Appendices

Appendix A
Hydrologic Model Update

A1 Hydrologic modelling update

The Border Rivers Catchments is presented in Figure A1. Initial hydrologic modelling for NS2B was conducted using three separate URBS hydrologic models of the major Macintyre River tributaries upstream of Boggabilla that were used for the BRVFMP, being:

- Upper Macintyre River catchment ending at Holdfast
- Dumaresq River catchment ending at Mauro
- Macintyre Brook catchment ending at Booba Sands

It is understood that the BRVFMP models were calibrated initially to the major February 1976 flood event (which remains the flood of record in the Macintyre River at Boggabilla and many other areas of the catchment) and then to a number of smaller events that occurred in 1996, the most significant of which occurred in late January. During this calibration process, different reach length factors (modifiers used to adjust the storage attenuation in different parts of the model) were used for each of the calibration events. These differences were not reconciled, effectively creating a different set of models for each flood event rather than a single set of models capable of reproducing flows from different events. Although it is acknowledged that catchment characteristics can vary between events, this situation is not ideal, particularly when conducting Design Event simulations that require the model to be used for events smaller or larger than the calibration event. Due to project and time constraints, the initial hydrologic NS2B modelling validated the BRVFMP models using data obtained for the January 2011 flood, but did not attempt to recalibrate or reconcile or the models.

A recalibration of the BRVFMP models has subsequently been undertaken for the purpose of creating a set of consistent models capable of the reproducing all three design events using a fixed set of parameters, thereby greatly improving confidence in the model calibration as well as the models' ability to produce flows for non-calibration events. The recalibration has included:

- Review and update of previous model data including rainfall and gauge ratings
- Inclusion of additional rainfall and stream gauge data where available
- Increased emphasis on calibration to the January 2011 flood, which provides a significant amount of more recent and reliable data not available in the previous BRVFMP calibration

In addition, new URBS hydrologic models have been developed for Ottleys Creek and for the lower Macintyre River floodplain covering the extent of the TUFLOW hydraulic model. The lower floodplain model provides a single junction taking inflows from the upstream tributary models (Mainctyre Brook, Dumaresq River, Macintyre River and Ottleys Creek) and producing tributary and local sub-area inflows for the hydraulic modelling.

A2 Calibration limitations and focus

The hydrologic modelling has been undertaken using the Unified River Basin Simulator (URBS) software package. URBS is a runoff-routing networked model that features separate routing of sub-catchment and channel routing using non-linear Muskingum storage routing. URBS is capable of performing flood routing through dam reservoirs and representing flow splits and diversions.

Hydrologic model calibration is performed by using recorded rainfall data to generate runoff hydrographs that are compared to recorded stream gauge information. Hydrologic models are generally recognised as utilising simplified procedures to represent what are in reality complex phenomenon, including the transition of rainfall to surface runoff to streamflow, infiltration and rainfall losses and the generation of baseflow. The model calibration is further complicated by limitations on the availability and reliability of the rainfall data used generate the runoff, and the accuracy of the rating curves used to estimate the streamflow. Nevertheless, the simplified numerical procedures can usually be demonstrated to provide a relatively robust representation of the runoff characteristics of real catchments, while calibration to multiple different events and use of sound engineering judgement can overcome much of the uncertainty in the input data.

Although peak flow is a key characteristic of the magnitude of a flood event and may provide the most information in terms of water level (e.g. debris and high-water marks), in a hydrologic model calibration the flood peak usually corresponds to the least reliable part of the rating curve used to determine the flow, particularly when the flood is larger than the highest flow measurements and/or there is a change in channel shape or flow characteristics (see also Section A3). The calibration process has therefore placed emphasis on matching the timing and shape of the flow hydrographs generated by the model to ensure that flows are correctly routed throughout the model and that tributary inflows combine in the correct proportion.

The calibration has also focussed on ensuring that catchment routing characteristics are correctly represented throughout the entire model, rather than just focussing on the outlet. The major catchments all have multiple stream gauges that allow the contributing tributaries to be independently calibrated. Continuity between the gauges has been maintained (i.e. flow cannot be removed between an upstream gauge and a downstream gauge, nor created except by rainfall in the intervening catchment). Consistency between the gauges improves confidence in the model reliability, while conflicting values have been used to identify rating or other data issues. When encountered, engineering judgement has been used to identify the most likely cause of the conflict and adopt the most reliable information.

A3 Stream gauge ratings

Stream gauges record the water level at the gauge site. Ratings tables are then used to convert the recorded water levels into an equivalent flow. Ratings are typically based on flow gaugings or measurements physically recorded during flood events. These are most commonly available for small to moderate flows as it is often difficult and/or dangerous to obtain physical measurements during major floods. The rating must then be extrapolated to higher flows, which may be done by a variety of means ranging from a basic best-fit curve through the available gauging data to using a calibrated hydraulic model. The reliability of a rating to predict high flows is dependent on the reliability of this projection. Discontinuities in the channel shape with elevation can significantly affect the accuracy of the projection, particularly if simplistic projection methods are employed.

Stream gauges may also be affected by backwater effects, where the water level at the gauge is increased due to conditions downstream of the gauge rather than the stream flow passing the gauge. Gauges located upstream of a major tributary are particularly susceptible to this. A gauge with an unreliable or inaccurate rating may still provide useful information on the timing of flow through the system.

Review of the stream gauge ratings identified that a number of the gauge ratings had changed since the BRVFMP models were developed. Gauge ratings may change for a number of reasons, including:

- Change in gauge location or control, in which case historical events should use rating appropriate for gauge location/control at time of flood
- Additional or more reliable data and/or improved extrapolation methods, in which case historical events should be re-rated using the improved rating

Stream gauges used in the calibration are described in Table A1 and are also shown in the calibration figures.

Table A1 Summary of key stream gauges used in the model calibration

Catchment	Gauge Name	Gauge No.	Area [a]	Description
Macintyre Brook	Macintyre Brook @ Barongarook	DNRME 416410A	114 km²	Small catchment upstream of Coolmunda Dam. Relatively reliable rating. Site ceased in 2002.
	Bracker Creek @ Terraine	DNRME 416404C	685 km²	Small catchment upstream of Coolmunda Dam. Relatively reliable rating. Site ceased in 2002.
	Canning Creek @ Woodspring	DNRME 415404A	1,245 km²	Rating appears reasonable but based on limited flow gauging. Site ceased in 1980.
	Macintyre Brook @ Coolumunda T/W	DNRME 416416A	1,760 km²	Immediately downstream of Coolmunda Dam. Unknown rating quality. Site ceased in 2002.
	Macintyre Brook @ Inglewood CBM	Unknown	~1800 km²	Upstream of the confluence of Macintyre Brook and Canning Creek. No information about this gauge is currently available.
	Macintyre Brook @ Inglewood	DNRME 416402B/C	3,430 km²	Downstream of the confluence of Macintyre Brook and Canning Creek. Site changed from 'B' to 'C' in 1981, keeping the same location but a modification of the control weir and rating.
	Macintyre Brook @ Booba Sands	DNRME 416415A	4,092 km²	Relatively reliable rating but site has only been operational since 1987
Dumaresq River	Pike Creek @ Glenlyon T/W	DNRME 416309B	1,320 km²	Immediately downstream of Glenlyon Dam. Reasonable rating quality.
	Dumaresq River @ Farnbro	DNRME 416310A	1,310 km²	Small tributary in the upper Dumaresq River catchment. No high flow stream gauging. High flow rating appears reasonable but of unconfirmed quality
	Mole River @ Donaldson	WaterNSW 416032	~1,290 km²	Small tributary in the upper Dumaresq River catchment. No high flow stream gauging. High flow rating appears reasonable but of unconfirmed quality
	Dumaresq River @ Riverton	DNRME 416301 (Possibly)	~5,090 km²	DNRME stream gauge operated only from 1920 to 1954. Source of data from BRVFMP calibration is unknown. Rating is not from the site but rather is based on the downstream gauge at Roseneath. Rating is therefore unreliable but useful for order-of-magnitude and timing.
	Dumaresq River @ Roseneath	WaterNSW 416011	~5,560 km²	Mid- Dumaresq River gauge between the upper catchments and Beardy River. Site has been operational since 1937.
	Beardy River @ Haystack	WaterNSW 416008	~280 km²	Small tributary in the southern Dumaresq catchment. Site has been operational since 1934.
	Dumaresq River @ Bonshaw	WaterNSW 416007	~7240 km²	Lower Dumaresq River weir at Bonshaw Weir downstream of the Beardy River confluence.
	Dumaresq River @ Texas	Unknown	~7,810 km²	Dumaresq River gauge believed to be located at the town of Texas upstream of the Oaky Creek confluence. Location and details of the gauge are unknown.
	Oaky Creek @ Texas	DNRME 416312A	422 km²	Small tributary in the lower Dumaresq River catchment. NOTE: This gauge is referred to as the Oaky Ck gauge in the calibration to avoid confusion with the Dumaresq River gauge at Texas.

Catchment	Gauge Name	Gauge No.	Area [a]	Description
	Dumaresq River @ Cunningham Wr	DNRME 416308A	8,755 km²	Located in the lower Dumaresq River upstream of Beebo. Appear to be significant issues with the high flow rating. Site ceased in 1988.
	Brush Creek @ Beebo	DNRME 416308A	335 km²	Minor creek catchment in the lower Dumaresq River catchment.
	Dumaresq River @ Mauro	Unknown	9,090 km²	Location and details of the gauge are unknown. Believed to be a short distance downstream of the Brush Creek confluence based on URBS model setup and catchment area.
	Dumaresq River @ Glenarbo	WaterNSW 416040	~10,004km²	Located in the lower Dumaresq River downstream of Beebo. Reliable rating for low flows but appear to be significant issues with the high flow rating.
Macintyre River	Severn River @ Fladbury	WaterNSW 416022	~1,110 km²	Located in the upper Severn River. Rating based only on low flow gaugings and appears to have issues with the high-flow rating.
	Severn River @ Strathbogie	WaterNSW 416039	~1,740 km²	Located in the upper Severn River between Fladbury and Pindari Dam. Rating based only on relatively low flow gaugings and appears to have issues with the high-flow rating.
	Severn River @ Pindari T/W	Unknown	~2,100 km²	Site details are unknown. Low flow rating is similar to Ducca Marri gauge.
	Severn River @ Ducca Marri	WaterNSW 416067	~2,100 km²	Located just downstream of Pindari Dam. Site has only been operational since 2002. Relatively reliable rating.
	Frazers Creek @ Westholme	WaterNSW 416021	~810 km²	Small tributary in the middle of the Macintyre River model catchment. Joins Severn River upstream of Ashford. High-flow rating potentially unreliable and/or backwater affected.
	Severn River @Ashford	WaterNSW 416006	~3,285 km²	Long record gauge on the Severn River downstream of Pindari Dam and Frazers Creek. Rating is well gauged but has changed between the DPIE and current calibration.
	Macintyre River @Inverell	WaterNSW 416016	~745 km²	Located in the upper Macintyre River catchment. Gauge is theoretically well rated but high-flow rating appears to be potentially unreliable and/or backwater affected.
	Macintyre River @ Tintot	WaterNSW 416068	~1,740 km²	Located between Inverell and Wallangra. Site commenced in 2002. Rating based on limited flow gauging but to relatively high level.
	Macintyre River @ Wallangra	WaterNSW 416010	~2,130 km²	Long record gauge upstream of the confluence with the Severn River. Rating is well gauged but has changed between the BRVFMP and current calibration.
	Macintyre River @ Ridgelands	WaterNSW 416031	6,170 km²	Located downstream of the confluence of Macintyre and Severn Rivers. Site reportedly commenced in 1967, however stream gauge data is only available after 1997.
	Macintyre River @ Holdfast	WaterNSW 416012	~6,890 km²	Located upstream of the Dumaresq River confluence. Well rated up to bank-full but appear to be issues with the rating above floodplain level. Minor changes to the rating between the BRVFMP and current calibration.

Catchment	Gauge Name	Gauge No.	Area [a]	Description
Ottleys Creek	Ottleys Creek @ Coolatai	WaterNSW 416312A	~385 km²	Located in the upper Ottleys Creek catchment. Site reportedly commenced in 1967, however stream gauge data is only available after 1978.
Lower Macintyre	Macintyre River @ Boggabilla	WaterNSW 416002	~22,500km²	Operational since 1894 but the gauge has changed location several times. Significant breakout from the Macintyre River occurs upstream of the gauge. Rating has been reviewed and updated as part of the current study.
	Macintyre River @ Goondiwindi	DNRME 416201A	23,090km²	Rating is based on significant flow gauging data but appears to become ineffectual above bank-full due to significant floodplain and bypass flows.

Table notes:

a Catchment areas for DNRME gauges are based on data published online. Areas indicated with ~ do not have published values and areas are estimated from the URBS model layout.

A4 Calibration events

Calibration of the hydrologic models involves simulation of recorded historic rainfall events. Three rainfall/flood events have been used for the hydrologic model recalibration. Each of the events have a unique rainfall distribution:

- **February 1976**. This is one of the largest and most widespread rainfall events recorded in the Macintyre River catchment and resulted in a significant flood event in much of the catchment (flood of record at Boggabilla and Goondiwindi). Most of the rainfall occurred within a 24 hour period on the 10 February, with almost the entire catchment receiving between 80 and 200mm on that day. Much of the catchment also received rainfall on the preceding day, wetting the catchment and initiating runoff, and there was also some follow-up rainfall.
- **January 1996**. Several different floods were recorded in the Macintyre River in 1996. The main flood at Boggabilla, subsequently referred to as the 1996 flood event, was actually the combination of several relatively short-duration storms that fell across the catchment over successive days from 21 to 27 January. Rainfall distributions were highly variable, even between relatively closely spaced gauges, with rainfall more strongly concentrated in in different parts of the catchment on different days. The rainfall depths shown in Figure A3 are the cumulative depth of all the storm events.
- **January 2011**. The January 2011 actually consisted of two major rainfall events approximately two days apart, and most of the recorded gauge hydrographs display two distinct peaks. The concentration of the rainfall varied across the catchment, however in most areas the second burst was the more significant. The rainfall was most heavily concentrated across the eastern side of the catchment.

Importantly, the January 2011 flood event has provided a significant opportunity to improve the calibration of the hydrologic models. Firstly, there has been a significant increase in the number of rainfall gauges recording continuous pluviograph data, providing improved rainfall detail not present in the earlier events, and there are also a number of additional stream gauges (unfortunately excluding the Macintyre Brook catchment where the number of gauges has decreased since 1996). Secondly, the spatial and temporal distribution of the rainfall has several features that are advantageous for model calibration:

- Much of the rainfall occurred in the upper parts of the catchment, producing a large upstream flow that can then be routed downstream through subsequent gauges, greatly increasing confidence that the models are reliably representing the routing speed through the model.
- Assumed rainfall losses can have a significant influence on the rainfall distribution, and hence the generated hydrograph. The two strong distinct bursts and runoff peaks allow the effects of the initial catchment losses, which predominantly affect only the first peak, to be separated from the effects of the continuing losses on the second peak.

A5 Rainfall data

Rainfall data was sourced from Bureau of Meteorology (BoM) as well as WaterNSW and Queensland Department of Natural Resources, Mines and Energy (DNRME). Detailed pluviograph data (rainfall distribution with a timestep less than 1 hour) is typically available at a relatively limited number of gauges across the catchment. This data is supplemented by daily (24 hour) rainfall data,

The number of rainfall gauges used for each calibration event are summarised in Table A2, noting that some of these gauges are located outside the catchment boundaries. The gauges are also not located uniformly across the catchment, and some areas of the catchment have significantly higher detail in terms of both spatial and temporal distribution of the rainfall. Rainfall gauge locations available for the three calibration events are shown in Figure A2 to A4, together with the total rainfall depth of the event.

The gauge pluviograph data for each event was reviewed for quality to identify suspect or missing data and also for consistency with nearby gauges. A number of cases were identified where several days of rainfall were accumulated in a single record or where a gauge had the similar depths to surrounding gauges but offset by a day, most likely the result of errors in the transposition of manual record data.

Table A2 Number of rainfall gauges used in the model calibration

Event	Detailed Pluviograph Gauges			BoM Daily Gauges
	BoM	DNRME (QLD)	WaterNSW	
February 1976	15	-	-	202
January 1996	18	4	2	165
January 2011	16	6	23	162

A6 Macintyre River to Holdfast

The Macintyre River URBS model covers an area of 6890km² to Holdfast. The catchment has been subdivided into 50 sub-areas. Pindari Dam is located on the Severn River upstream of Ashford. The dam was constructed in 1969 and was raised in 1994, significantly increasing the capacity. The dam was not included in the 1976 calibration model. Due to the magnitude of the flood event and the low capacity of the pre-upgrade dam, this approach is considered reasonable and has not been changed. The BRVFMP calibration appears to have been conducted primarily using the downstream gauge at Holdfast and the major gauges at Wallangra on the Macintyre River and Ashford on the Severn River, with some supplementary information from Pindari Dam. A significant factor in the model recalibration is that the high-flow ratings for Holdfast, Wallangra and Ashford have all changed since the BRVFMP calibration was conducted. The recalibration has also examined a number of additional gauges, including Fladbury, Strathbo and Westholme in the Severn River catchment and Inverell and Tintot in the Macintyre River catchment.

A6.1 February 1976 Flood

Calibration hydrographs for the Macintyre River gauges in the February 1976 flood are shown in Figure A5-A. The effect of the changes to the Wallangra and Ashford ratings are most pronounced on the February 1976 calibration, as the Holdfast gauge failed prior to the peak and these gauges represent the primary focus points of the calibration. The recalibrated model produces similar quality of match of the recorded hydrographs at these locations, however with a reduction in the magnitude of the flows. Downstream at Holdfast, the recalibrated model provides a better match of the rising limb of the hydrograph until the gauge failed. The calculated and rated flows begin to deviate once the water level reaches the level of the floodplain, suggesting an issue with the high-flow rating (see further discussion of the 2011 flood below). The modelled peak flow of 2860m³/s compares well with the reported peak flow of 250,000ML/d (2893m³/s) at Yetman No. 3 gauge upstream of Holdfast (Source: Border Rivers Floods Report, Table 12 Summary of February 1976 Flood, Department of Land & Water Conservation, January 1996). Data for this site is not available from WaterNSW webservice.

The BRVFMP calibration matched the magnitude and timing of the peak flow at the Pindari Tailwater gauge downstream of Pindari Dam but did not match the overall shape of the hydrograph particularly well. Details of the Pindari Tailwater gauge and the origin of its rating are not known. The WaterNSW gauge on the Severn River at Ducca Marri is located just downstream Pindari Gauge, but only commenced operation in 2002 (i.e. the gauge was not present in the 1976 flood). The Ducca Marri low flow rating is similar to the Pindari Tailwater rating from the BRVFMP model but deviates at high flows. The recalibrated model reasonably matches flows calculated using the Ducca Marri rating.

Westholme, on Frazers Creek upstream of Ashford, was not considered by the BRVFMP calibration. The recalibrated model provides a good fit of the rising and falling limbs hydrograph but underestimates the peak flow. This could potentially be attributed to a poor high flow rating, noting that the deviation between the rated and calculated flows occurs at around the level where the main channel breaks out onto the floodplain, which is significantly higher than the largest gauged flow measurement at the site. Alternatively, the gauge could potentially be affected by backwater given its proximity to the Severn River confluence at Ashford. The BRVFMP model does not match the gauged hydrograph well.

Similarly, issues with the high flow rating and/or backwater effects potentially affect rated flows at Inverell in the upper Macintyre River catchment. The BRVFMP calibration matches the peak flow relatively well (noting that this is partly coincidental as the Inverell gauge was not considered) but significantly overpredicts the flow on the rising and falling limbs of the hydrograph The recalibration process found that it could the full shape of the hydrograph using realistic routing and loss parameters. The recalibration has chosen to match the timing and the rising and falling limbs of the hydrograph as these are the most reliable aspects of the rated hydrograph and higher peak flows are inconsistent with the (revised rating) flows downstream at Wallangra.

A6.2 January 1996 Flood

The January 1996 flood consisted of several short-duration storm events across several days. Several of the gauge hydrographs show multiple peaks. Calibration hydrographs for the Macintyre River gauges in the January 1996 flood are shown in Figure A5-B. The BRVFMP calibration was based on relatively limited stream gauge information.

Flows from the upper Severn River were calibrated against the inflow into Pindari Dam. It is understood that this inflow was reverse-routed from changes to the reservoir level. The recalibration has included information from stream gauges at Fladbury and Strathbogie in the upper catchment. The BRVFMP calibration did not consider these gauges and, although it provides a reasonable match of the rated peak, it does not match the shape and timing of the hydrograph particularly well. The recalibrated model matches the shape and timing of the hydrographs well but overestimates the rated peaks, which may be an issue with the high-flow ratings. Neither calibration matches the calculated Pindari inflow particularly well – the recalibrated model appears to have too high a peak while the BRVFMP model has too much volume at the tail. The Pindari inflows do not appear particularly consistent with the upstream gauge at Strathbogie and the accuracy of these calculated inflows is unknown.

Levels in Pindari Dam were low prior to the January 1996 flood and the dam did not release during the flood. Flows from the upper Severn River catchment therefore have no influence on the lower catchment. The flow recorded at Ashford is almost entirely generated in Frazers Creek (the Westholme gauge does not have a record for this event). The BRVFMP calibration at Ashford is a reasonable match of the gauged hydrograph shape although the timing appears out by approximately 3 hours. The recalibration produces lower flows due to the newer Ashford rating and provides a good fit of the timing and shape of the hydrograph.

Based on the model data provided, the BRVFMP calibration did not have and/or consider a rated flow at the Wallangra gauge. Consequently, the calibration of flows from the upper Macintyre River catchment was based solely on the combined Macintyre and Severn flow at Holdfast The recalibration has included the Wallangra gauge record as well as the upstream gauge at Inverell. The BRVFMP calibration significantly overpredicts the amount of flow at Inverell, and although it provides a reasonable match of the flow magnitude at Wallangra (based on the old rating), the peak and trough pattern of the hydrograph is notably nowhere near as pronounced.

The BRVFMP calibration achieves a relatively good match of the rated hydrograph at Holdfast (based on the old rating). The revised calibration achieves a good match of the first peak and the receding limb of the hydrograph (using the current rating) but does not replicate the second 'hump' of the hydrograph occurring on 24 January. This second peak could not be matched without worsening the calibration of the upstream gauges at Ashford and Wallangra (the latter of which was not considered in the BRVFMP calibration).

Considering the good match of the upstream ratings, a likely explanation is that the 'missing' flow was caused by localised rainfall poorly represented by the surrounding gauges. As shown in Figure A.1, there is very limited rainfall gauge information in the region between the major tributary gauges at Ashford and Wallangra and the downstream gauge at Holdfast. Rainfall Gauge 54161, located just north of Ashford, recorded zero rainfall between 9:00AM on 23 January to 9:00AM on 24 January, which would correspond to the second peak. The gauge at Wallangra recorded 56mm in this same period, while the gauge further west at Coolatai recorded over 80mm. Due to triangulation of the gauges, the zero rainfall at Gauge 54161 affects much of the eastern side of the catchment between Ashford and Holdfast, potentially representing a significant underestimation of the rainfall. This conclusion is corroborated by the issue also affecting the Dumaresq River calibration, which uses the same rainfall data but otherwise was calibrated independently, as discussed in Section A7.2.

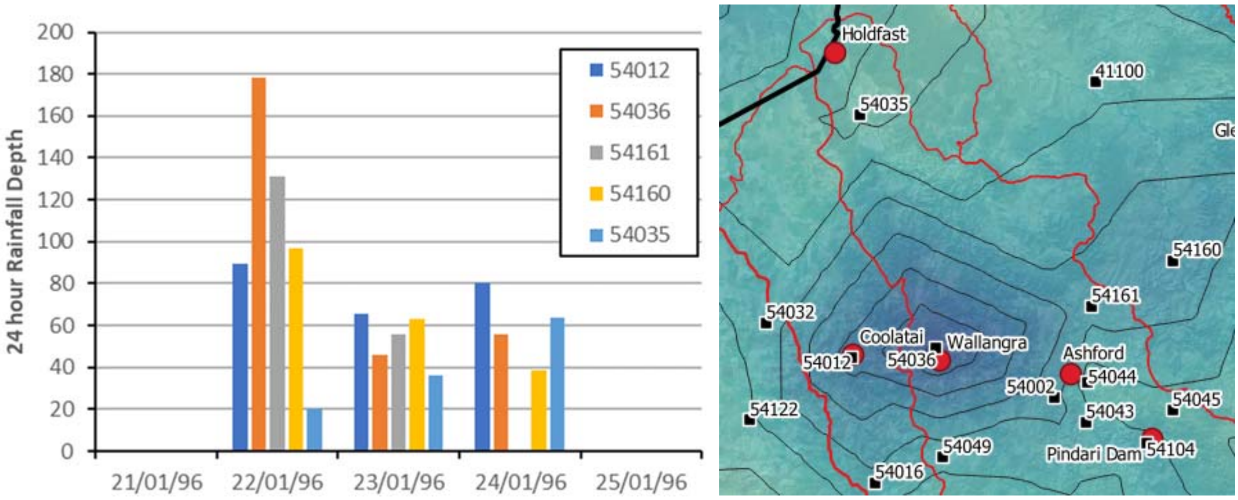


Figure A.1 Rainfall gauge between Ashford/Wallangra and Holdfast for 1996 event

A6.3 January 2011 Flood

Like the January 1996 flood, the 2011 flood was generated by the combination of several short duration bursts. Significantly more continuous pluviographs were available for this event. A large number of these gauges are located in the upper Macintyre River catchment upstream of Inverell. Examination of the rainfall records shows that there was significant spatial variability (i.e. the rainfall was in the form of concentrated localised bursts), making it difficult to match the exact rainfall patterns, particularly across the upper Severn River catchment where there are no continuous rainfall records. Nevertheless, the January 2011 flood is an excellent event for calibrating the stream routing of the model. Much of the runoff was generated as short bursts in the upper catchment. Additional stream gauge locations not available for previous events, including Tintot and Ridgelands, allow these bursts to be tracked downstream providing a concise record of stream travel times.

Overall, the recalibrated model provides a very good match of the gauged hydrographs throughout the catchment, as shown in Figure A5-C. The model has difficulty in matching some of the burst peaks generated in the upper catchments (e.g. upstream of Inverell). As discussed above, the flow was generated by short, localised rainfall bursts and the spatial detail of the available rainfall data, the model catchment resolution and timestep will all tend to smooth/average out the peaks. There are also some apparent issues with the gauged flows, some of which can be attributed to uncertainty in the high-flow gauge ratings (notably the smaller catchment gauges of Fladbury, Strathbogie and Westholme), and some of which cannot be readily reconciled (e.g. the peak Pindari Headwater gauge is higher than the downstream gauge at Ashford).

Parameters were selected to provide good match of the rising and falling limbs of the flood (the most reliable record) and a balanced overall fit of the available gauge data.

A6.4 Summary

The BRVFMP calibration achieved a reasonable match of Ashford and Wallangra gauges for the 1976 flood event (noting that the Holdfast gauge failed during the event) and of the Ashford and Holdfast gauges for the 1996 flood event (Wallangra was not considered and not particularly well matched), but did so using different model routing parameters. Significantly for this catchment, the ratings for these three primary calibration gauges have been updated since the BRVFMP calibration was conducted.

Calibration of the Macintyre River model has been affected by changes to gauge ratings as well as the inclusion of additional upstream stream gauge information to improve the accuracy of the model representation of the upper catchments. The revised calibration is considered of equivalent or better accuracy than the previous modelling at each of the stream gauges throughout the catchment. This calibration has been achieved using a single set of model routing parameters for all three events, confirming that the adopted routing parameters provide a good representation of the routing characteristics of the catchment.

A7 Dumaresq River to Mauro/Glenarbon Weir

The original BRVFMP Dumaresq River model covered an area of 9090km² down to Mauro, the largest of the tributaries contributing to the Macintyre River upstream of Boggabilla. The catchment has been subdivided into 79 sub-areas. Glenlyon Dam is located on Pike Creek, one of the tributaries in the upper Dumaresq catchment, with a contributing catchment area of 1290km². Stream gauges are located on many of the major tributaries, however there is relatively limited reliable gauge information in the lower reaches of the river. Mauro is not a registered DNRME or WaterNSW gauge and the exact location of the gauging station is unknown (the model setup implies that it is just downstream of the confluence with Brush Creek, upstream of Glenarbon Weir). The Dumaresq URBS model has been extended down to the DNRME gauge at Glenarbon Weir, which provides an additional calibration point for the 2011 flood.

A7.1 February 1976 Flood

Calibration hydrographs for the Dumaresq River gauges in the February 1976 flood are shown in Figure A6-A. No gauge information was available at Mauro, and it appears that the primary focus of the BRVFMP calibration was the gauges further upstream at Texas and Bonshaw Weir, noting that the former gauge is not an official WaterNSW gauge and details of the site and rating have not been provided. The BRVFMP calibration achieved a reasonable match of the rated peak flows at these gauges, although the peak flow at Bonshaw and the receding limb of the hydrograph at Texas are not particularly well represented. The calibration becomes increasingly poorer further upstream, noting that there appears to be a significant issue with the Riverton rating used in the BRVFMP calibration, and the constant flow at Glenlyon Tailwater gauge is not considered realistic indicating an issue with the gauge (Glenlyon is not a regulated outflow). The BRVFMP calibration at Farnbro matches the timing of the peak but otherwise is a poor fit, suggesting that the calibration at this gauge was either not considered important or had to be sacrificed in order to improve the calibration downstream. Good matches of the downstream minor tributaries at Beebo and Oaky Creek were achieved.

The recalibration has improved the match of all the upstream gauges and achieved a generally good fit at Bonshaw and Texas gauge hydrographs. The recalibration has also sourced and included additional data at the now-closed Cunningham Weir gauge, upstream of Mauro. Although the high-flow rating (>1000m³/s) at this site appears highly suspect, the start and end of the hydrograph are well matched, giving increased confidence in the channel routing that occurs downstream of Texas.

A7.2 January 1996 Flood

As previously discussed, the January 1996 flood was generated by a series of short-duration storm events scattered across the catchment over several days. Although there are a large number of stream gauges in the catchment, rainfall gauge data in the Dumaresq catchment is relatively sparse (refer Figure A3) limiting the accuracy of the rainfall distribution. Calibration hydrographs for the Dumaresq River gauges in the January 1996 flood are shown in Figure A6-B.

The original BRVFMP calibration appears to have focussed almost exclusively on matching the stream gauge at Mauro, where a good match is achieved. At Texas, the model matches the general magnitude of the flood event but not the rise and fall of two peaks evident in the gauge record before it appears to have failed. Neither Mauro nor Texas are government-controlled gauges and details of the gauge ratings have not been provided. The BRVFMP model does not appear to have included or examined the WaterNSW gauge at either Bonshaw Weir or Roseneath. Further upstream, the BRVFMP calibration is generally poor. At the Haystack, Donaldson and Farnbro gauges the rated flows are all significantly over- or underestimated, and at Riverton (acknowledging that there appear to be significant issues with the rating) the timing of the calculated hydrograph appears to be out by nearly 24 hours.

The recalibration has significantly improved the match at virtually all the upstream gauges. A good match is achieved at the WaterNSW Dumaresq River gauges at Roseneath (the gauge does not appear to have properly recorded the first peak, the general magnitude of which can be confirmed from the upstream gauges) and at Bonshaw.

The recalibration appears to produce a worse match at the downstream gauge of Mauro, however the calibration at Mauro could not be improved without correspondingly worsening the match at Bonshaw and Texas, as well as the other calibration events. Differences between the rated and calculated flows can be attributed to:

- The overestimate of the flow at the peak on late 23 January/early 24 January may be due to inaccuracy of the high-flow rating (details of the Mauro rating are unknown, and both Cunningham Weir upstream and Glenarbon Weir downstream exhibit this traits, possibly due to significant floodplain flow, see Sections A7.2and A7.3) and/or poor rainfall data.
- The subsequent underestimate of flow on late 24 January/early 25 January corresponds to the same 'missing' flow observed between Ashford and Holdfast in the Macintyre River catchment, which is immediately adjacent to the local Dumaresq catchment between Bonshaw and Mauro, and may be related to the same rainfall issue discussed in Section A6.2.
- The overestimate of flow on the receding hydrograph on 26 January is most likely again related to poor distribution of rainfall, this time having too much rainfall. This is evident in the calculated hydrographs at both the Oaky Creek and Beebo gauges.

A7.3 January 2011 Flood

The January 2011 flood was caused by significant rainfall concentrated most heavily across the eastern side of the catchment, although the heaviest rainfall actually fell outside the catchment as shown in Figure A4. The event consisted of several separate storm bursts, with moderate rainfall on 5 and 6 January and then heavier rainfall from 9 to 11 January, resulting in two distinct peaks with a small initial peak followed by the main flood.

The calibration hydrographs for the Dumaresq River gauges in the January 2011 flood in Figure A6-C show a relatively good match at all the assessed stream gauges despite the relatively sparse rainfall data available in the Dumaresq catchment. The downstream extent of the model has been extended to the WaterNSW gauge located at Glenarbon Weir, which provides an additional reference point. Although as with Cunningham Weir there appears to be a significant issue with the high-flow rating at the gauge, the model achieves a good match of the lower flows, including the smaller flood peak that occurred prior to the larger flood event, and timing of the major peak is relatively well matched.

A7.4 Summary

The Dumaresq River catchment is unusual from a calibration perspective in that there is a large amount of stream gauge data (up to 10 gauges have been used in the calibration process) but comparatively limited detail in the rainfall gauge data, particularly for the earlier calibration events.

The BRVFMP calibration achieved a reasonable match of mainstream gauges at Bonshaw and Texas for the 1976 event but had no calibration data further downstream. The 1996 event calibration parameters produced a good match of the gauged hydrograph at the downstream gauge of Mauro, but had a poor match at many of the contributing tributary gauges, acknowledging the limitations on the available rainfall data but nevertheless suggesting issues with the routing characteristics of the major tributaries and raising concerns that the model could be used to represent other events with any confidence.

The recalibration has derived a single set of model routing parameters that produce a good and consistent match of the rated hydrographs at almost all the gauges for all three calibration flood events. Calibration of the mainstream routing downstream of Bonshaw and Texas is problematic due to the lack of reliable stream gauge data for the events. The Cunningham and Glenarbon Weir gauges, although not having reliable high-flow ratings, provide increased confidence in the model routing. The recalibrated model match of the 1996 hydrograph at Mauro does not appear as good as the original BRVFMP model, however there is a plausible explanation for the differences. Considering the improvement of the calibration at the gauges throughout the rest of the catchment, the recalibration of the model is considered significantly more robust.

A8 Macintyre Brook to Booba Sands

The Macintyre Brook URBS model covers an area of 3983km² to Booba Sands, subdivided into 43 sub-areas. Coolmunda Dam is located upstream of Inglewood. The catchment has limited rainfall gauge information, with few continuous gauges (none in 1976) and no gauges of any kind across much of the northern catchment upstream of Barongarook. Several of the stream gauges historically located in the catchment appear to have ceased operation in the early 2000's.

A8.1 February 1976 Flood

Calibration of the 1976 flood event is challenging to the limited amount of reliable rainfall and stream gauge data. Calibration hydrographs for the Macintyre Brook gauges in the February 1976 flood are shown in Figure A7-A. The BRVFMP calibration matches the general shape of the hydrographs at the DNRME stream gauges at Terraine and Barongarook upstream of Coolmunda Dam, although the peak flow at the latter is significantly underestimated. The source of the recorded inflows into Coolmunda Dam is unknown, and although the start of the hydrograph can be matched, the receding limb after the flood peak, do not appear consistent with the upstream gauges or the rainfall. The Coolmunda Headwater gauge appears to mirror the inflow. The BRVFMP calibration matches the timing of the peak inflow but not the magnitude, and also underestimates the peak flow at the Coolmunda Tailwater gauge (only peak flow is available).

At Woodspring on Canning Creek, the major tributary downstream of Coolumnda Dam, the BRVFMP calibration matches the rated peak flow but does not reproduce the shape of the recorded hydrograph particularly well. The shape of the hydrograph is also poorly matched at the Inglewood CBM and Inglewood gauges. The rated peak flow is matched at this latter gauge, however there is significant uncertainty regarding the accuracy of this value (see discussion below). There are no further calibration points downstream for the 1976 event.

The recalibration of the MacIntrye Brook model has produced a good match of the hydrographs at the tributary gauges of Terrain, Barangarook and Woodspring, as well as a good representation of the flow through Coolmunda Dam based on matching the Coolmunda inflow and headwater peak hydrograph, the tailwater rated peak and the hydrograph at Inglewood CBM.

The DNRME stream gauge at Inglewood, located downstream of the confluence of Macintyre Brook and Canning Creek, would ideally provide a key calibration point for the catchment as the downstream gauge at Booba Sands was not established until 1987. Critically, the Inglewood gauge changed from the now-closed 416402B to the current 416402C in 1981. Based on information from the DNRME Water Monitoring Information Portal, the gauge location appears to have remained relatively unchanged, however there has been a change in the control structure. This has resulted in (or at least contributed to) a significant change to the flow rating at the gauge. Figure A.2 shows the ratings for the 'B' and current 'C' gauges together with the recorded flow gauging data used to derive the ratings.

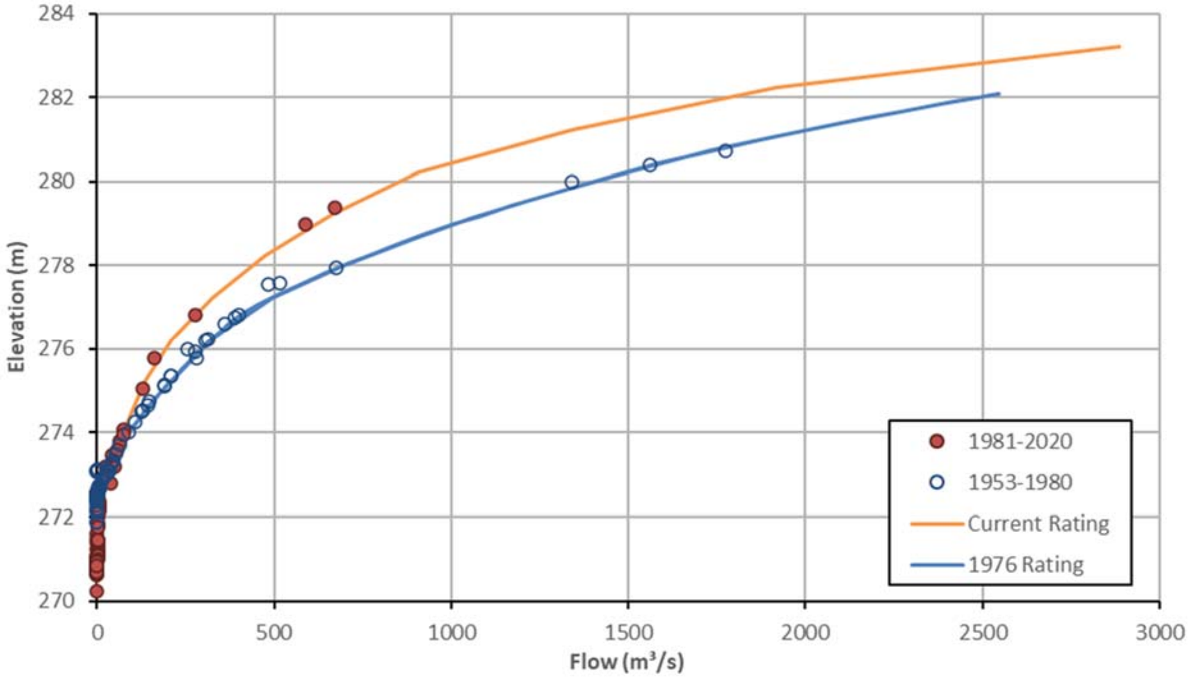


Figure A.2 1976 flood hydrograph at Inglewood calculated using 416402B and current (416402C) ratings

The original BRVFMP calibration appears to have taken levels recorded at the 'B' gauge present at the time of the 1976 flood but then, after adjusting for the change in gauge datum, applied the rating for the current 'C' gauge to calculate flow. This method does not seem appropriate, particularly for low flows, due to the changes introduced by the modified control weir. Use of the more recent rating for high flows is debatable as it is unknown how much (if any) the changes to the control weir structure would affect the high-flow rating. The 'B' gauge is theoretically well rated being based on high recorded flows, however these gaugings were all obtained in 1956. The methods used to obtain the more recent flow measurements and derive the flow rating for the 'C' gauge would likely be more reliable.

The revised calibration produces a good match of the general shape and timing of the hydrograph, with the only real uncertainty being the exact magnitude of the flow. The recalibration process found that it was impossible to achieve consistency between the upstream gauges and the peak flow estimate using either rating (i.e. matching the higher 'B' rating requires overestimating the upstream flows, while matching the lower 'C' rating requires underestimating the upstream flows). The adopted hydrograph matches the low flows using the 'B' rating, consistent with the control structure that was present during the 1976 flood. The peak of the hydrograph, which lies between the 'B' and 'C' rated values is considered a reasonable compromise given the uncertainty in the rating and is consistent with the calibration at the upstream gauges.

A8.2 January 1996 Flood

The January 1996 flood was caused by a number of short, concentrated storms over a period of several days. Due to the limited number of rainfall gauges in the catchment the accuracy of the rainfall distribution across the catchment is likely to be limited. A number of the stream gauges also provide only limited information (the gauges recorded only a few levels and/or failed part-way through the flood). Calibration hydrographs for the Macintyre Brook gauges in the January 1996 flood are shown in Figure A7-B.

The BRVFMP model calibration appears to match the general timing of the hydrographs at the gauges in the Macintyre Brook catchment upstream of Inglewood relatively well, although the detail and distribution of the individual flood bursts is not particularly good. This can likely be attributed to limitations in the rainfall distribution in the BRVFMP model. The main downstream gauges of Inglewood and Booba Sands generally reflect the shape and peak of the recorded hydrographs, although the later peak occurring on the 26 January is significantly overestimated. It is unknown whether this is due to poor rainfall distribution for this burst or whether the calibration of the model and loss parameters focussed too heavily on the major peak.

The BRVFMP calibration of the major tributary of Canning Creek at Woodspring appears to be poor. Acknowledging that the Woodspring gauge does not provide the full hydrograph, a very large reach length factor has been deliberately applied to this reach, suggesting that the calibration at this gauge has been sacrificed to improve the downstream calibration at Inglewood and Booba Sands.

The revised calibration conducted a review of available rainfall data that has potentially sourced a few additional rainfall pluviographs, but has also employed more advanced techniques for distributing the rainfall across the catchment. This appears to have allowed a better calibration of the tributary stream gauges, although there are still evident discrepancies (for example the third distinct peak occurring on 24 January is present in the calculated flow at Barangarook, but completely missing at Terraine). Overall, a good calibration is achieved at each of the stream gauges considering the limited detail of the input data.

A8.3 January 2011 Flood

The January 2011 flood was produced by two distinct rainfall events resulting in two distinct flood peaks. In the Macintyre Brook catchment these were of roughly equal magnitude (whereas in the Macintyre and Dumaresq River catchments the second event was typically significantly larger). The rainfall was more heavily concentrated over the eastern catchment upstream of Coolmunda Dam. Many of the stream gauges in the Macintyre Brook catchment were removed from service between the 1996 and 2011 floods, meaning that there is less calibration information available for this event. Several of these stream gauges also provided continuous rainfall data for the 1996 event that was therefore not available for the 2011 calibration.

The calibration hydrographs for the Macintyre Brook gauges in the January 2011 flood in Figure A7-C demonstrate a reasonable match of the rated flows at the major gauges at Inglewood and Booba Sands. The Coolmunda Headwater gauge rated flow is also relatively well matched for the first peak. The absence of the second peak from the rated hydrograph is surprising but not critical. Coolmunda Dam is a regulated dam with the gated outflow theoretically controlled as a function of the reservoir level. The first major peak and second minor peak appear to have been operated in a manner consistent with the published headwater rating (noting that maximum outflow of nearly 600m³/s corresponds to a reservoir level increase of only around 160mm above the zero flow level), however review of the headwater level record indicates that the reservoir was drawn down and maintained at a level approximately 100mm below full supply level throughout the second burst. Therefore, although there was almost certainly release from the dam during this period, with the outflow approximately equal to the inflow, this is below the zero-flow level of the headwater gauge rating.

A8.4 Summary

Calibration of the Macintyre Brook catchment is based on the least reliable data of the three major tributaries, with relatively little detailed rainfall data and issues identified at a number of the stream gauges. The original BRVFMP calibration of the February 1976 flood event achieved a good match of the rated peak flow at Inglewood (although the actual value of this rated peak is questionable) but did not match the overall shape of the hydrograph particularly well. A reasonable match of the hydrographs at the downstream gauges at Inglewood and Booba Sands was achieved for the 1996 event, however the match at some of the upstream gauges was not as good.

The recalibration has achieved a good representation of the shape of the hydrograph at the primary calibration gauge at Inglewood for the February 1976 flood (although there is some ambiguity over the magnitude due to uncertainty in the gauge rating for this event) as well as a good match of the upstream

stream gauges. Good matches were also obtained for the almost all of the available stream gauges for both the 1996 and 2011 flood events. The model is therefore considered to be well calibrated throughout the catchment.

A9 Ottleys Creek

The original Ottleys Creek hydrologic model provided by DPIE was developed in an old version of the XP-RAFTS software package rather than the URBS software used for the major tributaries. Calibration details for this model are unknown. For the current investigation this has been replaced by a new URBS model. The model has been developed from available 5m LIDAR survey supplemented by 1second (approximately 30m) SRTM using in-house GIS manipulation software. The Ottleys Creek URBS model layout is shown in Figure A8. The model covers an area of 1210km² to the transfer boundary where the model interfaces with the lower Macintyre River floodplain model. The stream gauge at Coolatai, with a catchment area of 385km² is the sole calibration point within the catchment.

A9.1 February 1976 Flood

The Coolatai stream gauge was not operational during the February 1976 flood, hence there is no valid calibration data for the Ottleys Creek catchment for this event. The current modelling has adopted model routing parameters derived from the other calibration events combined with rainfall losses consistent with values derived for the surrounding catchments (Macintyre River and lower Macintyre Floodplain). Calculated hydrographs for Ottleys Creek in the February 1976 flood are shown in Figure A10-A.

The outflow hydrograph produced by the BRVFMP RAFTS model is shown for comparison. The peak outflow predicted by the BRVFMP model is significantly lower than the current URBS model and only slightly higher than the 1996 event. Although there is no data to confirm one way or the other, this is somewhat surprising because, as shown in Figures A2 and A3, the rainfall depth across the Ottleys Creek catchment was significantly greater in 1976 and concentrated into a single event rather than a series of bursts.

A9.2 January 1996 Flood

The January 1996 flood in the Ottleys Creek catchment comprised two short storms on sequential days. The rainfall was most strongly concentrated over the central part of the catchment around Coolatai and Wallangra. Calibration hydrographs for Ottleys Creek in the January 1996 flood in Figure A10-B show that a good match is achieved at the Coolatai stream gauge. There is no calibration data for the lower catchment, so the same routing and loss parameters have been adopted. The outflow hydrograph produced by the BRVFMP RAFTS model is shown for comparison, with the hydrograph having a delayed and reduced peak. Calibration information for the BRVFMP model at Coolatai has not been provided.

A9.3 January 2011 Flood

The rainfall that generated the January 2011 flood was concentrated primarily over the eastern side of the Macintyre River catchment. Comparatively little rain fell within the Ottleys Creek catchment, and only a minor flood peak was observed at Coolatai. The calibration hydrographs for Ottleys Creek in the January 2011 flood in Figure A10-C match the Coolatai stream gauge record.

A9.4 Summary

A new URBS hydrologic model of the Ottleys Creek catchment has been developed to replace the old XP-RAFTS model used in the BRVFMP. The model appears to be well calibrated against the stream gauge at Coolatai, although there is no gauge data to allow calibration of the lower catchment. The new model appears to produce shorter, higher peaks at the downstream boundary than the previous BRVFMP model. Details of the BRVFMP model calibration have not been provided for comment.

A10 Lower Macintyre Floodplain

The original BRVFMP hydraulic modelling used inputs from the four major tributaries (Macintyre River, Dumaresq River, Macintyre Brook and Ottleys Creek) but did not include hydrologic (rainfall) inputs from the lower Macintyre floodplain, A new URBS hydrologic model has therefore been developed for the current investigation covering the area downstream of the major tributary catchments. Outputs from the major tributary models are used as upstream inflows for the lower Macintyre floodplain model. The model has been developed using in-house GIS manipulation software from available 2m and 5m LIDAR survey sets covering the majority of the catchment area, supplemented by 1second (approximately 30m) SRTM data in areas where LIDAR was not available. The Lower Macintyre floodplain URBS model layout is shown in Figure A9. The model can be divided into several separate regions:

- The main river channel system including the Macintyre River channel from Holdfast to downstream of Goondiwindi and the lower reaches of the Dumaresq River downstream of Glenarbon Weir and Macintyre Brook downstream of Booba Sands, as well as additional local tributaries flowing into the Macintyre River (Subareas 1 to 24)
- The southern creek catchments that share the southern Macintyre River floodplain, consisting of Whalan Creek and its tributaries, including Mobbindry Creek, Back Creek and Forrest Creek (Subareas 25 to 95). A more detailed discretisation of the catchment has been used to allow generation of rainfall data for the local creek flood event flows at the proposed rail alignment.
- The southern floodplain breakouts, including Morella and Boobera Watercourses (Subareas 96 to 114)
- The Brigalow Creek catchment north of Boggabilla (Subareas 123 to 129)

The primary purpose of the Lower Macintyre Floodplain model is to provide inflows for the TUFLOW hydraulic model. This includes:

- Translation of the Macintyre Brook and Dumaresq River inflows between the current downstream extent of the URBS models and the TUFLOW model inflow location (these URBS models currently terminate upstream of the TUFLOW model boundary)
- Generation of inflow hydrographs for Brigaglow Creek and a number of minor external catchments around the periphery of the TUFLOW model boundary
- Generation of local catchment runoff for the areas within the TUFLOW model boundary

Although the Lower Macintyre Floodplain model is largely overlapped by the TUFLOW hydraulic model, it has been set up to function as a stand-alone model capable of performing (hydrologic) flood routing of the river system down to Goondiwindi. Modelling of the lower Macintyre River is complicated by the floodplain flow characteristics. In larger flood events, the main Macintyre River system overflows into the adjacent catchments. Hydrologic modelling is generally based on a simple upstream to downstream routing procedure. URBS can however represent breakout flows in the form of a loss as a linear (or step-linear) function of the channel flow, which can then be input back into the system at another location. Using this technique to represent the floodplain breakout patterns requires complex continuous flow characteristics to be approximated by discrete linear relationships. The relationships between breakout flow and main channel flow were determined from the calibrated TUFLOW hydraulic model. Several breakout locations have been identified and included in the hydrologic model:

- Across the southern floodplain into Whalan Creek upstream of Boggabilla
- Across the southern floodplain into Morella watercourse upstream of Boggabilla
- Northwards into the Brigalow Creek system downstream of Boggabilla

The locations of these breakouts are shown in Figure A9. There is likely to be additional breakout into the Morella Watercourse between Boggabilla and Goondiwindi. This breakout flow has not currently been included in the model, and all floodplain and/or breakout flow is included in the reported Goondiwindi flow.

A10.1 Lower Macintyre stream gauges

Stream gauges are located at Boggabilla and Goondiwindi. The calibration results at the Boggabilla gauge presented below have been assessed using updated ratings developed as part of the current FFJV investigation. Results of the calibrated TUFLOW model were combined with flow gauging measurements as part of a more rigorous assessment that accounts for hysteresis (an offset or lag between change in flow and change in level at the gauge, usually caused by downstream storage effects) and provides a clear distinction between the flow at the gauge and the total upstream catchment flow. This is discussed further in Appendix F. Separate ratings were developed relating the stream gauge level recorded at the Boggabilla to:

- Flow at the Boggabilla gauge site, located downstream of Boggabilla that includes the main river flows and breakout to Brigalow Creek system (which occurs at and downstream of the gauge site) but exclusive of upstream breakout to Whalan Creek and Morella Watercourse
- Correlated total flow from the upstream catchment (measured approximately 7km east of Boggabilla where Bruxnor Highway crosses the floodplain)

Calibration results presented below use the rating derived for the flow at the Boggabilla gauge site, noting that there is a delay of several hours between the total flow upstream and the gauge level at Boggabilla.

Review of the Goondiwindi gauge rating and record indicate that there is a significant issue with the high flow rating. During larger flood events the river level rises to and plateaus at approximately 10.5m gauge datum (~1400m³/s rated flow). This can be attributed to the significant floodplain flow and breakouts that occur upstream of and around the gauge site. Large changes in flow above this level cause very little change in river level. The derived gauge rating, based on extrapolation of entirely in-stream flow gaugings, does not accurately register the total river and floodplain flow above this level.

A10.2 February 1976 Flood

Calibration hydrographs for the lower Macintyre floodplain model in the February 1976 flood are shown in Figure A10-A. Only the peak level is available at the Boggabilla gauge for this event. The modelled peak shows good agreement with the rated flow. At Goondiwindi, although the gauged flow plateaus at approximately 1400m³/s as discussed above, the calculated hydrograph shows a very good match of the start and end of the hydrograph, This indicates that the combined models are representing the timing of the flood hydrograph very well.

A10.3 January 1996 Flood

The multiple short storm events that formed the January 1996 flood merge to form a single broad peak in the lower Macintyre River. The calibration hydrographs for the lower Macintyre floodplain model in the February 1976 flood are shown in Figure A10-B. A very good match of the rated flow is obtained at the Boggabilla stream gauge. The underestimate of the flow on back end of the flood peak on the 26 January can be directly related to the ‘missing’ flow in the Macintyre River and Dumaresq River catchment models, discussed in Sections A6.2and A7.2 respectively. The stream gauge at Goondiwindi also shows a good match of the timing of the hydrograph.

A10.4 January 2011 Flood

The January 2011 flood produced a minor peak in the lower Macintyre River on the 9th to 10th of January, followed by a larger second peak on the 14 January. The calibration hydrographs for the lower Macintyre floodplain model in the January 2011 flood in Figure A10-C show a good match of the shape and timing of the recorded hydrographs at Boggabilla and Goondiwindi.

A10.5 Summary

A new URBS hydrologic model of the Macintyre River floodplain has been developed to cover the area from the upstream tributary models to downstream of Goondiwindi. The model includes Whalan Creek and its tributaries to the south of the Macintyre River and parts of Brigalow Creek catchment to the north. The primary purpose of the model is to provide both major inflow and local subarea runoff for input into the TUFLOW hydraulic model.

The complex flow characteristics of the Macintyre River floodplain test the limits of what would typically be expected from a hydrologic routing model. The lower floodplain model is almost entirely overlapped by the TUFLOW hydraulic model. Therefore, although desirable, it is not critical that a perfect calibration of the URBS hydrologic model is achieved. Nevertheless, the calibration results suggest that the model produces a very good representation of the river routing and that the breakout flow relationships derived from the TUFLOW modelling and implanted in the URBS model provide an acceptable approximation of the behaviour of the floodplain. The model shows a very good calibration at the Boggabilla stream gauge and a good representation of the in-channel flows at Goondiwindi, noting that additional work is required to represent the floodplain flow/breakout between Boggabilla and Goondiwindi and/or to improve the Goondiwindi rating so that it includes floodplain flows.

A11 Conclusions

Operation of the FFJV Macintyre River TUFLOW model is heavily dependent on the input from three URBS hydrologic models of the upstream Macintyre River, Dumaresq River and Macintyre Brook tributaries originally developed for the BRVFMP. These models were initially calibrated against the major February 1976 flood event, and later recalibrated to against a series of floods that occurred in January and May of 1996. However, these later calibrations used different channel routing parameters without revisiting the original 1976 calibration, resulting in two (or more) dissimilar models.

Recalibration of the BRVFMP hydrologic models has been undertaken primarily for the purpose of developing a single set of models capable of replicating these (and other) events. The recalibration has taken advantage of additional stream gauge and rainfall information, improved rainfall distribution methodology, as well the significant additional information obtained during the more recent major flood event in January 2011. The recalibration has achieved several significant outcomes:

- The models have been successfully calibrated at multiple stream gauges within the catchment, demonstrating that they are internally consistent and that they successfully represent the runoff contributions from all parts of the catchment in terms of both magnitude and timing
- Multiple events of different magnitude and duration have been simulated using a single set of parameters, demonstrating that the routing characteristics are representative of the real catchment and are consistent over a wide range of flows. Adopted calibration parameters are summarised in Table A3.
- Inclusion of additional rainfall, stream gauge and event information not available for the previous calibration has provided additional calibration data at key points in the model, particularly the downstream reaches. The models are believed to provide an improved representation of the magnitude and timing of inflows into the lower Macintyre floodplain.
- Overall, these improvements indicate that the model is reliably representing the physical stream routing characteristics present in the catchment, providing improved confidence the models can be used to reliably represent events other than the specific calibration floods

New models have also been developed for the Ottleys Creek catchment, and the lower Macintyre River floodplain area covering the area from the upstream catchments to downstream of Goondiwindi. Although the primary purpose of the lower floodplain model is to provide inputs for the hydraulic modelling, the model has nevertheless attempted to replicate the floodplain flow characteristics which see larger flood events overflow into the Whalan Creek, Morella Watercourse and Brigalow Creek systems. The lower floodplain model has been successfully calibrated to the stream gauges at Boggabilla and Goondiwindi. This successful calibration indicates that although the methods used to model the breakout patterns are relatively simplistic, they nevertheless provide a reasonable representation of the river flow properties. Importantly, this good calibration also confirms that the upstream catchment models are well representing the magnitude and timing of the inflows used by the lower catchment model.

Table A3 Hydrologic model calibration parameters

Parameters	Macintyre River	Dumaresq River	Macintyre Brook	Ottleys Creek	Macintyre Floodplain
Alpha	0.45	0.45	0.45	0.45	0.45
n	0.85 [a]	0.85	0.85 [b]	0.85	1.0
Beta	1.2	1.2	1.2	1.2	1.2
m	0.8	0.8	0.8	0.8	0.8
x	0.3	0.3	0.3	0.3	0.1
Reach Length Factors	0.6 to 1.6	1.0 to 3.0	0.8 to 2.0	1.0	0.3 to 3.0
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

Table notes:

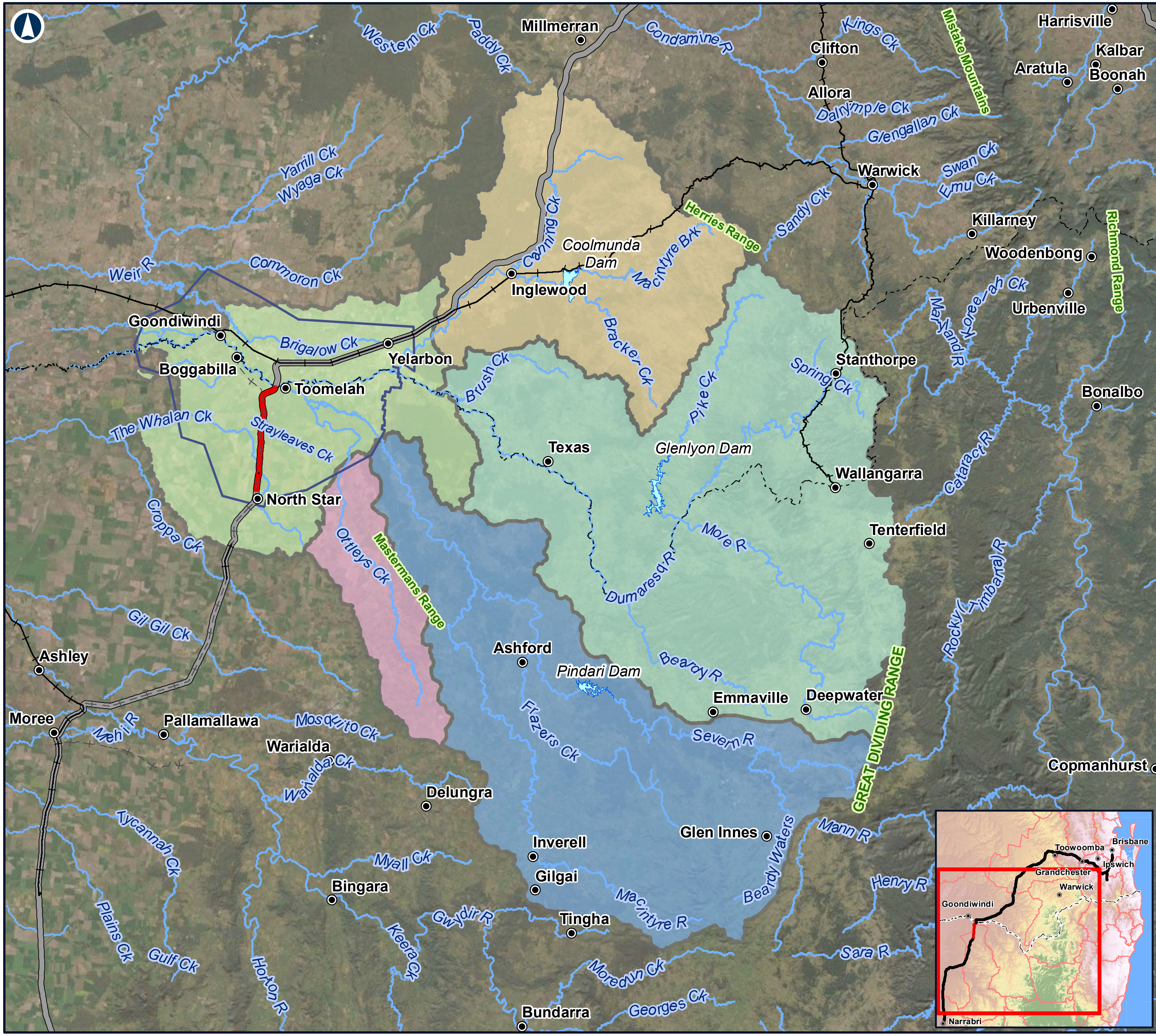
a n=1.0 for lower reach between Ridgeland and Holdfast
b n=1.0 for lower reach between Inglewood and Booba Sands

A12 Limitations

The assessment has been conducted using best available information and practices. The model is dependent upon data provided by outside sources.

- Modelling of the three major tributary catchments (Macintyre River, Dumaresq River and Macintyre Brook) has been conducted using URBS models provided by DPIE. The model information includes subarea connectivity, catchment areas and reach lengths in text format. Subarea centroid locations were provided however other GIS information (e.g. subarea boundaries and reach alignments) was not provided. The general configuration of the model has been assumed to be correct. Errors were identified with a number of the subarea centroid locations. These were repositioned using best-estimate of the correct location.
- The calibration has used stream gauge and rainfall data sourced from third parties (predominantly BoM, DNRME (QPD) and WaterNSW. Data was cross-checked and verified where possible, and a number of apparent translation errors in the data records were identified and corrected, however the data still potentially contains errors outside Aurecon's control.
- The source of stream gauge data for a number of sites from the original BRVFMP calibration are unknown
- Flows at stream gauges have been calculated using level-flow ratings. These ratings have been subject to change historically and will likely continue to change as additional information is recorded at the gauges. Flow calculations have used the best understanding of the appropriate stream gauge rating

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, USGS, NOAA



ARTC InlandRail

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

NORTH STAR TO NSW/QLD BORDER

Figure A1:
Catchment plan

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- North Star to NSW/QLD border alignment
- Adjoining alignments
- NSW/QLD border
- Watercourses
- NS2B upstream dams
- TUFLOW model boundary

Model catchments

- Macintyre Brook
- Dumaresq River
- Macintyre River
- Ottleys Creek
- Lower floodplain

30 km

Coordinate System: GDA 1994 MGA Zone 56

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1:1,400,000

Basemap Imagery & Terrain Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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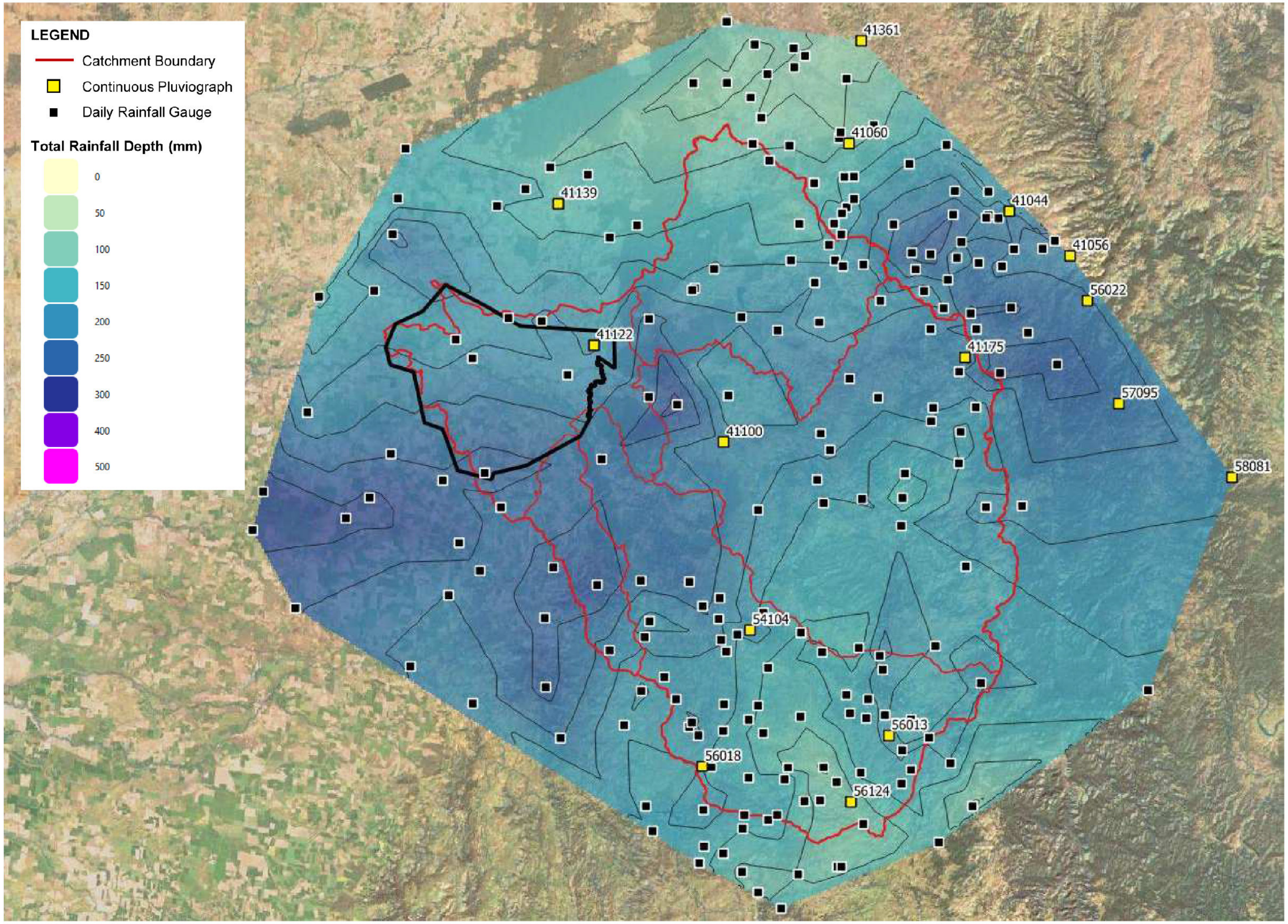
NORTH STAR TO NSW/QLD BORDER

Figure A2:
Calibration event total rainfall depth
February 1976



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Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

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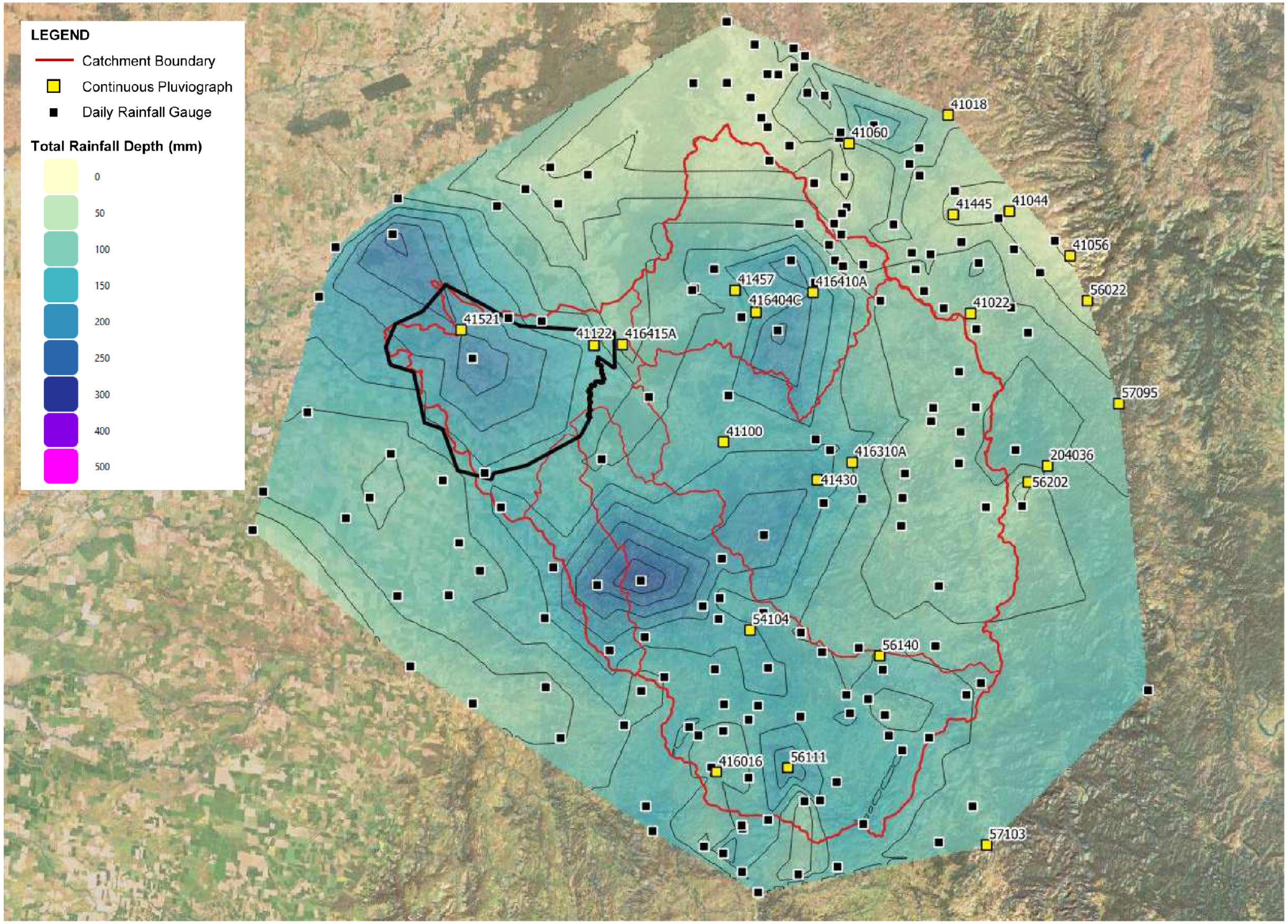

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NORTH STAR TO NSW/QLD BORDER

Figure A3:
Calibration event total rainfall depth
January 1996

Coordinate System: N/A for templated Images

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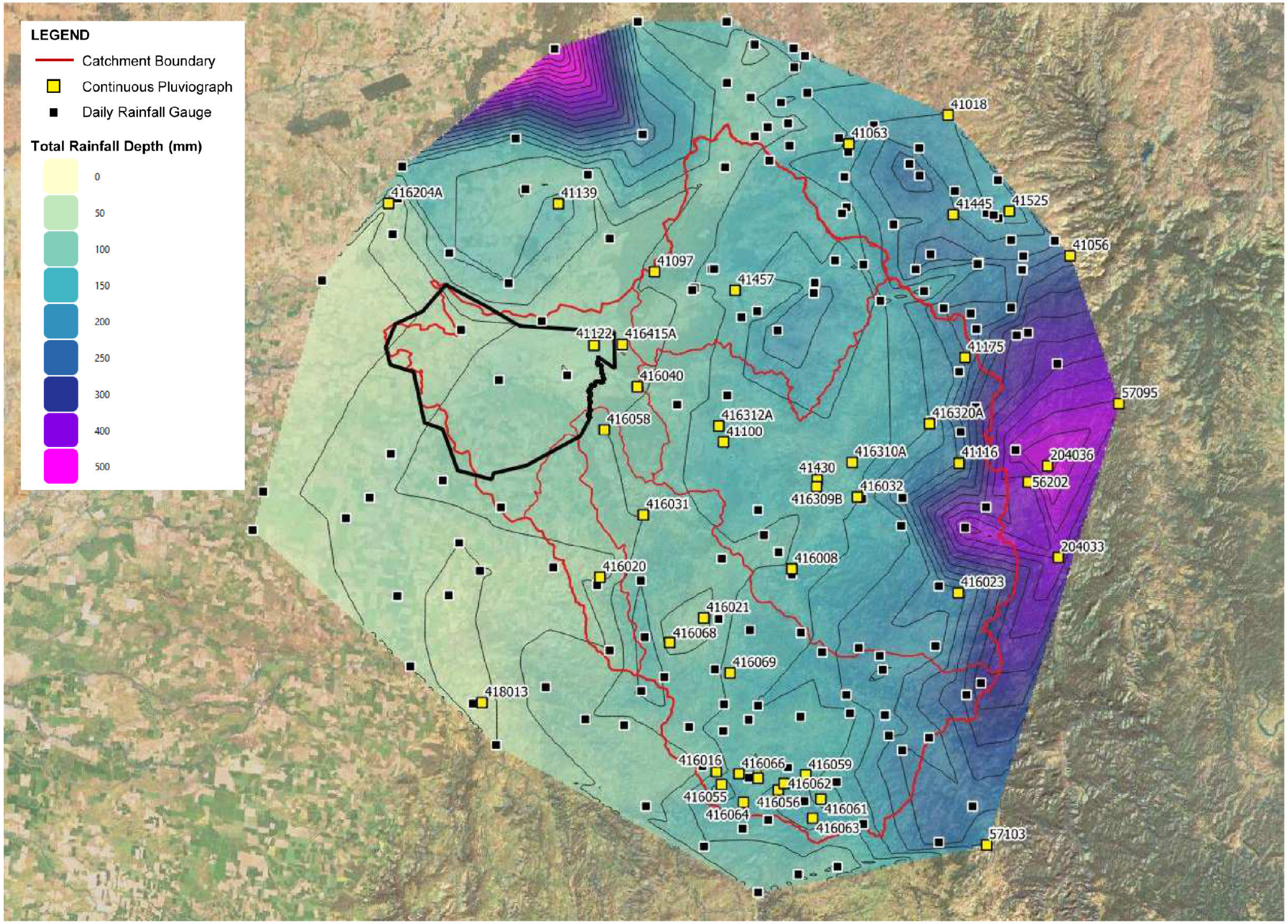

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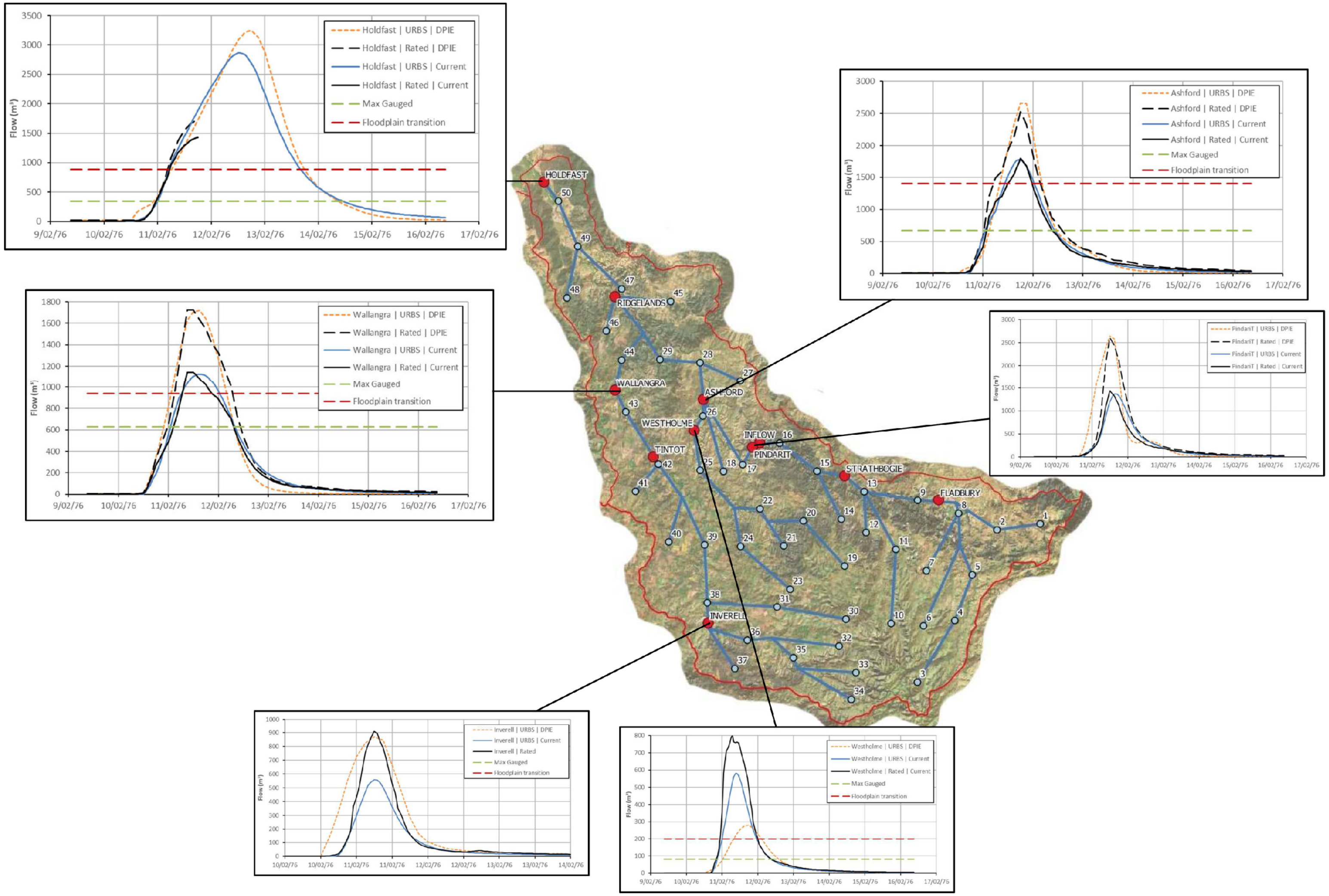
NORTH STAR TO NSW/QLD BORDER

Figure A4:
Calibration event total rainfall depth
January 2011

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

MACINTYRE RIVER TO HOLDFAST – 1976



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NORTH STAR TO NSW/QLD BORDER

Figure A5-A:
Macintyre River to Holdfast
1976 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

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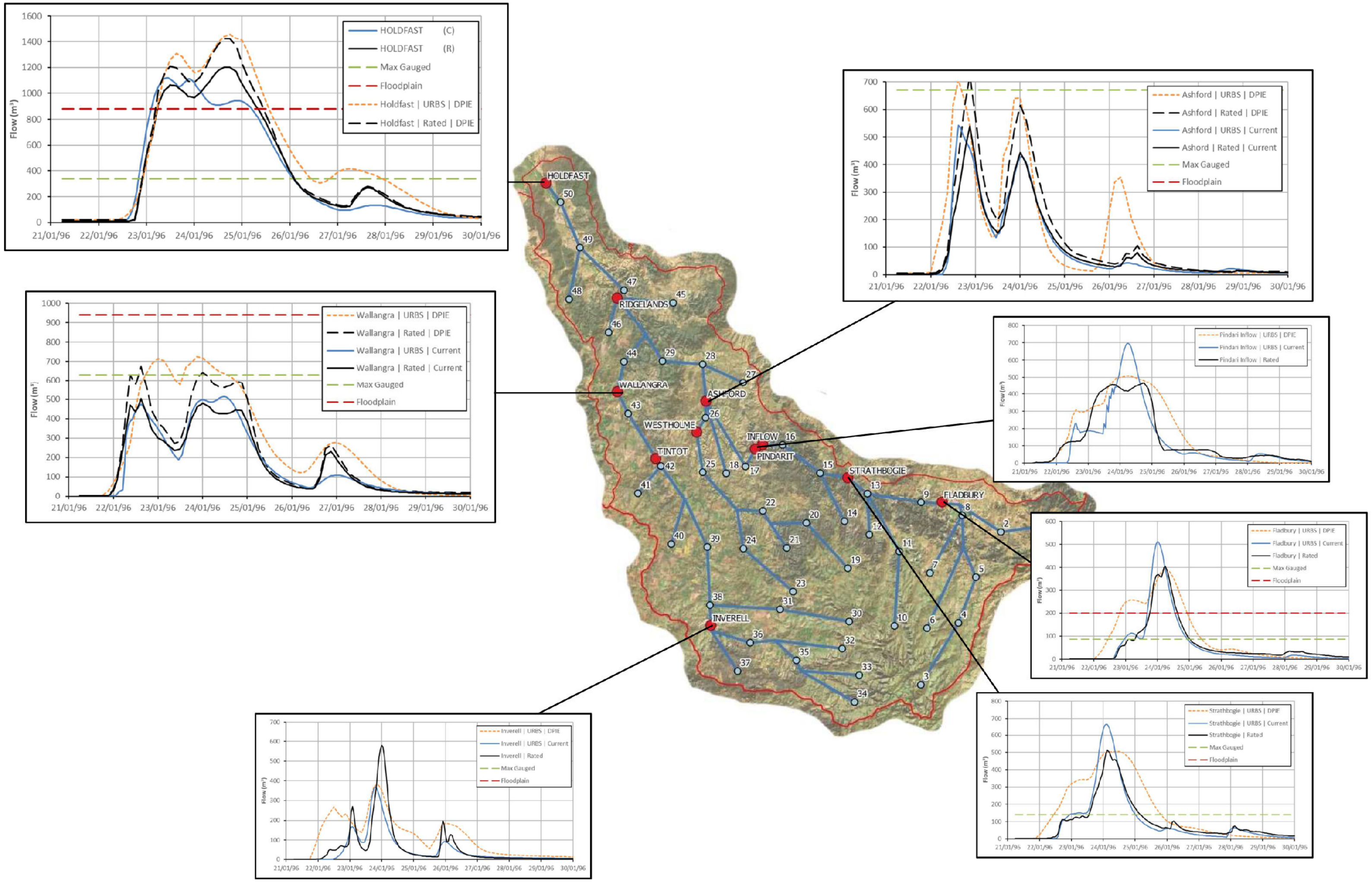
MACINTYRE RIVER TO HOLDFAST – 1996



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NORTH STAR TO NSW/QLD BORDER

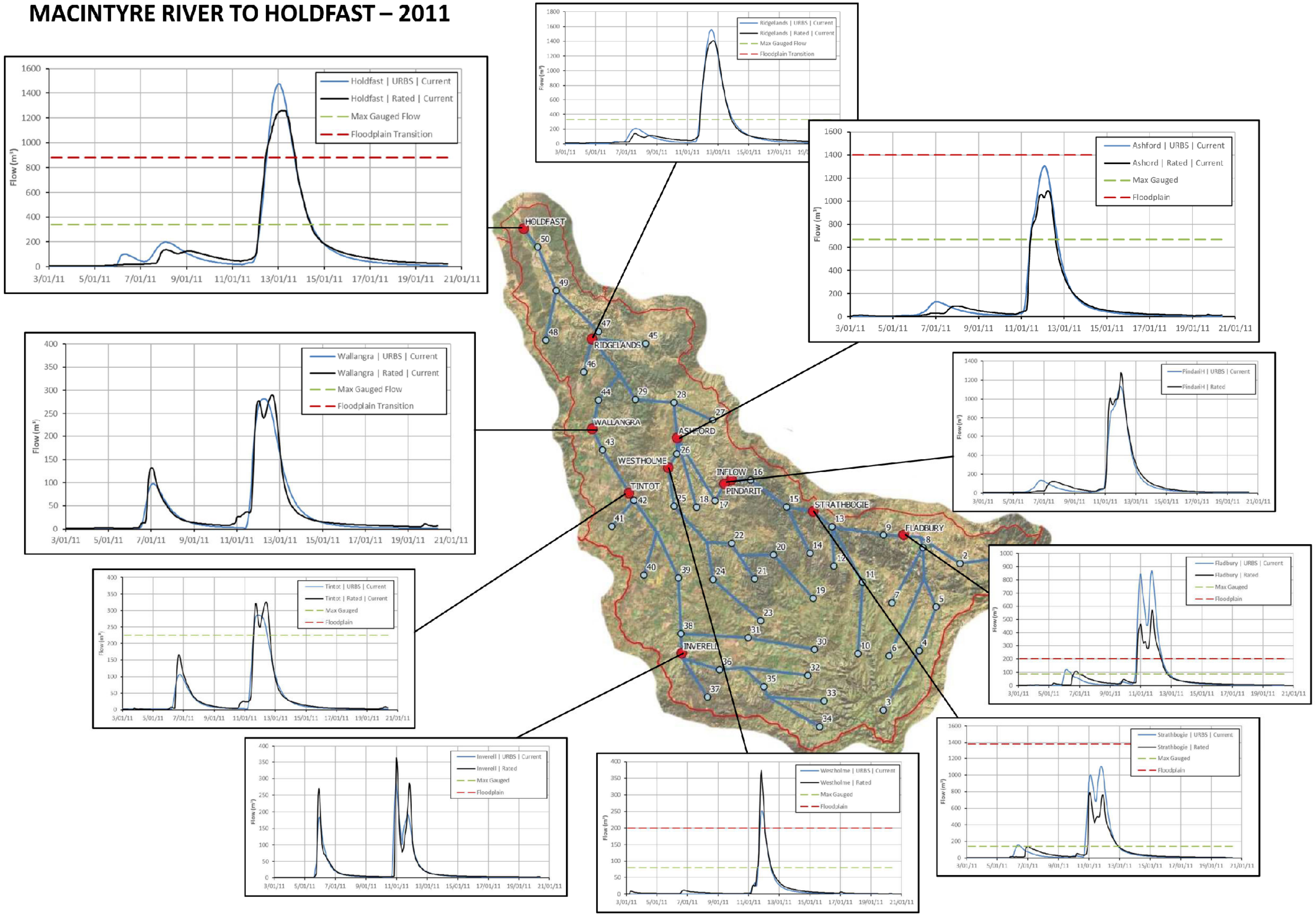
Figure A5-B:
Macintyre River to Holdfast
1996 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS 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_ddImages2_A4L_v1.mxd Date: 15/03/2021 14:14

MACINTYRE RIVER TO HOLDFAST – 2011



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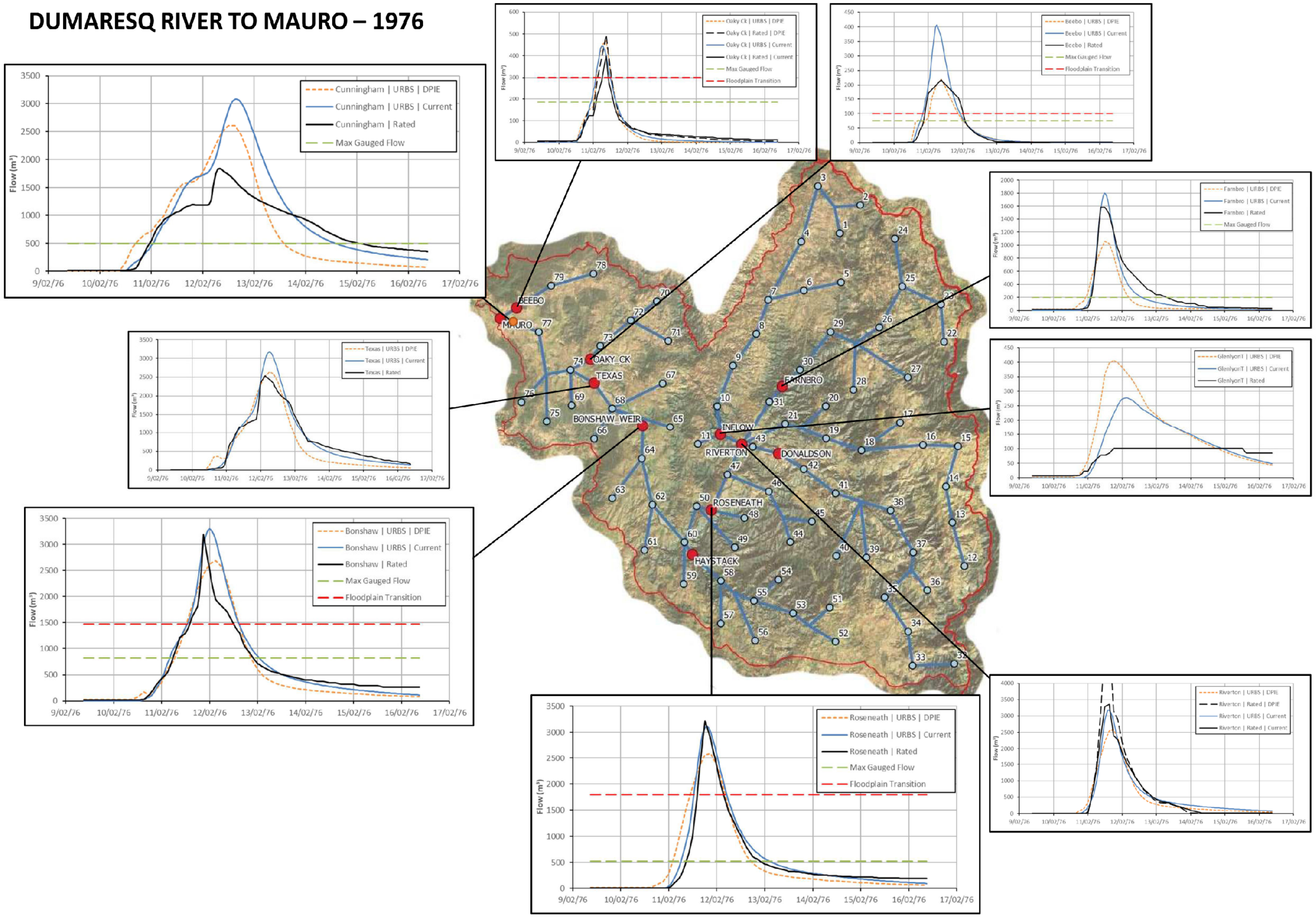
NORTH STAR TO NSW/QLD BORDER

Figure A5-C:
Macintyre River to Holdfast
2011 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

DUMARESQ RIVER TO MAURO – 1976



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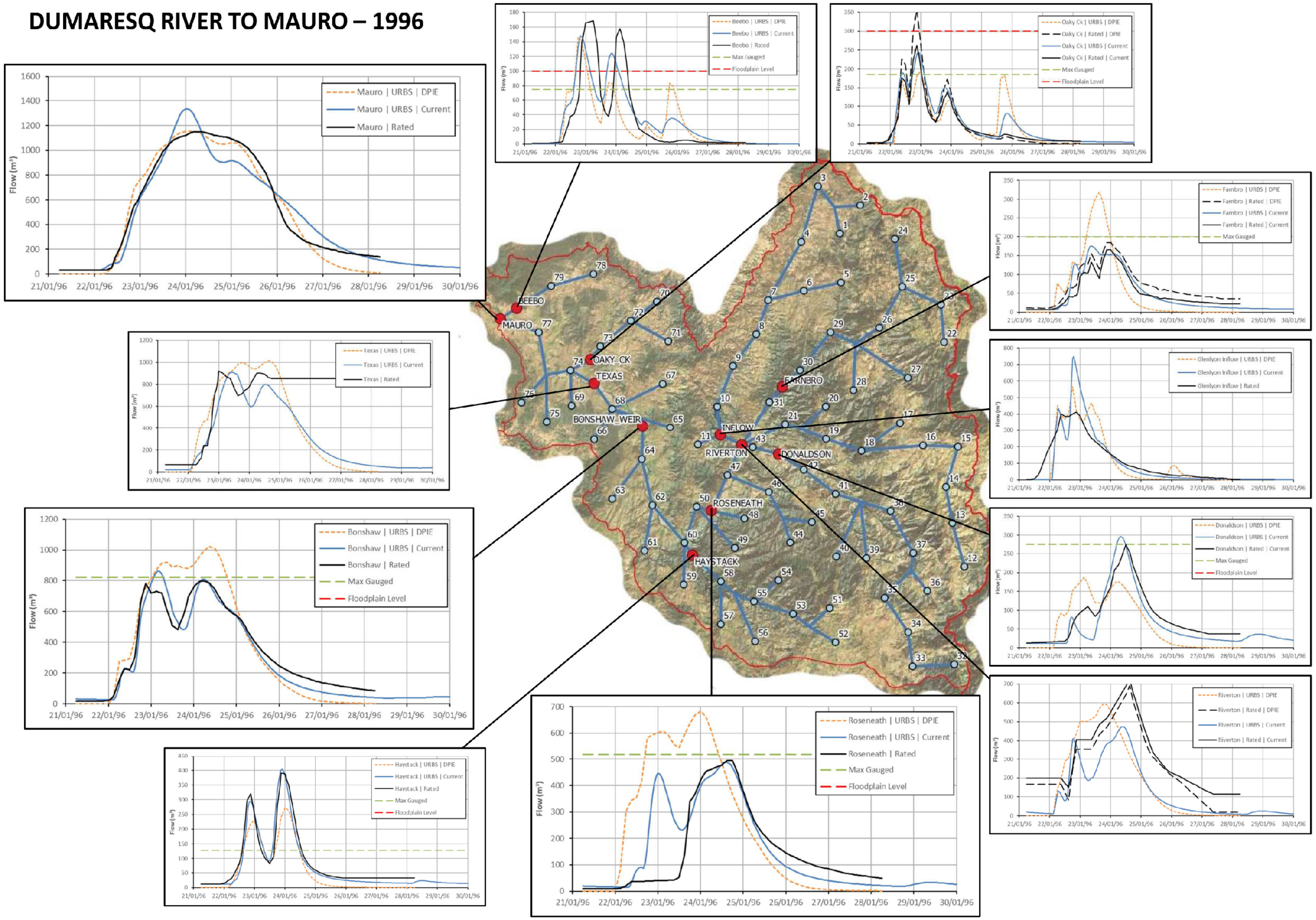
NORTH STAR TO NSW/QLD BORDER

Figure A6-A:
Dumaresq River to Mauro
1976 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

DUMARESQ RIVER TO MAURO – 1996



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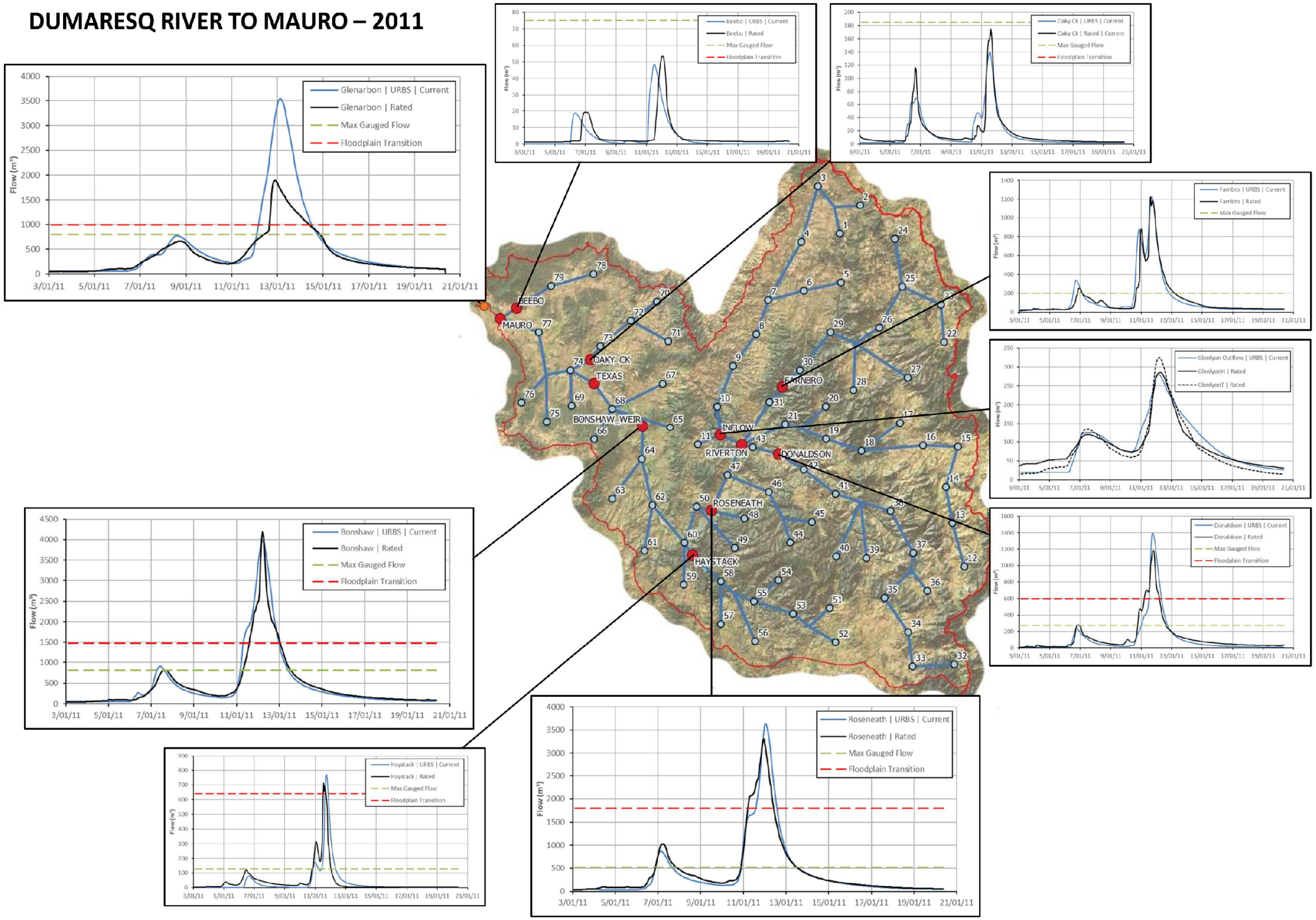
NORTH STAR TO NSW/QLD BORDER

Figure A6-B:
Dumaresq River to Mauro
1996 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

DUMARESQ RIVER TO MAURO – 2011



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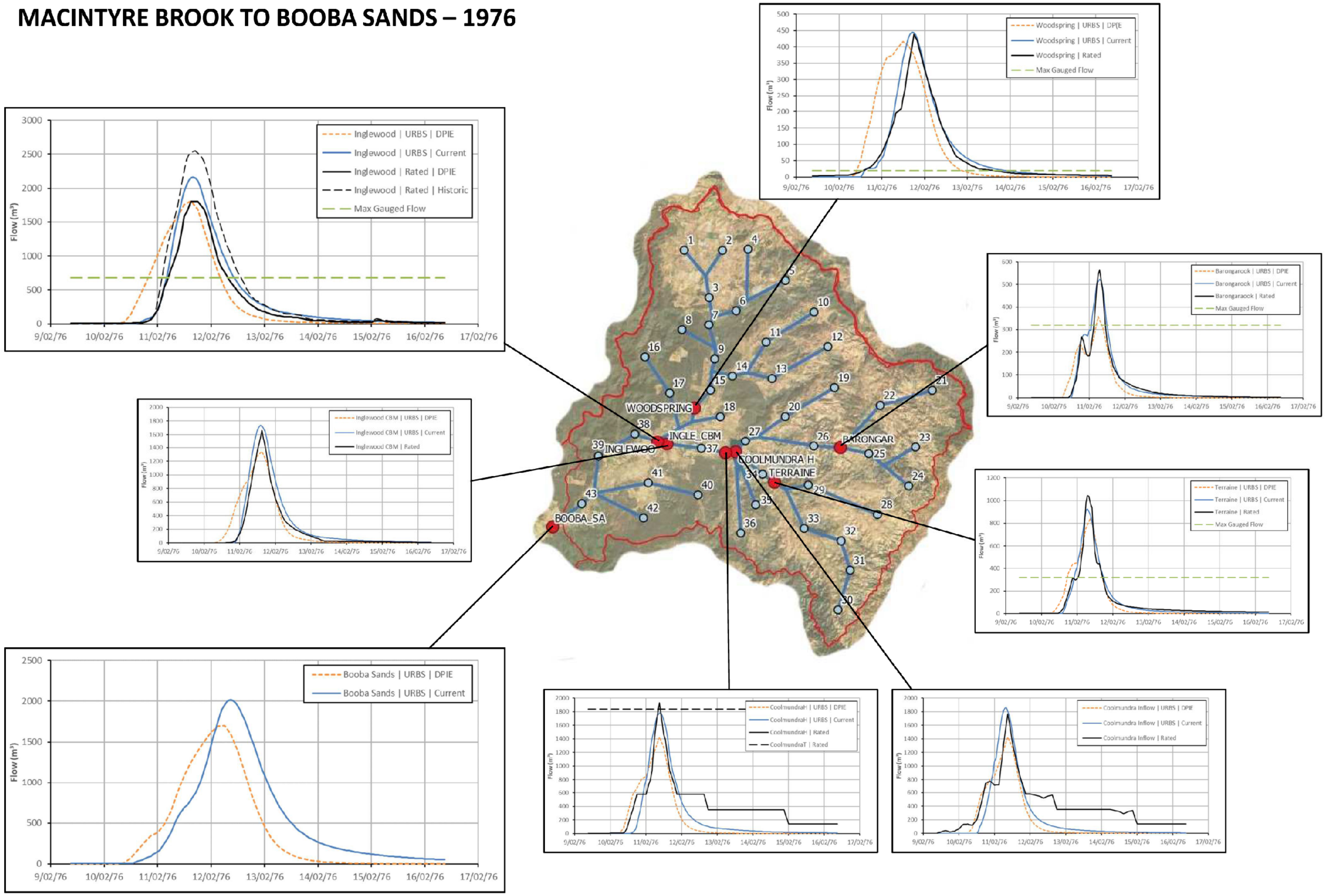
NORTH STAR TO NSW/QLD BORDER

Figure A6-C:
Dumaresq River to Mauro
2011 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

MACINTYRE BROOK TO BOOBA SANDS – 1976



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NORTH STAR TO NSW/QLD BORDER

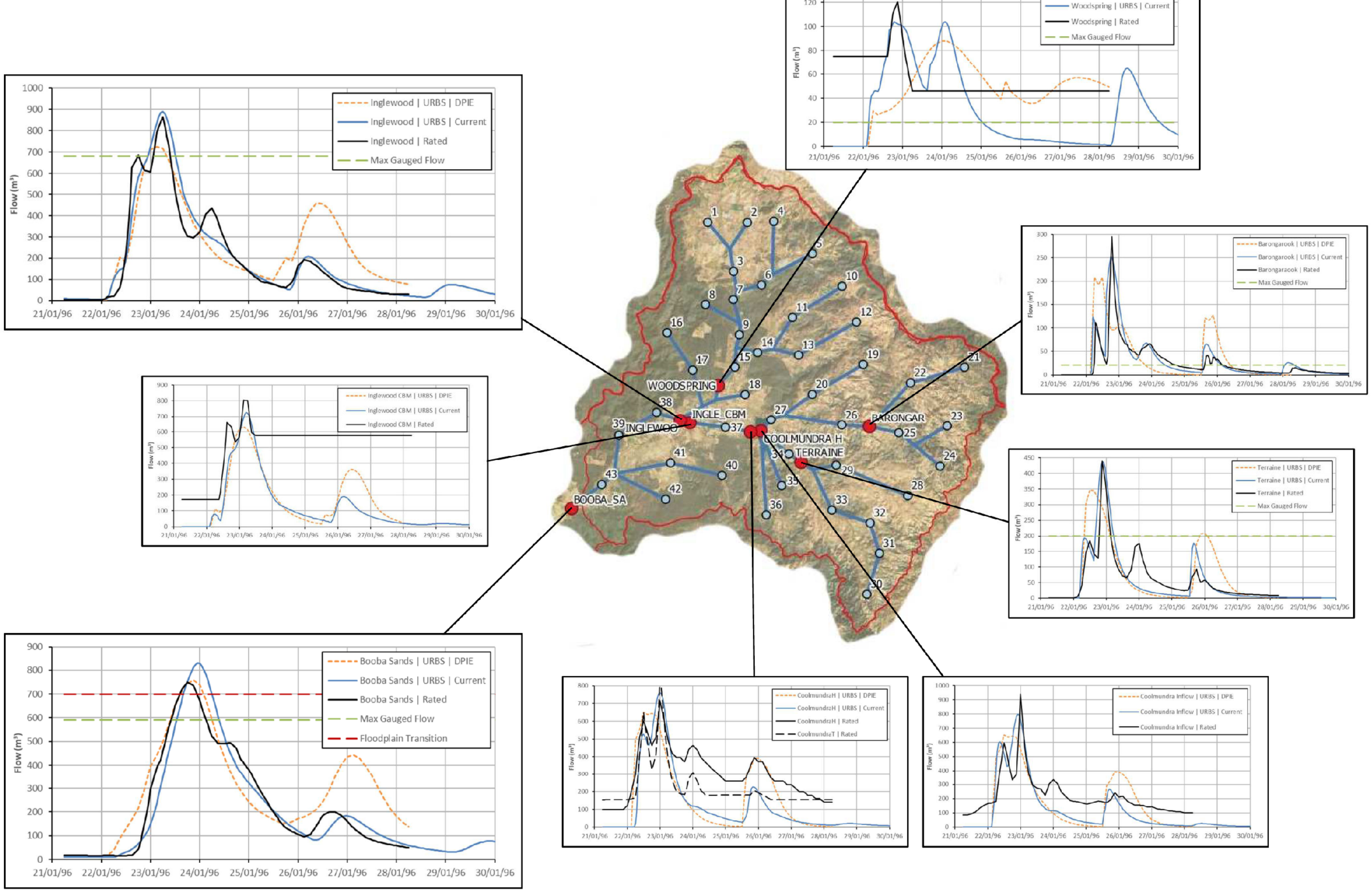
Figure A7-A:
Macintyre Brook to Booba Sands
1976 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS 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_ddImages2_A4L_v1.mxd Date: 15/03/2021 14:15

MACINTYRE BROOK TO BOOBA SANDS – 1996



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NORTH STAR TO NSW/QLD BORDER

Figure A7-B:
Macintyre Brook to Booba Sands
1996 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

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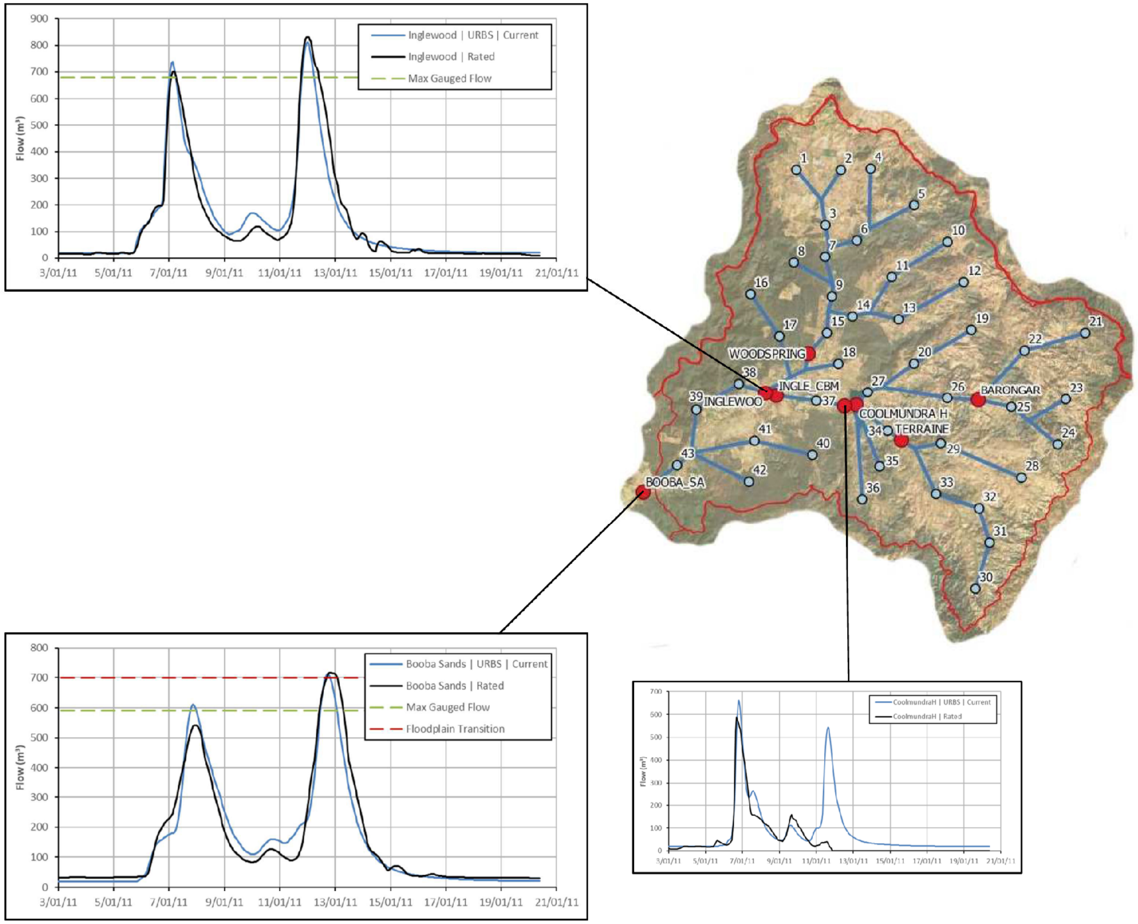
MACINTYRE BROOK TO BOOBA SANDS – 2011



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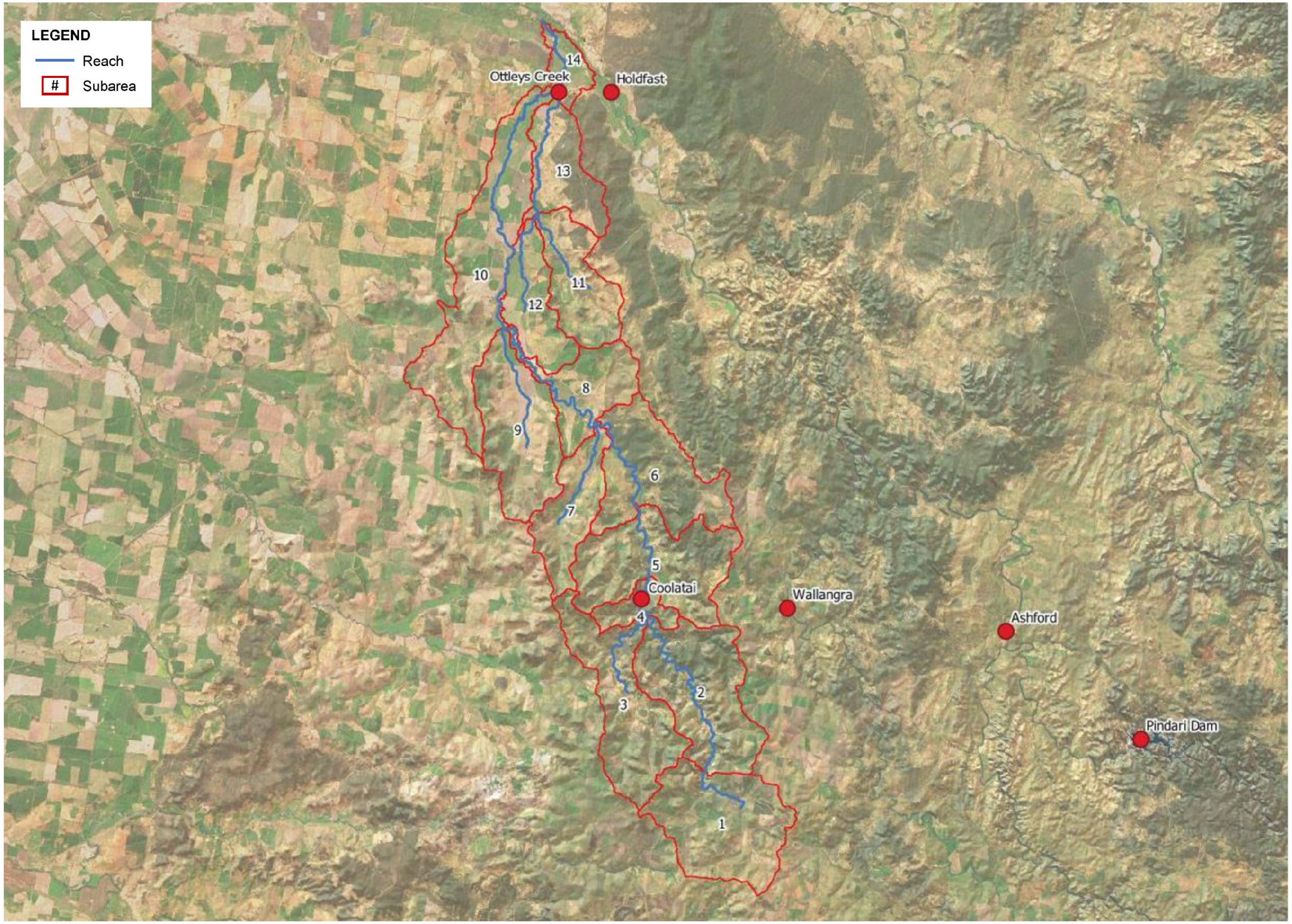
NORTH STAR TO NSW/QLD BORDER

Figure A7-C:
Macintyre Brook to Booba Sands
2011 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021
Paper: A4
Author: FFJV GIS
Scale: 1: N/A



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NORTH STAR TO NSW/QLD BORDER

Figure A8:
Ottleys Creek URBS Model Layout

Coordinate System: N/A for templated Images

Date: 15/03/2021
Paper: A4
Author: FFJV GIS
Scale: 1: N/A

Basemap Imagery & Terrain Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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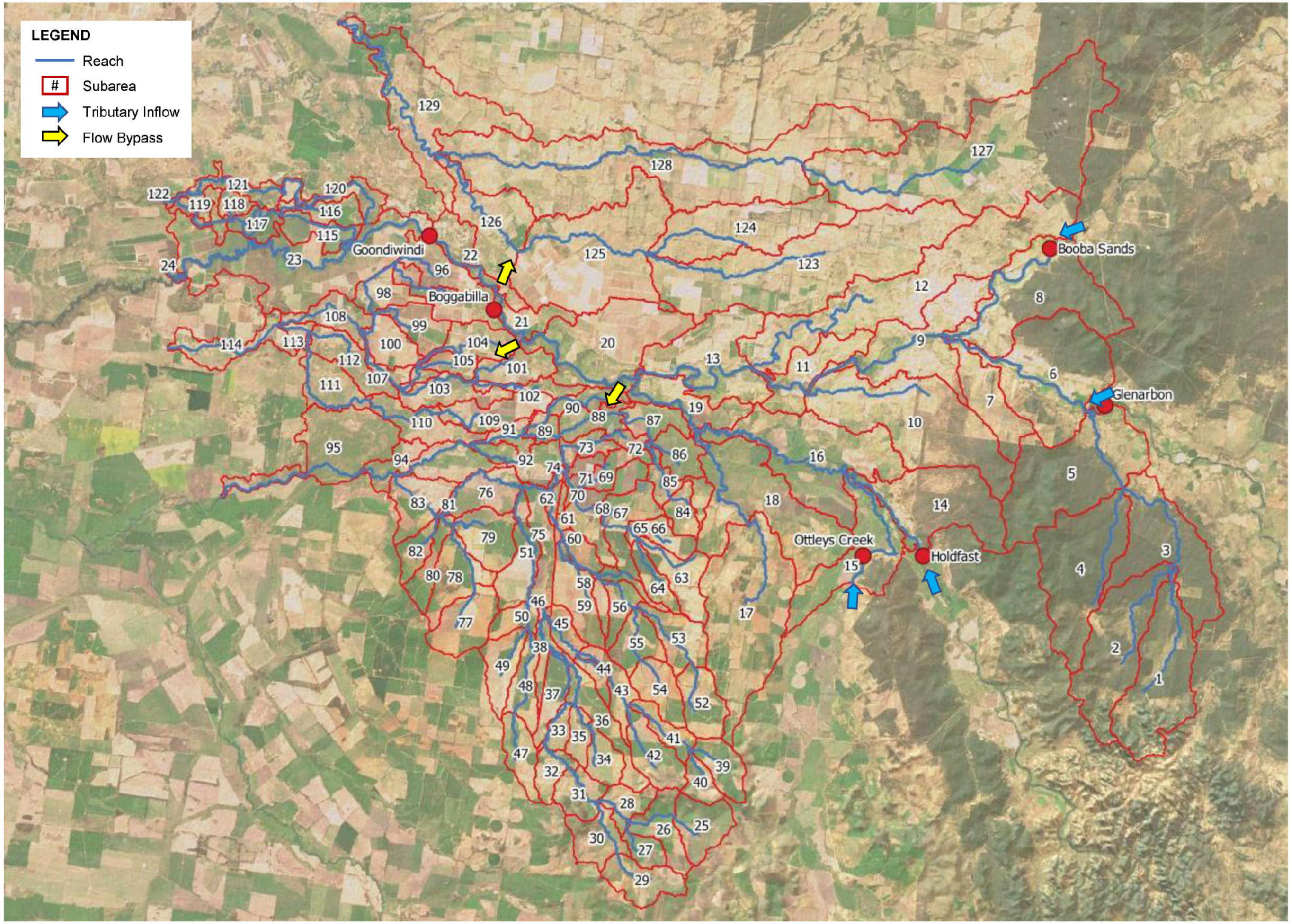

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NORTH STAR TO NSW/QLD BORDER

Figure A9:
Lower Macintyre Floodplain URBS Model Layout

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS 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_ddImages1_A4L_v1.mxd Date: 16/03/2021 14:07

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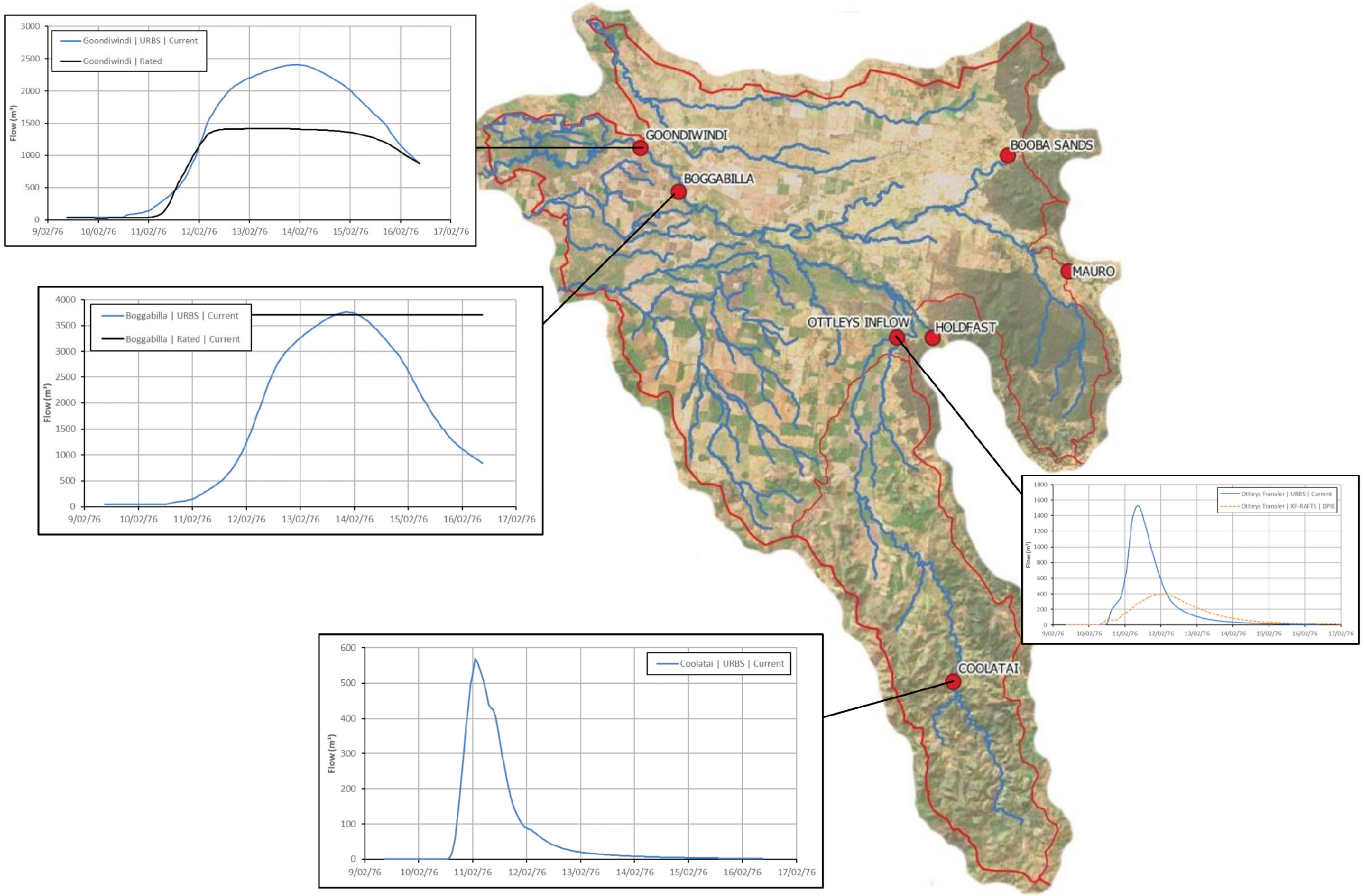
OTTLEYS CREEK AND LOWER MACINTYRE TO GOONDIWINDI – 1976



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NORTH STAR TO NSW/QLD BORDER

Figure A10-A:
Ottleys Creek and Lower Macintyre to Goondiwindi

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS 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_ddImages2_A4L_v1.mxd Date: 16/03/2021 14:24

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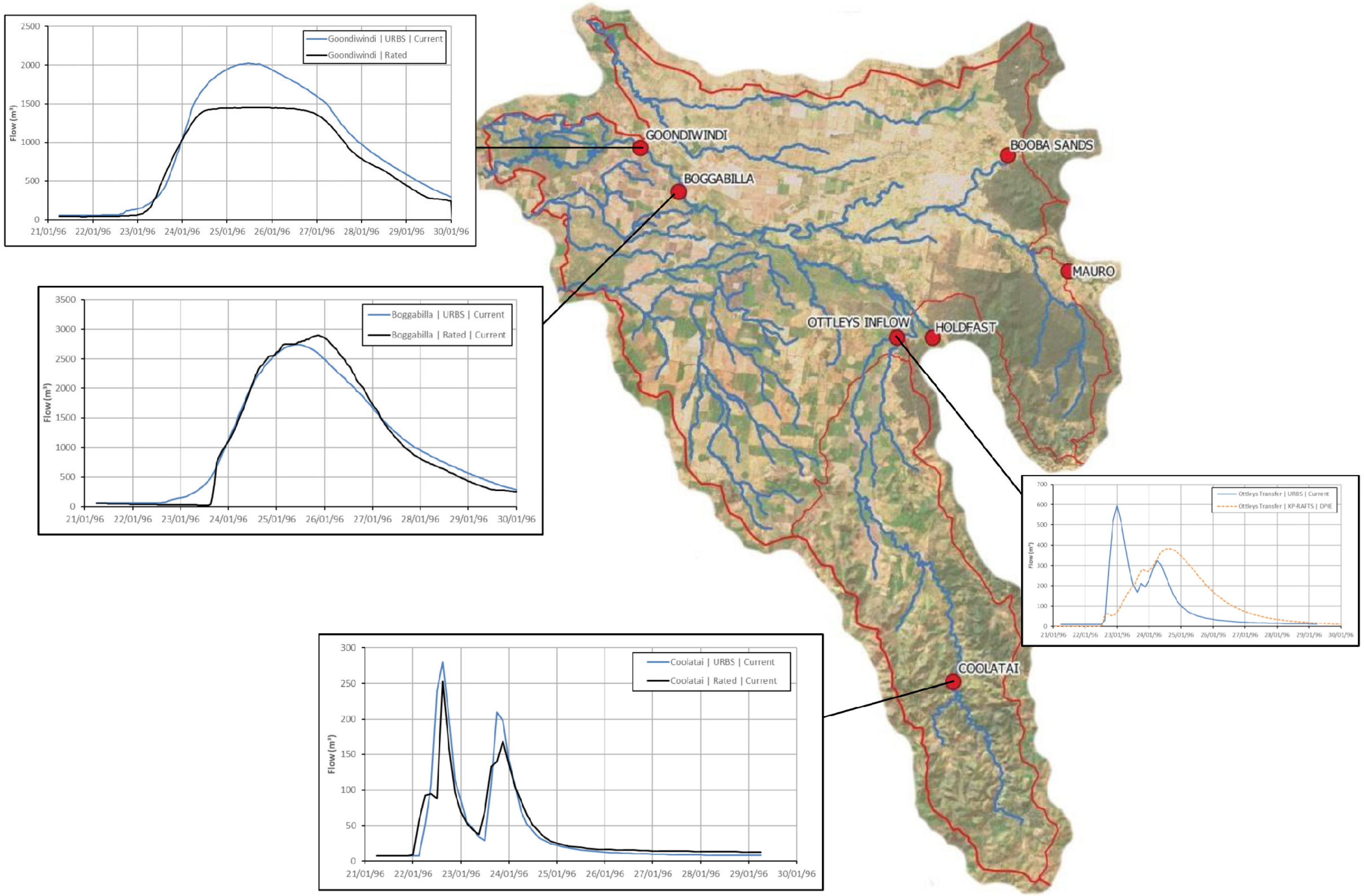
NORTH STAR TO NSW/QLD BORDER

Figure A10-B: Ottleys Creek and Lower Macintyre to Goondiwindi

OTTLEYS CREEK AND LOWER MACINTYRE TO GOONDIWINDI – 1996



Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS Scale: 1: N/A

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NORTH STAR TO NSW/QLD BORDER

Figure A10-C:
Ottleys Creek and Lower Macintyre to Goondiwindi

OTTLEYS CREEK AND LOWER MACINTYRE TO GOONDIWINDI – 2011

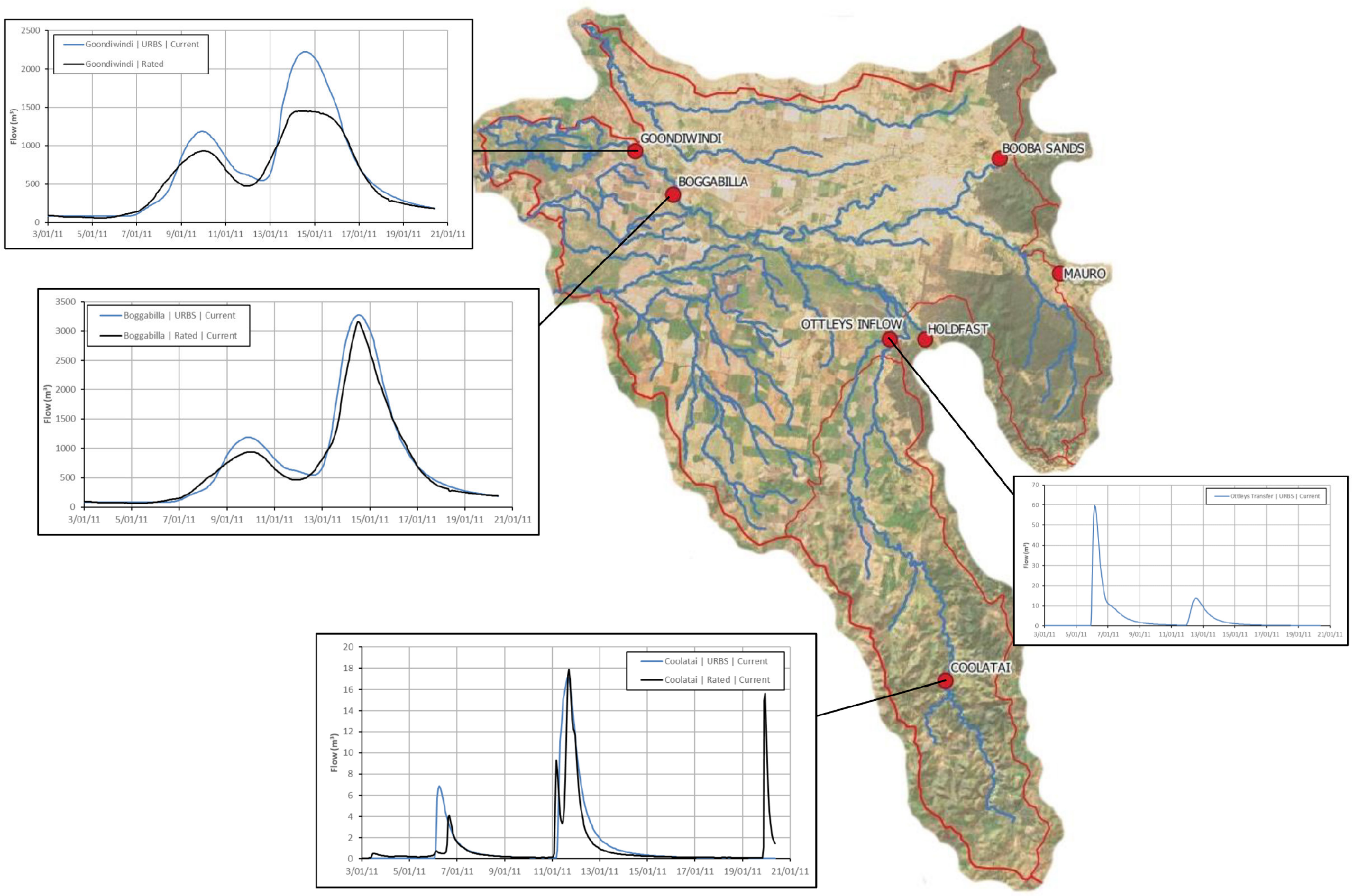

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Figure A18 Ottleys Creek and Lower Macintyre to Goondiwindi – 2011 Calibration

Coordinate System: N/A for templated Images

Date: 15/03/2021 Paper: A4
Author: FFJV GIS 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_ddImages2_A4L_v1.mxd Date: 16/03/2021 14:39

Appendix B
Hydraulic Model Update

B1 Hydraulic Model update

The TUFLOW hydraulic sub-model developed used in the EIS (developed from the BRVFMP hydraulic model) was adopted for the current updated assessment. The hydraulic model extent is as used in the EIS (i.e. from upstream of junction of rivers to approximately 18km downstream of Goondiwindi). The key updates to the hydraulic model are detailed in the following sections.

B1.1 Hydraulic model inflows

Figure B1 presents the extents and key elements of the hydraulic model. Key changes adopted include:

- Revised inflow locations for main upstream catchments consistent with the updated hydrologic model
- Revised inflows from southern tributaries consistent with the updated hydrologic model
- Inclusion of inflows from the lower floodplain area and Brigalow Creek from the updated hydrologic model

B1.2 Advanced modelling techniques

In 2020 an updated version of the TUFLOW modelling software was released with a number of new applications that were able to be applied to the hydraulic modelling. These are:

- Sub-Grid Sampling (SGS), and
- Quadtree analysis.

The use of these new modelling improvements enables an improved representation of conveyance across the floodplain. This additional detail is important in areas constrained by the presence of levees and between Ch 20 km to Ch 25 km, where the proposal alignment is in close proximity to existing levees and Bruxner Way. For this updated modelling SGS has been applied to the hydraulic model. In detailed design Quadtree will be applied to assist with detailed design of structures and scour protection. Introduction of Quadtree has a significant impact on model run time and sensitivity testing showed limited benefit in using Quadtree for the impact assessment modelling.

B1.3 Update of existing drainage structures

A review of the existing drainage structures on the floodplain was undertaken using all available information. The available information is limited to some initial survey of a number of cross-drainage structures along North Star Road, Bruxner Way and the existing non-operational rail line. A number of these structures are located at the major creek crossings associated with the southern tributaries of the lower Macintyre River floodplain being Mobbindry Creek, Back Creek and Forest Creek. The following existing structure information was available from the initial survey capture:

- Mobbindry Creek – a three span bridge on North Star Road and five span bridge on the existing non-operational rail line. Invert/deck levels as well as opening/pier geometry information were not captured.
- Back Creek:
  - A four span bridge along the existing non-operational rail line. Invert/deck levels and opening/pier geometry information were not captured
  - A set of five circular culverts under North Star Road. Invert levels and pipe diameter information were captured

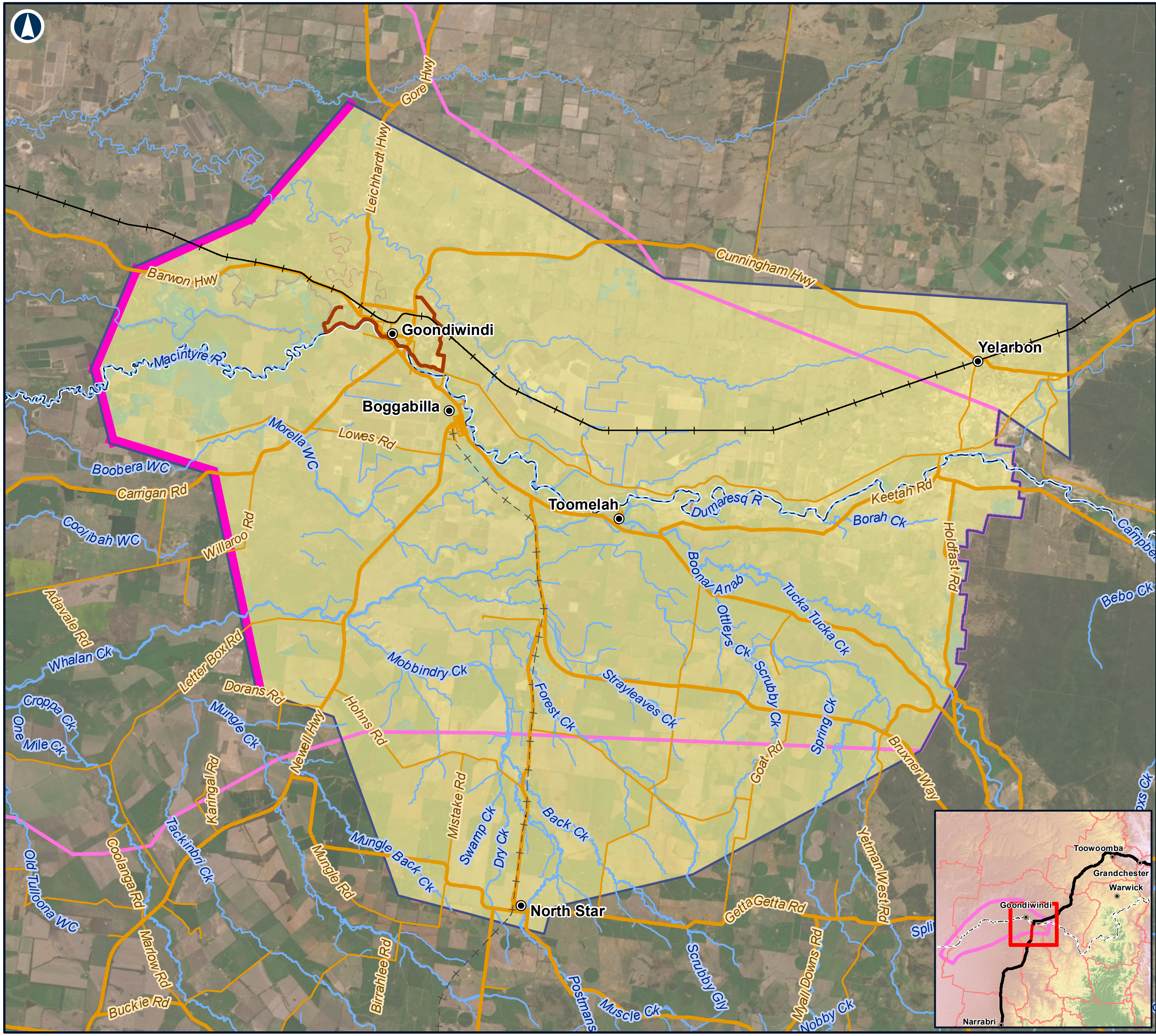
- Forest Creek – A set of 33 box culverts under North Star Road. Invert levels and box geometry information were captured

The bridges listed above were modelled as 2D “Layered Flow Constriction Shapes” (2d_lfcsh) features in TUFLOW, which adopts form and blockage factors in order to represent flow conveyance and restriction through the structures. The culverts were represented as 1D “Domain Network” (1d_nwk) features in TUFLOW, within which the culvert geometry and invert levels were incorporated along with conventional form losses.

These structures were included in the Existing Case hydraulic model. For the Developed Case the structures on North Star Road were included and the existing structures under the non-operational rail line are removed as they are replaced by the proposal alignment with associated new structures.

Several other cross-drainage structures were identified from available imagery covering the model area. For structures where only satellite imagery was available, these structures were represented as “Z Shape Layers” (2d_zsh) which lowers the digital terrain to provide appropriate flow conveyance. Some locations of known cross-drainage structures did not require additional representation in the model as they were already represented by Z Shape Layers of watercourses, such as along Whalan Creek. Any remaining existing structures not included in the hydraulic model are small with limited conveyance and located under roadways that would be substantially inundated during the flood events under consideration.

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure B1:
Macintyre River hydraulic sub-model extent

LEGEND

- Localities
- Existing rail (operational)
- Existing rail (non-operational)
- Major roads
- Minor roads
- NSW/QLD border
- Watercourses
- Goondiwindi levee
- DPIE model extents (OUTLINE)
- Sub-model extent
- Downstream boundary

Materials

- Floodplain
- Vegetated floodplain
- Waterway

20 km

Coordinate System: GDA 1994 MGA Zone 56

Date: 12/03/2021 Paper: A4
Author: FFJV GIS Scale: 1:400,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigB1_SubModelSetup_A4L_v1.mxd Date: 14/03/2021 20:25

B2 Revised calibration

Hydrologic models are based on simplistic empirical runoff routing equations using coefficients determined primarily by calibration to a specific point of interest. By contrast, hydraulic models are more physically based, providing a (relatively) realistic representation of the catchment geometry and solving equations of motion within the model domain. Some differences between the hydrologic and hydraulic routing must realistically be expected. Nevertheless, the hydraulic model should closely replicate the flow characteristics (attenuation, timing etc.) that in the hydrologic model have been validated by calibration to historical flood events.

The hydraulic model must also produce flood levels consistent with the flows. This can be confirmed by comparison with flood levels recorded during historical flood events, although the reliability is dependent upon the accuracy of the modelled flows, which are in turn dependent on the accuracy of the recorded rainfall. Further validation across a wide range of flows can be achieved by comparison of the modelled level-flow relationships at the stream gauge sites with the gauge ratings, which allows the level-flow relationship to be confirmed without necessarily having to exactly match a specific flow.

The TUFLOW hydraulic model has been validated using historical events. The primary objectives of the calibration process have been:

- To confirm hydraulic model roughness factors required to match level-flow relationships at the stream gauges, particularly those where the ratings are well defined by in-streamflow measurements
- To confirm that the flood routing through the TUFLOW hydraulic model reasonably matches the hydrologic model (TUFLOW physically represents storage and other catchment characteristics that are represented in hydrology software by empirical coefficients) and that the adopted roughness parameters do not adversely affect the timing or attenuation of the flood routing.

The historical events were selected to represent a range of magnitudes and duration. The hydraulic sub-model was run using the updated inflows from the hydrologic model as detailed in Appendix A for each of the three historical calibration events (1976, 1996 and 2011). An iterative joint calibration process was undertaken between the hydrologic and hydraulic models to achieve the best overall match to the available historical flood data across the three historical flood events.

A number of the hydraulic model parameters were adjusted as part of the calibration process including:

- Roughness values
- Definition of waterway channel invert levels to improve in-channel conveyance
- Use of sub-grid sampling to improve representation of conveyance
- Inclusion of flows from lower floodplain area, the southern tributaries and Brigalow Creek
- Variation of inflows from hydrologic model based on varying hydrologic model calibration outcomes

The following datasets have been used to assess the calibration of the hydraulic model:

- Data from Boggabilla (416002) and Goondiwindi (416201A) stream gauges, including:
  - Recorded peak water levels and estimated flows
  - Match in shape and timing of recorded flood hydrographs
  - Comparison against the level-flow relationships at the stream gauges
- Recorded flood markers across the floodplain for each event – these markers come from a range of sources and have been collated from previous studies and/or survey of property
- Comparison against the BRVFMP calibration outcomes (Refer Section 3.3)

- Anecdotal flood information, including flood markers, for the historical flood events collected from many sources including:
  - Previous studies
  - DPIE
  - Landholders and stakeholders including Goondiwindi Regional Council, Gwydir Shire Council and Moree Plains Regional Council

  Anecdotal data includes information obtained from a wide range of sources and as such it is of varying levels of accuracy and reliability. The anecdotal data has been used to assess of the performance of the hydraulic model to replicate historical flood conditions.

The following sections detail the outcomes of the hydraulic model calibration for each of the historical flood events.

B2.1 1976 Historical flood markers

There were 38 recorded flood marks provided by DPIE or extracted from the Goondiwindi Environs Study (Lawson and Treloar 2007) within the floodplain area for the 1976 flood event. A further flood marker was surveyed by ARTC on a landholder's property in 2020 (ID 76-39).

A comparison of the peak water levels from the hydraulic model against the recorded flood markers is presented in Figure B2A to Figure B2C and detailed in Table B1.

Table B1 1976 event flood marker comparison

Location	Source	Recorded level at Flood Marker (m AHD)	Modelled level (m AHD)	Difference (m)
76-01	Border Rivers Valley Floodplain Management Plan	214.60	214.40	-0.20
76-02		213.80	213.11	-0.69
76-03		210.50*	210.16	-0.34
76-04		224.72	225.26	0.54
76-05		218.10	218.35	0.25
76-06		224.93	225.25	0.32
76-07		220.12	220.19	0.07
76-08		223.62	223.74	0.12
76-09		224.96	225.01	0.05
76-10		217.90	217.89	-0.01
76-11		224.72	224.71	-0.01
76-12		223.68	223.54	-0.14
76-13		223.31	223.07	-0.24
76-14		222.39	222.28	-0.12
76-15		222.32	222.13	-0.19
76-16		224.96	224.72	-0.24
76-17		219.60	219.10	-0.50
76-18		224.63	224.31	-0.32
76-19		226.51*	225.91	-0.60
76-20		227.33*	226.71	-0.62
76-21		224.26	223.70	-0.56
76-22		226.10*	225.38	-0.72

Location	Source	Recorded level at Flood Marker (m AHD)	Modelled level (m AHD)	Difference (m)
76-23		226.92*	226.09	-0.83
76-24		217.78	216.94	-0.84
76-25		218.85*	218.37	-0.49
76-26		208.87*	207.77	-1.10
76-27		207.42*	Dry	-
76-28		217.78	217.03	-0.75
76-29		217.05	217.01	-0.04
76-30		212.60*	212.32	-0.28
76-31		213.00*	212.29	-0.71
76-32		212.40	211.94	-0.46
76-33		215.88	216.04	0.16
76-34		213.00	212.04	-0.96
76-35		210.56*	210.94	0.38
76-36		219.88	220.16	0.28
76-37	Goondiwindi Environs Flooding Investigation	218.06	218.34	0.28
76-38		209.06*	Dry	-
76-39	Field survey on property	234.15	235.28	0.13

Table note:

*Outliers – inconsistent with adjacent flood markers or near hydraulic model boundary.

Given the size and the recognition of the 1976 event amongst the community and its use in development control/planning, this event is a key calibration event. The calibration achieved is reasonable as shown in Table B2 with 62% of flood markers in the +/- 0.3m range. This takes into account the age of the event, the changes to the floodplain since this event, uncertainties regarding the quality of the flood marker data and changes to stream gauges since the event occurred.

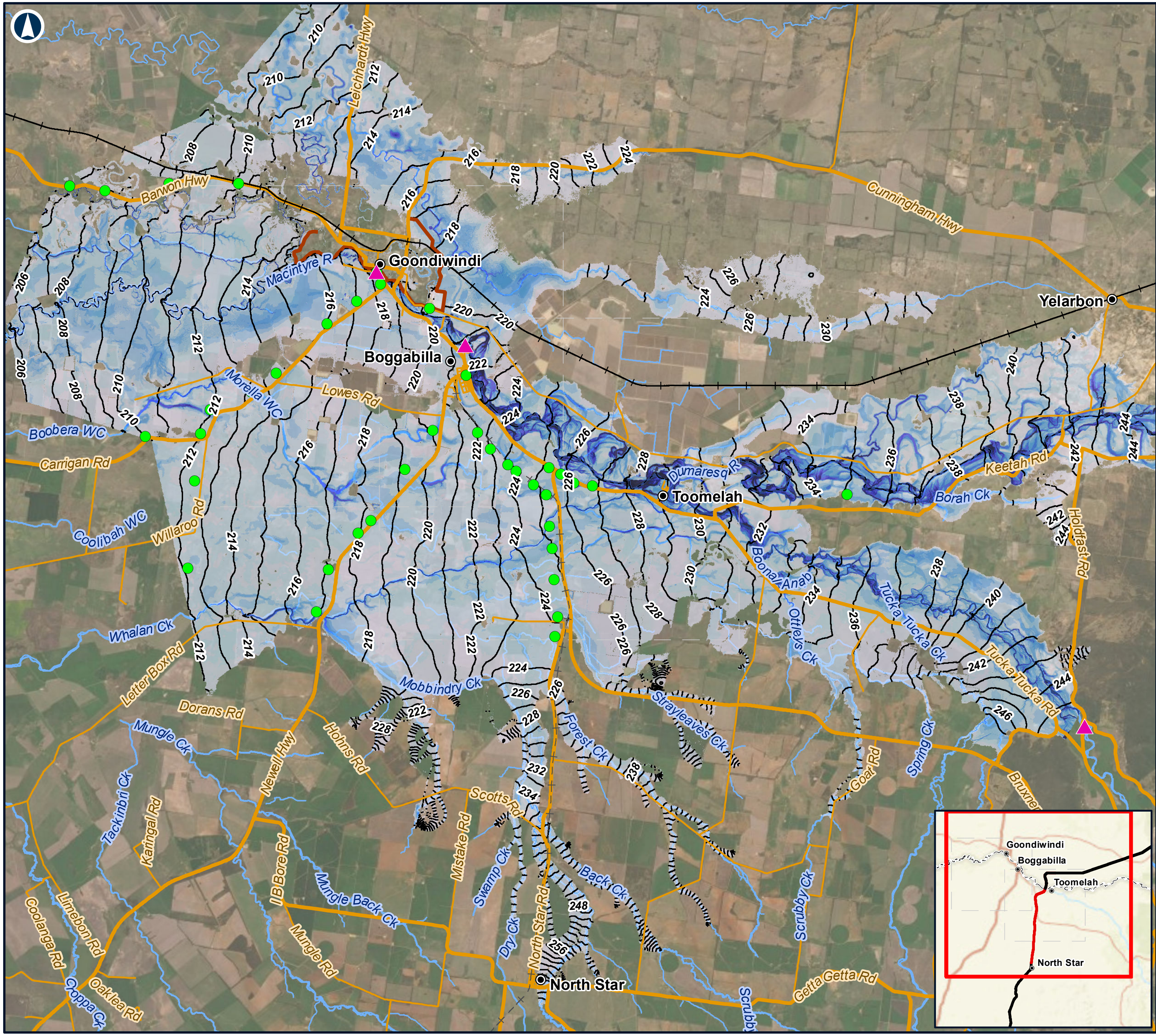
Table B2 Summary of calibration against 1976 recorded flood markers

Model accuracy range (m)	1976 event	
	No of flood markers	% in range
Flooded but predicted to be dry	0	0%
<0.3	8	30%
-0.3 to -0.2	3	11%
-0.2 to -0.1	3	11%
-0.1 to 0	3	11%
0 to 0.1	2	7%
0.1 to 0.2	3	11%
0.2 to 0.3	3	11%
>0.3	2	7%
Outliers removed*	12	-
Total number of markers	39	-

Table note:

*Outliers – inconsistent with adjacent flood markers or near hydraulic model boundary.

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 B2-A:
1976 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

- Localities
- Stream gauge locations
- Flood marker (1976)
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Goondiwindi levee
- 1m contour (mAHD)

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

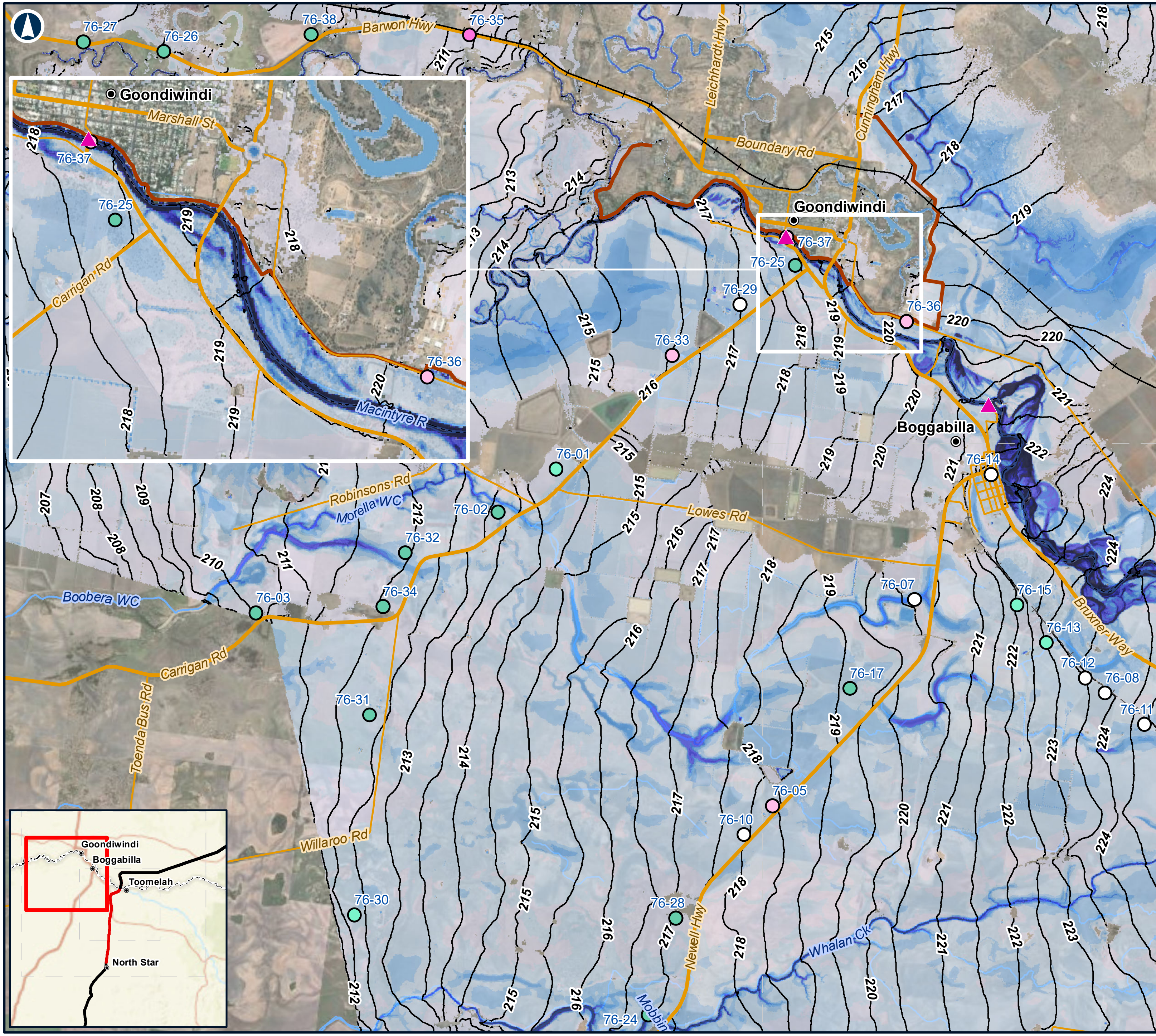
10km

Coordinate System: GDA 1994 MGA Zone 56

Date: 10/03/2021 Paper: A4
Author: FFJV GIS Scale: 1:320,000

Map by: DTH Z:\GIS\GIS_270_NS2B\Tasks\270-IHY-202102151444_Hydrology_and_Flooding_PIR\270-IHY-202102151444_ARTC_FigBX.X_CalibrationFloodplain_A4L_v1.mxd Date: 10/03/2021 11:26

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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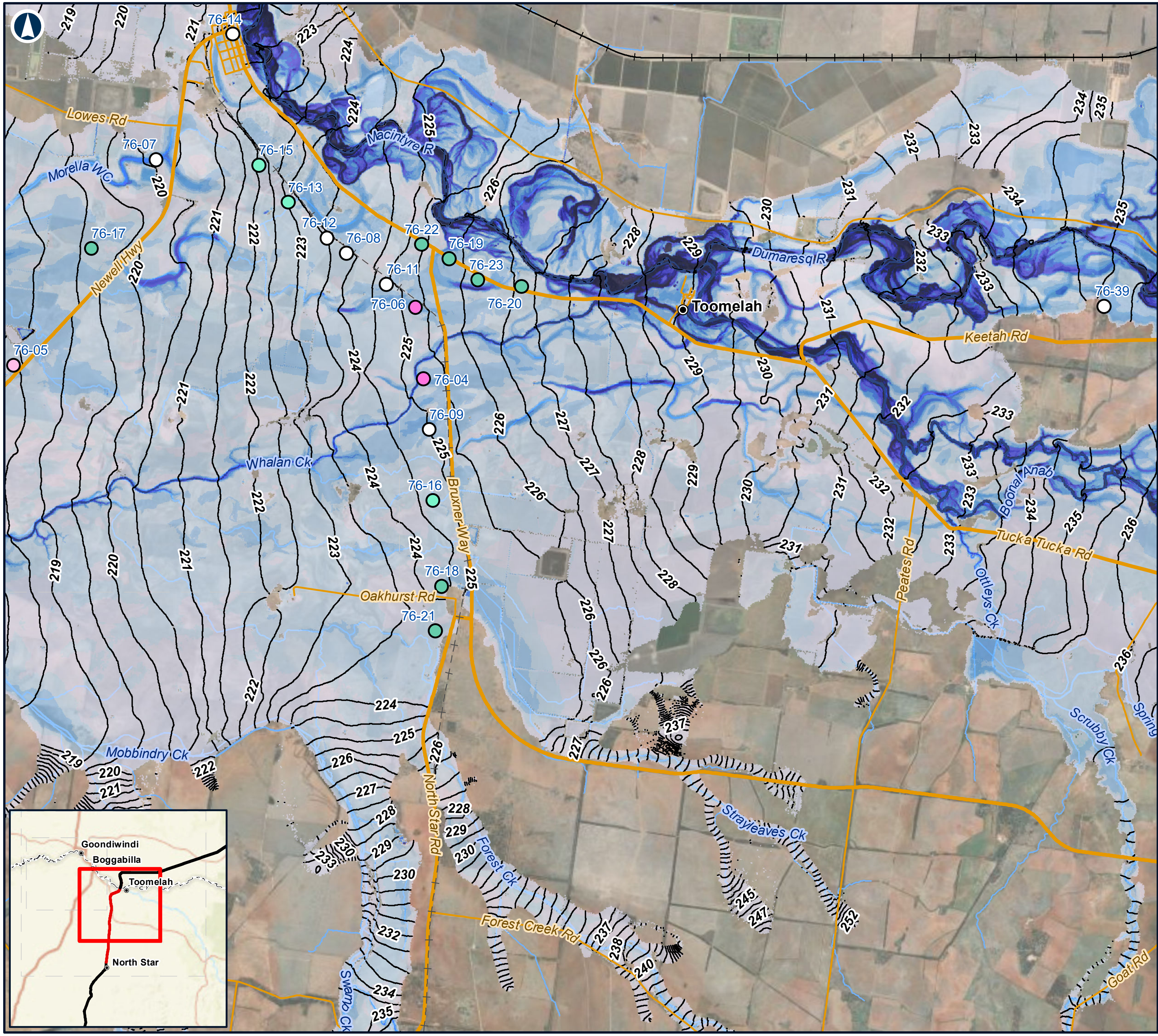

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NORTH STAR TO NSW/QLD BORDER

Figure B2-C:
1976 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

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

Flood marker difference (m)

- < -0.3m
- -0.03 to -0.15m
- -0.15 to 0.15m
- 0.15m to 0.30m
- > 0.3m
- 76-08 Flood marker ID (year/number)

Depth (m)

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

7 km

Coordinate System: GDA 1994 MGA Zone 56

Date: 10/03/2021 Paper: A4
Author: FFJV GIS Scale: 1:140,000

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B2.2 1996 event flood marker comparison

There were eight recorded flood marks provided by DPIE or extracted from the Goondiwindi Environs Flooding Investigation (Lawson & Treloar 2007) for the 1996 flood event within the floodplain area. The location of the recorded flood marks is shown in Figure B3A to Figure B3C. The recorded and predicted flood levels are presented in Table B3.

Table B3 1996 flood marker comparison

Location	Source	Recorded level at Flood Marker (m AHD)	Modelled level (m AHD)	Difference (m)
96-01	DPIE – marks derived from high water marks on signposts etc.	220.95	220.85	-0.10
96-02		219.23	219.23	0.00
96-03		218.73	218.64	-0.09
96-04		218.13	218.50	0.37
96-05	Goondiwindi Environs Flooding Investigation	215.73	215.65	-0.09
96-06		221.71	221.92	0.21
96-07	Border Rivers Valley Floodplain Management Plan	221.10*	222.08	0.98
96-08	Goondiwindi Environs Flooding Investigation	215.04	215.17	0.13

Table note:

*Outlier – inconsistent with adjacent flood markers or near hydraulic model boundary.

The revised hydraulic model flood levels generally compare well to the 1996 recorded flood heights with six of the eight points within 0.3 m of the recorded heights. For the 1996 event, 85% of the flood markers lie within the +/- 0.3m range although this event has a reduced number of flood markers to compare against.

The recorded level 96-07 is 221.1 m AHD and located approximately 3 km upstream of the Boggabilla stream gauge which recorded a peak flood height of 221.03 m AHD. Hence the hydraulic model was unable to match this level (predicted level 222.08 m AHD). It is likely there is an error in this recorded flood level.

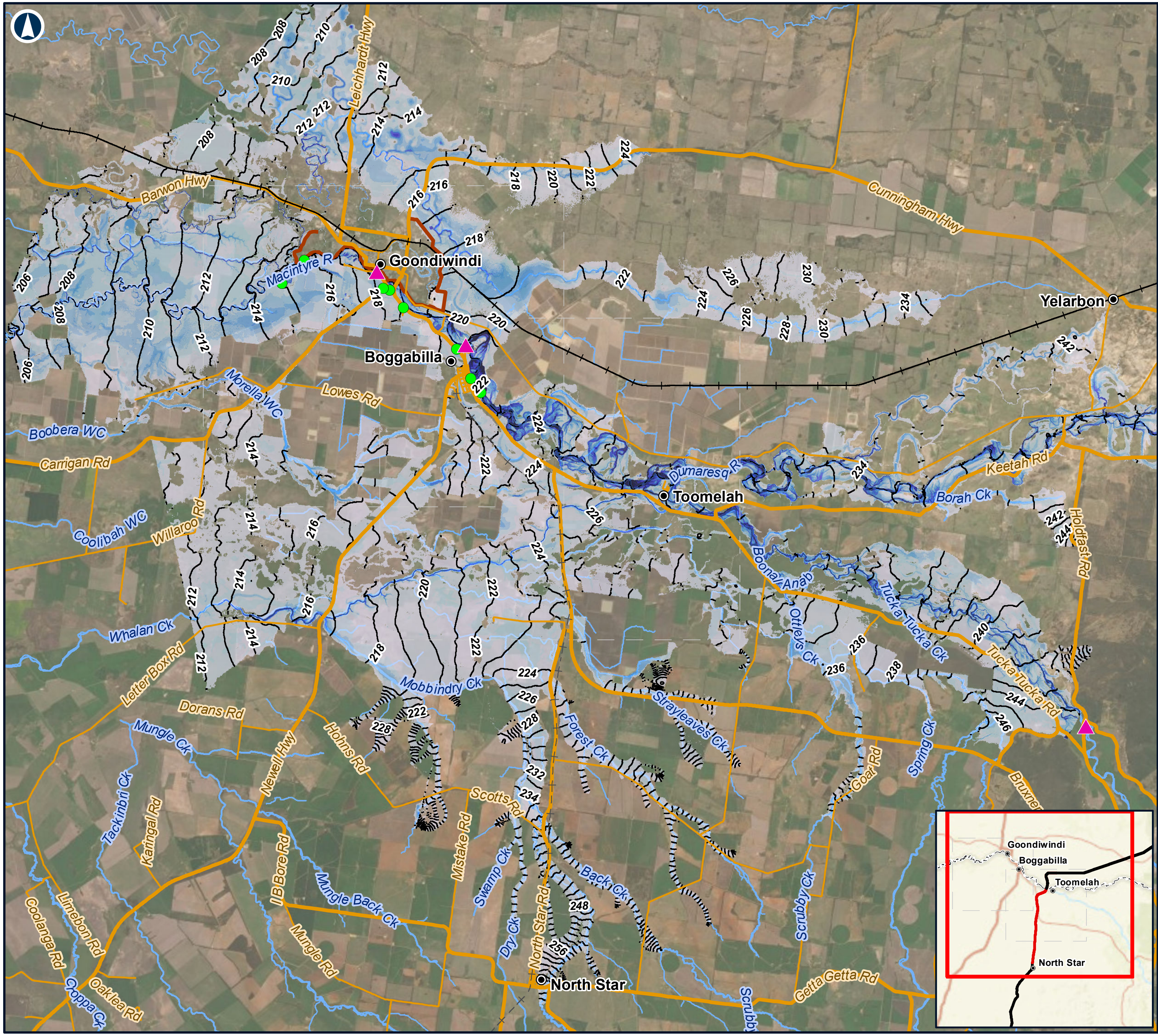
Table B4 Summary of calibration against 1996 recorded flood markers

Model accuracy range (m)	1996 event	
	No of flood markers	% in range
Flooded but predicted to be dry	0	0%
<0.3	0	0%
-0.3 to -0.2	0	0%
-0.2 to -0.1	0	0%
-0.1 to 0	4	57%
0 to 0.1	0	0%
0.1 to 0.2	1	14%
0.2 to 0.3	1	14%
>0.3	1	14%
Outliers removed*	1	-
Total number of markers	8	-

Table note:

*Outliers – inconsistent with adjacent flood markers or near hydraulic model boundary.

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 B3-A:
1996 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

- Localities
- Stream gauge locations
- Flood marker (1996)
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Goondiwindi levee
- 1m contour (mAHD)

Depth (m)

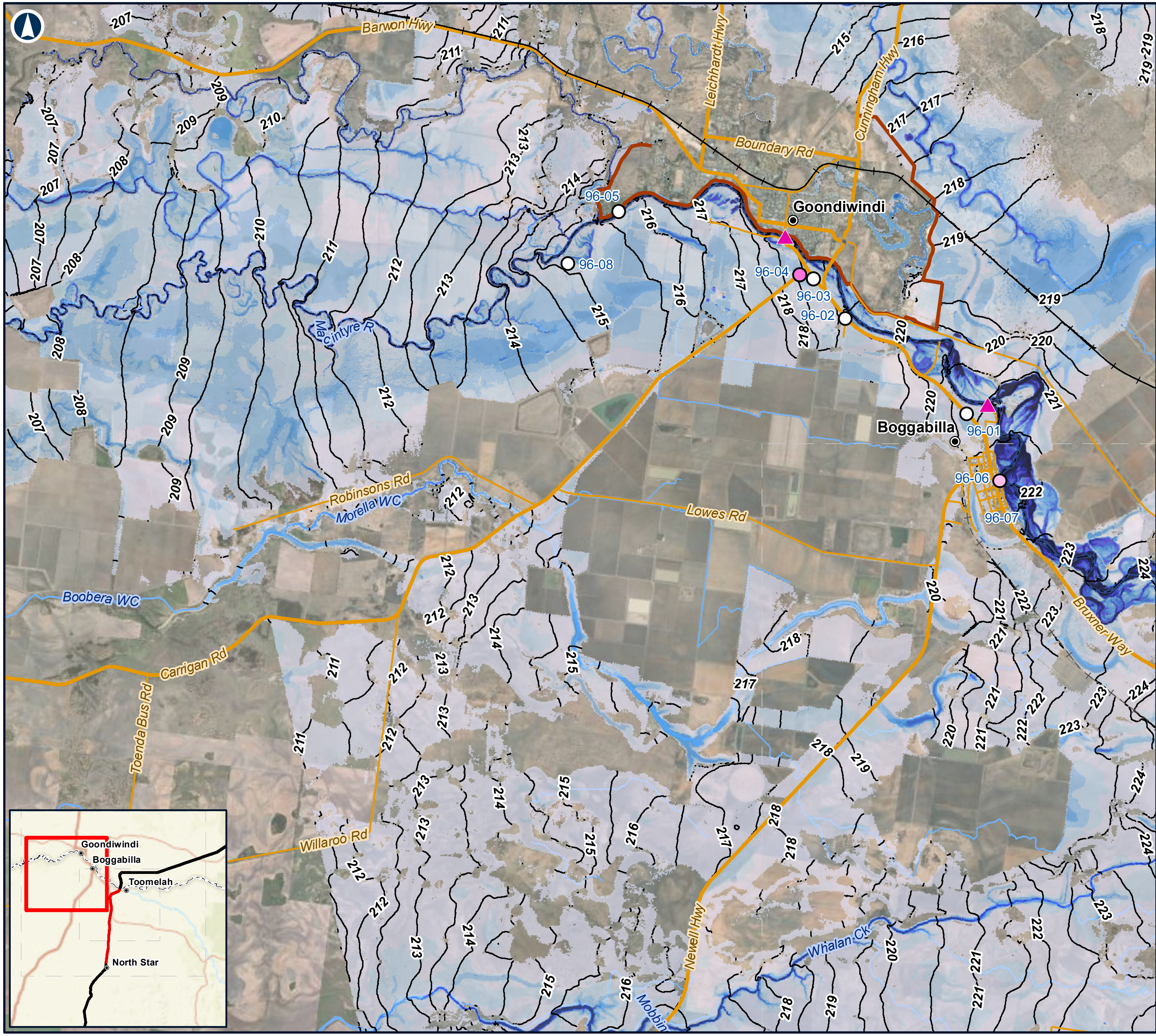
- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

10km

Coordinate System: GDA 1994 MGA Zone 56

Date: 10/03/2021 Paper: A4
Author: FFJV GIS Scale: 1:320,000

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 B3-B:
1996 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

- Localities
- Stream gauge locations
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Goondiwindi levee
- 0.5m contour (mAHD)

Flood marker difference (m)

- < -0.3m
- -0.03 to -0.15m
- -0.15 to 0.15m
- 0.15m to 0.30m
- > 0.3m

76-08 Flood marker ID (year/number)

Depth (m)

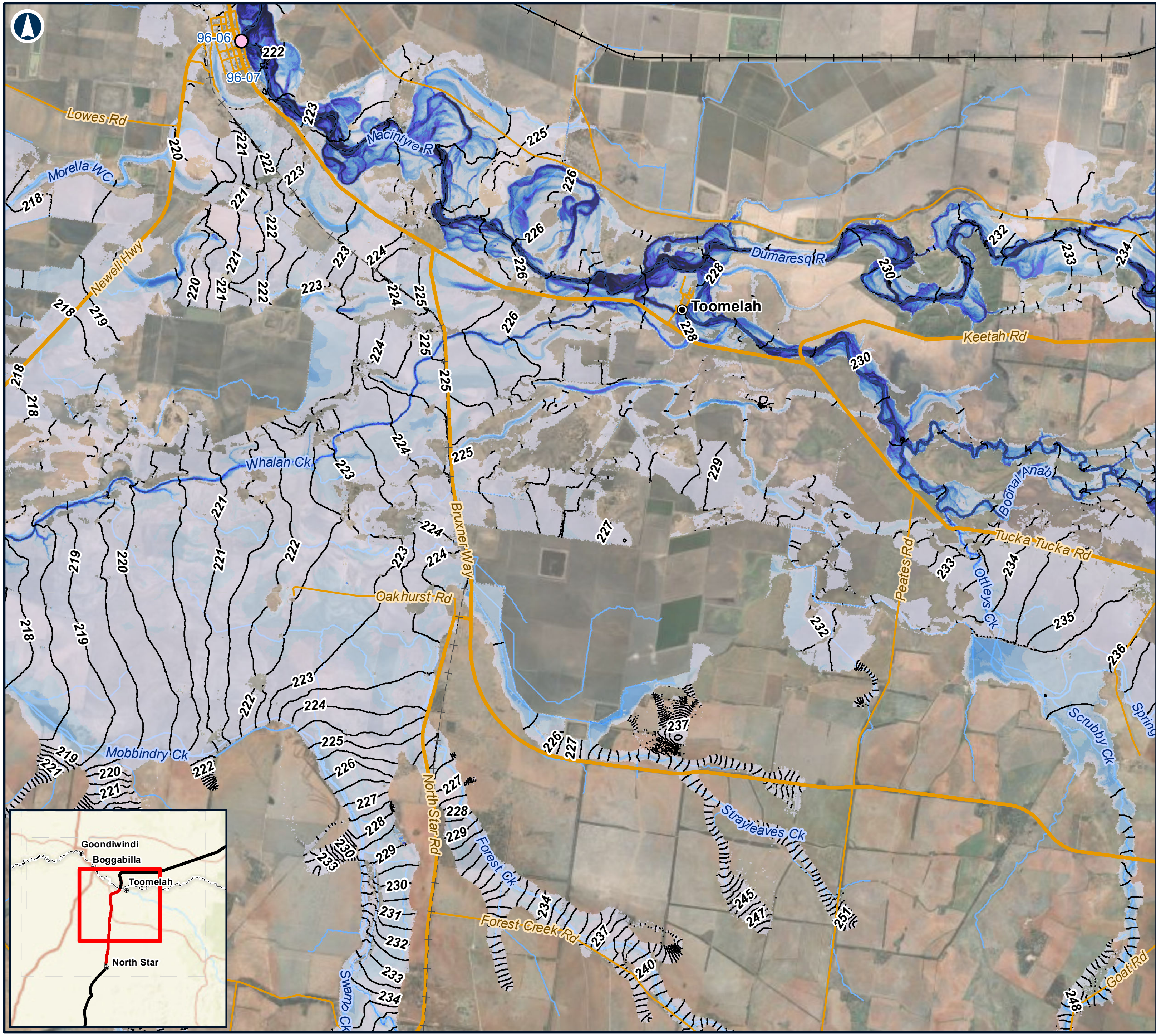
- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

7 km

Coordinate System: GDA 1994 MGA Zone 56

Date: 10/03/2021 Paper: A4
Author: FFJV GIS Scale: 1:140,000

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 B3-C:
1996 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

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

Flood marker difference (m)

- < -0.3m
- -0.03 to -0.15m
- -0.15 to 0.15m
- 0.15m to 0.30m
- > 0.3m

76-08 Flood marker ID (year/number)

Depth (m)

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

7 km

Coordinate System: GDA 1994 MGA Zone 56

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B2.3 2011 event flood marker comparison

For the 2011 historical flood event there were 52 historical flood markers available for comparison. These are summarised in Table B5 and presented in Figure B4A to Figure B4C.

Table B5 2011 flood marker comparison

Name	Source	Recorded level at Flood Marker (m AHD)	Modelled level (m AHD)	Difference (m)
11-01	DPIE – marks derived from high water marks on signposts etc.	219.15	219.60	0.46
11-02		220.98	221.21	0.23
11-03		224.79*	225.52	0.74
11-04		219.23	219.46	0.22
11-05		221.85	222.12	0.27
11-06		218.28*	219.20	0.93
11-07		219.60	219.61	0.00
11-08		219.57	219.86	0.28
11-09		221.94	222.12	0.18
11-10		217.87	218.11	0.23
11-11		220.32*	219.91	-0.41
11-12		220.41	220.30	-0.12
11-13		220.44	220.45	0.01
11-14		220.79	220.50	-0.30
11-15		220.85	220.84	-0.01
11-16		221.05	221.19	0.14
11-17		222.22	221.90	-0.31
11-18		221.12	221.19	0.07
11-19		223.96	224.00	0.04
11-20		220.79	220.50	-0.29
11-21		224.02	223.99	-0.02
11-22		224.06	223.95	-0.11
11-23		224.06	223.92	-0.14
11-24		224.06	223.96	-0.10
11-25		224.06	223.89	-0.17
11-26	DPIE – marks derived from high water marks on signposts etc.	220.73	220.38	-0.36
11-27		228.27	228.14	-0.14
11-28		225.73	Dry	-
11-29		216.96	216.99	0.03
11-30		216.80	216.85	0.05
11-31		216.50	216.15	-0.34
11-32		216.34	216.07	-0.28
11-33		215.19	215.09	-0.11
11-34		214.89*	214.49	-0.40
11-35		214.83*	214.52	-0.31
11-36		217.53	217.30	-0.23

Name	Source	Recorded level at Flood Marker (m AHD)	Modelled level (m AHD)	Difference (m)
11-37		217.96	217.78	-0.18
11-38		218.55	218.33	-0.23
11-39		218.44	218.61	0.17
11-40		213.52*	212.71	-0.82
11-41		213.73*	212.71	-1.03
11-42		215.87	215.49	-0.38
11-43		218.49	218.40	-0.09
11-44		218.69	219.01	0.31
11-45		219.21	219.48	0.27
11-46		219.35	219.57	0.22
11-47		219.56	219.70	0.15
11-48		219.98	220.09	0.12
11-49		218.54	219.22	0.68
11-50		218.46	218.36	-0.10
11-51		217.13	217.67	0.55
11-52		216.18*	212.71	-3.47

Table note:

*Outliers – inconsistent with adjacent flood markers or near downstream model boundary.

With 2011 being the most recent event on the floodplain, and most representative of current floodplain conditions, it was deemed important that this event be considered the primary calibration event for the modelling. As can be seen from Table B6 a good match is achieved with 79% of flood markers within the +/- 0.3m range.

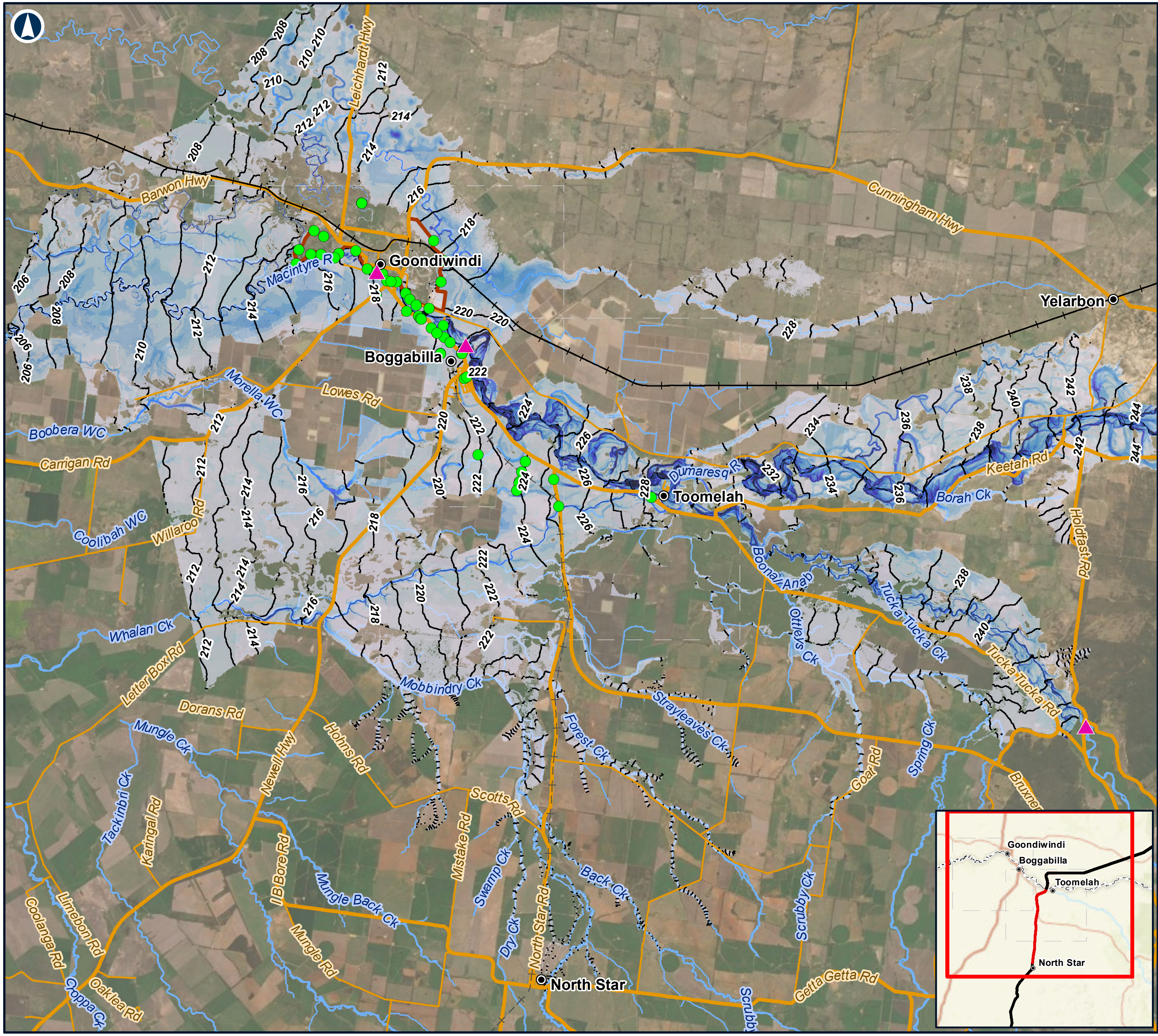
Table B6 Summary of calibration against 2011 recorded flood markers

Model accuracy range (m)	2011 event	
	No of flood markers	% in range
Flooded but predicted to be dry	1	2%
<0.3	4	9%
-0.3 to -0.2	5	11%
-0.2 to -0.1	7	16%
-0.1 to 0	5	11%
0 to 0.1	6	14%
0.1 to 0.2	5	11%
0.2 to 0.3	7	16%
>0.3	4	9%
Outliers removed*	8	-
Total number of markers	52	-

Table note:

*Outliers – inconsistent with adjacent flood markers or near hydraulic model boundary.

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 B4-A:
2011 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

- Localities
- Stream gauge locations
- Flood marker (2011)
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Goondiwindi levee
- 1m contour (mAHD)

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

10km

Coordinate System: GDA 1994 MGA Zone 56

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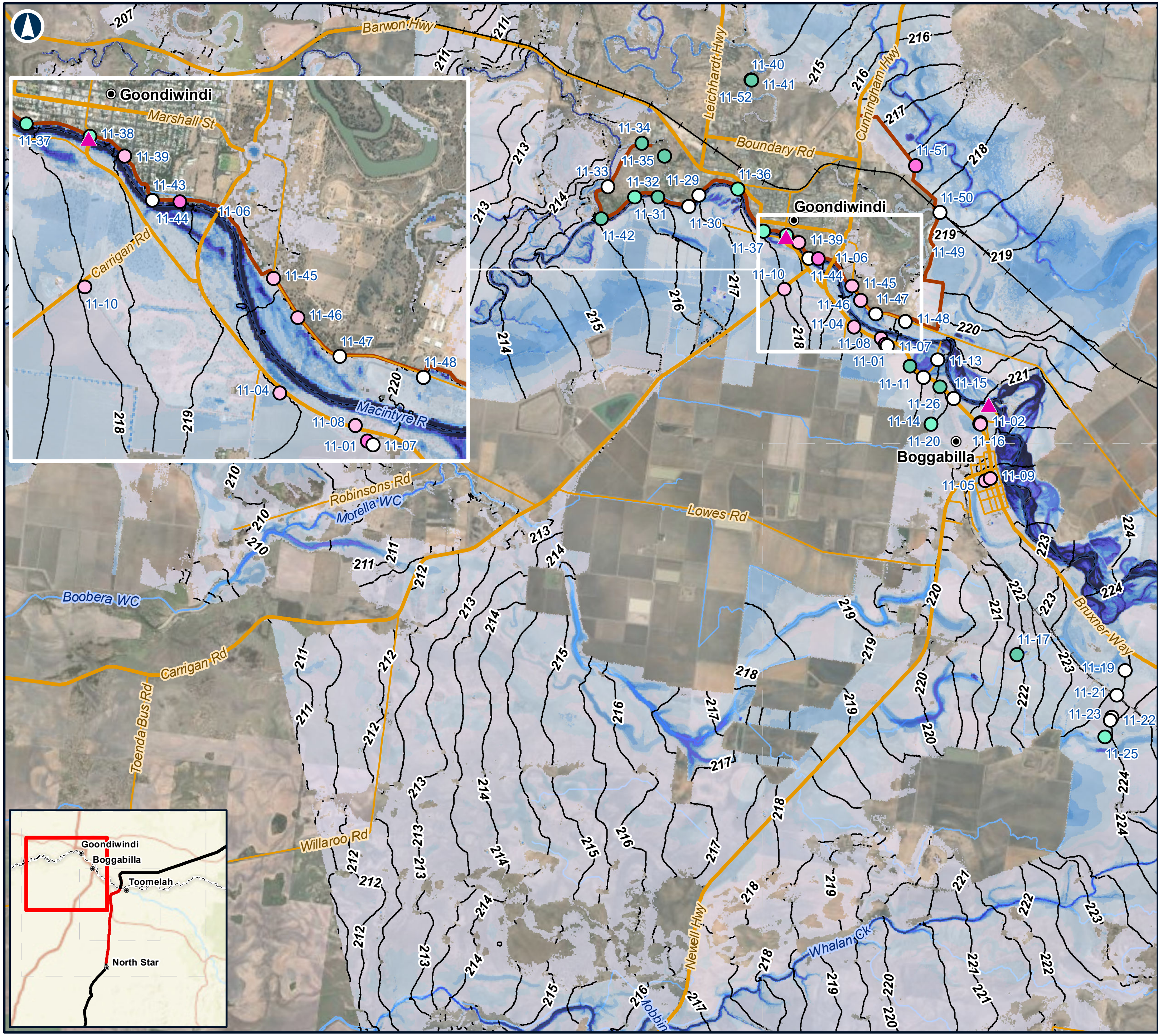
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure B4-B:
2011 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

- Localities
- Stream gauge locations
- Existing rail (operational)
- Existing rail (non-operational)
- NSW/QLD border
- Watercourses
- Goondiwindi levee
- 0.5m contour (mAHD)
- 76-08 Flood marker ID (year/number)

Flood marker difference (m)

- < -0.3m
- -0.03 to -0.15m
- -0.15 to 0.15m
- 0.15m to 0.30m
- > 0.3m

Depth (m)

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

7 km

Coordinate System: GDA 1994 MGA Zone 56

Date: 10/03/2021 Paper: A4
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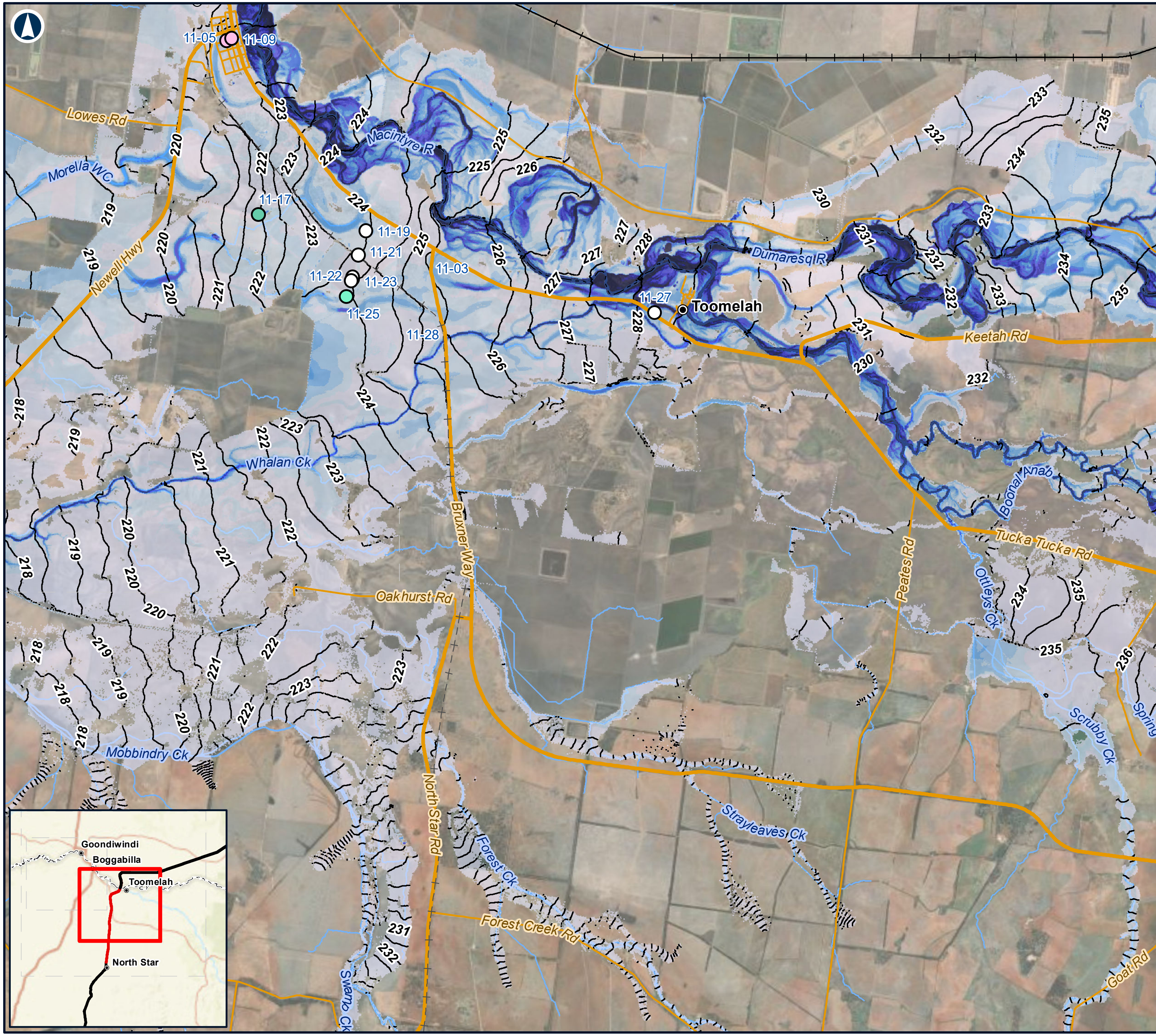
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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NORTH STAR TO NSW/QLD BORDER

Figure B4-C:
2011 Calibration Event
Peak Depths and Water Surface Levels

LEGEND

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

Flood marker difference (m)

- < -0.3m
- -0.03 to -0.15m
- -0.15 to 0.15m
- 0.15m to 0.30m
- > 0.3m

76-08 Flood marker ID (year/number)

Depth (m)

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

7 km

Coordinate System: GDA 1994 MGA Zone 56

Date: 10/03/2021 Paper: A4
Author: FFJV GIS Scale: 1:140,000

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B2.4 Boggabilla stream gauge

The recorded and predicted flood levels and flows at the Boggabilla stream gauge are presented in Table B7. As discussed in Appendix F, the current rating curve (used for 1996 and 2011 events) includes floodplain flows that break out into Whalan Creek and Morella Watercourse, i.e. represents flows across the wider floodplain upstream of Boggabilla. For comparison purposes flows have been extracted at two locations being upstream (U/S) of Boggabilla to give the floodplain wide flow and downstream (D/S) of Boggabilla to give the flows at Boggabilla township, as presented in Table B7.

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 U/S of Boggabilla	Flow D/S of Boggabilla
1976	221.27	n/a[a]	3,700 m³/s (319,600 ML/d)	221.22 (-0.05m)	n/a[a]	3,680m³/s (317,952 ML/d)
1996	221.03	3,486 m³/s (301,200 ML/d)	2,485 m³/s[b] (214,700 ML/d)	220.98 (-0.05m)	3,470 m³/s (299,808 ML/d)	2,791 m³/s (241,142 ML/d)
2011	221.12	3,803 m³/s (328,600 ML/d)	n/a	221.11 (-0.01m)	4,493m³/s (388,195 ML/d)	3,197 m³/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

Figure B.1 presents a comparison of the modelled flows and level information at Boggabilla for each of the three historical events against the rated data from the stream gauge (i.e. measured during events). The rising limbs of the modelled events are the lower lines with the receding hydrograph limbs resulting in the high peak levels. As recordings are typically taken on the falling limb of flood events, the model results are a good match to the rated data.

For all three historical events, the hydraulic model results give a good representation of conditions at the Boggabilla stream gauge. With close matches in peak water levels, good matches in peak flows and hydrograph shapes and timing as demonstrated in Figure B.2 to Figure B.7. It should be noted that only a peak water level was recorded at Boggabilla in 1976 as shown in Figure B.3. The flow hydrograph presented in Figure B.2 therefore is an estimation only and not based on recorded data.

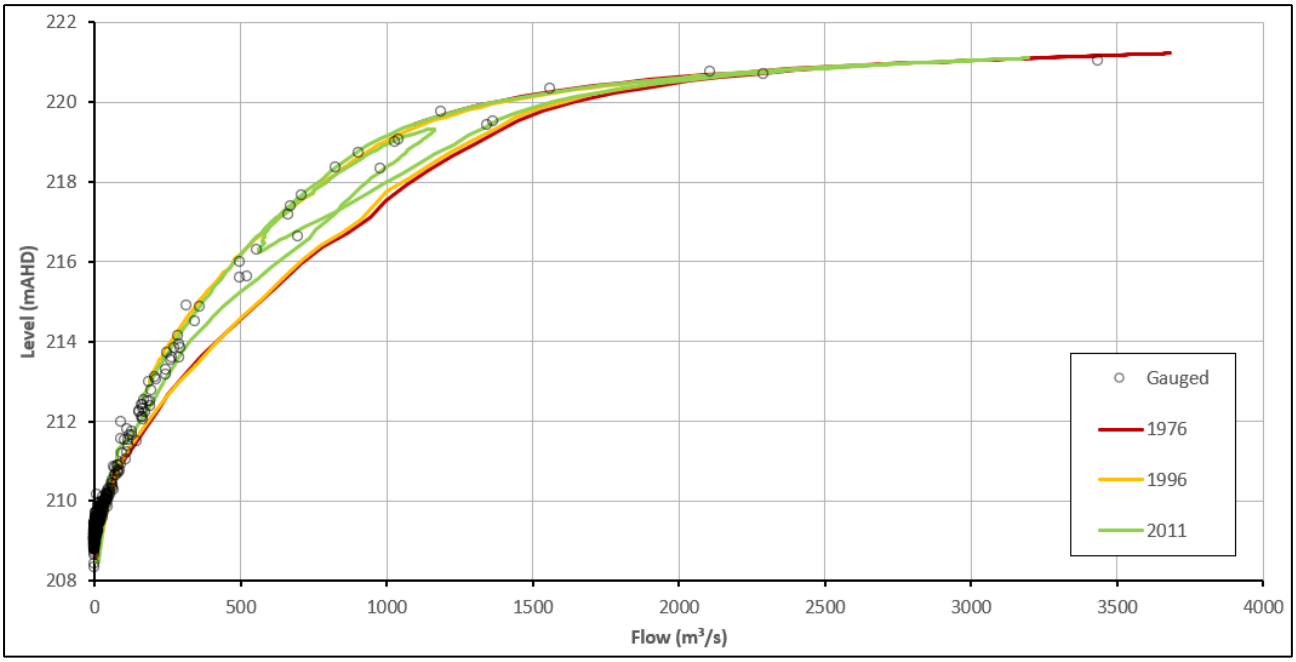

Figure B.1 Boggabilla stream gauge – model results compared to rated data

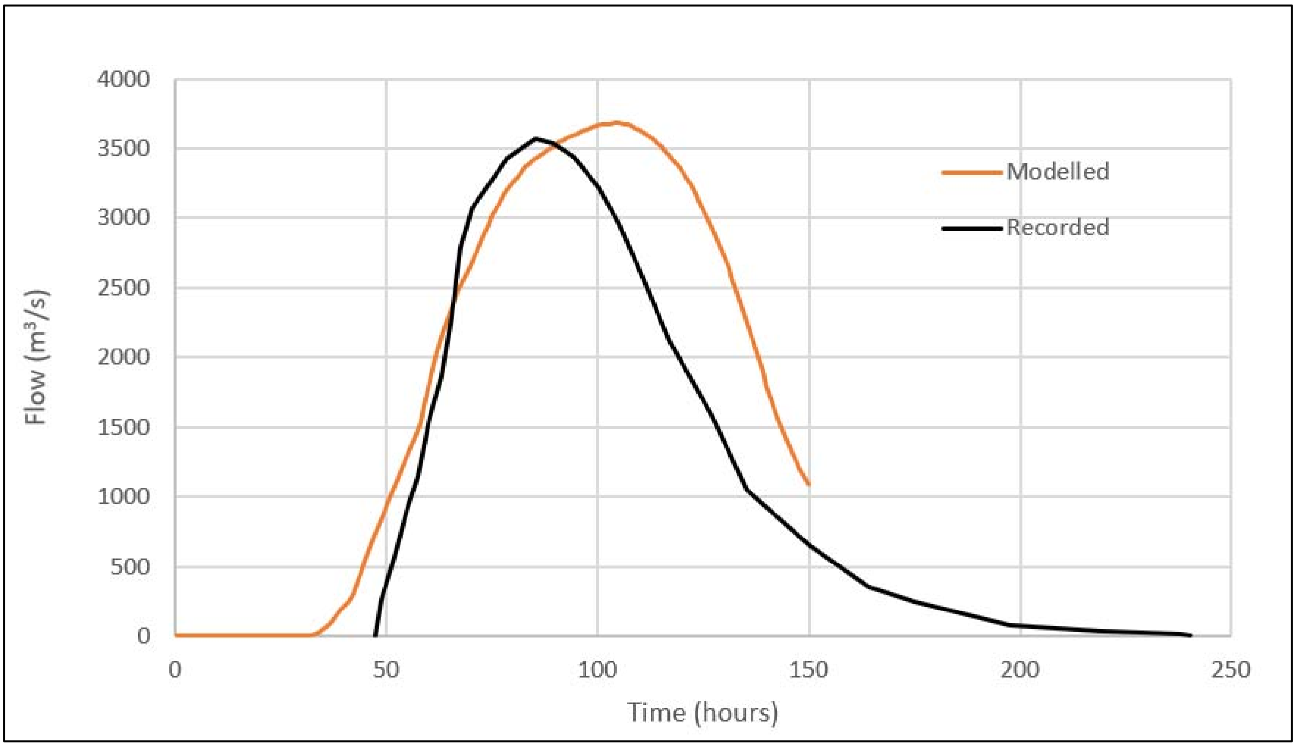

Figure B.2 Boggabilla Gauge – 1976 flows recorded and modelled

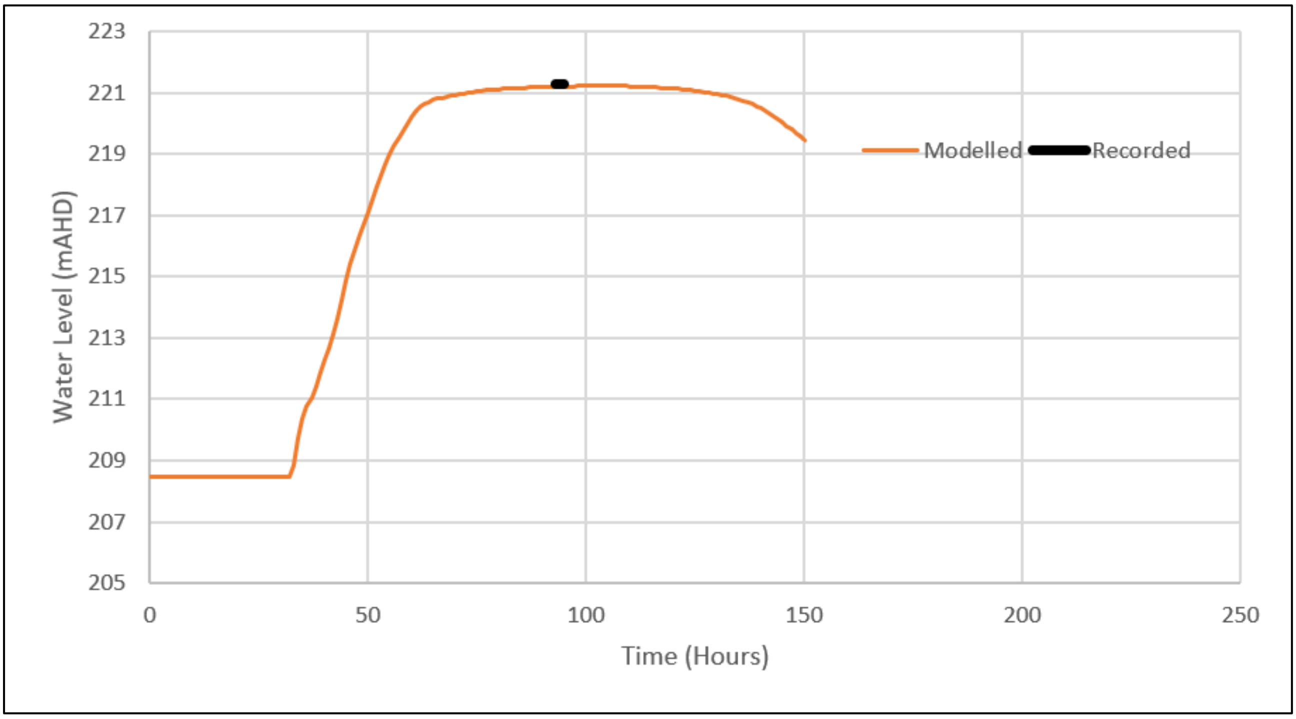

Figure B.3 Boggabilla Gauge – 1976 levels recorded and modelled (time series not available for 1976 recorded level)

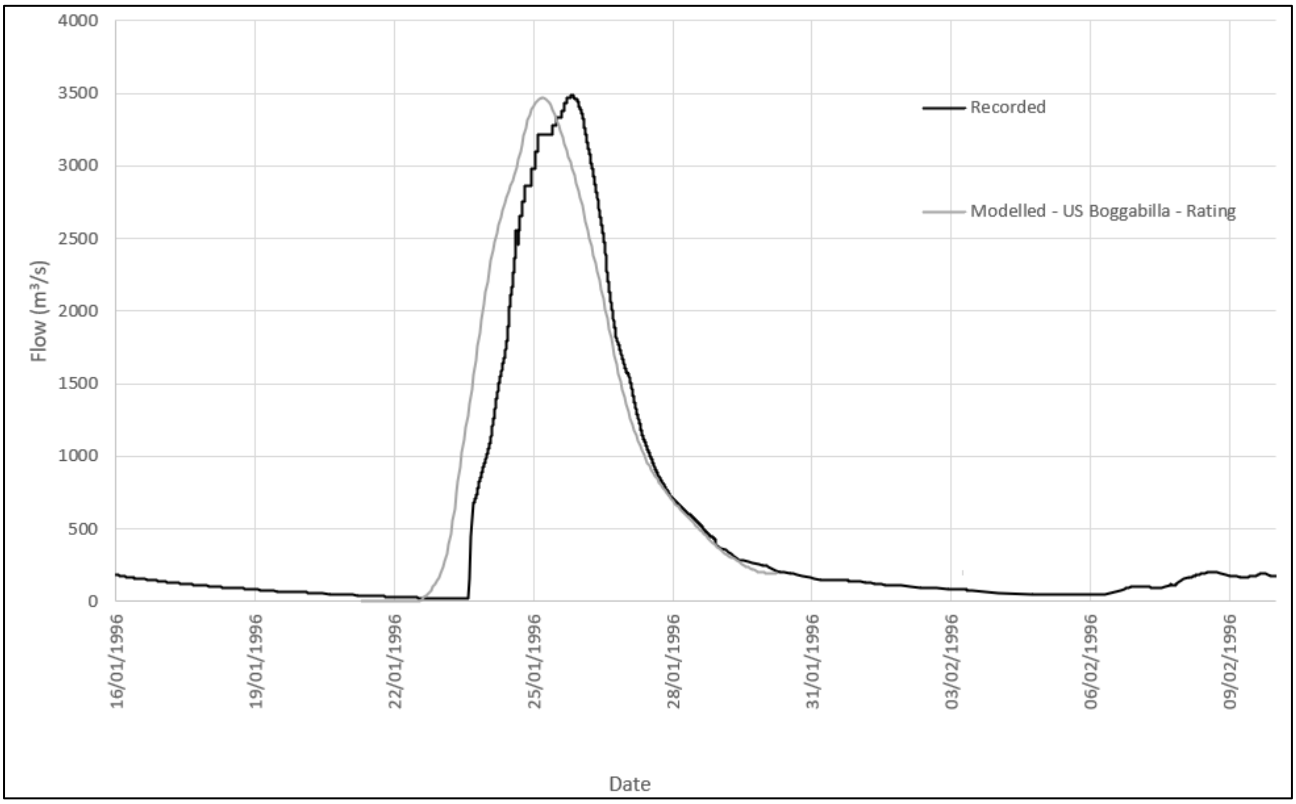

Figure B.4 Boggabilla Gauge – 1996 flows recorded and modelled

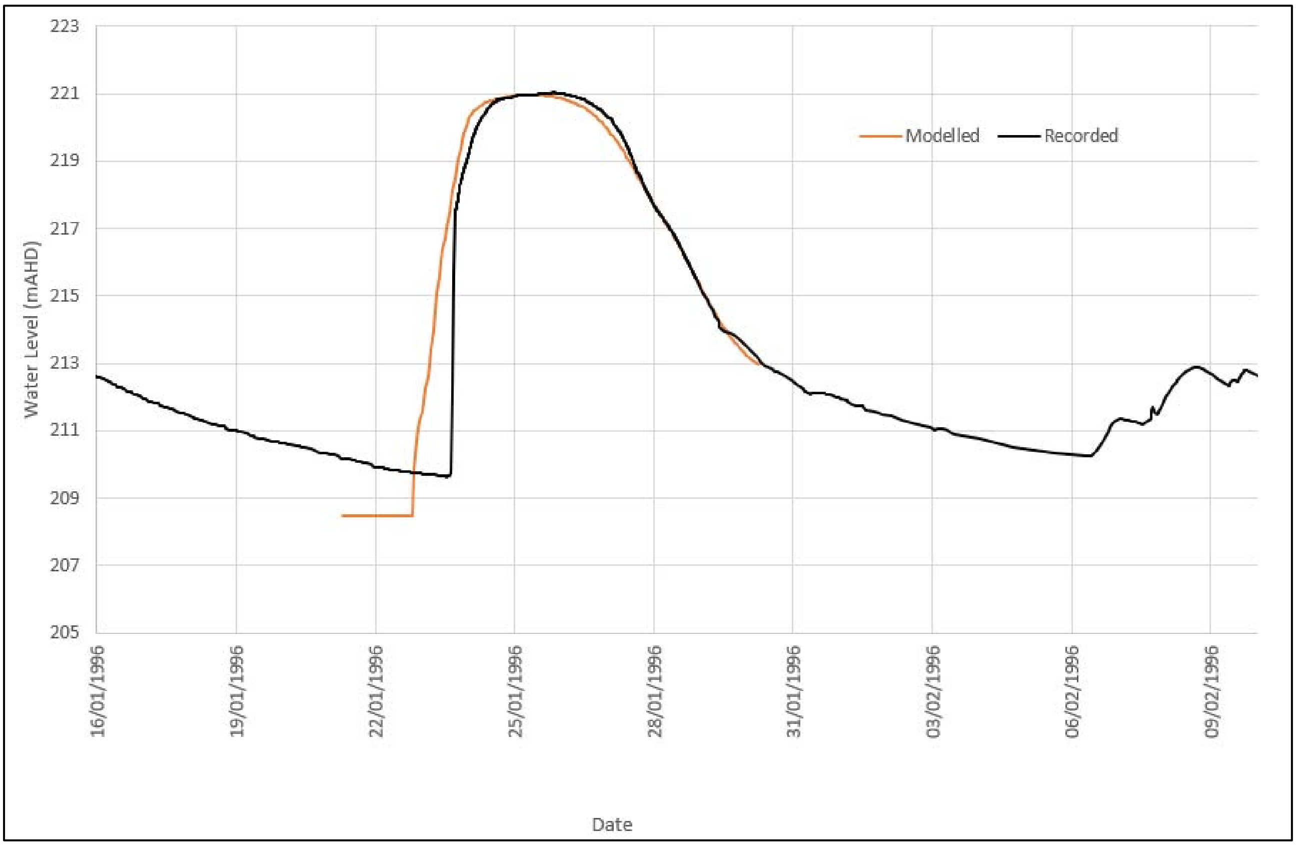

Figure B.5 Boggabilla Gauge – 1996 levels recorded and modelled

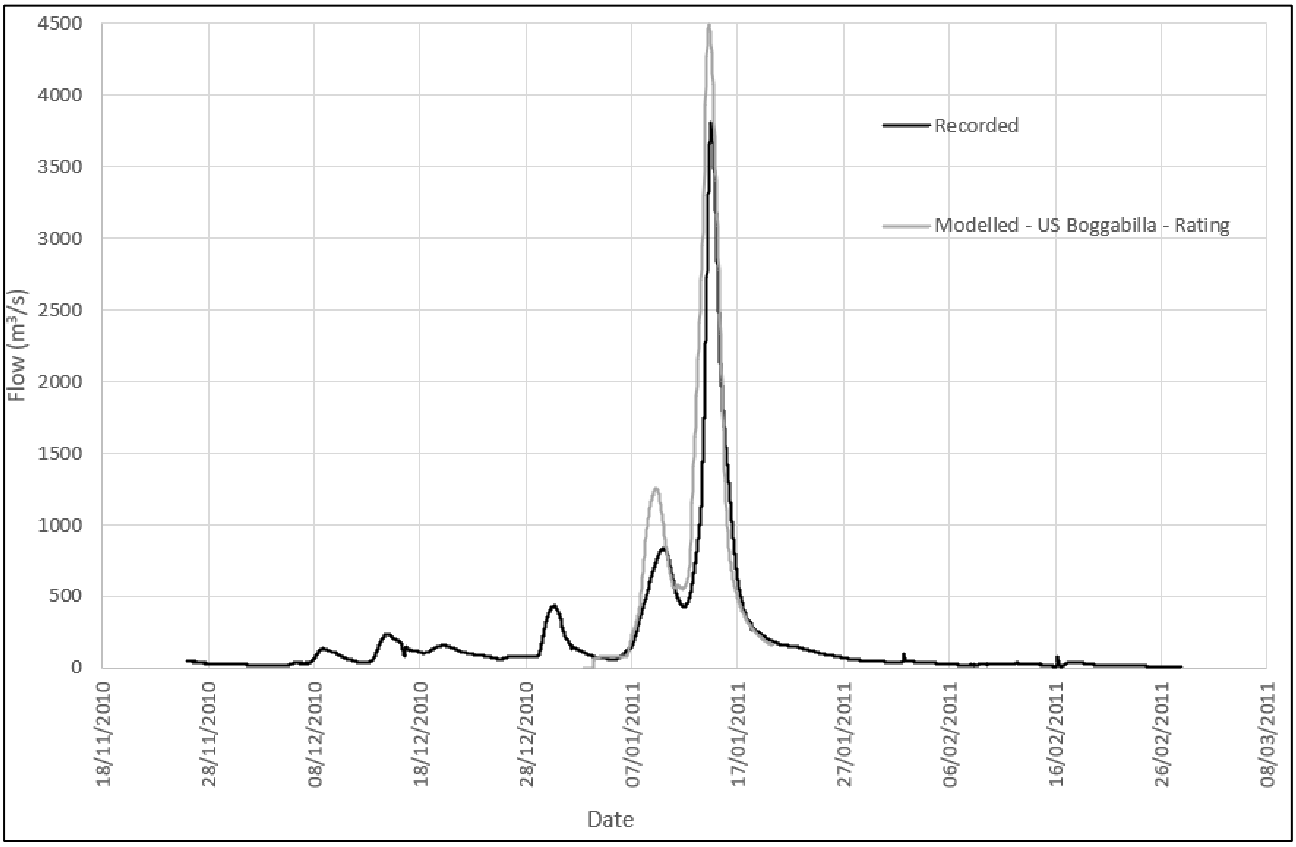

Figure B.6 Boggabilla Gauge – 2011 flows recorded and modelled

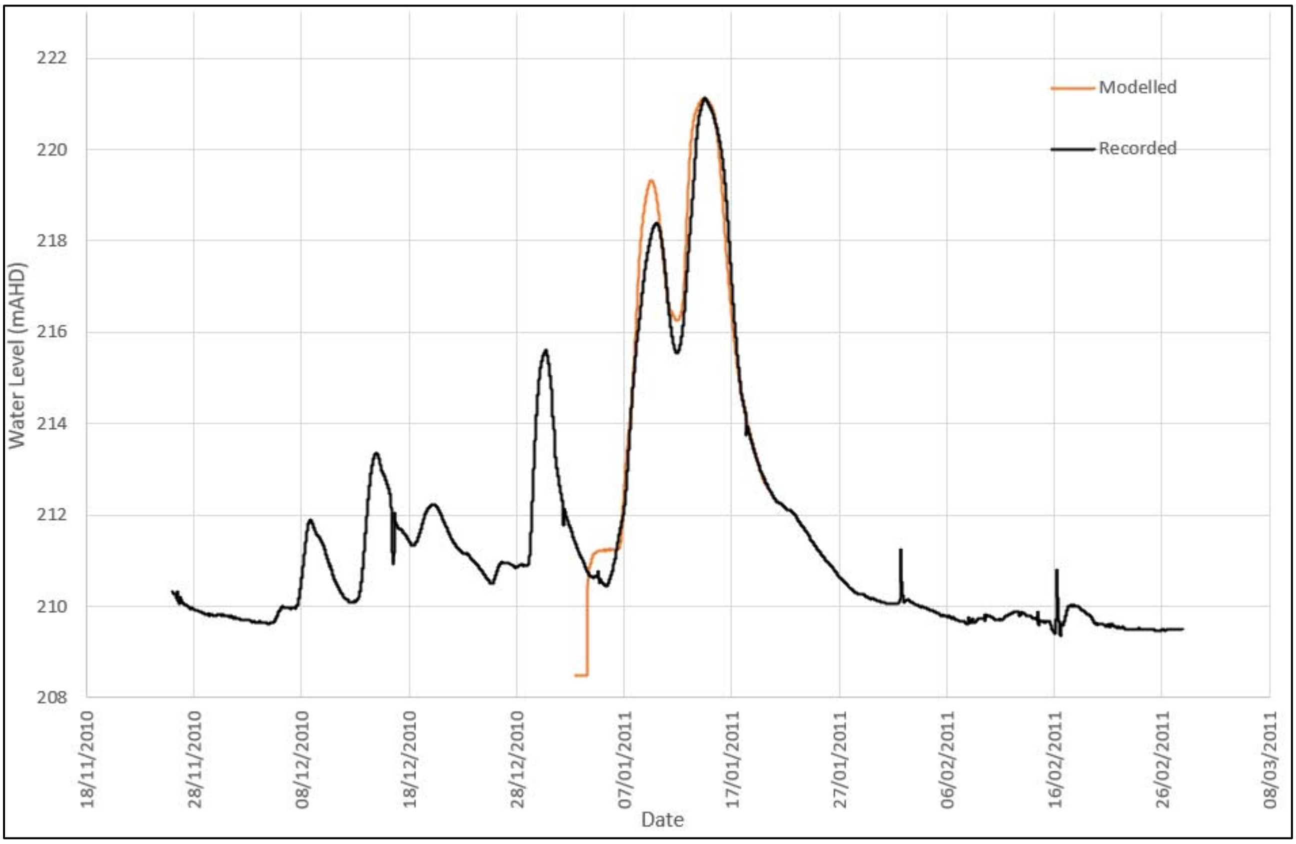

Figure B.7 Boggabilla Gauge – 2011 levels recorded and modelled

B2.5 Goondiwindi stream gauge

The recorded and predicted flood levels and flows at the Goondiwindi stream gauge are presented in Table B8.

Table B8 Comparison of results at the Goondiwindi stream gauge

Event	Recorded level (m AHD)	TUFLOW modelled level (m AHD)	Rated gauge flow (m^3/s)	Rated gauge flow (ML/D)	TUFLOW modelled flow (m^3/s)	Modelled flow (ML/day)
1976	218.08	218.37 (+0.29)	1,560	134,784	2,128	183,859
1996	218.19	218.34 (+0.15)	1,767	152,669	1,987	171,677
2011	218.195	218.36 (+0.16)	1,767	152,669	2,128	183,859

Figure B.8 presents a comparison of the modelled flows and level information at Goondiwindi for each of the three historical events against the rated data from the stream gauge (i.e. measured during events). The rising limbs of the modelled events are the lower lines with the receding hydrograph limbs resulting in the high peak levels. As recordings are typically taken on the falling limb of flood events, the model results are a good match to the rated data.

For all three historical events, the hydraulic model results give a good representation of conditions at the Boggabilla stream gauge. With good matches in peak water levels, peak flows and hydrograph shapes and timing as demonstrated in Figure B.9 to Figure B.14.

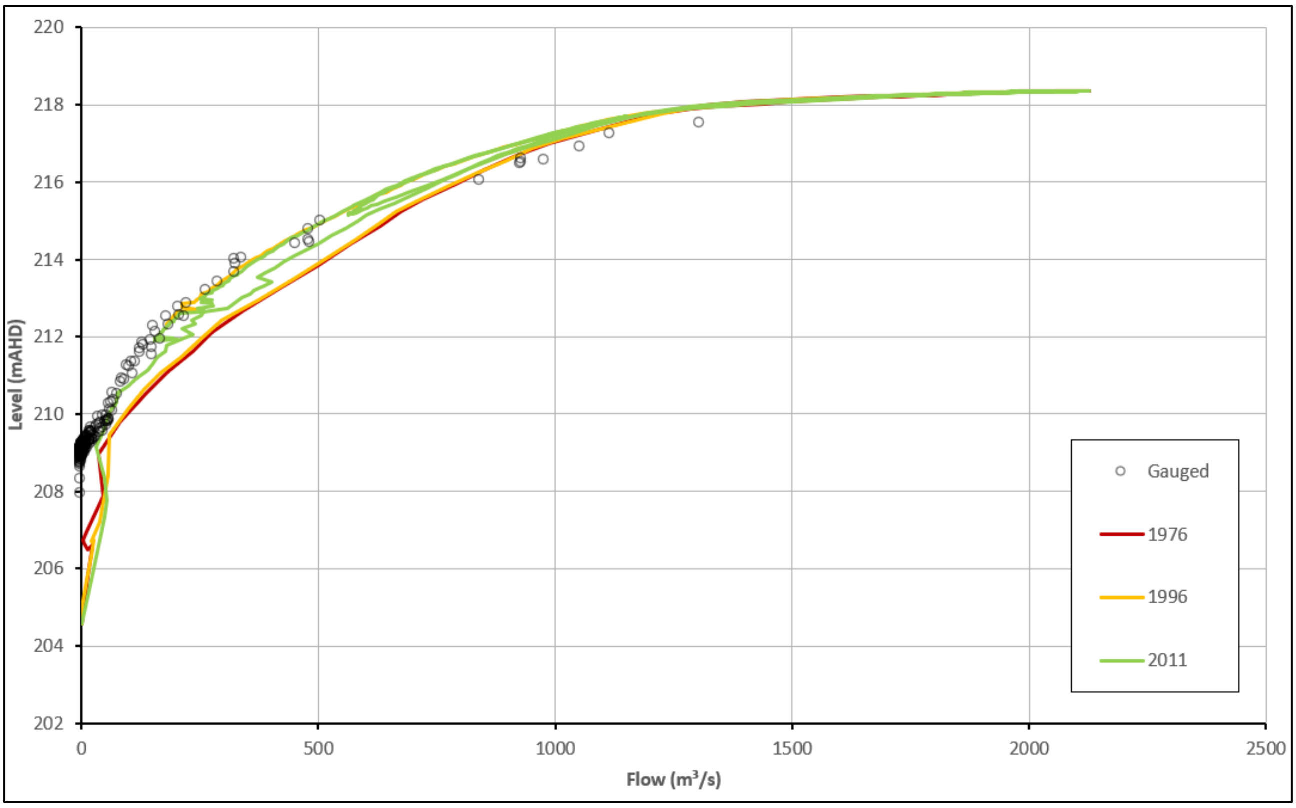

Figure B.8 Goondiwindi stream gauge – model results compared to rated data

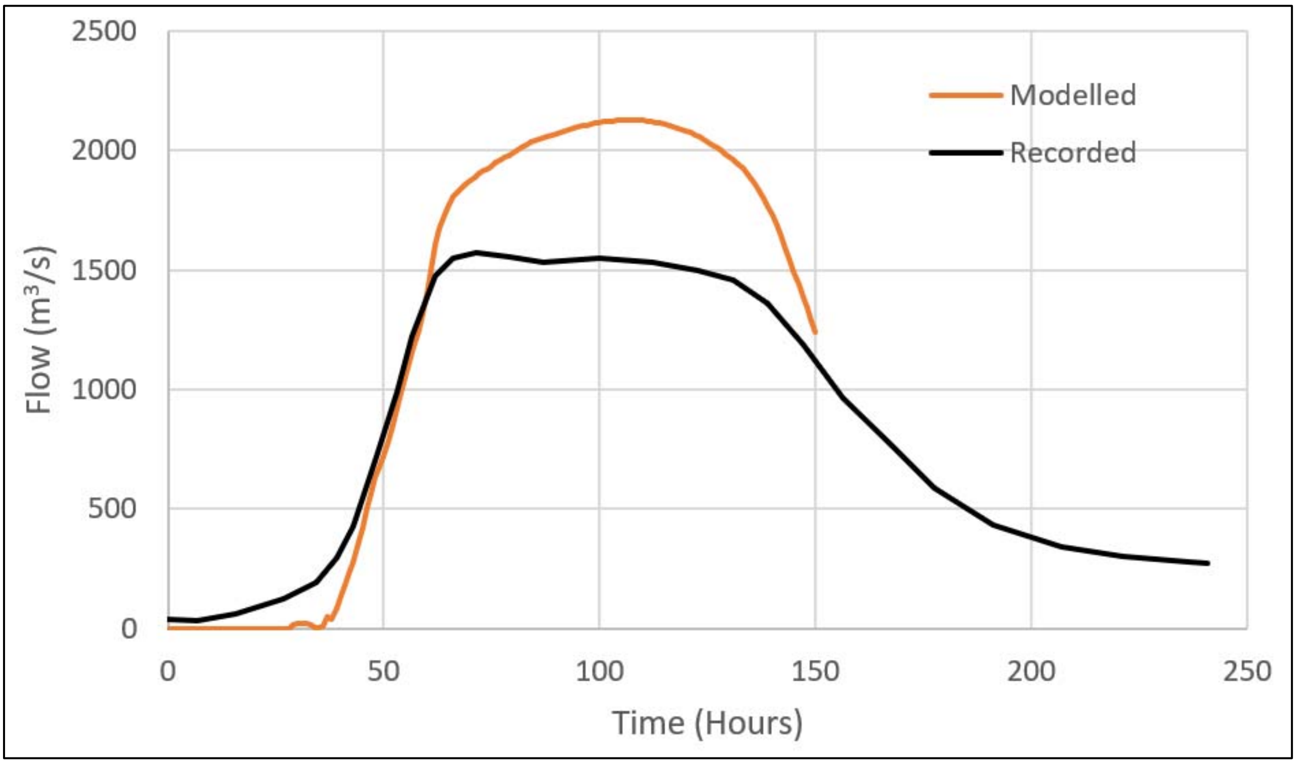

Figure B.9 Goondiwindi Gauge – 1976 flows recorded and modelled

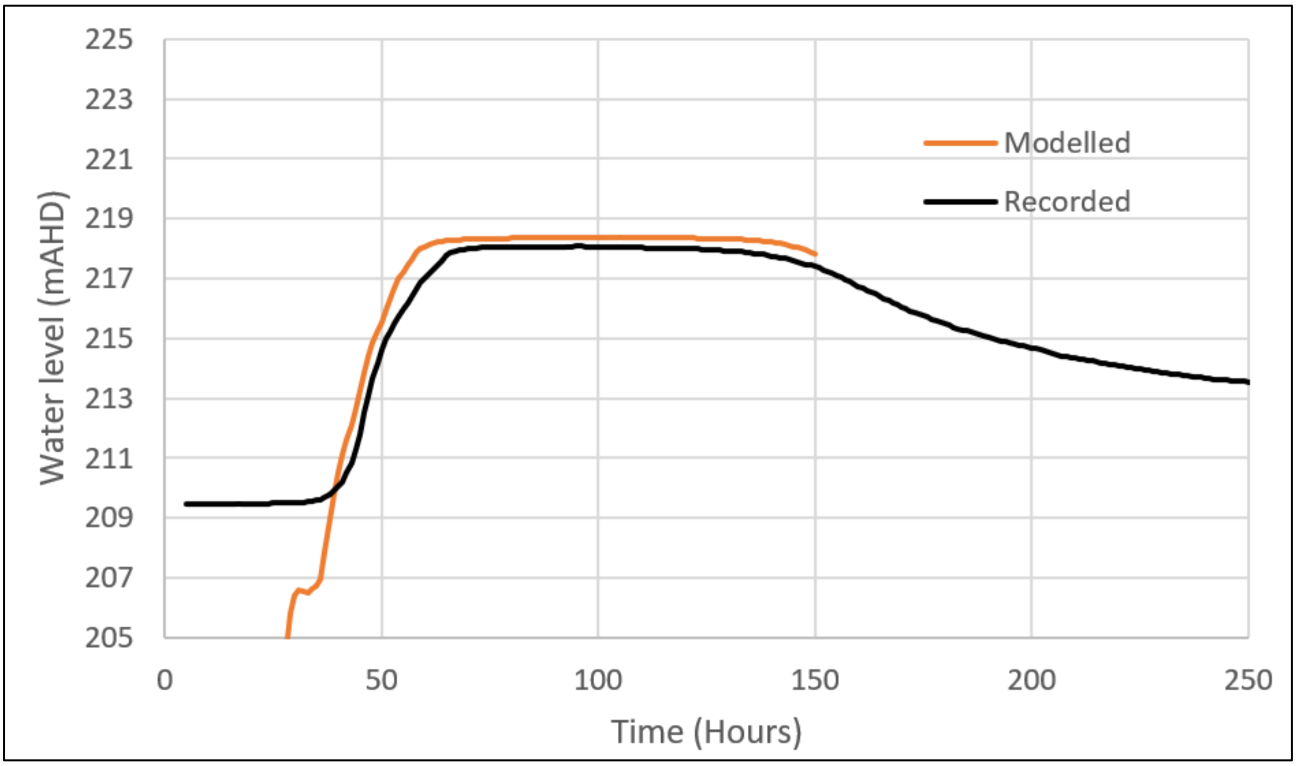

Figure B.10 Goondiwindi Gauge – 1976 levels recorded and modelled

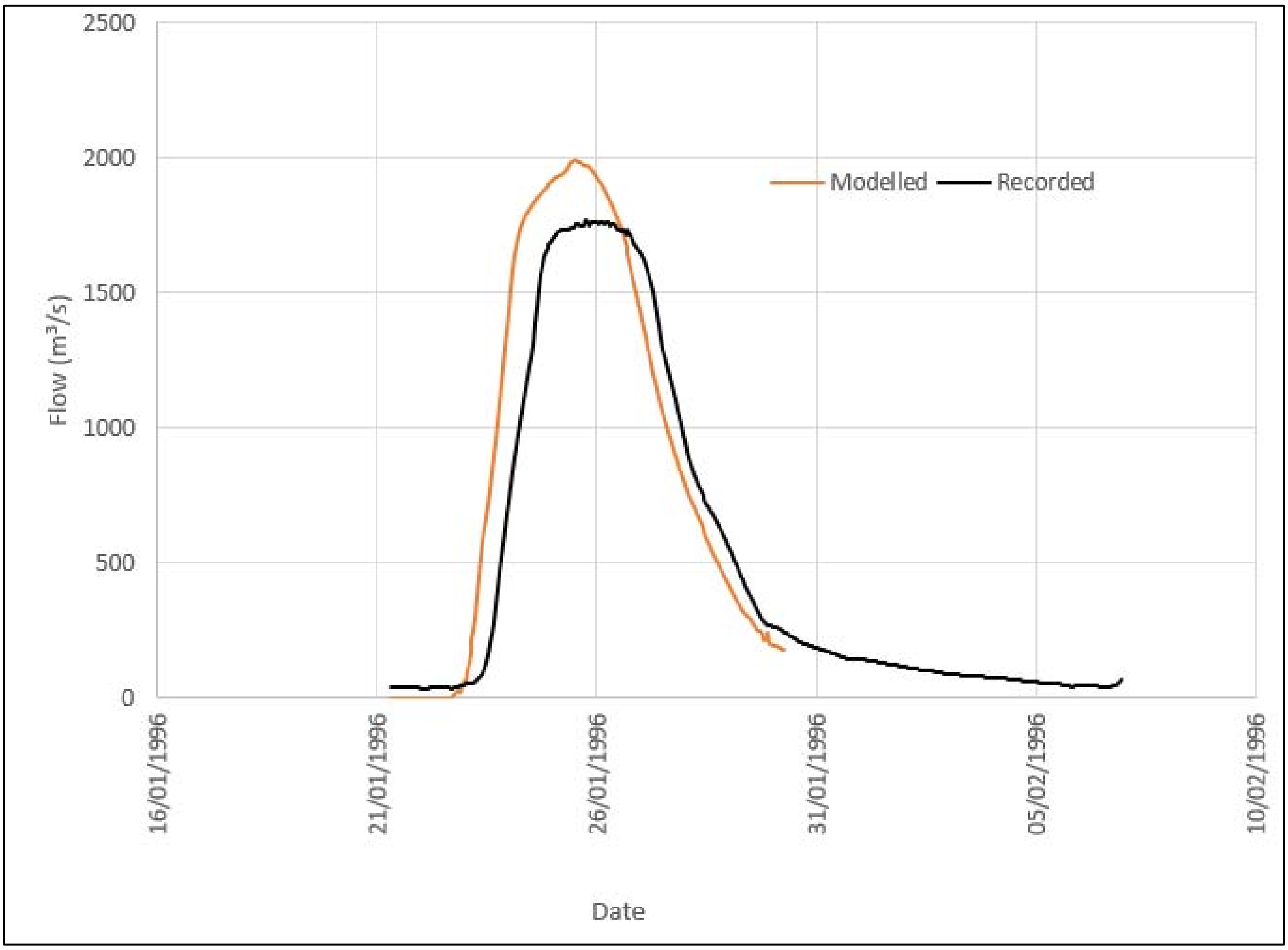

Figure B.11 Goondiwindi Gauge – 1996 flows recorded and modelled

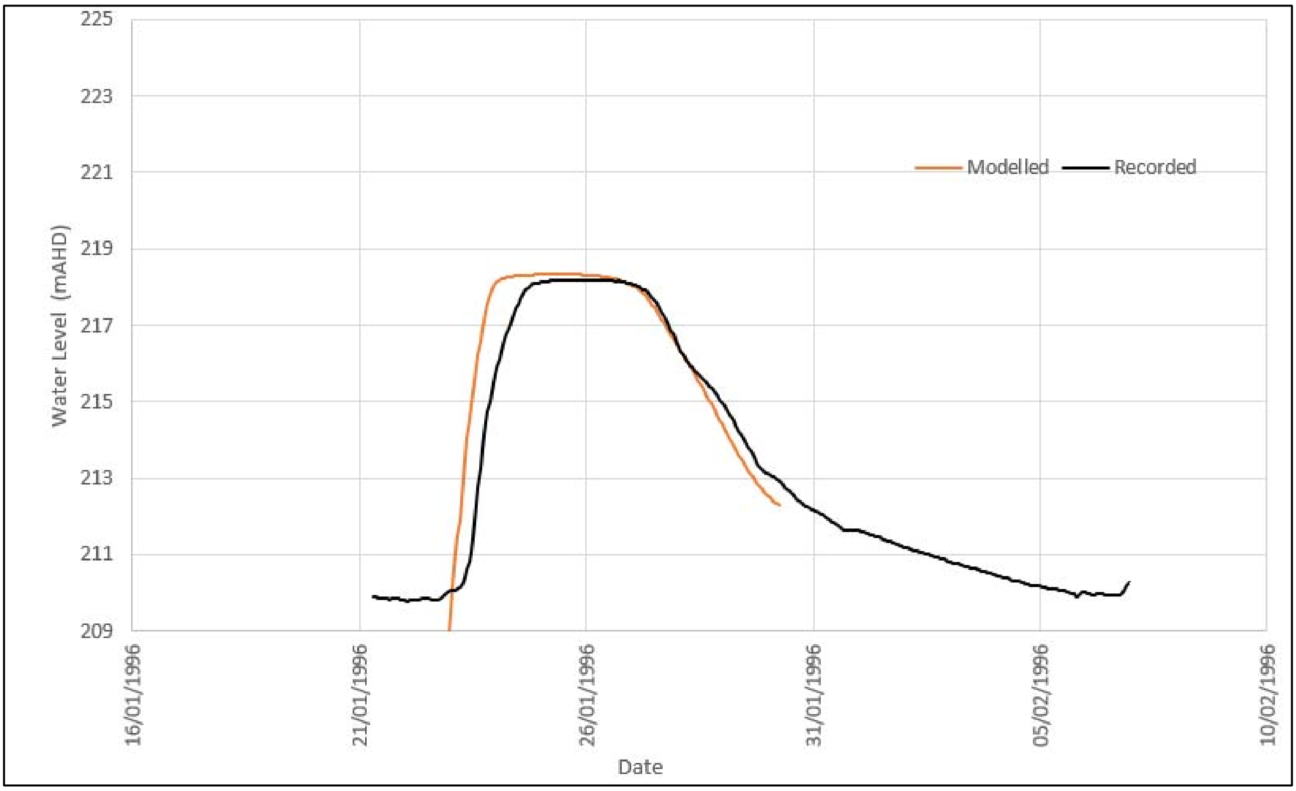

Figure B.12 Goondiwindi Gauge – 1996 levels recorded and modelled

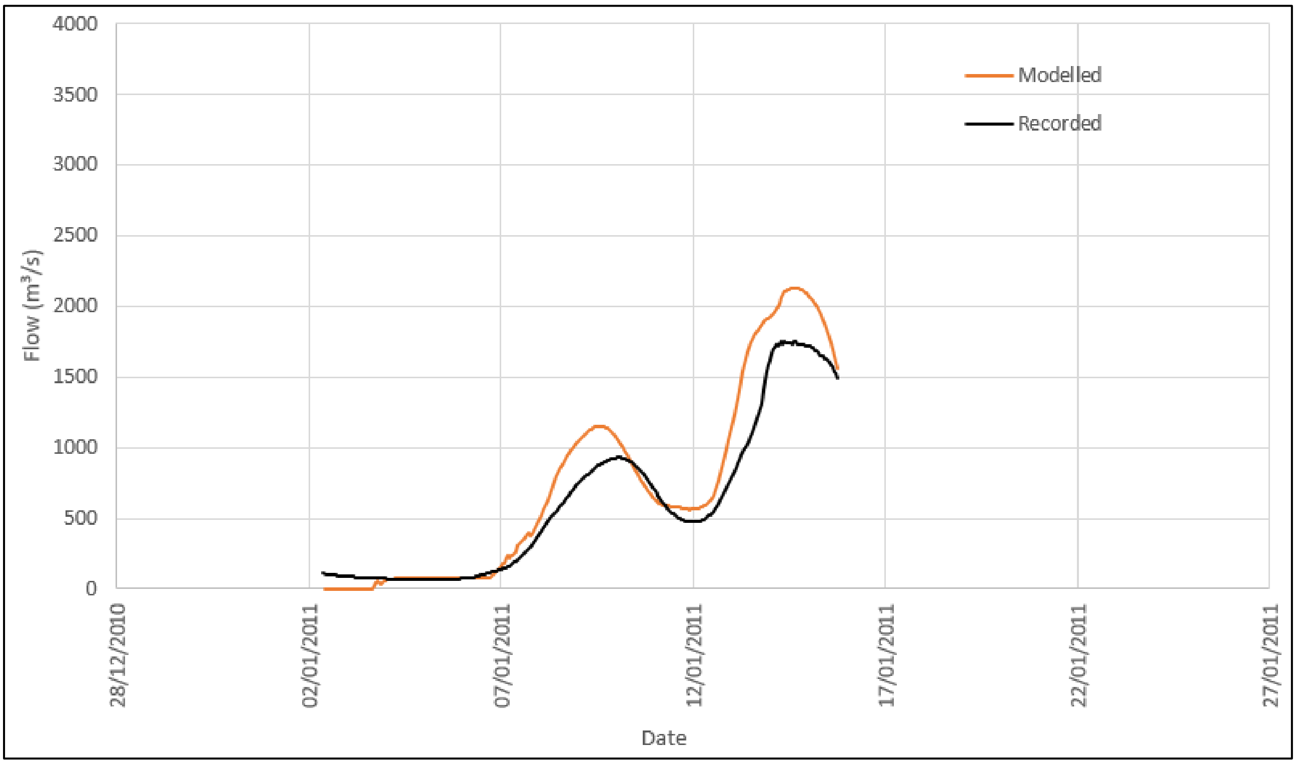

Figure B.13 Goondiwindi Gauge – 2011 flows recorded and modelled

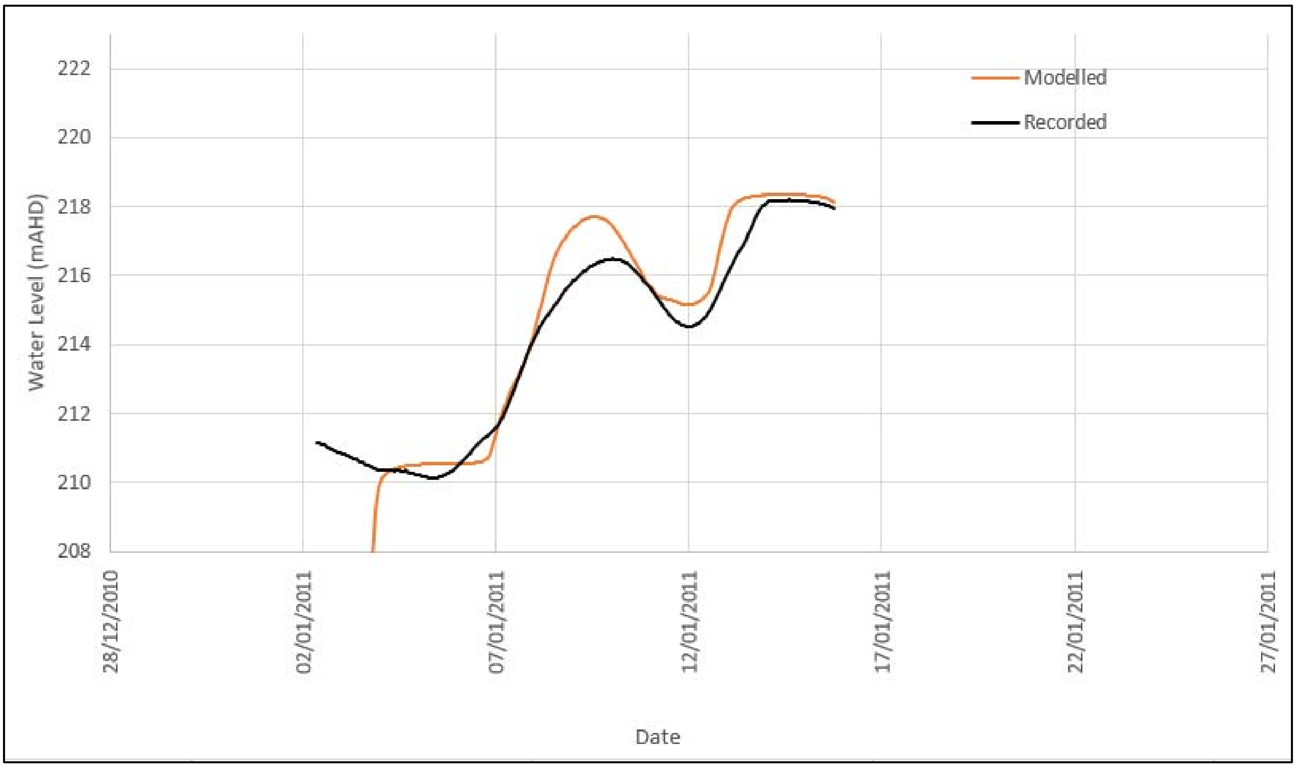

Figure B.14 Goondiwindi Gauge – 2011 levels recorded and modelled