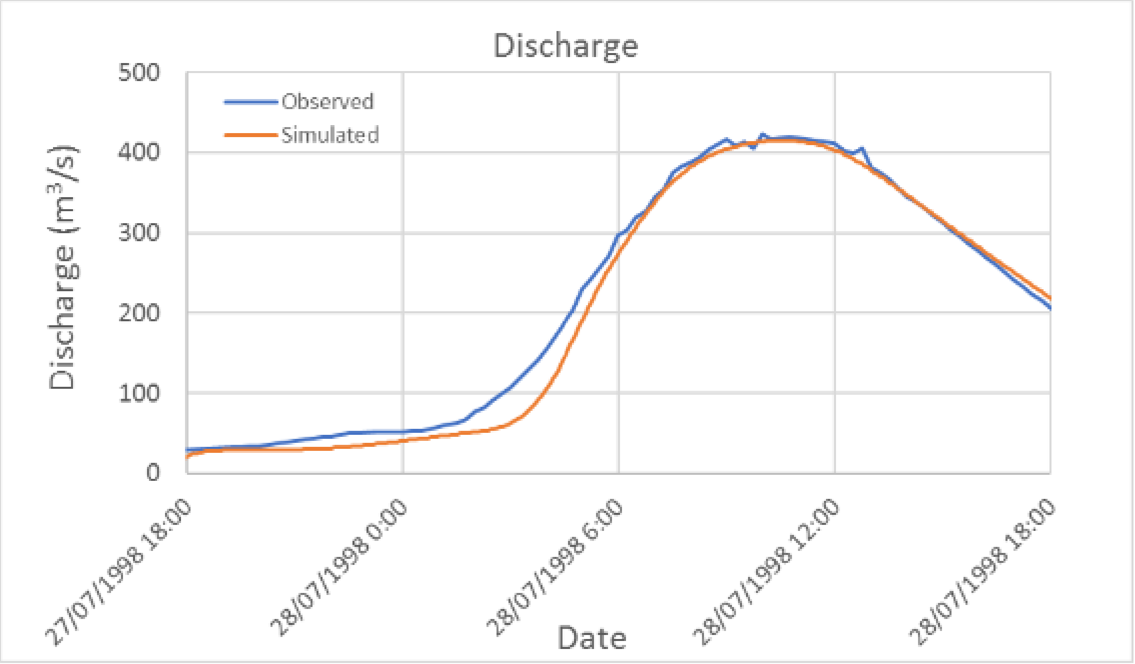

Figure E.25 - July 1998 event – discharge calibration result

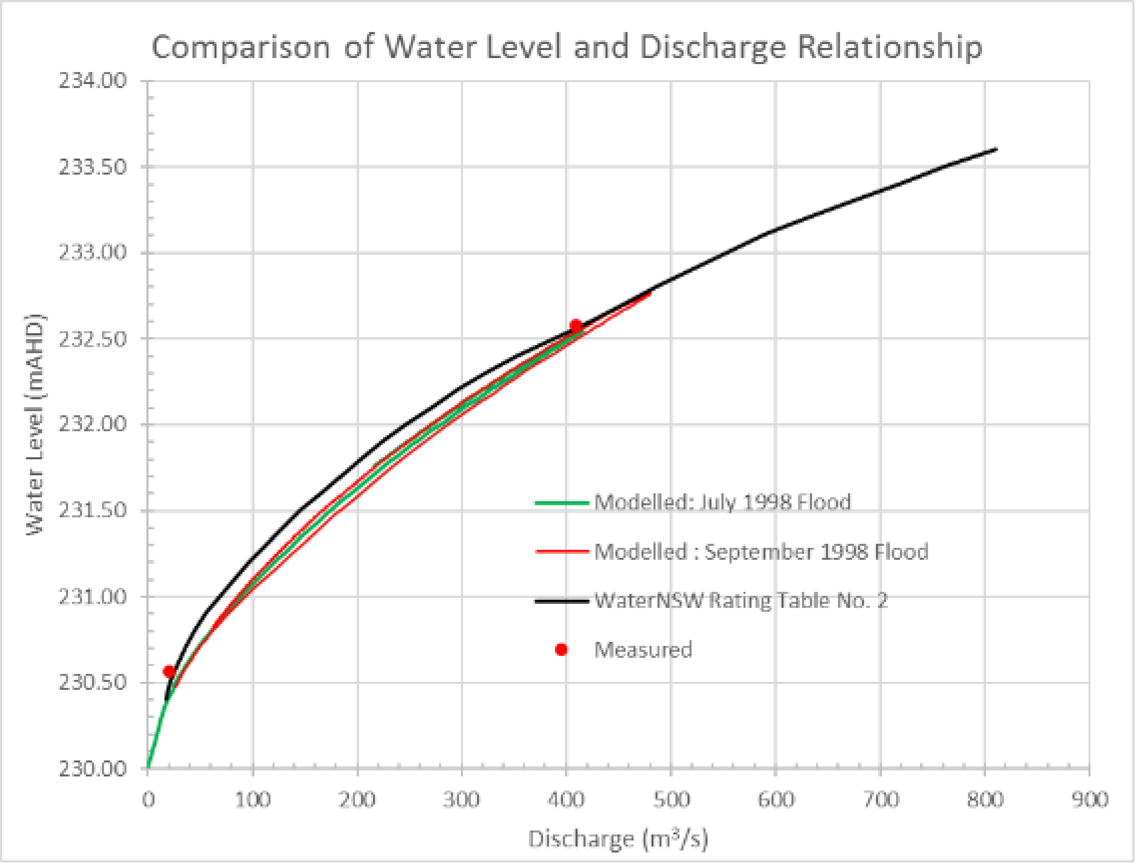

Figure E.26 - Comparison of rating curves

JacobsGHD

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