Peer Review of Flood Modelling undertaken for the Macintyre River Floodplain

Inland Rail Project
North Star to Queensland Border (NS2B)

Goondiwindi Regional Council

1283-02-D1, 27 November 2020

Report Title	Peer Review of Flood Modelling undertaken for the Macintyre River Floodplain, Inland Rail project, North Star to Queensland Border (NS2B)
Client	Goondiwindi Regional Council LMB 7, Inglewood QLD 4387
Report Number	1283-02-D1

Revision Number	Report Date	Report Author	Reviewer
Draft	6 October 2020	SM	DN
0	27 November 2020	SM	DN

For and on behalf of WRM Water & Environment Pty Ltd
Level 9, 135 Wickham Tce, Spring Hill
PO Box 10703 Brisbane Adelaide St Qld 4000
Tel 07 3225 0200

Sharmil Markar
Director

Contents

List of Figures

List of Tables

1 Introduction

1.1 BACKGROUND

The Inland Rail Project's proposed North Star to Queensland Border (NS2B) section provides a connection between North Star in New South Wales (NSW) and the NSW and Queensland (QLD) Border. The proposed rail line crosses the Macintyre River and its floodplain near the NSW/QLD border.

The Future Freight Joint Venture (FFJV) have undertaken flood modelling for the Macintyre River and its floodplain, on behalf of Australian Rail Track Corporation (ARTC), for the NS2B section of the Inland Rail Project to support the Reference Design of the proposed rail line and fulfil requirements of the Environmental Impact Study (EIS) for the NS2B Project.

FFJV have used hydrologic and hydraulic models to predict the flooding behaviour in the Macintyre River, its floodplain and the associated waterways. These models have been configured and used first to predict flooding behaviour under existing (pre-NS2B) floodplain conditions for a wide range of flood events ranging from the 20% Annual Exceedance Probability (AEP) event up to the Probable Maximum Flood (PMF) event. The Existing Conditions models have then been modified to incorporate the proposed rail line Reference Design (Developed Conditions) before running them for the same range of design flood events and comparing the Developed Conditions results against the Existing Conditions results to determine potential impacts of the proposed rail line on peak flood levels, discharges, flood flow distribution and velocities in the area of interest. The proposed rail line design has then been refined iteratively until the adopted design (Reference Design) satisfied the hydraulic design criteria and flood impact objectives set for the NS2B project (shown in Table 13.4 and Table 13.5 respectively of the NS2B EIS).

Goondiwindi Regional Council (GRC) are concerned about the accuracy, reliability and robustness of the flood modelling undertaken by FFJV for the Macintyre River and its floodplain, as well as the potential impact of the NS2B section on flood behaviour in Goondiwindi. GRC requested WRM Water & Environment Pty Ltd (WRM) to undertake a review of the flood modelling and associated reports prepared by ARTC and FFJV for the NS2B EIS and advise Council on the adequacy, accuracy and robustness of the flood modelling undertaken and modelling results produced for the Reference Design. This report is in response to that request.

1.2 SCOPE OF ENGAGEMENT

The scope of this engagement has been as follows:

- Undertake a review of the hydrologic and hydraulic modelling undertaken by FFJV for the NS2B Reference Design and the NS2B EIS. This has included an assessment of the following:
    - the adequacy and suitability of the base data and information relied upon for the modelling;
    - the appropriateness of the models and model configurations used;
    - the adequacy and accuracy of the model calibration;
    - the accuracy and reliability of the model results; and
    - the reliability of the flood modelling findings.
- Prepare a report to GRC presenting the findings of the review.

This report has been prepared on the basis of information and data gathered from:

- a desktop review of the hydrologic and hydraulic models, modelling files and modelling results provided to WRM by ARTC and FFJV;
- a review of Chapter 13 (Surface Water and Hydrology) and Appendix H (Hydrology and Flooding Technical Report) of the NS2B EIS (dated 11 May 2020) (FFJV 2020a, b);
- meetings and discussions with ARTC representatives and FFJV modellers on 23 July 2020, 2 September 2020 and 13 November 2020;
- two Technical Notes prepared by FFJV on 4 September 2020 and 30 September 2020 respectively in response to a set of queries from WRM (on 31 August 2020 and 23 September 2020 respectively) to clarify a number of flood modelling issues that were unclear or, in my opinion, inadequately addressed in Chapter 13 and Appendix H of the NS2B EIS (FFJV 2020c, d);
- a Technical Note prepared by FFJV on 14 October 2020 providing comments on my draft report dated 6 October 2020 (FFJV 2020e); and
- a site visit and meetings with GRC officers and local landholders on 15 October 2020.

No independent hydrologic or hydraulic modelling has been undertaken by WRM as part of this review. Further, this review has been limited only to flood modelling undertaken for the Reference Design representing the preferred Option D1 alignment for the proposed NS2B section.

Not all the models, data and results provided by ARTC and FFJV have been reviewed in detail for the preparation of this report. The level of this review has been commensurate with the scope of this engagement, with specific focus on the modelling approach, adopted methodology, model calibration and the use of the calibrated models for existing and developed conditions design flood event assessment.

2 Design requirements, standards and guidelines

2.1 OVERVIEW

The Reference Design of the NS2B section of the Inland Rail Project requires a detailed hydrologic and hydraulic assessment to establish flood behaviour in the potentially impacted area under existing conditions followed by the consideration of the proposed rail works and refinement of the proposed drainage structures required to minimise flood impacts to acceptable (pre-determined) levels under post-NS2B project conditions.

Appendix H of the NS2B EIS outlines the design requirements, standards and guidelines to be adhered to by FFJV for their NS2B Reference Design hydrologic and hydraulic assessments. The following requirements are of particular relevance to this review:

- the hydrologic and hydraulic analyses and designs have to be undertaken in accordance with the current Australian Rainfall and Runoff (ARR) standards and guidelines; and
- the flood modelling and flood impact assessments have to comply with the Secretary's Environmental Assessment Requirements (SEARs).

2.2 SECRETARY'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS

The Secretary's Environmental Assessment Requirements (SEARs) for the NS2B Reference Design are detailed in Table 13.1 in Chapter 13 of the NS2B EIS. The SEARs key issues and desired performance outcome condition items 8.2.a and 8.2.e are of particular relevance to this review of the ARTC and FFJV flood modelling:

- the SEARs item 8.2.a requires ARTC to assess flooding behaviour for the full range of flood events up to and including the PMF using hydrologic and hydraulic models in a manner consistent with current best practice and utilising topographic and infrastructure data that is of sufficient spatial coverage and accuracy to ensure the resultant models can accurately assess existing and proposed water flow characteristics. This includes undertaking flood modelling in accordance with the latest Australian Rainfall and Runoff (ARR) standards and guidelines; and
- the SEARs item 8.2.e requires ARTC to assess the consistency (or inconsistency) of the flood modelling with the applicable Council or OEH (now Department of Planning, Industry and Environment (DPIE)) floodplain management plans, including the Border Rivers Valley Floodplain Management Plan (BRVFMP).

Based on my interpretation of the NS2B Reference Design requirements, including the above two SEARs requirements:

- ARTC and FFJV have to undertake the required flood modelling in a manner consistent with current best practice, and ensure that the modelling undertaken can accurately assess existing and proposed water flow characteristics. This would require adherence to the current ARR standards and guidelines; and
- ARTC and FFJV have to only assess the consistency (or inconsistency) of the flood modelling with the BRVFMP. There does not appear to be an obligation for ARTC and FFJV to use any of the DPIE hydrologic or hydraulic models. On the other hand, if there was such an obligation to use the DPIE models as the basis for the Reference Design, there do not appear to be any restrictions on modifying or improving the DPIE models in order to comply with current modelling best practice and the current ARR standards and guidelines.

3 Data and information used for flood modelling

3.1 OVERVIEW

The FFJV have collected and used data and background information from a number of sources including the DPIE, the Bureau of Meteorology (BOM), previous flood studies, Councils and local landholders. Data and background information collected and collated have included previous hydrologic and hydraulic models, topographic data (including levee and hydraulic structure data), field survey data, rainfall data, streamflow data and anecdotal flood level and flood behavioural data, including landholder photographs and aerial photographs

The following subsections provide a general description of the data and information that were reported to have been available to FFJV for the NS2B project flood modelling. A detailed review of the data described below and used by FFJV has not been undertaken as part of this investigation.

3.2 TOPOGRAPHIC DATA

It appears that three different sets of topographic data have been available and used in the BS2B flood modelling:

- a Digital Elevation Model (DEM) compiled from two LiDAR data sets created in 2013 and supplemented with Shuttle Radar Topography Mission (SRTM) 1-second resolution data;
- a DEM compiled from a LiDAR data set created from surveys undertaken between September 2014 and January 2015; and
- a DEM compiled from a LiDAR data set created in November 2019.

Based on the FFJV reports, the 2019 data set has been used to represent current topographic conditions, including current levee heights and floodplain features, in the modelled area. This data has been used for the hydraulic modelling undertaken for the Existing Conditions as well as the Developed Conditions and for flood impact and flood mitigation assessments.

It appears that the older topographic datasets have been used with some adjustments as seen fit for the historical (1976, 1996 and 2011) event hydraulic model calibration.

It appears that the drainage structure data used for historical event modelling have been obtained from previous flood studies, site inspections and LiDAR data sets best representing the time of the modelled event. For the Existing Conditions and Developed Conditions modelling, it appears that the historical event data, especially along the NS2B alignment, has been supplemented with limited field surveys.

The topographic data used for hydraulic modelling appears to be generally appropriate and sufficiently accurate for use in the hydraulic modelling.

3.3 RAINFALL, STREAMFLOW AND FLOOD LEVEL DATA

The daily rainfall and pluviograph data used for the 1976 and 1996 event model calibrations have been sourced from the respective DPIE hydrologic models, except for the Ottleys Creek catchment for the 1996 event. The rainfall data for the 2011 calibration event and Ottleys Creek 1996 event has been sourced from BOM and a previous (2016) SMEC RORB model. It does not appear that a thorough review of additional rainfall data that may be available for the modelled calibration events has been undertaken as part of the FFJV investigations.

Based on information presented in Appendix H (Table 5.5) of the NS2B EIS, historical streamflow data for model calibration events and peak height records were available for only eight stream gauging stations within the Border Rivers catchment. BOM and other state agencies operate a large number of stream gauging stations in this catchment. Therefore, it is surprising that historical data for these modelled events was unavailable for other key stations that are located within the Macintyre River, Macintyre Brook and Dumaresq River catchments. Such data could have been used to improve the model calibrations.

Based on available information, it appears that FFJV have undertaken a review of the rating curve at the Boggabilla and Goondiwindi stream gauges. However, it is unclear from the available information whether the rating curves at the stream gauging stations used for the hydrologic model calibration have been sufficiently reviewed prior to using their rated discharges for model calibration.

Anecdotal flood data collected from previous studies, DPIE, Councils and land holders has been used for model calibration. These data, which have varying levels of accuracy and reliability, have comprised mainly aerial photographs, landholder photographs and surveyed debris mark levels.

3.4 HYDROLOGIC AND HYDRAULIC MODELS

FFJV had identified that the DPIE's Border Rivers Floodplain hydrologic and hydraulic models were the most detailed and suitable of the previous study models for the assessment of flooding behaviour in the Macintyre River floodplain and the investigation of flooding impacts of the proposed NS2B rail line.

Therefore, the hydrologic and hydraulic models for the Macintyre River system developed by the DPIE have been obtained and used as the basis for the NS2B flood modelling including the proposed rail line Reference Design.

The DPIE's hydraulic model covers an area of approximately 11,000 km^2 extending from approximately 50 km upstream of Boggabilla to 40 km downstream of Mungindi. It appears that the FFJV have adopted a truncated version of the DPIE's hydraulic model for their hydraulic modelling. It also appears that all constructed and approved structures on the floodplain as configured in the DPIE model have been adopted, with some adjustment to levee configurations. The implications of using the DPIE hydraulic model are discussed in Sections 4, 5 and 7 of this report.

FFJV have stated that because the DPIE modelling was only recently undertaken (in 2017) to support the updated BRVFMP, they considered it appropriate to adopt the models provided by DPIE for the NS2B flood modelling. FFJV considers this modelling to be current best practice on this floodplain. I disagree with this assessment because the DPIE models were not developed for use in design event modelling and they were developed prior to the release of the current ARR standards and guidelines. The best practice that was current at the time of the DPIE model development has now been superseded by the current ARR standards and guidelines.

It appears that FFJV have used DPIE's hydrologic model configurations with little or no modifications. The implications of using the DPIE hydrologic models for the NS2B Reference Design flood modelling are discussed in Sections 4, 5 and 7 of this report.

4 Adopted models and model configurations

4.1 OVERVIEW

The URBS model has been used for hydrologic modelling and the TUFLOW model has been used for hydraulic modelling. The adopted models are appropriate for flood modelling undertaken for the proposed NS2B project.

The proposed NS2B alignment crosses the Macintyre River floodplain traversing both the Macintyre River channel, and several tributaries including Whalan Creek, Strayleaves Creek, Forest Creek, Back Creek and Mobbindry Creek. Figure 4-1 shows the waterways crossing the NS2B alignment.

Figure 4-2 shows the extent of the URBS model catchments and the TUFLOW model extent used in the NS2B flood modelling.

- The hydrologic models used comprise four URBS models for the four major waterways (Macintyre River, Macintyre Brook, Dumaresq River and Ottleys Creek) and four URBS models for the four minor waterways (Mobbindry Creek, Back Creek and Forest Creek) crossing the NS2B alignment. The Macintyre River, Macintyre Brook and Dumaresq River URBS models have been sourced from the DPIE. New URBS models have been developed for Ottleys Creek, Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek; and
- A single TUFLOW model, a truncated version of the DPIE TUFLOW model, incorporating the upstream inflows predicted by each of the above URBS models has been developed for the study area. The adopted FFJV TUFLOW model covers an area of about 2,600 km^2 when compared to the DPIE TUFLOW model used for the BRVFMP, which covers an area of about 11,000 km^2.

There are a number of significant technical shortcomings in the adopted URBS and TUFLOW model configurations and therefore, in my opinion, the models used by FFJV are technically flawed and do not comply with SEARs condition 8.2.a. The adopted model configurations are not consistent with current best practice and are not sufficiently accurate to assess the existing and proposed flooding behaviour in the study area for the full range of design flood events up to the PMF. These shortcomings, which are discussed in the following subsections, would have potentially significant impacts on the accuracy and robustness of the flood modelling that has been undertaken for the NS2B Reference Design.

4.2 HYDROLOGIC MODEL

4.2.1 Model extent

The total catchment area draining to the downstream boundary of the hydraulic model is approximately 25,000 km^2. Of this area, approximately 23,090 km^2 is upstream of Goondiwindi and approximately 22,600 km^2 is upstream of Boggabilla (excluding the four southern minor tributary catchments). The catchment areas covered by the various URBS models are:

- Macintyre Brook - 3,983 km^2
- Dumaresq River – 9,093 km^2
- Macintyre River – 6,892 km^2
- Ottleys Creek – 1,219 km^2
- Minor tributaries – 467 km^2

The hydrologic models used for the NS2B flood modelling do not cover the total catchment draining to the modelled area (see Figure 4-2). The hydraulic model extends downstream of Goondiwindi but the hydrologic models do not extend far enough downstream to cover the extent of the hydraulic model. As a consequence, the adopted hydrologic models do not account for local catchment inflows to the hydraulic model area from an area of about 3,250 km^2, and of this, about 2,050 km^2 is upstream of the NS2B alignment (see Figure 4-2).

In response to one of my queries, FFJV have stated that the hydrologic models were not extended to Goondiwindi and downstream because of the complexity of the flow breakout patterns upstream of Boggabilla and Goondiwindi, which cannot easily or reliably be replicated in a hydrologic model. I agree that the hydrologic model cannot easily or reliably model the complex breakout patterns upstream of Boggabilla and Goondiwindi. In fact, that complexity is the reason for the use of a detailed hydraulic model. In my opinion, the adopted hydraulic model would not be able to produce accurate results without the local inflows from the unaccounted catchment area of about 3,250 km^2.

I believe an appropriately configured downstream hydrologic model, which could have been used to link all the upstream sub models, would have easily and reliably provided local catchment inflows from the large area that is currently not accounted for in the hydraulic model. This approach would have more accurately simulated the above-mentioned complex breakout patterns by taking into account the filling of floodplain storages prior to the arrival of upstream flows. I believe such an assessment would have also eliminated the need for the FFJV modellers to make major assumptions (without satisfactory justification) such as that the unaccounted local catchment inflows do not materially affect the model results. In response to one of my queries, FFJV have acknowledged this shortcoming and have suggested that the extension of the URBS model could be undertaken with the Boggabilla and Goondiwindi stream gauges included in the hydrologic model as part of their Detail Design modelling.

4.2.2 Focal point of modelling

Based on current ARR guidelines, the 'focal' point of the FFJV hydrologic modelling for the Reference Design should be Boggabilla or the proposed NS2B rail line crossing of the Macintyre River. The adopted modelling approach and model extent do not use the correct focal point for the NS2B flood modelling.

In a response to one of my queries, FFJV have acknowledged that they have not used the correct focal point for the design event modelling.

As a consequence of the above shortcoming, FFJV have undertaken their design event modelling with inappropriate model inputs for design rainfalls, rainfall temporal patterns, rainfall aerial reduction factors and rainfall losses. I believe this is most likely the reason why FFJV had to factor down (i.e. reduce) all design discharges predicted by the hydrologic models for Macintyre River, Dumaresq River, Macintyre Brook and Ottleys Creek (in an unconventional manner) by 30% to reconcile hydrologic model results with flood frequency analysis (FFA) results (as outlined in Section 8.2.4 of Appendix H, NS2B EIS).

The reduction of the hydrologic model predicted flood discharges as inflows to the hydraulic model is also likely to have resulted in significant reductions in predicted flood volumes draining to the hydraulic model area.

It is also likely that the adopted approach may have resulted in the selection of inappropriate critical storm durations because the larger Macintyre River catchment draining to the hydraulic model area is likely to have a longer critical storm duration than that of the Macintyre River at Holdfast or that of Macintyre Brook, Dumaresq River and Ottleys Creek.

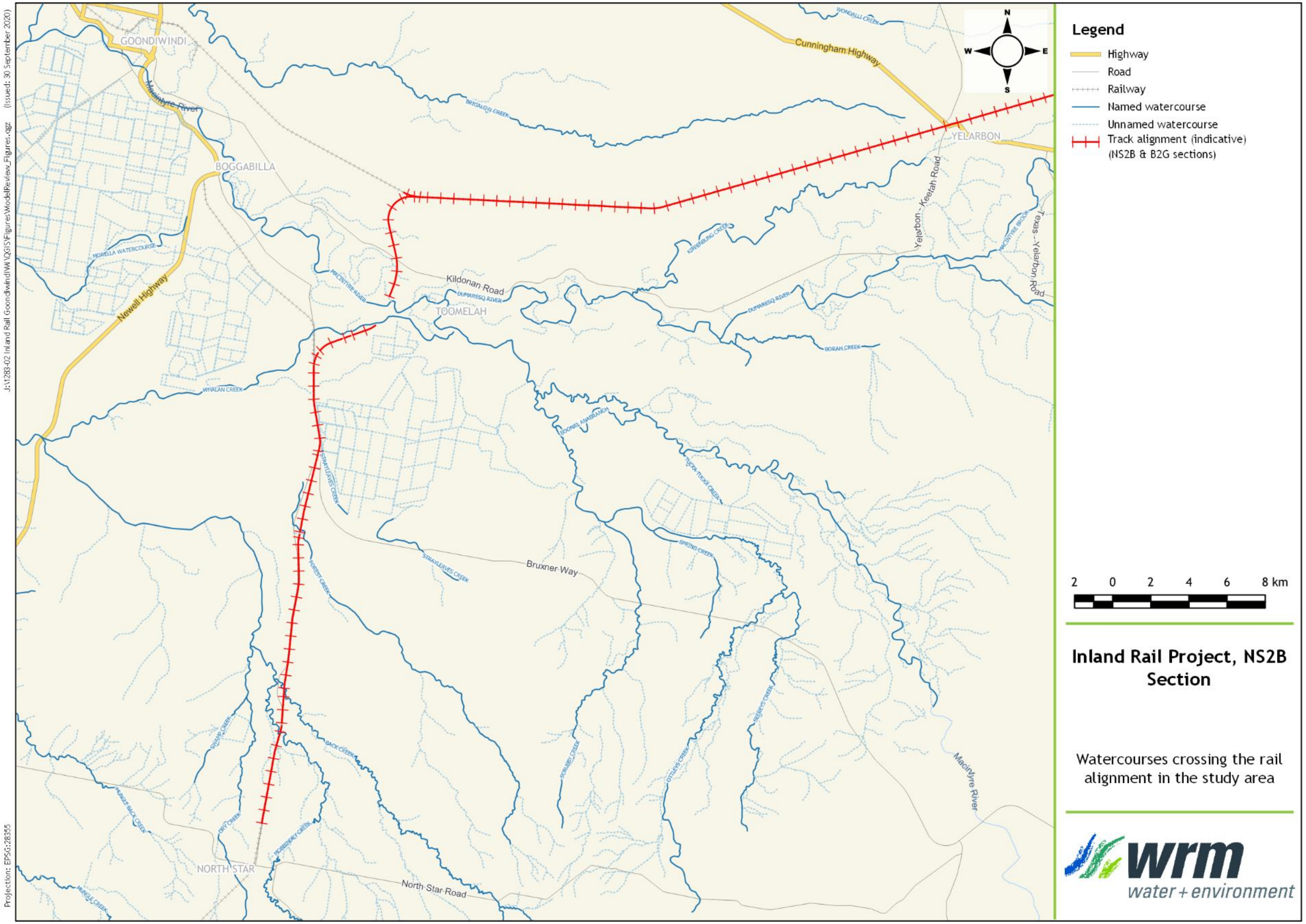


Figure 4-1 – Waterways crossing the NS2B alignment through the study area

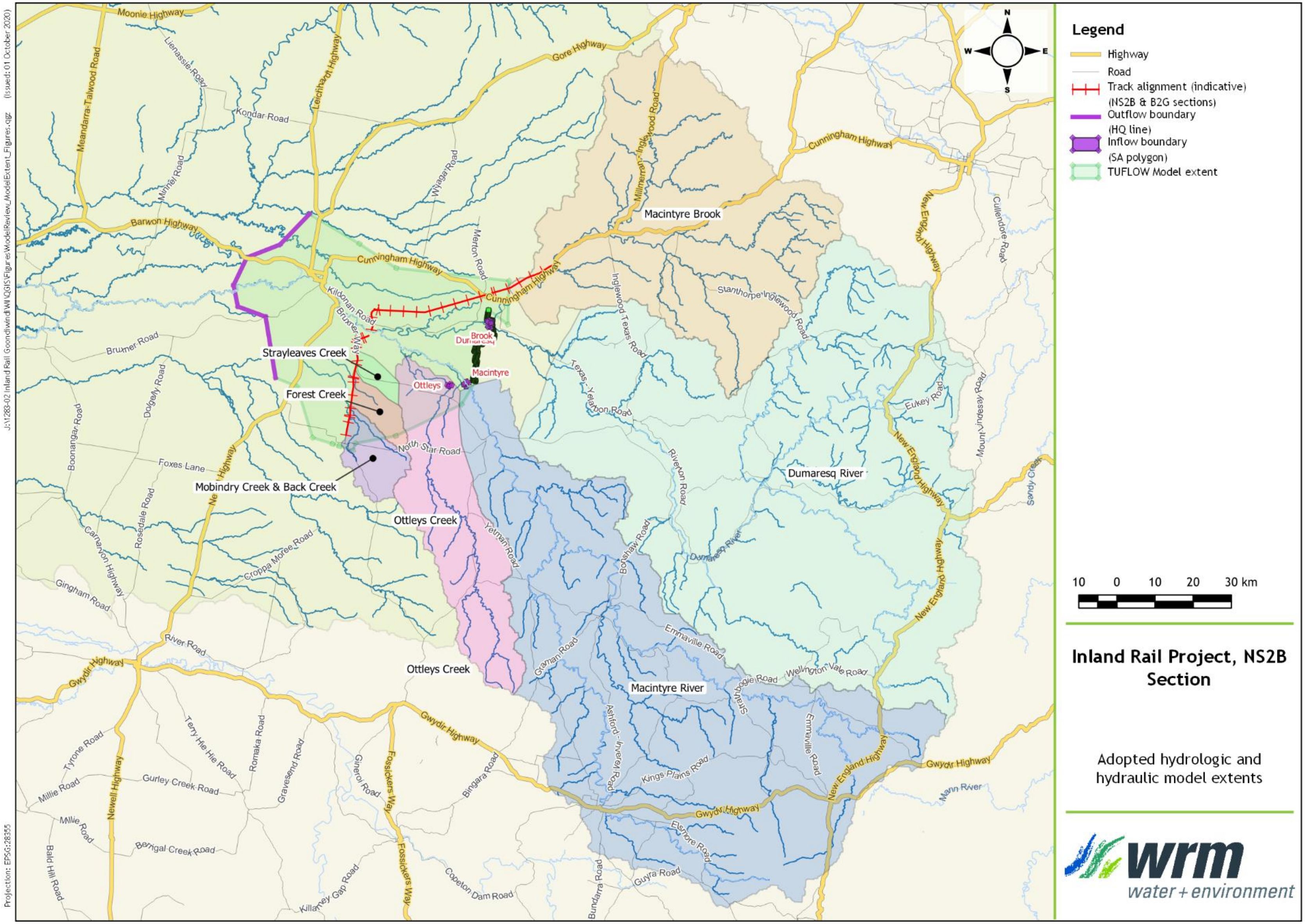


Figure 4-2 – Extents of the adopted hydrologic and hydraulic models

4.3 HYDRAULIC MODEL

4.3.1 Model extent and configuration

Figure 4-2 shows the adopted extent of the FFJV hydraulic model. The available DEM suggests that there are potential interactions between Macintyre Brook and Kippenbung Creek as well as Brigalow Creek at Yelarbon, as well as Macintyre River and Brigalow Creek upstream of Goondiwindi, during large flood events. This inference from the DEM is consistent with information provided to me by Eddie Belling, a local landholder who is quite familiar with historical flooding behaviour in the Macintyre River catchment. According to Eddie Belling there were significant breakouts from the Macintyre Brook into Kippenbung Creek and Brigalow Creek during the 1956 flood event. Figure 4-3 shows these potential locations of interactions between the modelled waterways and waterways external to the modelled area. It appears that these potential interactions have not been adequately considered when configuring the hydraulic model for large flood events, especially when accurate modelling is required to be undertaken up to the PMF event.

The Macintyre Brook total inflow boundary is located 14 kilometres downstream from the locations where that inflow has been derived from the hydrologic model (at Booba Sands). In this case, the adopted Macintyre Brook TUFLOW model extent, and the location of the adopted Macintyre Brook inflow location, would prevent any potential breakouts into Kippenbung Creek and Brigalow Creek during large flood events. The prevention of these breakout flows would likely overestimate the Macintyre River discharges at the NS2B crossing and may also result in the Reference Design underestimating the cross-drainage requirements at locations where these waterways cross the Inland Rail B2G alignment.

In a response to one of my queries, FFJV has acknowledged that the adopted model configuration does not accurately represent the interactions between Macintyre Brook, Kippenbung Creek and Brigalow Creek near Yelarbon for large flood events. FFJV have argued that these interactions are not significant and the adopted model provides conservative results for large flood events when such interactions potentially take place.

FFJV have further stated that they did consider the interaction between Macintyre Brook, Kippenbung Creek and Brigalow Creek around Yelarbon. FFJV believes that, because the timings of the peak discharges in each of these waterways vary considerably, and because the Macintyre River flows are much larger than Kippenbung Creek flows, they expect model results to provide the ‘worst case’ outcome.

It is noted that the SEARs condition 8.2.a requires the adopted FFJV models to accurately (and not conservatively) assess existing and proposed conditions flooding for the full range of design floods up to the PMF.

FFJV believe that the inclusion of the potential Macintyre Brook interactions with Kippenbung Creek and Brigalow Creek in their hydraulic model would not alter their Reference Design or the NS2B project impact outcomes. FFJV have also stated that they will consider these interactions during Detail Design.

Based on available topographic data, flooding behaviour and flood levels at Goondiwindi can be influenced by the interaction between the Macintyre River and Brigalow Creek upstream of the eastern section of the Goondiwindi levee. In response to a query from me about the adopted hydraulic model not being able to accurately model the flooding behaviour at Goondiwindi because the model does not take into account the interaction between the Macintyre River and Brigalow Creek at Goondiwindi, FFJV have stated that they did consider the potential for impact from Brigalow creek catchment during a Border Rivers Flood. They note that:

- The hydraulic model has been developed to model the NS2B alignment located upstream of Boggabilla, not the timing and interaction of minor creek systems at Goondiwindi. The inclusion of Brigalow Creek flows into the model is not expected to impact results at the proposed rail alignment;

- The timing of peaks would be significantly different resulting in the Brigalow Creek rising and falling before the Macintyre River peaks; and
- The contributing catchment for Brigalow Creek is significantly smaller than the Macintyre River and tributaries such that it is expected the Macintyre River flood would provide the 'worst case' outcome at the NS2B alignment. Brigalow Creek was also not included in the DPIE hydraulic model. Under extreme events where flow from the Macintyre Brook may spill into Brigalow Creek this breakout is not represented in the current modelling, however this is a conservative approach as it means that the flows are retained in the Macintyre Brook system and reach the floodplain and thus are assessed for the NS2B alignment.

Based on the above comments, FFJV appear to accept that their model would not accurately predict flood behaviour at Goondiwindi. Further, it is likely that conservative (i.e. 'worst case') modelling for existing flooding conditions would also result in an underestimation of the actual flood impacts of the NS2B rail line because of the overestimation of peak flood levels under Existing Conditions.

The hydraulic model calibrations for the 1976 and 1996 events have used the current (2019) configuration including crest levels of the Goondiwindi levees rather than the configuration of the smaller levees that existed at the time of those events. FFJV have stated that they adopted the 2019 levee configuration for the historic event modelling because they had very limited data on the levee configuration at those times. This would have resulted in errors in the predicted 1976 and 1996 flood behaviour in Goondiwindi.

The model configuration for the Developed Conditions does not include miscellaneous infrastructure associated with the proposed rail line (fencing, road works, property access road upgrades, etc). These will need to be included, and their impacts assessed, in modelling undertaken for the Detail Design.

4.3.2 Local catchment inflows

4.3.2.1 Major waterways

The local (residual) catchment inflows downstream of Macintyre Brook (at Booba Sands), Dumaresq River (at Beebo), Macintyre River (at Holdfast) and Ottleys Creek (at Macintyre River confluence) are not included in the hydraulic model. This means local inflows from an area of approximately 3,250 km^2 are not included in the hydraulic model. I believe this will have a material impact on the model results.

Based on responses to my queries, FFJV believes that the local catchment inflows would have peaked and moved downstream before the main flood arrives from upstream and hence, they did not consider it necessary to include them in the hydraulic modelling. They also believe that the local catchment inflows are unlikely to change the results in the vicinity of the NS2B alignment and would have moved downstream before any major flood flows. FFJV have not presented any sensitivity analyses to justify their decision not to include local inflows, except to say that DPIE also did not do so in their modelling for the BRVFMP investigations. In my opinion, this is a flawed argument because any filling of the flood storage by local catchment inflows would not only have a material impact on peak flood levels, but also likely have an impact on flow distributions in the modelled area.

FFJV's above reasoning regarding the influence of local inflows on flooding in the study area is also inconsistent with local landholder observations. According local landholders, the local waterways and floodplains are generally full of water from local rainfall during significant flood events when the upstream water from the major waterways arrives.

4.3.2.2 Minor waterways

There are a number of local creeks that cross the NS2B alignment as shown on Figure 4-1. These creeks which drain towards Whalan Creek floodplain include Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek. Inflows from these minor waterways have not been used in model calibration and have been input to the hydraulic model only for the design event modelling. Further, these adopted design inflows are not consistent with the URBS model outputs for these creeks.

For Mobbindry Creek and Back Creek, it appears that the residual inflows downstream of the hydraulic model's upstream boundaries representing about 16% of the Mobbindry Creek and about 29% of the Back Creek catchment areas upstream of the proposed rail alignment are not accounted for in the TUFLOW model. In my opinion, this could have a significant impact on the sizing of hydraulic structures at these creek crossings.

Further, for Forest Creek and Strayleaves Creek, rather than specifying the URBS model outputs as inflows to the hydraulic model, a large number of local inflow boundaries along these creeks have been specified for the design events (see Figure 4-5). In addition, all local inflows input along these creeks appear to be a scaled version of each other, with the same hydrograph shape and timing at all inflow locations as shown in Figure 7-1. These adopted local inflows do not appear to account for any catchment routing through the URBS models and therefore do not appear to be correct.

4.3.3 Placement of inflow boundary conditions

Figure 4-4 and Figure 4-5 show the locations (i.e. placements) of inflow boundary conditions in the hydraulic model for calibration events and design events respectively. The placement of model inflow boundaries raises a number of significant issues with respect to accuracy and reliability of model results, including:

- Calibration events have only 4 upstream total inflows, there are no local inflows for an area of approximately 3,250 km^2 not covered by the hydrologic models plus the minor tributaries covering 467 km^2 for which no flows have been included (a total area of about 3,700 km^2). This means that the TUFLOW model has been calibrated with lower than actual inflows to the modelled area.
- Some of the major waterway inflows to the model are located several kilometres in from the model boundary (e.g. Ottleys Creek, Macintyre River). This would allow some of the inflows to also propagate upstream rather than only downstream along the channel, especially in flat floodplains such as in the Macintyre river system.
- Some of the major waterway inflows to the model are located several kilometres downstream or upstream from the locations where the inflows were derived (e.g. Macintyre Brook, Ottleys Creek). In the case of Macintyre Brook, this may prevent potential breakouts into Kippenbung Creek, Brigalow Creek, etc during large flood events.

In response to my queries, FFJV have stated that their inflow placements are as per the DPIE model, with the exception of Ottleys Creek, which has been shifted upstream to better represent the flow around drainage structures. If the Ottleys Creek inflow location could be changed, I see no reason why FFJV could not also change some of the other DPIE model inflow locations (e.g. Macintyre Brook) to better represent the inflows to the modelled area.

FFJV do not believe the position of the adopted inflows has a material impact on the model results, particularly in the vicinity of the proposed NS2B alignment. Again, this statement has been made without undertaking any quantitative assessment.

4.3.4 Model grid size

The TUFLOW model has been configured using a 30 m grid size. The adoption of a 30 m cell size is understandable when looking at the totality of the model domain. However, this grid size appears to be too coarse and inappropriate for representing channels and drainage features in the vicinity of the proposed rail alignment. Several creek channels, especially along the minor waterways, in the study area have channel cross sections in the approximately 5 m to 10 m range.

In response to one my queries, FFJV have stated that the features that are in the 5 m to 10 m range are completely inundated during major flood events. This may be correct during major flood events but may not be correct during small flood events. Also, if these features are not represented correctly in the existing conditions model, the predicted flood impact results may not be sufficiently accurate for the full range of modelled flood events. Some examples of this impact are presented in Section 7.3.5.

FFJV have done a sensitivity run with the adopted TUFLOW model using a 15 m grid size to assess the sensitivity of the adopted grid size. They have reported that a 15 m grid hydraulic model predicted that peak flood levels would be generally lower by about 50 mm across the modelled area and by about 150 mm along the NS2B alignment. This is a significant reduction in peak flood level along the NS2B alignment in the context of the Macintyre River floodplain near Boggabilla where a 100 mm difference in peak flood level represents a few thousand cubic meters per second difference in peak Macintyre River discharges through the modelled area.

FFJV has stated they will use the newer version of TUFLOW with a finer grid size where required in next stage of design. Based on the above sensitivity analysis results, it is likely that the hydraulic model will have to be recalibrated when a finer grid size is adopted.

4.3.5 Hydraulic structures

4.3.5.1 Representation of cross drainage structures

There appears to be a number of cross drainage structures along the existing rail and road alignments which are not represented in the hydraulic model under existing conditions (e.g. road cross drainage and bridge structures) because the LiDAR appears to be read in ‘as-is’, without adequate openings or other modifications. However, these structures are being represented under developed conditions (e.g. Mobbindry Creek, Back Creek) with designed hydraulic structures. Some of the approximate locations where existing hydraulic structures may not be adequately represented are shown in Figure 4-6.

The hydraulic structures along the existing B2G alignment also do not appear to be represented in the Existing Conditions model (either as structures or simple openings), but these structures are included as structures in the Developed Conditions model.

In response to one of my queries, FFJV has stated that minor hydraulic structures that are exposed to major flood inundation are not included in the hydraulic model. As described earlier, some of these structures appear to be along the existing road and rail corridors. The non-inclusion of these structures, with appropriate blockage factors, has the potential to significantly underestimate the impact of the proposed rail line especially during small flood events and when assessing potential impacts on future access to private properties. Some examples of these impacts are presented in Section 7.3.5.

4.3.5.2 Representation of culvert and bridge blockage

It appears that blockage factors have been adopted when modelling culverts. This is appropriate.

Bridges have been modelled using Layered Flow Constriction shapes, which represent structures as a set of three (3) layers (L1 being the waterway section, L2 being the bridge deck and L3 being handrails or guard rails above the bridge deck), each requiring the provision of a blockage factor (to represent the reduction in flow area across the affected model cells) and a Form Loss Coefficient (FLC) (to represent energy losses due to contraction and expansion of flow around piers). It appears that for the two flow layers above the waterway section (i.e. L2 and L3) blockages of 100% and 50% respectively have been assumed, with a FLC of zero (0). However, for L1 0% blockage has been assumed, with a 0.2 FLC.

For a 30 m grid hydraulic model with large bridges, this approach to modelling the waterway section does not appear to be consistent with guidelines provided by the TUFLOW model software developer, as the appropriate definition of the flow area (using blockage factors) impacts on the estimated velocity, which in turn impacts the energy losses calculated using the FLC (https://wiki.tuflow.com/index.php?title=TUFLOW_2D_Hydraulic_Structures).

The rationale for the adopted approach and the justification for the use of a FLC value of 0.2 with no blockage factors for the NS2B bridge waterways are unclear and should be explained clearly, as the appropriate modelling of bridges is important for the accurate estimation of potential flood impacts of the NS2B rail design.

4.3.5.3 Representation of Newell Highway

It appears that the recent upgrade of the Newell Highway may not be correctly represented in the hydraulic model. FFJV have found inconsistencies between the design details of the Newell Highway upgrades and the 2019 LiDAR, aerial imagery and ground levels. Therefore, due to time constraints, the Newell Highway has been included in the hydraulic model based on LiDAR rather than the provided design levels. These inconsistencies would need to be resolved and rectified prior to the flood modelling that would be undertaken for the Detail Design of the proposed rail line.

4.3.6 Different NS2B and B2G models

ARTC have used two different hydraulic and hydrologic models with different model configurations, inflows, etc for the Macintyre River floodplain for Inland Rail's NS2B and B2G section assessments.

Based on available information, FFJV have adopted the DPIE hydrologic models for the NS2B flood modelling of the common B2G section after a review of previous flood studies. The B2G project flood modelling (for the same rail section) has been done using hydrologic models developed for the Macintyre River catchment in a different flood study (Inglewood Flood Study) undertaken for the GRC in 2015.

FFJV found that the Inglewood Flood Study hydrology produced higher flows down Macintyre Brook than the DPIE models. Therefore, FFJV considered the Back-Creek 1% AEP estimates for the flows from the Inglewood Flood Study to be high. According to FFJV, they did not adopt the Inglewood Flood Study flows because they considered that adopting the higher flows for Macintyre Brook for inflow to the Macintyre River floodplain would be unreasonably conservative.

Based on available information, the differences and inconsistencies between the NS2B and B2G modelling results, including flood impact results, for the B2G rail section common to the NS2B and B2G flood modelling investigations are not known.

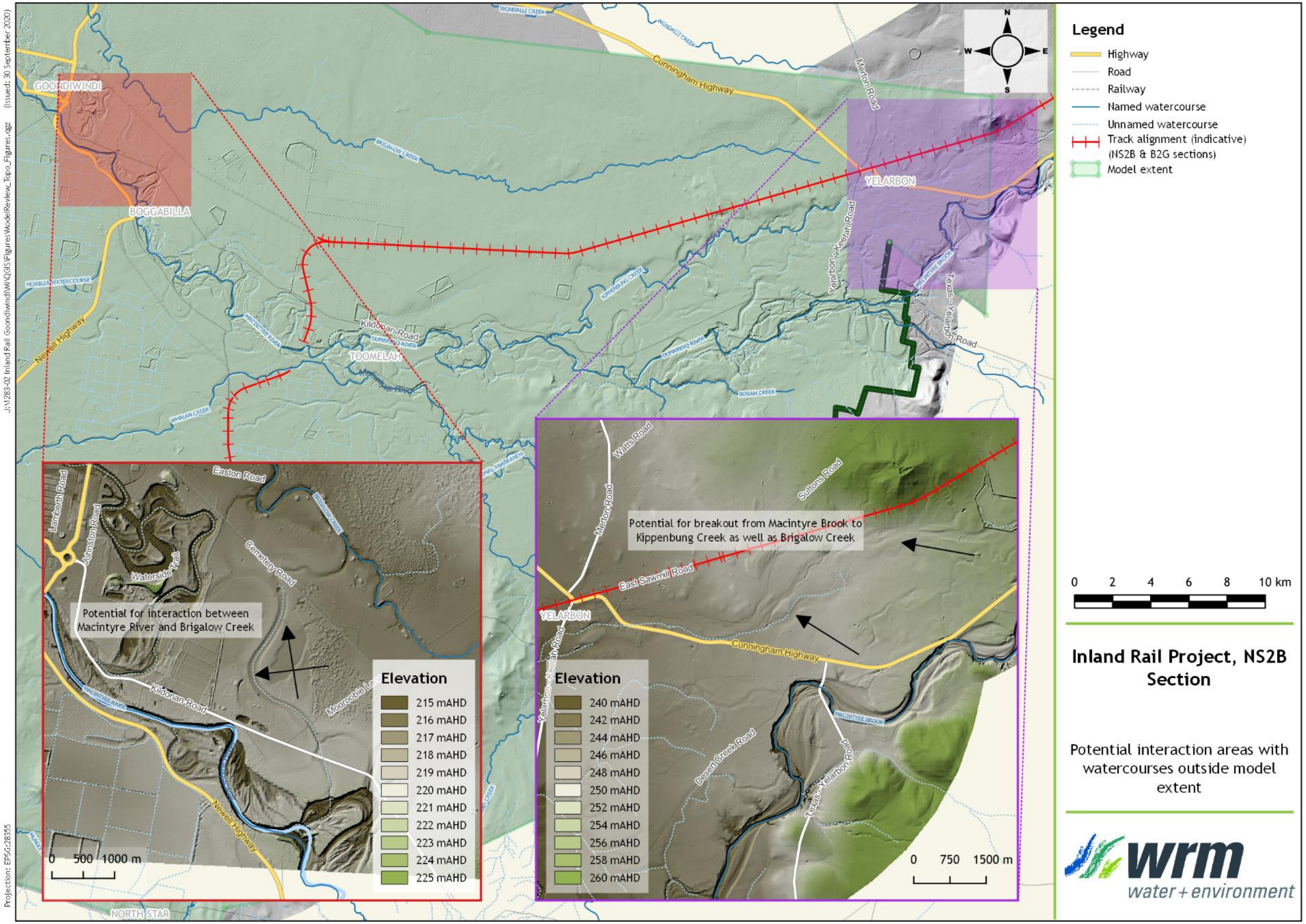


Figure 4-3 – Locations of potential interactions between the hydraulic model extent and waterways outside the model extent

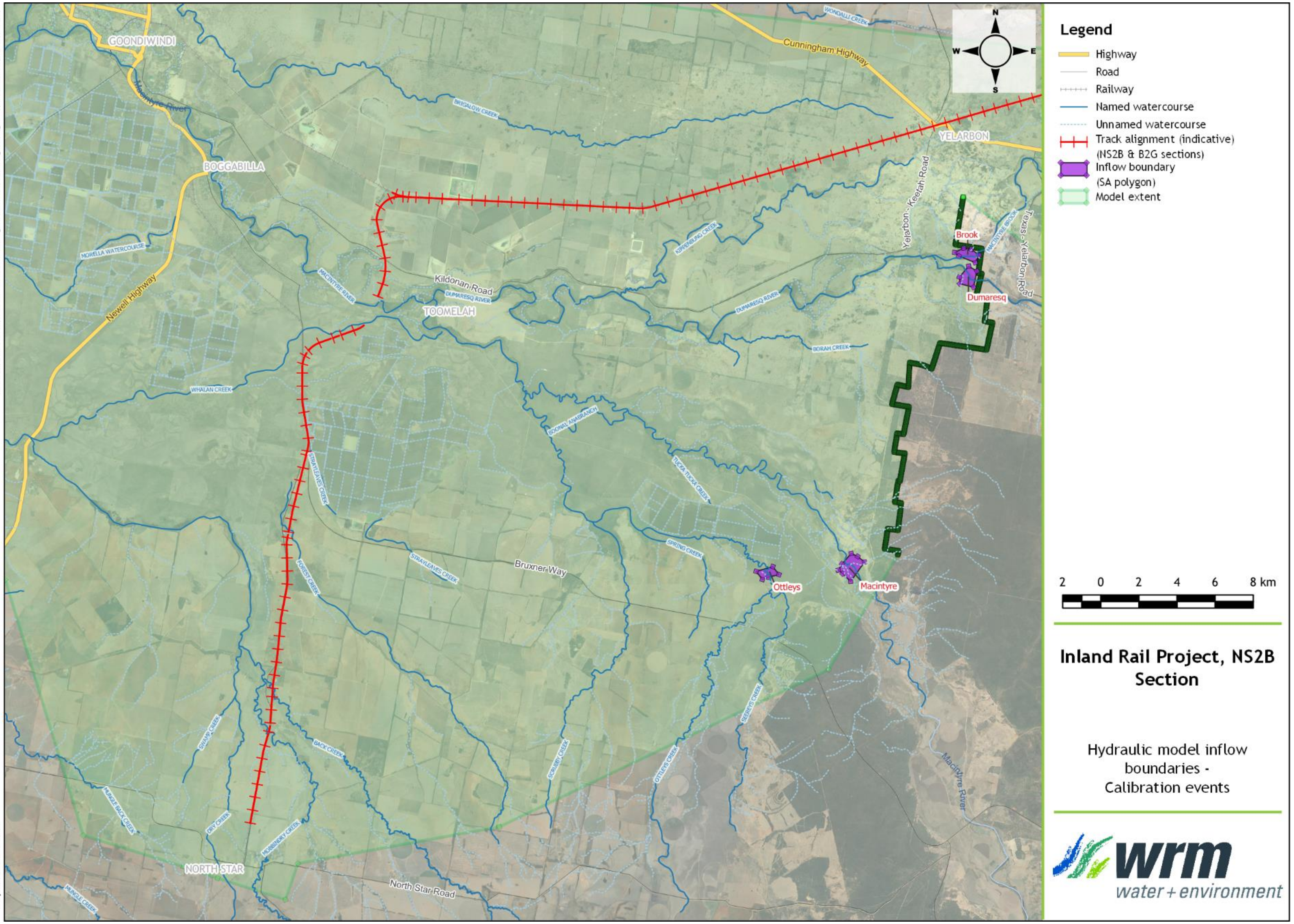


Figure 4-4 – Locations of adopted hydraulic model inflow boundaries, calibration events

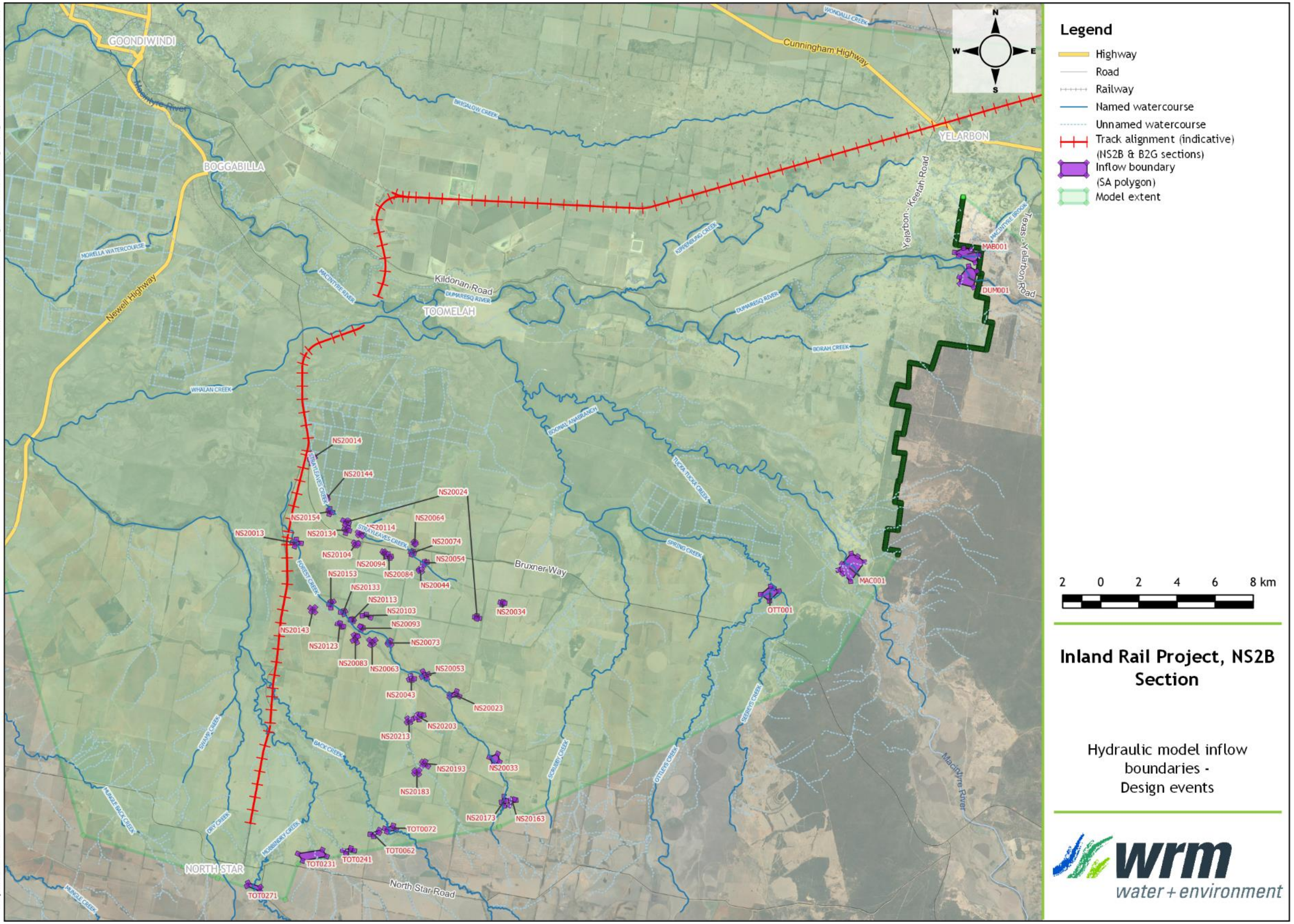


Figure 4-5 – Locations of adopted hydraulic model inflow boundaries, design events

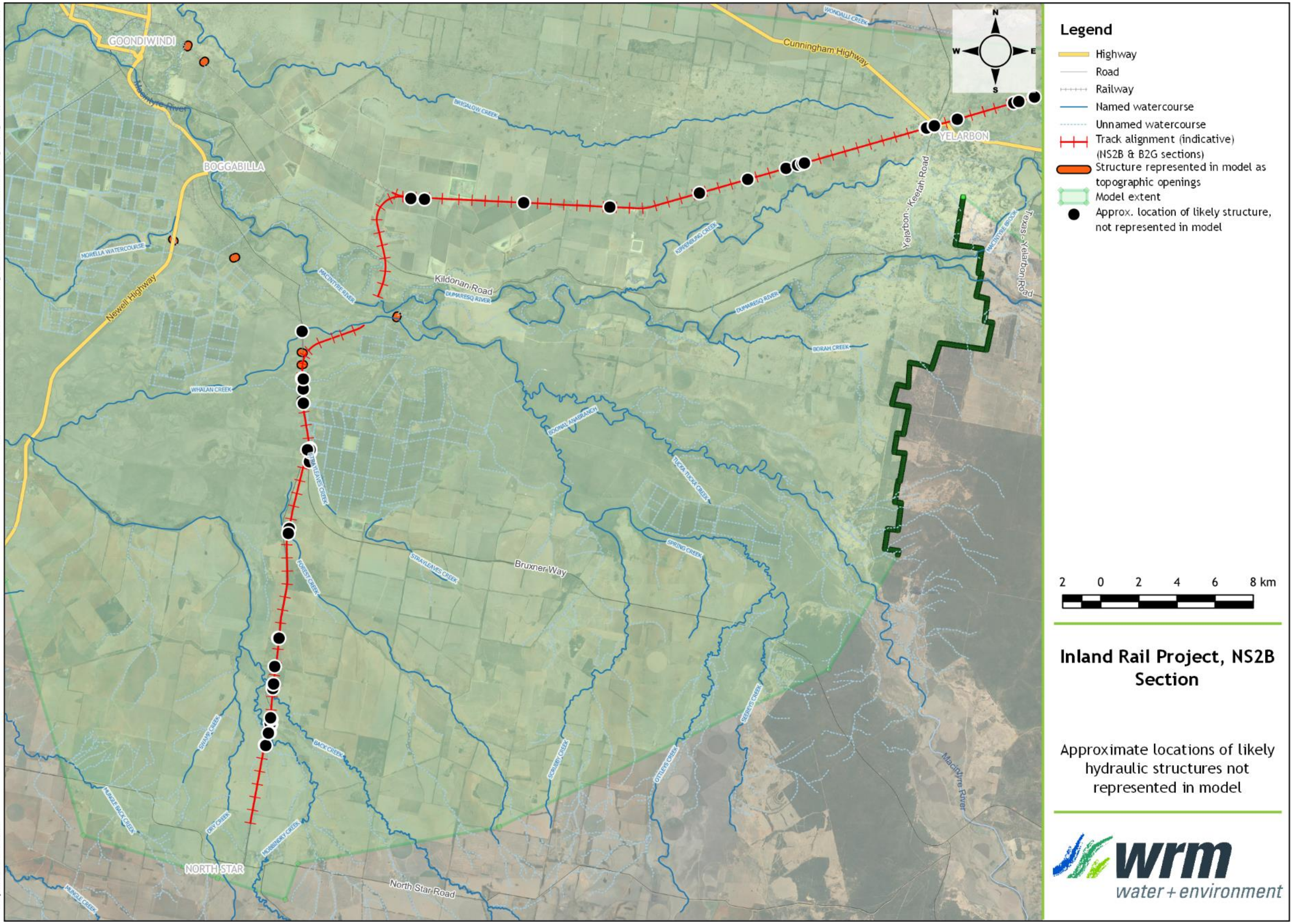


Figure 4-6 – Approximate locations where hydraulic structures may not be adequately represented in the TUFLOW model

5 Model calibration

5.1 OVERVIEW

FFJV's URBS and TUFLOW models have been calibrated against 3 historical flood events: February 1976, January 1996 and January 2011. Of these, the DPIE had calibrated their hydrologic and hydraulic models to the February 1976 and January 1996 events. FFJV have accepted and used the DPIE's hydrologic models and their calibrations with little or no change for their NS2B flood modelling. Based on their review of the DPIE models, FFJV have stated that the DPIE URBS model calibrations for the 1976 and 1996 events are reasonable and therefore there was no justification not to adopt DPIE calibration.

However, FFJV have found that there are uncertainties with DPIE's hydrologic and hydraulic models and their calibrations for the 1976 and 1996 flood events due to the quality of topographic and rainfall distribution data that was available to model those two events. Therefore, FFJV have also calibrated their hydrologic and hydraulic models to the January 2011 flood event to 'validate' the use of the previous DPIE modelling and to demonstrate the FFJV's hydrologic and hydraulic model performance for a recent flood event. Based on FFJV's reporting, the topography used in the models was varied to represent development on the floodplain, including levees, that existed at the time of each flood event.

Chapter 13 and Appendix H of BS2B EIS refer to a joint calibration of hydrologic and hydraulic models. This is misleading because no joint calibration has been undertaken. In response to one of my queries, FFJV have acknowledged that they have not undertaken a joint calibration of the hydrologic and hydraulic models, and stated that joint calibration was not the correct terminology to have been used in their reporting. They have clarified what they did by stating that their hydrologic models were calibrated to the upstream stream gauges and hydraulic model was then calibrated to Boggabilla and Goondiwindi stream gauges plus all the available flood markers, aerial and landholder photographs etc.

The URBS model calibrations have been limited to the Macintyre Brook, Dumaresq River, Macintyre River (upstream of Holdfast) and Ottleys Creek catchments. There was no calibration data for Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek catchments. Therefore, the URBS model results for these minor catchments have been validated against results from the Regional Flood Frequency Estimation (RFFE) model.

There are a number of technical shortcomings in the adopted model calibration and the adopted methodology is not consistent with current best practice. As a consequence, the adopted models are not, in my opinion, sufficiently reliable to assess the existing and proposed flooding behaviour in the modelled area. These shortcomings, which are discussed in the following subsections, would have an impact on the accuracy and reliability of the flood modelling that has been undertaken for the NS2B Reference Design.

The model validation undertaken for the four minor waterways also has technical shortcomings. These shortcomings are discussed in Section 6.3 of this report.

5.2 HYDROLOGIC MODELS

5.2.1 Overview

Sufficient details are not provided in Chapter 13 and Appendix H of BS2B EIS to assess the quality of DPIE's hydrologic model calibrations of the 1976 and 1996 flood events. However, sufficient details were available to assess the quality of their calibration for the 2011 flood event. The hydrologic models have been calibrated to rated January 2011 discharge data at the following five stream gauging stations:

- Macintyre Brook flows at Booba Sands;

- Dumaresq River flows at Farnbro and Roseneath;
- Macintyre River at Holdfast; and
- Ottleys Creek at Coolatai.

DPIE had used a XP-RAFTS model for the Ottleys Creek catchment. FFJV have converted this model into an URBS model for use in the NS2B flood modelling. FFJV's URBS model calibration of Ottleys Creek has also been tested against the 1996 flood event. Details of the Ottleys Creek calibration were also available for review.

5.2.2 Calibration shortcomings

Current modelling best practice, including the current ARR guidelines, requires hydrologic model calibrations to multiple historical flood events to be achieved with the same model and with a common (i.e. average or weighted) set of model parameters. In other words, FFJV should have used the same URBS models with a common set of model parameters for all three calibration events. This has not been done for the NS2B hydrologic modelling and therefore I believe this is a significant technical shortcoming in the flood modelling undertaken for the Reference Design.

For the model calibrations of Macintyre Brook, Dumaresq River and Macintyre River to the 1976, 1996 and 2011 flood events:

- DPIE calibrations for the 1976 and 1996 events have been achieved with different URBS models (i.e. with different model configurations).
- FFJV have used URBS models with different routing characteristics to calibrate against the 2011 event when compared to the 1996 event. Further, the 2011 URBS model for the Macintyre River does not include the Pindari Dam.

In response to one of my queries, FFJV has investigated the impact of including Pindari Dam on model results. FFJV state that the dam was at 100% capacity and spilling water throughout December 2010 and January 2011. Therefore, to assess the attenuation of flows through the reservoir they had undertaken a sensitivity run with the dam included in their model and this has shown that not including the dam results in peak water levels for the 2011 event that are 15 to 20 mm lower at the proposed NS2B alignment with the dam included. They have also noted that there is less than 1 mm difference in the vicinity of Goondiwindi. I note that in the context of the Macintyre River floodplain at the Proposed rail alignment, a 15 to 20 mm difference in flood level translates to at least a several hundred cubic meters difference in discharges.

The model calibration for Ottleys Creek also has technical shortcomings:

- Appendix H (Section 7.4 and Figure 7.7) of the NS2B EIS states that the 2011 event was an insignificant event in the Ottleys Creek catchment because the recorded rainfall and rated peak discharge at Coolatai were very small (27 mm and 3 m^3/s respectively). The daily rainfalls recorded at Coolatai, which appear to be consistent with rainfalls recorded at nearby stations during this event, were smaller than a 24-hour 50% AEP rainfall (based on Appendix H, Table 8.1).
- The above assessment and justification for an insignificant flood event in Ottleys Creek is contradicted by the adopted 2011 calibration event hydrologic model results, and the use of Ottleys Creek inflows of up to 546 m^3/s in the 2011 event hydraulic model calibration.
- In response to one of my queries, FFJV have stated that, if the hydrologic modelling was adjusted to match the rated flows at the Coolatai gauge then it was not possible to replicate the observed flooding downstream of the gauge. The FFJV have justified the adoption of such high Ottleys Creek inflows based on conversations they had with the community on flooding in lower Ottleys Creek before the main river event during the 2011 event. No details on this anecdotal information collected has been provided for review. It is noted that the modelled 2011 flows in Ottleys Creek are significantly higher than the modelled flows for the 1976 event (399 m^3/s) and the 1996 event (383 m^3/s), and significantly higher rainfalls were

recorded in this catchment during the 1976 and 1996 events when compared to the 2011 event. Further, based on the provided design discharges, the modelled 2011 flow has an AEP of between 5% and 2%. Based on available recorded rainfalls, it is extremely unlikely that the 2011 event flows were higher than the 1976 event and 1996 event flows and that the 2011 event was between a 5% and 2% AEP event.

- The above anecdotal evidence on lower Ottleys Creek flooding in 2011 relied on by FFJV is not consistent with information provided by the local landholders I met during my site visit. According to those local landholders, the 2011 flooding in Ottleys Creek was not significant. The largest flood event they have experienced in Ottleys Creek was in 1996 and that event was larger than in 1976. It is of note that the local landholder information on the 2011 event is consistent with recorded data reported in Appendix H of the NS2B EIS.

5.3 HYDRAULIC MODEL

5.3.1 Overview

The TUFLOW model has been calibrated to recorded water levels at Boggabilla and Goondiwindi stream gauging stations, surveyed debris mark levels and anecdotal data provided by different sources for the February 1976, January 1996 and January 2011 flood events. This adopted approach is appropriate. It appears that there was no recorded or anecdotal data for model calibration along the four minor waterways crossing the NS2B alignment to the south of the Macintyre River.

Based on Sections 5.1 and 5.3 of Appendix H of the NS2B EIS, DPIE have identified many constraints and deficiencies with their 1976 and 1996 hydraulic model calibrations because of the uncertainties in floodplain conditions at that time. The following is of note with respect to the 1976 and 1996 model calibrations:

- DPIE has had to factor up (i.e. increase) all 1976 event Macintyre Brook, Dumaresq River, Macintyre River and Ottleys Creek URBS model calibrated inflows to their hydraulic model by 120% to achieve an acceptable calibration downstream of Goondiwindi; and
- DPIE has had to factor up all 1996 event Macintyre Brook, Dumaresq River, Macintyre River and Ottleys Creek URBS model calibrated inflows to their hydraulic model by 160% to achieve an acceptable calibration in their modelled area.

The hydraulic model calibrations for the above two historical events have been undertaken with model inflows at only four inflow locations. That is, the DPIE hydraulic model has been calibrated ignoring local inflows from an area of more than 11,000 km^2. In my opinion, it is likely that inflows to the hydraulic model had to be factored up to compensate for the non-inclusion of local (residual) catchment inflows in their hydraulic model.

The hydrologic model outputs for the 2011 flood event have been used in the FFJV hydraulic model without any factoring. It is of note that this FFJV hydraulic model is only 2,600 km^2 in area when compared to the 11,000 km^2 area in the DPIE hydraulic model.

5.3.2 Calibrations results

Overall, in my opinion, the FFJV calibration results are not as good as it has been claimed in the NS2B EIS. The reasons for this opinion are given below.

5.3.2.1 Gauging stations

The model calibrations have attempted to achieve a stated target accuracy of ±0.15 m at the Boggabilla and Goondiwindi stream gauging stations:

- The modelling achieves the stated target accuracy at the Boggabilla gauge for all three calibrations events:

- When unfactored inflows are used for the calibration, the differences between modelled and recorded peak water levels for the 1976, 1996 and 2011 calibration events are 0.09 m, 0.12 m and 0.05 m respectively. For all three events, the model has underestimated peak flood levels when compared to recorded peak flood levels.
- When factored inflows are used for the calibration, the predicted peak flood levels increase by 0.04 m for the 1976 event and by 0.20 m for the 1996 event when compared to the unfactored flows. For this scenario, the modelled peak flood level for the 1976 event is 0.05 m lower than the recorded peak level and the modelled peak flood level for the 1996 event is 0.08 m higher than the recorded peak level.

- The modelling does not generally achieve the stated target accuracy (±0.15m) at the Goondiwindi stream gauging station:
  - When unfactored inflows are used for the calibration, the predicted peak flood levels are 0.33 m higher for the 1976 event, 0.12 m lower for the 1996 event and 0.23 higher for the 2011 event when compared to the recorded peak flood levels.
  - When factored inflows are used for the calibration, the modelled peak water levels for the 1976 and 1996 calibration events are 0.34 m and 0.24 m respectively higher than the recorded peak flood levels. Factoring the inflows has raised the 1976 peak flood level by 0.01 m and the 1996 peak flood level by 0.05 m when compared to unfactored flows.
  - The Goondiwindi levees are not configured correctly in the TUFLOW model for the 1976 and 1996 model configuration. This, together with the inaccurate representation of the potential interactions between the Macintyre River and Brigalow Creek, is likely to have affected the ability of the model to achieve a better calibration to recorded water levels at the Goondiwindi gauge.

Based on factored inflow results (Table 7.7 in Appendix H, NS2B EIS), it appears that the Macintyre River total flows at Boggabilla (and hence at the proposed rail crossing) are significantly overestimated by the hydraulic model for all three calibrations events. FFJV have attributed this to the significant uncertainty in the Boggabilla rating projection. I agree that there are significant uncertainties regarding the Boggabilla gauge rating curve, however these uncertainties are expected only for rated discharges significantly above its highest gauged flow (which is approximately 3,500 m^3/s gauged during the 1996 flood event). Therefore, I would expect the differences between the calibrated hydraulic model peak discharges and rated total peak discharges at Boggabilla for the 1996 event (rated - 3,486 m^3/s vs TUFLOW – 5,104 m^3/s) and 2011 event (rated - 3,803 m^3/s vs TUFLOW – 4,449 m^3/s) to be much closer.

5.3.2.2 February 1976 event

There is a significant difference between the rated (approximately 4,500 m^3/s - see Figure 8.9, Appendix H) and predicted (8,700 m^3/s - see Figure 7.21 and Table 7.13, Appendix H) total peak discharges at Boggabilla for the 1976 event. Even after taking into account the uncertainties associated with the Boggabilla rating curve, it appears that the hydraulic model is significantly overestimating the breakouts into Whalan Creek and Morella Watercourse for the 1976 event. This is consistent with Figure A5-C in Appendix H of the NS2B EIS, which shows that the hydraulic model is significantly overestimating these breakouts.

The February 1976 peak flood levels obtained at 38 locations across the modelled area have been available for the hydraulic model calibration. As described in Section 3.4, it is understood that these peak flood levels have been obtained from multiple sources, including some debris mark surveys, and would have varying levels of accuracy and reliability. Based on the available peak flood levels, Table 5-1 shows a comparison of the number of these 38 locations (and as a percentage of the total number of locations) for which predicted peak flood levels fall within various accuracy level ranges for peak flood levels predicted by FFJV's hydraulic model. A negative accuracy value means that the modelled level is lower than the recorded level. Comparisons are shown for both the adopted model calibration and the model sensitivity results undertaken without the 120% factoring of model inflows. The comparisons show that:

- About 50% of the calibration point differences are outside the ± 0.3 m target band, and if the locations that were flooded but predicted by the model to be dry are included, more than 50% of the calibration points would be outside the ±0.30 m accuracy range. This percentage does not change much even for results without the factored inflows.
- The hydraulic model results are generally biased low with the TUFLOW model predicting lower peak flood levels at more than 65% of the survey locations. This percentage increases to more than 75% when the inflow factoring is removed.

It appears that most of the peak flood level overestimations shown in Table 5-1 occur across Whalan Creek and Morella Watercourse, suggesting that peak flood levels elsewhere across most of the modelled area are underestimated (and are biased low) with or without the factoring of model inflows.

Table 5-1 Comparison of accuracy levels achieved for the 1976 flood event with factored and unfactored inflows

Model accuracy range (m)	FFJV model (factored flows)		FFJV model (unfactored flows)	
	No of Flood Marks	%	No of Flood Marks	%
Flooded but predicted to be dry	2	5.3	3	7.9
<-0.30	15	39.5	17	44.7
-0.30 to -0.20	2	5.3	4	10.5
-0.20 to -0.10	2	5.3	1	2.6
-0.10 to 0.0	4	10.5	4	10.5
0.0 to 0.10	3	7.9	3	7.9
0.10 to 0.20	4	10.5	2	5.3
0.20 to 0.30	2	5.3	2	5.3
>0.30	4	10.5	2	5.3
Totals	**38**	**100**	**38**	**100**

5.3.2.3 January 1996 event

The 1996 calibration is biased too high (see Table 7.14 and Figures 7.22 & 7.23 of Appendix H, NS2B EIS). This is consistent with Figure A6-B in Appendix H of the NS2B EIS. It is recalled that the 1996 event hydraulic model calibration has been achieved using output from a hydrologic model with a different configuration to that used for the 1976 event.

The January 1996 peak flood levels obtained at only 8 locations across the modelled area have been available for the hydraulic model calibration. Again, the accuracy and reliability of the available peak flood data is not known. Based on the available peak flood levels, Table 5-2 shows a comparison of the number of these 8 locations (and as a percentage of the total number of locations) for which predicted peak flood levels fall within various accuracy level ranges for peak flood levels predicted by FFJV's hydraulic model. Comparisons are shown for both the adopted model calibration and the model sensitivity results undertaken without the 160% factoring of model inflows. The comparisons show that:

- 37.5% (3) of the calibration point differences are outside the ± 0.3 m target band. This percentage reduces to 25% for model results without the factored model inflows.

- The hydraulic model results are generally biased high with the model predicting higher peak flood levels at 87.5% (7) of the survey locations. This percentage reduces to 75% when the inflow factoring is removed.

Table 5-2 Comparison of accuracy levels achieved for the 1996 flood event with factored and unfactored inflows

Model accuracy range (m)	FFJV model (factored flows)		FFJV model (unfactored flows)	
	No of Flood Marks	%	No of Flood Marks	%
Flooded but predicted to be dry	0	0	0	0
<-0.30	0	0	0	0
-0.30 to -0.20	0	0	0	0
-0.20 to -0.10	1	12.5	2	25
-0.10 to 0.0	0	0	0	0
0.0 to 0.10	2	25	3	37.5
0.10 to 0.20	1	12.5	1	12.5
0.20 to 0.30	1	12.5	0	0
>0.30	3	37.5	2	25
Totals	**8**	**100**	**8**	**100**

5.3.2.4 January 2011 event

The 2011 calibration has been achieved using Ottleys Creek inflows of up to 540 m^3/s and this is not consistent with FFJV's reporting for this event (see Section 5.5.2 of this report). The adopted Ottleys Creek inflows are quite significant and are likely to have significant implications for the 2011 calibration (as later discussed in Section 7.3.4 of this report). It is also recalled that the 2011 event hydraulic model calibration has been achieved using output from a hydrologic model with a different configuration to that used for the 1996 event.

The January 2011 peak flood levels obtained at 52 locations across the study area have been available for the hydraulic model calibration. Again, the accuracy and reliability of the available peak flood data is not known. Based on the available peak flood levels, Table 5-3 shows a comparison of the number of these 52 locations (and as a percentage of the total number of locations) for which predicted peak flood levels fall within various accuracy level ranges for peak flood levels predicted by FFJV's hydraulic model. Comparisons are shown for both the adopted (30 m grid) model calibration and model sensitivity results undertaken with a smaller (15 m) grid size. The comparisons show that:

- About 23% of the calibration point differences are outside the ± 0.3 m target band, and if the locations that were flooded but predicted by the model to be dry are included, more than 30% of the calibration points would be outside the ±0.30 m accuracy range. This percentage increases a little to about 33% for results with the smaller model grid size.
- Overall, the model results show less bias when compared to the 1976 and 1996 events, with about 55% of the modelled peak flood levels being lower than equivalent recorded levels. This percentage increases to about 57% for the smaller grid size model.

For the 2011 event, it appears that predicted Macintyre River flood levels between Boggabilla and Goondiwindi are underpredicted most likely because the TUFLOW model does not take into account flows coming down Brigalow Creek. Also, the modelled flow distribution between Macintyre River and Whalan Creek/Morella Watercourse for this event does not appear to be sufficiently accurate (see Figure A7-B in Appendix H, BS2 EIS).

Table 5-3 Comparison of accuracy levels achieved for the 2011 flood event with 30 m and 15 m grid sizes

Model accuracy range (m)	FFJV model (30 m grid)		FFJV model (15 m grid)	
	No of Flood Marks	%	No of Flood Marks	%
Flooded but predicted to be dry	4	7.7	2	3.8
<-0.30	4	7.7	8	15.4
-0.30 to -0.20	6	11.5	6	11.5
-0.20 to -0.10	6	11.5	6	11.5
-0.10 to 0.0	9	17.3	8	15.4
0.0 to 0.10	4	7.7	5	9.6
0.10 to 0.20	4	7.7	4	7.7
0.20 to 0.30	7	13.5	6	11.5
>0.30	8	15.4	7	13.5
Totals	**52**	**100**	**52**	**100**

6 Flood frequency analyses

6.1 OVERVIEW

FFJV have undertaken flood frequency analyses (FFA) to reconcile their hydrologic and hydraulic model design discharge estimates against FFA results for the four major waterways (Macintyre Brook, Dumaresq River Macintyre River and Ottleys Creek). For the four minor waterways (Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek), in the absence of calibration results, FFJV have undertaken Regional Flood Frequency Estimations (RFFE) to validate (reconcile) their hydrologic model results. This approach is appropriate and current best practice. However, there a number of technical shortcomings in the FFA's that have been undertaken as well as the reconciliations undertaken between FFA and RFFE results and URBS and TUFLOW model design discharge estimates.

6.2 MAJOR WATERWAYS

6.2.1 Hydrologic model results reconciliation

FFJV have used Generalised Extreme Value (GEV) frequency distributions to fit peak annual discharges at Macintyre Brook at Booba Sands, Dumaresq River at Farnbro, Macintyre River at Holdfast and Ottleys Creek at Coolatai stream gauging stations (see Figures 8.1 to 8.5 in Appendix H, NS2B EIS) when Log Pearson III (LPIII) frequency distributions appear to provide better fits to recorded peak discharges at these stations.

In response to one of my queries, FFJV have stated that the GEV distributions were adopted based on preliminary advice from ARR 2016 at the time these investigations commenced. I believe the preliminary FFA results should have been updated with LPIII distribution results and the updated results should have been used for reconciliation with design event results when further and more appropriate information became available prior to the completion of the NS2B Reference Design.

In response to one of my queries, FFJV have stated that they examined the fitted distributions for all gauges, and they noted that the gauges at Macintyre Brook at Booba Sands, Macintyre River at Holdfast and Ottleys Creek at Coolatai did not exhibit significant differences between the LPIII and GEV distributions. Therefore, they did not see any justification to adopt the LPIII over the GEV. This assessment is not consistent with available data, which shows that:

- The GEV and LPIII distributions provide similar results only for Ottleys Creek at Coolatai (see Figure 6-1);
- For the Macintyre River at Holdfast, the LPIII discharges are about 21% and 15% respectively higher than the GEV discharges for the 2% and 1% AEP events (see Figure 6-2);
- For the Dumaresq River at Roseneath, the LPIII discharges are about 22% and 23% respectively higher than the GEV discharges for the 2% and 1% AEP events (see Figure 6-3); and
- For the Macintyre Book at Booba Sands, the LPIII discharges are about 16% and 5% respectively higher than the GEV discharges for the 2% and 1% AEP events (see Figure 6-4);

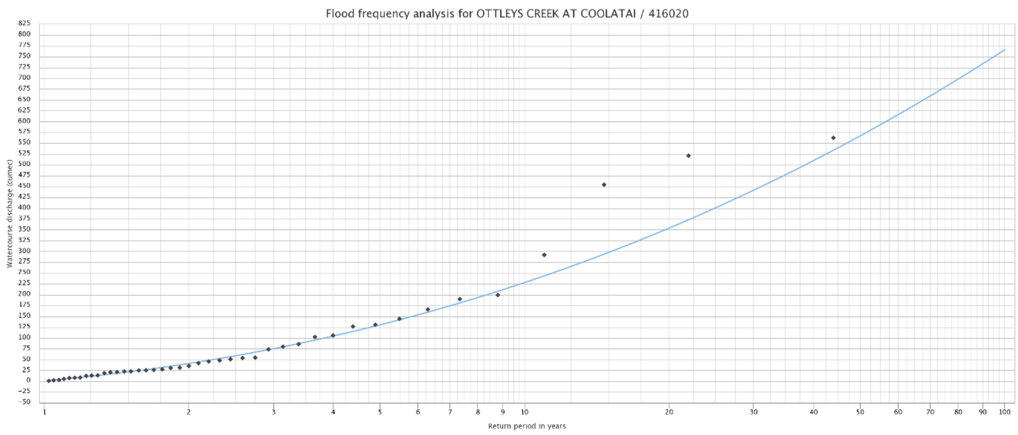
The adoption of more appropriate LPIII distributions would have produced different FFA results and, in my opinion, this would have had significant implications for the adopted design discharges and reconciliation of the URBS model results against FFA results, including the adopted rainfall losses for the Macintyre Brook, Dumaresq River and Macintyre River.

Based on information available, it is unclear how well the reconciliation between the FFA results and design event results has been done because the discussion provided in Section

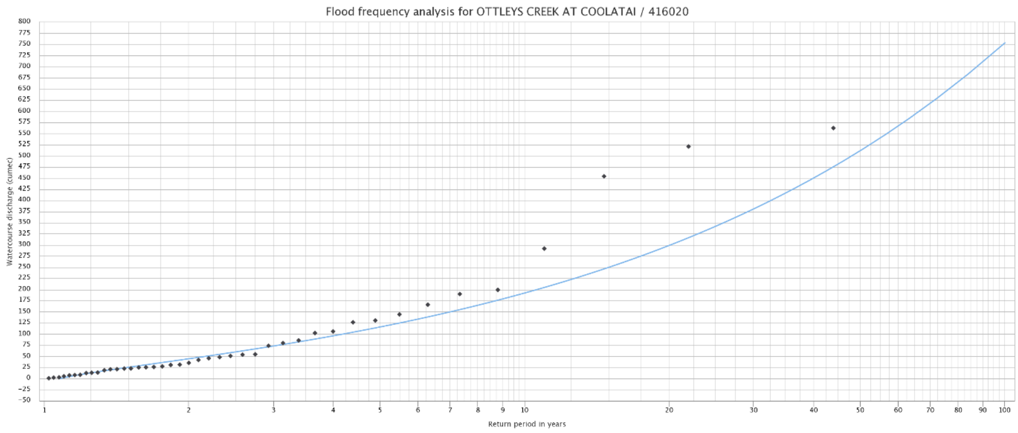
8.1.4 of Appendix H, NS2B EIS on how the adopted design rainfall losses (IL/CL) were derived is inadequate. It does not appear that FFA's for Macintyre Brook, Dumaresq River and Macintyre River have been reconciled by adequately adjusting losses. The adopted losses do not appear to have any similarity to the ARR data hub or calibrated loss values.

There are also a number of reporting errors with respect to FFA results presented in the NS2B EISs. These include:

- The plotted modelled design 1% AEP discharge for Macintyre Brook at Booba Sands does not appear to be correct. The plotted value in Appendix H (Figure 8.1) is about 1,100 m^3/s whereas the URBS model predicted value is 2,278 m^3/s.
- The plotted 1996 flood discharge in Appendix H (Figure 8.5) for the Ottleys Creek at Coolatai should be larger than a 2% AEP after the required correction for the incorrectly plotted recorded discharges in Appendix H (Figure 7.6).

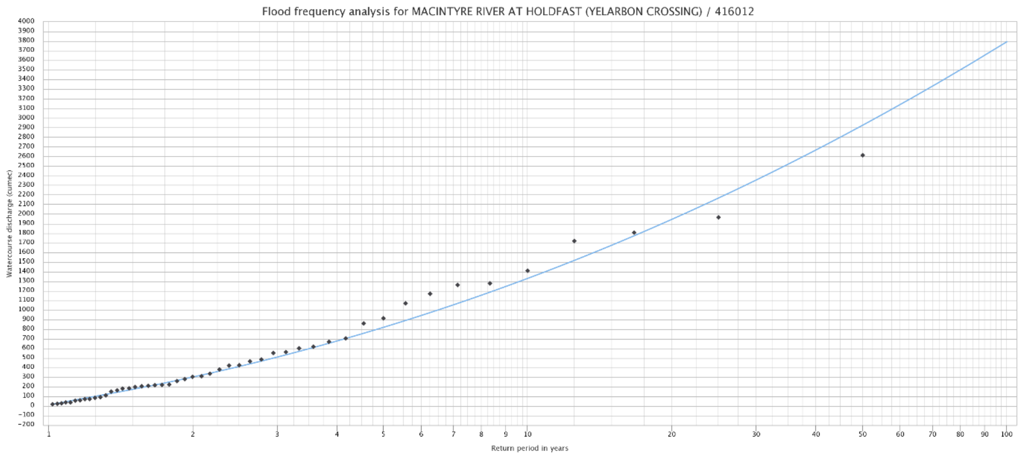


LPIII

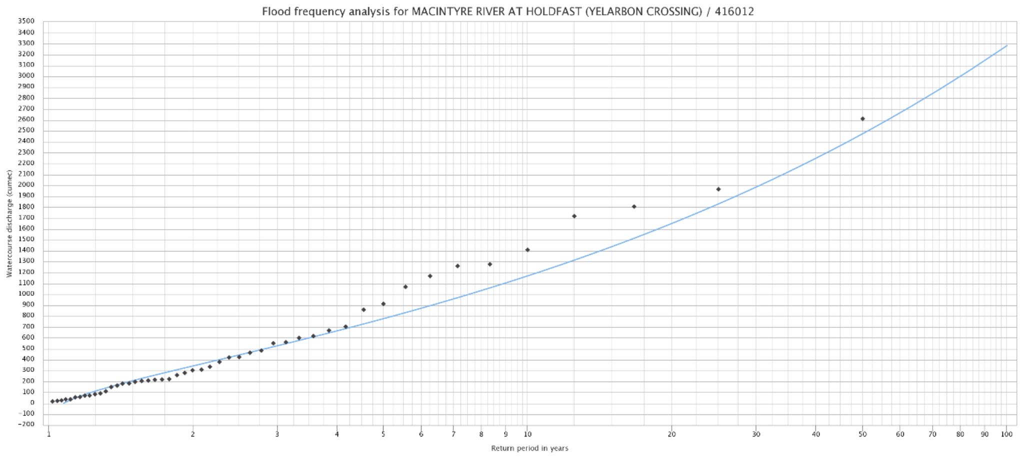


GEV

Figure 6-1 - Comparison of GEV and LPIII flood frequency distributions for Ottleys Creek at Coolatai (source: BOM Water Data Online)

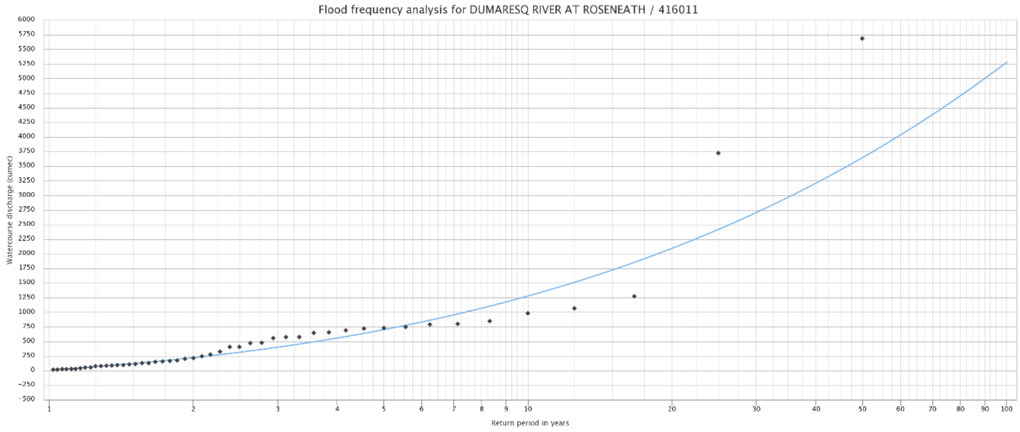


LPIII

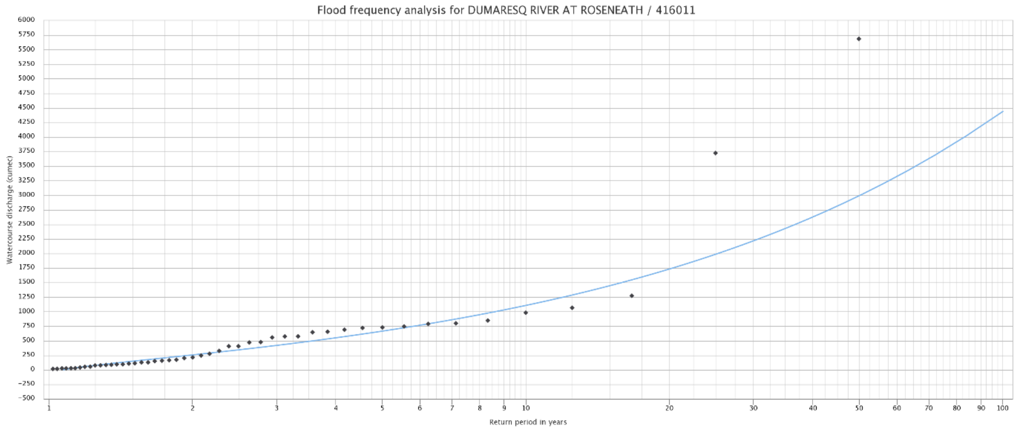


GEV

Figure 6-2 – Comparison of GEV and LPIII flood frequency distributions for Macintyre River at Holdfast (source: BOM Water Data Online)

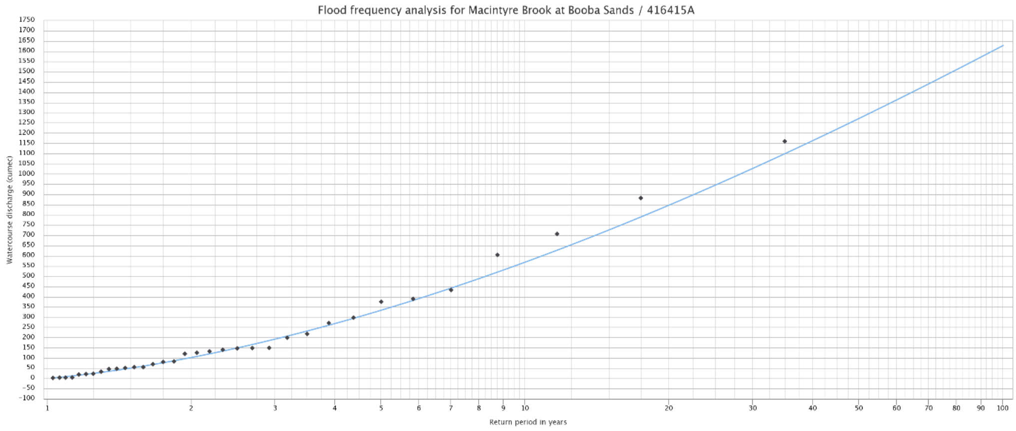


LPIII

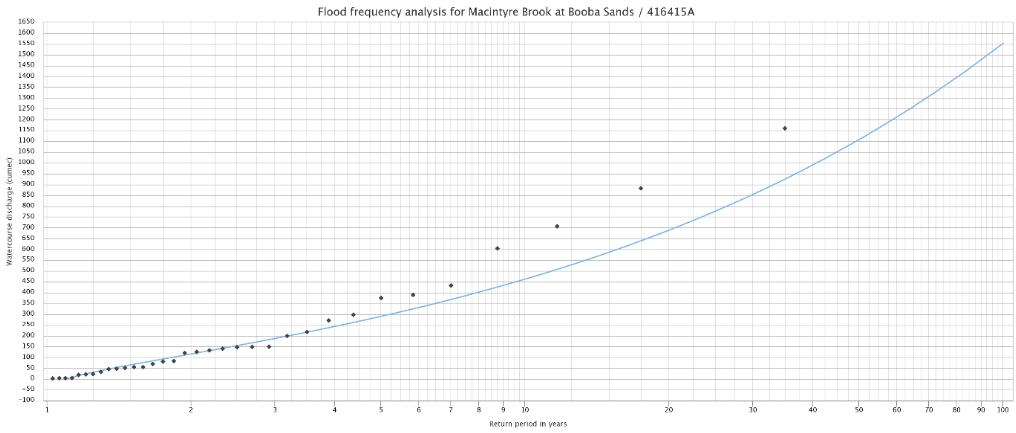


GEV

Figure 6-3 – Comparison of GEV and LPIII flood frequency distributions for Dumaresq River at Roseneath (source: BOM Water Data Online)



LPIII



GEV

Figure 6-4 – Comparison of GEV and LPIII flood frequency distributions for Macintyre Brook at Booba Sands (source: BOM Water Data Online)

6.2.2 Hydraulic model results reconciliation

The Boggabilla stream gauge is the key reconciliation point for the combined hydrologic and hydraulic modelling for the NS2B alignment. Because of the significant uncertainties associated with the Goondiwindi gauge rating above bankfull discharge, Goondiwindi gauge is not considered suitable for the derivation of a reliable FFA.

For the above reason, I believe a flood reconciliation of FFA results and modelled design discharges at Boggabilla is very important for the accuracy of NS2B flood modelling.

Based on information provided by FFJV, anecdotal historical flood data available prior to the period of recorded data for any of the gauging stations has not been considered or used in any of the FFA's undertaken for the NS2B project. Current best practice is to incorporate this anecdotal information in the FFA.

Based on information available from the BOM website, it appears that there were two major flood events in 1886 and 1890 in Boggabilla prior to the period of record dating back to 1896/97 used for the Boggabilla FFA. Because of the long (117 year) period of record available and used for the Boggabilla gauge, the inclusion of this additional anecdotal data may not materially change the FFA results. However, they should be considered to ensure that this anecdotal data has no material impact on adopted FFA results.

The reliability of the Boggabilla Rating Curve for very large flows is low. However, based on information provided in response one of my queries, FFJV state that the Boggabilla rating is reasonably consistent with gauged flows, as shown in Appendix H (Figure 8.6), except for rated flows higher that the highest gauged flow of about 3,500 m^3/s. Therefore, as stated in the BS2B EIS, a good reconciliation between the FFA results and the design discharges at Boggabilla should have been achieved for events more frequent than the 1% AEP. This has not been achieved.

The TUFLOW model predicted design discharges at Boggabilla for all events between 20% AEP and 1% AEP are considerably higher than the FFA results (even after reducing TUFLOW model inflows by 30% to apparently to try and match the FFA results - see Section 8.2.4 of Appendix H). For example, the modelled 20% AEP design discharge at Boggabilla is about 18% higher than the FFA and the modelled 10% AEP design discharge is about 28% higher than the FFA. In my opinion, these differences between FFA and TUFLOW model results are too large.

In response to one of my queries, FFJV have stated that their reconciliation at Boggabilla must:

- be appropriately conservative for the purpose and level of detail required for the NS2B Reference Design investigation; and
- consider the magnitude and expected frequency of the historical events and produce results acceptable to stakeholders (i.e. further decreasing the rainfall intensity would increase the equivalent AEP of estimated 1976 flow to in excess of 1 in 500 to 1 in 2000). While statistically possible, this would be more difficult to pass review by stakeholders who would demand/expect a realistic estimate.

FFJV have also stated that, given the ‘complexities of the stream gauge and the upstream floodplain flows’, they believe that a good reconciliation has been achieved for the purposes of the Reference Design. FFJV have further stated that their reconciliation to the FFA will be reviewed further during future stages of the project.

In my opinion, the above statements from FFJV do not reflect a best practice approach to engineering analysis and design. I do not agree with their reasoning for not achieving an accurate reconciliation at Boggabilla. Their reasoning appears to provide an implicit acknowledgment that the flood modelling undertaken by FFJV for the NS2B project is not sufficiently accurate or reliable to estimate design discharges and flood levels.

6.3 MINOR WATERWAYS

In the absence of calibration data, the URBS model results for Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek have been validated against RFFE estimates. I believe this approach is appropriate. However, the model validations have been undertaken against the RFFE results for the 1% AEP event only.

The RFFE estimates at all four locations used to reconcile the URBS model results are based only on 30 to 40 years of recorded discharges at the nearest stream gauging stations. Therefore, the RFFE estimates at these stations are likely to be reliable only for AEPs up to 5% at best. The 1% AEP results used for the URBS model validations would be the least reliable of the RFFE estimates available for model validations. A comparison of the adopted URBS discharges and RFFE results shows that the URBS discharges for the more frequent events are significantly higher than the RFFE estimates. For example, for the 20% AEP events, the URBS model estimates for the four minor waterways are between 78% and 174% higher than the RFFE estimate, and for the 10% AEP event, the URBS model estimates are between 50% and 111% higher than the RFFE estimates. It is recalled that SEARs condition 8.2.a requires accurate and best practice modelling for the full range of flood event, not just the 1% AEP event.

Based on responses to one of my queries, FFJV have stated that the focus for their flood impact assessment was the 1% AEP event and therefore the RFFE estimate comparison also focused on the 1% AEP event, noting that the RFFE approach is an approximate method only and less reliable for larger floods primarily due to the available length of records. They have also stated that further refinement of flows on the southern tributaries could be undertaken and would be likely to result in reduction in the 1% AEP flows for the southern tributaries, and the flows therefore used in the current assessment are expected to be conservative in nature.

7 Design event modelling

7.1 OVERVIEW

The hydrologic and hydraulic modelling for design event analyses are required to be undertaken in accordance with the current best practice, including current Australian Rainfall and Runoff (ARR) standards and guidelines for a range of design flood events from 20% AEP up to the PMF.

Based on my review of the design event modelling, there are some significant technical shortcomings in design event modelling undertaken by FFJV. These shortcomings and some of the apparent implications of these shortcomings are discussed in the following sub sections.

7.2 HYDROLOGIC MODELLING

7.2.1 Adopted model

According to the NS2B EIS, the 2011 flood event was added to the model calibration to confirm and validate the model calibration and provide more confidence in the modelling results due to the uncertainties associated with the 1996 flood event model. Yet FFJV have run the design flood events using a different URBS model configuration to the configuration they used for the 2011 event calibration. In my opinion, this is a major technical shortcoming in the design event analyses and does not reflect current best practice and ARR guidelines.

In response to one of my queries, FFJV have acknowledged that the design event modelling was undertaken with a different configuration of the URBS model to that used for the 2011 flood event. The stated reason for this is that FFJV used the DPIE model calibrated to the 1996 flood event as the basis for their design event analyses because the FFJV modellers had to provide design discharge information to the wider design team when the 2011 model calibration was still in progress. It is not known why the design discharge information was not updated with a properly calibrated model once the 2011 calibration was completed. This appears to suggest that the design discharges and flood levels used for the Reference Design and the flood impact assessment are not based on FFJV's latest calibrated models and the Reference Design has been undertaken with preliminary (not the latest) design discharges and flood levels. This information is not presented in Chapter 13 and Appendix H of the NS2B EIS.

The URBS model used for the Macintyre River design event analysis (and therefore the Reference Design) does not include the Pindari Dam, which is likely to influence design discharges in the Macintyre River, and therefore the downstream design flood levels.

7.2.2 Adopted approach

FFJV have undertaken design event modelling using an approach that is not consistent with the current ARR guidelines (see Section 4). As a consequence, the design event analyses have been undertaken using inappropriate design rainfalls, rainfall aerial reduction factors, rainfall temporal patterns and rainfall losses. This is most likely the reason why FFJV had to reduce (i.e. factor down) all their design inflows into the hydraulic model by 30% (see Section 8.2.4 of Appendix H, NS2B EIS). This is likely to have also resulted in significant reductions in modelled flood volumes (in addition to the reduction in flood volume caused by the omission of local catchment inflows) possibly explaining why the design event results are not consistent with calibration event results (see Section 7.3.4).

7.2.3 Critical storm durations

The adopted approach also may have resulted in the selection of inappropriate critical storm durations for the catchment draining to NS2B rail alignment for reasons discussed below.

Based on Appendix H (Table 8.5) of the NS2B EIS and the provided modelling data and results, it appears that the TUFLOW model has not been run for some of the contributing catchment critical storm durations. For example, FFJV have estimated the critical duration for Macintyre Brook at Booba Sands for all AEPs to be 72 hours, the critical duration for Dumaresq River at Beebo for the 20% AEP to be 36 hours, and the critical duration for Macintyre River at Holdfast for AEPs up to 5% AEP to be 96 hours. Yet, based on model input and output files provided for review, there is no evidence to show that FFJV have run their TUFLOW model for these durations.

Further, the critical durations for the Macintyre River at Boggabilla and Goondiwindi are likely to be longer than the critical durations at the upstream inflow gauging stations. Based on model files and results provided for review, no hydraulic modelling has been undertaken for durations greater than 48 hours for the 1% AEP event and greater than 72 hours for the more frequent events. This is could potentially have a significant impact on the design event results for the full range of flood events modelled for the BS2B flood modelling.

In response to one of my queries, FFJV have stated that a ‘full critical duration assessment was previously undertaken up to and including the 96 hour duration’. They have also stated that, ‘from this earlier work a reduced suite of durations was selected for iterations of the design to be able to complete the modelling in a realistic timeframe’. Details of this earlier work and its results have not been available for this review.

7.3 HYDRAULIC MODELLING

7.3.1 General

There are question marks on the accuracy, reliability and robustness of the hydraulic modelling undertaken and its results used for the Reference Design because of the shortcomings in hydrologic and hydraulic modelling, including model configuration, model input and model calibration, as identified and described earlier in this report.

It appears that shortcomings in the flood modelling undertaken by FFJV have resulted in unreliable and inconsistent results. Based on information that was made available to me, I have picked up some of the issues potentially causing modelling inaccuracies, which are discussed below.

7.3.2 Minor waterway modelling

Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek inflows input to the TUFLOW model do not appear to be consistent with the URBS model outputs for these creeks.

For Mobbindry Creek and Back Creek, the residual inflows downstream of the hydraulic model upstream boundaries representing 16% of the Mobbindry Creek and 29% of the Back Creek catchments upstream of the proposed rail line are not accounted for in the model. In my opinion, this could have a significant impact on the sizing of hydraulic structures at these creek crossings.

For Forest Creek and Strayleaves Creek, all adopted local inflows appear to be a scaled version of each other, with the same hydrograph shape and timing at all inflow locations along these creeks as shown in Figure 7-1. It also appears that the same inflow has been incorrectly allocated to two locations (labelled NS20024) along Strayleaves Creek as shown in Figure 4-5.

In response to one of my queries, FFJV have stated that, with regards to the Forest Creek and Strayleaves Creek inflows, the same rainfall depth information and temporal patterns are applied to each of the URBS model sub-catchments. Therefore, the subarea runoff will be similar and be proportional to the sub-catchment area. They have also noted that the local inflows applied to the hydraulic model only have a small degree of routing through the URBS model. I note that, based on the adopted subcatchment inflow hydrographs shown in Figure 7-1, no subcatchment routing is apparent.

In addition, it appears that some of the critical durations as per the URBS model results have not been run through the TUFLOW model. In response to one of my queries, FFJV have stated that a 'full critical duration assessment was previously undertaken' and that 'from this earlier work a reduced suite of durations was selected for iterations of the design to be able to complete the modelling in a realistic timeframe'. Details of this earlier work and its results have not been available for this review.

7.3.3 Impact of miscellaneous infrastructure

The modelling undertaken for the Reference Design does not include miscellaneous infrastructure that would be associated with the proposed rail line (fencing, road works, property access road upgrades, etc). These will need to be included, and their impacts assessed and mitigated, in modelling undertaken for the Detail Design.

7.3.4 Inconsistent results

FFJV have reported the AEPs of the three modelled historical flood events at Boggabilla as follows:

- February 1976 event – an AEP of between 1 in 200 (0.5%) and 1 in 500 (0.2%), with concurrent flooding in the Dumaresq and Macintyre rivers;
- January 1996 event – an AEP of between 1 in 30 (3.33%) and 1 in 50 (2.0%), with concurrent flooding in the Dumaresq and Macintyre rivers;
- January 2011 event – an AEP of between 1 in 60 (1.67%) and 1 in 75 (1.33%).

Figure 7-2, Figure 7-3 and Figure 7-4 show a comparison of the modelled February 1976, January 1996 and January 2011 event peak flood levels with the modelled 1% AEP peak flood levels. These figures show some apparently significant inconsistencies between the modelled historical flood event and the modelled 1% AEP design event results.

- The 1976 peak flood levels are expected to be higher than the 1% AEP peak flood levels because the 1976 event has been determined to be between a 1 in 200 and 1 in 500 AEP event. However, for the Macintyre River reach between Boggabilla and Goondiwindi, parts of the floodplain between the Newell Highway and the proposed rail corridor and the Ottleys Creek floodplain, the modelled 1% AEP peak flood levels are higher than the 1976 peak flood levels (see Figure 7-2). The reasons for this apparent inconsistency are not explained.
    - It is likely that in some of the floodplain areas the 1976 flood levels may be lower due to changes in the floodplain topography (including levee construction) between 1976 and 2019. However, this does not appear to be the reason for apparent inconsistencies in all parts of the floodplain;
    - It is unclear why the modelled 1% AEP flood levels between Boggabilla and Goondiwindi are higher than the 1976 flood levels when the latter event has been determined to be much more severe; and
    - The impact on modelled flood levels along the minor southern tributaries and the southern end of the Macintyre River floodplain to the immediate west of the NS2B alignment due the 1976 calibration not including these tributary inflows is readily apparent. The interaction between these creeks and the Macintyre River floodplain is missing in the model calibration.
- The 1996 peak flood levels are expected to be lower than the 1% AEP peak flood levels because the 1996 event has been determined to be between a 1 in 30 and 1 in 50 AEP event. However, for the Macintyre River upstream of its confluence with the Dumaresq River including Ottleys and Scrubby creeks, and a significant part of the Whalan Creek floodplain, the modelled 1% AEP peak flood levels are lower than the 1996 peak flood levels (see Figure 7-3). The reasons for this apparent inconsistency are not explained. Again, the impact on modelled flood levels along the minor

southern tributaries and the southern end of the Macintyre River floodplain to the immediate west of the NS2B alignment due the 1996 calibration not including these tributary inflows is readily apparent. The interaction between these creeks and the Macintyre River floodplain is missing in the model calibration.

- The 2011 peak flood levels are expected to be lower than the 1% AEP peak flood levels because the 2011 event has been determined to be between a 1 in 60 and 1 in 75 AEP event. However, for Ottleys and Scrubby creeks, the 1% AEP peak flood levels are lower than the 2011 peak flood levels. The reasons for this apparent inconsistency are not explained.
    - It appears that the inconsistent and higher modelled Ottleys and Scrubby creek flood levels are due to the application of incorrect Ottleys Creek boundary inflows in the hydraulic model (see Section 5.3.2.4).
    - Again, the impact on modelled flood levels along the minor southern tributaries and the southern end of the Macintyre River floodplain to the immediate west of the NS2B alignment due the 2011 calibration not including these tributary inflows is readily apparent. The interaction between these creeks and the Macintyre River floodplain is not included in the model used for calibration.

7.3.5 Flood impact maps

In response to one of my queries, FFJV have acknowledged that the design flood impact maps presented in Chapter 13 and Appendix H of the NS2B EIS are not accurate, especially for the southern minor creek (Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek) crossings of the proposed NS2B rail alignment. FFJV have indicated that they have re-checked the smaller creeks flooding for both the Macintyre River system critical storm durations and their individual critical storm durations. Upon re-checking their published mapping, they have found that the maps published in the EIS reports show the smaller creek affluxes only for the Macintyre critical duration impact, rather than the actual critical impact duration for the smaller creeks. They have undertaken to correct this error in future reporting and provided updated afflux maps for review.

FFJV believes the corrected impact results generally comply with the flood impact objectives set for the NS2B rail line and are similar to those that have been currently reported. However, they also state that the corrected mapping shows some additional impacts especially along the southern tributaries for their critical durations that are higher than currently reported and exceeding the flood impact objective limits set for the NS2B project. In addition, FFJV have stated they propose to include this updated mapping information in their Submissions and Preferred Infrastructure Report which follows the public exhibition period.

Figure 7-5 to Figure 7-9 show the updated flood impact maps for 20% AEP to 1% AEP design flood events along the NS2B alignment, including the locations where the impacts exceed the flood impact objective limits. These flood maps also show that:

- The flood impacts of the proposed rail line vary for different flood magnitudes.
- The flood impacts are generally in areas immediately upstream and downstream of the proposed rail alignment.
- There are upstream impacts that are greater than the flood impact objective limits upstream of the Whalan Creek floodplain crossing for all flood events larger than a 20% AEP event.
    - For some of the mapped events, there are localised areas with impacts greater than 0.5 m, and other areas with impacts between 0.2 m and 0.5 m.
    - For some events (e.g. 5% AEP) there also appears to be some redistribution of flows near this crossing.

- At the Strayleaves Creek crossing, there are upstream impacts that are greater than the flood impact objective limits upstream of the rail line for all flood events shown.
    - For the mapped events, the flood impacts generally increase with flood magnitude.
    - There are some localised areas with impacts greater than 0.5 m for the larger flood events.
- At the Forest Creek crossing, the flood impact results appear to be inconsistent with the results at the other crossings. At this crossing, the developed conditions upstream flood levels are lower than the existing conditions flood levels for the smaller flood events and higher for the larger flood events.
    - It appears that the TUFLOW model here is not configured correctly for the existing hydraulic structures near this crossing. FFJV have proposed refined modelling of this area during Detail Design.
    - For the larger flood events, there are localised areas with impacts greater than the flood impact objective limit, with the impacts generally increasing with flood magnitude.
- At the Back Creek crossing, the flood impact results appear to be inconsistent with the results at the other crossings. At this crossing, the developed conditions upstream flood levels are lower than the existing conditions flood levels for the smaller flood events and higher for the larger flood events.
    - It appears that the TUFLOW model here is not configured correctly for the existing hydraulic structures near this crossing. FFJV considers the existing conditions modelling at this crossing as appropriate and believes the results at this crossing are influenced by an access road directly upstream that acts as a low level causeway.
    - For the larger flood events, there are localised areas with impacts greater than the flood impact objective limit, with the impacts generally increasing with flood magnitude.
- At the Mobbindry Creek crossing, there are upstream impacts that are greater than the established flood impact objective limits upstream of the rail line for all flood events shown.
    - For the mapped events, the flood impacts generally increase with flood magnitude.
    - There are some localised areas with impacts greater than 0.5 m for the larger flood events.

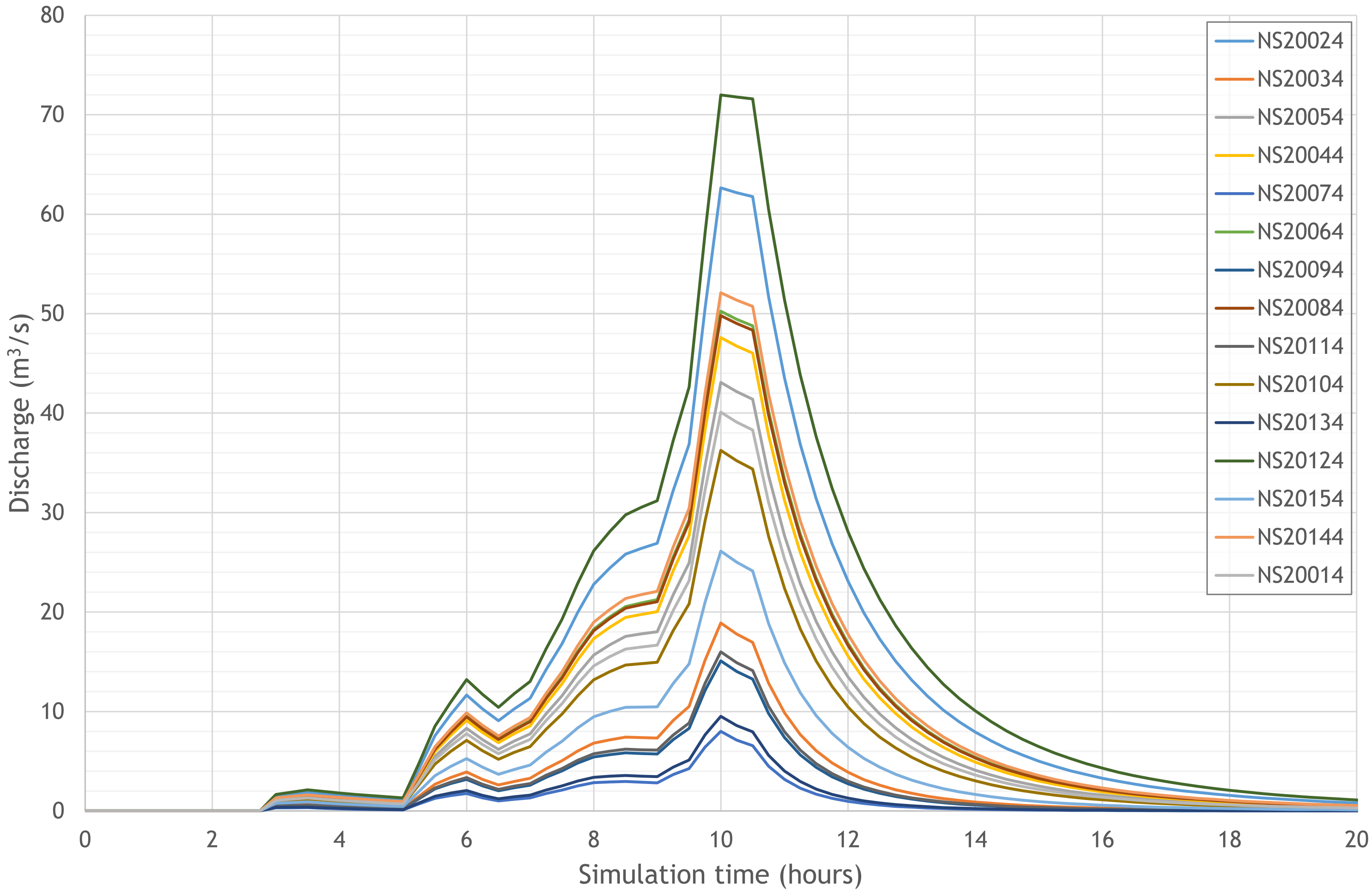


Figure 7-1 - Adopted local inflows along Strayleaves Creek, 1% AEP, 12 hours design event

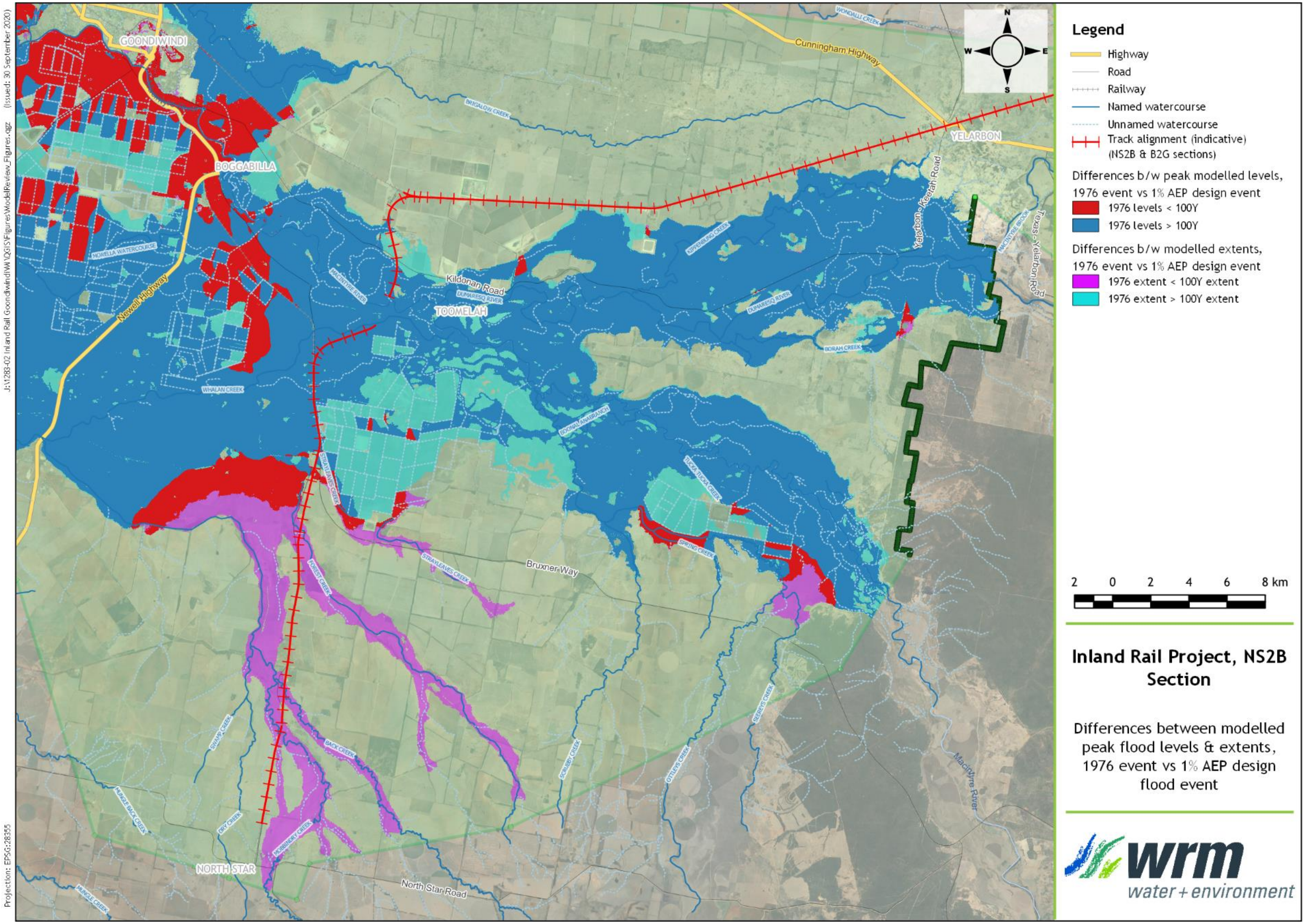


Figure 7-2 – Differences in modelled peak flood levels between the 1976 event and the 1% AEP design event

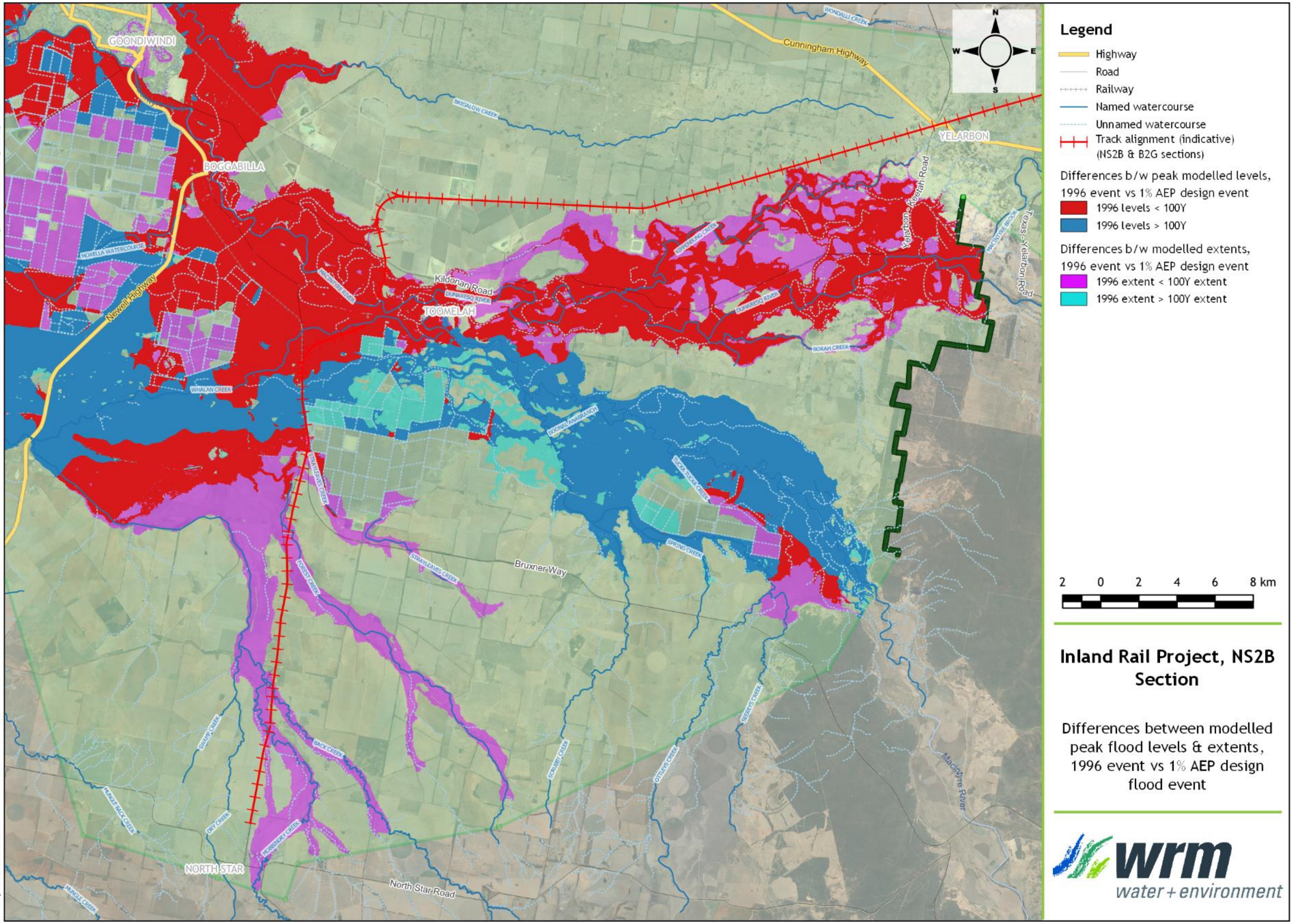


Figure 7-3 – Differences in modelled peak flood levels between the 1996 event and the 1% AEP design event

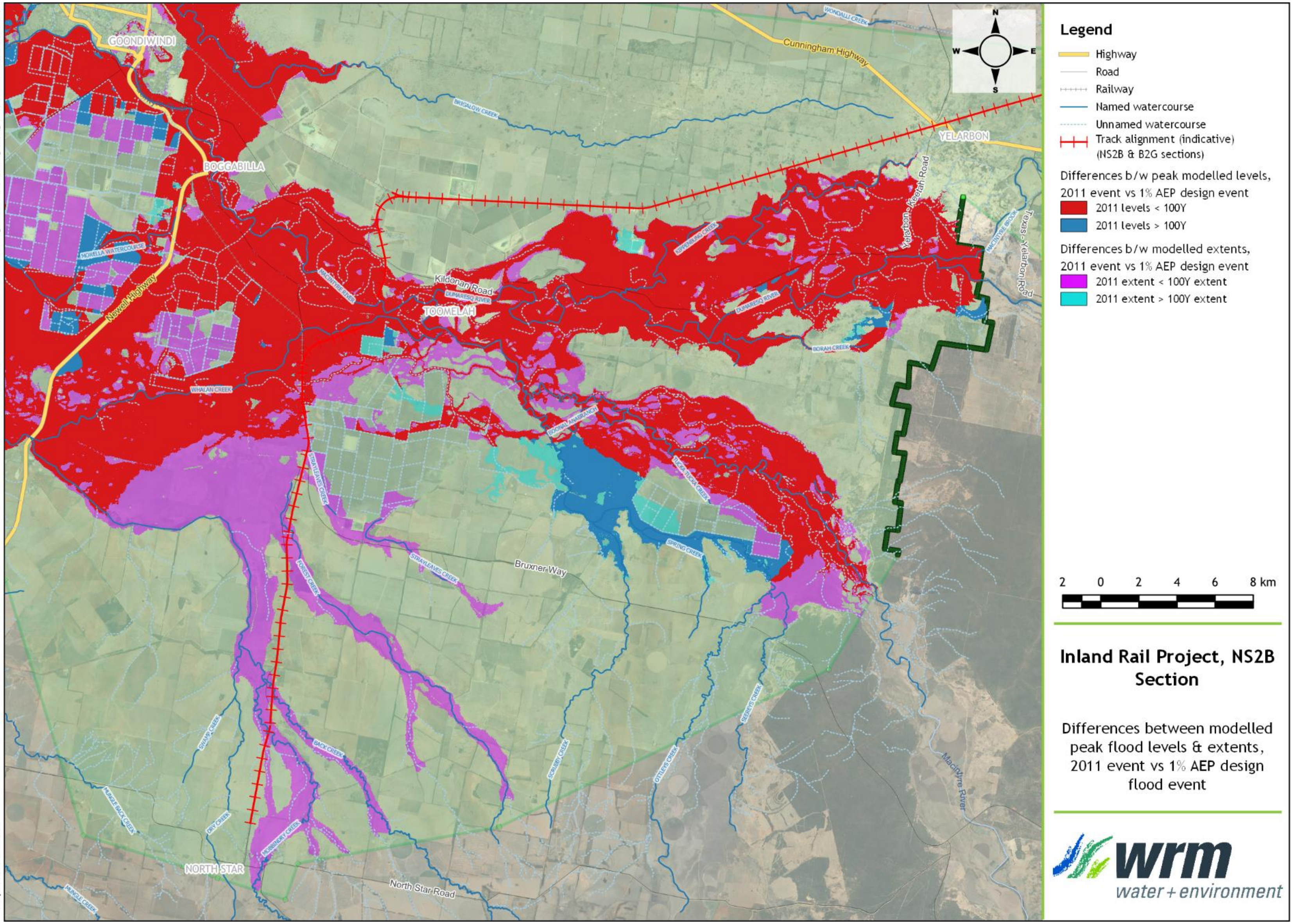


Figure 7-4 – Differences in modelled peak flood levels between the 2011 event and the 1% AEP design event

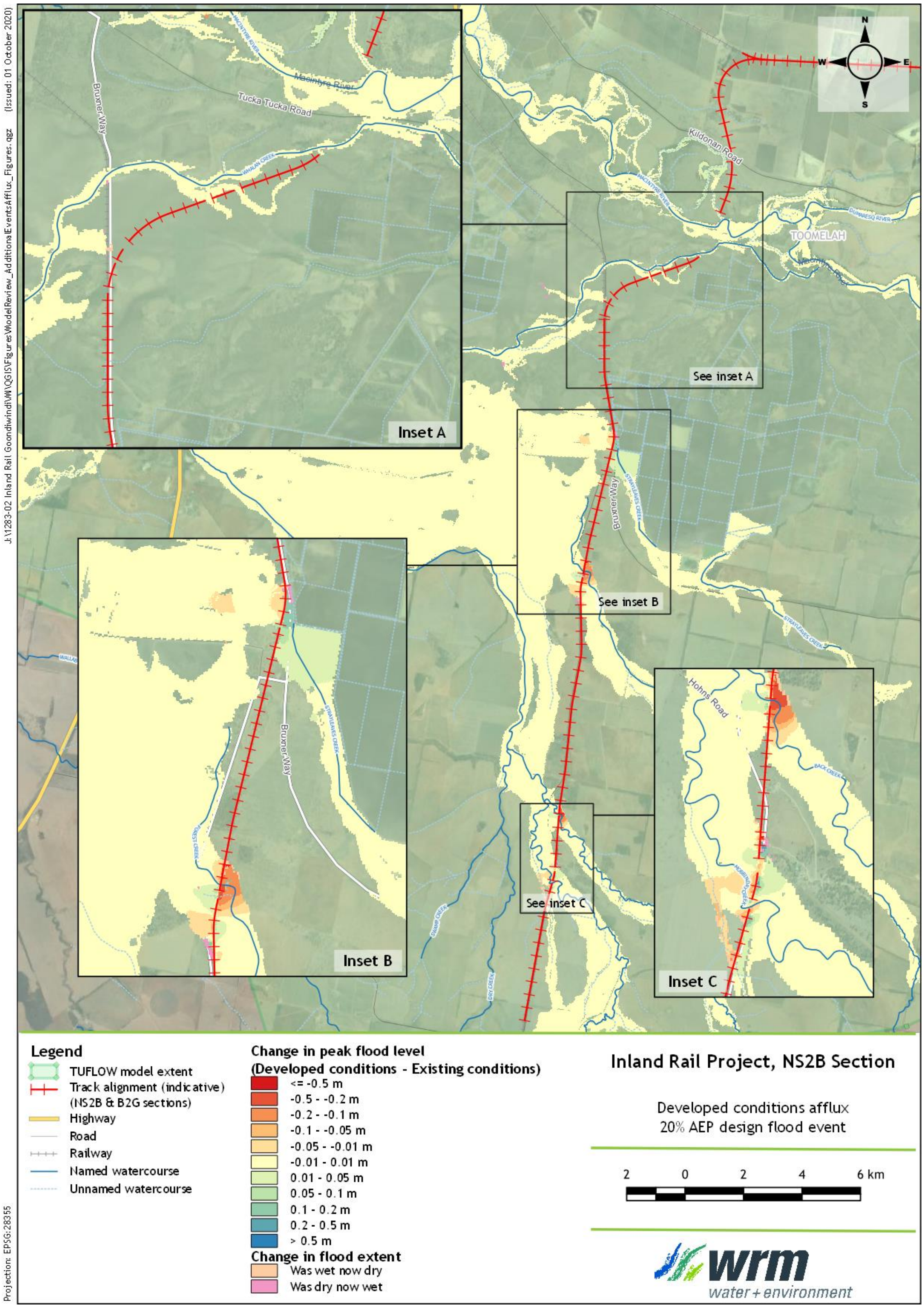


Figure 7-5 – Updated flood impacts for the 20% AEP design event

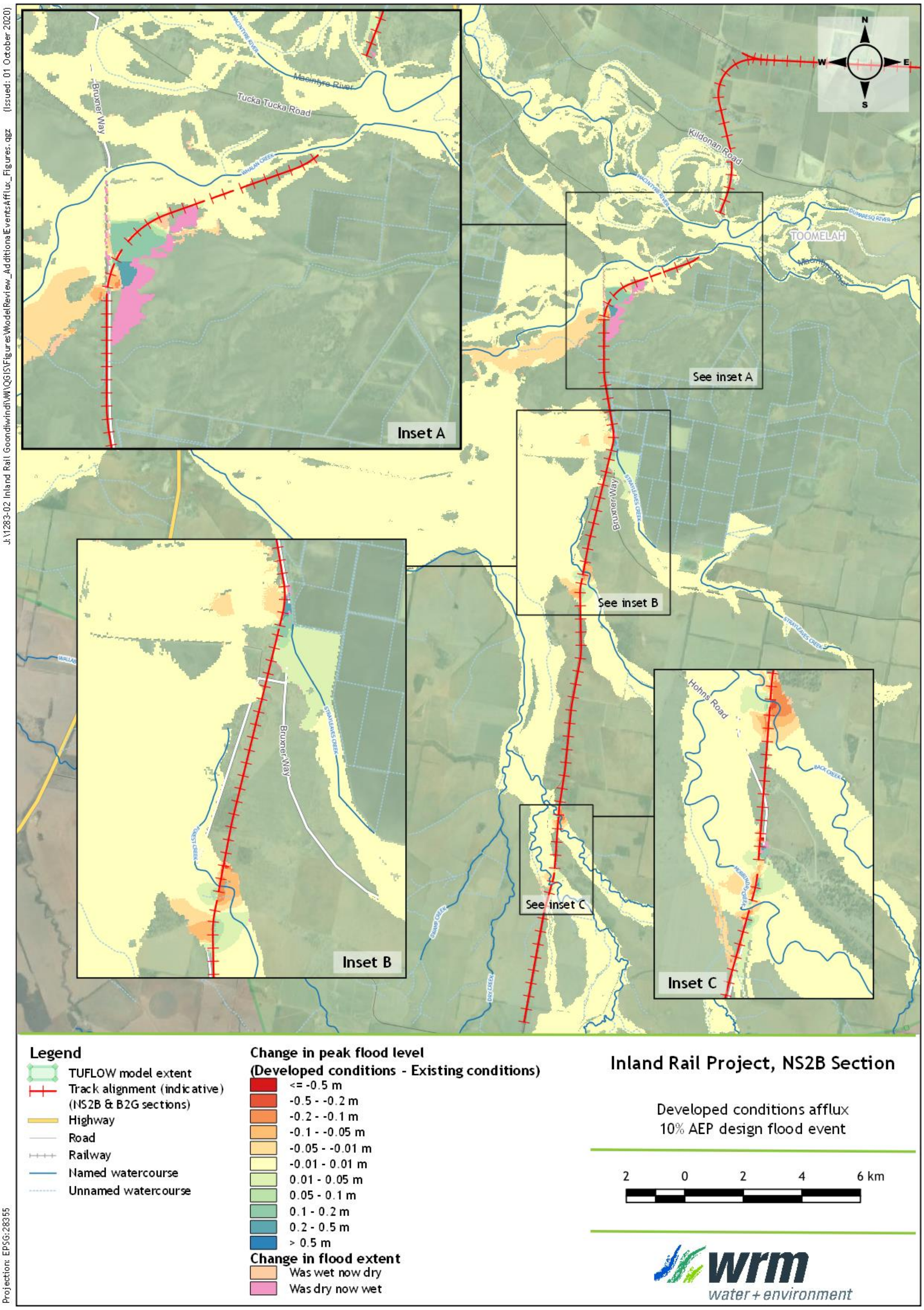


Figure 7-6 – Updated flood impacts for the 10% AEP design event

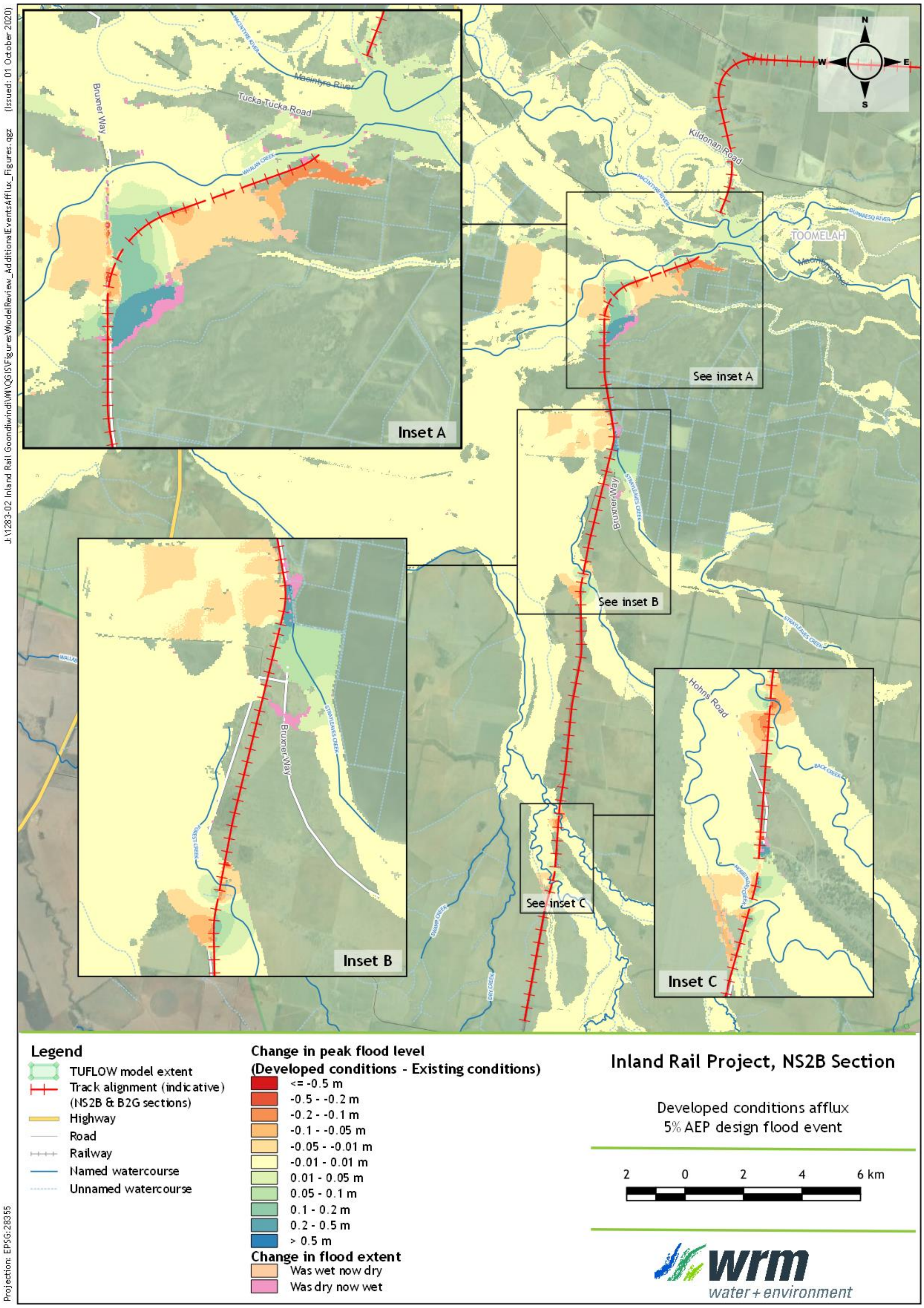


Figure 7-7 – Updated flood impacts for the 5% AEP design event

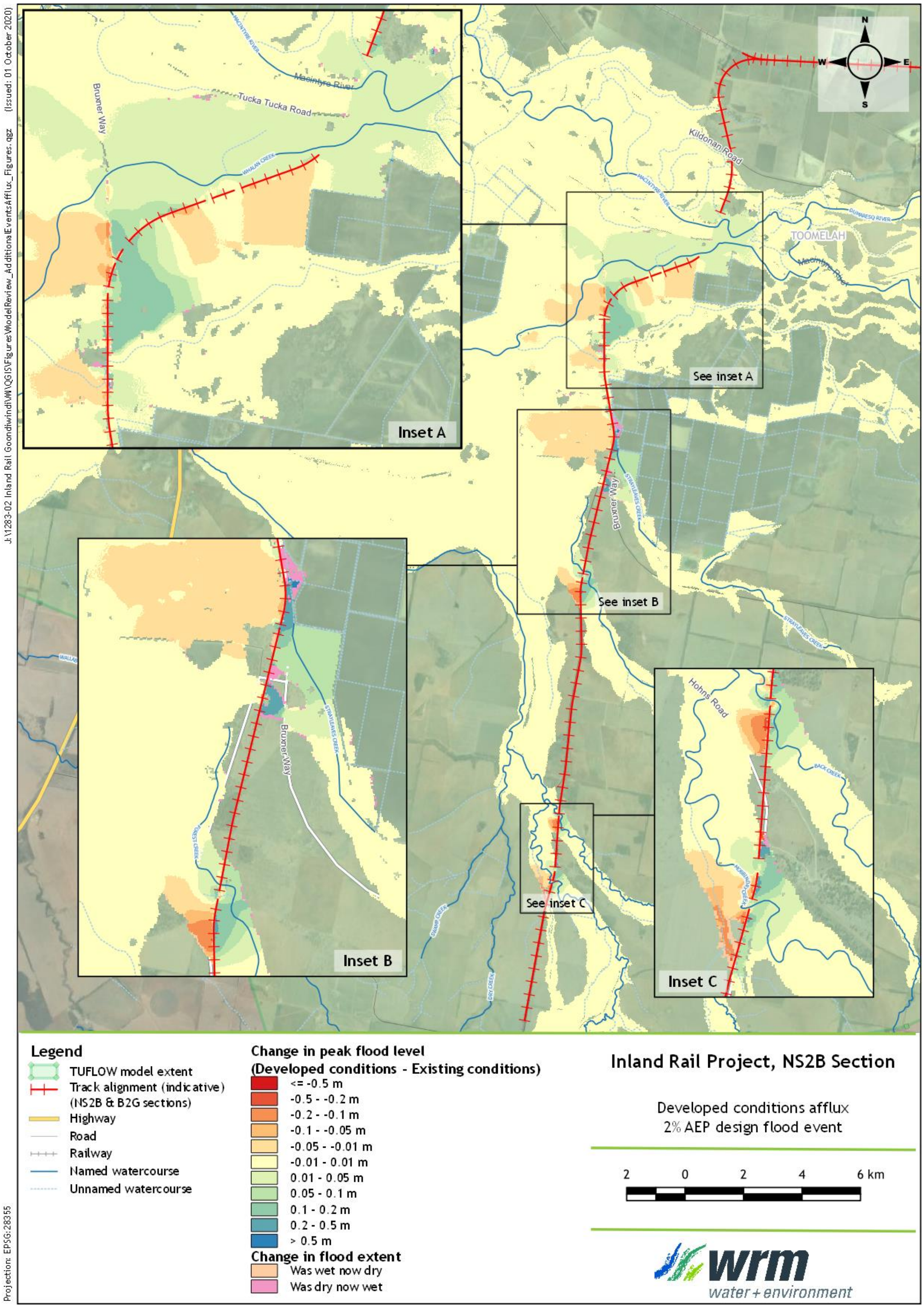


Figure 7-8 – Updated flood impacts for the 2% AEP design event

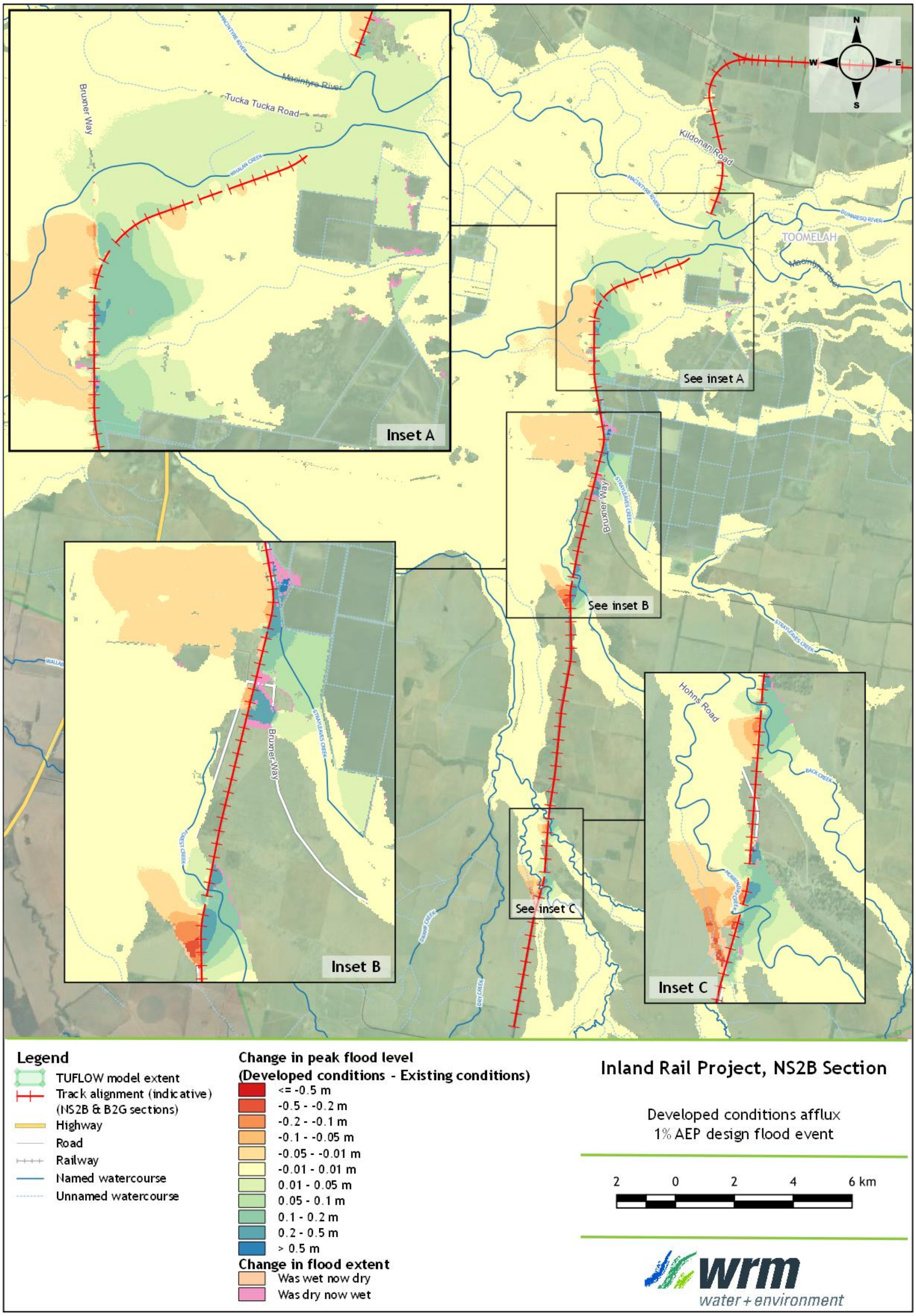


Figure 7-9 – Updated flood impacts for the 1% AEP design event

8 Summary of findings

8.1 OVERVIEW

There are significant technical shortcomings in the flood modelling undertaken for the NS2B section Reference Design of the Inland Rail Project. These shortcomings are in all aspects of the modelling undertaken including hydrologic and hydraulic modelling approaches, model configurations, model calibrations, flood frequency analyses and design event analyses.

The cumulative impact of all the individual shortcomings identified in this report could potentially be significant but is currently unknown. However, it is possible to say that, as a result of the identified shortcomings, there is considerable uncertainty on the accuracy, reliability and robustness of the flood modelling and modelling results that have been presented in the NS2B EIS for both existing and developed conditions. Therefore, there is considerable uncertainty regarding the predicted flood impacts as well.

In my opinion, several aspects of the flood modelling undertaken for the NS2B alignment do not reflect current best practice, and are not compliant with current ARR standards and guidelines. As a consequence, I believe the flood modelling undertaken for the NS2B project does not appear to meet the requirements of SEARs condition 8.2.a.

8.2 FLOOD MODEL CONFIGURATIONS

The URBS model has been used for hydrologic modelling and the TUFLOW model has been used for hydraulic modelling. The adopted models are appropriate for flood modelling undertaken for the proposed NS2B project.

The hydrologic models used comprise four URBS models for the four major waterways (Macintyre River, Macintyre Brook, Dumaresq River and Ottleys Creek) and the four URBS models for the four minor waterways (Mobbindry Creek, Back Creek and Forest Creek) crossing the NS2B alignment. The Macintyre River, Macintyre Brook and Dumaresq River URBS models have been sourced from the DPIE. New URBS models have been developed for Ottleys Creek, Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek.

A single TUFLOW model incorporating the upstream inflows predicted by each of the above URBS models has been developed for the modelled area. The adopted FFJV TUFLOW model, which is a cut-down version of the DPIE TUFLOW model used for the BRVFMP, covers an area of about 2,600 km^2. The DPIE TUFLOW model covered an area of about 11,000 km^2.

There a number of technical shortcomings in the adopted URBS and TUFLOW model configurations. The adopted model configurations are not sufficient to accurately assess the existing and proposed flooding behaviour in the modelled area for the full range of design flood events up to the PMF. The shortcomings identified in this report could have potentially significant impacts on the accuracy and reliability of the flood modelling that has been undertaken for the NS2B Reference Design.

Based on current ARR guidelines, the ‘focal’ point of the FFJV hydrologic modelling for the Reference Design should be Boggabilla or the proposed NS2B rail line crossing of the Macintyre River. The adopted modelling approach and model extent have not used the correct focal point for the NS2B flood modelling. As consequence, FFJV have undertaken their design event modelling with inappropriate model inputs for design rainfalls, rainfall temporal patterns, rainfall aerial reduction factors and rainfall losses. The magnitude of inaccuracy introduced by the adopted approach is unknown but could potentially be significant.

Based on the available DEM and local landholder accounts, there are potential interactions between Macintyre Brook and Kippenbung Creek as well as Brigalow Creek at Yelarbon, as well as Macintyre River and Brigalow Creek upstream of Goondiwindi, during large flood events. It appears that these potential interactions have not been adequately considered when configuring the hydraulic model for large flood events. This means that the adopted TUFLOW model configuration may not accurately represent large flood events.

The local (residual) catchment inflows downstream of Macintyre Brook (at Booba Sands), Dumaresq River (at Beebo), Macintyre River (at Holdfast) and Ottleys Creek (at Macintyre River confluence) are not included in the TUFLOW model. This means that the local inflows from an area of approximately 3,250 km^2 are not accounted for in the hydraulic model.

There are a number of local creeks that cross the NS2B alignment. These creeks that drain towards Whalan Creek include Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek. Inflows from these four minor waterways have not been used in model calibration and have been input to the hydraulic model only for the design event modelling. Further, the design inflows adopted in the TUFLOW model are not consistent with the URBS model outputs for the respective creeks.

The adopted TUFLOW model inflow boundaries poorly represent inflows and raise a number of significant issues with respect to the accuracy and reliability of model results, including:

- Calibration events have only 4 upstream total inflows. There are no local inflows for an area of approximately 3,250 km^2 not covered by the hydrologic models plus the minor tributaries covering 467 km^2 for which no flows have been included (a total area of about 3,700 km^2). This means that the TUFLOW model has been calibrated with lower than actual inflows to the modelled area.
- Some of the major waterway inflows are input to the TUFLOW model several kilometres in from the model boundary (e.g. Ottleys Creek, Macintyre River). This would allow some of the inflows to also propagate upstream rather than only downstream along the channel, especially in flat floodplains such as in the Macintyre river system.
- Some of the major waterway inflows are input to the TUFLOW model several kilometres downstream or upstream from the locations where the inflows were derived (e.g. Macintyre Brook, Ottleys Creek). In the case of Macintyre Brook, this would prevent potential breakouts into Kippenbung Creek, Brigalow Creek, etc during large flood events.

The TUFLOW model has been configured using a 30 m grid size. The adoption of a 30 m cell size is understandable when looking at the totality of the model domain. However, this grid size appears to be too coarse and inappropriate for representing some of the channels and drainage features in the vicinity of the proposed rail alignment. A sensitivity run undertaken by FFJV has shown that a 15 m grid sized hydraulic model predicted peak flood levels are generally lower by about 50 mm across the modelled area and by about 150 mm along the NS2B alignment. This is a significant reduction in peak flood level in the context of the Macintyre River floodplain near Boggabilla where a 100 mm difference in peak flood level represents a few thousand cubic meters per second difference in peak Macintyre River discharges through the modelled area.

A number of cross drainage structures along the existing rail and road alignments do not appear to be adequately represented in the TUFLOW model under existing conditions (e.g. road cross drainage and bridge structures), but are being represented by proposed drainage structures under developed conditions (e.g. Mobbindry Creek, Back Creek).

8.3 MODEL CALIBRATION

FFJV's URBS and TUFLOW models have been calibrated against 3 historical flood events, namely February 1976, January 1996 and January 2011 events. Of these, the DPIE had calibrated their hydrologic and hydraulic models to the February 1976 and January 1996 events. FFJV have accepted and used the DPIE's hydrologic models and their calibrations with little or no change for their NS2B flood modelling. Based on their review of the DPIE models, FFJV have stated that the DPIE URBS model calibrations for the 1976 and 1996 events are reasonable and therefore there was no justification not to adopt DPIE calibration.

There a number of technical shortcomings in the adopted model calibration and the adopted calibration methodology is not consistent with current best practice. The primary shortcoming is the use of different model configurations with different routing characteristics for the different calibration events. As a consequence, in my opinion, the adopted models are not sufficiently reliable to assess the existing and post-NS2B flooding behaviour in the study area. These shortcomings would have an impact on the accuracy and reliability of the flood modelling that has been undertaken for the NS2B Reference Design.

The current modelling best practice, including the current ARR guidelines, requires hydrologic model calibrations to multiple historical flood events to be achieved with the same model and with a common (i.e. average or weighted) set of model parameters. In other words, FFJV should have used the same URBS models with a common set of model parameters for all three calibration events. This has not been done for the NS2B flood modelling.

8.4 FLOOD FREQUENCY ANALYSIS

For the reconciliation of hydrologic model design event discharges with FFA results for the catchments upstream of the hydraulic model area, FFJV have used GEV frequency distributions to fit peak annual discharges at Macintyre Brook at Booba Sands, Dumaresq River at Farnbro, Macintyre River at Holdfast and Ottleys Creek at Coolatai stream gauging stations when LPIII frequency distributions provide better fits to recorded peak discharges at these stations.

In the absence of calibration data, the URBS model results for Mobbindry Creek, Back Creek, Forest Creek and Strayleaves Creek have been validated against RFFE estimates. This adopted approach is appropriate. However, this model validation has been undertaken against the RFFE results for the 1% AEP event only.

The RFFE estimates at all four locations used to reconcile the URBS model results are based only on 30 to 40 years of recorded discharges at the nearest stream gauging stations. Therefore, the RFFE estimates at these stations are likely to be reliable only for AEPs up to 5% at best. The 1% AEP results used for the URBS model validations would be the least reliable of the RFFE estimates available for model validations. A comparison of the adopted URBS design discharges and RFFE results shows that the URBS discharges for the more frequent events are significantly higher than the RFFE estimates. For example, for the 20% AEP events, the URBS model estimates for the four minor waterways are between 78% and 174% higher than the RFFE estimate, and for the 10% AEP event, the URBS model estimates are between 50% and 111% higher than the RFFE estimates.

The Boggabilla stream gauge is the key reconciliation point for the combined hydrologic and hydraulic modelling for the NS2B alignment. FFJV state that the Boggabilla rating is reasonably consistent with gauged flows, except for rated flows higher than the highest gauged flow of about 3,500 m^3/s. Therefore, as stated in the BS2B EIS, a good reconciliation between the FFA results and the design discharges at Boggabilla should have been achieved for events more frequent than the 1% AEP. This has not been achieved.

Hydraulic model predicted design discharges at Boggabilla for all events between 20% AEP and 1% AEP are considerably higher than the FFA results. For example, the modelled 20% AEP design discharge at Boggabilla is about 18% higher than the FFA and the modelled 10% AEP design discharge is about 28% higher than the FFA. In my opinion, these differences between FFA and TUFLOW model results are too large.

8.5 DESIGN EVENT MODELLING

FFJV have added the 2011 flood event to the model calibration to confirm and validate their model calibration and provide more confidence in the modelling results due to the uncertainties associated with the DPIE 1996 flood event model. Yet, FFJV have run the design flood events using a different URBS model configuration to that used for the 2011 event calibration. In my opinion, this is major technical shortcoming in the design event analyses and is not in accordance with current best practice and current ARR guidelines.

FFJV have acknowledged that the design event modelling was undertaken with a different configuration of the URBS model to that used for the 2011 flood event. The stated reason for this is that FFJV had to use the DPIE model calibrated to the 1996 flood event as the basis for their design event analyses because the FFJV modellers had to provide design discharge information to the wider design team when the 2011 model calibration was still in progress. It is not known why the design discharge information was not updated with a properly calibrated model and once the 2011 calibration was completed. This indicates that the design discharges used for the Reference Design and the flood impact assessment are not based on FFJV's latest calibrated models and the Reference Design has been undertaken with preliminary (not the latest) design discharges. This issue is not identified in Chapter 13 and Appendix H of the NS2B EIS.

The design event modelling approach undertaken by FFJV has not followed the recommendations of the current ARR guidelines for the selection of design rainfalls, rainfall aerial reduction factors, rainfall temporal patterns and rainfall losses.

8.6 POTENTIAL IMPACTS NEAR THE PROPOSED RAIL ALIGNMENT

To provide an accurate, reliable and robust assessment of the impacts of the proposed rail alignment, the flood models developed and used for the NS2B Reference Design should accurately simulate existing floodplain conditions for the full range of flood events up to the PMF prior to these models being used for the developed conditions and flood impact assessment. Without an accurate Existing Conditions model it would not be possible to accurately assess whether the potential flood impacts of the NS2B project would be within the flood impact objectives.

There are question marks on the accuracy, reliability and robustness of the hydrologic and hydraulic modelling undertaken and their results used for the Reference Design because of the hydrologic and hydraulic modelling shortcomings identified and described in this report including in model configurations, model inputs and model calibrations. The cumulative impact of these identified shortcomings is not known. Therefore, there is significant uncertainty regarding the accuracy of the predicted flood impacts of the proposed NS2B rail line.

8.7 POTENTIAL IMPACTS ON GOONDIWINDI

FFJV have acknowledged that the flood modelling undertaken to date for the NS2B project is not sufficiently accurate or suitable for reliable flood investigations in the Goondiwindi town area. Therefore, the flood impacts on Goondiwindi predicted by the FFJV models are not expected to be accurate. However, based on the provided FFJV model results, the flood impacts of the NS2B project on the Goondiwindi town are likely to be much less significant than at the NS2B alignment.

9 Recommendations

In response to my queries, FFJV have acknowledged most of the flood modelling shortcomings identified and described in this report. However, FFJV maintain that the flood modelling and model results presented in Chapter 13 and Appendix H of the NS2B EIS are appropriate and sufficiently accurate for the purposes of the Reference Design.

FFJV have indicated that current Reference Design flood modelling can be refined further during Detail Design. The refinements the FFJV have indicated they will consider include:

- Changing the focal point of the hydrologic modelling and extending the URBS models to include the Boggabilla and Goondiwindi stream gauges;
- Improving the TUFLOW model configuration, including placement of model inflows;
- Revisiting and improving the model calibrations;
- Using a finer grid TUFLOW model; and
- Using a joint probability assessment (JPA) to address some of the issues associated with standard modelling practice such as assumptions on uniform temporal patterns, partial area effects, aerial reduction factors, etc.

I endorse the above FFJV undertaking to address the current flood modelling shortcomings.

FFJV have already identified the approximate flood impacts of some of the modelling shortcomings identified in this report by undertaking model sensitivity runs. The results of these runs have shown approximately 150 mm reduction in flood levels along the NS2B alignment with a finer hydraulic model grid size and up to 20 mm reduction in flood levels along the NS2B alignment due to the exclusion of Pindari Dam in the hydrologic model. The potential flood impacts of the various modelling shortcomings identified to date, as well as the cumulative impact of all the identified shortcomings in this report, across the full range of flood events that have to be investigated are currently unknown.

I recommend that the above refinements identified by FFJV, except for the JPA, as well as the additional shortcomings identified and described in this report be addressed and completed prior to the finalisation of the Reference Design. In my opinion, this is required to provide accurate and reliable information, as well as confidence in the accuracy of information provided to the community and other stakeholders on the existing and future flooding behaviour in the modelled area for the full range of flood events up to the PMF, and the flooding impact of the NS2B rail line during these events.

This report has also identified and described a number of errors and inaccurate statements in the current NS2B EIS reporting, including flood mapping. I recommend that these reporting errors also be addressed.

The model configuration for the Reference Design does not include miscellaneous infrastructure associated with the proposed rail line (fencing, road works, property access road upgrades, etc). These will need to be included, and their impacts assessed, in the modelling undertaken for the Detailed Design.

10 References

FFJV, 2020a *'Chapter 13: Surface Water and Hydrology'* NS2B EIS, Document No: 2-0001-270-EAP-10-RP-0203, Revision 0, 11 May 2020.

FFJV, 2020b *'Appendix H – Hydrology and Flooding Technical Report'* NS2B EIS, Document No: 2-0001-270-EAP-10-RP-0407, Revision 1, 11 May 2020.

FFJV, 2020c *'Technical Note: Response to GRC (Dr Sharmil Markar) Issues and Comments Memorandum 30-08-20 - RevB'*, 4 September 2020.

FFJV, 2020d *'Technical Note: Response to GRC (Dr Sharmil Markar) Issues and Comments Memorandum 23-09-20 – Rev A', 30* September 2020.

FFJV, 2020e *'Technical Note: Comments on WRM Draft Report 06-10-20 (1283-02-D)', 14 October* 2020.