Appendix F
Review of Flood Frequency Analysis at Boggabilla stream gauge

F1 Gauge history

F1.1 Period of record

The Macintyre River stream gauge at Boggabilla (Site No. 416002) has been in operation since October 1894, although Bureau of Meteorology records include three additional floods dating back to 1886. Continuous gauge records are available from the online WaterNSW Real Time Data portal since 1982.

F1.2 Gauge location

The stream gauge is located downstream of the town of Boggabilla. It is understood that the physical location of the stream gauge has changed over time. In particular, construction of the Boggabilla Weir in 1991 rendered the existing gauge ineffective due to ponding behind the weir. The current gauge was established in October 1991 downstream of the weir (Goondiwindi Environs Flooding Investigation 2007).

A key feature of the Macintyre River system is that, during larger flood events, flow breaks out across the southern floodplain upstream of Boggabilla into the Whalan Creek and Morella Watercourse systems, as shown in Figure F.1. This flow therefore does not pass the stream gauge, which is located downstream of Boggabilla. Further flow breaks out northwards into the Brigalow creek system between Boggabilla and Goondiwindi.

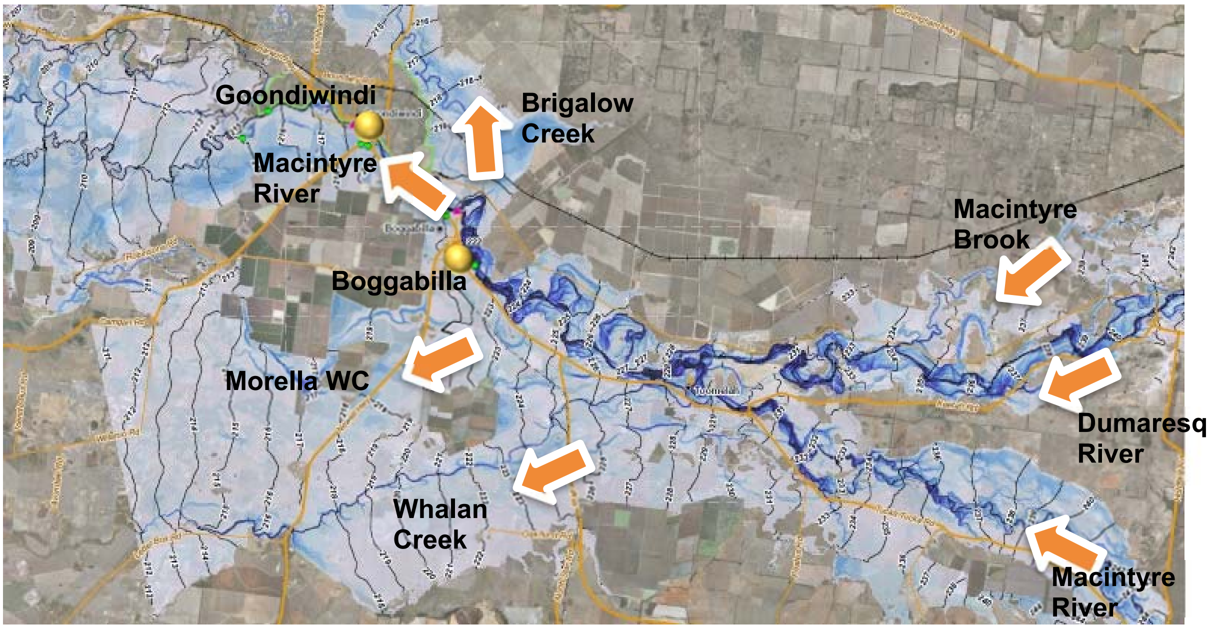

Figure F.1 Flood conditions around Boggabilla (1996 flood event)

F1.3 Gauge rating

The Boggabilla stream gauge rating is based on 594 gaugings (measured flow and flood level) recorded between 1924 and 2018, Although there are reasonably few high-flow gaugings prior to the relocation of the gauge in 1991, the historical consistency of the data suggests that the rating (relationship between level and flow) at the gauge is consistent with time and unaffected by the location of the gauge site. The stream gauge rating has nevertheless changed over time, typically as additional gaugings have come available. In particular, the projection to high flows is strongly influenced by a number of high-flow gaugings recorded during the 1996 flood.

The 1996 gaugings include an estimate of breakout flows into the Whalan Creek system that occur upstream of Boggabilla. Prior stream gaugings (and hence rating) are believed to record only flows in the Macintyre River. There has been a significant change in the high-flow rating since 1996. The current WaterNSW gauge rating is theoretically the total river flow including breakout flow upstream of Boggabilla. However, the results of the current study suggest that the projection of the current rating above the 1996 flood levels is suspect (see Section F3.1).

F2 Review of previous FFA

F2.1 Flood Study for Boggabilla (2004)

In 2004, Lawson and Treloar prepared a Flood Study for Boggabilla for Moree Plains Shire Council that conducted 2D hydraulic modelling (SOBEK) of the local area around Boggabilla. Design flows were based on flood frequency analysis (FFA) of the rated stream gauging station at Boggabilla. Lawson and Treloar noted that the rated flow for the 1976 flood event was lower than for the 1996 flood event, as listed in Table F1, despite the 1976 flood level being over 1m higher than 1996. A potential explanation is that rated flow for 1976 that Lawson and Treloar obtained was derived from an older rating (see discussion in Section F1.3).

In order to address this inconstancy, Lawson and Treloar (2004) states that “As the rated flows did not relate to this flood level difference, a joint calibration using the 2D hydraulic model was undertaken to obtain a more accurate flow rating”. The revised flows derived by Lawson and Treloar are listed in Table F1.

Due to the limited extent of the SOBEK model domain, the model flows would not include breakout into the Whalan Creek system but could include part of the breakout into Morella Watercourse system. This makes it difficult to directly compare the Lawson and Treloar flows with either total catchment flows or river flows at the gauge. Nevertheless, the current TUFLOW modelling predicts flows of approximately 5,200m^3/s inclusive of Morella Watercourse and exclusive of Whalan Creek breakout for the 1976 event. The Lawson and Treloar flows are therefore a reasonable order-of-magnitude for the flow through the model domain but do not represent a consistent data set for FFA. This issue is discussed further in Section F2.2.

The Lawson and Treloar FFA is reproduced in Figure F.2. The 1976 event was identified as an outlier with an AEP between 0.03% and 0.02% (1 in 3000 to 1 in 5000).

Table F1 Boggabilla historic event peak flows (from Lawson and Treloar 2004)

Flood	Peak Flow (m^3/s)	
	Rated Flow	2D hydraulic Model Joint Calibration
1976	3241	5500
1996	3308	2300

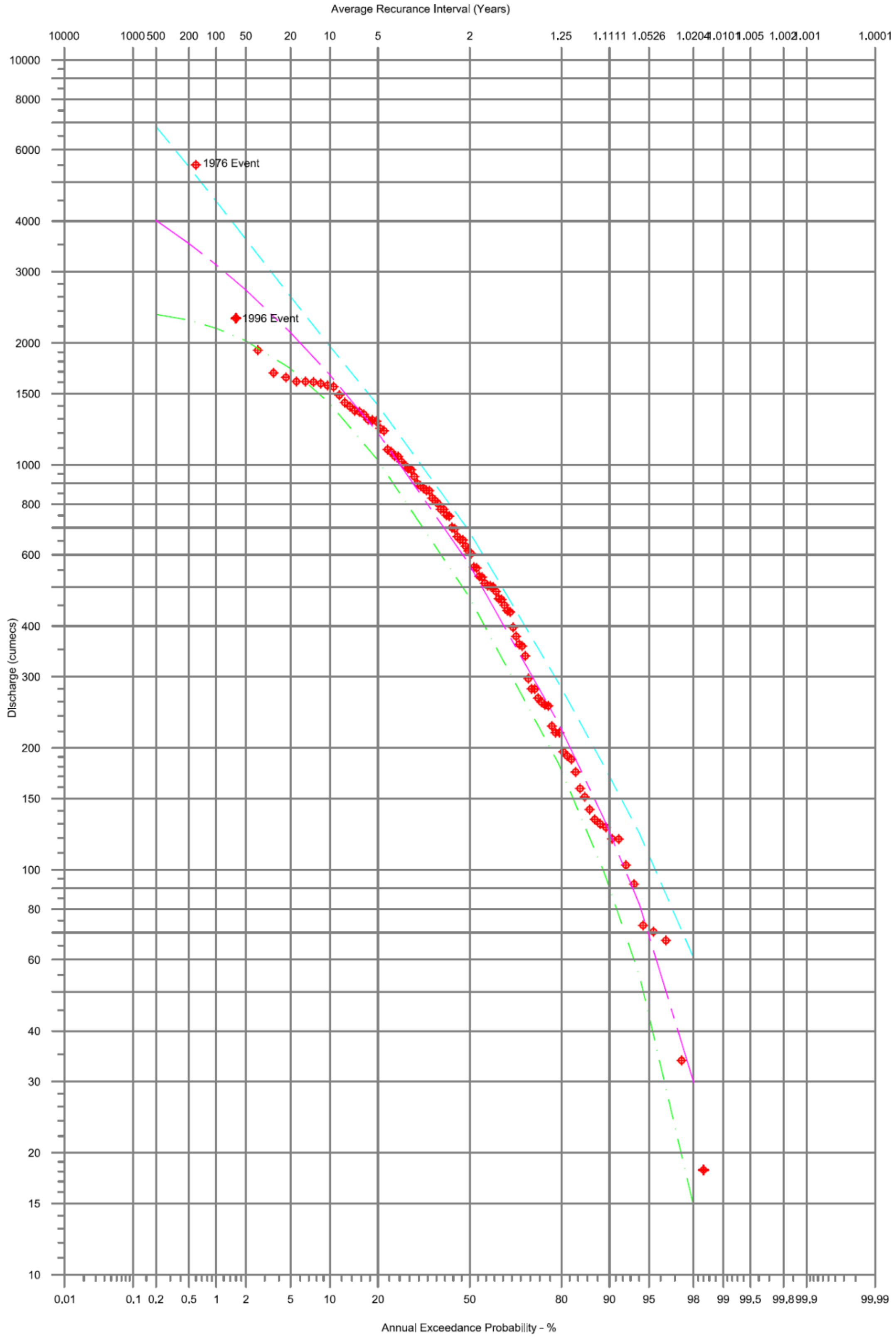

Figure F.2 **Boggabilla Gauge, Log Standard Normal Probability (from Lawson and Treloar 2004)**

F2.2 Draft Border Rivers Valley Floodplain Management Plan

Appendix 5 of the Floodplain Management Plan for the draft Border Rivers Valley Floodplain (BRVFMP, DPIE 2020) presents flood frequency analyses for several stream gauges including Boggabilla. The FFA plot for Boggabilla from Figure 5.2 of the BRVFMP is reproduced in Figure F.3 below. The equivalent AEP of several major flood events are reported in Table 5.2 of the BRVFMP and are summarised in

Table F2. These appear to have been calculated as the AEP of the flood peak flow derived from the FFA relationship. The 1976 flood of record is attributed an AEP of 1.3%, or 1 in 77.

There appear to be two significant issues with the BRVFMP assessment:

- The origin of the flows used in the FFA are not referenced and hence unverifiable. The largest value in Figure F.3 (presumably the 1976 flood) is less than 3000m³/s, which does not match either the current WaterNSW rated flow of ~4,500m³/s (noting that this is an estimate of total flow, see Section F1.3) or what is understood to be the previously rated flow of 3,241m³ (see Section F2.1). In Figure 6.2 of the BRVFMP the modelled and observed flows at Boggabilla for 1976 are shown as approximately 3,500 and 3,700m³/s respectively. It may be noted that these correspond to an AEP of approximately 1 in 200 or higher using the FFA in Figure F.3 (acknowledging the issues with the FFA validity discussed below).
- The FFA appears to have been conducted using flows at Boggabilla rather than total flows for the Macintyre River catchment (total catchment flows for 1976 were much higher than 3,000m³/s, flows in excess of 3,400m³/s were physically measured during the 1996 flood). There is significant breakout of flow upstream of the Boggabilla gauge that only occurs for larger events. This is likely to introduce a significant discontinuity in the flood frequency relationship since the majority of the flow record, which is the largest constituent of the FFA probabilistic relationship, has little to no breakout flow whereas the largest events have an increasingly large percentage (i.e. the rare events do not belong to the same statistical dataset as the frequent events). The validity of the FFA, and in particular its projection to rare events, is therefore highly questionable.

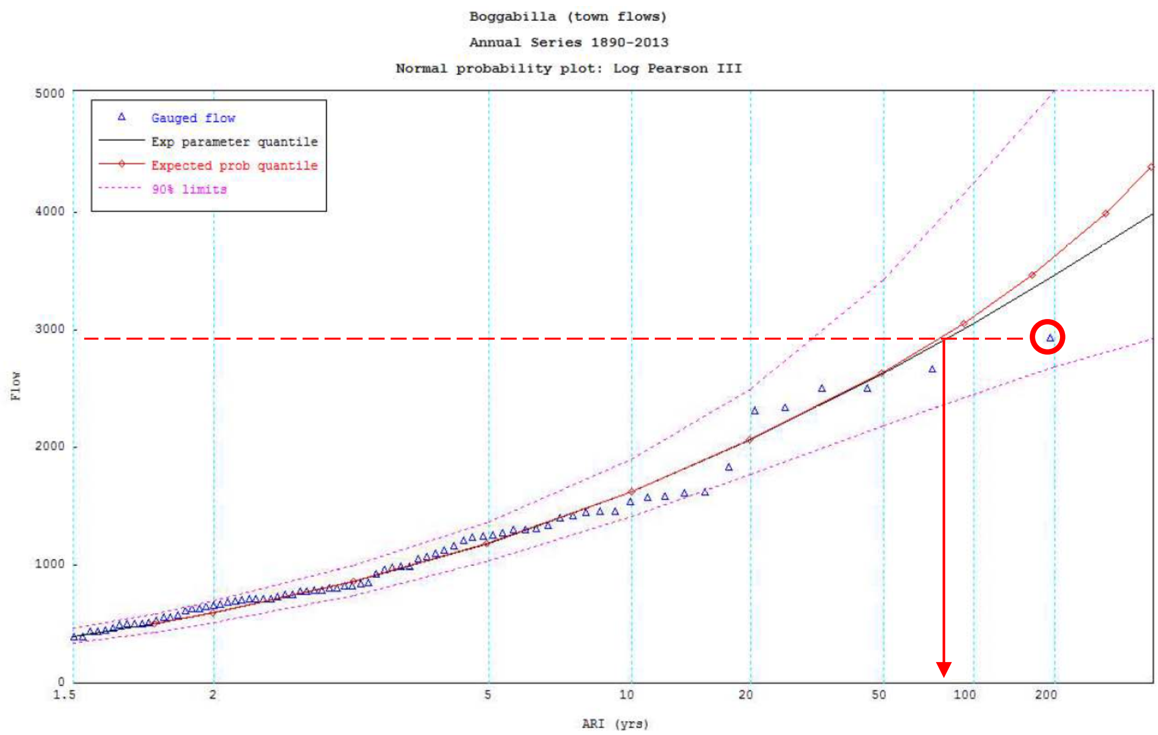

Figure F.3 Flood frequency curves for Boggabilla (416002) from BRVFMP Figure 5.2

Table F2 Annual exceedance probability (AEP) for historic flood events from BRFMP Table 5.2

Location (Gauging Station No)	Site open since	Reason for gauging station selection	Flood Event AEP (%)							
			1890	1976	1996	1998	2000	2001	2011	2013
Macintyre at Boggabilla (416002)	1894	Long period of record and located at the centre of the valley	2.4	1.3	2.4	6.7	12	25	1.9	33

F3 Updated FFA analysis

The Boggabilla stream gauge is a complex site and review of previous studies has highlighted the difficulty in compiling and analysing a consistent and reliable dataset from the historical gauge record. It is generally recommended practice that FFA should be conducted using total catchment flows. Inconsistencies between the rated and modelled flows (particularly 1976) have also been identified. The Inland Rail NS2B project has therefore undertaken to review and update the stream gauge rating, particularly the extrapolation to the 1976 event, and to conduct a FFA of the total catchment flows using current best practice methods.

F3.1 Rating curve review

The Boggabilla stream gauge would generally be considered very well rated, with a large number of recorded stream flow gaugings over a long period of time, which importantly include high level/flow recordings. However, the gauge rating becomes very sensitive at high flows (small changes in water level represent a large change in flow) and there are significant complications relating the flow and level at the gauge site to the total catchment flow due to the breakouts that occur upstream of the site. The current WaterNSW rating is based on nearly 600 gaugings. These tend to be relatively consistent although there is some scatter at high levels. The current rating curve is plotted through the bulk of the data, which tends to have higher levels/lower flows than the 'outliers'.

The TUFLOW model was calibrated to match, as closely as possible, the flow gauging data, as shown in Figure F.4. Significant hysteresis is observed for flood levels above approximately 213mAHD with the flood level lagging two to three hours behind the flow so that the water level on the rising limb of the flood is lower than on the falling limb of the flood for the same flow. Most of the flow gaugings lie on the falling (higher level) limb of the flood, which may be related to the time required to recognise that a noteworthy flood is occurring and mobilise recording equipment.

The dynamic effects can be accounted for using Jones' method, which adjusts the steady-state rated discharge $Q_r(z)$ as a function of the rate of change in the water level z as:

$$Q = Q_r(z)\sqrt{1 + \frac{1}{c\bar{S}}\frac{dz}{dt}} \qquad \text{i)}$$

where S is the bed slope and c is the kinematic wave speed. The inverse of this equation can be used to collapse the dynamic model results to produce a steady-state rating curve, as shown in Figure F.5. The adjusted steady-state rating curve predicts slightly higher flows (up to 10% at 218mAHD) but lies within the bounds of the flow gaugings. The TUFLOW model results and steady-state rating in Figure F.5 are for the Macintyre River flow at the Boggabilla gauge location. The rating was subsequently adjusted to correlate the flow at the stream gauge to the total flow upstream of Boggabilla (ie inclusive of attenuation and breakout flows) shown in Figure F.6. Examination of the different calibration event runs suggests that changes to the floodplain (construction of levees) subsequent to the 1976 flood results in less breakout from the river and increased flows at Boggabilla.

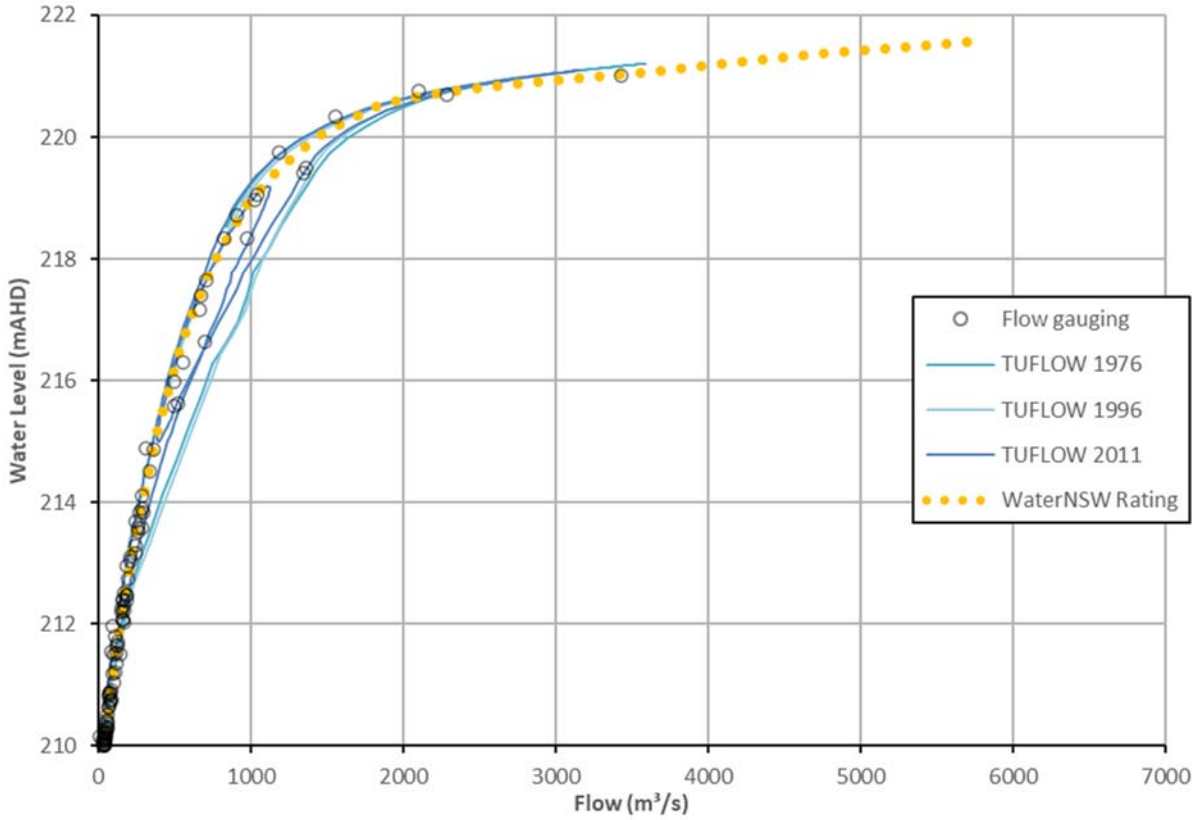

Figure F.4 Comparison of flow gauging and current WaterNSW rating with TUFLOW model results

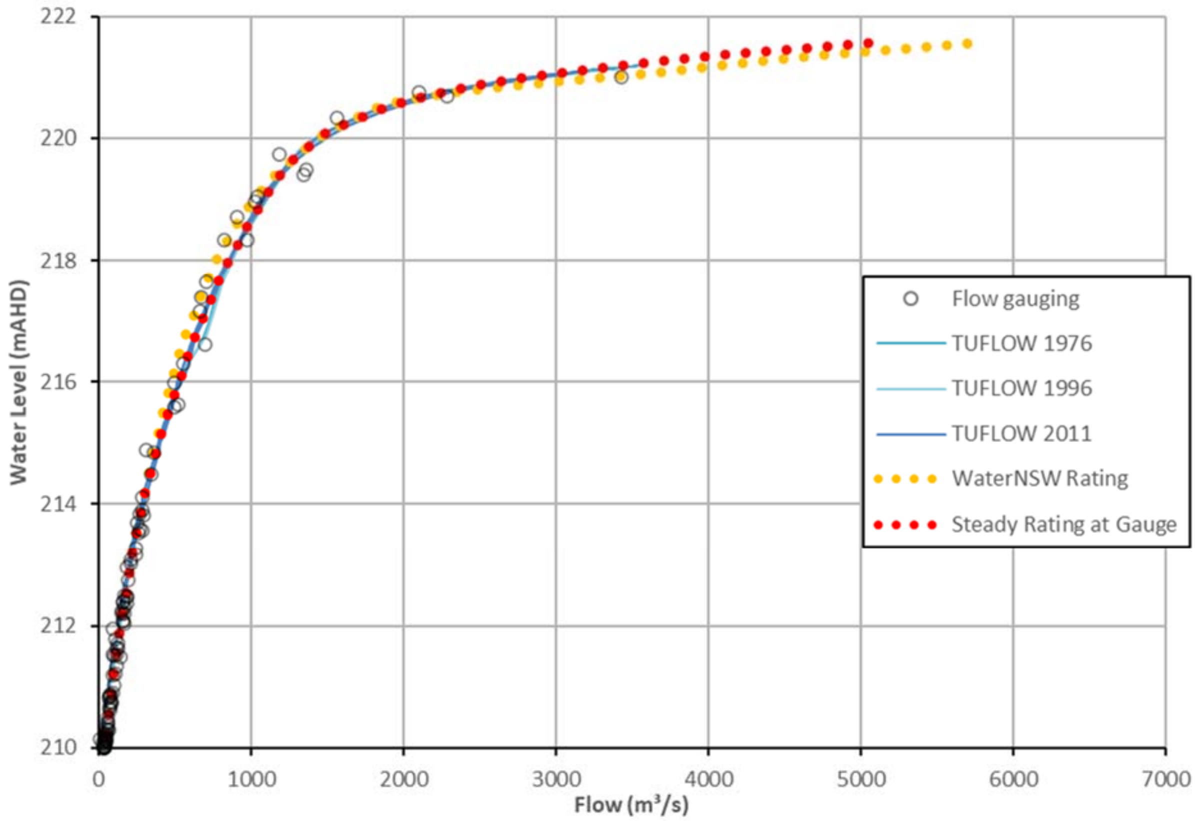

Figure F.5 TUFLOW model results adjusted for dynamic response and proposed steady-state rating

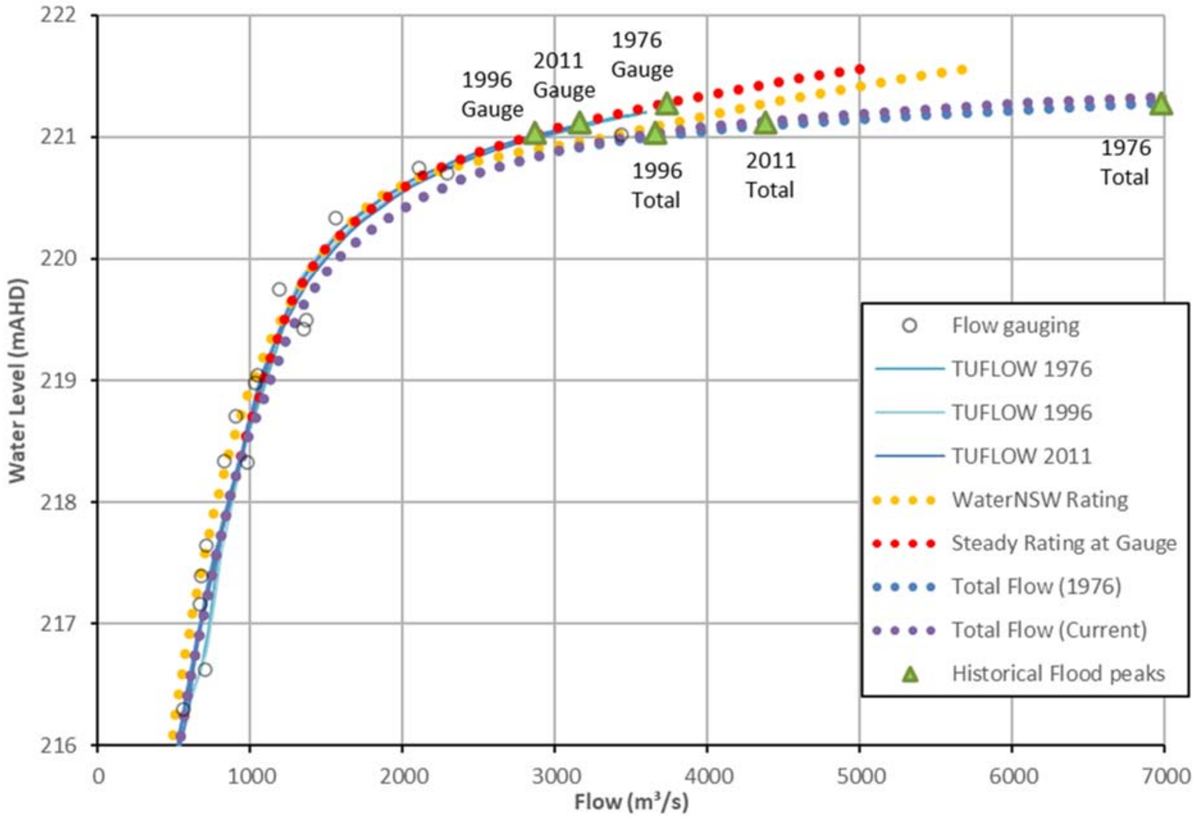

Figure F.6 **Proposed Boggabilla rating adjusting for upstream breakout flow**

F3.2 Flood Frequency Analysis

Flood frequency analysis has been conducted using the FLIKE software package. The assessment has been based on 129 years of data from 1986 to 2021 (including historical floods from 1886, 1890 and 1893 with missing years included as censored data) using annual flood maxima extracted on a water year commencing in September. 14 years with flows less than 150m³/s were censored from the data set to avoid undue influence on the high-flow rating. To ensure consistency of data, all flows were recalculated from the Boggabilla stream gauge levels using the updated total catchment flow ratings.

The FFA was assessed against both the standard Log Pearson III and GEV distributions. As shown in Figure F7, the distributions give similar results but begin to diverge for AEPs rarer than 1 in 100. The GEV projection falls closer to the plotting position of the largest flood event 1976 however since the AEP of this event is highly uncertain this is not proof that the GEV is necessarily a better fit. Other studies, such as the Brisbane River Catchment Flood Study, have found that the LPIII distribution often provides a better fit of catchment response in Queensland and NSW catchments. It is also cautioned that the Boggabilla flood record is not homogeneous, having been successively affected by the construction of Coolmunda and Glenlyon Dams and the Pindari Dam upgrade. This affects the confidence with which a standard probability distribution and also whether the FFA fit represents current catchment conditions. Results of the FFA will be combined with other methods, including rainfall-based Design Event modelling to improve confidence in the projection to extreme events.

FFA results for a range of AEPs are summarised in Table F3. Values from the Lawson and Treloar and BRVFMP FFA results have been included for comparison. The previous study results are lower than the total catchment flows from the current assessment but are relatively similar to the flows that would be observed at the stream gauge location (noting that the At Gauge values in Table F3 were calculated from the total catchment FFA results rather than a separate FFA of 'at gauge' rated flows).

Based on the current FFA assessment, the AEP of the 1976 flood flow is estimated to be approximately 1 in 500, although the Design Event modelling in Appendix H suggests this may be closer to 1 in 200, in part due to the homogeneity issues discussed above. The peak flow of 5,500m³/s estimated by Lawson and Treloar for the 1976 event that resulted in an AEP in excess of 1 in 2000 appears to include a proportion of the breakout flow from upstream of Boggabilla and is therefore inconsistent with either an at-gauge or total catchment flow FFA. The FFA and historical flood event AEP estimation could not be validated or reconciled with other data available for the Boggabilla gauge. The flow of less than 3,000m³/s used by the BRVFMP assessment and the corresponding AEP of

1 in 77 is considered too low and is not substantiated by the current or previous gauge ratings or even the data presented in Section 6 of the BRVFMP.

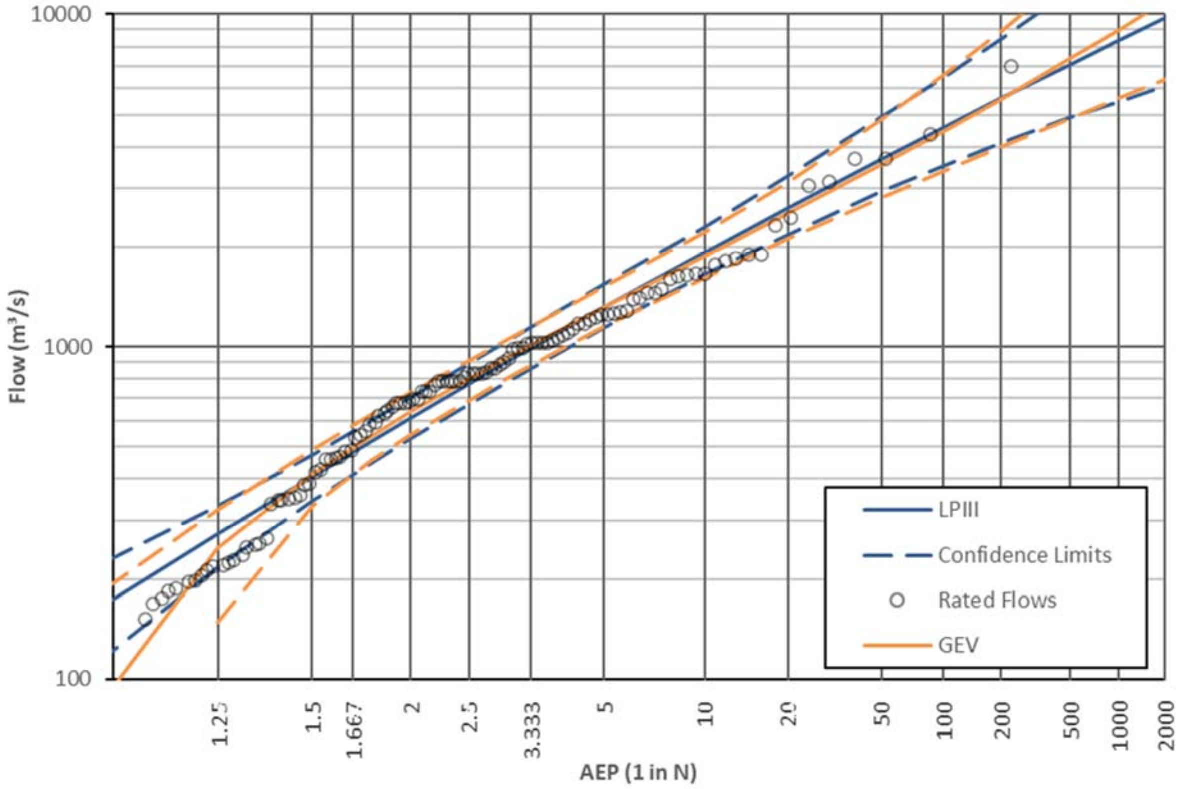

Figure F7 FFA probability relationship for total Macintyre River catchment flows to Boggabilla

Table F3 Summary of previous and current FFA flows (m^3/s)

AEP (1 in N)	Previous studies		Current study (LPIII)	
	L&T (2004)	BRVFMP (2018)	Total Flow	At Gauge [a]
5	1200	1180	1315	1235
10	1670	1610	1930	1730
50	2725	2615	3680	2925
100	3120	3030	4590	3265
200	3555	3440	5595	3625
500	4045	3950	7080	3965

Table notes:

a At Gauge flows are the (estimated) proportion of the Total Flow value that remain in the Macintyre River at the gauge location, not the result of separate At Gauge FFA.

Appendix G
Independent Peer Review Report

G1 Independent Peer Review of updated modelling

North Star to Borders River Review

Reference: R.B23635.00.00_WD_G1.docx
Date: May 2021
Confidential

Document Control Sheet

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	Title:	North Star to Borders River Review
	Project Manager:	Anthony Charlesworth
	Author:	Neil Collins and Anthony Charlesworth
	Client:	FFJV
	Client Contact:	John Carr
	Client Reference:	
Synopsis:		

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	31 May 2021	NC	31/05/2021	ATC	31/05/2021

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
FFJV	x										
BMT File	x										
BMT Library											

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1 Introduction

1.1 Scope of Works

BMT was engaged by Australian Rail Track Corporation (ARTC) to undertake the following scope of works:

(1) Independent hydrology and flooding review for the North Star to Borders (NS2B) project.

(2) Support during the NS2B EIS assessment process to assist with responses to regulator comments, community submissions and independent flood panel review.

This review follows on from our previous review provided on 12 May 2020 and has included a detailed review of the Future Freight Joint Ventures (FFJV), Preferred Infrastructure Report (PIR), March 2021 and has also considered the WRM (Oct 2020) report and ongoing discussions with ARTC including digital data provided by FFJV from February 2021 through to April 2021.

This review largely supersedes the BMT provided 12 May 2020 as the catchment flood modelling system (i.e. integrated hydrological and hydraulic models) presented in the 11 May 2020 report was re-calibrated and updated.

1.2 General Comments

Provided below are our general comments on the numerical catchment flood modelling system.

(1) The latest flood model developed by FFJV is the most comprehensive and accurate model developed for the Border Rivers floodplain system to date and incorporates current best practice approaches and techniques as outlined in 2019 Australian Rainfall and Runoff (ARR 2019) including flood modelling and flood impact assessments.

(2) The latest model developed by FFJV updates all previous models, in terms of accuracy, as this model is based on the current (2019) LiDAR topographic survey that was flown specifically by ARTC for this project.

(3) The LiDAR data is of high accuracy and allows a good representation of flow paths and inundation areas with all existing levees accurately represented. thus allowing, with the flood modelling, for these levees to overtop when flood levels are higher than the levees.

Previous models have assumed that many levee banks do not overtop. The modelling, which is the subject of this review, demonstrates significant overtopping of levee banks will occur in severe flood events. This can have significant effects on flow paths and flood levels predicted across the floodplain.

(4) The resultant flood model, based on the latest LiDAR survey of a very large area of the floodplain, from upstream of Boggabilla to well downstream of Goondiwindi, coupled with the full range of design events produced, provides an opportunity for local and state authorities in both New South Wales and Queensland to take advantage of this contemporary robust tool, for future development and infrastructure project assessments.

(5) The latest hydrologic model has been assessed for the adequacy of its calibration, and in relation to design events produced based on ARR 2019, has been found to be fit for purpose. The latest calibration is more robust than previous model calibrations and is more defendable in terms of its accuracy, and its basis using current best practice methods.

(6) The process that has been undertaken in the latest hydrologic and hydraulic model upgrades has resulted in models that are consistent with the requirements of ARR 2019.

(7) With all the additional rigour that has been applied to the latest modelling, similar results, in terms of rail design levels and hydraulic structure requirements, and the general impacts of the rail on adjacent properties, to those considered in our previous review report have been predicted.

(8) The investigations to date have presented clear guidance for the detailed design requirements and landowner consultation to enable the final design to achieve an acceptable outcome for all parties.

(9) A large range of floods had been simulated in the flood modelling in the previous EIS (FFJV, May 2020) from relatively frequent events, up to extreme events well in excess of any historic floods. Whilst the full range of floods will ultimately need to be re-assessed on the updated flood model, the similarity between the models indicates that a full and comprehensive understanding of flooding under all events has been established, and the assessment of impacts from the proposed rail line is well understood for a full range of events.

Whilst no two floods are alike in such a complex system as the Border Rivers, the updated flood model, along with actual historic event simulations, provides an acceptable level of confidence that the range of possible flood impacts has been captured up to a 1976 flood magnitude event.

1.3 Qualifications

This review is based largely on a desktop assessment. As a result, it is based on the FFJV (March 2021) report, limited numerical data received during February 2021 through to April 2021 and discussion with the technical team. The report documents the methodology of calibration, validation and application of the base TUFLOW flood model, and its use for assessment of impacts as a result of the proposed infrastructure.

As noted in item (9) above, the detailed design will need to consider further the full range of flood events based on the 'Risk-Based Design' concepts detailed in ARR 2019. This is to ensure where necessary, the flood impacts associated with the proposed railway line for the full range of flood events are appropriately managed with particular regards to (1) impacts to evacuation routes, (2) potential increase to loss of life at flood sensitive receptors (FSR); and (3) property damage

2 Flood Frequency Analysis (FFA)

2.1 General Comments

The proposed Inland Rail infrastructure requires the estimation of peak flood flows for the design of the cross-drainage structures (i.e. culvert and bridges)within the Macintyre River basin. Peak flood flows in the Macintyre River are influenced by the large floodplain and dams associated with the river basin that can store an appreciable portion of the flood volume.

As part of the ARTC best practice approach and as documented in ARR 2019 (Book 3, Chapter 1, Section 1.1), '*where adequate data of sufficient quality are available, it is recommended that an at-site Flood Frequency Analysis (FFA) be used for estimation of the design peak flood discharge quantiles'.* The FFJV (May 2020) report and the present re-calibration presented in the FFJV (March 2021) report has undertaken a detailed FFA for the catchment.

ARR 2019 (refer to Book 3, Section 2.4.1) notes that for an '*at site*' FFA, there is *'no universally accepted flood probability model. Many types of probability distributions have been applied to Flood Frequency Analysis*'. ARR 2019, Book 3 also notes the following:

(1) *'As a general rule, the selected probability distribution family should be consistent with available data. It is recognised that more than one probability distribution family may be consistent with the data. One approach to deal with this problem is to select the distribution family on the basis of best overall fit to a range of catchments within a region or landscape space' (*refer to ARR 2019, Book 3, Section 2.4.1)

(2) *'Two distribution families are suggested as reasonable initial choices for annual maxima (AM) series, namely the Generalized Extreme Value (GEV) and Log Pearson III (LP III) families. These families fit most AM (*i.e. Annual Maxima*) flood data adequately' (*refer to ARR 2019, Book 3, Section 2.4.2*)*.

The present re-calibration undertaken by FFJV has updated the FFA assessment and has included 11 gauging sites (9 upstream of Boggabilla) as presented in Appendix A. FFJV has also undertaken the analysis based on both the Generalised Extreme Value (GEV) and Log Pearson (LP) III families. This represents a significant improvement on the Border Rivers Valley Floodplain Management Plan (BRVFMP) that presents six (6) FFA analyses (i.e. including Boggabilla), whereby three (3) of these assessments are downstream of Boggabilla (Terrewah, Kanowna and Mungindi). The two gauges upstream of Boggabilla assessed by BRVFMP are Holdfast and Glenarbon Weir. The latter had only 27 years of record and has an uncertain high-flow rating (i.e. the rated peak flow of approximately 1,800m³/s compared to approximately 4,000m³/s upstream at Bonshaw).

The 11 gauges used by FFJV provides a distributed and robust selection of catchment flows to validate (reconcile) the peak flood discharges developed for design purposes. A review of the FFA presented by FFJV is provided below.

2.2 Gauging Data

Table 2-1 below provides the stream gauging data used by FFJV that consists of 11 gauge locations (i.e. excluding Goondiwindi).

Table 2-1 Available Stream Gauge Data and Characteristics

Waterway	Gauge	Period (yrs)	Catchment Area (km2)
Macintyre River	Boggabilla	126	22,600
	Holdfast	**47**	**6,740**
	Ashford	87	3,010
	Wallangra	86	2,020
Macintyre Brook	**Booba Sands**	**33**	**4,092**
	Inglewood	32	3,340
Dumaresq	Farnbro	58	1,310
	Bonshaw Weir	86	7,280
	Roseneath	83	5,550
	Cunningham/Glenarbon	**24**	**9,235**
Ottleys Creek	Coolatai	41	402

Note: **Bold** denotes catchment outlet

As detailed in FFJV (March 2021) report, Table A1, there is adequate data of sufficient quality to enable a FFA to be undertaken and also to allow a detailed calibration of the hydrological and hydraulic model for design purposes.

From discussion with FFJV, it is understood that whilst several other gauges could potentially be assessed, such as Texas (catchment area = 422 km^2) that has a very good period of record, Donaldson (catchment area = 1,610 km^2) and Terraine (catchment area = 685 km^2), these have significantly smaller catchments areas than those that have been used in the assessment and would provide limited additional benefit to the study. Riverton also has a long period of historical record, but there is some uncertainty with the rating and Roseneath is located not far downstream. Most of the other gauges either have a short period of record (Tintot, Ridgelands, Woodspring), potentially unreliable data or backwater affected rating (e.g. Westholme, Inverell) or both (e.g. Fladbury, Strathbogie). The inclusion of the FFA of the gauges listed in Table 2-1 is comprehensive and addresses the concerns raised by WRM (2020, refer to Section 3.3)

Of all the gauges available, the Boggabilla gauge is the most important gauge having over 100 years of data, is located in close proximity to the proposed inland rail alignment and provides a key reconciliation (verification) point for the hydrologic and hydraulic models. FFJV have undertaken a detailed assessment of the Boggabilla gauge (refer to FFJV, 2021 Appendix F) and, consequently, a separate review of the Boggabilla gauge is provided in Section 2.3 below due to its importance in the overall assessment. A review of the local catchment gauges that were used for calibration and that also included a FFA is also provided in Section 2.4.

2.3 Boggabilla Stream Gauge FFA

2.3.1 Quality of Data

The quality of data at Boggabilla is of importance to ensure the reliability of the FFA to enable it to be used for estimation of the design peak flood discharges . The key points and assumptions associated with the Boggabilla gauge as noted by FFJV are as follows:

(1) The stream gauge is located downstream of Boggabilla and significant break-out flows occur upstream of the gauge into the Whalan Creek and Morella watercourse.

(2) In 1991 the Boggabilla gauge was rendered ineffective due construction of the Boggabilla Weir by the Borders Rivers Commission (BRC). The current gauge location was re-established in October 1991 downstream of the Boggabilla Weir.

(3) The 1996 gauging (i.e. post-1991 derived flows) includes an estimate of breakout flow into the Whalan Creek system that occurs upstream of Boggabilla, however it is understood that the 1976 flow estimate <u>does not include</u> the breakout flow into the Whalan Creek system.

(4) The current WaterNSW gauge rating is theoretically the total river flow upstream of Boggabilla. The current gauge rating is provided in Figure 8.6 in the FFJV report (May 2020) and is provided below for ease of reference. The gauge rating is generally reliable up to 3,500m^3/s as per FFJV (May 2020) report, but perhaps unreliable above this flow (refer to FFJV, March 2021, Section F1.3).

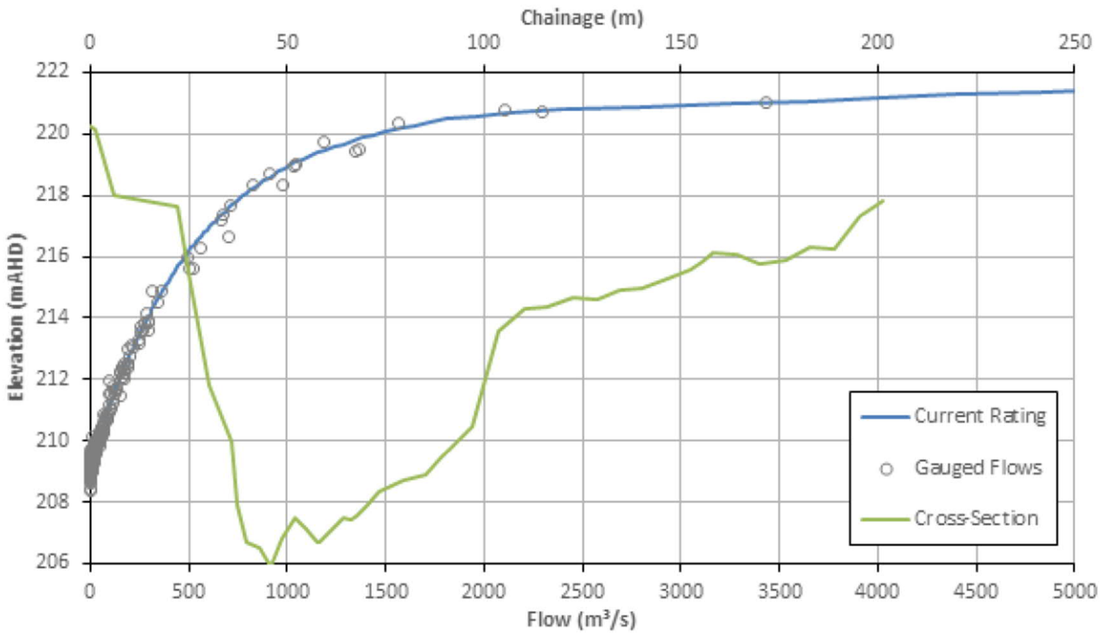


Figure 8.6 Boggabilla stream gauge rating

From a consideration of the above assumptions, there remains a degree of uncertainty associated with the gauge flows and total catchment flows that is unlikely to be entirely resolvable with currently available data, however, FFJV have assessed the gauge data in further detail as described in Section 2.3.2 below to provide the most robust assessment to date. Furthermore, the updated assessment has included the historical floods of 1886, 1890 and 1893 as identified by WRM (2020, refer to Section 6.2.2)

2.3.2 Updated FFA Analysis (FFJV, March 2021)

Due to the inconsistencies and uncertainties associated with the Boggabilla stream gauge, FFJV (March 2021) has updated the FFA and hence the predicted total flows through a joint calibration with TUFLOW. As presented in the FFJV (March 2021), the hydraulic model was used to improve the flow gauge rating by calibrating the TUFLOW model to match the gauge data. The hydraulic model represents the gauging data to 3,500m^3/s reasonably well and to account for hysteresis.FFJV adopted the Jones Method through the application of the TUFLOW results.

The adjusted Jones Method TUFLOW results provide a very good correlation to the flow gauging as presented in FFJV (March 2021) report Figure F.5 and provided below for ease of reference, whilst the proposed rating (i.e. FFJV, March 2021, Figure F.6) is also provided below for ease of reference.

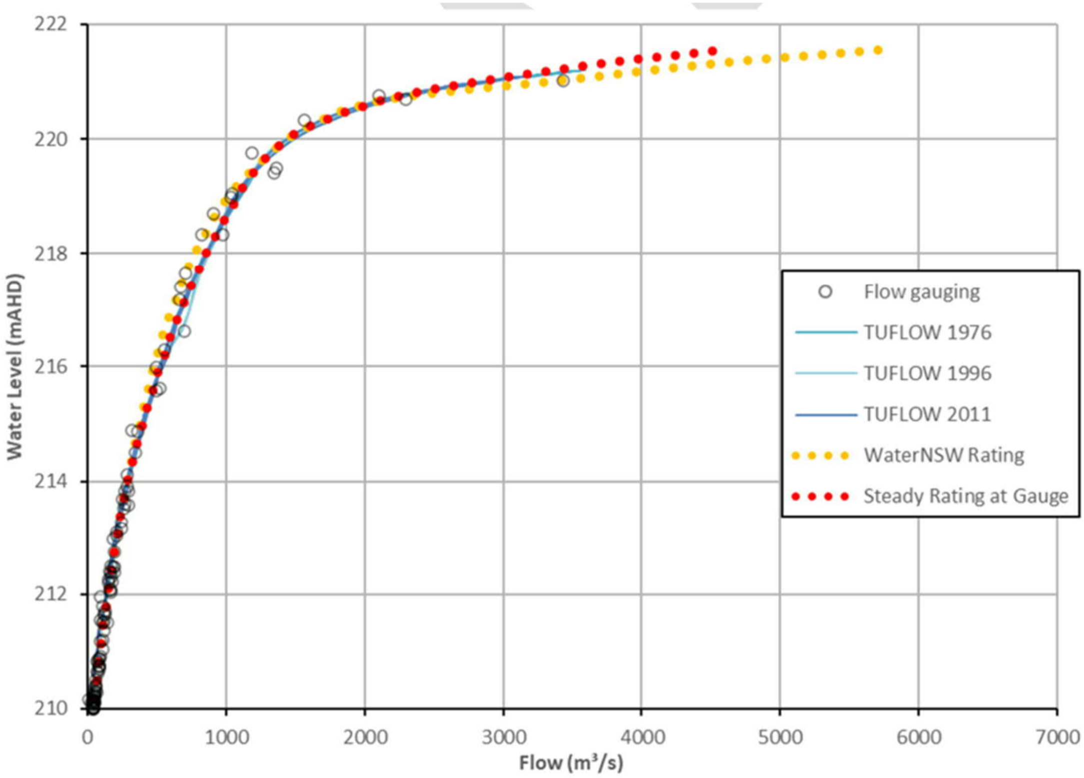


Figure F.5 TUFLOW model results adjusted for dynamic response and proposed steady-state rating

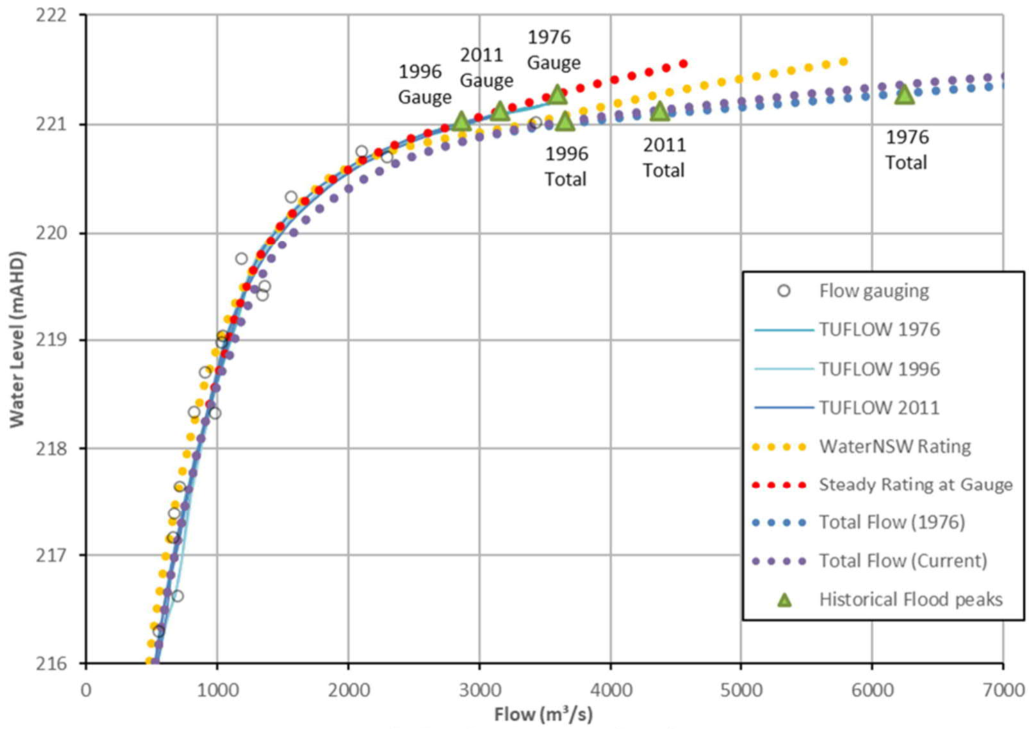


Figure F.6 Proposed Boggabilla rating adjusting for upstream breakout flow

Based on the adjusted gauge rating developed by FFJV (March 2021) an updated FFA was undertaken and the results are provided below for ease of reference.

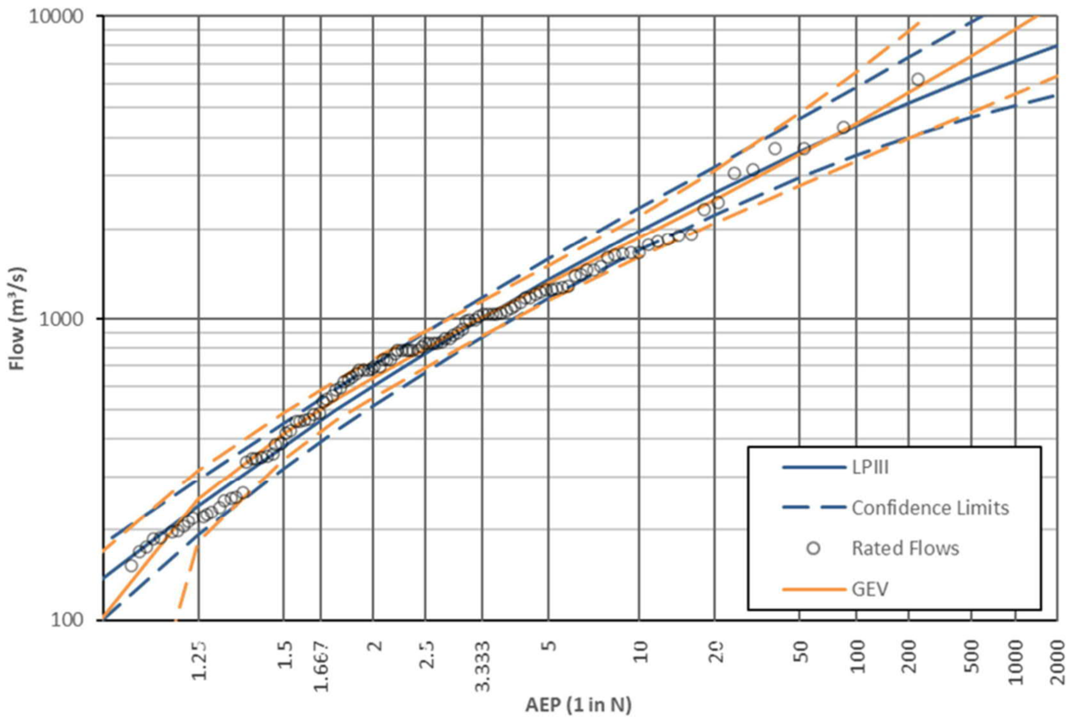


Figure F.7 FFA probability relationship for total Macintyre River catchment flows to Boggabilla

The adopted approach undertaken by FFJV provides a robust assessment of the 'total flows' that occur on the Macintyre River/ floodplain at Boggabilla. The re-rating of the gauge data through the use of the calibrated TUFLOW model and the Jones method provides an assessment that was not previously undertaken as part of the BRVFMP or FFJV (May 2020). The current assessment provides the best assessment undertaken to date to resolve the inconsistencies associated with the Boggabilla gauge through quantifying the break-out flows to enable the most appropriate FFA to be undertaken.

As noted by FFJV (May 2020 & March 2021) many FFA assessments have been undertaken with an array of results. It is considered that the current assessment presented by FFJV is the most thorough and reliable to date and that this addresses the concerns raised by WRM (2020, refer to Section 3.3 and Section 6.2.2).

A review of the updated results are provided below and compared to the previous FFJV (May 2020) assessment.

2.3.3 Review of Updated Boggabilla Stream Gauge Results

A review through a comparison of the latest FFJV (March 2021) FFA with previous assessments was undertaken based on the results provided in the FFJV (May 2020) Technical Report. Table 2-2 summarises the total upstream flow (i.e. including Whalan Creek and Morella Watercourse) at Boggabilla while Table 2-3 provides the partial flows at (i.e. excluding Whalan Creek and Morella Watercourse) Boggabilla. A comparison of the full catchment flows and partial flows is also provided in Table 2-4.

A summary of the revised FFA and TUFLOW model results indicates that the:

(1) **1976** flood event has:

(a) An adjusted rated total flow of approximately 6,200m^3/s (i.e. FFJV March 2021), compares with the previous FFJV (May 2020, refer to Figure 8.9) FFA of 4,520m^3/s.

A modelled (i.e. TUFLOW) total peak flows between 7,000 m^3/s to 8,460 m^3/s for an un-factored and factored flood event (FFJV May 2020). The resulting modelled flow (i.e. un-factored or factored 1976) was significantly higher than the FFJV (May 2020) FFA of 4,520 m^3/s.

The current FFA assessment (i.e. FFJV, March 2021, refer to Figure F.7) indicates a resulting rated total flow of approximately 6,200 m^3/s.

(b) A current Annual Exceedance Probability (AEP) estimate in the range of 1 in 200yr to 1 in 500yr, however from our understanding the FFJV (March 2021) indicates a 1 in 500yr AEP flood is more likely based on LPIII extrapolation.

(2) **1996** flood event has:

(a) A current rated total flow of approximately 3,600m^3/s (FFJV, 2021) compared with the previous FFJV (May 2020) assessment of 3,486 m^3/s. As previously noted the gauge is reasonably reliable up to 3,500 m^3/s.

(b) Modelled (i.e. TUFLOW) total peak flows were previously assessed (i.e. FFJV May 2020) at between 3,175m^3/s to 5,104m^3/s for un-factored and factored models respectively.

The current assessment (FFJV, March 2021) indicates a total peak flow of 3,470m^3/s, similar to the previous FFA of 3,486 m^3/s.

(c) An AEP in the range of 1 in 20yr to 1 in 50yr.

(3) 2**011** flood event has:

(a) A rated total flow of approximately 4,300m^3/s (FFJV, 2021), this compares with the previous FFJV (May 2020) assessment of 3,800m^3/s.

(b) Modelled (i.e. TUFLOW) peak flows were previously assessed (i.e. FFJV May 2020) at 4,449m^3/s, while the current assessment (FFJV, 2021) indicates 4,493m^3/s

(c) An AEP in the range of 1 in 90yr.

(4) 1 in 100yr AEP has:

(a) A previous FFJV (May 2020) rated a total flow of 3,800m^3/s (LPIII), but a modelled TUFLOW total flow of 5,400 m^3/s was adopted. This flow was notably higher than the FFA, but lower than the 1976 flood event between 7,000 m^3/s to 8,460 m^3/s.

(b) A revised FFJV (March 2021) rated flow of 4,375m^3/s, whilst the design 1 in 100yr AEP 'current' flood event is 4,565 m^3/s assuming a quantum of storage is available in the dam prior to the flood event (i.e. dam not full). With the dams full this peak flood flow increases to 5,445 m^3/s.

The above comments highlight the magnitude of the 1976 flood event (i.e. 6,200 m^3/s) compared to the 1 in 100-year AEP flood 'current' flood event (i.e. 4,565 m^3/s), with the 1976 event being approximately 36% larger. However, the FFJV (May 2020) adopted a design (i.e. TUFLOW) flow of 5,400 m^3/s while the present 1976 flood flow used for the FFJV (March 2021) PIR report is approx. 6,300 m^3/s (i.e. approx. 16% larger).

From a review of the summary tables and comments provided above, a level of residual uncertainty remains associated with the Boggabilla gauge. The residual uncertainty is due to the inherent problem of deriving rated flows that appropriately account for the full (i.e. total) upper catchment flows that escape upstream of Boggabilla along Whalan Creek and the Morella Watercourse during large flood events. However, further confidence in the FFJV updated assessment at Boggabilla is provided through the extensive calibration/ verification of their hydrologic and hydraulic (i.e. catchment) modelling system. In particular, FFJV (March 2021) have compared their flood hydrographs to 25 upstream gauges for the 1976, 1996 and 2011 flood events and have undertaken additional FFA at a further 10 gauges upstream of Boggabilla.

Notwithstanding the uncertainty associated with the Boggabilla gauge, the FFJV (March 2021) assessment of the 2011 and 1996 flood event (un-factored) flows have not changed significantly from the FFJV (May 2020) assessment. The current FFJV assessment of the 1976 flood has increased the rateable flow from approximately 4,500 m^3/s to 6,200 m^3/s. The 1976 flood event remains with a degree of uncertainty due to the state of the floodplain in 1976 and the Boggabilla gauge shifting.

Table 2-2 Comparison of Gauged, Model Flows and Levels (Total Flows Only, not Partial Flows at Gauge) Boggabilla

		Flood Events			Design			
		Feb 1976	**Jan 1996**	**Jan 2011**	**1 in 100yr AEP**	**1 in 200yr AEP**	**1 in 500yr AEP**	**1 in 50yr AEP**
FFJV May 2020 Results								
Recorded Level (FFJV May 2020, Table 7.1) m AHD		221.27	221.03	221.12				
TUFLOW Flood Level Results (May 2020, Table 7.7) m AHD	Unfactored	221.18	220.91	221.07				
	Factored	221.22	221.11	-	221.20			
Boggabilla Gauged Flows (May 2020, Table 7.5) m^3/s		4,700 Table 7.5 NA, however Refer to Fig. 8.10	3,486 (total flow)	3,803 (total flow)	-	-	-	-
Numerical TUFLOW Results (May 2020, Table 7.7, Table 8.9 / Fig 8.10) Total Flows (m^3/s)	Unfactored	7,000 (Approx. Fig 8.10)	3,175 (Table 7.7 & Fig 8.10)	4,449 (Table 7.7 & Fig 8.10)				
	Factored	8,730 (Approx. Fig 8.10 & perhaps Table 7.13?)	5,104 (Table 7.7 & Fig 8.10)	NA	5,379 (Table 8.9 TUFLOW US)	6,800 (approx.) Fig 8.10 Design US	8,700 (approx.)- Fig 8.10 Design US	4,235 (Table 8.9 TUFLOW US)
FFA (May 2020, Fig 8.10 / Table 8.9) Predicted AEP / Total Flows (m^3/s)		1 in 200yr AEP	1 in 75yr AEP	1 in 100yr AEP	3,800 Table 8.9 LPIII	4,600 (approx.) Fig 8.10 LPIII	5,800 (approx.) Fig 8.10 LPIII	3,100 Table 8.9 LPIII
FFJV Feb 2021 Results								
Numerical TUFLOW Results (FFJV, Jan 2021b) from Excel		3,400	Approx. 3,600 (modelled rating)	Approx. 4,400 (modelled rating)				
FFJV (Technical Note, Feb 2021, Fig 6 & Table 3 / Fig 7) Total Flow - LPIII - (m^3/s)		Approx. 7,000 LPIII 1 in 500yr AEP GEV 1 in 210yr AEP	Approx. 3,500 1 in 50yr AEP	Approx. 4,300 1 in 90yr AEP	4,375	LPIII 5,175 GEV 5,500	LPIII 6,275 GEV 7,200	3,610
Summary / Range	**AEP**	1 in 200 – 500yr	1 in 50yr-75yr	1 in 90 – 100yr	-	-	-	-
	Peak Flows (m3/s)	4,354 – 8,730	**3,379 – 5,104**	3,803 – 4,449	**3,800 – 5,379**	**5,175 – 6,800**	**6,275 – 8,700**	**3,100 - 4,235**

Table 2-3 Comparison of Gauged, Model Flows and Levels (Partial Flows at Gauge)

		Flood Events			Design			
		1976	**1996**	**2011**	**1 in 100yr AEP**	**1 in 200yr AEP**	**1 in 500yr AEP**	**1 in 50yr AEP**
FFJV May 2020 Results								
Recorded Level (m AHD)		221.27m AHD	221.03	221.12	221.20 (TUFLOW – May 2020)			
Rated Flow – Partial Flows (m^3/s)		3,700	What would this be?	What would this be?				
TUFLOW Results (May 2020) Table 7.10, 7.15, Partial Flows (m^3/s)	unfactored	3,628 (Table 7.10) 3,626 (Table 7.7)	2,542	3,057				
	factored	3,836 (Table 7.7)	3,237	NA	3,294			-
FFA (May 2020, Fig 8.10) Predicted Partial Flows (m^3/s)					3,200	3,500	4,000	2,900
FFJV Feb 2021 Results								
Numerical TUFLOW Results (FFJV, Jan 2021b) from Excel		Partial Results not provided (?)						
FFJV (Technical Note, Feb 2021, Fig 6, Table 3 / Fig 7) Partial Flow - LPIII - (m^3/s)		Approx. 3,500	Approx. 2,800	Approx. 3,200	3,130	3,475	3,885	2,860
Range (m^3/s)		3,500 – 3,836	2,542 - 3,237	3,057 – 3,200	3,130 – 3,294	Approx. 3,500	Approx. 4,000	2,860 - 2,900

Table 2-4 Comparison of Partial and Total Flows Ranges at the Gauge

		Flood Events			Design			
		Feb 1976	**Jan 1996**	**Jan 2011**	**1 in 100yr AEP**	**1 in 200yr AEP**	**1 in 500yr AEP**	**1 in 50yr AEP**
FFJV May 2020 Results								
Total Flow Summary / Range	**AEP**	1 in 200 – 500yr	1 in 50yr-75yr	1 in 90 – 100yr	-	-	-	-
	Peak Flows (m3/s)	4,354 – 8,730	**3,379 – 5,104**	3,803 - 4449	**3,800 – 5,379**	**5,175 – 6,800**	**6,275 – 8,700**	**3,100 - 4,235**
Partial Flow Range (m^3/s)		3,500 – 3,836	2,542 - 3,237	3,057 – 3,200	3,130 – 3,294	Approx. 3,500	Approx. 4,000	2,860 - 2,900

2.4 Local Catchment FFA

The FFJV have used the local catchment gauges identified in Table 2-1 for calibration of their hydrological model (refer to Section 3) and also undertaken detailed FFA. The results of the FFA are presented in Appendix A and a summary of the assessment is provided in Table 2-5.

From the FFA the following is noted:

(1) 1976 flood event at the catchment outlets of Holdfast, Booba Sands and Cunningham/ Glenarbon was approximately a 1 in 100yr AEP flood event on the Macintyre River, Macintyre Brook and Dumaresq River respectively, resulting in a 1 in 200yr AEP at Boggabilla.

(2) 2011 flood event at the catchment outlets Cunningham/ Glenarbon (i.e. Dumaresq River) was approximately a 1 in 200yr AEP flood event, whilst on Macintyre River and Macintyre Brook it was significantly less at 1 in 10yr AEP to 1 in 15yr AEP; resulting in a 1 in 90yr AEP at Boggabilla.

(3) 1996 flood event at the catchment outlets of Holdfast, Booba Sands and Cunningham/ Glenarbon was approximately a 1 in 10yr AEP flood event on Macintyre River, Macintyre Brook and Dumaresq River respectively, resulting in a 1 in 40-yr AEP at Boggabilla;

The FFA has identified that different combinations of flood events on each of the three catchments from frequent to rare can cause rare to very rare flood events at Boggabilla. This combination of joint probabilities on each catchment is however largely reconciled at the Boggabilla gauge.

The use of the local catchment FFA and also the use of the flood hydrographs within the catchment for calibration of the hydrological model is an improvement on the FFJV (May 2020) flood assessment and the Department of Planning, Industry and Environment (DPIE) flood assessment. This improvement provides a robust outcome based on all the relevant and available data within the catchment and addresses the concerns raised by WRM (2020, refer to Section 3.3).

Table 2-5 Available Stream Gauge Data and Characteristics

Waterway	Gauge	Flows (m^3/s)					
		1976	1996	2011	100yr	200yr	500yr
Macintyre River	Boggabilla	6,100 (1 in 200yr AEP)	3,800 (1 in 40yr AEP)	4,200 (1 in 90yr AEP)	4,200	5,000 LPIII 5,500 GEV	6,000 LPIII 7,200 GEV
	Holdfast	**2,900** **(1 in 90yr AEP)**	1,200 (1 in 9yr AEP)	1,200 (1 in 15yr AEP)	3,000	3,700	4,500
	Ashford	1,900 1 in 90yr AEP)	500 1 in 5yr AEP	900 (1 in 15yr AEP	2,000		
	Wallangra	1,100 1 in 90yr AEP)	500 1 in 9yr AEP	300 1 in 3yr AEP	1,200		
Macintyre Brook	**Booba Sands**	**2,000** (1 in 100yr AEP)	**700** (1 in 15yr AEP)	**600** **(1 in 10yr AEP)**	**2,000**	**2,200 LPIII** **2,900 GEV**	
	Inglewood	2,700 (1 in 40yr AEP)	800 (1 in 8yr AEP)	800 (1 in 10yr AEP)	5,000	7,500	
Dumaresq	Farnbro						
	Bonshaw Weir	1,100 1 in 30yr AEP)		4,000 (1 in 70yr AEP)			
	Roseneath	3,200 (1 in 50yr AEP)	1,100 (1in 10yr AEP)	3,200 (1 in 80yr AEP)	4,000	5,500	8,000
	Cunningham/Glenarbon	**3,000** **(1 in 100yr AEP)**	1,100 (1 in 9yr AEP)	3,500 (1 in 200yr AEP)	**3,000**		

Note: **Bold** denotes catchment outlet
Green shading indicates a flood flow approximately equal to or greater than the 1 in 100-yr AEP

3 Hydrological Catchment Simulation (URBS)

3.1 Overview

The FFA (refer to Section 2) undertaken by the FFJV uses the recommended method identified in ARR 2019 and therefore provides confidence in its use for the design of flood flows. However, this is only one aspect of providing a robust catchment model. For the Macintyre River, the volume of the flood hydrograph and timing will also have a dominant influence on the calibration of the catchment model and ultimately on the FFJV design (mitigation) in meeting the Floodplain Management Objectives (FMO).

As documented in ARR 2019 (refer to ARR 2019, Book 7, Chapter 5, Section 5.8) '*the ultimate requirement for model parameter determination is to apply the calibrated model to certain design situations'*. The FFJV (March 2021) has reviewed, collated and calibrated a revised hydrological model suite using all of the relevant and available data through a single parameter set as recommended by ARR 2019 and noted by WRM (2020, refer to Section 5.2.2).

For the Macintyre River and associated tributaries, there is an extensive set of data available for calibration with regards to a range of flood magnitudes and conditions and the flood data is generally accurate, reliable and consistent. The key floods for calibration are 1976, 1996 and 2011 with the 2011 flood having the most accurate and reliable data set. From our understanding, the Department of Planning, Industry and Environment (DPIE) has not yet updated their hydrological model to include the calibration of the 2011 flood event. The FFJV models provide a substantial improvement in verifying the catchment response and provides confidence in the adopted model parameters without the factoring of flows, which is required for the DPIE models.

This review of the FFJV hydrological model has been based upon the FFJV (March 2021) report and subsequent discussions.

3.2 Hydrological Data

3.2.1 Rainfall

From a review of the FFJV (March 2021) report, the number of rainfall gauges sourced and used in the calibration has significantly increased from the DPIE modelled calibration events of 1976 and 1996, and all available gauges for the 2011 flood event were also included.

For the re-calibration work, FFJV has used 16 Bureau of Meteorology (BOM) pluviographs for the 1976 flood event and 24 pluviographs for the 1996 flood event, representing a modest increase in the number of pluviographs, noting that a number of these new pluviographs are outside the catchment. The greatest improvement is with regards to the 2011 flood event, where 45 pluviographs have been used, although these are not uniformly distributed across the catchment.

The FFJV (March 2021) has also decreased the timestep of the DPIE model from 3 hours to 1-hour, which improves the calibration to the gauges in the upper catchment, particularly for 1996 which was a combination of multiple short storm events. The pluviographs were supplemented by 150 to 200 daily rainfall gauges. The rainfall isohyets are provided in FFJV (March 2021) Appendix A.

Ultimately, the increased number of rainfall gauges represents an improvement on the DPIE model and that used by FFJV (May 2020) by more accurately quantifying the rainfall (i.e. volume) in the catchment. This improvement provides a robust outcome based on all the relevant and available data within the catchment and also addresses the concerns raised by WRM (2020, refer to Section 3.3).

3.3 URBS – Calibration Model Parameters

ARR 2019 notes that the adopted parameters should consist of a single set since this is required for design application after the calibration process. However, ARR 2019 also notes that rather than a 'simple' averaging approach of parameters to maintain a single set, an alternative approach is to:

(1) weight them more towards rarer floods; or

(2) adopt a set that is estimated from a historic flood that is most similar to the design flood requirements.

The adopted parameter set for the FFJV (May 2020) report is presented in Table 3-1 and for the updated model of FFJV (March 2021) Table 3-2 below.

Table 3-1 URBS Parameters and Losses Applied for Each Calibration Event (FFJV 2020)

Parameters		URBS Models		
		Macintyre River	Dumaresq	Macintyre Brook
Alpha		0.2	0.1 (2011 & 1976) 0.2 (1996)	0.2
n				
Beta		1.2	1.2	1.2
m		0.8	0.8	0.8
x				
Reach length factors		0.45 to 1.95	1.0 to 2.0 Factor of 9 used for Brush Creek to Beebo)	1.0 to 2.0
Initial Loss	1976	36.5	42.9	0.0
	1996	26.2	40.0	25.0
	2011	50.0	47	60
Continuing Loss	1976	2.32	4.34	2.5
	1996	0.85	0.94	2.0
	2011	3.30	0.50	0.80

Table 3-2 URBS Parameters and Losses Applied for Each Calibration Event (FFJV 2021)

Parameters		URBS Models		
		Macintyre River	Dumaresq	Macintyre Brook
Alpha		0.45	0.45	0.45
n		0.85[a]	0.85	0.85[b]
Beta		1.2	1.2	1.2
m		0.8	0.8	0.8
x		0.3	0.3	0.3
Reach length factors		0.6 to 1.6	1.0 to 3.0	0.8 to 2.0
Initial Loss	1976	20 - 60	30 to 70	60 to 80
	1996	50 - 100	40 to 80	45 to 60
	2011	25 - 50	20 to 40	30
Continuing Loss	1976	2.4 to 3.3	2.5 to 4.5	2.8 to 4.0
	1996	1.2	0.5 to 3.0	0.5 to 3.0
	2011	1.6 to 3.5	0.8 to 2.7	1.0 to 1.4

Notes: (a) n=1.0 for the lower reach between Ridgeland and Holdfast: (b) n=1.0 for the lower reach between Inglewood and Booba Sands

From a review of Table 3-1, whilst a single set of parameters would be preferable the ‘Alpha’ factor used by FFJV (May 2020) for the design event assessment also adopted a value of 0.1. An Alpha value of 0.1 is consistent with the largest two flood events (i.e. 2011 and 1976) on the Dumaresq River and this is also consistent with ARR 2019 recommendations. With regards to the 1996 flood event, the Dumaresq River had limited flow (refer to Table 3-3) when compared with the 1976 and the 2011 floods.

Recalibration of the URBS model parameters was however undertaken by FFJV (March 2021) to produce an improved single set of parameters as recommended by ARR 2019 and WRM (2020). From a review of the URBS parameters, they are within typical bounds used for other catchments throughout Queensland and New South Wales and comply with ARR 2019 recommendations. However, given the design requirements to comply with the Floodplain Management Objective (FMO’s) as detailed in FFJV (March 2021) Section 2.3, the calibration/ verification to the 1976 and 2011 flood events are the most relevant when mitigation measures are proposed for the rail line.

3.4 Calibration Results

For the three flood events of 1976, 1996 and 2011, the URBS model was calibrated to match as close as possible to approximately 25 (i.e. dependent upon flood event) flow gauges available upstream of Boggabilla. The results are presented in FFJV (March 2021) Appendix A.

3.4.1 Peak Flow

A peak flow comparison is provided in Table 3-3 for each of the flood events used for calibration and the peak flow per kilometre squared ($m^3/s/km^2$) is provided to normalise the flow.

Table 3-3 Peak Flow Comparisons at Key Gauge Locations

Gauge Location	1976		1996		2011	
	Peak Q	Q/km²	Total Q	Q/km²	Total Q	Q/km²
Macintyre River (Holdfast) – 6,892 km²	2,859	**0.415**	1,109	0.161	1,479	0.215
Dumaresq River (Mauro) – 9,093 km²	3,083	**0.340**	1,331	0.146	3,630	**0.399**
Macintyre Brook (Booba Sands) 3,983 km²	1,848	**0.464**	823	0.207	723	0.181
Ottleys Creek – 1,375 km²	1,524	**1.108**	599	**0.436**	60	0.044

From the graphs presented in FFJV (March 2021) Appendix A and the table above, the following key points are noted:

(1) **1976** represents a flood event that was generated relatively evenly across the greater catchment with a flow of approximately 0.4 $m^3/s/km^2$. As noted in Section 2.4, the flood event corresponded with a 1 in 100-year in the Macintyre River, Dumaresq River and Macintyre Brook. The flood event/ runoff on Ottleys Creek was notably higher at 1.1 $m^3/s/km^2$.

(2) **1996** represents a flood event significantly smaller flood event than the 1976 and 2011 flood events and notably smaller on the Dumaresq River.

(3) **2011** represents a significant flood event that occurred primarily within the Dumaresq River catchment (i.e. approx. 1 in 200yr AEP) with a runoff rate in the order of 0.4 $m^3/s/km^2$. The flows within the Macintyre River and Macintyre Brook were notably smaller (i.e. approx. 1 in 15yr to 10yr AEP respectively) than the 1976 flood event with a runoff rate in the order of 0.2 $m^3/s/km^2$ and similar to the 1996 flood event.

These three flood events represent a range of flood magnitudes and conditions that, as per ARR 2019, provide a reasonable calibration set of flood events for a catchment model when designing infrastructure for rare flood events.

3.4.2 Local Catchment Flood Hydrographs

As previously noted, the local catchment flood hydrographs for calibration are presented in FFJV (March 2021) Appendix A and depict the timing, peak flow and volume comparisons. The calibration to the largest three flood events of 1976, 1996 and 2011 considered the following upper catchment gauges:

(1) **Macintyre River** – Holdfast (area = 6,740km^2), Wallangra, Tintot, Inverell, Westholme, Strathbogie, Fladbury, Ashford (area = 3,285 km^2), Ridgelands and Pindari

(2) **Dumaresq River** – Glenarbon (area = 9,235 km^2), Bonshaw (area = 7,280 km^2), Bebo, Oakey, Farnbro, Glenlyon, Donaldson, Haystack, Roseneath, Cunningham, Texas, Riverton, and Mauro

(3) **Macintyre Brook** – Booba Sands (area = 4,092 km^2), Inglewood, Woodspring, Terraine, Coolmundra, Barongarook, Inglewood (CBM) and Inglewood.

These three gauges represent 89% (i.e. total area of 20,067 km^2) of the contributing catchment area to the Boggabilla gauge that has a total area of 22,600km^2. A summary of the calibration hydrographs is provided in Table 3-4.

Table 3-4 Summary of Calibration of Local Catchments

Catchment	Gauge	2011 (Frequent Flood)	1976 (Rare Flood)	1996 (Frequent to Rare Flood)	General Comment
Macintyre River	Holdfast	1. The hydrograph depicts an initial low peak flow that exceeds initial losses, indicating the resulting hydrograph is dominated only by continuing losses and calibration parameters. 2. Calibration indicates an 'on time' to 'slightly early' timing of peak flood flow, noting the rated flow tapers off towards the peak. 3. A good correlation occurs on the rising and falling limb.	1. FFJV calibration peaks approximately 3hrs-6hrs earlier than DPIE, but both correlate with rising limbs. 2. Unfortunately, verification against the gauge was not possible for the full flood event.	1. The hydrograph is a double peak flow which again reduces the influence of initial losses. 2. The FFJV calibration does not predict the 2nd peak flood flow, while the DPIE model represents the shape reasonably well.	1. The Macintyre is the 2nd largest catchment of the 3 and represents approximately 33% of the total catchment area 2. The FFJV generally predicts the flood timing earlier than DPIE (approx. 3hrs to 6 hrs for the 1976 & 2011) at Holdfast, but similar at Ashford and Wallangra. 3. The FFJV timing for the 1996 flood is better than the DPIE model 4. The FFJV timing for 2011 is reasonable to good. 5. We note the DPIE rated flows match the DPIE URBS model, while the FFJV rated flows match the FFJV URBS model. 6. Based on the DPIE model result and the FFJV, there does not appear any reason for DPIE to factor flows by 20% for the 1976 flood event in this catchment.
	Ashford	7. The rising and falling limb is well represented and the timing of the peak flow appears reasonable to good.	1. Both the DPIE and FFJV represent the shape of the rated hydrograph well, 2. notably, there is a large difference in peak flows between DPIE (2,600m^3/s) and FFJV (1,750m^3/s), with the latter being lower.	1. The hydrograph while notably smaller in peak flow than 1976 and 2011 represents a flood with 2 distinct peaks. 2. The DPIE and FFJV 1st flood peak are both too early by approximately 3 to 6 hrs. 3. The DPIE and FFJV 2nd flood peaks are both reasonably on time.	
	Wallangra	4. The initial and peak and the major peak are reasonably well predicted. 5. The peak flow (approx. 290m^3/s) is however reasonably small for a calibration event, but it does highlight the timing is well predicted.	1. Both DPIE and FFJV predict the peak flow slightly late (approx. 3hrs), but the rising and falling limbs correlate quite well. 2. Again, a notable difference in peak flow occurs between DPIE (1,70m^3/s) and FFJV (1,100m^3/s)	1. The FFJV predicts the shape and peak flow reasonably well. 2. The DPIE model does not predict the timing or shape very well.	
		2011 (Rare Flood)	**1976 (Rare Flood)**	**1996 (Frequent to Rare Flood)**	**General Comment**
Dumaresq River	Mauro	1. The FFJV predict the peak flow slightly late (approx. 3hrs), but the rated flow appears unreliable at high flows. 2. The timing of the initial peak low flow is slightly early.	1. Both DPIE and FFJV predict the peak flow slightly late (approx. 3hrs), but the rated flow appears unreliable.	2. Both DPIE and FFJV model predict the rated peak flow reasonably well, while the FFJV overpredicts the peak flow, although the gauge looks unreliable.	1. The Dumaresq represent nearly 50% of the total catchment area. 2. The peak flood flow in the Dumaresq for 2011 was approximately 1 in 100yr AEP (refer to FFA), hence given the number of pluviographs and daily gauges available for calibration greater confidence should be applied to the 2011 flood for this catchment. 3. FFJV timing and peak flood flow throughout the catchment are generally very good for 2011 and 1976. 4. The DPIE & FFJV typically predict the timing of the peak flow reasonably well and the DPIE and FFJV are generally consistent with each other, but FFJV has a higher peak flow for 1976, typically by about 20% in the lower catchment.
	Texas/ Bonshaw	3. The FFJV predict the peak flow and timing very well. 4. FFJV predict the peak flow slightly late at Haystack (i.e. further upstream) the FFJV timing is very good with the rated flow. 5. The peak flood flow in the Dumaresq for 2011 was approximately 1 in 100yr AEP.	1. Both DPIE and FFJV predict the peak flow slightly late (approx. 3hrs), but the rated flow appears slightly unreliable. 2. At Bonshaw (ie. slightly upstream), the DPIE and FFJV also predict the peak flow slightly late (approx. 3hrs), however at Roseneath (i.e. further upstream) the FFJV timing is very good with the rated flow.	1. The FFJV predicts the shape and peak flow reasonably well, both DPIE and FFJV are slightly late. 2. At Bonshaw, the DPIE model does not predict the shape very well, however, the timing of the peak flow is reasonable.	
	Roseneath	6. The FFJV predict the peak flow and timing very well, but perhaps slightly late. 7. Based on other upstream gauges the FFJV predict the peak flood on time.	1. FFJV predict the peak flood flow and timing very well. 2. DPIE predict the rising limb too early and under-predict the peak flow, however, the timing is reasonable.	1. The DPIE predicts the peak flow quite early (approx. 12hrs) while the FFJV predicts the timing reasonably well. 2. Both the DPIE and FFJV predict a 1st peak that is not picked up by the gauge and hence any comparisons are unreliable.	
		2011 (Frequent Flood)	**1976 (Rare Flood)**	**1996 (Frequent to Rare Flood)**	**General Comment**
Macintyre Brook	Booba Sands	3. FFJV provides a very good correlation to the rated gauge with regards to timing and peak flow;	3. No comparisons to the gauge are possible, the DPIE and FFJV predict similar flow with the FFJV being higher and slightly later (approx. 3hrs and about 15% higher)	1. Both the DPIE and FFJV provide a good correlation to the rated flow. 2. The FFJV provides a better correlation to the rising limb, but slightly late to the peak flood flow.	1. The Macintyre Brook is the smallest catchment of the 3 representing approximately 20% of the total catchment area. 2. Generally, the FFJV flow hydrographs correlate to the rated gauge better than the DPIE model. 3. FFJV provides a good correlation to the 2011 data. 4. Based on the DPIE model result and the FFJV, there does not appear any reason for DPIE to factor flows by 20% for the 1976 flood event in this catchment
	Inglewood	4. FFJV provides a very good correlation to the rated gauge regards to timing and peak flow;	5. The FFJV provide a better match to the rated flow with regards to both timing and peak flow. 6. Generally, the FFJV provides a better correlation for other gauges in the catchment than DPIE and most notably at Woodspring, Coolmundra and Terraine.	3. Both the DPIE and FFJV provide a good correlation to the rated flow. 4. The remaining in-catchment correlations are variable for both DPIE and FFJV.	

3.4.3 Volume Comparison

A comparison of the flood volumes calculated as part of FFJV update and the volumes presented in the BRVFMP (or calculated in the BRVFMP model) is provided in Table 3.5 in the FFJV report (March 2021) and is provided below for ease of reference.

Catchment/Location	Verified 2019 levees and validated 1976 flows (Flood volume in ML)	BRVFMP levees and factored flows (Flood volume in ML)	Difference (%)
Dumaresq River	596,014	541,177	+10%
Macintyre River	502,236	642,669	-22%
Macintyre Brook	329,119	265,910	+24%
Ottley's Creek	131,927	80,820	+63%
Extracted from hydraulic model across full floodplain just upstream of junction of rivers	1,507,783	1,487,899	+1%

As shown in the above table, the flood volumes calculated for the 1976 flood for the two studies are relatively close for the Dumaresq River while notable differences are identified for Ottley's Creek, Macintyre River and Macintyre Brook. A visual comparison of the total catchment flood volumes from the FFJV and BRVFMP are presented in charts of Figure 3-1.

From these charts, it can be seen that Ottley's Creek represents a small fraction (less than 10%) of the total catchment volume. When Ottley's Creek is combined with the adjacent catchment of the Macintyre River there is only a 6% difference between FFJV and the BRVFMP catchment models.

Overall, the charts of Figure 3-1 indicate that the flood volumes between FFJV (2021) and the BRVFMP correlate reasonable well and are in a similar proportion. The FFJV predict slightly greater volumes in the Macintyre Brook and Dumaresq River and slightly lower volumes in the combined Ottley's Creek and Macintyre River.

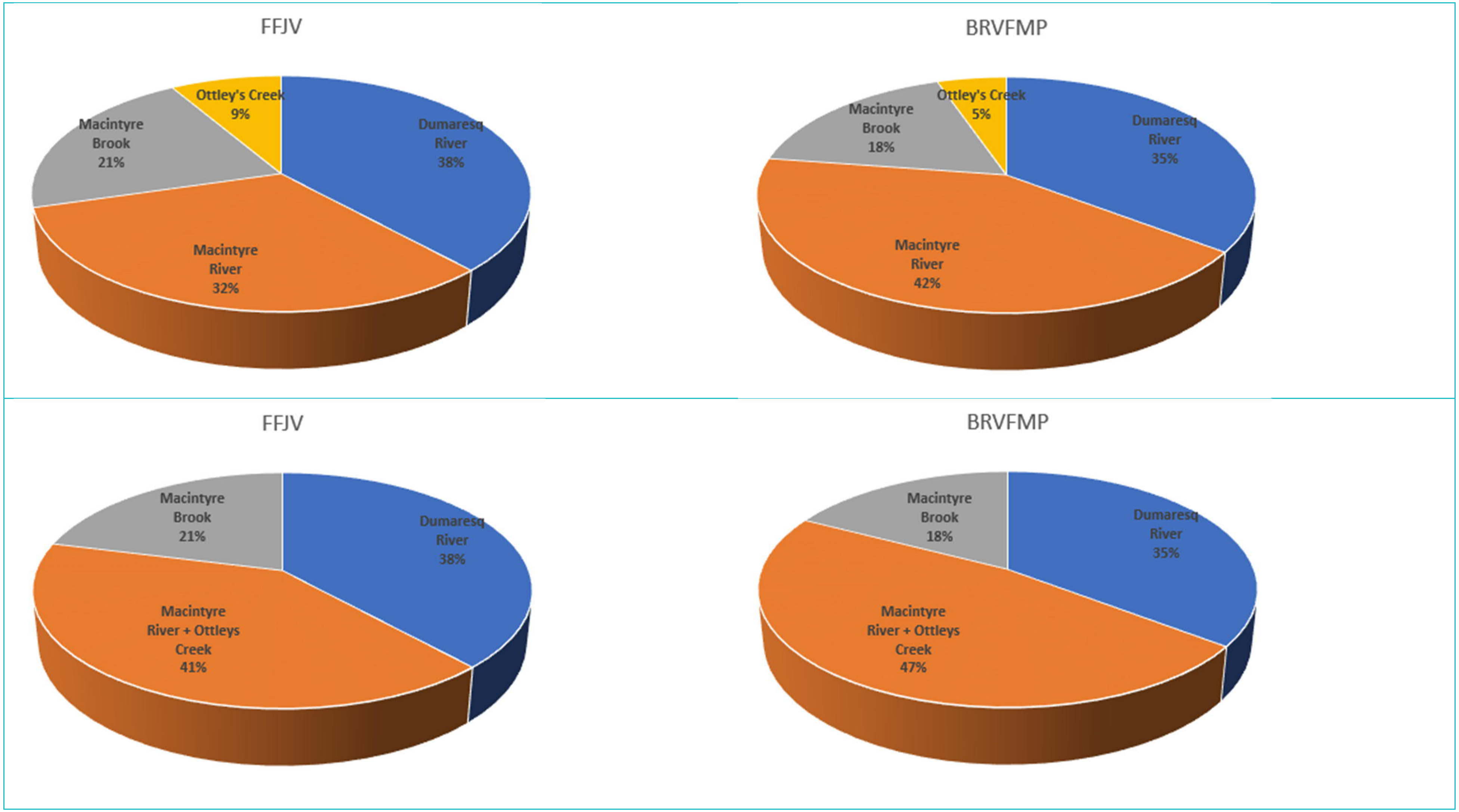


Figure 3-1 Comparison of 1976 Flood Volumes between FFJV (March 2021) and BRVFMP

3.4.4 Flood Peak Timing

A comparison of the 1976 flood peak flood timing between FFJV (March 2021) and BRVFMP is) is provided as Figure 1 in the FFJV report (March 2021) and is provided below for ease of reference.

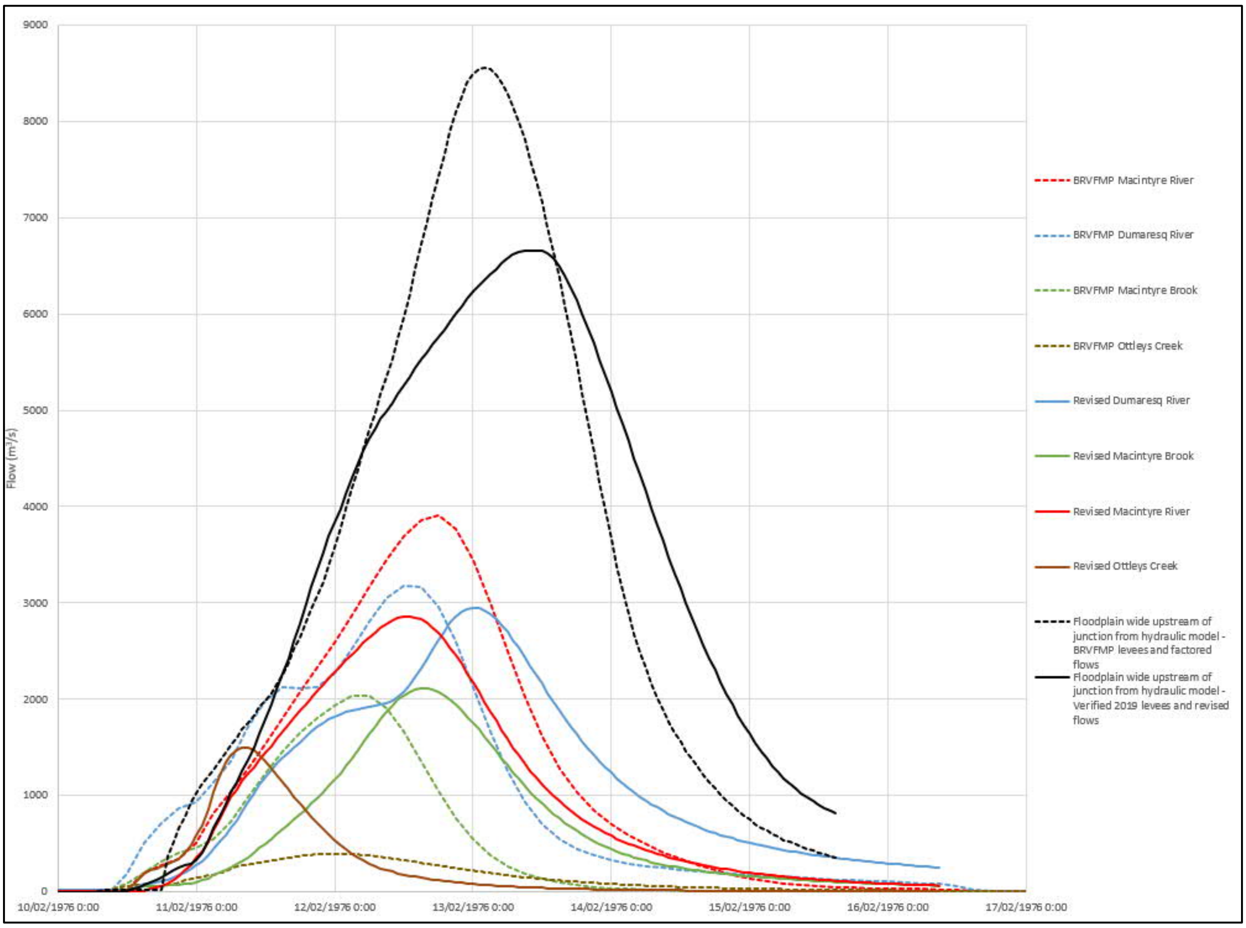


Figure 3-2 FFJV Hydraulic Inflow Hydrograph Plot

Whilst the flood volumes are comparable between BRVFMP and FFJV (March 2021), a key difference between the two models is the timing between flood peak. We note the following key differences:

(1) BRVFMP Macintyre River peak flow occurs approximately 3 hours after the BRVFMP Dumaresq River, while for the FFJV the Macintyre River peaks approximately 12 hours earlier than the FFJV Dumaresq River.

(2) The timing between BRVFMP Dumaresq River and the FFJV Dumaresq River is notably different, with the FFJV peak flow occurring approximately 12 hours later.

(3) A large difference in peak flow occurs between BRVFMP and Ottleys Creek, however, the peak is well before the three major catchments of Macintyre River, Macintyre Brook and Dumaresq River and is likely to have little influence on the overall peak flood levels.

From discussion with FFJV, the difference in timing was surmised by FFJV to be from the following:

(1) FFJV have '*used a larger reach length factor for the lower end of the hydrological model based on calibration to Cunningham for 1976, Mauro for 1996 and Glenarbon for 2011. The DPIE 1976 had no end-reach calibration point*'; and

(2) FFJV '*hydrology calibration plots shown for 1976 is at Cunningham Weir (upstream of Mauro). The 'inflows' plot is not quite*' comparing the same location '*as the DPIE flows were taken at Mauro, whereas the FFJV model is extended further downstream to Glenarbon to get a calibration point for the 2011 event*'.

Further to the above comments by FFJV, we also note the following:

(1) The DPIE hydrological model does not extend to the downstream extent of the hydraulic model for the Dumaresq River and the Macintyre Brook, while the hydrological and hydraulic model for the Macintyre River correlates, hence inaccurate timing differences will occur between:

    (a) Dumaresq River and the Macintyre River; and

    (b) Macintyre Brook and the Macintyre River.

(2) The FFJV updated hydrological model (refer to FFJV, March 2021 Figure A9) was extended to the hydraulic (TUFLOW) model boundary and incorporated the additional catchment area to more accurately reflect catchment runoff volume and timing. This update also addresses concerns from WRM (2020, refer to Section 4.2.1 and Section 4.3.3) regarding catchment extent.

(3) The timing between DPIE and FFJV hydrological model at Cunningham Weir for the 1976 flood event (refer to Figure 3-3 and FFJV Figure A6-A) is relatively close (i.e. generally at midday on the 12 Feb 1976), however:

    (a) The hydraulic inflow plot (refer to Figure 3-2) depicts the DPIE peak flow on the Dumeresq River just after midday on 12 Feb 1976 (i.e. approx. 3hrs after the plot shown at Cunningham Weir, refer to FFJV Fig. A6-A), while the hydraulic inflow location is approx. 20km downstream (refer to Figure 3-3); hence a delay in the order 8hr should occur;

    (b) The FFJV timing on the hydraulic inflow plot more accurately depicts the delay of approx. 12hrs from Cunningham Weir, due to the hydrological model correlating with the hydraulic model.

(4) The FFJV flood peak timing from the hydrological model for the 2011 flood event on the Dumaresq River (i.e. close to a 1 in 100-yr AEP flood) is very close to the flood peak timing at the Glenarbon gauge, which indicates the FFJV hydrological model represents the timing with a high degree of confidence.

The accuracy of the timing of the FFJV hydrological and hydraulic model is also presented at the Boggabilla gauge for the 1976, 2011 and 1996 flood events via the hydrographs of Figure B.2, B.4 and B6 of the FFJV (March 2021) report. The hydrographs at Boggabilla depict the following results:

(1) **1976 Flood Event**:

(a) The recorded flood flow hydrograph appears unreliable since only one flood peak level was recorded, but a flow hydrograph was somehow developed. Notwithstanding this, the flood peak occurs at approx. 75hrs (no date provided/ recorded).

(b) FFJV predicted the flood peak to occur approximately 30 hours later at approx. 105 hrs

(2) **2011 Flood Event**:

(a) Recorded flood peak flow was midday on 14 January 2011.

(b) FFJV predicts the peak timing at approx. 7 am on 14 January 2011, approximately 5 hours early,

(3) **1996 Flood Event**:

(a) Recorded flood peak flow was approx. 8 pm on 25 January 1996, however;

(b) FFJV predicts the peak timing at approx. 4 am on 25 January 1996, approximately 18 hours early, although the recorded level was only 60mm below the peak at 4 am on 25 January 1996.

In summary, the 2011 flood event is the 2nd largest flood event and a relatively recent flood with the difference in flood peak timing at Boggabilla being only 5 hours early, indicating a very good result. The recorded flood timing for the 1976 flood appears unreliable and indicates the FFJV is predicting the flood peak approx. 24 hours late, while conversely, the flood peak for the 1996 flood event is predicted to occur 18 hours early. Consequently, more confidence can be placed in the 2011 flood event and the earlier timing of the 1976 cannot be readily justified.

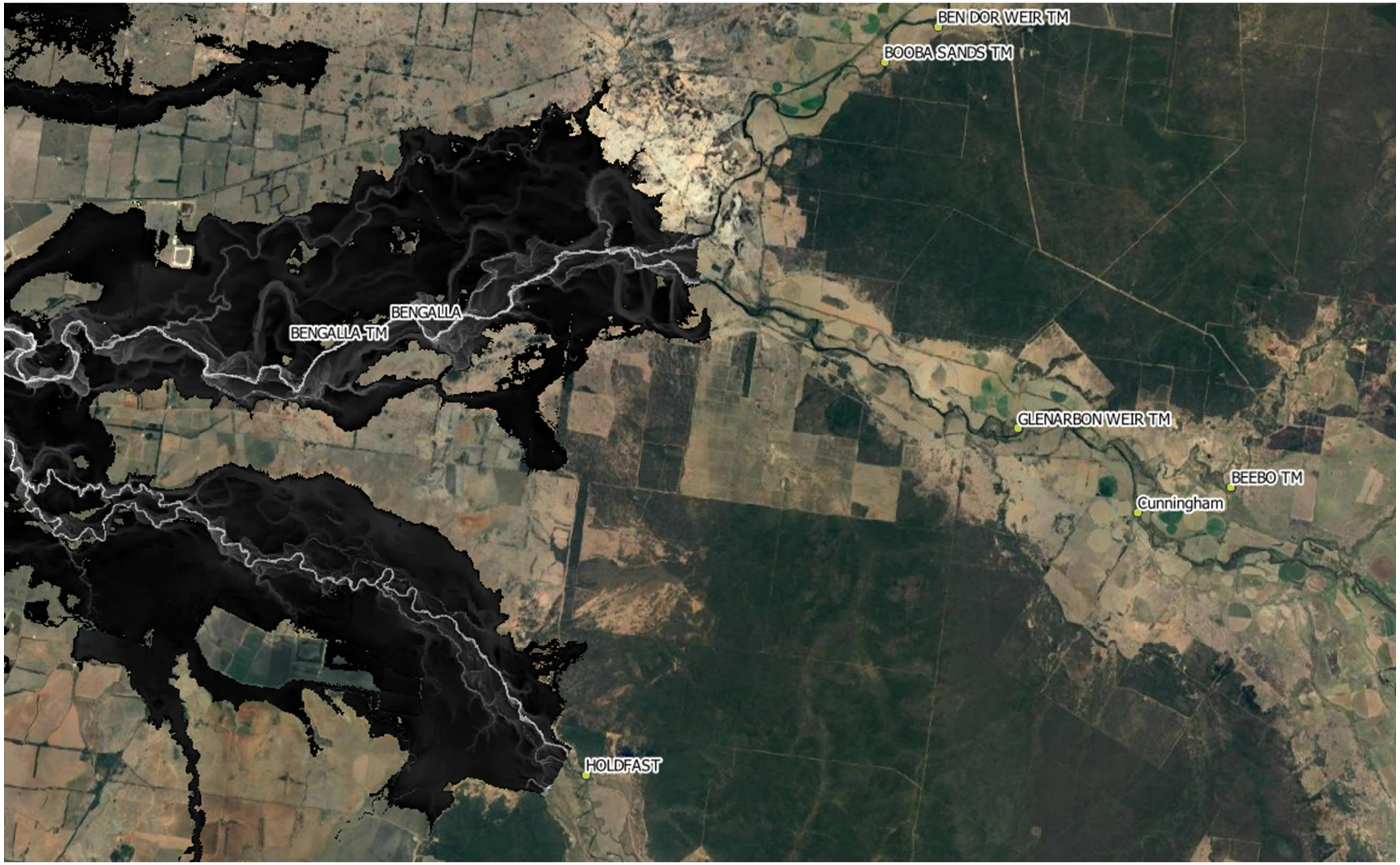


Figure 3-3 Model Extent to Gauge/Hydrological Model Extent

4 Hydraulic Calibration

4.1 Overview

As part of the revised modelling that FFJV has undertaken (FFJV March 2021) the TUFLOW hydraulic model was updated and the peak flood level was recalibrated based on the revised hydrology. This section reviews the following elements that have been updated and provides a review of the suitability of the changes:

(1) Grid Resolution – an improved topographic representation through the incorporation of the latest TUFLOW release (2020) that includes Sub-Grid Sampling (SGS).

(2) Topographic modifiers – main drainage channels/ rivers, levees and existing drainage structures.

(3) Inflows - Revised inflow locations and inclusion of lower catchment flows based on the latest hydrological model.

(4) Calibration – improved calibration to observed data.

(5) Sensitivity Analysis

Each of these items has improved the representation of the Macintyre floodplain with the FFJV (2021) hydraulic model and provided a more reliable and robust model compared to the DPIE model.

4.2 Sub-Grid Sampling and Quadtree

As noted by WRM (2020) a reduction in cell size caused a reduction in peak flood levels as detailed in FFJV (May 2020) assessment. The updated flood model developed by FFJV (2021) is now using the latest version of the TUFLOW that includes SGS. SGS allows a more '*detailed representation of the cell volume and face flux area/width, compared with the traditional single elevation per cell and per face approach, significantly reduces or removes, the sensitivity of regular meshes to mesh orientation and mesh cell size*' (Kitts et al 2020). Whilst a sensitivity has not been undertaken to date, the use of SGS should enable a change in cell size (e.g. 15m compared to 30m) that results in acceptable changes in results compared with much greater and sometimes unacceptable changes in results for the single elevation per cell approach.

Notwithstanding the above, FFJV (2021) propose to use Quadtree for detailed design. Quadtree will allow a finer resolution around the proposed inland rail cross drainage structures without changing the calibration (i.e. distribution of flood flows across the floodplain). This approach is considered appropriate and best practice, provided appropriate checks are undertaken to ensure the calibrated model does not result in unacceptable changes.

4.3 Topographic Modifiers

With regards to the Macintyre River, floodplain, channels and creeks, the SGS functionality improves the representation of fine-scale topography at coarse grid resolutions. Consequently, SGS combined with the improved grid resolution provides a significant improvement in the topographic representation of the Macintyre system.

Notwithstanding the improvements in the general topographic representation of the Macintyre system, modifications were made to the TUFLOW model where the underlying digital elevation model (DEM) based on LiDAR cannot be accurately resolved (e.g. below the water surface level). These included:

(1) Lowered major watercourses by 0.5m over 2 cells.

(2) Goondiwindi watercourses based on survey levels at the gauges.

(3) 2d_zsh_watercourses_e422.MIF - 2d_zsh_watercourses_e422.MIF Lower reaches (downstream of Goondiwindi) Points inspected from DEM to improve flow paths shown as green lines.

Ideally, further survey of the major watercourses would confirm the assumptions used in the updated model, however, the hydraulic model has been calibrated with the above topographic modifiers and the total flows for the catchment were developed from the hydrological model.

4.4 Structures

As noted by WRM (2020, refer to Section 4.3.5) and from our understanding, FFJV (2021, refer to Section B1.3) has updated the flood model to include all known and available (i.e. existing) cross drainage structures. Bridge blockage factors as per ARR 2019 have also been included in the updated model, while culvert blockage was previously adopted as per FFJV (2020).

Where required, and as part of the detailed design, reconciliation of the existing drainage structure should be undertaken to ensure the resulting afflux is accurately determined. Bridge blockage factors as per ARR 2019 may also be refined as part of the detailed design of the structures.

4.5 Calibration

4.5.1 Flood Levels

The hydraulic model was calibrated to the three flood events of 1976, 1996 and 2011. As detailed in the FFJV (March 2021) report, the 1976 flood event was approximately a 1 in 200-yr AEP flood event, while the 2011 flood was approximately a 1 in 100-yr AEP flood event. The 2011 flood event has the most accurate and available flood data, particularly when compared with the 1976 flood event data.

As noted in ARR 2019, there is an inherent difficulty in preparing data to reflect conditions specific to a particular event in time. The 1976 flood event is particularly challenging due to changes in topography, predominantly due to the construction of levees over the last 45 years, but also as a result of changes to gauge location and general accuracy of surveyed debris levels. The 2011 flood event provides a recent flood of significant magnitude that benefits from current LiDAR.

A summary of the accuracy of the hydraulic model flood level results to the Flood Marker is provided in Table 4-1.

Table 4-1 Calibration of Hydraulic Model to Flood Markers

	1976	1996	2011
No. of Flood Markers	39	8	52
± 0.1m	18%	57%	25%
± 0.2m	40%	71%	52%
± 0.3m	62%	85%	79%
RMSE	0.46m	NA (limited data)	0.25m

Given the uncertainty associated with the 1976 flood event, this review has justified higher weighting on the 2011 flood event. For the 2011 flood event, we note the following:

(1) 19% of the calibration points are within ± 0.1m.

(2) 52% of the calibration points are within ± 0.2m.

(3) 48% of the calibration point are either below or above 0.2m tolerance but are spread relatively evenly (i.e. 23% below and 25% above).

Overall, the 2011 flood event is considered to be well calibrated to the flood level markers an represents an event at or near the 1 in 100-yr AEP that will be used predominately for the impact and trigger level assessment.

4.5.2 Flood Volumes, Timing and Peak flows

Calibration of the flood volumes and timing was previously discussed in Section 3.4.3 and Section 3.4.4 and their accuracy is largely due to the calibration of the hydrological model. Peak flood flows are however compared by FFJV (March 2021) from the TUFLOW hydraulic model at Boggabilla and the results are presented in FFJV Table B7 presented below for ease of reference.

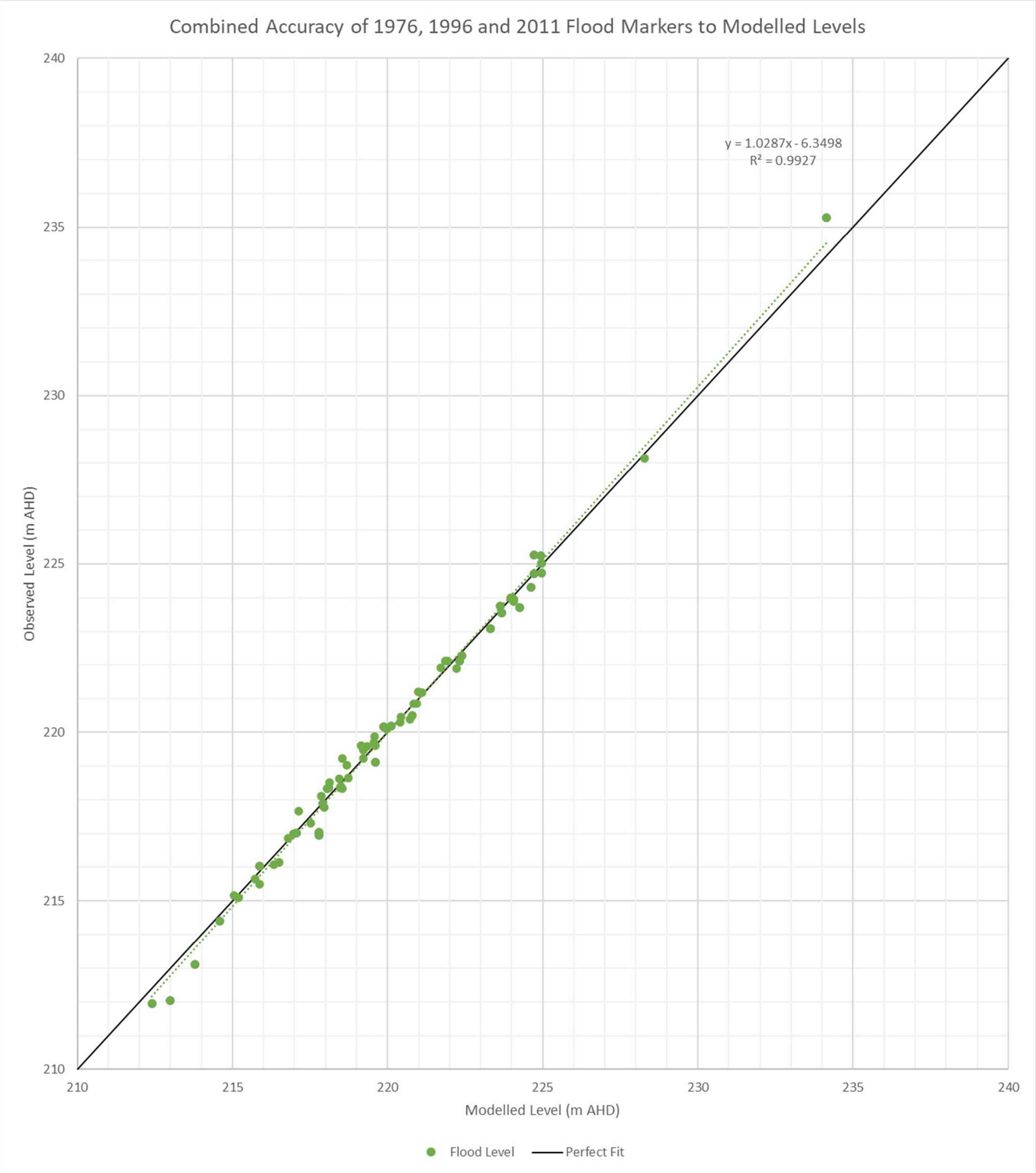


Figure 4-1 General Comparison of Observed and Modelled Flood Levels (FFJV 2021)

Table B7 Comparison of results at the Boggabilla stream gauge

Event	Recorded stream gauge data			TUFLOW results		
	Level (m AHD)	Flow US of Boggabilla	Flow DS of Boggabilla	Level (m AHD)	Flow US of Boggabilla	Flow DS of Boggabilla
1976	221.27	n/a[a]	3,700 m^3/s (319,600 ML/d)	221.22 (-0.05m)	n/a[a]	3,680m^3/s (317,952 ML/d)
1996	221.03	3,486 m^3/s (301,200 ML/d)	2,485 m^3/s[b] (214,700 ML/d)	220.98 (-0.05m)	3,470 m^3/s (299,808 ML/d)	2,791 m^3/s (241,142 ML/d)
2011	221.12	3,803 m^3/s (328,600 ML/d)	n/a	221.11 (-0.01m)	4,493m^3/s (388,195 ML/d)	3,197 m^3/s (276,221 ML/d)

Table notes:

a 1976 event rating curve only considered flows at Boggabilla and not the full floodplain
b From flow measurement data

Comparisons between recorded stream gauge data and the hydraulic model TUFLOW indicate that a very good correlation has been achieved between the revised rating curve and the FFJV hydraulic model.

5 Quantitative Design Limits

5.1 Overview

A review of the Quantitative Design Limits (QDL) as provided in the FFJV (March 2021) report is provided. Typically, QDL limits are applied to standard design floods from frequent to the 1 in 100-yr AEP event.

As provided in the FFJV (March 2021) report, the 1976 flood event is considered to be in the order of a 1 in 200yr AEP to 1 in 500-yr AEP and therefore is more severe than the typical 1 in 100-yr AEP used for design purposes. Discussion is provided below regarding the application of QDL to larger flood events (e.g. 1976 flood event or larger than the 1 in 100-yr AEP).

5.2 QDL Application

The QDLs are presented in FFJV (March 2021) and provided below with our specific comments in Table 5-1. The QDL were sourced from the Narrabri to North Star (N2NS) Phase 1 Infrastructure Approval. As previously noted, typical industry practice is to apply the QDLs up to the 1 in 100-yr 1% AEP. However, we consider there are exceptions to the prescribed standards that should be recognised during landholder negotiations whereby unacceptable flood impacts may arise in rarer flood events (e.g. 1976 flood), such as:

(1) Flood events greater than the 1% AEP may cause an unacceptable flood risk to third parties/ landholders. For example, achieving a design that causes no flood impact on floor levels in the 1% AEP may cause an unacceptable flood hazard (e.g. risk to life and/or evacuation routes) to occupants in rarer flood events.

(2) Whilst discussed further in Table Table 5-1, QDLs for flood impacts (i.e. level and duration) on agricultural land in more frequent events may be of particular importance to landholders. As an example, a prescribed impact of 150mm on a flat and wide floodplain may cause more economic loss than a 500mm flood level increase in a rare flood event. These potential impacts will need to be considered further during third party/ landholder negotiations.

As previously highlighted in this report, uncertainty will remain with the adopted design flood event flows. The use of sensitivity analyses/ checks (e.g. the 1976 flood event) as assessed in the FFJV (March 2021) should be used to assist third party/ landholder negotiations to ensure the upper and lower bounds of flood impacts and hazards are appropriately addressed. The use of sensitivity analyses/ checks (i.e. design events up to the PMF) will ensure impacts and flood risk (ie. risk to life and/ or evacuation) are acceptable to landowners and that potential liability is addressed to an acceptable level at the design stage.

5.3 QDL Comments

Provided in Table 5-1 are comments concerning the QDLs with respect to their application for the 1 in 100-yr AEP flood, applicability to the 1976 flood event and where required more extreme flood events.

Table 5-1 Acceptability of Quantitative Design Limits (QDLs) for the 1in 100-year AEP and 1976 Flood Event (i.e. 1 in 200-year to 1 in 500-year AEP Flood Event)

Parameter	Land or Land Use	Limits (DRAFT N2NS Hydrology Conditions)	BMT Comments in relation to QDLs being applied to the 1976 Flood Event
Afflux i.e. increase in flood level resulting from the implementation of IR	Habitable floors[1]	≤10mm increase	A 10mm limit is standard industry practice up to the 1 in 100-year AEP. Typically, the 10mm increase will apply to both above and below floor flooding as the limit is typically the limit of numerical modelling accuracy. The criteria is a tight tolerance and should not be applied to flood event greater than the 1 in 100-year AEP and could be varied subject to individual landowner 3rd party agreement. A 'Risk Assessment' approach is recommended for rare to extreme flood events to ensure impact that may cause loss of life are appropriately mitigated.
	Non-habitable floors[1]	20mm increase	The criteria is a relatively tight tolerance and should not be applied to flood events greater than the 1 in 100-year AEP. Where required further investigation with affected 3rd party to ensure there are no valuable possessions susceptible to flood damage. This criteria should also be considered on a case by case basis during landowner/ 3rd party negotiations where inundation of existing non-habitable structures (e.g. agricultural sheds, pump houses) may result in significant cost and/ or agricultural production issues.
	Other urban and recreational	100mm increase	Again, this limit should only be applied up the 1 in 100-year AEP flood event, however this may require further investigation with affected 3rd parties to ensure there are no valuable possession susceptible to flood damage. A 'Risk Assessment' approach is recommended for rare to extreme flood events to ensure impacts that may cause loss of life are appropriately mitigated
	Agricultural	150mm increase	This limit should be further investigated with affected 3rd parties to ensure there are no unanticipated impacts for both the 1 in 100-year AEP and the 1976 flood event including inundation durations. Impact of greater than 150mm (or less) under some circumstances may cause overtopping of levees and damage to some sensitive crops in more frequent or severe flood events.
	Forest and unimproved grazing land	300mm increase	This limit should only be applied up to the 1 in 100-year AEP and subject to appropriate investigations (e.g. agronomist). Higher increases could be tolerated in the 1 in 100-year AEP and larger flood events such as the 1976 flood e.g. in already flooded forests, provided inundation durations are not significantly increased.
	Highways and sealed roads >80km/hr[2]	No increase in depth where aquaplaning risk exists and remains unmitigated. Otherwise 50mm increase	The flood risk should be considered on an individual basis and the highway should be checked to ensure evacuation routes are not hindered.
	Unsealed roads and sealed roads <80km/hr[2]	100mm increase	The flood risk should be considered on an individual basis and consideration should be given to frequent events where the road may otherwise not be flooded. Similar to highways, the road should be checked ensure evacuation routes are not hindered.
Scour/Erosion Potential i.e. increase in flood velocity resulting from the implementation of IR.	Ground surfaces that have been sealed or otherwise protected against erosion. This includes roads and most urban, commercial, industrial, recreational and forested land	20% increase in velocity where existing velocity already exceeds 1m/s	For non-erodible surfaces; however, in certain circumstances a higher increase may be tolerable, subject to 3rd party negotiations.
	Other areas including watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas	No velocities to exceed 0.5m/s unless justified by site-specific assessment conducted by an experienced geotechnical or scour/erosion specialist. In addition, the increase in velocity is to be limited to 20% where the existing velocity already exceeds 1m/	This limit should only apply to areas with no vegetation cover and exposed erodible soils. Assuming the 0.5 m/s is a velocity increase, this limit under some circumstances can still be too high for erodible, exposed soil surfaces, hence any increases in velocity for erodible soils should be investigated further.
Flood Hazard i.e. increase in velocity~depth product (vd) and/or flood hazard category resulting from the implementation of IR. (Does not apply where vd>0.1m^2/s).	Urban, commercial, industrial, highways[2] and sealed roadways[2]	10% increase in vd where H1 or H2 category. 0% increase in vd where H3 or greater hazard category.	A 'Risk Assessment' approach is recommended (i.e. rare to extreme flood events) to ensure no unexpected or unacceptable impacts, hence the flood risk should be considered on an individual basis.
	Elsewhere	20% increase in vd	While limits readily identify increases, the flood risk should always be considered on an individual basis and should be subject to variation under 3rd party negotiations, provided the risk to people and property is adequately managed e.g. additional protection levee banks around farm houses may be an acceptable outcome through negotiation. NS2B (refer to Section 2) criteria for 'Flood Hazard' refers to a risk assessment approach with a focus on land-use and flood sensitive receptors. A 'Risk Assessment' approach is recommended. Extreme event risk management should be included in this criteria to ensure no unexpected or unacceptable impacts.

Parameter	Land or Land Use	Limits (DRAFT N2NS Hydrology Conditions)	BMT Comments in relation to QDLs being applied to the 1976 Flood Event
Flood Duration i.e. increase in duration of inundation resulting from implementation of CSSI. (Does not apply to inundated areas less than 100m²).	Habitable floors[1]	No increase in inundation duration above floor level. 10% increase in inundation duration where below floor level and when existing inundation duration exceeds one hour. Otherwise inundation duration not to exceed one hour.	While limits readily identify increases, the flood risk should always be considered on an individual basis and shall consider more extreme events. This criteria is too rigid for short duration inundation and therefore should be subject to variation through individual landowner agreements. A 'Risk Assessment' approach is recommended.
	Highways and sealed roads >80km/hr[2]	10% increase in inundation duration.	While limits readily identify increases, the flood risk should always be considered and assessed on an individual basis through 3rd party negotiations, particularly when periods of isolation/ accessibility are considered. A 'Risk Assessment' approach is recommended
	Elsewhere	10% increase in inundation duration when existing inundation duration exceeds one hour. Otherwise inundation duration not to exceed one hour.	While limits readily identify increases, the flood risk should always be considered and assessed on an individual basis through 3rd party negotiations, particularly when periods of isolation are considered. A 'Risk Assessment' approach is recommended

[1] Habitable floors/rooms are defined consistent with the use of this term in the NSW Floodplain Development Manual. In a residential situation this comprises a living or working area such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. In an industrial, commercial or other building, this comprises an area used for an office or to store valuable possessions, goods or equipment susceptible to flood damage in the event of a flood.
[2] Including where located within CSSI corridor

6 Impact Assessment

6.1 Overview

An impact assessment was undertaken by FFJV (March 2021) based on the following scenarios:

(1) Scenario 1 - Verified 2019 levees and validated 1976 flows;

(2) Scenario 2 - BRVFMP levees and validated 1976 flows; and

(3) Scenario 3 - BRVFMP levees and factored DPIE 1976 flows.

Based on the updated FFA (FFJV, 2021), the 1976 flood event was of the order of 1 in 200-yr to 1 in 500-yr AEP and the impacts were reviewed with comparison to the QDL (refer to Section 5). As noted in Section 5, the 1976 flood impact comparisons with the QDL should be cognisant that this event exceeds the typical limits applied to the 1 in 100-year AEP design event. The impacts associated with the 1 in 100-yr AEP design event are presented in 7.

Ultimately, the full range of flood impact due to the construction of the inland rail for flood events larger than the 1 in 100-yr AEP and the 1976 flood event (i.e. up to PMF) should be considered with due regard to ARR 2019 'Risk-Based Design' concepts. This is to ensure the full range of risks are understood and where necessary appropriately managed (e.g. risks to loss of life, damage to property and evacuation routes).

6.2 Review of Preferred Flood Impact Scenario

6.2.1 Flood Flows (1976 Validated or Factored DPIE Flows)

As part of the FFJV (2021) PIR, the 'key purpose' of the 1976 flood assessment besides the use for calibration is for comparisons to the QDL triggers. The FFJV validated 1976 flows (e.g. scenarios 1 and 2 from above) are considered the most accurate estimate to date and are verified to the 2011 flood. As previously noted, the validated 1976 flows are considered to be in the range of 1 in 200-yr to 1 in 500-yr AEP, whilst the DPIE factored flows (i.e. scenario 3) based upon the FFJV (March 2021) assessment are in the range of 1 in 750-yr to 1 in 2,000-yr AEP as shown in Figure 6-1 (i.e. mark-up of FFJV, Figure F.7). As discussed in Section 5, the 1976 flood event was not intended to be used directly for comparison to QDL triggers due to its resulting magnitude.

Flood events larger than the 1 in 100-yr AEP (i.e. up to the PMF) should however be assessed in line with ARR 2019 'Risk-Based Design' to ensure risks such as risk to life, damage to property and evacuation routes, etc are appropriately managed. As discussed in Section 6.3, flood level impacts are notably increased with the use of the 1976 factored flood flows regardless of the proposed levee option.

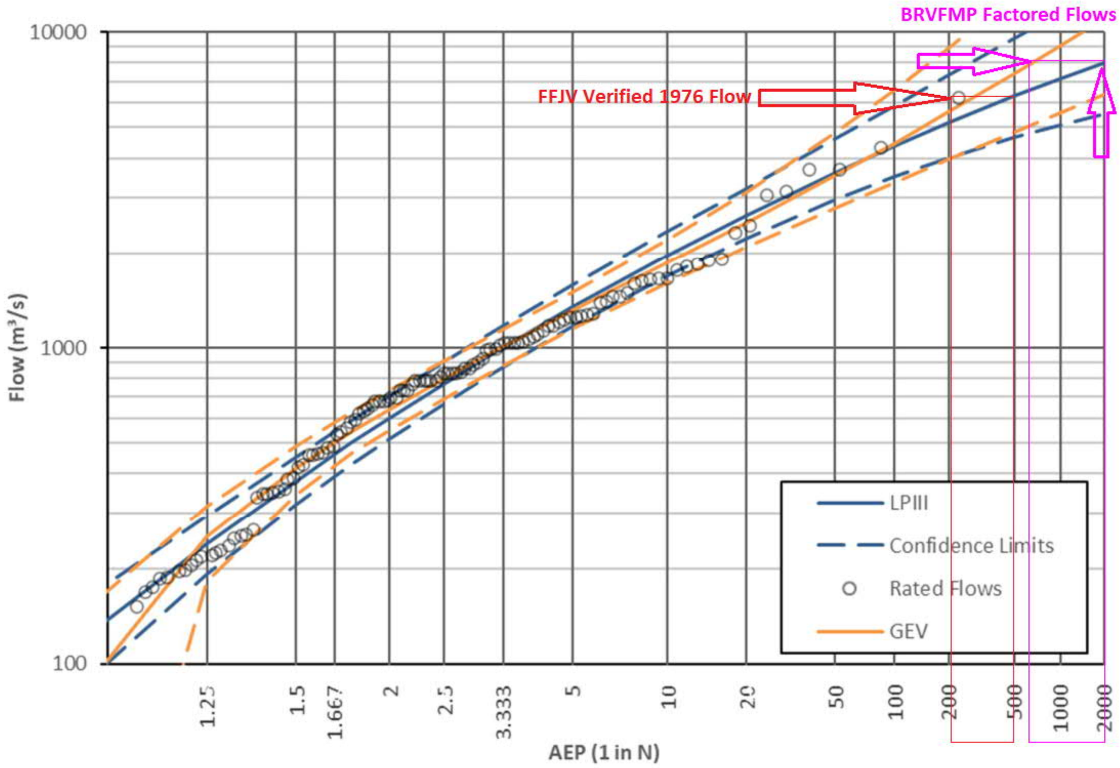


Figure 6-1 FFJV (March 2021, Figure F.7) FFA at Boggabilla

6.2.2 Levees (Verified Levees and BRVFMP Levees)

Two levee scenarios were presented by FFJV (March 2021), including BRVFMP Levees and Verified 2019 Levees. The difference in levee heights is provided in Figure 6-3 and of particular note is that the BRVFMP levees have an increase in height near the following locations:

(1) South of Goondiwindi;

(2) North and north-west of Toomelah; and

(3) Mid-way between chainage 20km to 25km along the proposed inland rail alignment.

The most predominant impacts due to the levee difference between scenarios are discussed in Section 6.3 below and are within the vicinity of chainage 25km.

6.3 Peak Flood Levels Differences

Flood level impacts are presented in FFJV (March 2021) Figure C6-A, Figure D6-A and Figure E6-A. A comparison of the flood level impacts is presented in Figure 6-2 at three locations across the Macintyre floodplain. The following impacts are noted from Figure 6-2 between the three impact scenarios:

(1) Cross-Section 1 - Minor differences in flood level (i.e. <20mm) occur north of chainage 30km, between post-developed BRVFMP levees and Verified 2019 Levees scenarios regardless of the flow scenario adopted.

(2) Cross-Section 2: The difference in flood level impacts around chainage 25 km are relatively sensitive to post-developed BRVFMP levees and factored flow. Post-developed factored flows and BRVFMP levees cause nearly 800mm of afflux, whilst an increase of approx. 400mm occurs with the FFJV (2021) verified flows regardless of levee scenario; and

(3) Cross-Section 3: Flood level impacts along the alignment south of chainage 25km are notably higher for post-developed BRVFMP levees and factored DPIE 1976 flows with an impact of 1.4m compared with 0.9m impact from the FFJV (2021) post-developed verified flows regardless of levee scenario.

As noted in Figure 6-2, effectively BRVFMP levees and factored DPIE 1976 flows cause approx. 400mm increase in post-developed peak flood levels south of chainage 25km. The impact plot effectively demonstrates that if no limit to the height of the levee occurs then significant increases in flood impacts will occur for rare to the extreme flood event.

6.4 Flood Impacts on Sensitive Receptors (FSR)

Flood level impact assessment has been undertaken on flood sensitive receptors (FSRs), impact on roads and the general impact of the flood extent. From this review the following general comments are noted concerning the 3 levee and flow scenarios investigated:

(1) FSR –

(a) Limited change in level (typically 10mm to 15mm) is noted between verified levees and BRVFMP levees with verified flows except for the house at FSR 12.

(b) Flood level changes are largest with BRVFMP levee with factored flows, with flood level increases in the order of 10mm to 40mm compared with verified levees and verified flows.

(c) Two FSR (i.e. house-12 & pump shed-32) have notable increases in flood level (200mm & 500mm respectively) as a result of the BRVFMP factored flows.

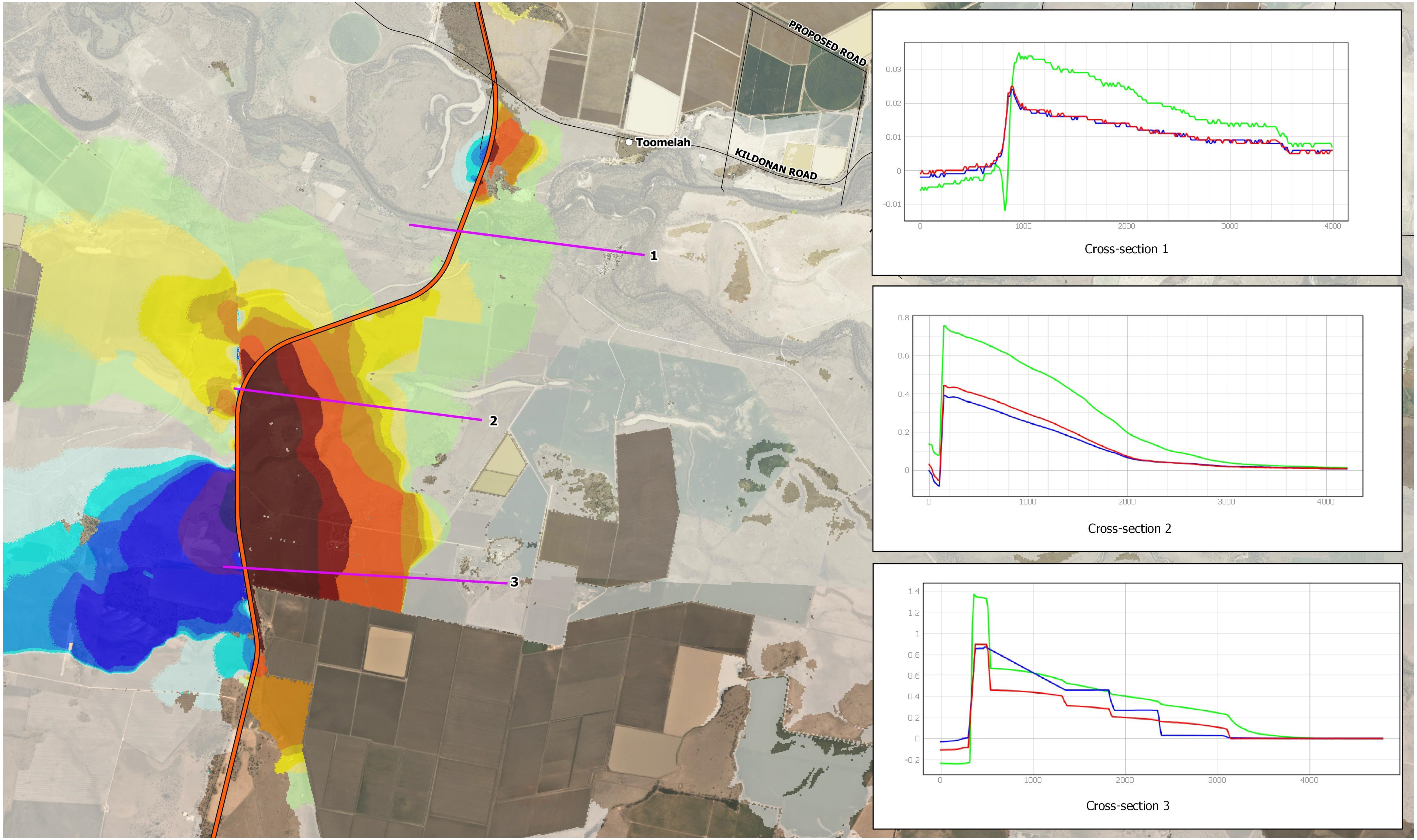
It will be important to ensure the flood hazard around FSR houses is not further increased by reducing their time to evacuate and/or causing notable flood level increases in rare to extreme events. During detailed design and through land-holder negotiations the ultimate impact on safety (i.e. potential impact to loss of life) and potentially on the property may need further consideration to mitigate impacts in these rare to extreme events

(2) Impact on Road –

(a) Typically impacts are limited to 10mm to 40mm except for a few notable exceptions: and

(b) Impacts of between 500mm to 960mm (i,e. BRVFMP Levee and factored flow) are identified and are located generally between Chainage 20km to 27km along Bruxner Way and the adjacent access roads in this vicinity.

Further to the typical flood impacts assessed as part of the QDL, it will be important to ensure the evacuation routes are not materially impacted by the IR.



Legend

- Cross Sections
- NS2B Rail Alignment
- Roads

Title:

Cross Sections

Drawing: 6-2

Rev: A

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Legend

NS2B Rail Alignment

Roads

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Rev: A

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7 Design Events - Combined Catchment Modelling System

7.1 Overview

As discussed in ARR 2019 (refer to Section 1.2), '*it is worth noting that there is a considerable difference in the modelling approaches required to simulate historic (or observed) and design floods'*. In particular, ARR 2019 this notes that the '*estimation of a design flood involves the derivation of the relationship between the magnitude and probability of a given flood characteristic. The objective of the analysis is to provide information for risk-based planning or design purposes'*.

As outlined in the FFJV (2021) report, 'Design Flood' modelling has been undertaken to derive the '*best estimate of the relationship between flood magnitude and exceedance probability*' (ARR 2019), whereas the calibration and validation of the FFJV (2021) catchment model of actual floods (i.e. 1976, 1996, 2011) '*represent the best estimate of flood characteristics for that particular point in time*'. As previously discussed in Section 5 concerning QDL, these limits (i.e. triggers) are typically applied to design flood events to enable ARTC to understand the risk for design purposes (i.e. including risks to adjacent stakeholders).

FFJV (2021) have undertaken Design flood modelling based upon ARR 2019 'Ensemble Event' methodology.

7.2 Hydrology

7.2.1 Rainfall and Losses

FFJV (2021) has used the ARR 2019 rainfall Intensity Frequency Duration (IFD) which is the current best practice for frequent to rare flood events (i.e. up to the 1 in 2,000-yr AEP) including the associated 'Areal Reduction Factors'.

Catchment losses have been reviewed from the ARR 2019 data hub and are presented in FFJV (2021) Table 6 and provided below for ease of reference.

Table 6 ARR Regionalised and adopted at-site FFA reconciled losses

Catchment	ARR Data Hub Losses		Reconciled Losses	
	Initial	Continuing	Initial	Continuing
Macintyre River to Holdfast	35 mm	2.4 mm/h	25 mm	2.4 mm/h
Dumaresq River to Glenarbon	29 mm	4.6 mm/h	29 mm	3.0 mm/h
Macintyre Brook to Booba Sands	27 mm	1.2 mm/h	30 mm	2.5 mm/h
Ottleys Creek	57 mm	0.1 mm/h	30 mm	3.5 mm/h
Lower Macintyre Floodplain	47 mm	0.3 mm/h	30 mm	3.0 mm/h

Whilst not directly appropriate to compare historical losses to 'design neutral losses' the comparison does enable the appropriateness of the adopted losses to be evaluated. The calibrated losses are presented in the FFJV (2021) report in Table A3 and a portion of this table is reproduced below here for ease of reference.

Table A3 Hydrologic model calibration parameters

Parameters	Macintyre River	Dumaresq River	Macintyre Brook	Ottleys Creek	Macintyre Floodplain
Initial Loss (mm)					
1976	20 to 60	30 to 70	60 to 80	30	60
1996	50 to 100	40 to 80	45 to 60	30	30
2011	25 to 50	20 to 40	30	50	30
Continuing Loss (mm/h)					
1976	2.4 to 3.3	2.5 to 4.5	2.8 to 4.0	3.5	2.0
1996	1.2	0.5 to 3.0	0.5 to 3.0	3.5	3.0
2011	1.6 to 3.5	0.8 to 2.7	1.0 to 1.4	2.1	2.1

From a high-level comparison, we note for each catchment based on the two largest events of 1976 and 2011 the following losses:

Macintyre River –

(1) initial losses - 1976 and 2011 are in the range of 20 mm to 60 mm, while ARR 2019 recommended 35 mm and the adopted loss is 25 mm; and

(2) continuing losses - 1976 and 2011 are in the range of 1.6 mm/hr to 3.3 mm/hr, while ARR 2019 recommended 2.4 mm/hr and the adopted loss is 2.4 mm/hr.

Dumaresq River –

(1) initial losses - 1976 and 2011 are in the range of 30 mm to 70 mm, while ARR 2019 recommends 29 mm and the adopted loss is also 29 mm; and

(2) continuing losses - 1976 and 2011 are in the range of 0.8 mm/hr to 4.5 mm/hr, while ARR 2019 recommended 4.6mm/hr and the adopted loss is 3.0 mm/hr.

Macintyre Brook –

(1) initial losses - 1976 and 2011 are in the range of 30 mm to 60 mm, while ARR 2019 recommends 27 mm and the adopted loss is also 30 mm; and

(2) continuing losses - 1976 and 2011 are in the range of 1.0 mm/hr to 4.0 mm/hr, while ARR 2019 recommended 2.5mm/hr and the adopted loss is 2.5 mm/hr.

From the above review, the reconciled losses adopted by FFJV (2021) are considered appropriate and are either in line with ARR 2019 or slightly conservative.

7.2.2 Reservoirs

FFJV (2021) have reviewed the storages within the catchment to endeavour to provide a probability neutral Volume Below Full (VBF); effectively the probability neutral starting water level in the reservoir.

From FFJV (2021), the median VBF capacity is adopted for use in the design event hydrology. Table 7-1 provides the adopted characteristics of the median VBF with regards to the percent of storage available before a flood event and the effective loss of rainfall.

Table 7-1 Median VBF Characteristics

Dam	VBF (ML)	Storage (ML)	Catchment Area (km^2)	% VBF	Effective Loss Rainfall
Pindari Dam	110,000	312,000	2,110	35%	52 mm
Glenlyon Dam	148,000	253,000	1,295	58%	114 mm
Coolmunda Dam	22,000	69,000	1,760	32%	12.5 mm

As noted by FFJV (2021) no correlation between reservoir volume and rainfall magnitude occurs, whilst as noted in Table 7-1 above, the median VBF provides a significant reduction in the runoff volume and peak flow downstream into the Macintyre Floodplain as detailed in the FFJV (2021) report Table 9 with the 1 in 100-yr AEP peak flow reducing from 5,445 m^3/s to 4,565 m^3/s (i.e. approx. 2011 flood event). Further discussion is provided in 7.2.3 and Section 7.4 regarding the uncertainty associated with the median VBF.

7.2.3 Peak Flows

FFJV (2021) has provided details concerning the reconciliation of design peak flows to the FFA undertaken with the local in-catchment gauges and at the Boggabilla gauge. The assessment is robust and the results of the assessment are provided in FFJV (2021) Table 9 and also provided below for ease of reference, including the FFA at Boggabilla Gauge and reproduced in Figure 7-1.

Table 9 Reconciled and current catchment design flows upstream of Boggabilla

AEP (1 in N)	Loss Multiplier	DEA Flow (m^3/s)	
		Reconciled	Current
2	0.82	691	511
5	0.85	1309	995
10	0.90	1906	1506
20	0.95	2648	2145
50	1.0	4002	3322
100	1.0	5445	4565
200	1.0	7317	6208
500	1.0	10091	8785
1000	1.0	12547	11147
2000	1.0	15261	13767

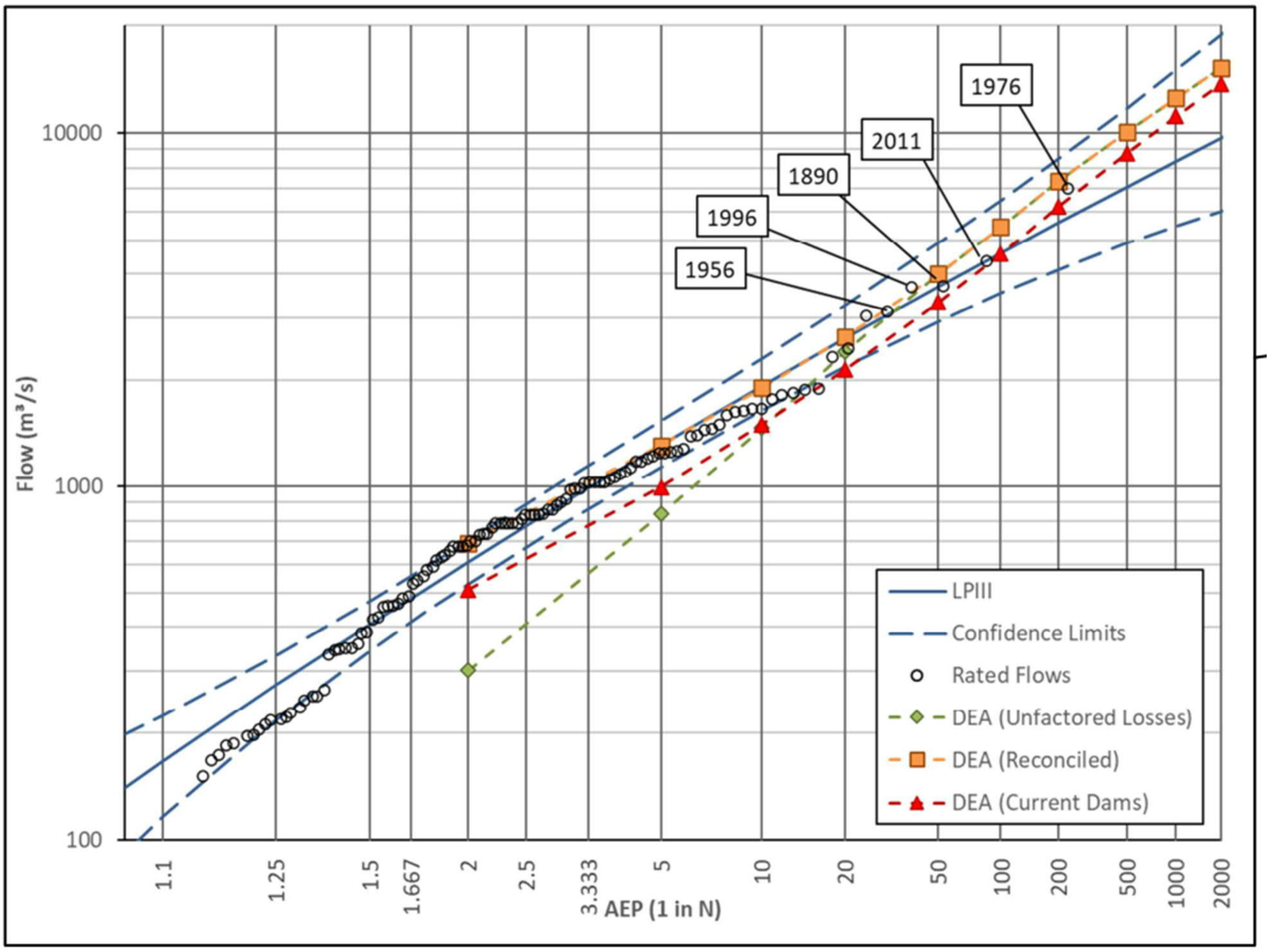

Figure 7-1 FFA & Design Flow Plot at Boggabilla Gauge

Our understanding is that the ‘reconciled’ flows are the weighted average pre- and post-developed reservoir flows, while ‘current’ flows represent current catchment conditions with reconciled parameters. Based on the above table and Figure 7-1, the 1 in 100-year AEP will differ by approx. 17 % (i.e. 4,565m^3/s to 5445m^3/s) with the ‘current’ catchment conditions reconciled to the LPIII assessment. However, the ‘reconciled’ flows of 5445m^3/s are also within the upper confidence limit.

Typically, due to a range of uncertainties associated with the catchment modelling system (i.e. combined hydrological and hydraulic modelling), a potentially conservative assumption is made to adopt a ‘dam full’ starting condition for design purposes particularly for the rarer flood events where the uncertainty increases.

A review of the hydraulic flood impacts associated with ‘reconciled’ and ‘current’ flows is provided in the following section.

7.3 Hydraulic Impacts

The difference in hydraulic impact between adopting ‘reconciled’ and ‘current’ flows are presented in Appendix C. The results indicate:

(1) Increases in flood impacts immediately behind the culverts north of the Macintyre River bridge crossing (i.e. north of chainage 30 km);

(2) Increase in flood impacts south of chainage 30 km that vary from approximately 20mm-30mm and increasing to the south by over 300mm.

7.4 Uncertainty, Impacts and Design

FFJV (2021) discusses the uncertainty surrounding the FFA, catchment modelling and the Design Event modelling whilst this report has also provide comment on the uncertainties associated with the catchment modelling.

Whilst detailed analysis has been undertaken to justify the adopted parameters and dam levels uncertainty will remain. It is considered acceptable that for flood impact assessments whereby comparisons are made to the QDL, that the ‘current’ design flood and moreover the 1 in 100-yr AEP design event is appropriate and the ‘dam full’ and or the validated 1976 flows be used for sensitivity to determine the upper bounds.

For design purposes of the structures and risk-based planning for rare (i.e. 1 in 100-yr AEP) to extreme (i.e. PMF) flood events, it is considered more appropriate to use the dam full scenario. The available storage in the dam should not be relied upon for risk-based planning and design of the structures.

8 Summary

8.1 Overview

The FFJV (2021) has updated the catchment modelling system (i.e. integrated hydrological and hydraulic models) that incorporates current best practice approaches and techniques as outlined in 2019 Australian Rainfall and Runoff (ARR 2019). The models are considered to be comprehensive and represent a significant improvement to the DPIE models.

A large range of floods had been simulated in the flood modelling in the previous EIS (FFJV, May 2020) from relatively frequent events, up to extreme events well in excess of any historic floods. Whilst the full range of floods will ultimately need to be re-assessed on the updated 2021 flood model, the similarity between the models still indicates that a full and comprehensive understanding of flooding for all events has been established, and the assessment of impacts from the proposed rail line is understood for a full range of events. Whilst no two floods are alike in such a complex system as the Border Rivers, the updated flood model, along with actual historic event simulations provides an acceptable level of confidence that the range of possible flood impacts has been captured up to the 1976 flood event on the updated model.

The investigations to date have presented clear guidance for the detailed design requirements and landowner consultation to enable the final design to achieve an acceptable outcome for all parties.

8.2 Hydrology

8.2.1 Calibration

The hydrological models have been re-calibrated in detail to the 1976, 1996 and 2011 flood events using all readily available data, updated to remove deficiencies identified in the original DPIE models and used for design events with a single parameter set as recommended in ARR 2019. The updated hydrologic models have been assessed for the adequacy of their calibration, and in relation to design events produced, based on ARR 2019 and found to be fit for purpose. The latest calibration is more robust than previous model calibrations and is more defendable in terms of its accuracy and the use of current best practice methods.

The FFA, undertaken by FFJV is comprehensive, particularly in relation to the Boggabilla gauge which is a key reconciliation point and close to the Inland Rail alignment. It is considered the FFJV 1976 validated flows are the most reliable estimate to date with an expected AEP in the range of 1 in 200 year to 1 in 500 year. The DPIE factored flows are considered to be too conservative, largely due to the 20% factoring applied and inaccuracies associated with flood timing.

8.2.2 Design Flood Events

Design Flood modelling has been undertaken to derive the ‘best estimate of the relationship between flood magnitude and exceedance probability’ (ARR, 2019). FFJV (2021) has undertaken design flood modelling based upon ARR 2019 ‘Ensemble Event’ methodology and reconciled design flows with the FFAs undertaken.

Initial loss and continuing losses adopted are considered appropriate based on ARR 2019 and from the calibrated hydrological model. No factoring of hydrological flows has been necessary for rare flood events (e.g. 1 in 50-yr AEP or greater) for which the hydrological model was calibrated to (i.e. 1976, 1996, 2011). Appropriate factoring for the more frequent flood is considered acceptable.

The adopted volume below full (VBF) within the dams (i.e. assumed standing water level in the dam) before a design flood event is relatively uncertain but verified/ reconciled to FFA. However, the residual uncertainty associated with the VBF assumptions for rare to extreme floods is further discussed in Section 8.4.

8.3 Hydraulics

FFJV has updated and re-calibrated the hydraulic model that includes the following changes:

(1) Grid Resolution – an improved topographic representation through the incorporation of the latest TUFLOW release (2020) that includes Sub-Grid Sampling (SGS).

(2) Topography– FFJV have used the current (2019) LiDAR topographic survey that was flown specifically by ARTC for this project.

(3) Topographic modifiers - main drainage channels/ rivers, levees and existing drainage structures.

(4) Inflows - Revised inflow locations and inclusion of lower catchment flows based on the latest hydrological model.

(5) Calibration – improved calibration to observed data.

Each of these items has improved the representation of the Macintyre floodplain by the FFJV (2021) hydraulic model and provided a more reliable and robust model than the DPIE model.

The 2019 LiDAR data is of high accuracy and allows a good representation of flow paths and inundation areas with all existing levees accurately represented, thus allowing, within the flood modelling, for these levees to overtop when flood levels are higher than the levees. Previous models have assumed that many levee banks do not overtop, and this can have significant effects on flow paths and flood levels predicted across the floodplain.

The hydraulic model has been well calibrated to the three flood events of 1976, 1996 and 2011. Flood volumes, timing and peak flows have been assessed and verified, where possible to FFA, flood markers and to the DPIE model.

With all the additional rigour that has been applied to the latest modelling, similar results, in terms of rail design levels and hydraulic structure requirements, and the general impacts of the rail on adjacent properties, to those considered in our previous review report have been predicted.

8.4 Residual Uncertainty

FFJV (2021) discusses the uncertainty surrounding the FFA, catchment modelling and the Design Event modelling whilst this report has also provided comments on the uncertainties associated with the catchment modelling.

It is considered acceptable that for flood impact assessments, where comparisons are made to the QDL, that the ‘current’ design flood (i.e. the 1 in 100-yr AEP design event) is appropriate, while the ‘dam full’ and/ or the validated 1976 flood flows with verified levees should be used for sensitivity testing to determine the upper bounds.

For design purposes, for the structures and for risk-based planning (i.e. risk to loss of life, evacuation planning, property damage) for rare (i.e. 1 in 100year AEP) to extreme (i.e. PMF) flood events, it is considered more appropriate to use the dam full scenario.

9 References

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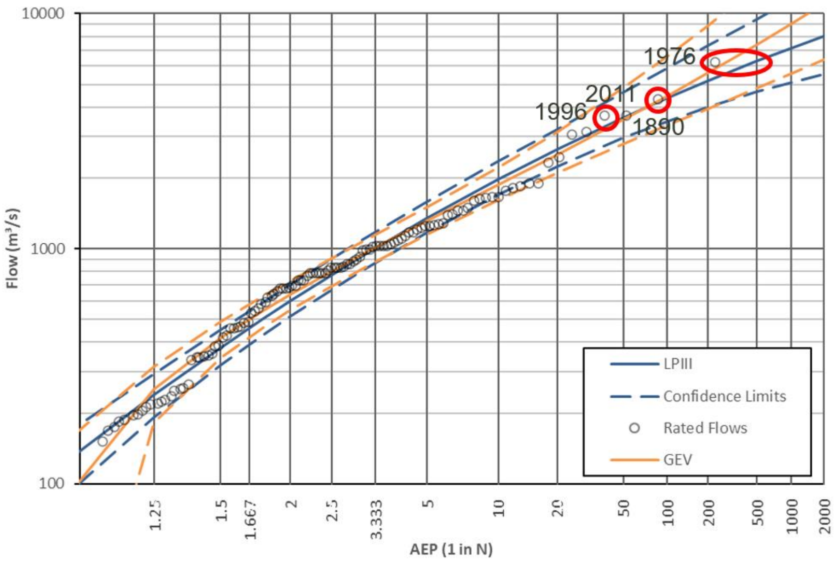
WRM (Oct 2020), *Peer Review of Flood Modelling undertaken for the Macintyre River Floodplain, Inland Rail Project, North Star to Queensland Border* (NS2B).

Kitts, D., Syme, W., Gao, S., Collecutt, G. and Ryan, P., 2020. Mesh orientation and cell size sensitivity in 2D SWE solvers. In *Submitted paper for the IAHR 10th Conference on Fluvial Hydraulics, River Flow.*

Appendix A FFA Graphs (Macintyre River)

FFA – Macintyre River @ Boggabilla

Bringing ideas to life



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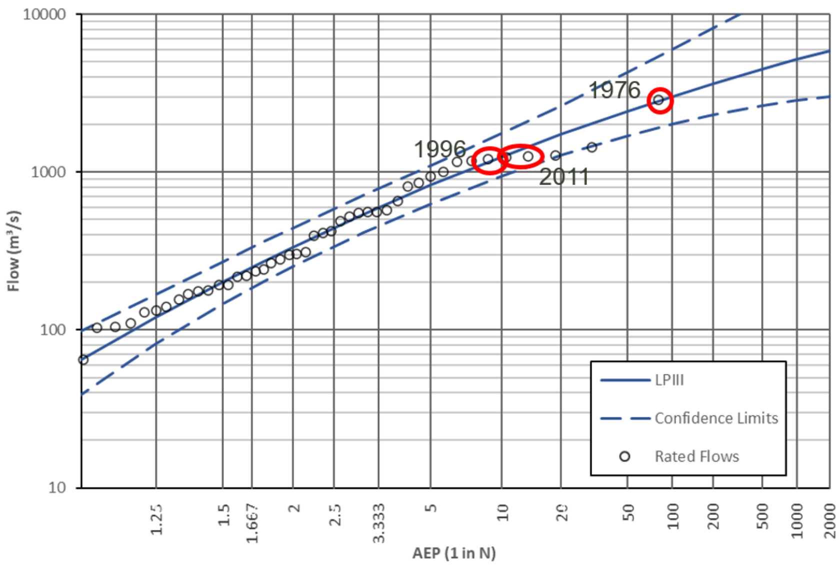
FFA – Macintyre River @ Holdfast

Bringing ideas to life



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FFA – Macintyre River @ Ashford

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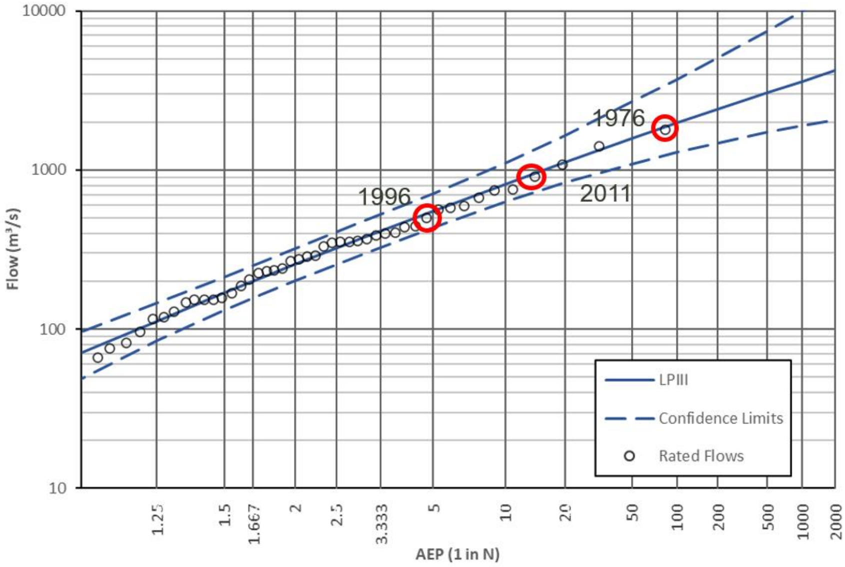

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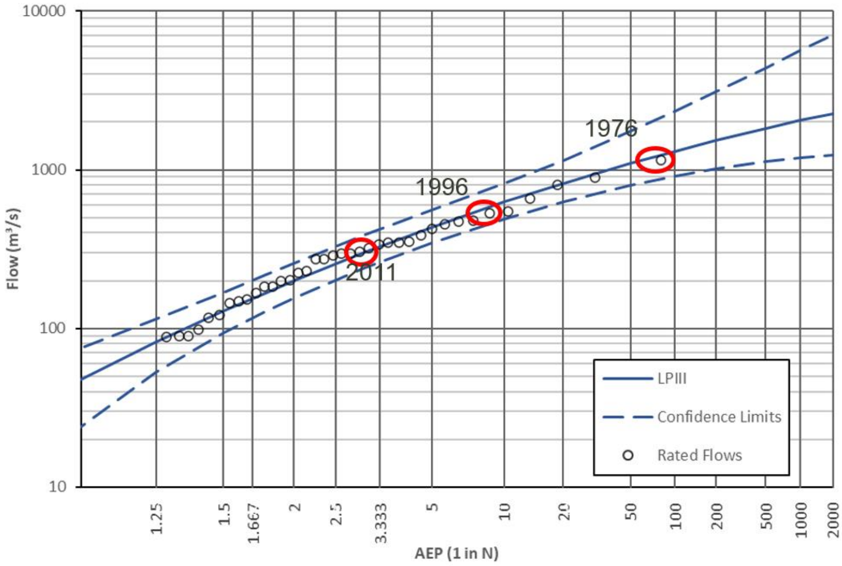
FFA – Macintyre River @ Wallangra

Bringing ideas to life



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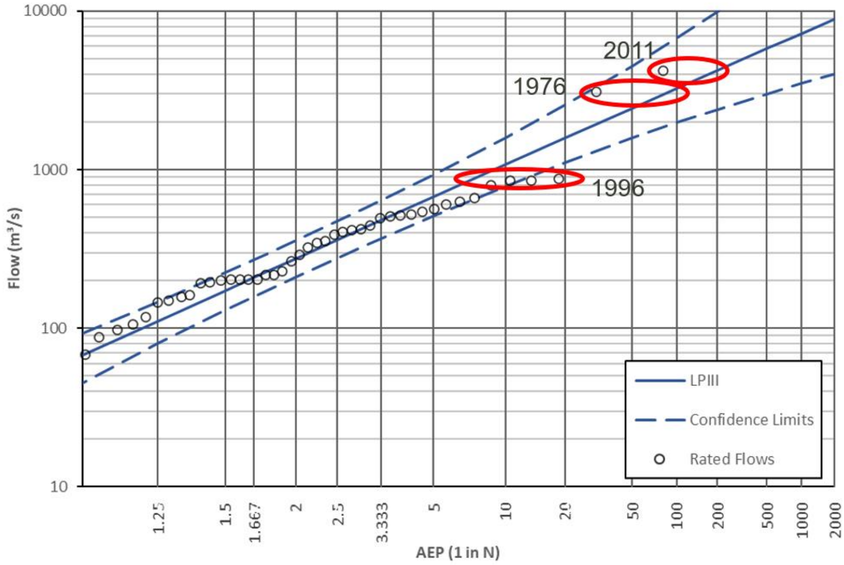
FFA – Dumaresq River @ Bonshaw Weir

Bringing ideas to life



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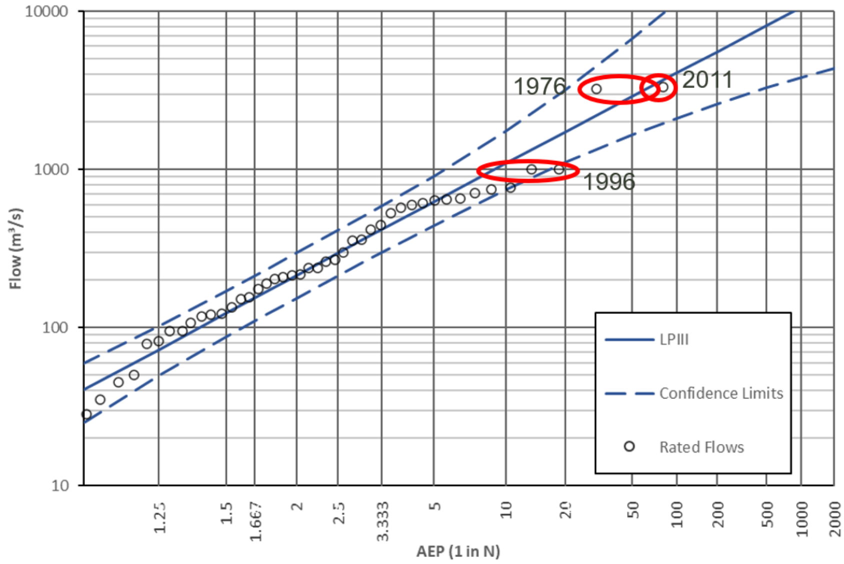
FFA – Dumaresq River @ Roseneath

Bringing ideas to life



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FFA – Dumaresq River @ Cunningham/Glenarbon

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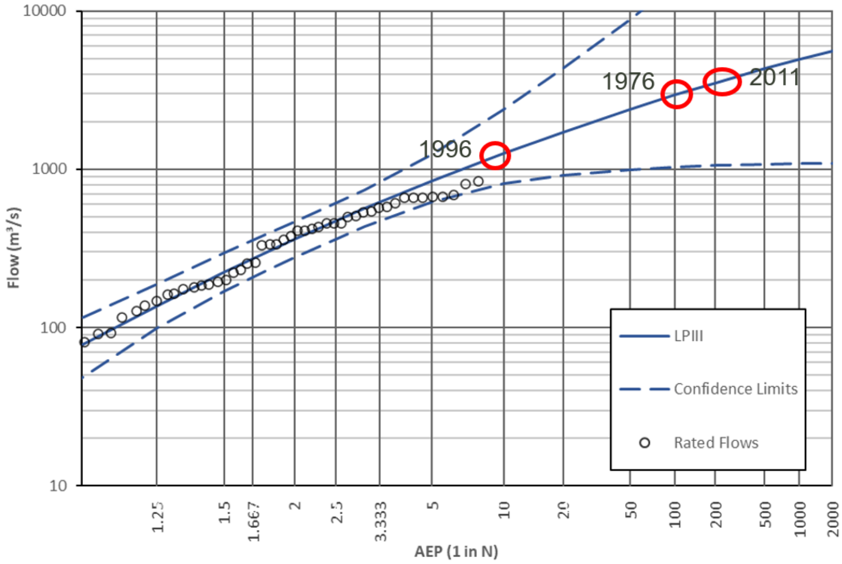

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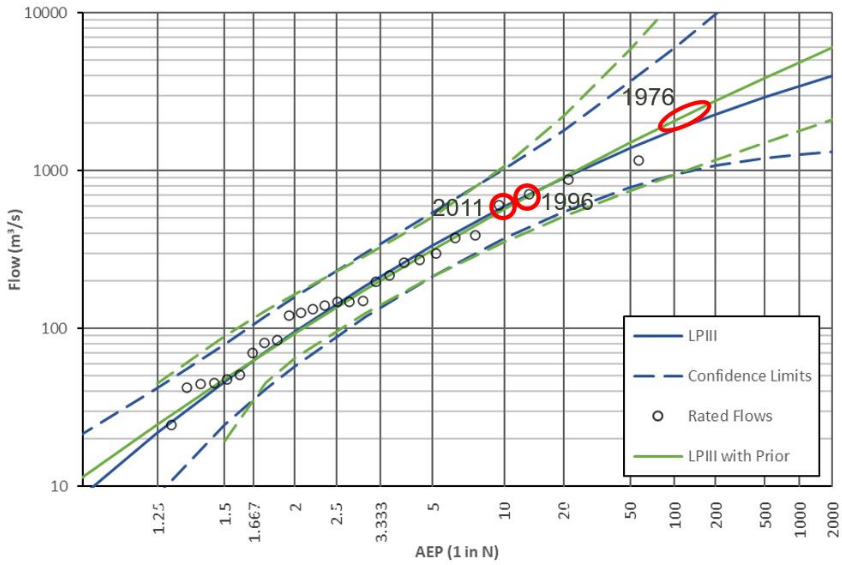
FFA – Macintyre Brook @ Booba Sands

Bringing ideas to life



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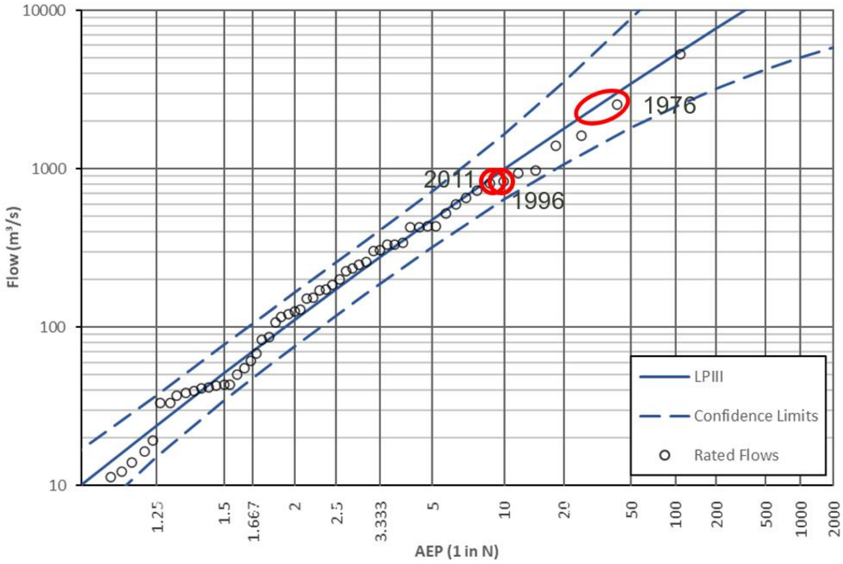
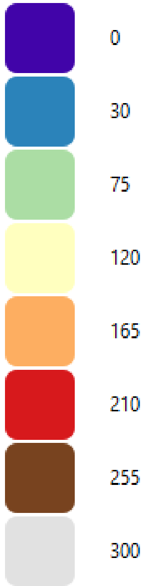
FFA – Macintyre Brook @ Inglewood

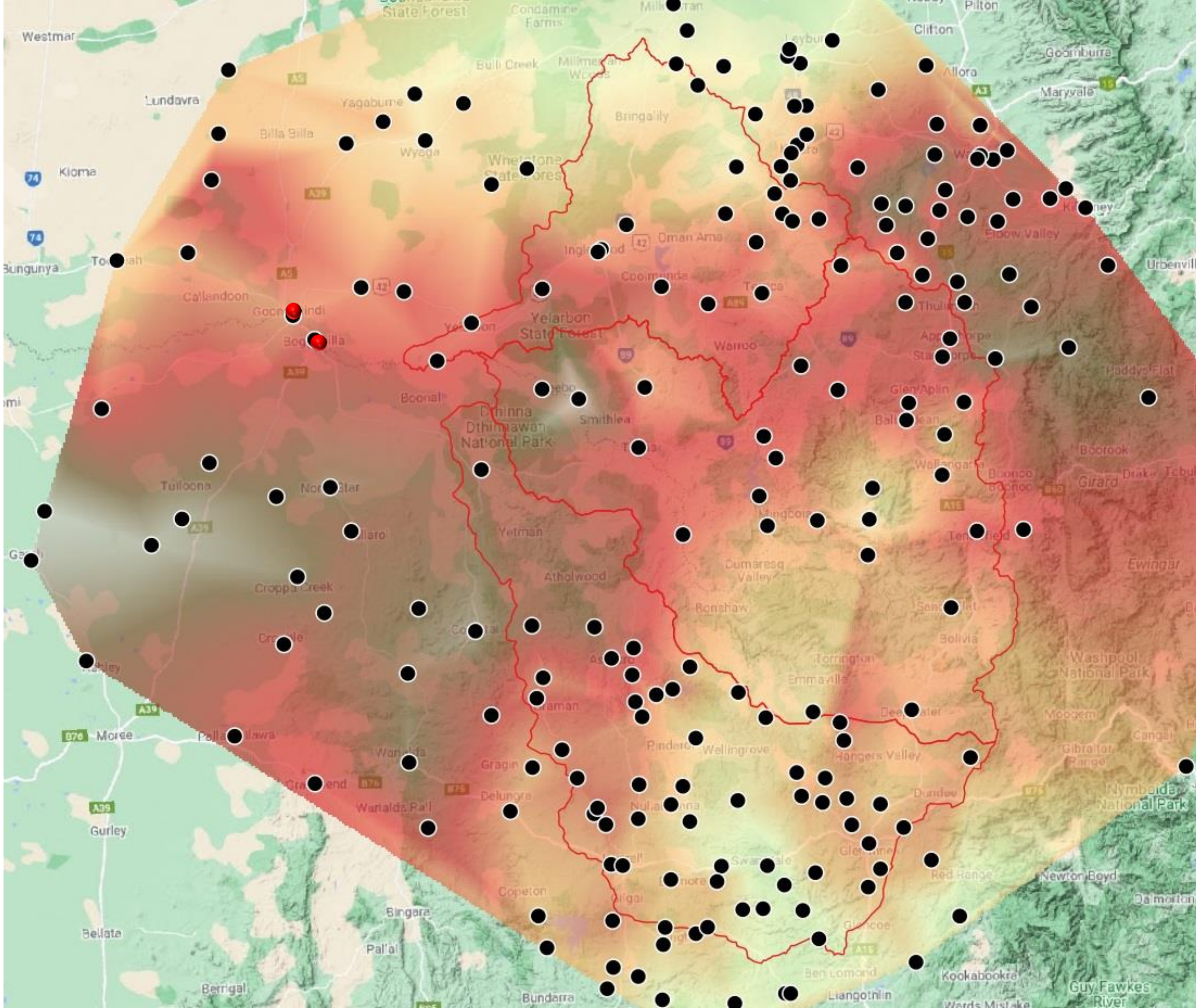


Appendix B Rainfall Data

Calibration Events

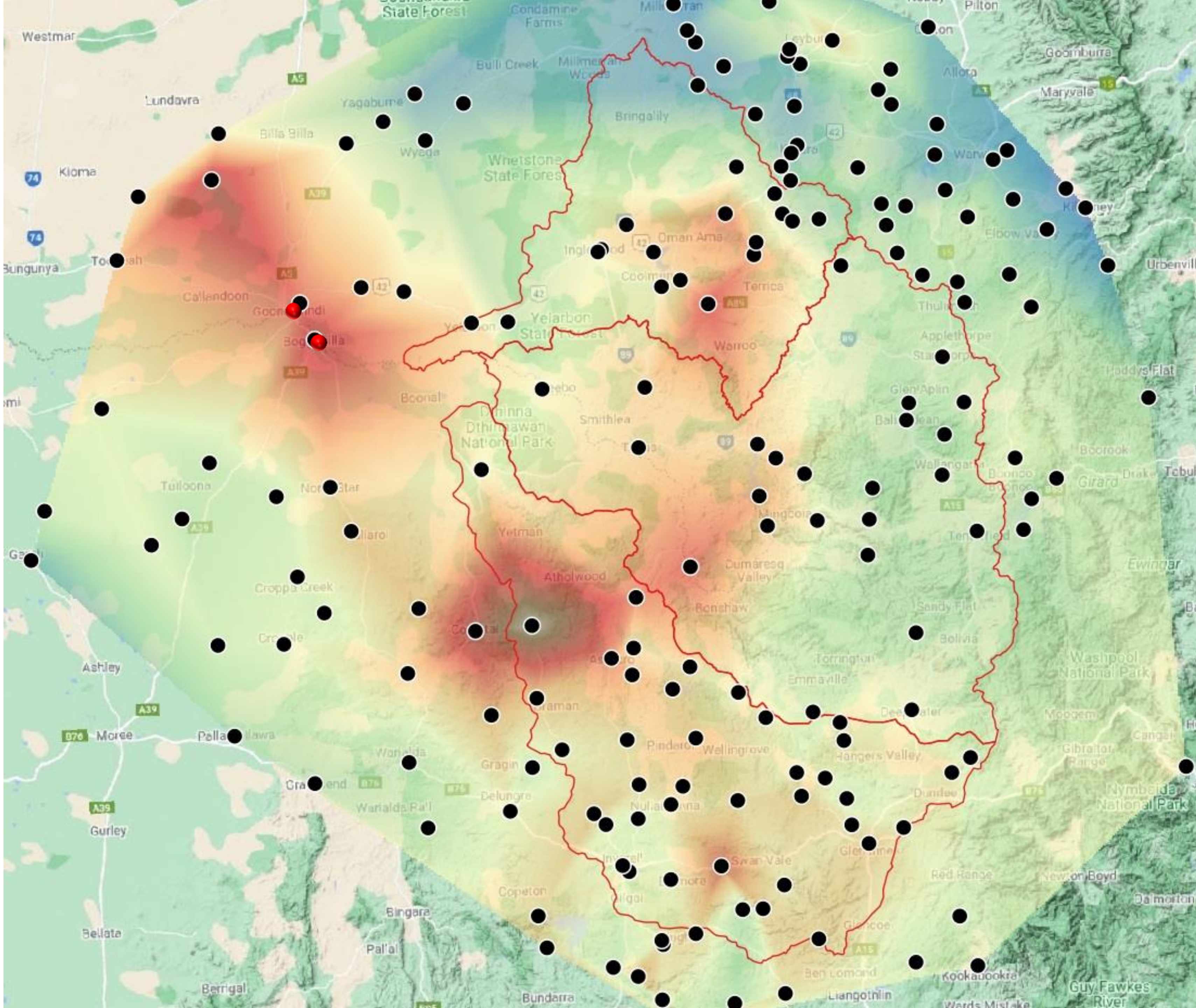
1976 Rainfall Depth





Calibration Events

1996 Rainfall Depth



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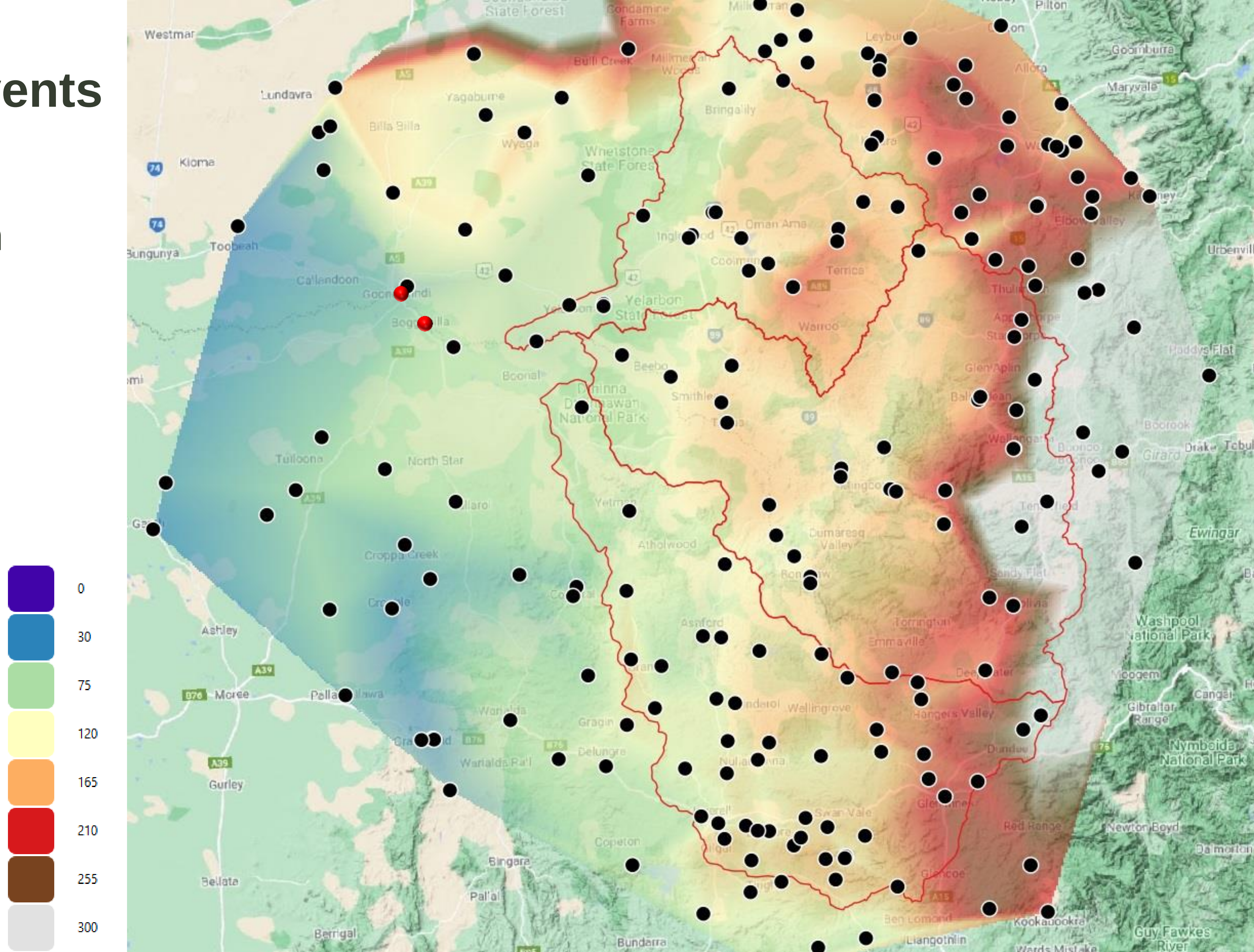
210

255

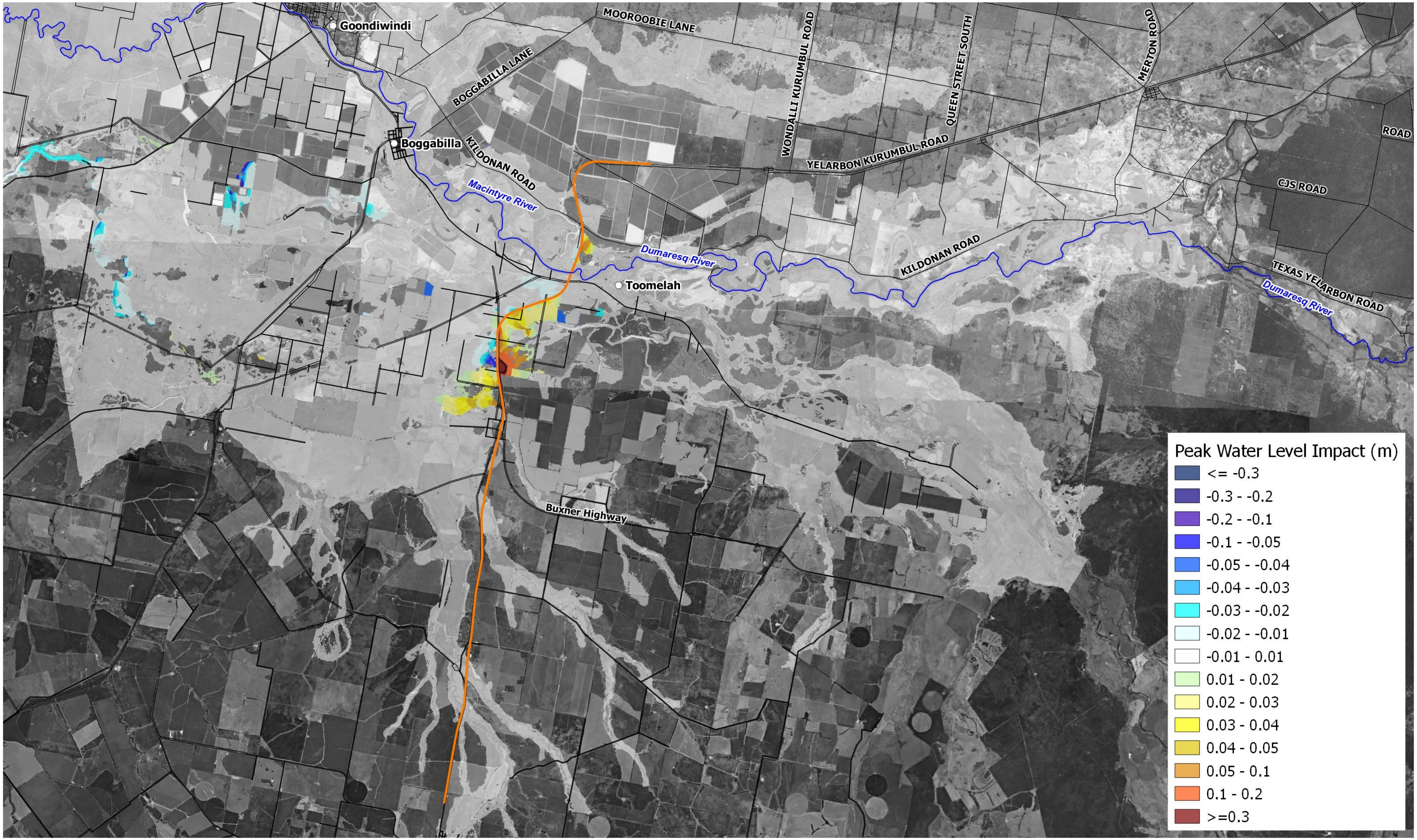
300

Calibration Events

2011 Rainfall Depth



Appendix C Hydraulic Impact ‘Reconciled’ & ‘Current’ Flows



Legend

- Towns
- Macintyre River
- NS2B Rail Alignment
- Roads

Title:

Afflux (Dam Full Minus Median Dam - conservative bridge losses)

Drawing: **C-1**

Rev: **A**

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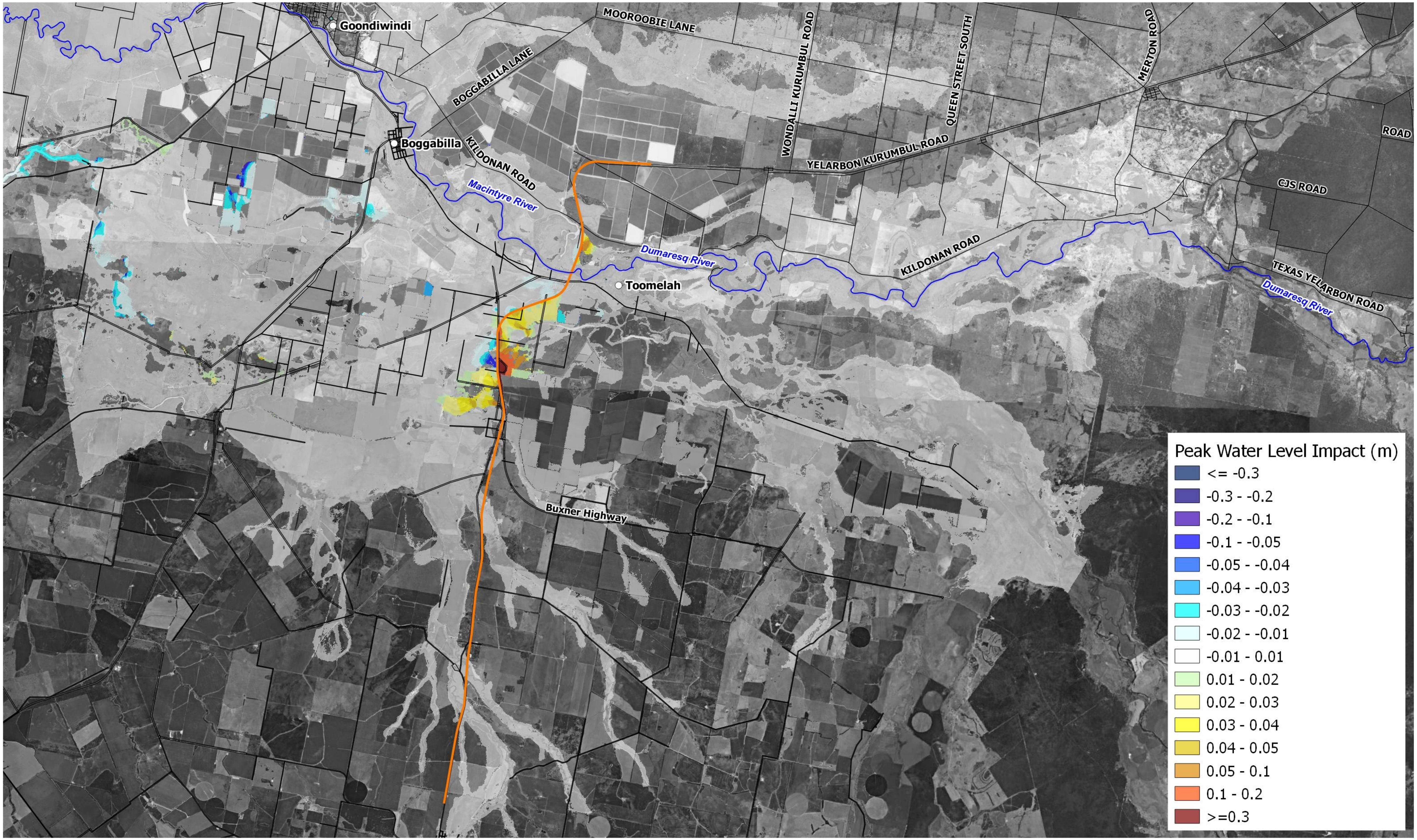

Legend

- Towns
- Macintyre River
- NS2B Rail Alignment
- Roads

Title:
Afflix (Dam Full Minus Median Dam - revised bridge losses)

Drawing: **C-2**

Rev: **A**

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Appendix H
Design event modelling

H1 Design Event modelling approach

Hydrologic modelling to determine design flows for the Macintyre River system has been undertaken using a Design Event Approach (DEA) based on the Ensemble Event methodology described in Australian Rainfall and Runoff (ARR).

A Design Event is the simulation of a synthetic storm event with rainfall intensity of a particular duration and frequency (typically defined as an Annual Exceedance Probability or AEP) and a defined temporal pattern, catchment losses and other catchment properties. Key characteristics of the Ensemble approach include:

- Events covering a range of durations are assessed for each AEP to determine the duration that produces the highest (worst-case) flow
- An ensemble of ten temporal patterns are simulated for each duration and AEP. These are assessed to produce a characteristic value for each duration and AEP (see discussion below).
- Multiple event durations are assessed for each AEP. The highest characteristic value and the event duration that produces it are taken as the Design Flow and the critical duration respectively.

There is some ambiguity as to how the characteristic value should be determined from the 10 patterns. The Average and Median flood peaks tend to produce similar but non-identical values. The Median value is theoretically less sensitive to the influence of outliers (noting that these may be high or low, so the average is not necessarily more or less conservative). The limitation of both these options is that they do not have an associated temporal pattern, which is necessary for dynamic hydraulic modelling. For the purposes of this investigation:

- The Median (50% probability) value has been adopted for reconciliation with the Flood Frequency Analysis (FFA). Since 10 patterns are simulated, the median value actually lies halfway between the 5th and 6th highest values.
- The Rank 6 hydrograph has been adopted for simulation in the hydraulic model. This produces a peak flow that is conservative, typically slightly higher but within the uncertainty of the modelling and reconciliation process. Each adopted Rank 6 hydrograph was reviewed to confirm that it had a relatively 'typical' shape as well as the peak. (The hydrograph shape is a function of both the temporal pattern and the catchment. Most hydrographs tend to have a similar shape characteristic of the catchment unless the causal pattern is highly unusual).

H1.1 Rainfall IFD

Rainfall Intensity-Frequency-Duration (IFD) tables are used to describe the probability of occurrence of a rainfall depth or intensity within a specified duration. Rainfall Intensity-Frequency-Duration (IFD) relationships for the study were compiled using:

- Frequent to Rare probability (1EY to 1 in 2000 AEP) data sourced from the Bureau of Meteorology's online Design Rainfall Data System (2016)
- Probable Maximum Precipitation (PMP) depths calculated using the data and methodologies prescribed in BoM (2003) for durations up to 6 hours and BoM (2005) for longer durations
- Intermediate values were interpolated using the methods described in ARR 2019

Individual IFD relationships were obtained at each of the subarea centroids. The Design Event methodology assumes that the rainfall across the catchment has the same frequency and duration for each modelled event but varies spatially according to the IFD relationship at each location.

The BOM rainfall IFD relationships are for specific points in the catchment and are not representative of the areal average rainfall intensity across the entire catchment. Areal Reduction Factors (ARF) are used to provide a correction between the catchment rainfall depth and the mean of the point rainfall depths across a catchment (for the same AEP and duration combination). ARR 2019 provides the methodology for calculating ARF as a complex function of catchment area, event duration and AEP. The ARF affects the average depth of rainfall across the catchment and does not account for variability in the spatial or temporal distributions over the catchment. The PMP calculation methodologies include depth as a function of catchment area and no ARF is required.

H1.2 Temporal and spatial distribution

The Ensemble modelling was conducted using the standard set of temporal distribution patterns obtained from the online ARR Data Hub. This provides an ensemble of ten patterns for each standard burst durations for a range of different catchment sizes. The Macintyre River catchment lies within the Central Slopes region.

Each Design Event has a single temporal pattern that is applied simultaneously across the whole catchment. The standard Design Event methodology also assumes a constant AEP and ARF across the catchment. That is, for an event of specified AEP, the total rainfall depth at every point in the catchment has the same AEP (although the actual depth may vary in accordance with the statistical IFD relationship which may vary across the catchment, as discussed in Section H1.1).

Real storm events over large catchments are usually characterised by concentrations of rainfall in different parts of the catchment and bursts that occur at different times in different areas. This potentially has significant impact on the relative magnitude and timing of the contributing flows from each of the tributaries.

H1.3 Catchment losses

Rainfall losses have been modelled using a standard Initial Loss/Continuing Loss model. Although continuing losses are typically assumed to be relatively constant for a catchment (although they reduce during very long duration events as the catchment substrata becomes saturated), initial losses are dependent on catchment conditions at the start of the event. Rainfall depths from the BoM IFD tables and the ARR Data Hub temporal patterns are both derived for storm bursts (a burst is not necessarily a complete storm and may be preceded and followed by additional rainfall).

In reality, the variability of catchment and rainfall conditions means that a flood of a particular AEP may be the product of a rainfall event of rarer AEP (higher intensity) with higher catchment losses, or of more frequent AEP (lower intensity) with lower losses. A fundamental aspect of the Design Event methodology is the requirement to use 'probability-neutral' losses (and other catchment parameters such as dam levels, discussed in Section H1.4 below) that produce a direct relationship between Rainfall AEP and the AEP of the resulting flood.

The initial losses adopted for design event modelling must therefore consider antecedent rainfall prior to the modelled storm burst and be probability neutral. The ARR Data Hub provides regionalised values for initial storm loss and continuing loss, as well as pre-burst depths (rainfall that occurred prior to the design storm burst, nominally in the prior 7 days) as a function of rainfall burst AEP and duration. These theoretically allow the probability-neutral burst initial depth to be calculated as the pre-burst depth subtracted from the storm initial depth. The ARR Data Hub losses for each catchment are listed in Table H1. Significant differences between different catchments are noted, particularly in the continuing loss rate, which appear to unrealistically distort the contributions from the tributaries (for example, for minor events there is almost no contribution from the Dumaresq River catchment if the regionalised losses are applied).

The ARR Data Hub also reports that a review by the NSW Office of Environment and Heritage identified a bias in the standard ARR 2016 design event method when using the default ARR data hub losses and pre-burst depths. Probability-Neutral Burst Initial Loss as a function of AEP and duration are now available from the ARR Data Hub for use in NSW regions. This method is difficult to implement for the current study because a portion of the Macintyre River catchment is located outside NSW where probability-neutral burst losses are not available. A consistent methodology is required to enable entirety of the catchment to be modelled.

These issues are not considered to be significant as both the regionalised storm losses and NSW reconciled losses are intended for use only where more reliable and/or site-specific information is unavailable. Loss values based on experience with the model calibration and reconciliation to at-site stream gauge. Flood Frequency Analyses have been used in preference to the ARR Data Hub values. The reconciliation process is discussed further in Section H3. The reconciled losses adopted for the Design Event modelling are summarised in Table H1. (It should be noted that for calibration events, the applied catchment losses also represent a tool for correcting for errors/uncertainties in the rainfall data. Therefore, although the median losses over multiple events would be expected to be similar to the typical catchment losses, the losses used for any particular event do not necessarily match the actual losses).

Table H1 ARR Regionalised and adopted at-site FFA reconciled losses

Catchment	ARR Data Hub Losses		Reconciled Losses	
	Initial	Continuing	Initial	Continuing
Macintyre River to Holdfast	35 mm	2.4 mm/h	25 mm	2.4 mm/h
Dumaresq River to Glenarbon	29 mm	4.6 mm/h	29 mm	3.0 mm/h
Macintyre Brook to Booba Sands	27 mm	1.2 mm/h	30 mm	2.5 mm/h
Ottleys Creek	57 mm	0.1 mm/h	30 mm	3.5 mm/h
Lower Macintyre River Floodplain	47 mm	0.3 mm/h	30 mm	3.0 mm/h

H1.4 Reservoirs

Three notable reservoirs are located upstream of Boggabilla and included in the hydrologic models – Pindari Dam on the Severn River in the Macintyre River catchment upstream of Ashford, Glenlyon Dam on Pike Creek in the upper Dumaresq River catchment, and Coolmunda Dam on Macintyre Brook upstream of Inglewood. All three dams were completed between 1969 to 1972, with Pindari Dam undergoing a major upgrade in 1994 that significantly increased its capacity. Reservoir details are summarised in Table H2.

The storage upstream of the reservoirs provides a retarding and attenuating effect on the flood hydrograph. This includes any initial empty capacity below the full supply level present at the start of the event that must be filled before the dam begins to spill, represented in the hydrologic model as an initial Volume Below Full (VBF), and the storage routing through the reservoir represented as a storage-discharge relationship in the model.

As with rainfall losses, for the Design Event approach it is necessary to adopt probability-neutral VBF values. Analysis of the historical rainfall and reservoir volume data identified that there was no correlation between reservoir volume and rainfall magnitude, meaning that large rainfall events are equally likely to occur when the reservoir is empty as full. The reconciliation discussed in Section H3 identified that using a median VBF achieved good consistency between the Design Event and FFA.

Table H2 Reservoir storage details

Reservoir Name	Catchment	Stream	Completion Date	Storage Volume (ML)	Median VBF (ML)
Pindari Dam	Macintyre River	Severn River	1969 1994	38,000 312,000	1,000 110,000
Glenlyon Dam	Dumaresq River	Pike Creek	1972	253,600	148,000
Coolmunda Dam	Macintyre Brook	Macintyre Brook	1968	69,000	22,000

H2 Flood Frequency Analysis methodology

At-site flood frequency analysis involves the statistical analysis of flood data recorded at in the catchment (typically a stream gauge) to identify and fit a probability distribution function, which can then be used to perform risk-based design and flood risk assessment. FFA has been conducted at ten of the major stream gauges throughout the catchment to provide input to design flow estimates and to help determine probability-neutral catchment parameters for the Design Event modelling. Period of record and catchment area to each of the gauges are listed in Table H3.

Table H3 FFA Gauge Data Summary

Catchment	Gauge Name	Stream	Catchment Area	Period of Record
Macintyre River	Ashford Wallangra Holdfast	Severn River Macintyre River Macintyre River	3,285 km² 2,130 km² 6,800 km²	1970 – 2021 1972 – 2021 1972 – 2021
Dumaresq River	Roseneath Bonshaw Cunningham/Glenarbon [a]	Dumaresq River Dumaresq River Dumaresq River	5,560 km² 7,240 km² ~9,000 km²	1972 – 2021 1972 – 2021 1954–88, 1997–2021

Catchment	Gauge Name	Stream	Catchment Area	Period of Record
Macintyre Brook	Inglewood Booba Sands	Macintyre Brook Macintyre Brook	3,430 km² 4,092 km²	1954 – 2021 1984 – 2021
Ottleys Creek	Coolatai	Ottleys Creek	385 km²	1979 – 2021
Lower Macintyre	Boggabilla	Macintyre River	22,500 km²	1886 – 2021[b]

Notes: a Flood records from the gauges at Cunningham and Glenarbon Weir have been combined
b Only significant flood peaks available prior to 1982

Stream gauge data has been obtained from the Continuous Water Monitoring Network webservice provided by WaterNSW and the *Water Monitoring Information Portal* operated by the Queensland Government Department of Regional Development, Manufacturing and Water (DRDMW), formerly the Department of Natural Resources, Mines and Energy (DNRME). A brief review of the gauge history was undertaken for each gauge and, where considered appropriate, historical peak flows were re-rated using current rating information.

The analysis has been conducted using an annual series of peak flows, extracted using a 'Water Year' commencing in September. The FLIKE software package has been used to identify low outliers using the multiple Grubbs Beck test and to fit both the Log-Pearson Type III (LPIII) and Generalised Extreme Variable (GEV) probability distributions. The LPIII and GEV are two distributions commonly used for flood frequency fitting in Australia. ARR does not recommend one distribution over the other, and current practice is usually to adopt the distribution that best fits the data. Where multiple gauges in a catchment examined, the same distribution would be adopted for all gauges.

For the Macintyre River gauges, the LPIII distribution generally appears to provide a better fit for the majority of gauges, which is common for catchments in Queensland and New South Wales, however it should be noted that the appropriateness of the distribution and validity of the FFA at a number of gauges is affected by non-homogeneity of the gauge record, discussed in Section H3.1 below. The reconciliation process has focussed on matching the Design Event flows to the historical frequency distribution for frequent events, where both probability distributions tend to give similar results.

H3 Reconciliation to At-Site FFA

Design Event modelling and at-site flood frequency analysis provide two independent methods for estimating design flows. Each method has specific strengths and weaknesses:

- Flood Frequency Analysis is based on site-specific information. However, it is dependent on (amongst other things) the reliability of the rating used to derive the flow, the statistical representativeness of the historical data, and the validity of the probability distribution, all of which tend to decrease with increasing event magnitude.
- Design Event modelling uses rainfall frequency distributions based on amalgamation and filtering of multiple rainfall gauges that generally have access to longer historical record and are (theoretically) less susceptible to outliers that may affect individual site. However, it requires reliable model calibration and the estimation of appropriate probability-neutral catchment parameters.

Preferred practice is to use the frequent to infrequent range of the FFA distribution, which is the most reliable region of the FFA, to help derive probability-neutral catchment properties. Extrapolation to rare events is then conducted using the rainfall-based Design Event method, minimising the uncertainty in the projection of the at-site gauge data relationship. Reconciliation to produce probability-neutral catchment parameters included:

- Probability-neutral rainfall losses were derived based on reconciliation at typically two to three of the major gauges in each of the catchment models. Reconciliation was achieved using consistent losses for all gauges in each catchment model, however different loss rates were derived for each catchment. The losses used for the reconciliation are summarised in Table H1.
- A constant storm initial loss value was used for each catchment, with the burst initial losses required for the Design Event burst calculated using the median pre-burst depth relationships obtained from the ARR Data Hub typically producing a good reconciliation (see discussion in Section H3.1)
- Good reconciliation was achieved using the median VBF for the reservoirs allowing gauges unaffected or only partially affected by the reservoir to be reconciled using the same losses as those affected by the reservoir.

H3.1 Non-homogeneous record influence on FFA and Reconciliation

A fundamental principle of FFA is that the flood peak frequency distribution fits a standard probability distribution. The majority of the empirical evidence used to support the use of the LPIII and GEV distributions is from consistent record from natural catchments. The reduction in flood peak resulting from pre-flood reservoir storage availability is likely to be most pronounced for minor rainfall events. The reservoirs will therefore potentially alter the shape of the historical flood probability distribution, which would affect the ability of the theoretical distribution to fit the data and the reliability of the projection to rarer events.

An example of the effect of the dams on both the FFA and DEA is provided in Figure H1, which compares the FFA and DEA predictions with the historical flood record at Inglewood, which is located just downstream of Coolmunda Dam. (Note that the data in Figure H1 considers only the period post-1970 when Coolmunda Dam was constructed. The equivalent chart for Inglewood shown in Figure H10 (at end of Appendix) incorporates data back to 1954. The FFA confidence limits have been omitted for clarity). Figure H1 demonstrates that:

- The GEV distribution in particular does not provide a particularly good fit of the historical flood probability distribution, with the influence of the frequent events causing a significant deviation of the projection to rare events
- The initial storage volume has a significant effect on the frequent events. A similar effect could be achieved by increasing the Initial Loss (the reservoir effectively captures the initial runoff from the upstream catchment). The key difference is that the reservoir VBF affects only the area upstream of the reservoir. Use of a median historical VBF was found to allow reconciliation of different gauges within the same catchment using the same rainfall losses.

Additionally, for several of the examined stream gauges the reservoirs have not been present for the full period of the gauge record, in particular Ashford and Holdfast (upgrade of Pindari Dam), Inglewood (construction of Glenlyon Dam) and Boggabilla (construction of Coolmunda and Glenlyon then upgrade of Pindari). To address these issues and provide Design flows that represent the current condition of the catchment and reservoirs, the following approach has been adopted:

- The Design Event methodology has been conducted using models that represent both the current and pre-reservoir condition of the catchment. The reconciliation design flows have been calculated as the weighted average of the pre- and post-reservoir flows based on the period of the historical gauge record for which those conditions were present.
- Catchment parameters (losses and reservoir VBF) have been modified to reconcile the Design Event flows to the historical frequency distribution for frequent events. Projection to rare events removes dependence on the fit and appropriateness of the theoretical probability distribution.
- Flows for design have been calculated using models representing the current catchment condition with the reconciled catchment parameters. The current design flows may therefore be different to the reconciled flows due to the influence of the current reservoirs.

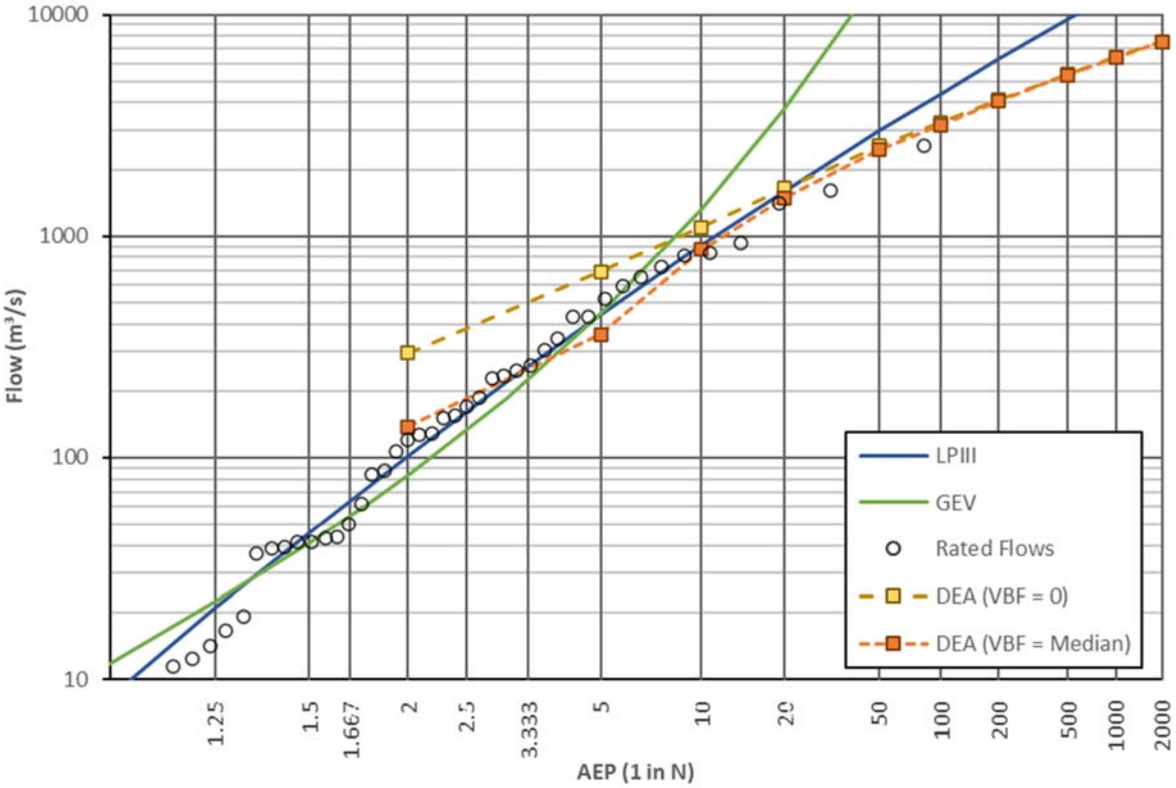


Figure H1 FFA fit and effect of Coolmunda VBF on the DEA flows at Inglewood

H3.2 Macintyre River to Holdfast

FFA and reconciliation has been conducted at three gauges – the Severn River at Ashford and the Macintyre River at Wallangra and Holdfast. All three gauges have roughly the same period of record (48 to 50 years). Pindiri Dam, which controls 64% of the catchment to Ashford and 30% of the catchment to Holdfast, underwent a major upgrade in 1994, roughly halfway through the Ashford and Holdfast gauge records.

Figure H2 demonstrates the significant effect of the Pindari Dam upgrade on the design flows at Ashford. (Note that Pindari Dam had comparative little capacity prior to the 1994 upgrade with a median historical VBF of ~1000ML compared to the current 110,000ML. The influence of the pre-upgrade dam has been neglected and the dam omitted from both the 1976 model calibration and pre-upgrade DEA modelling). The historical flood frequency distribution shows a very good agreement with the weighted average of the pre- and post-upgrade DEA flows. Use of the median historical VBF for Pindari Dam for the DEA approach allows the Ashford gauge to be reconciled using the same catchment losses as the Wallangra (no influence) and Holdfast (partial influence) gauges. The FFA and reconciled Design Event flows for these gauges are shown in Figure H8 (at end of Appendix). A very good reconciliation to all three gauges was achieved using an initial loss of 25mm and continuing loss of 2.4mm/h.

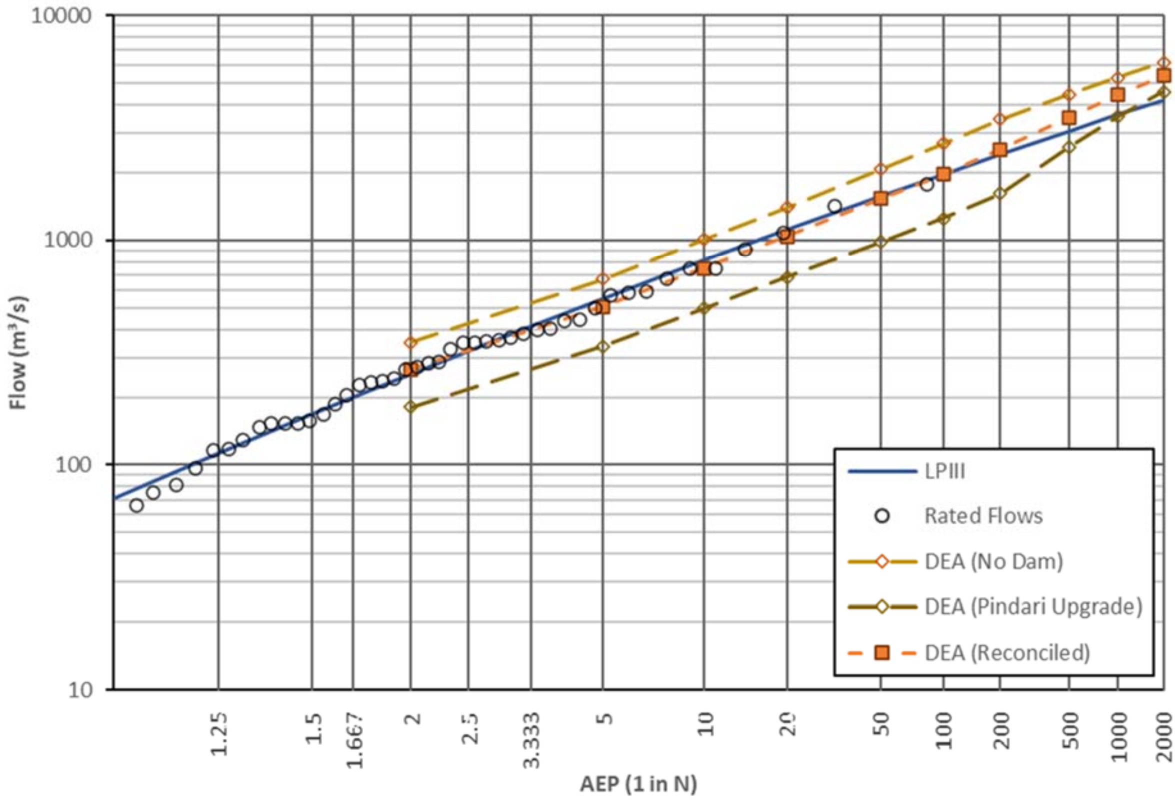


Figure H2 **Effect of Pindari Dam on the DEA flows at Ashford**

H3.3 Dumaresq River to Glenarbon

FFA and reconciliation has been conducted for the Dumaresq River gauges at Roseneath and Bonshaw. A combined historical record representative of the downstream end of the model has been compiled from the gauges at Cunningham Weir (closed in 1988) and Glenarbon Weir (opened in 1997). This was produced only to examine the reconciliation to frequent events as the high-flow ratings at both these gauges are considered highly unreliable (the FFA was conducted by censoring high flows greater than 1,000m³/s). Glenlyon Dam is located upstream of all these gauges, although it controls a relatively small proportion of the catchment compared to Pindari and Coolmunda Dams, decreasing from 23% at Bonshaw to 14% at Glenarbon.

FFA and reconciled Design Event flows for the Dumaresq River catchment are shown in Figure H9. A good reconciliation is achieved at Roseneath and Bonshaw using an initial loss of 29mm, continuing loss of 3mm/h and median VBF in Glenlyon Dam. However, if these values are used at Cunningham/Glenarbon then the Design Event flows are lower than the FFA for frequent events (< 1 in 5 AEP). This is possibly the uniform spatial rainfall distribution across the larger catchment exaggerating the effect of the losses, which is discussed in greater detail in Section H3.6. There are also potentially issues with the reliability of the now-closed Cunningham Weir rating – there is a significant difference in the median annual flow at the Cunningham gauge (500m³/s) and the Glenarbon gauge (190m³/s). The reconciled DEA 1 in 2 AEP flow actually shows good agreement with the probability-plot of the rated Glenarbon flows (noting that with less than 20 years data this is not a reliable FFA). Given these uncertainties, the reconciliation is considered reasonable based on the good agreement at the two other gauges.

H3.4 Macintyre Brook to Booba Sands

FFA and reconciliation has been conducted for the Macintyre Brook gauges at Inglewood and Booba Sands, shown in Figure H10. As identified in Section H3.1, Inglewood is located downstream of Coolmunda Dam, which has a significant influence on the gauge record and design flows. The Inglewood gauge control structure was modified in 1981. The high-flow rating from the older gauge is based on flow measurements recorded in 1956 and quite different from the current gauge rating despite being located at the same site (the control structure would be expected to be fully submerged and have only minor influence on high flows). There is therefore some uncertainty in the rated flow of the highest floods (which are all from the older gauge) and the effect that they have on the shape of the FFA probability curve. Nevertheless, the DEA flows can be reconciled relatively successfully to the historical flood probability distribution. good ma

The Booba Sands gauge has only been operational since 1984, which is the shortest period of record of the examined gauges and does not include the largest floods registered at Inglewood (1956, 1976 and 1971). The shorter record decreases the reliability of the FFA. Nevertheless, the DEA reconciles relatively well to the gauged data probability distribution. Reconciliation of both gauges was achieved using an initial loss of 30mm, continuing loss of 2.5mm/h and median VBF of 22,000ML for Coolmunda Dam.

H3.5 Ottleys Creek

Coolatai is currently the only stream gauge in the Ottleys Creek catchment. The gauge has been operational since 1979 (43 years of data) however review of the data from the WaterNSW webservice indicates that the gauge rating has been quite variable in this time. Photographs of the gauge site available on the WaterNSW webservice suggest that this may be due to scour damage circumventing the control weir, as shown in Figure H3. These issues reduce the reliability of the gauged flows and consequently the FFA results. Nevertheless, a reasonable reconciliation to frequent events can be achieved using an initial loss of 30mm and a continuing loss of 3.5mm/h, as shown in Figure H11.

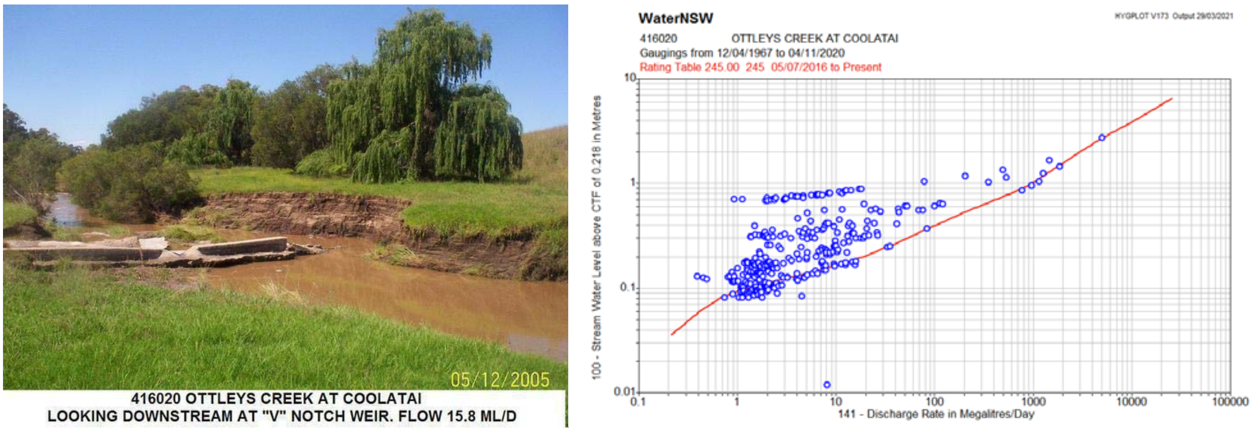


Figure H3 Control weir and comparison of flow gauging and current gauge rating at Coolatai

H3.6 Lower Macintyre River

FFA and DEA reconciliation has been conducted at the Boggabila stream gauge, shown in Figure H11. The Boggabilla gauge record extends back to 1886, although continuous gauge data is only available since 1982. The gauge site has changed location several times, however review of historical stream gauging information suggests that this has had little impact on the flow rating. Nevertheless, the site is complicated by significant flow breakout into the Whalan Creek and Morella Watercourse systems upstream of the gauge site, and there is significant uncertainty as to how much (if any) of this breakout has been included in the official historical flow ratings at the gauge. Rated flows used in the current FFA have been calculated using the rating for total catchment flow developed as part of the current study, which is discussed in Appendix C. This is considered to give the most reliable estimate of total flows generated by the catchment and consistency with the current hydrologic and hydraulic models.

The historical flood record is also non-homogeneous, being affected by the construction of Coolmunda, Glenlyon Dams and the original Pindari Dams between 1968 and 1971, and the later significant upgrade of Pindari Dam in 1994. The reconciled DEA flows have therefore been calculated using a weighted average of three stages of catchment condition – no dams, with Coolmunda and Glenlyon Dams only (neglecting minor impact of the original Pindari Dam), and current dam conditions.

Reconciliation of the DEA flows was initially conducted using the catchment parameters derived for each of the independent catchments. However, these produced design flows for the frequent events that were significantly lower than the FFA, as shown in Figure H11. Similarly, the DEA total catchment flows for the 50% (1 in 2) AEP event were lower than the reconciled DEA flows for the individual Macintyre River and Dumaresq River tributaries at Holdfast or Glenarbon (calculated using the areal reduction factor to those locations).

An issue potentially contributing to the flow underestimate for frequent events is the use of a unform AEP rainfall distribution. The areal reduction factor is intended to maintain AEP neutrality of the average rainfall depth across a large catchment (compared to point rainfall data), however in reality, rainfall would usually tend to have localised concentrations over parts of the catchment. When the average rainfall depth is of similar magnitude to the losses, the rainfall excess of concentrated bursts will be greater than the rainfall excess of a uniform pattern, noting that this applies to both concentrations in space and within the time interval of a temporal pattern. Figure H4 illustrates this principle assuming two constant areas/intervals. The larger catchment area both reduces the average intensity and increases the probability that the rainfall would not be uniform. The analysis discussed in Section 0 demonstrates that Macintyre River flood events at Boggabilla are frequently the result of flows from only part of the catchment.

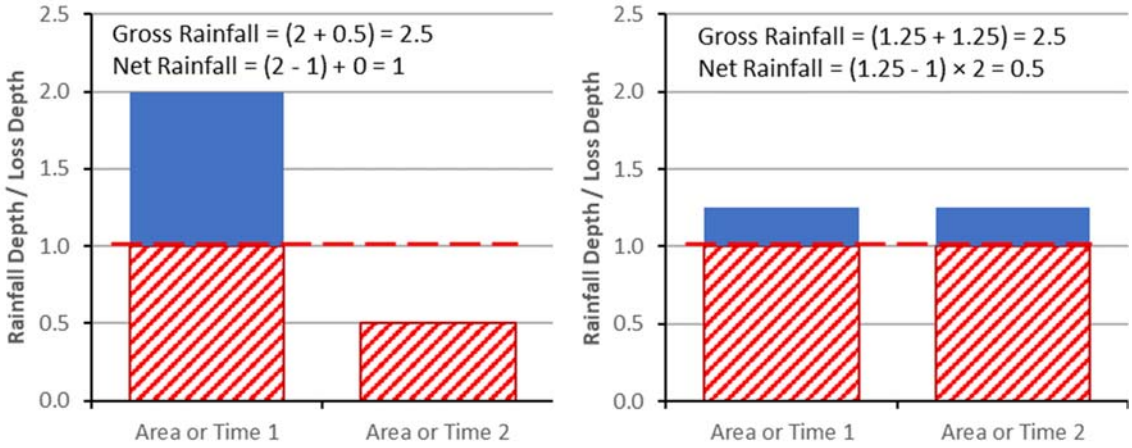


Figure H4 Effect of losses on concentrated vs uniform rainfall

In order to maintain probability-neutral loss values and reconcile the DEA flows to the historical record, the loss values have been decreased for events more frequent than 1 in 20. The significant increase in the 1 in 2 AEP design flow (130% increase for an 18% reduction in losses) highlights just how sensitive the frequent event DEA results are to the adopted losses. The reconciled and current catchment condition DEA flows are summarised in Figure H11 and Table H4.

Table H4 Reconciled and current catchment design flows upstream of Boggabilla

AEP (1 in N)	Loss Multiplier	DEA Flow (m^3/s)	
		Reconciled	Current
2	0.82	691	511
5	0.85	1309	995
10	0.90	1906	1506
20	0.95	2648	2145
50	1.0	4002	3322
100	1.0	5445	4565
200	1.0	7317	6208
500	1.0	10091	8785
1000	1.0	12547	11147
2000	1.0	15261	13767

H4 Limitations of the Design Event approach

The DEA modelling has been conducted using the procedures recommended in ARR (2019). One of the most significant limitations of the standard DEA methodology is the adoption of uniform catchment properties. Rainfall depth with constant AEP is applied across the catchment, reduced uniformly with the same areal reduction factor. An ensemble of temporal patterns is assessed to help minimise the sensitivity to the distribution, however this is still assumed to be distributed coincidently across the entire catchment. As discussed in previous sections of this report, a fundamental aspect of the DEA modelling is the requirement to adopt probability-neutral catchment parameters. This includes the losses (on which the effect of the uniform rainfall distribution is discussed in Section H3.6) and also the reservoirs, for which a median VBF was adopted for all events.

Figure H5 to Figure H7 show the relationship between the peak Macintyre River flow upstream of Boggabilla and the peak flow in the tributaries at Holdfast, Bonshaw and Inglewood. The blue circles represent all the modelled design events (1 in 2 to 1 in 2000 AEP, 12h to 120h durations). These demonstrate a distinct relationship between the tributary and combined flows, with the duration, temporal pattern and other variables having relatively little influence. The yellow circles show the gauged flows of historical flood events since 1972 (based on availability of gauge data). These demonstrate that there is significant variation in the possible distribution of tributary inflows for historical events – significant flood events (>1,000m³/s) can occur with negligible inflow from one or more of the tributaries, or conversely peak flow from a tributary may even exceed the peak flow downstream. Looking at the largest flood events, the 1976 flood event is relatively evenly distributed across the catchment, however the 2011 flood was strongly concentrated in the Dumaresq River while the recent 2021 flood had little inflow from Macintyre Brook. This assessment considers only the peak flow relationship, and there may also be differences in the relative timing of the peaks.

Although the DEA flow estimates theoretically return the median (or at least some characteristic) relationship between the contribution of the different tributaries for a given AEP, they do not capture the spatial or temporal variability of real flood events.

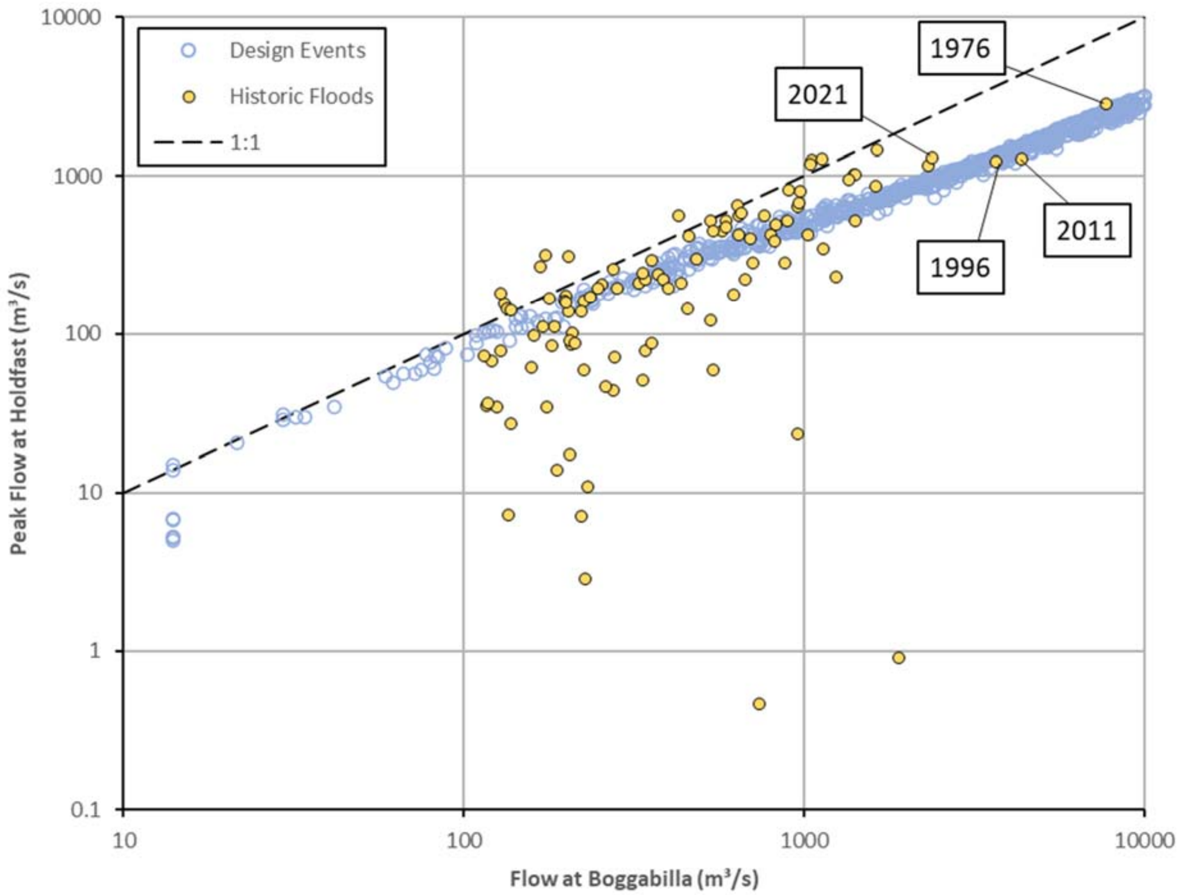


Figure H5 Relationship between total flow upstream of Boggabilla and Macintyre River flow at Holdfast

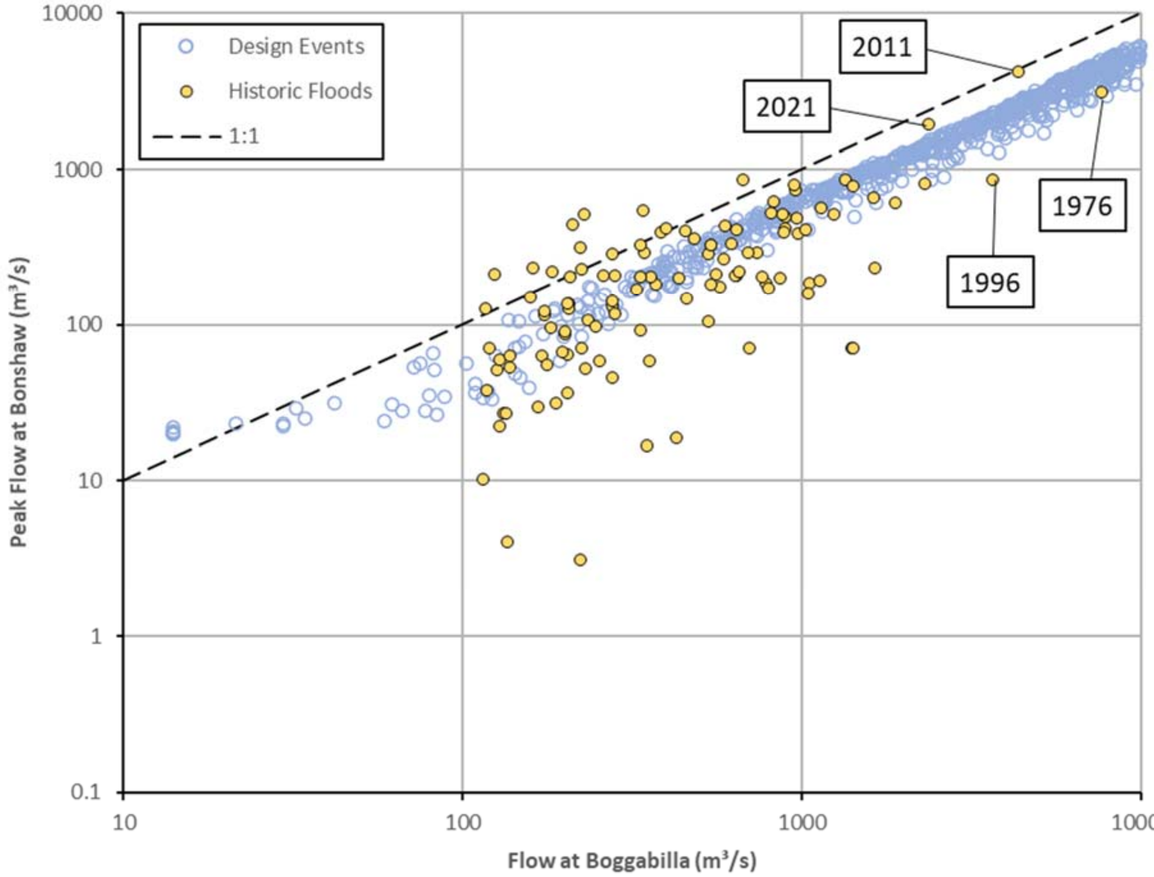


Figure H6 Relationship between total flow upstream of Boggabilla and Dumaresq River flow at Bonshaw

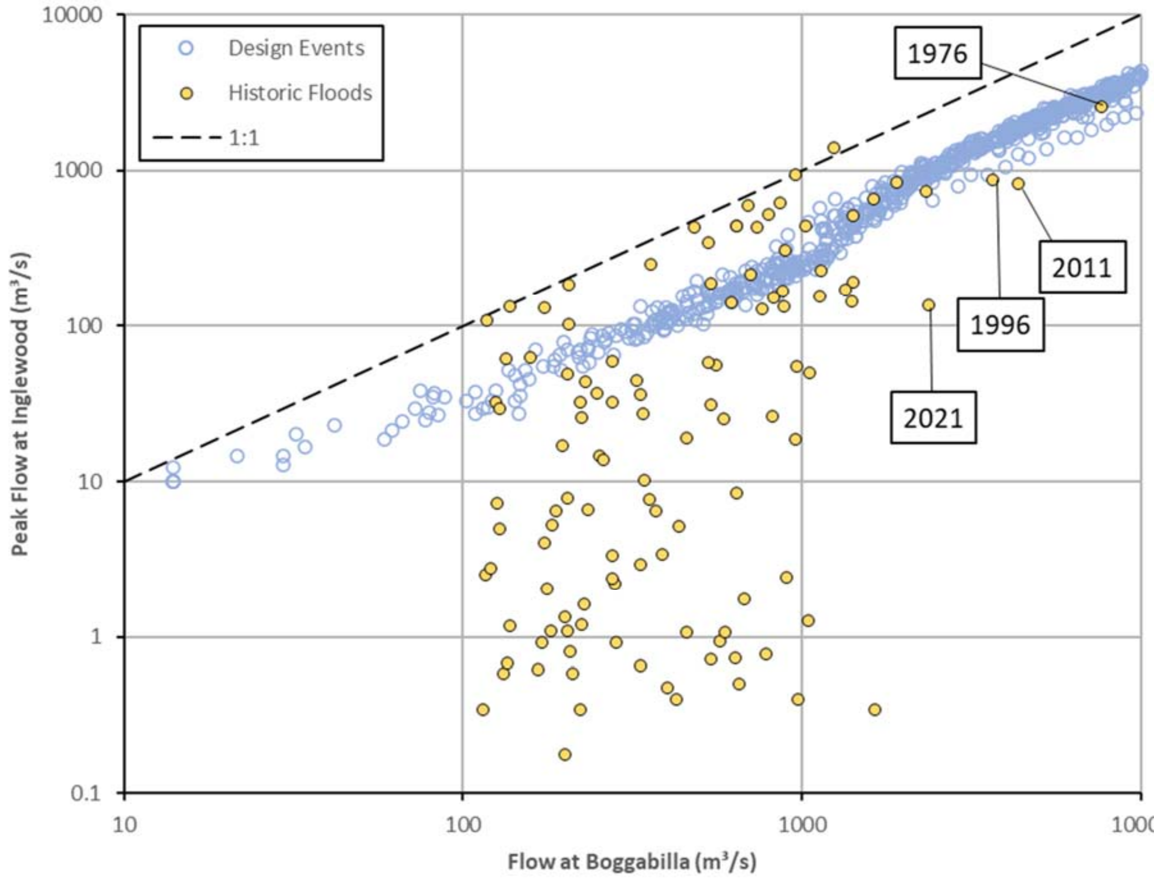
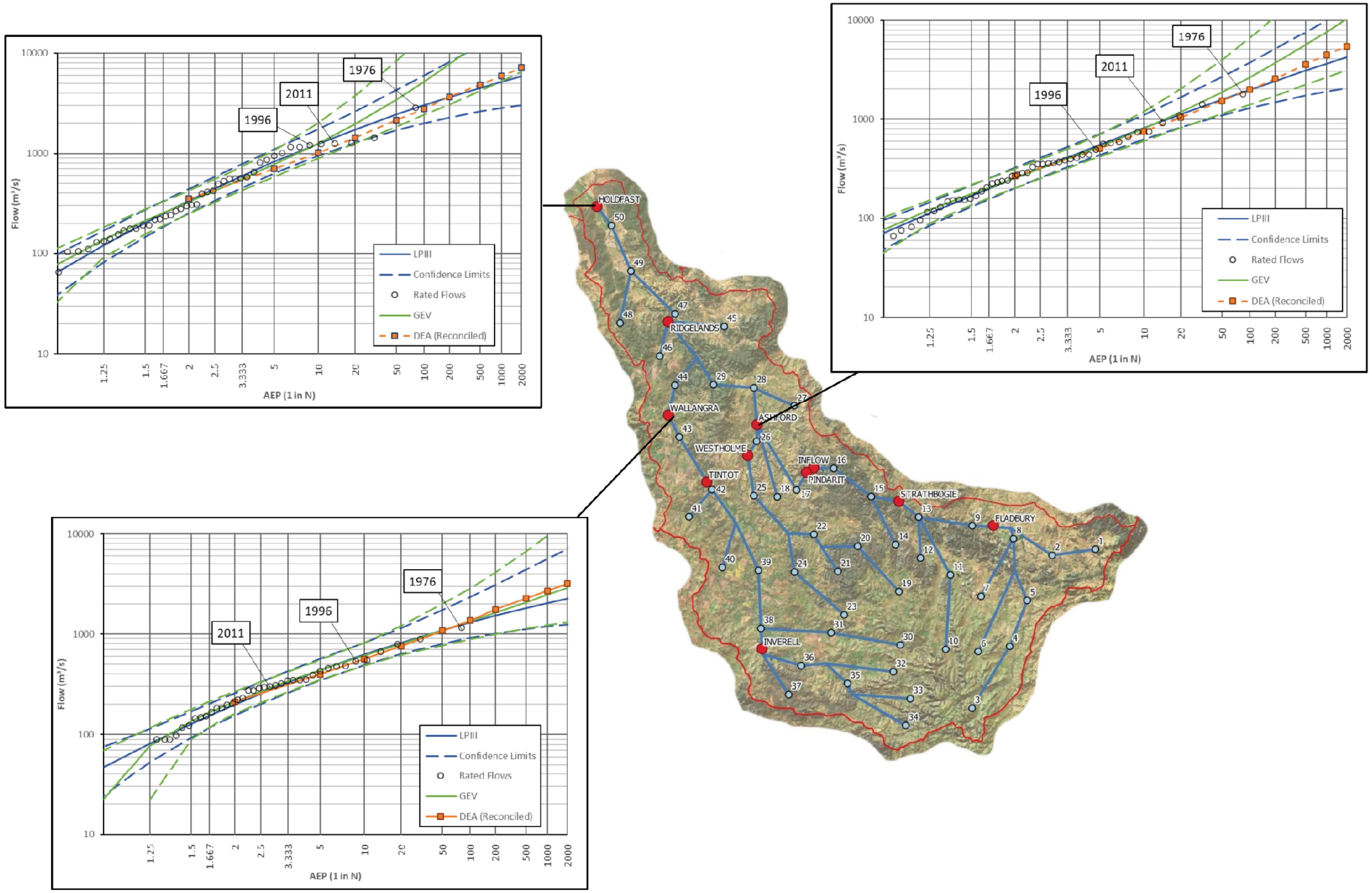


Figure H7 Relationship between total flow upstream of Boggabilla and Macintyre Brook flow at Inglewood

MACINTYRE RIVER TO HOLDFAST - RECONCILIATION



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NORTH STAR TO NSW/QLD BORDER

Figure H8:
Macintyre River to Holdfast Reconciliation

Coordinate System: N/A for templated Images

Date: 22/04/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

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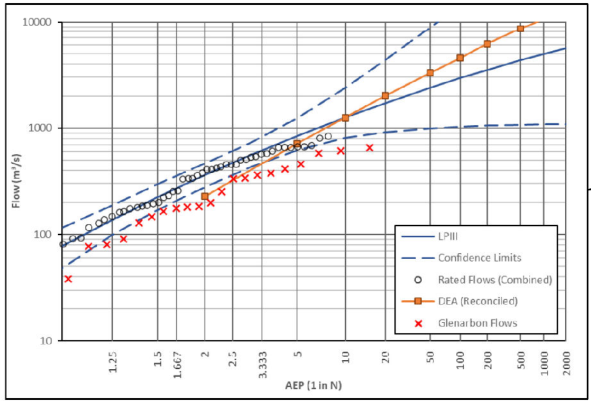
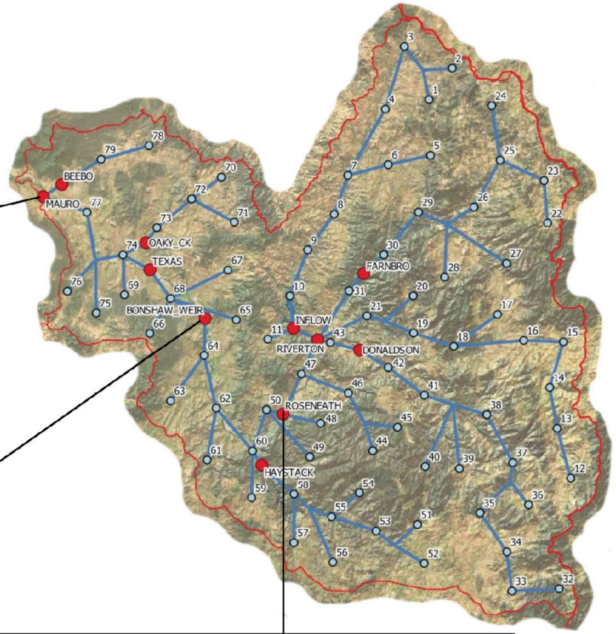
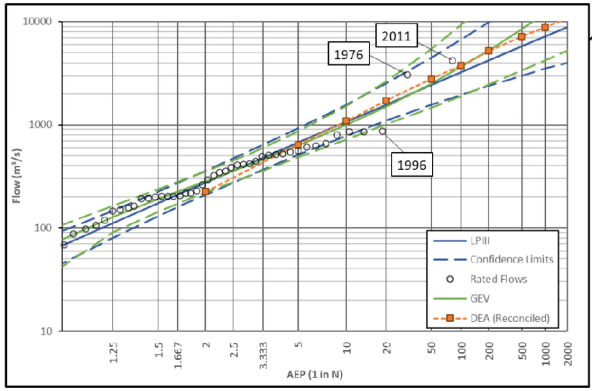
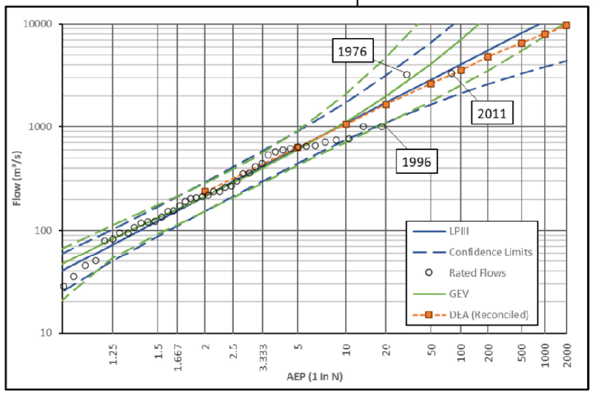
Figure H9: Dumaresq River to Glenarbon Reconciliation

DUMARESQ RIVER TO MAURO – RECONCILIATION







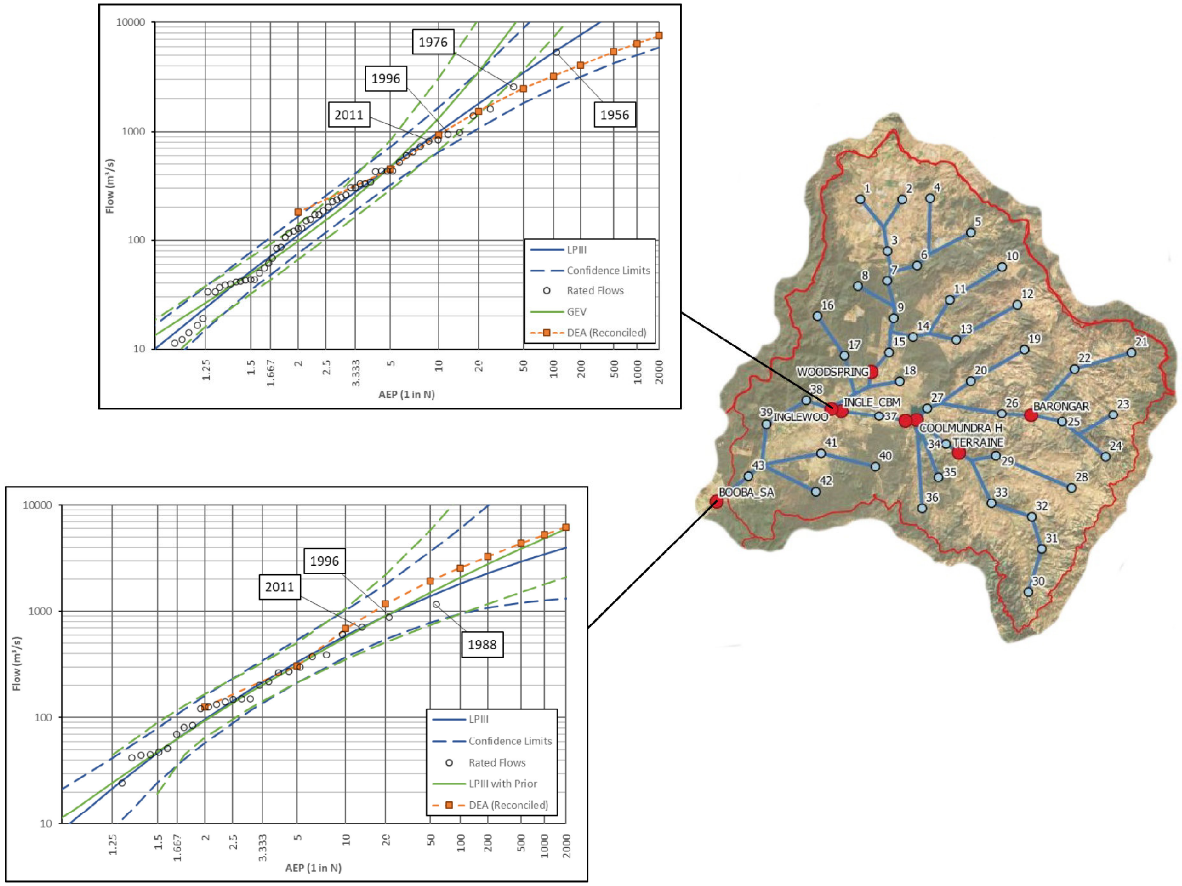


Coordinate System: N/A for templated Images

Date: 22/04/2021
Author: FFJV GIS
Paper: A4
Scale: 1: N/A

Map by: LT/DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAX_HydrologicModelCalibration_ddImages3_A4L_v1.mxd Date: 29/04/2021 10:41

MACINTYRE BROOK TO BOOBA SANDS – RECONCILIATION



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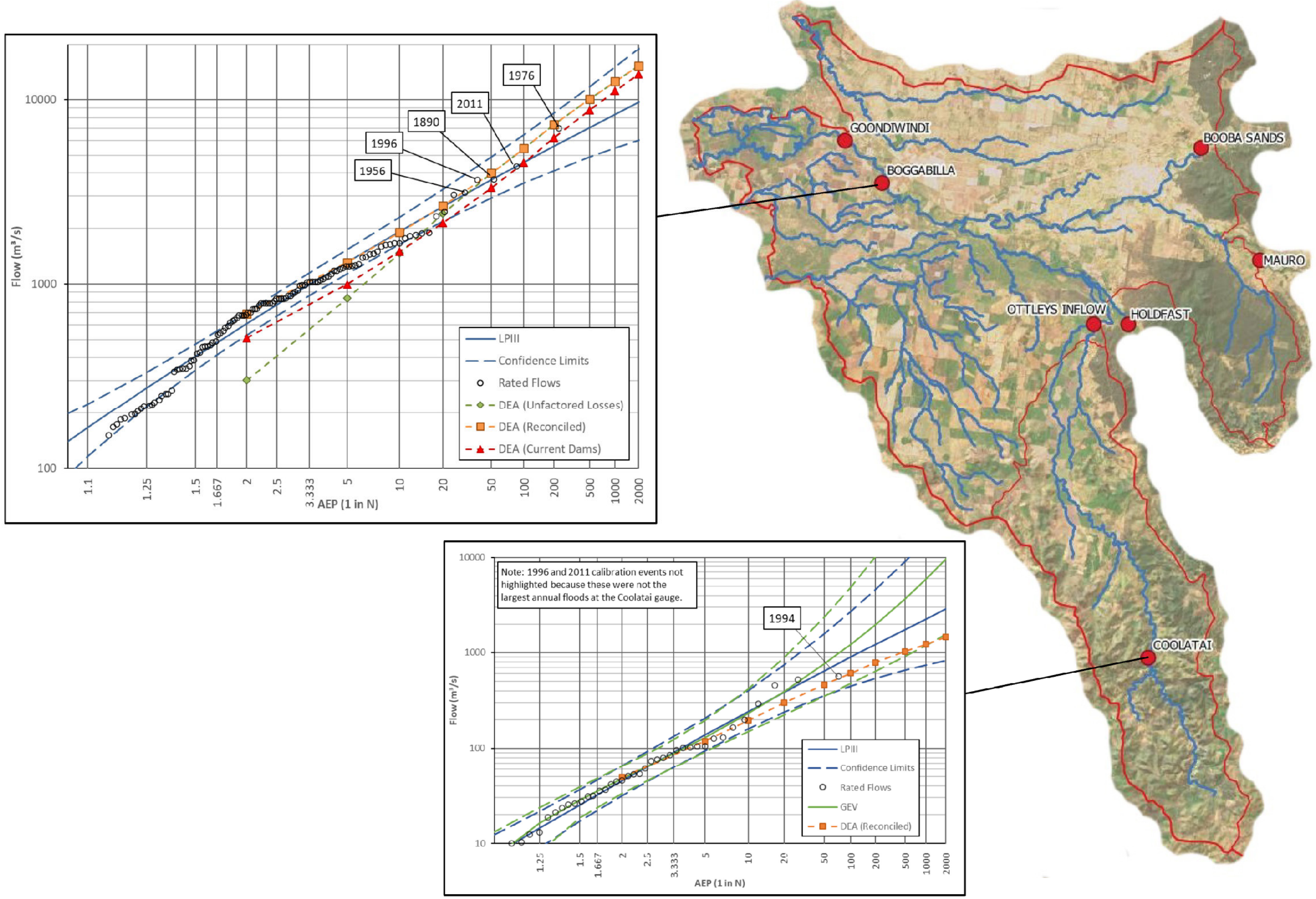
NORTH STAR TO NSW/QLD BORDER

Figure H10:
Macintyre Brook to Booba Sands Reconciliation

Coordinate System: N/A for templated Images

Date: 22/04/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

OTTLEYS CREEK AND LOWER MACINTYRE TO GOONDIWINDI – RECONCILIATION



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NORTH STAR TO NSW/QLD BORDER

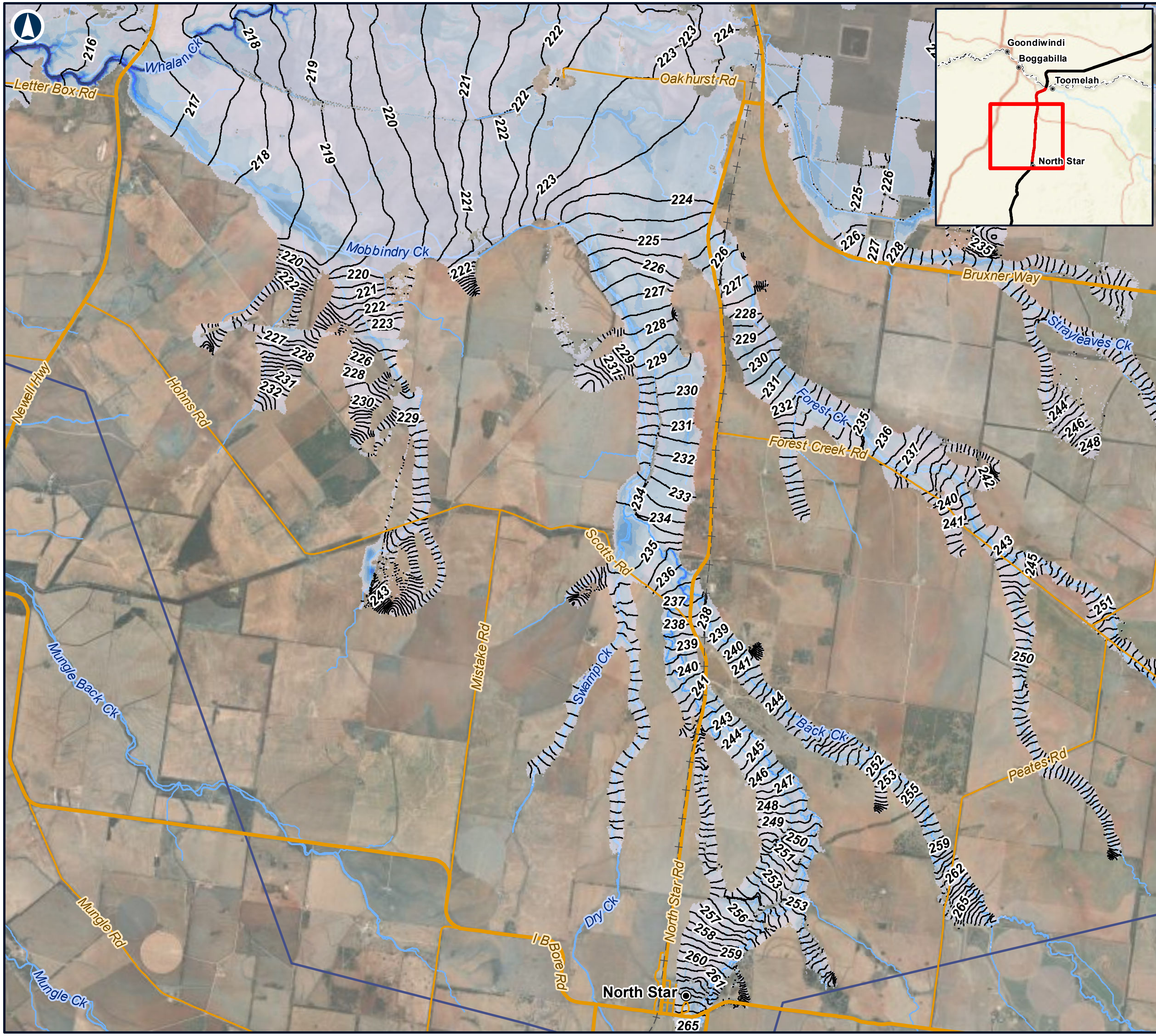
Figure H11: Ottleys Creek and Lower Macintyre to Goondiwindi Reconciliation

Coordinate System: N/A for templated Images

Date: 22/04/2021
Paper: A4
Author: FFJV GIS
Scale: 1: N/A

Appendix I
Figures – Verified levees and 1% AEP flows

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure I1: Existing Case
Verified 2019 levees and 1% AEP flows
Peak water levels

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Depth (m)

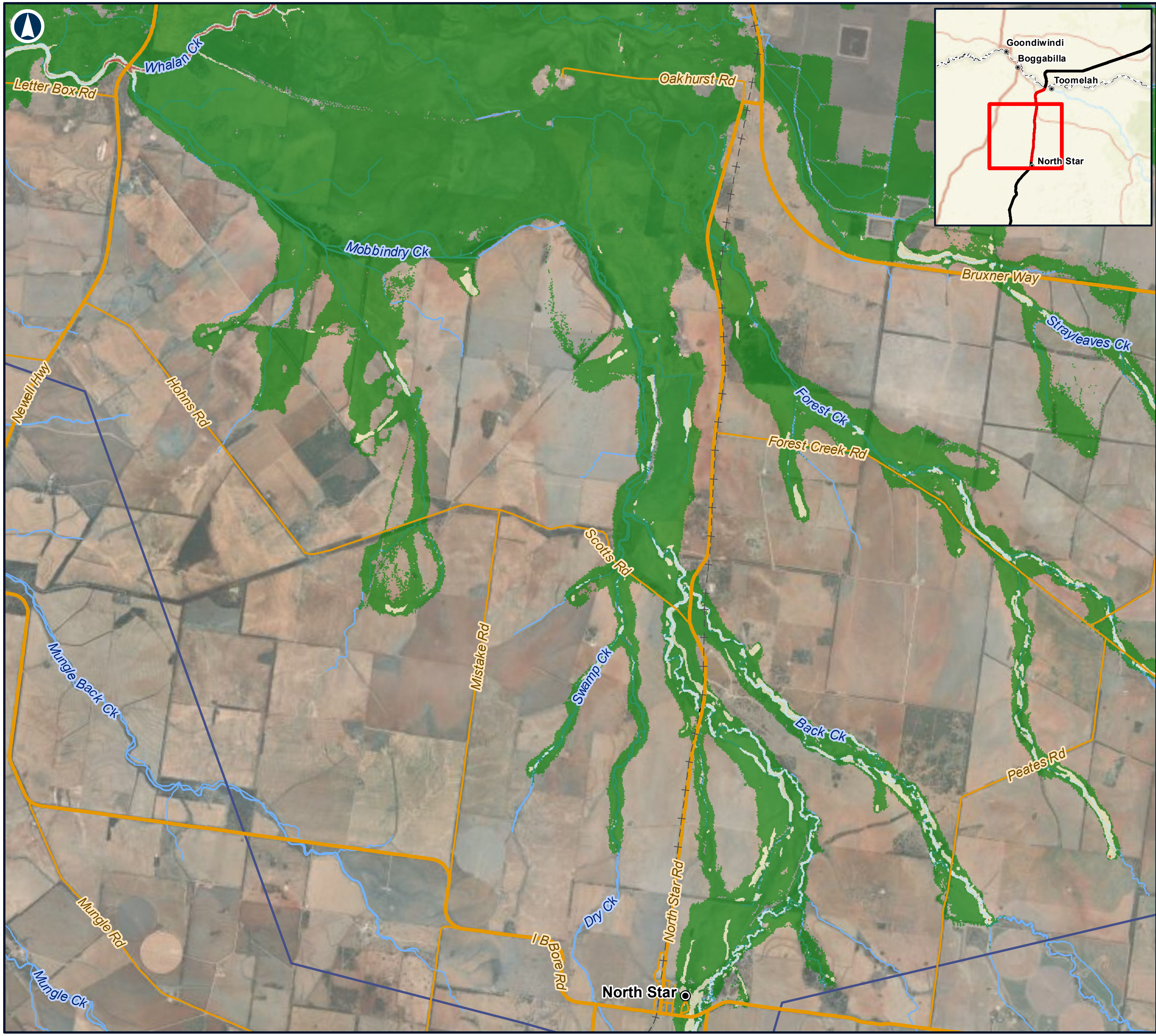
- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure I2: Existing Case
Verified 2019 levees and 1% AEP flows
Velocities

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Peak velocity (m/s)

- 0 to 0.5
- 0.5 to 1.0
- > 1.0

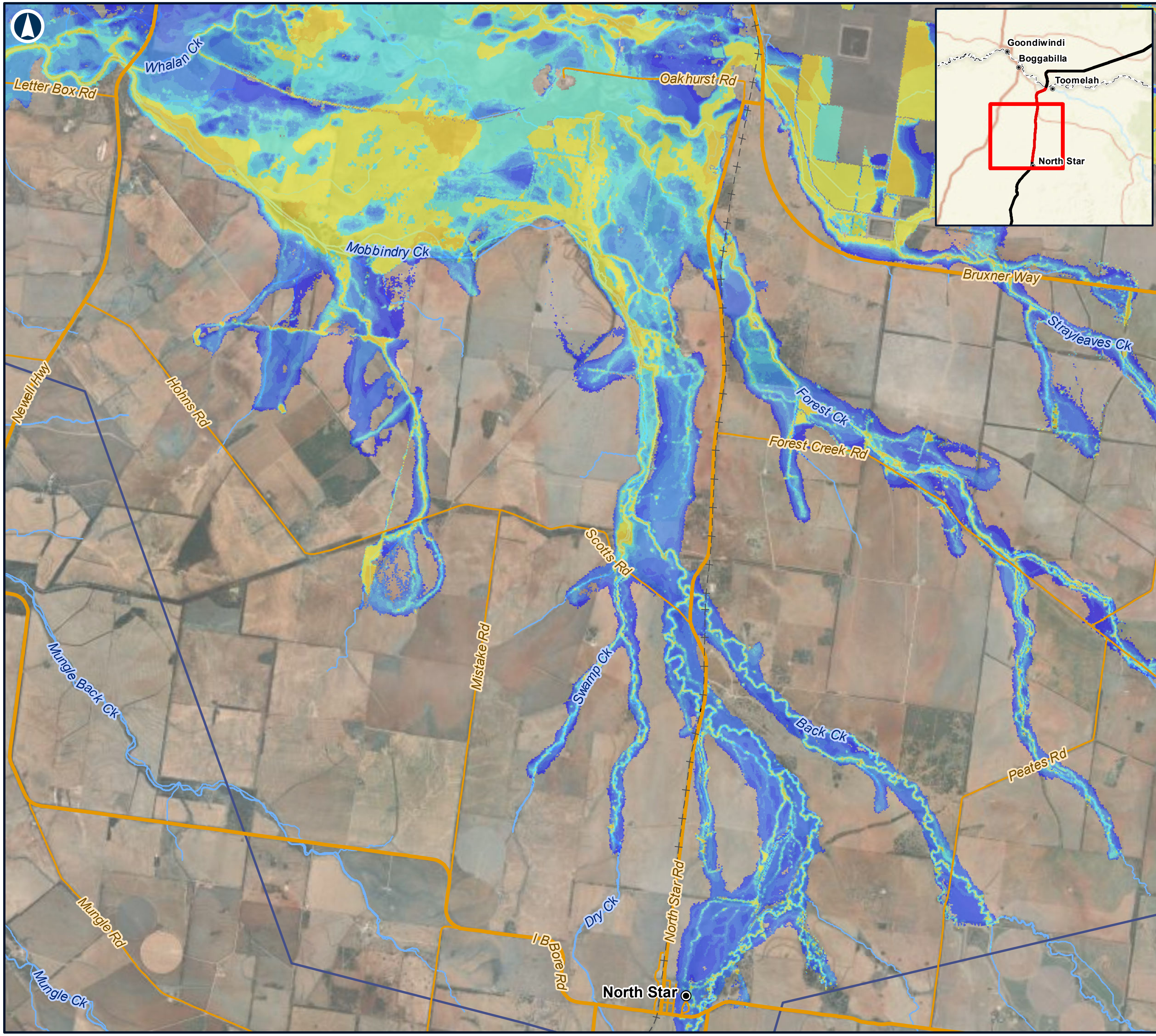
6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ2_EX_Velocity_A4L_v1.mxd Date: 29/04/2021 10:13

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure I3: Existing Case
Verified 2019 levees and 1% AEP flows
Duration of Inundation

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Duration of inundation (hours)

- 0 to 10
- 10 to 20
- 20 to 30
- 30 to 40
- 40 to 50
- 50 to 60
- 60 to 70
- 70 to 80
- 80 to 90
- 90 to 100
- > 100

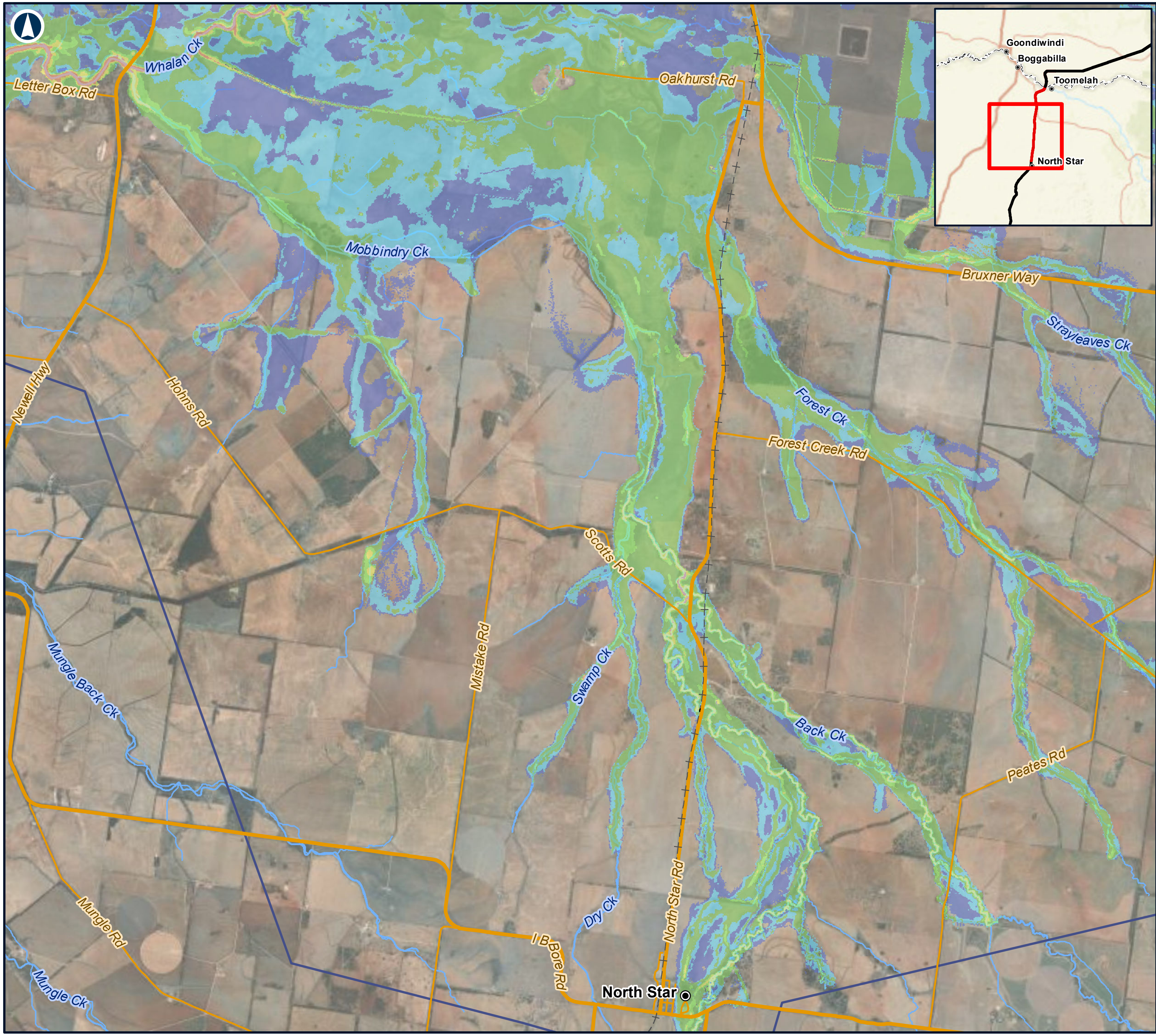
6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ3_EX_Duration_Inundation_A4L_v1.mxd Date: 29/04/2021 10:14

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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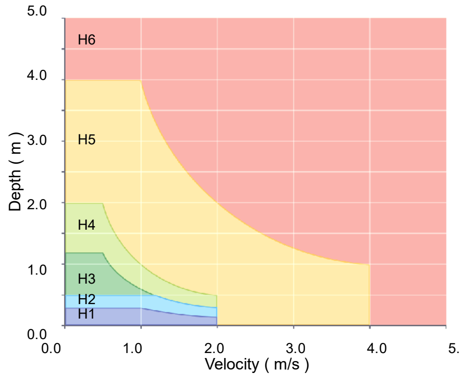
NORTH STAR TO NSW/QLD BORDER

Figure I4: Existing Case
Verified 2019 levees and 1% AEP flows
Hazard categories

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Hazard Categories



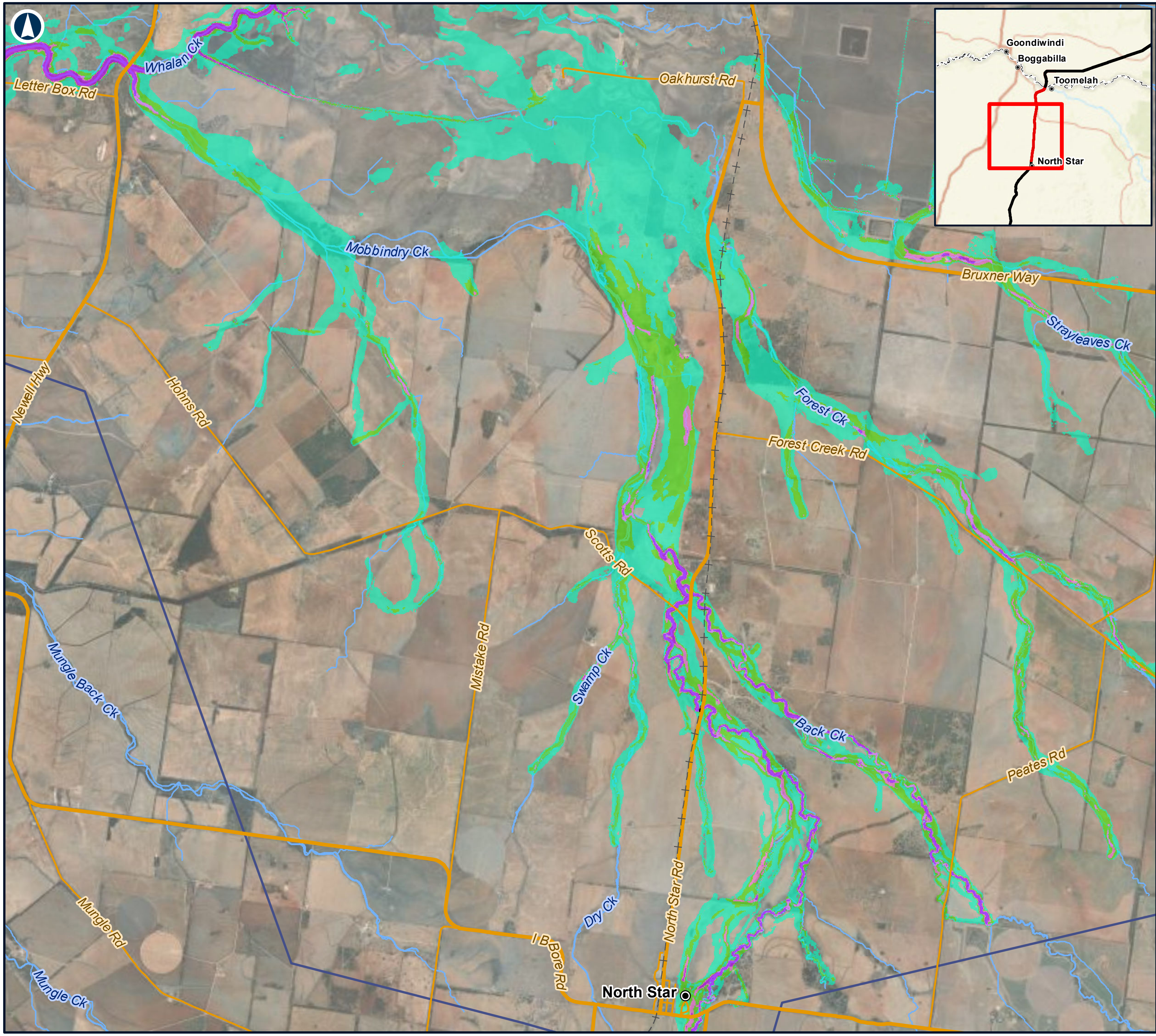
Source: Australian Disaster Resilience Handbook Guideline 7-3 (AIDR 2017)

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021
Paper: A4
Author: FFJV GIS
Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ4_EX_Hazard_A4L_v1.mxd Date: 29/04/2021 10:16



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NORTH STAR TO NSW/QLD BORDER

Figure I5: Existing Case
Verified 2019 levees and 1% AEP flows
Velocity x depth product

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Velocity x Depth product (m^2/s)

- (< 0.1 excluded)
- 0.1 to 0.3
- 0.3 to 0.6
- 0.6 to 1
- 1 to 40

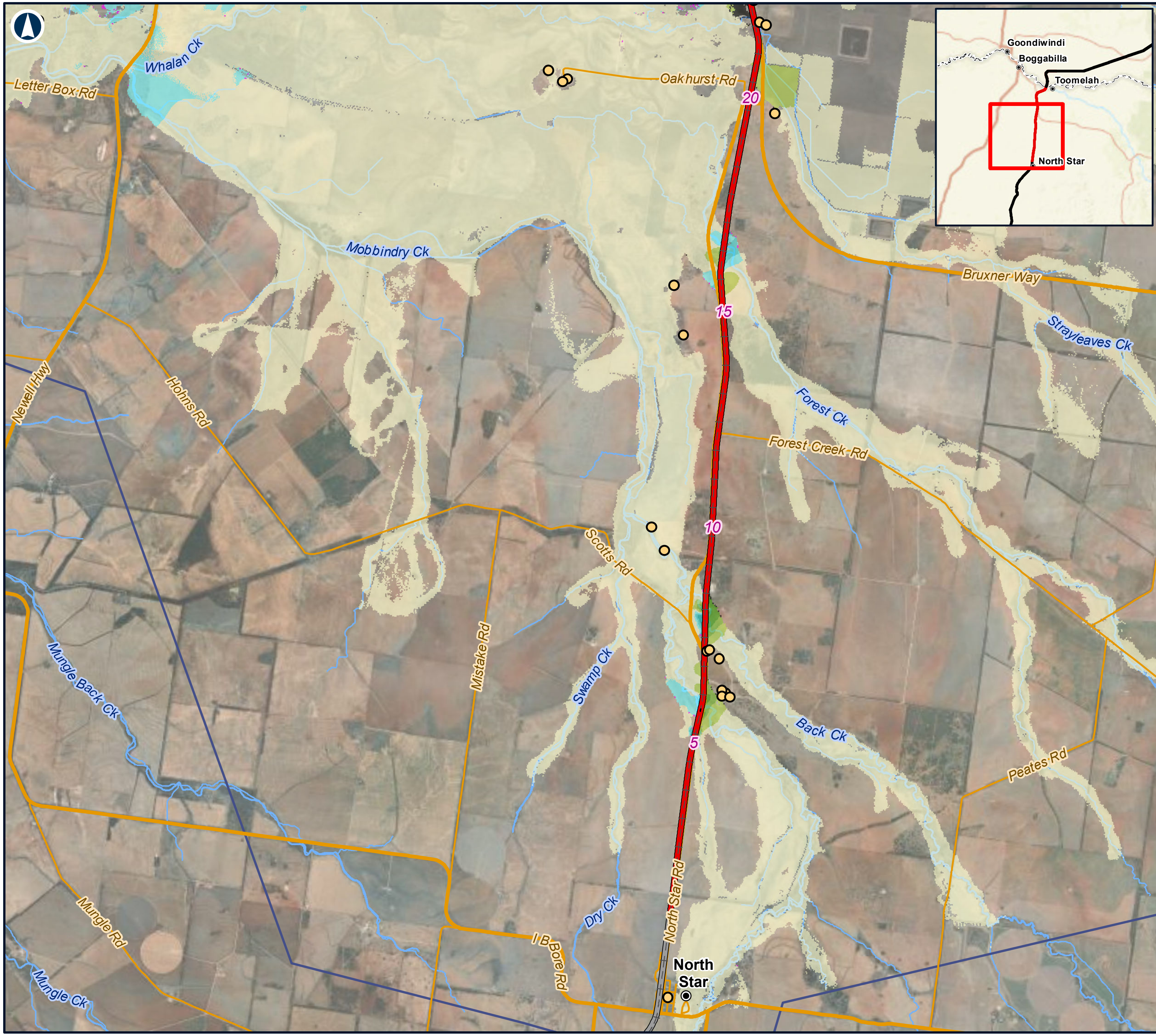
6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021
Paper: A4
Author: FFJV GIS
Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ5_EX_VelocityXDepth_A4L_v1.mxd Date: 29/04/2021 10:14

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure I6: Developed Case
Verified 2019 levees and 1% AEP flows
Change in peak water levels

LEGEND

- Flood sensitive receptor
- Localities
- 5 Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in peak water levels (m)

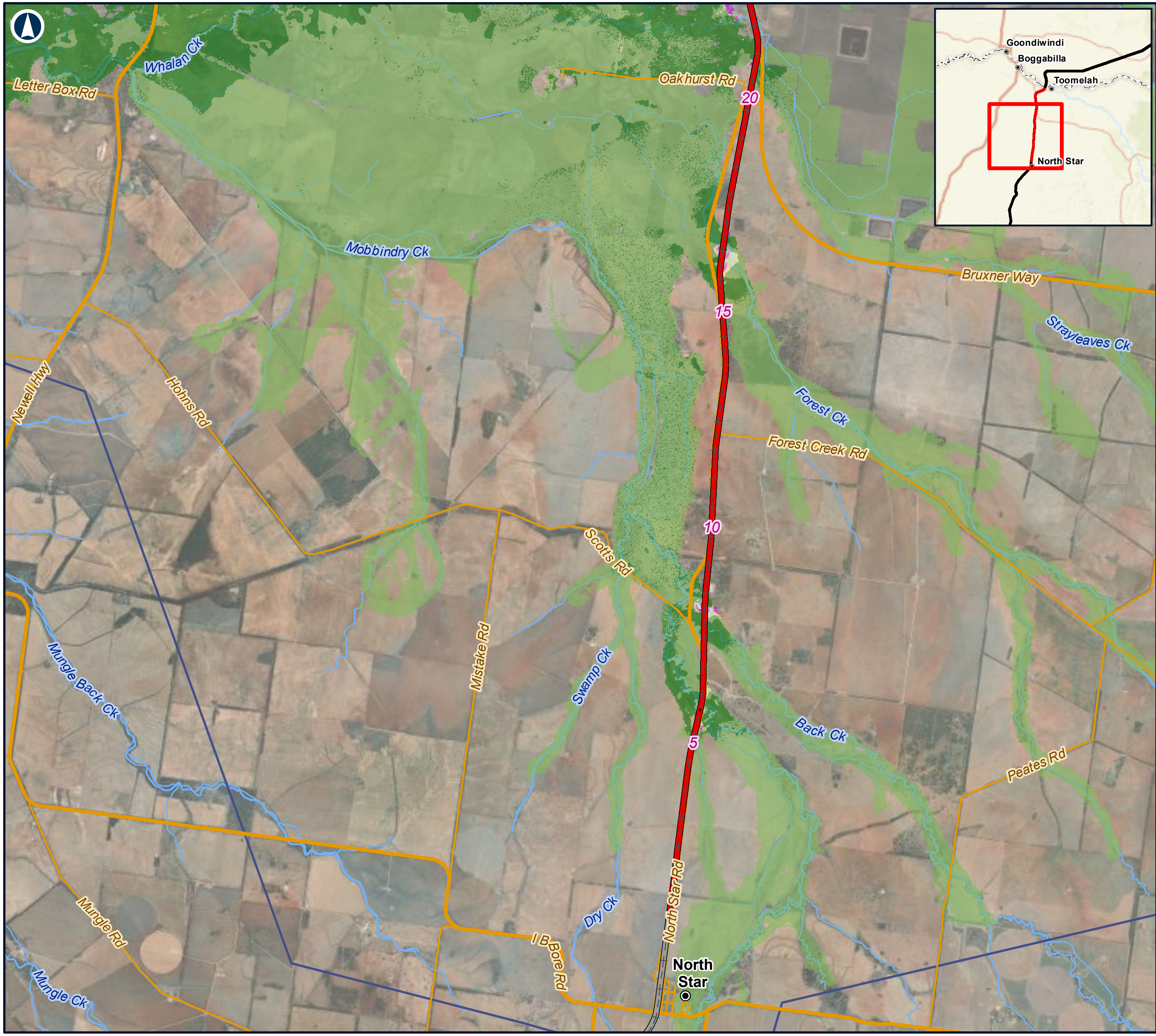
- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure I7: Developed Case
Verified 2019 levees and 1% AEP flows
Percentage change in velocities

LEGEND

- Localities
- Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in velocities (%)

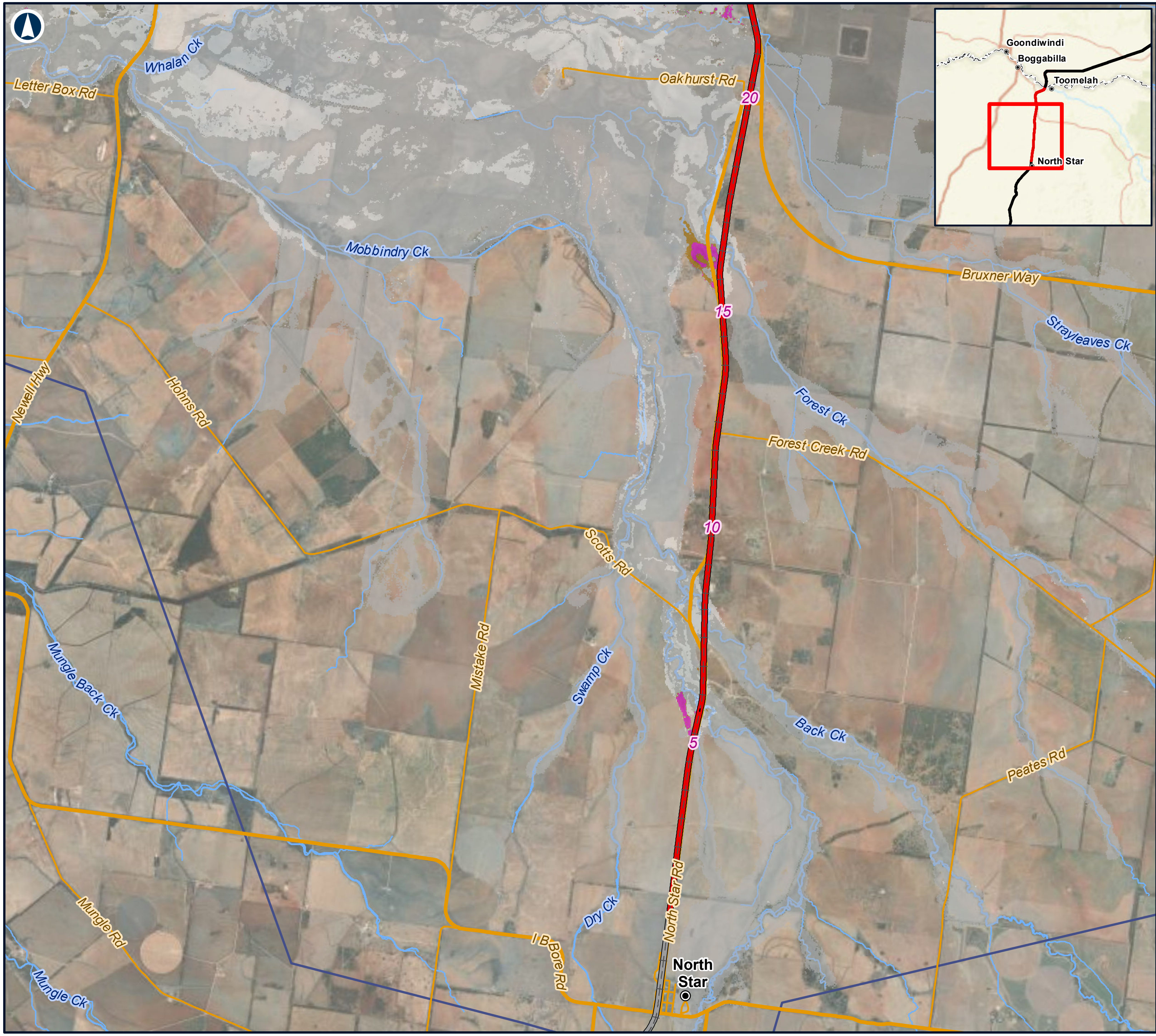
- < 0
- 0 to 10
- 10 to 20
- 20 to 30
- > 30

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure I8: Developed Case
Verified 2019 levees and 1% AEP flows
Percentage change in duration of inundation

LEGEND

- Localities
- 5 Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in duration of inundation (%)

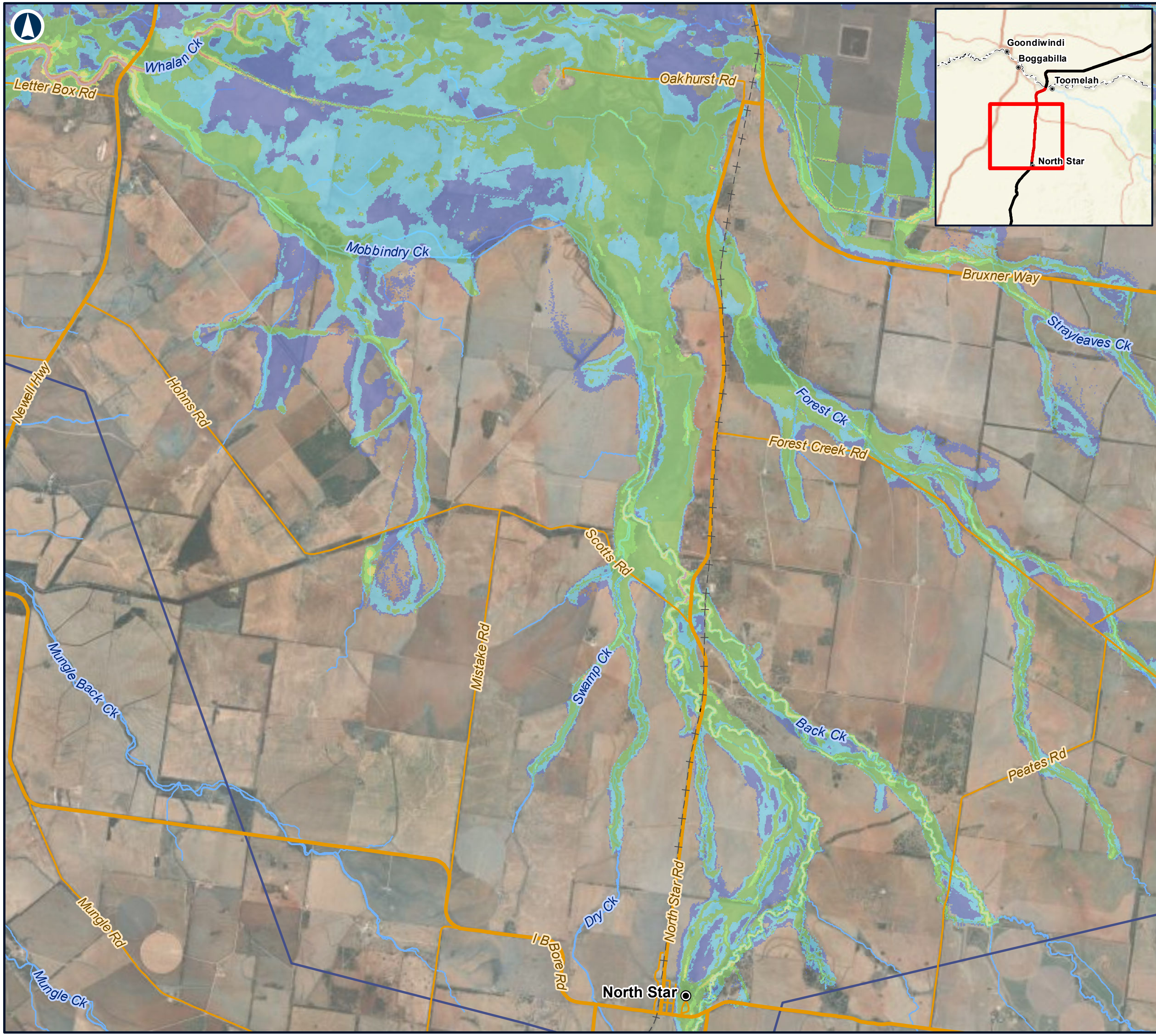
- < 0
- 0 to 10
- 10 to 20
- > 20

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ8_DV_PercentChangeTimeDur_A4L_v1.mxd Date: 29/04/2021 10:14



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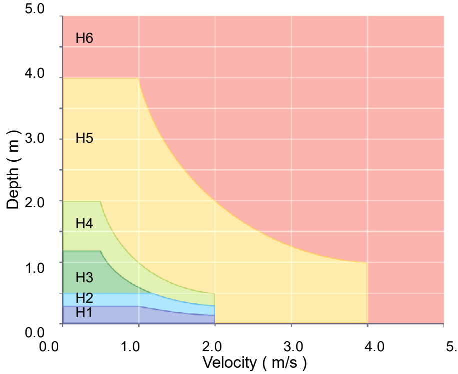
NORTH STAR TO NSW/QLD BORDER

Figure I9: Developed Case
Verified 2019 levees and 1% AEP flows
Hazard categories

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Hazard Categories



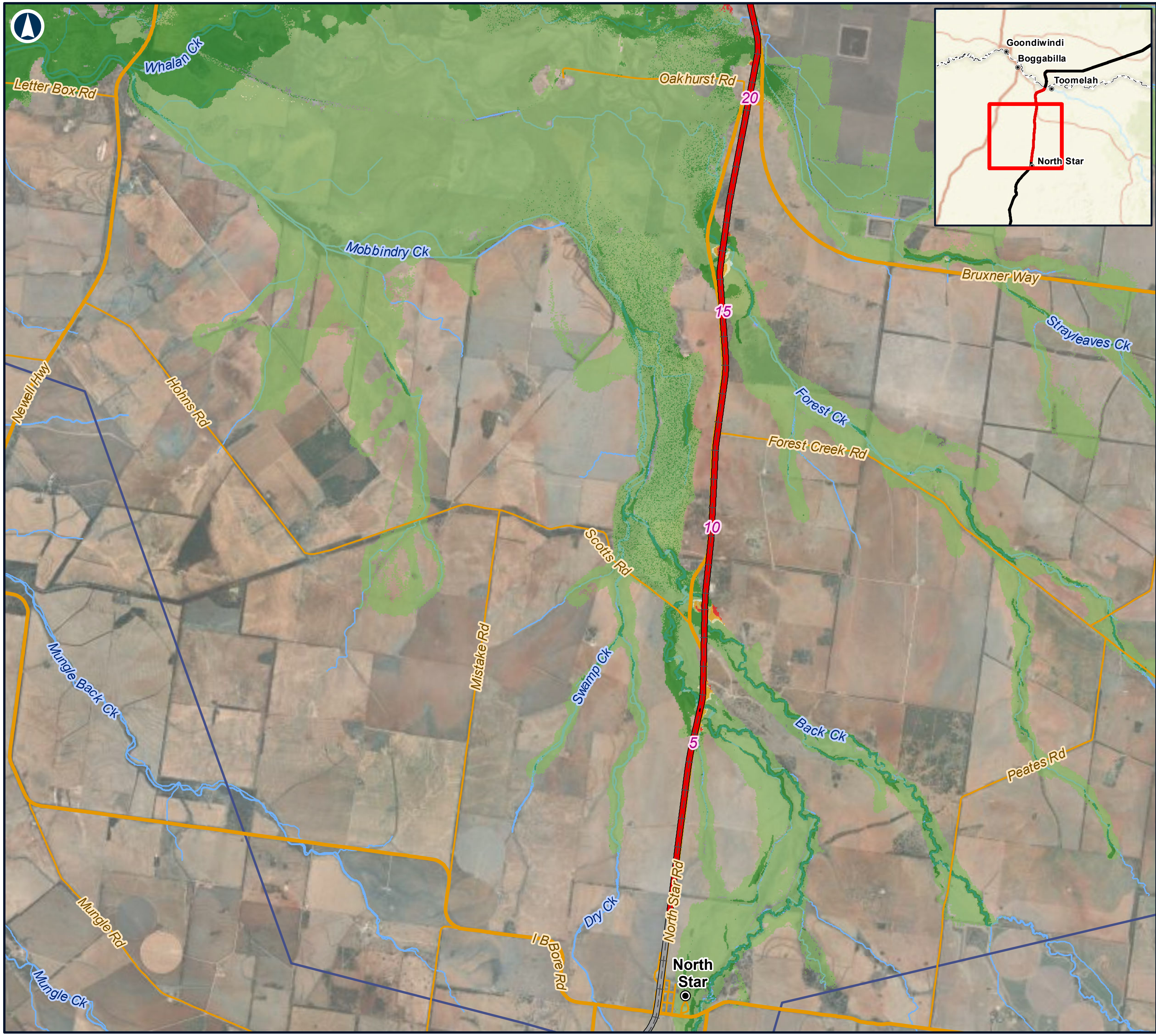
Source: Australian Disaster Resilience Handbook Guideline 7-3 (AIDR 2017)

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure I10: Developed Case
Verified 2019 levees and 1% AEP flows
Percentage change in velocity x depth product

LEGEND

- Localities
- 5 Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in velocity x depth product (%)

- < 0
- 0 to 10
- 10 to 20
- 20 to 30
- > 30

6km

Coordinate System: GDA 1994 MGA Zone 56

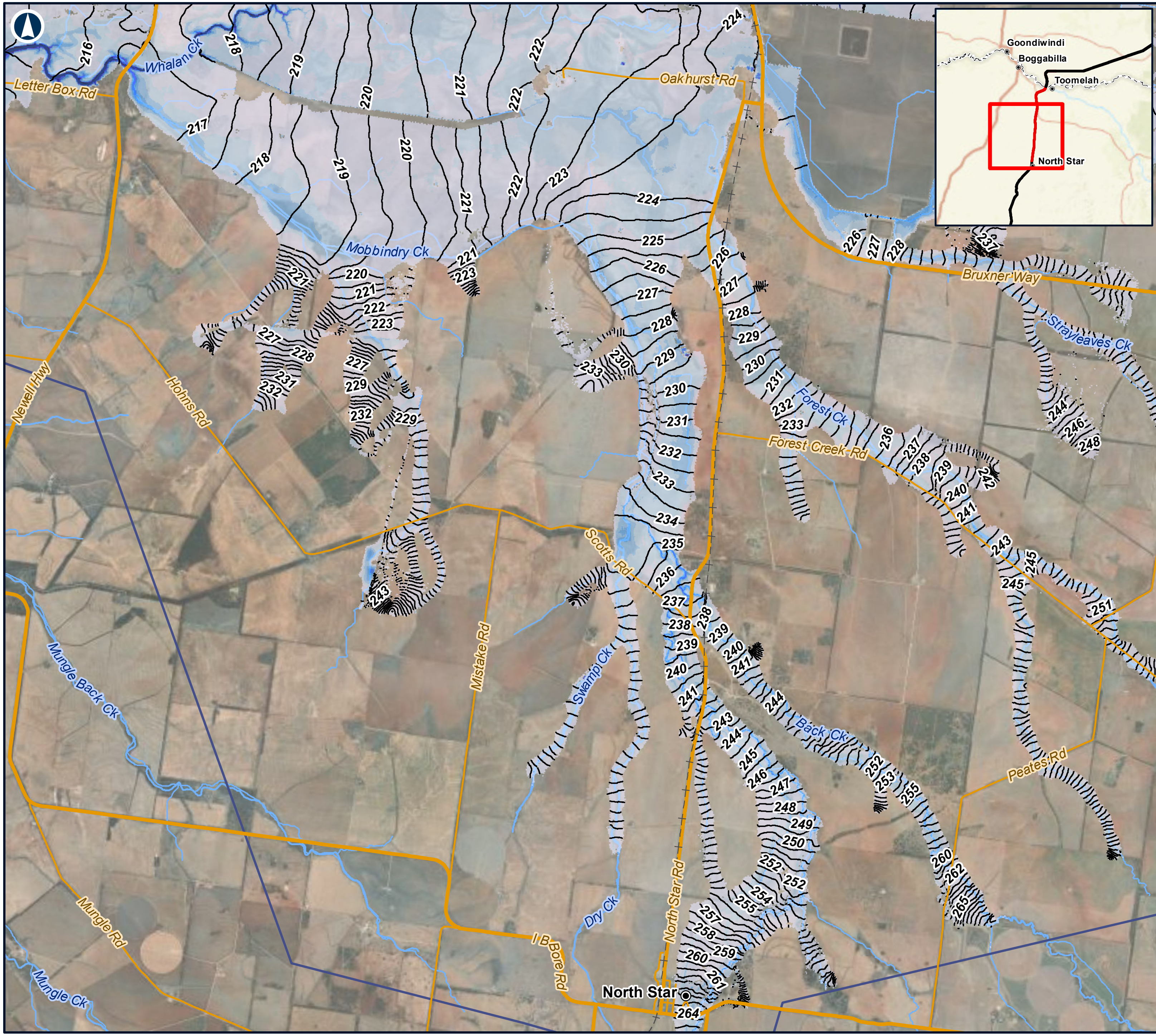
Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ10_DV_PercentChangeVelocityXDepth_A4L_v1.mxd Date: 29/04/2021 13:37

Appendix J

Figure – BRVFMP levees and 1% AEP flows

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure J1: Existing Case
BRVFMP levees and 1% AEP flows
Peak water levels

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- 0.5m contour (mAHD)
- Sub-model extent

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 | Paper: A4
Author: FFJV GIS | Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxJ1_EX_Depth_Flow_PWL_A4L_v1.mxd Date: 29/04/2021 10:16

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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NORTH STAR TO NSW/QLD BORDER

Figure J2: Existing Case
BRVFMP levees and 1% AEP flows
Velocities

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Peak velocity (m/s)

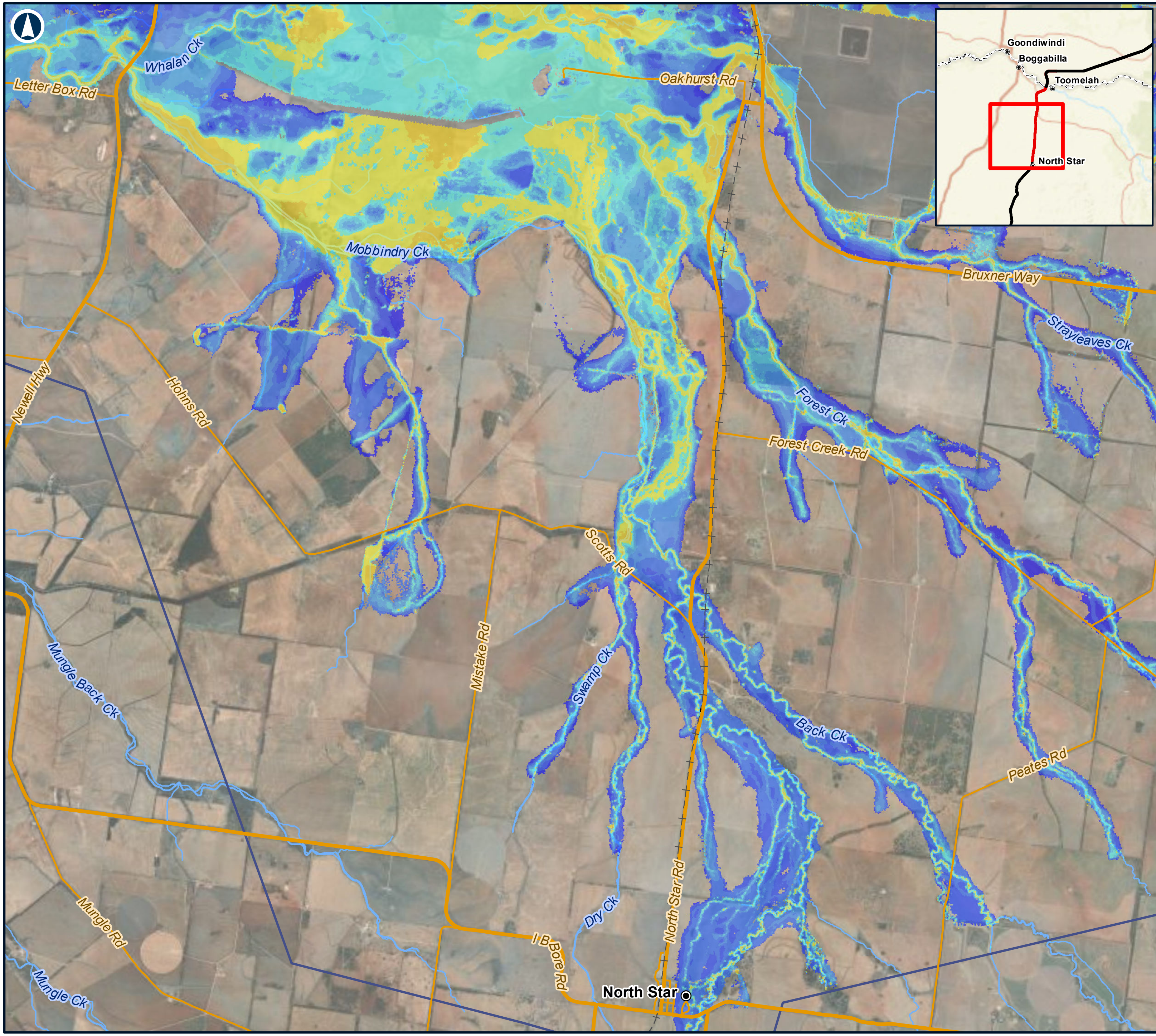
- 0 to 0.5
- 0.5 to 1.0
- > 1.0

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure J3: Existing Case
BRVFMP levees and 1% AEP flows
Duration of Inundation

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Duration of inundation (hours)

- 0 to 10
- 10 to 20
- 20 to 30
- 30 to 40
- 40 to 50
- 50 to 60
- 60 to 70
- 70 to 80
- 80 to 90
- 90 to 100
- > 100

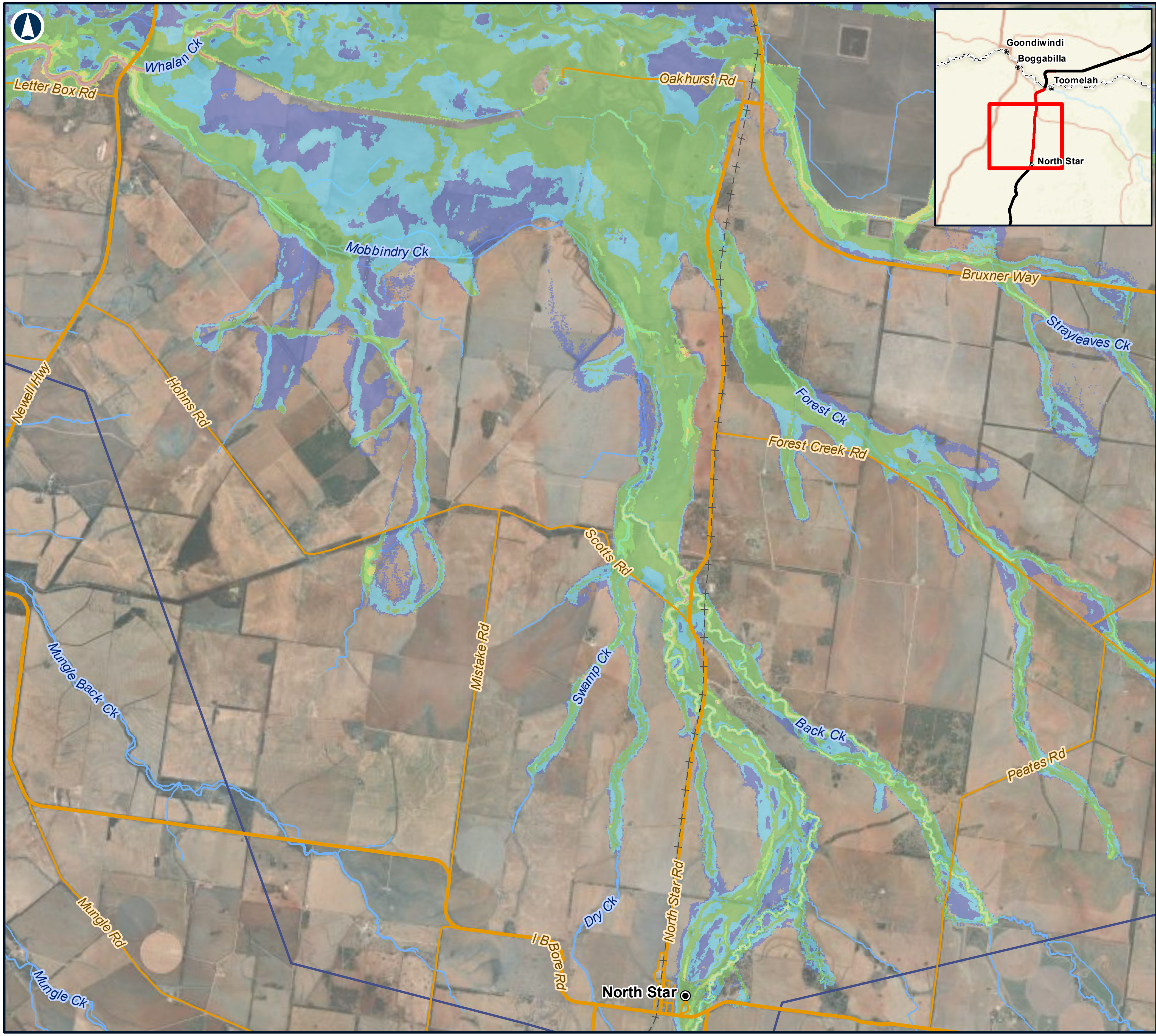
6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxJ3_EX_Duration_Inundation_A4L_v1.mxd Date: 29/04/2021 10:14

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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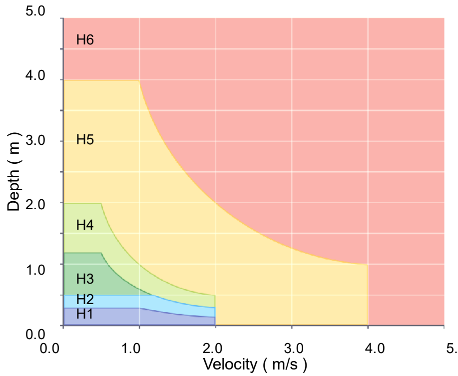
NORTH STAR TO NSW/QLD BORDER

Figure J4: Existing Case
BRVFMP levees and 1% AEP flows
Hazard Categories

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Hazard Categories



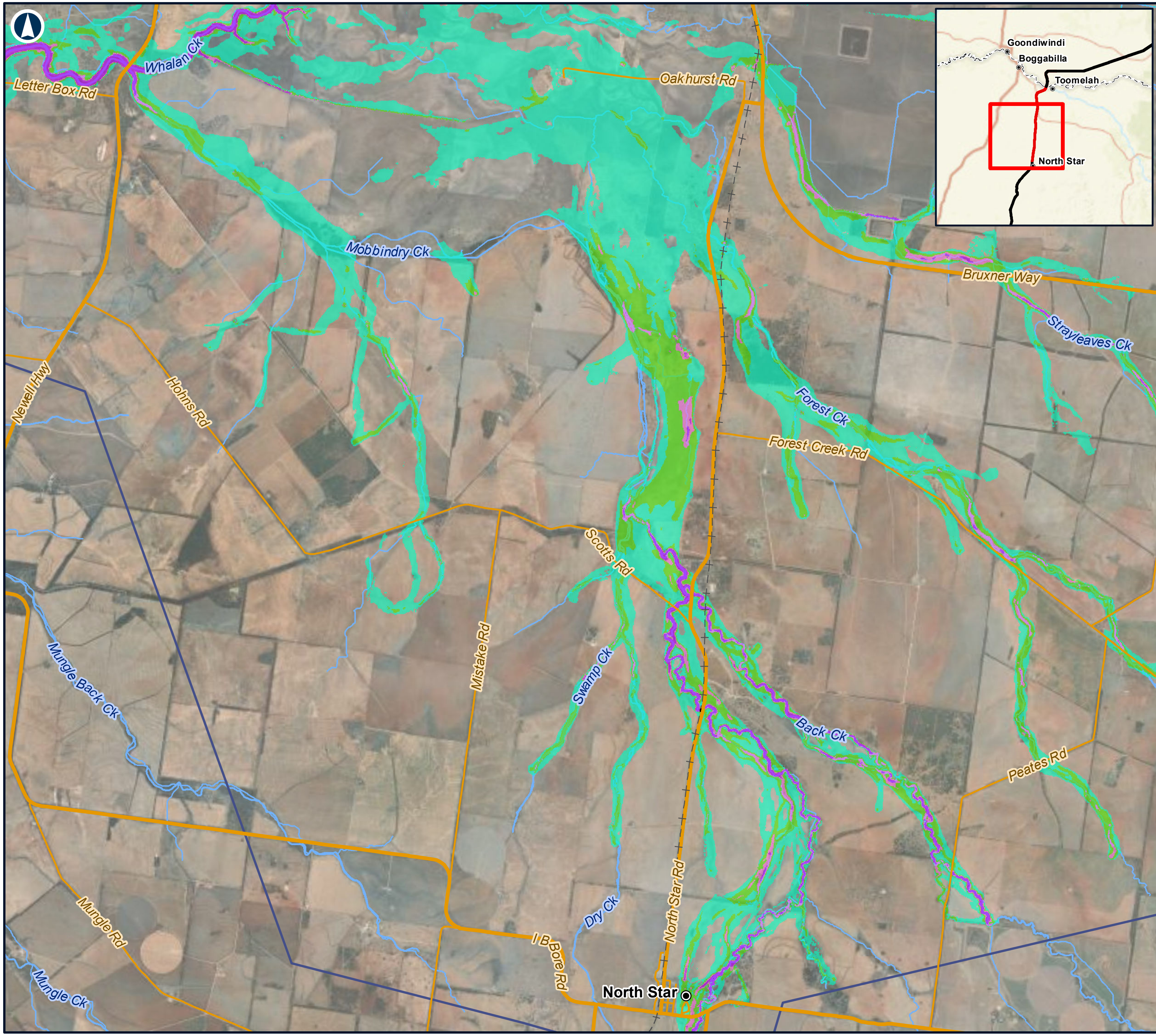
Source: Australian Disaster Resilience Handbook Guideline 7-3 (AIDR 2017)

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 | Paper: A4
Author: FFJV GIS | Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxJ4_EX_Hazard_A4L_v1.mxd Date: 29/04/2021 10:16



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NORTH STAR TO NSW/QLD BORDER

Figure J5: Existing Case
BRVFMP levees and 1% AEP flows
Velocity x Depth product

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Velocity x Depth product (m^2/s)

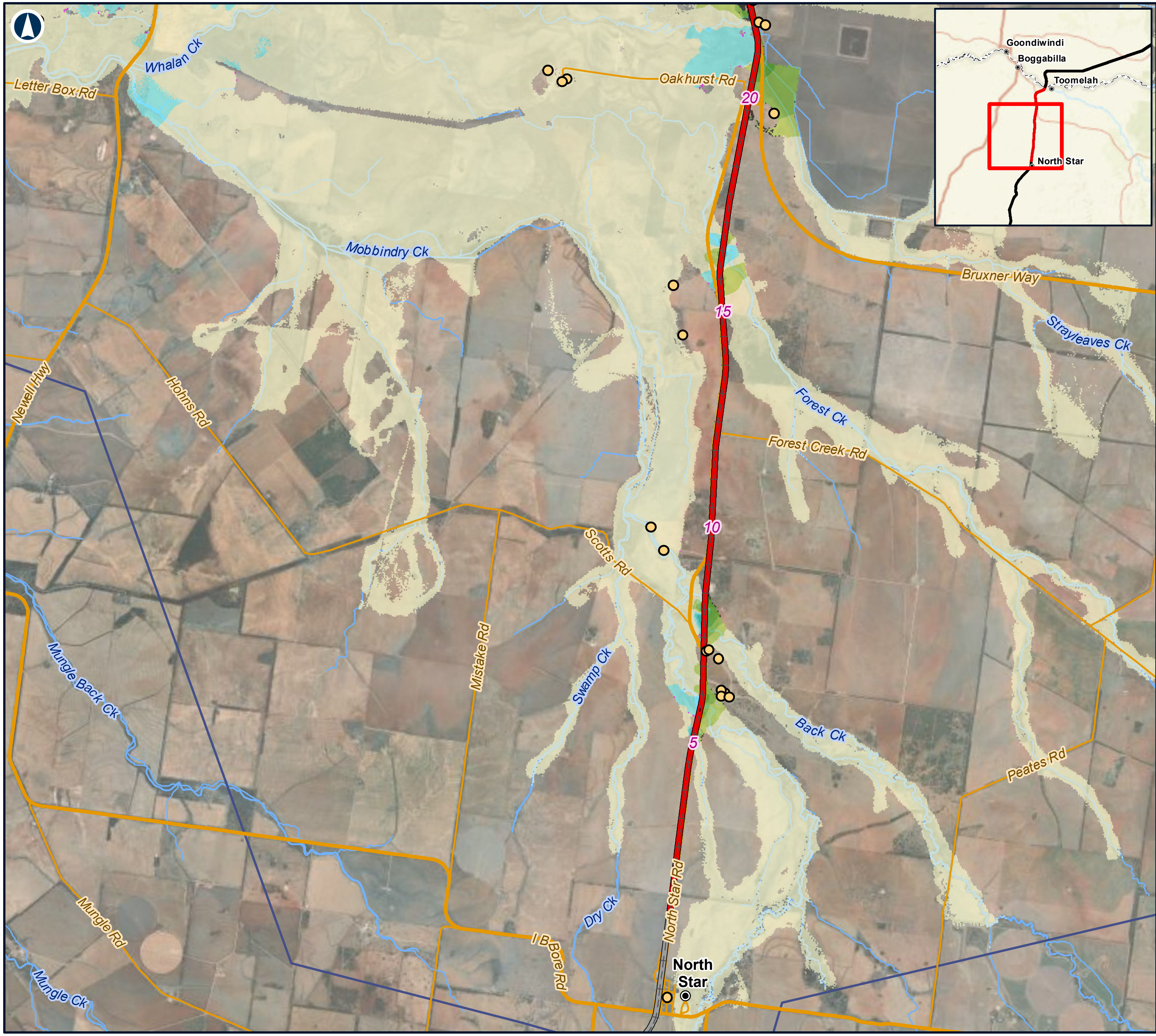
- (< 0.1 excluded)
- 0.1 to 0.3
- 0.3 to 0.6
- 0.6 to 1
- 1 to 40

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure J6: Developed Case
BRVFMP levees and 1% AEP flows
Change in peak water levels

LEGEND

- Flood sensitive receptor
- Localities
- 5 Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in peak water levels (m)

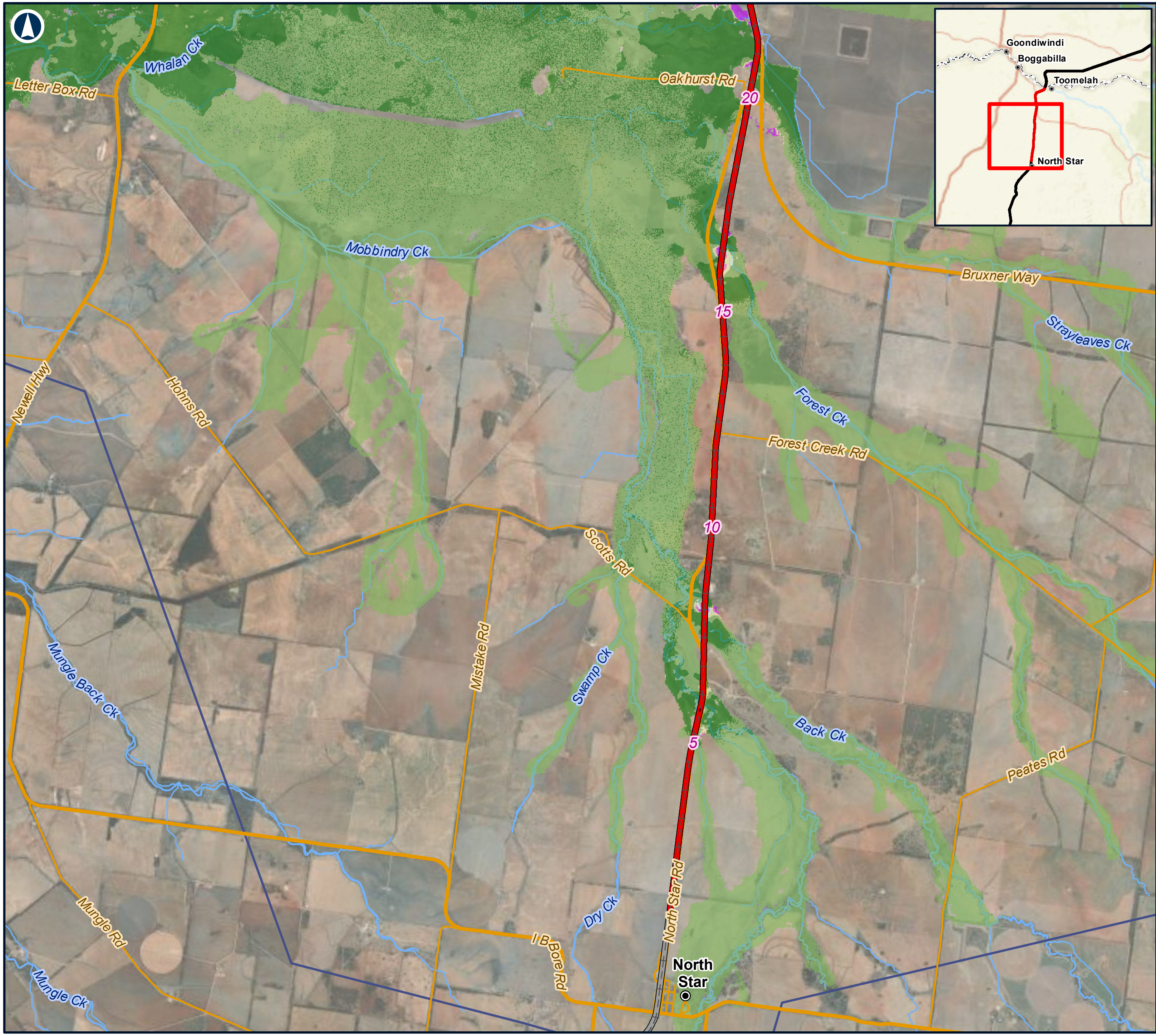
- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5
- Was Wet Now Dry
- Was Dry Now Wet

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure J7: Developed Case
BRVFMP levees and 1% AEP flows
Percentage change in velocities

LEGEND

- Localities
- 5 Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in velocities (%)

- < 0
- 0 to 10
- 10 to 20
- 20 to 30
- > 30

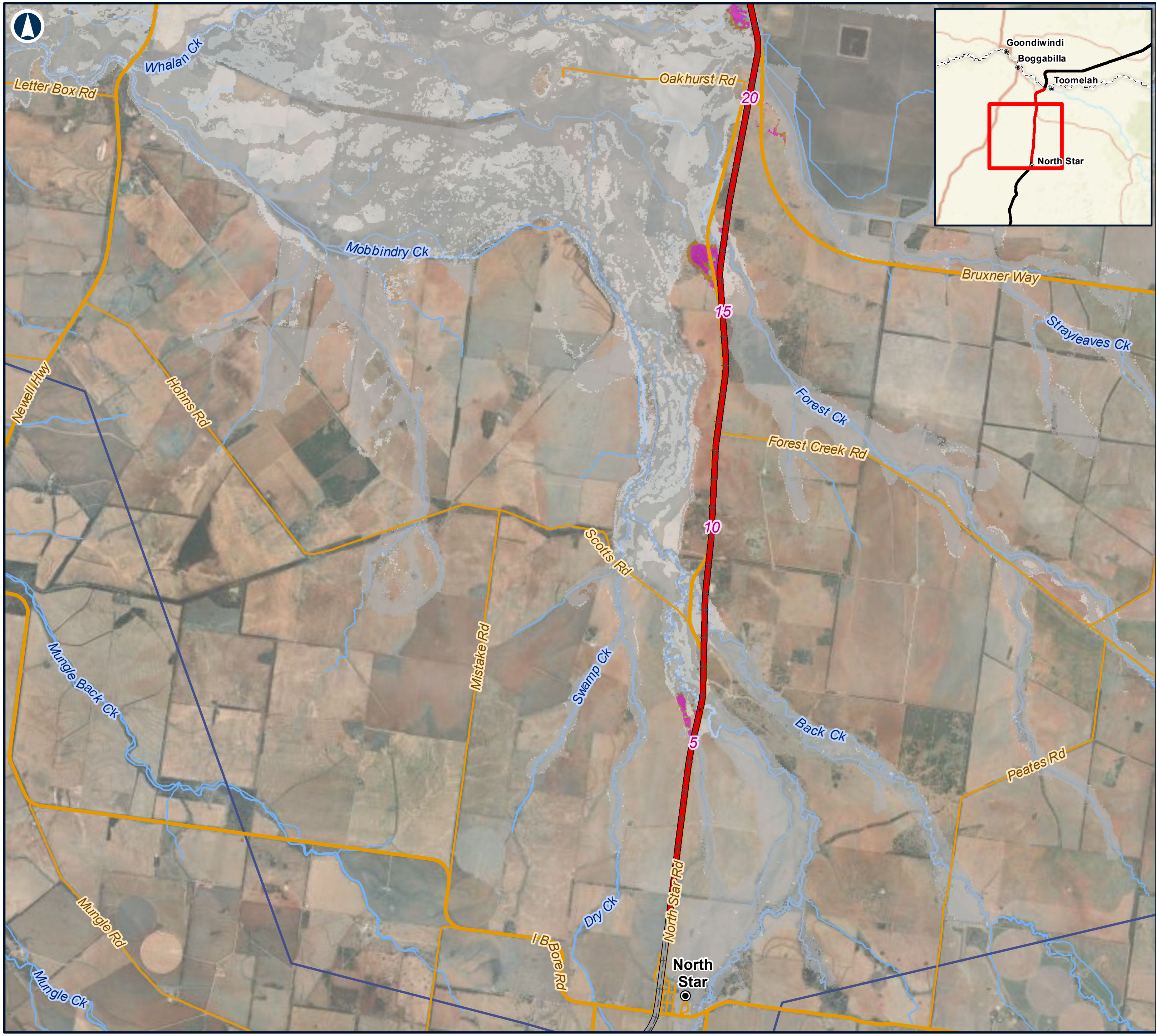
6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxJ7_DV_PercentChangeVelocity_A4L_v1.mxd Date: 29/04/2021 10:13

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure J8: Developed Case
BRVFMP levees and 1% AEP flows
Percentage change in duration of inundation

LEGEND

- Localities
- 5 Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in duration of inundation (%)

- < 0
- 0 to 10
- 10 to 20
- > 20

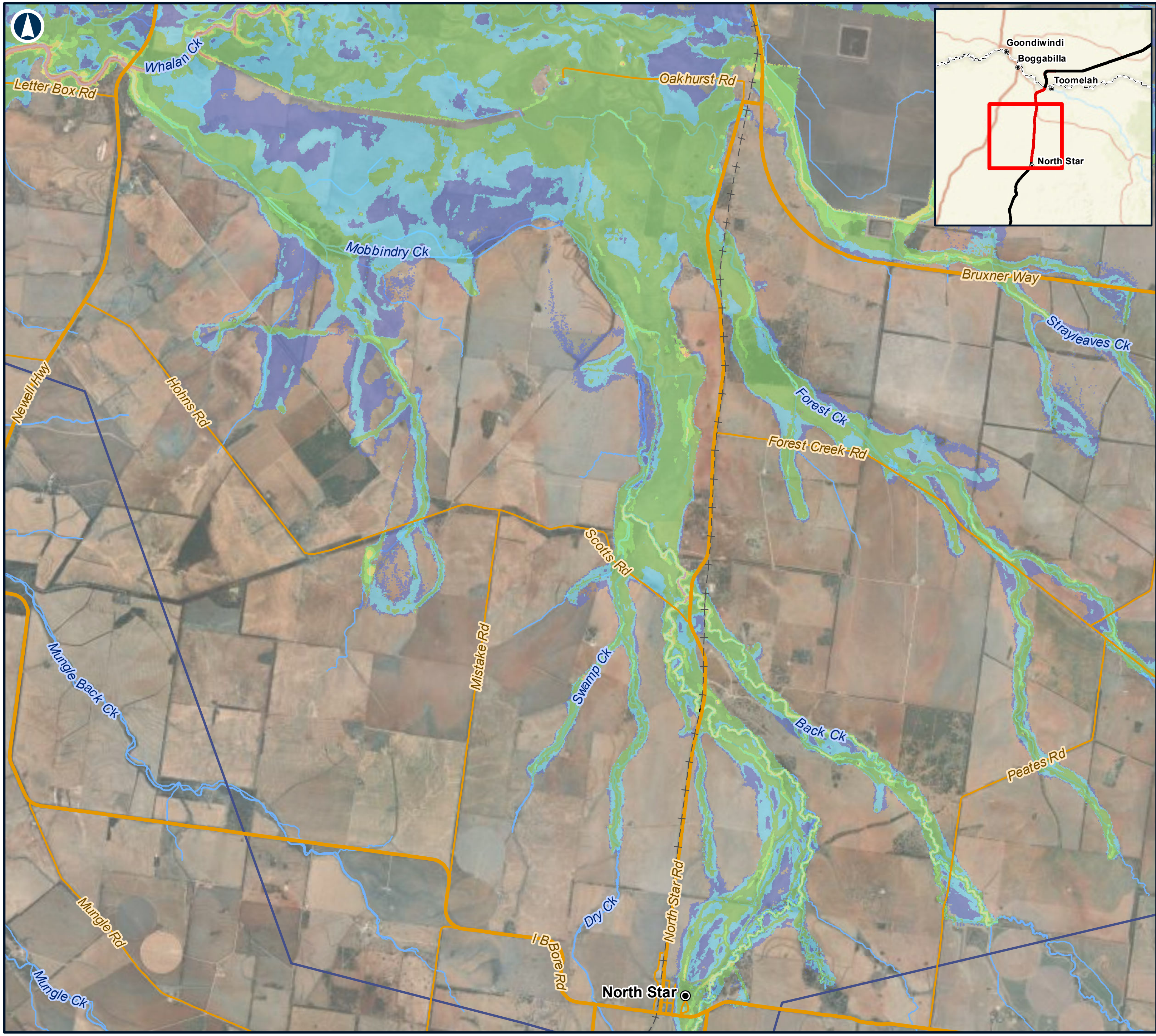
6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021
Paper: A4
Author: FFJV GIS
Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ8_DV_PercentChangeTimeDur_A4L_v1.mxd Date: 29/04/2021 10:14

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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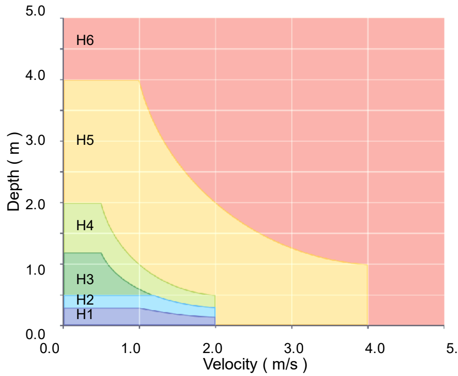
NORTH STAR TO NSW/QLD BORDER

Figure J9: Developed Case
BRVFMP levees and 1% AEP flows
Hazard categories

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Hazard Categories



Source: Australian Disaster Resilience Handbook Guideline 7-3 (AIDR 2017)

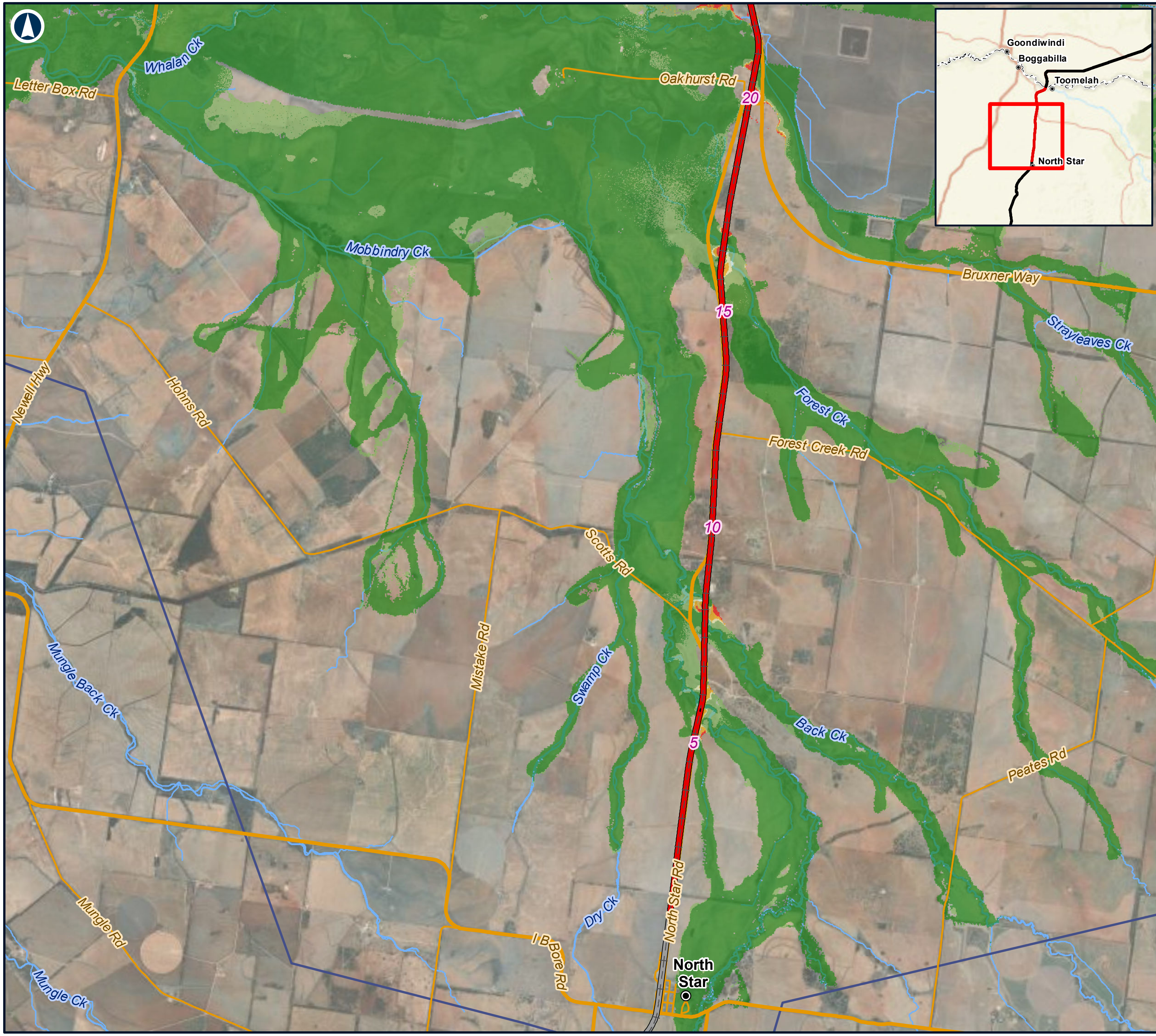
6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigAppxIJ9_DV_Hazard_A4L_v1.mxd Date: 29/04/2021 10:15

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure J10: Developed Case
BRVFMP levees and 1% AEP flows
Percentage change in velocity x depth product

LEGEND

- Localities
- Chainage (km)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Sub-model extent

Change in velocity x depth product (%)

- < 0
- 0 to 10
- 10 to 20
- 20 to 30
- > 30

6km

Coordinate System: GDA 1994 MGA Zone 56

Date: 29/04/2021 Paper: A4
Author: FFJV GIS Scale: 1:125,000

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