Tabulam Floodplain Risk Management Study and Plan

Kyogle Council

Final Flood Study Report

Revision C

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Tabulam Floodplain Risk Management Study and Plan

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B	18/1/2019	Draft Flood Study Report	L Chong	A Hossain	A Hossain
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Contents

Foreword

The primary objective of the New South Wales Government's Flood Prone Land Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods, utilising ecologically positive methods, wherever possible. Under the Policy, the management of flood prone land remains the responsibility of local government.

The policy provides for a floodplain management system comprising the following five sequential stages:

1.	**Data Collection**	Involves compilation of existing data and collection of additional data
2.	**Flood Study**	Determines the nature and extent of the flood problem
3.	**Floodplain Risk Management Study**	Evaluates management options in consideration of social, ecological and economic factors relating to flood risk with respect to both existing and future development
4.	**Floodplain Risk Management Plan**	Involves formal adoption by Council of a plan of management for the floodplain
5.	**Implementation of the Plan**	Implementation of flood, response and property modification measures (including mitigation works, planning controls, flood warnings, flood preparedness, environmental rehabilitation, ongoing data collection and monitoring by Council

Kyogle Council is undertaking this study for the village of Tabulam to define flooding behaviour and identify and develop measures to mitigate existing flooding flood risk to people and development in the catchment in accordance with the NSW Government's *Floodplain Development Manual*.

This study represents Stages 1, 2, 3 and 4 of the management process and was prepared for Council by Jacobs. This report is the Final Flood Study Report for the project.

Executive Summary

The village of Tabulam is located in the upper Clarence River catchment in northern NSW, within Kyogle Local Government Area (LGA). The River forms the LGA boundary, with Tenterfield LGA situated on the western side of the River. The main source of flooding is from the main river itself, with a catchment area upstream of the village of 4,550km^2, while the Timbarra River, a major tributary which joins the Clarence River 2km downstream of Tabulam (catchment area upstream of the junction of 2,000km^2), may contribute with backwater flooding from its own catchment. The Tabulam Rivulet (catchment area 315km^2) located immediately north of the village may also contribute to flooding. The catchments are a mixture of forested areas in addition to cleared rural lands on the floodplains and ridgetops.

Significant flood events occurred in 1976 and 2011. During the 2011 event a number of houses and their occupants were evacuated as floodwaters peaked, resulting in the village being isolated for a period. The 1976 flood level was 1m higher than the 2011 flood and is similar to preliminary estimates of the 1% AEP flood made by previous studies, noting that these estimates were updated in this study.

Kyogle Council ("Council") commissioned Jacobs to prepare a floodplain risk management study and plan for the village of Tabulam. This report is the Draft Flood Study Report which documents data collection and review, hydrological analysis, development and calibration of a computer flood model and estimation of flood behaviour for design flood events.

An existing computer flood model developed by consultants GHD (2015a) for the Bruxner Highway new replacement bridge crossing of the Clarence River at Tabulam was reviewed but found to be inadequate for this flood study. Hence a new computer flood model was developed as part of this study based on available data from Council and other sources, and topographic and hydraulic structures survey collected during this study. The model was developed with a focus on mainstream flooding originating from runoff from the Clarence River, Tabulam Rivulet and the Timbarra River. Inflows in the Clarence River and Timbarra River were estimated based on data recorded at stream gauges on the rivers for historic events, and from updated flood frequency analysis (FFA) of stream gauging data for design flood events. A RORB hydrologic model was developed to estimate design flow hydrographs for Tabulam Rivulet.

The TUFLOW model was calibrated to the Feb 1976 and Jan 2011 flood events based primarily on recorded water levels at the Tabulam gauge in addition to surveyed flood marks in the village collected by Council following the 2011 flood event (including three flood marks from the 1976 event). The model achieved a good fit (+/- 0.1m variance), while there is a fair (up to +/- 0.25m) to poor (> +/- 0.25m) fit to the reported flood marks, owing to the unexplained variability of the flood mark levels.

Parameter values for the TUFLOW model were adjusted to achieve a satisfactory fit to historic flood observations include model grid size, estimated inflows from the rating curve, hydraulic roughness of the floodplain and watercourse and timing of tributary inflows. An updated flood frequency analysis of recorded gauge data was undertaken to estimate design flows in the Clarence River and Timbarra River, which included a review of stream gauging and the rating curve. This review indicated that estimated peak flows for the largest historic flood events involve huge extrapolation of the rating curve. Hence, there is significant uncertainty at the higher end of the rating curve for discharges relevant to significant flood events and associated peak flow rates.

The updated FFA provides significantly higher design flow estimates than previously estimated by GHD (2015a). The updated FFA was based on fitting the recorded gauge data (instantaneous flow) to a Log Pearson III (LPIII) distribution as per ARR 2016 guidelines, while the previous estimate was based on Gumbel distribution and mean daily (rather than instantaneous) flows. Sensitivity of the FFA to using other statistical methods and tests, including fitting to Generalised Extreme Value distribution and using Multiple Grubbs Beck Test, validated the adoption of LPIII distribution.

Confidence in the current design flow estimates was taken from the hydraulic model calibration in this study using an extensive hydraulic model and which produced a satisfactory fit to the recorded flood levels at Tabulam gauge. The previous studies used a limited extent model with likely high influence of the assumed downstream boundary conditions, and additionally was not calibrated to historic flood levels. Given these factors, the current design flow estimates and hydraulic modelling in this study are considered more reliable.

A range of design flood events including the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events and an extreme flood event (3 x 1% AEP event) were simulated to estimate design flood levels in Tabulam Village. The Bruxner Highway new bridge at Tabulam was represented in the design flood estimation.

Peak flood levels and depths within the study area for all design events assessed are presented on Figures D-1 to D-8 in Appendix D. Flow velocities within the study area for all design events assessed are presented on Figures D-9 to D-16 in Appendix D. Long section water level profiles through the model domain are presented on Figure D-17 in Appendix D.

The peak flood levels at various points in the study area are summarized in Table 1. The selected locations are shown on Figure 6-2. Note that the construction of the new bridge necessitated relocation of the Tabulam River gauge from between the new and old bridge to a new location on the downstream side of the new bridge.

Table 1 Peak flood levels at selected locations in study area

ID	Event AEP							
	20%	10%	5%	2%	1%	0.5%	0.2%	Extreme
New Gauge Location	122.57	124.21	126.06	128.62	129.29	130.87	132.75	138.99
Old Gauge Location	122.59	124.25	126.10	128.91	129.70	131.45	133.28	138.95
P1	122.60	124.28	126.11	128.95	129.73	131.46	133.25	138.95
P2	-	-	-	128.90	129.69	131.45	133.26	138.93
P3	-	-	-	128.96	129.73	131.38	133.23	138.47
P4	-	-	-	128.97	129.65	131.14	132.99	138.74
P5	-	123.96	125.99	128.49	129.19	130.83	132.74	138.47
P6	-	-	-	128.34	129.07	130.84	132.78	138.54
P7	-	-	-	128.34	129.04	130.75	132.69	138.42
P8	-	-	-	128.33	129.03	130.68	132.58	138.25

* Dash (-) denotes not flooded at that location.

Flood behaviour in the village is summarised below:

- Overall, fringe flooding begins to encroach on some dwellings in the 10% and 5% AEP floods but there is generally no over floor flooding. There is one property with 0.8m deep overfloor flooding.
- Flooding of the village occurs both north and south of the Bruxner Highway in the 2% AEP event, creating a high flood island in the village. More than half of the buildings are inundated. The highway is inundated between Clarence Street and Lawrence Street but remains passable for larger vehicles (depths up to 0.4m). The new bridge deck is not overtopped in the 2% AEP event. Tabulam Rivulet bridge, with deck level of 127.6m AHD, is above the 5% AEP event and submerged to depths of 1.3m in the 2% AEP event
- In the 1% AEP event, flooding is extensive through the village, with many properties affected by flooding of 1 – 3m deep above ground, and a number of properties in the south of the village with 3 – 5m deep flooding above ground. A high flood island remains in the village in the 1% AEP event. The highway is cut off between Clarence Street and Lawrence Street to depths of 1.7m. The new bridge deck is partly submerged to 0.3m depth, on its western side.
- In the 0.5% AEP event the entire village is fully inundated with property flooding of 0.5m on the low flood island (i.e. a high point in the landscape which is a dry island at early stages of the flood but which then becomes submerged) up to 6.7m on low properties adjoining the floodway. There are several dwellings above the 0.5% AEP flood to the east of Lawrence Street. The new bridge deck is submerged to depths of 0.7 – 2m.

- The design extreme event flood is dominated by an extreme flooding event occurring in the Clarence River, with Tabulam Rivulet extreme flood event not being the critical event in any part of the study area. Flood depths in the village range from 8m to 15m.

Modelled flood rates of rise were determined for all design flood events and are summarised in Table 2, including the maximum rate of rise and the rate of rise from 120m AHD (approximately start of the flood wave) to peak flood level. The differences in the rate of rise between the design events is attributed to the 1976 flood hydrograph shape, with a faster rate of rise, being adopted for the 1% AEP event and rarer, while the 2011 flood hydrograph shape with a more gentle rate of rise was adopted for up to the 2% AEP event.

Table 2 Modelled flood level rates of rise for design events

Design event	Maximum rate of rise (m/hr)	Rate of Rise from start of flood to peak (m/hr)
20% AEP	1.3	0.1
10% AEP	1.9	0.3
5% AEP	1.5	0.2
2% AEP	1.6	0.2
1% AEP	2.8	0.9
0.5% AEP	3.3	0.9
0.2% AEP	3.7	1.0
Extreme Flood Clarence River	3.9	1.1
Extreme Flood Tabulam Rivulet	2.8	1.0

Flood hazard mapping was prepared from the modelling results and based on hazard classification from the Australian Institute for Disaster Resilience. Description of the flood hazard in the different flood events is summarised below:

- Parts of Tabulam village are affected by low to moderately high (up to H3 rating, localised H4 on low properties) in up to the 5% AEP event.
- In the 2% AEP event, flood-impacted properties are affected by H2 and up to H5 flood hazard rating. The highway is affected between Clarence Street and Lawrence Street by up to H2 flood hazard but remains passable for larger vehicles (depths up to 0.4m). The highway to the west of the Clarence River is cut at the Clarence Overflow No. 2 crossing, with flood hazard of H5.
- In the 1% AEP event, flooding is extensive through the village, with most properties affected at the dwelling by flood hazard of H3 up to H5. The Bruxner Highway is cut between Clarence Street and Lawrence Street by up to H5 flood hazard. The highway to the west of the Clarence River is cut at the Clarence Overflow No. 2 crossing, with flood hazard of H6. A high flood island remains in the village in the 1% AEP.
- In the 0.5% and 0.2% AEP events and the extreme event the entire village is affected by high and extreme flood hazard ratings of H4 up to H6.

The new bridge has higher flow capacity than the existing (old) bridge and was demonstrated in the model to pass greater flows with less backup and attenuation of flows.

An updated rating curve was derived based on the model results for the new bridge scenario and at the new gauge location downstream of the new bridge. The new bridge has different design aspects and has some impact to flows. Additionally, the gauge location was moved due to construction of the new bridge. The updated rating curve is compared to the current WaterNSW rating curve (rating curve number 227), which is based on the old bridge. There is reasonable agreement between the updated and current rating curves above the 20% AEP event, noting that the current rating curve is significantly extrapolated above the maximum gauged flow. There is minor variation between the curves for low flows, which is attributed to the absence of detailed bathymetric data in the hydraulic model.

Sensitivity of the modelled flood levels to changes in model parameters was assessed. The timing of Timbarra River inflows had negligible influence on peak flood levels in the Clarence River. Reducing the assumed downstream boundary flood surface gradient had negligible impact on flood levels in the study area. Varying the hydraulic roughness by +/- 10% has a substantial impact on peak flood levels in the Clarence River with up to +/- 0.9m change in flood levels in the 1% AEP event.

The impact of climate change on flood levels in the village were assessed based on design rainfall data, modelling results for rare flood events and published ARR 2016 climate change factors. Based on these guidelines the 1% AEP flood level is estimated to increase by approximately 1.4m in the year 2050 and approximately 2.6m in the year 2090.

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a floodplain risk management study and plan for the village of Tabulam, located in the NSW Northern Tablelands, in accordance with the scope of services set out in the contract between Jacobs and Kyogle Council (the Client). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client, third parties, and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

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1. Introduction

1.1 General

The village of Tabulam (refer Figure 1-1 and Figure 1-2) is located in the upper Clarence River catchment in northern NSW, within Kyogle Local Government Area (LGA). The River forms the LGA boundary, with Tenterfield LGA situated on the western side of the River. The main source of flooding is from the main river itself, with a catchment area upstream of the village of 4,550km^2, while the Timbarra River, a major tributary which joins the Clarence River 2km downstream of Tabulam (catchment area upstream of the junction of 2,000km^2), may contribute with backwater flooding from its own catchment. The Tabulam Rivulet (catchment area 315km^2) located immediately north of the village may also contribute to flooding. The catchments are a mixture of forested areas in addition to cleared rural lands on the floodplains and ridgetops.

Significant flood events have occurred in 1976 and 2011. During the 2011 event a number of houses and their occupants were evacuated as floodwaters peaked, resulting in the village being isolated for a period. The 1976 flood level was 1m higher than the 2011 flood and is similar to preliminary estimates of the 1% AEP flood made by previous studies, noting that these estimates were updated in this study.

Kyogle Council ("Council") commissioned Jacobs to prepare a floodplain risk management study and plan for the village of Tabulam. This report is the Final Flood Study Report which documents the flood modelling assessment, model calibration and estimation of design flooding.

1.2 Purpose of this Study

The purpose of this study is to investigate the existing and future flood risks in the study area and to provide information for the development of the subsequent floodplain risk management study and plan in accordance with the NSW Government's *Floodplain Development Manual*.

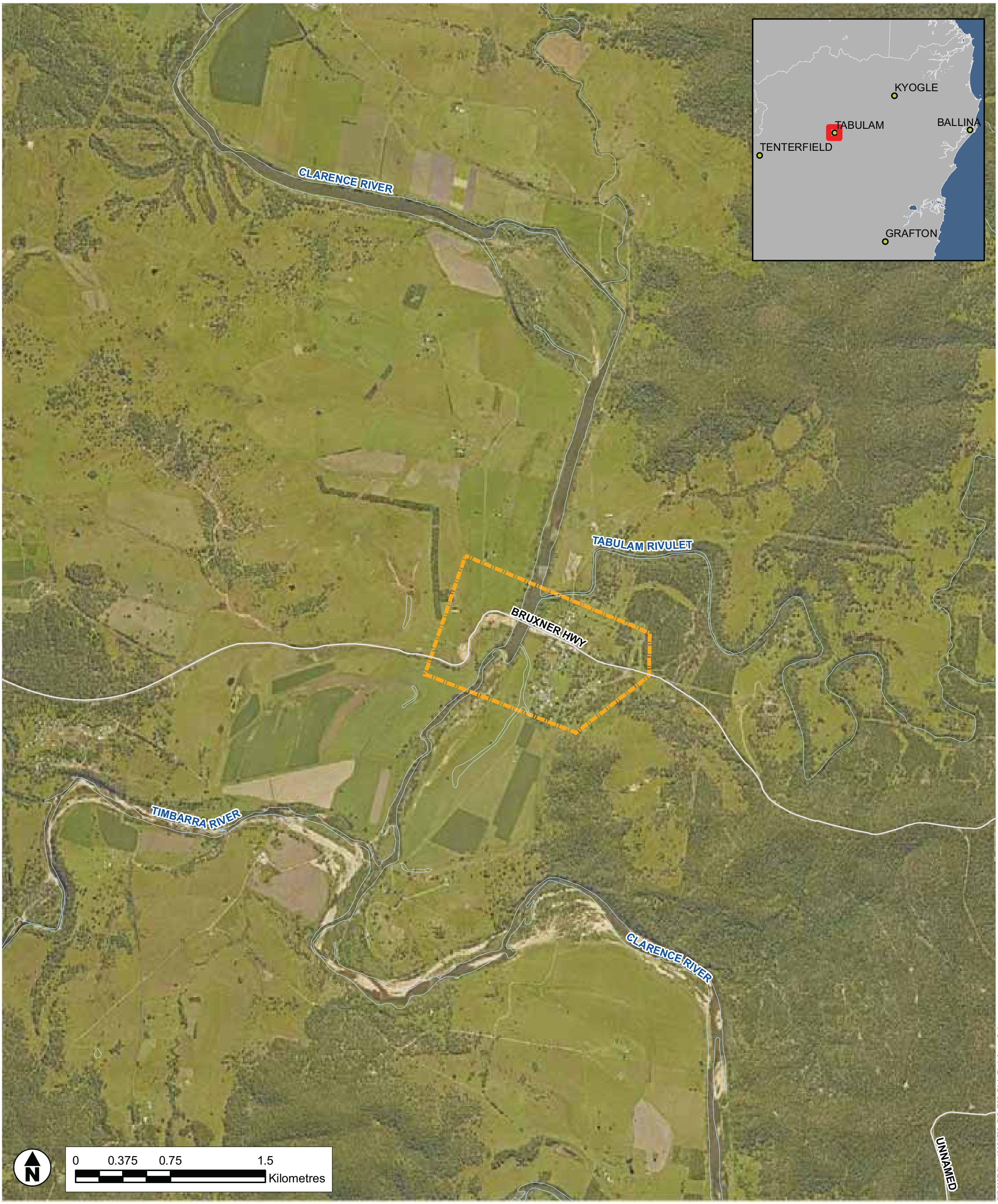
Key objectives of this study are to:

- Undertake a detailed analysis of flooding from mainstream watercourses and local catchments in order to define design flood behaviour for the village.
- Identify and describe impacts of flooding on the community, estimate flood damages and provide information to assist emergency response and management. Provide advice on land use planning.
- Identify flood problem priority areas and identify and develop structural and non-structural mitigation measures to manage flood risk.
- Prioritise the measures, including economic and multi criteria appraisal of structural options.
- Develop an implementation program for recommended measures including timing, responsibility and sources of funding.
- Conduct consultation with the community and key stakeholders to obtain information and intelligence for input into the study, and then to obtain feedback on the findings and recommendations of the study.

1.3 Structure of the Report

Details on the relevant reports and data available to this study are provided in Section 2 of the report. Catchment hydrology including flood frequency analyses and the development of a hydrologic model for Tabulam Rivulet are described in Section 3. Details on the TUFLOW hydraulic model set up are discussed in Section 4. Calibration and verification of the TUFLOW model are discussed in Section 5. Section 6 discusses the estimation of design flooding and validation of the flood study results. Conclusions and recommendations are provided in Section 7. References cited in the report are detailed in Section 8 Section 9 acknowledges contributions received from the community and organisations to undertake this study. A glossary of terms are provided in Section 10.

Six appendices are included in the report which contain supporting tables, figures and maps and study model peer review.



GIS MAP file : IA164700_GIS_R02_F1-1_StudyArea_r2v1

Legend

Study Area
Watercourse
Main Highway

A3

SHEET	1 of 1
	GDA 1994 MGA Zone 56
TITLE	Study Area
PROJECT	Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE 1-1	1	1
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AH	31/10/2018			

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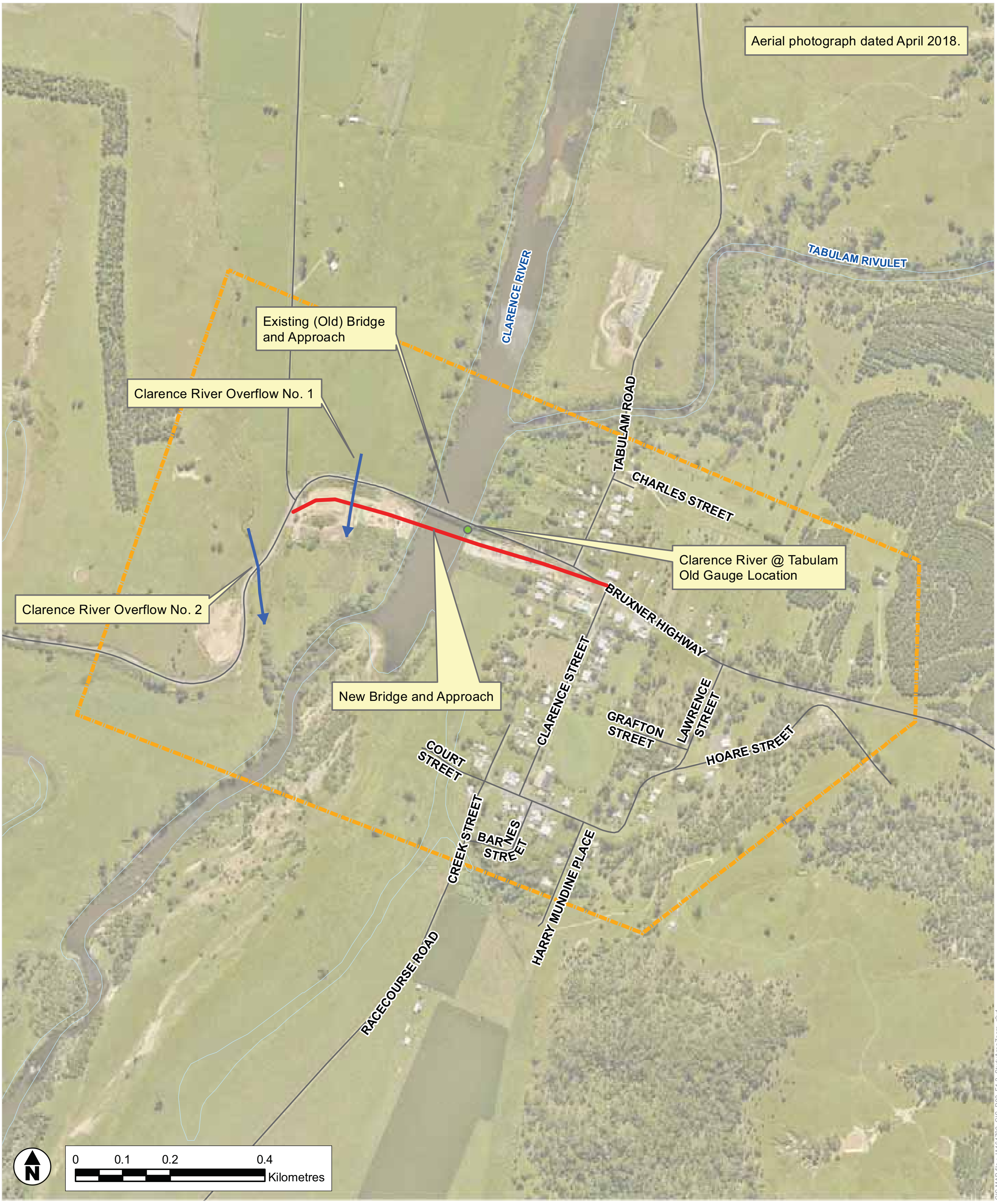

Legend

Study Area
Watercourse
Road

A3

SHEET	1 of 1
	GDA 1994 MGA Zone 56
TITLE	Study Area Tabulam Village Zoom
PROJECT	Tabulam Floodplain Risk Management Study and Plan
DRAWN	LC
PROJECT #	IA164700
MAP #	FIGURE 1-2
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2. Review of Available Information

2.1 General

A review of information available from Council was undertaken to determine what previous assessments have been conducted and to identify additional data which needs to be collected for this study. Existing flood models have been reviewed to determine if extension of these models will be sufficient for the purposes of this study or if the development of a new model will be required.

2.2 Previous Studies and Reports

2.2.1 Tabulam New Bridge Hydraulic Assessment

2.2.1.1 Description

GHD undertook a hydrologic and hydraulic assessment of flow conditions in the Clarence River as a part of the Bruxner Highway bridge replacement design at Tabulam for Roads and Maritime Services (RMS). Two reports were produced documenting the assessment:

- Tabulam New Bridge Hydraulic Assessment (GHD, 2015a); and
- Tabulam New Bridge Supplementary Report to Hydraulic Assessment (GHD, 2016).

The first report detailed the initial hydrologic and hydraulic analysis, including analysis of river gauge data for the Clarence River at Tabulam and Timbarra River at Drake, estimation of design flows, hydraulic modelling, scour assessment and groundwater impacts. The 0.2 Exceedances per Year ("EY". i.e. 20% AEP), 5% and 1% Annual Exceedance Probability ("AEP") flood events were assessed. Large and extreme events consisting of 2x 1% AEP flood flow and 3x 1% AEP flow respectively were also assessed. The flow depths, flood levels, velocities and afflux (change in peak flood levels from pre-development case) were determined. The 80% concept design drawings were provided in GHD (2015a), and 80% detailed design in GHD (2016). This report was peer reviewed by consultants BMT WBM.

The supplementary report documented the updated hydrologic and hydraulic assessments, whereby the design 1% AEP flood flows in the Clarence River were revised, and an estimate made of the 2% AEP flood flow and levels. The bridge vertical alignment was also raised such that the bridge girders were situated above the 2% AEP flood level. The previous design had the girders partially submerged by the 2% AEP event. Flow depths, flood levels, velocities and afflux estimates were updated. The 80% detailed design plans were provided.

The initial hydraulic assessment report describes previous flood events at the site, including the 1976 and 2011 events (refer to Section 2.2.2 for further description of these events). It describes the 2011 flood as having a rate of rise of 1.2m/hour. The report also describes the 1954 flood as being one of the largest floods in the adjacent Richmond River valley, however, since water levels were manually read at Tabulam at 9am daily prior to 1965, the peak of the 1954 flood may not have been recorded. The reported flood level for the 1954 flood is approximately 125m AHD.

The report also presents an oblique aerial photo of Tabulam and the downstream floodplain during the 2011 flood event, showing an area downstream of Tabulam that can form a large pool of relatively slow moving water during large floods. This figure also shows the relatively low lying terrain along the river channel, the Tabulam Rivulet and the first overflow channel. Some water is also visible in the second overflow channel. The photo is reproduced in Figure 2-1.

A review of the TUFLOW hydraulic modelling undertaken for the bridge hydraulic assessment is provided in Section 2.3.

Figure 2-1 Oblique aerial photo of Tabulam in the 2011 flood event, looking south-west (downstream). Reproduced from GHD (2015a)

2.2.1.2 Flow and Flood Level Estimates

The flow and flood level estimates from the GHD reports are summarised in Table 2-1.

Table 2-1 GHD Tabulam New Bridge assessments flow and flood level estimates

Flood Event	Flow (ML/day)		Flood Level[1] (m AHD)	
	Initial Report	Supplementary Report	Initial Report	Supplementary Report
0.2EY	180,000	Not available	121.47	Not available
5% AEP	470,000	470,000	126.46	126.47
2% AEP	Not available	590,000	Not available	127.42
1% AEP	700,000	680,000	128.2	128.2

1 Flood levels for the 0.2EY, 5% and 2% AEP events are based on TUFLOW hydraulic model for new bridge scenario, upstream of bridge. Flood level for the 1% AEP event is based on flood frequency analysis by GHD (2015) at Tabulam bridge.

2.2.2 Tabulam Flood Information

The Tabulam Flood Information report was prepared by Kyogle Council in May 2015 and summarises the occurrence of the 11 January 2011 flood event in the Clarence River at Tabulam, including the rainfall situation leading up to and during the event, the flooding conditions and timing and the emergency response. It compares the 2011 event to the February 1976 event, the latter being the largest recorded event at Tabulam and being approximately the 1% AEP event. The report presents the available automatic gauge data record for the site from 1965 to 2012, which indicates that the 2011 event was the second largest on record at this site. In summary:

- 2011 flood event: peak flood level 127.28m AHD
- 1976 peak flood level: peak flood level 128.25m AHD
- 1% AEP flood level: 128.2m AHD based on at-site flood level frequency analysis as estimated by GHD (2015a).

The report describes that heavy rain occurred in the catchment between 22 and 27 December 2010, followed further heavy rainfall between 5 and 12 January 2011. The report quotes Tabulam SES members saying the Clarence River peaked at 10pm at 15.02m above gauge zero at Tabulam gauge on 11 January 2011[1], with eight houses and at least 18 residents evacuated from their homes in Tabulam on 10 and 11 January 2011 following a flood warning issued at 4pm on 11 January for Tabulam by the local SES unit. The residents returned to their homes by 13 January and the village was isolated at various times during the flood event.

Flood marks were surveyed around the village and are presented in the report along with accompanying site photos and peak flood marks reached. There was minimal variation in surveyed flood levels across the village. No building floor levels were surveyed.

Photos presented in the GHD (2015a) report show flood levels reaching to approximately 0.5 – 1m below the existing bridge girders, taken at approximately 2pm on 14 January 2011. These photos are reproduced on Figure 2-2 and Figure 2-3.

[1] Note that Tabulam SES members mentioned during a floodplain management committee meeting during the draft flood study presentation of visual observations of the peak flooding at 15.1m (Gauge datum) at 11:48pm on 11 January 2011.

Figure 2-2 Tabulam bridge flooding at approx. 2pm on 14 January 2011. Reproduced from Kyogle Council (2015)

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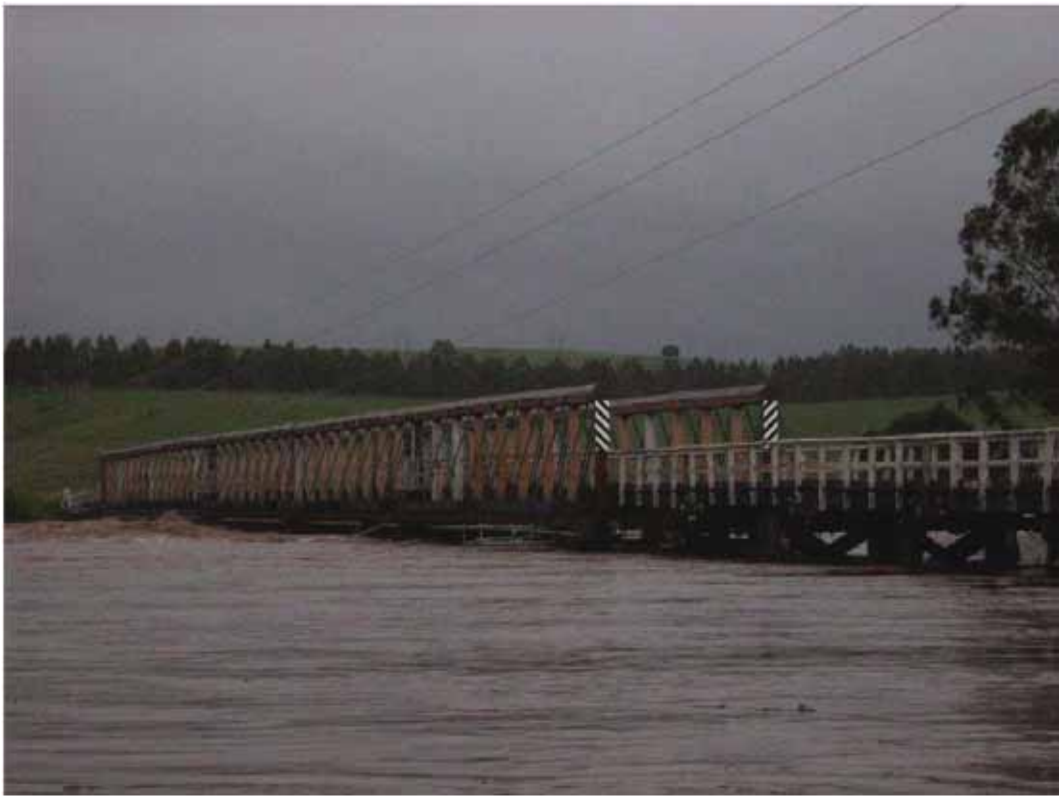
Figure 2-3 Tabulam bridge flooding at approx. 2pm on 14 January 2011. Reproduced from Kyogle Council (2015)



2.3 Flood Models

2.3.1 General

The TUFLOW 2D flood hydraulic model, developed by GHD for the Tabulam bridge replacement project was provided by Council. The model covers the vicinity of the bridge location, extending 800m upstream and 1km downstream, and approximately 1km laterally to the east and west of the bridge. The model was configured with a 12m grid resolution.

The model was not calibrated to known flood marks. It is assumed that the model was configured to provide a flood level consistent with the Tabulam gauge rating curve for the estimated 1% AEP event, although this is not stated in the Tabulam New Bridge hydraulic assessment report.

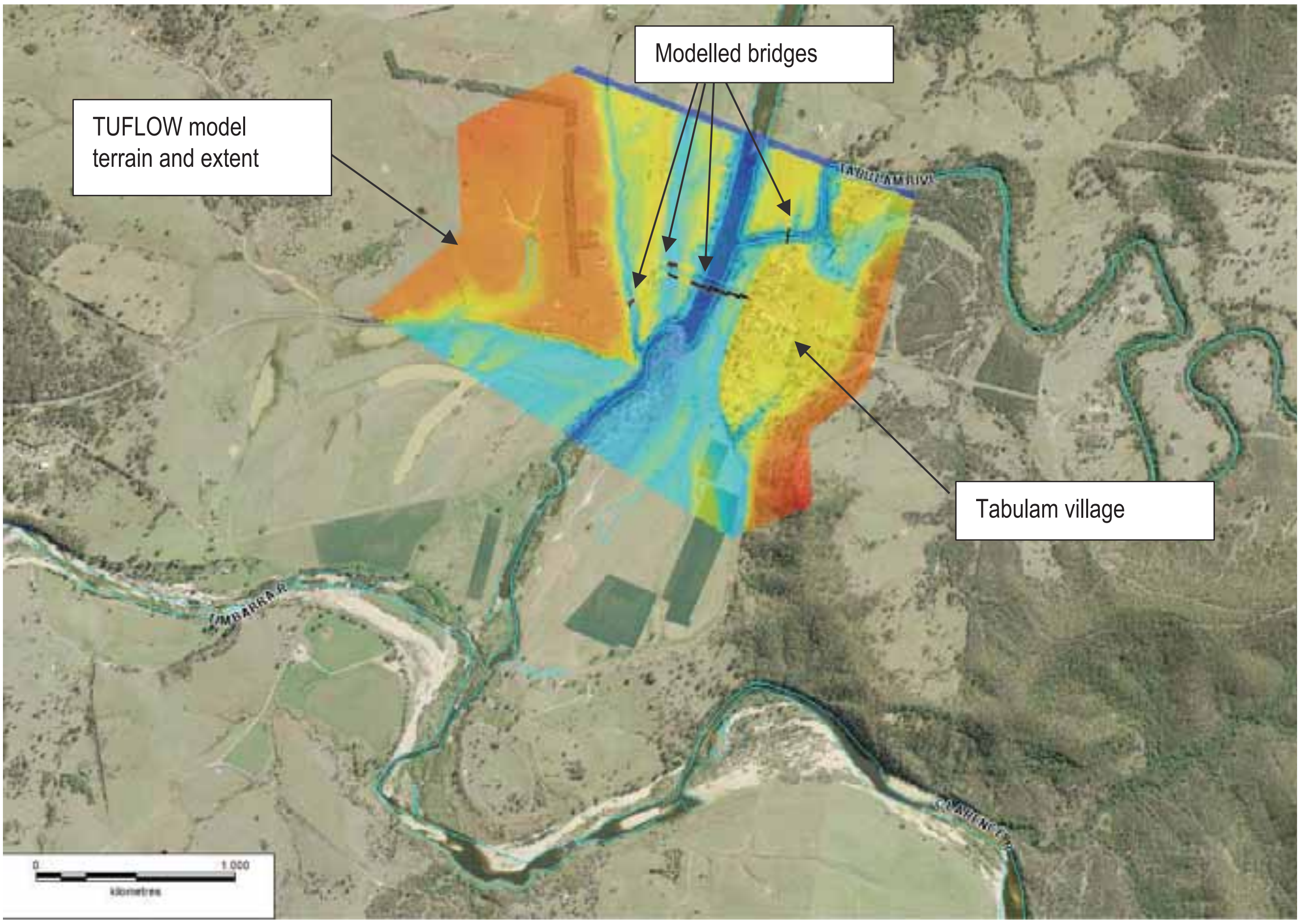
The model extent and features are shown on Figure 2-4.

2.3.2 Topography and Bathymetry

The topography in the model is based on LiDAR. Model bathymetry appears to be based on bathymetric survey of the river bed from bank-to-bank in the immediate vicinity (approximately 50m upstream and 80m downstream of the new bridge location). The modelled river bed levels away from this area are generally consistent with the survey, however, the source and the accuracy of these bed levels are not known.

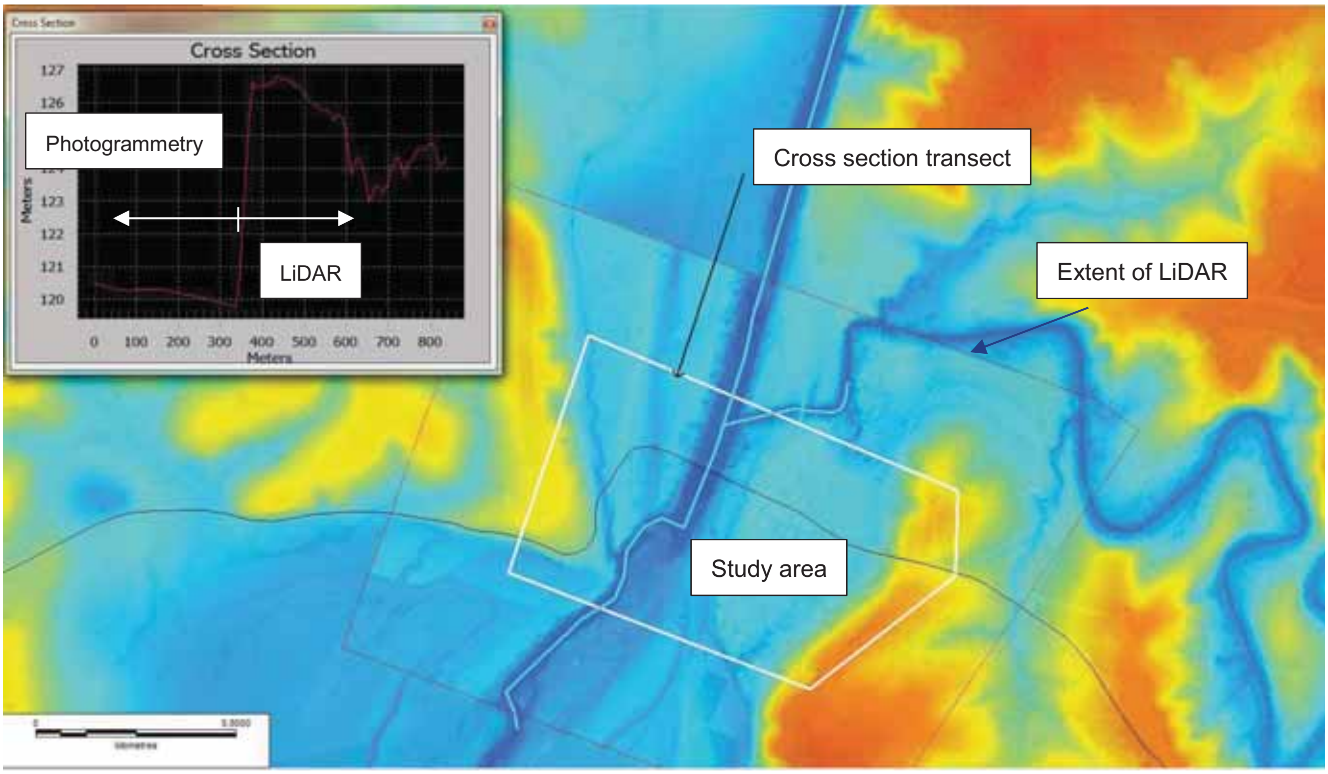
The model extends some way up the Tabulam Rivulet and includes the Clarence River overflows 1 and 2 located on the right (west) bank of the river. The Timbarra River is not represented in the model.

Figure 2-4 Tabulam New Bridge Design TUFLOW flood model



A digital elevation model (DEM) was received with the TUFLOW model data package. The DEM extends approximately 8km upstream and downstream of Tabulam. There are significant discontinuities in the DEM ground surface levels of up to 8m, which suggests that the DEM is a spliced data set of LiDAR around Tabulam and 10m contour or photogrammetry data further afield. This latter data has an accuracy of +/-5m which is insufficient for the purposes of this study. An example of poor accuracy and inconsistency of the photogrammetry elevations versus LiDAR elevations is shown on Figure 2-5, where there is a 7m inconsistency between the photogrammetry and the LiDAR, where the LiDAR is expected to be relatively accurate.

Figure 2-5 Example of large discontinuity in photogrammetry data versus LiDAR (source: DEM from GHD 2015 hydraulic assessment)



2.3.3 Boundary Conditions

The inflow from the upstream Clarence River catchment is represented, derived from flood-frequency-analysis of the Tabulam gauge recorded data. This inflow is distributed along the upstream boundary of the model, with a portion of the flows being input into the Tabulam Rivulet and the Clarence River overflows 1 and 2. This assumed distribution of flow is reasonable for the bridge hydraulics analysis but may not be entirely accurate for the purposes of this flood study. The inflow is ramped-up from zero to a peak flow rate, which is then maintained for the simulation. Hence the model is considered to be a steady flow model. Inflows from the catchment area of Tabulam Rivulet and overland flow paths running through the village are not represented in the model.

The tailwater boundary is represented as a static water level and for the 1% AEP event, the adopted tailwater level is 127.9m AHD, which is 0.3m lower than the 1% AEP design flood level estimated by flood frequency analysis at Tabulam gauge. It is expected that flood levels simulated by the TUFLOW model in the vicinity of the village would be highly sensitive to the adopted boundary condition. Hence it is necessary to extend the model downstream to ensure that modelled flood levels in the vicinity of the village are not highly sensitive to reasonable changes in the adopted tailwater boundary conditions.

2.3.4 Representation of Bridges

Separate versions of the model are available, one representing the existing (pre-upgrade) main river bridge and one of the design case (replacement) bridge, both represented as 2D features. The Clarence River Overflow 1 and 2 bridges (pre-upgrade and replacement scenarios) and the Tabulam Rivulet bridge are represented as 2D bridge features. The modelling of the replacement bridge scenario assumes that the existing (pre-upgrade) bridge approach embankments are retained. The geometry of the replacement bridge in the TUFLOW model is for the detailed design.

The independent review of the GHD modelling, undertaken by BMT WBM (developers of the TUFLOW software) and documented in the Supplementary Report, stated that while the overall approach adopted by GHD in representing bridge and pier hydraulic losses was not the preferred approach, independent checks suggested minimal differences in water levels compared to alternative modelling approaches, and hence the representation of the bridge and pier losses was considered satisfactory.

It is not clear whether the modelled bridge configurations match the final detailed design of the proposed bridges, as the final design was not available for the Draft Flood Study. However, minimal changes to the design bridge configuration (pier locations and widths, deck widths and levels) are expected.

2.4 Rainfall Data

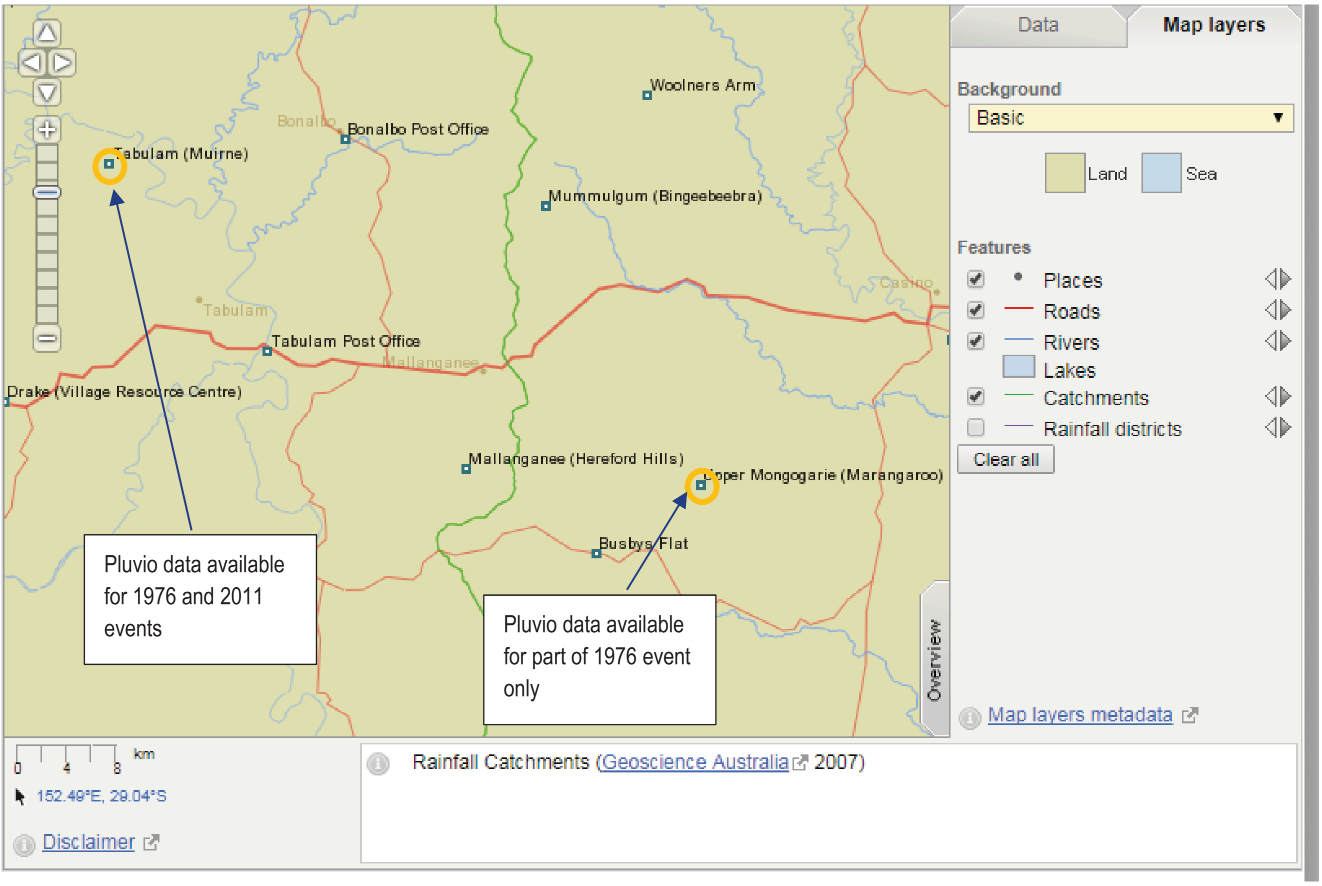
The available daily read rain gauges and pluviographs located in the vicinity of Tabulam are shown in Figure 2-6 and details on the availability of data at the gauging stations are shown in Table 2-2. Data was obtained from the Bureau of Meteorology (BoM) for each of these stations.

Sub-daily (pluviograph) data is required for the hydrologic modelling to be undertaken of the Tabulam Rivulet, to establish inflows into the TUFLOW hydraulic model for the model calibration to historic events.

Table 2-2 Rainfall gauge details

Gauge Number	Gauge Name	Distance (km)	Start Date	End Date	Length of record (years)	Completeness (%)	Capture of Historic Storm Events
Daily Read							
057018	Tabulam Post Office	0	23/05/1887	Current	130.6	96	1976, 2011
057003	Bonalbo Post Office	16.6	1/12/1913	Current	104.0	67	1976, 2011
057121	Mallanganee (Hereford Hills)	17.2	1/05/1987	31/10/2017	30.5	98	2011
057095	Tabulam (Muirne)	18.0	1/08/1970	Current	47.3	100	1976, 2011
057005	Drake (Village Resource Centre)	19.5	10/11/1891	Current	126.1	98	1976, 2011
Pluviograph							
057095	Tabulam (Muirne)	18.0	1/08/1970	Current	47.3	100	1976, 2011
058081	Upper Mongogarie (Kimberley)	25.7	Mar 1963	Feb 1984	19.6	92	1976 part only
058192	Upper Mongogarie (Marangaroo)	32.4	Jan 1987	May 2013	25.5	95	None

Figure 2-6 BoM Rainfall Gauges near Tabulam (source: BoM website. http://www.bom.gov.au/climate/data/)



As indicated on Table 2-2, most of the daily rainfall gauges recorded both the February 1976 and January 2011 storm events, with Station 057121 (Mullanganee – Hereford Hills) only recording the 2011 event. The daily read rainfall depths (to 9 AM as per BoM convention) for the February 1976 and January 2011 events are tabulated on Table 2-3 and Table 2-4. The stations are ordered by distance from Tabulam village.

Table 2-3 indicates that the rainfall spatial distribution was fairly uniform in the vicinity of Tabulam in the February 1976 event. Table 2-4 indicates a pronounced rainfall gradient, with rainfall depths to the west of Tabulam, at Tabulam (Muirne) and Drake (up to 450mm) being approximately double the depths recorded in Tabulam village and to the east, at Tabulam Post Office, Bonalbo and Mallanganee (200 - 270mm).

Table 2-3 Daily rainfall recorded depths at and around Tabulam – February 1976 event

Date	Station				
	057018 Tabulam Post Office	057003 Bonalbo Post Office	057121 Mallanganee (Hereford Hills)	057095 Tabulam (Muirne)	057005 Drake (Village Resource Centre)
2/02/1976	0	0	-	0	0
3/02/1976	12	0	-	7.4	8.2
4/02/1976	28	17	-	22.6	13.6
5/02/1976	0	13	-	17	23
6/02/1976	4	0	-	8.6	2.4
7/02/1976	7	-	-	13.6	2.6
8/02/1976	2	-	-	2.6	8.6
9/02/1976	2	15	-	2	2
10/02/1976	4	4	-	5	4.6
11/02/1976	196	203	-	214.6	200.4
12/02/1976	26	26	-	14.2	13
13/02/1976	0	0	-	0.6	0
Total	**281**	**278**	**0**	**308.2**	**278.4**

Table 2-4 Daily rainfall recorded depths at and around Tabulam – January 2011 event

Date	Station				
	057018 Tabulam Post Office	057003 Bonalbo Post Office	057121 Mallanganee (Hereford Hills)	057095 Tabulam (Muirne)	057005 Drake (Village Resource Centre)
3/01/2011	0	0	0	0	0
4/01/2011	0.4	1.6	0.4	-	40
5/01/2011	10.2	7.2	0.6	67.8	2.8
6/01/2011	34.2	54.2	31	46	90.2
7/01/2011	24.6	29.6	14	42.8	35.5
8/01/2011	2.6	35.2	4.4	16	9.8
9/01/2011	19.6	13.8	20	29.8	25.2
10/01/2011	56.4	58	57	68.8	82.4
11/01/2011	37.6	36.8	44	87.4	125.8
12/01/2011	22.8	26	13.4	57.2	36.6
13/01/2011	1.2	5.4	5	10.8	5.4
14/01/2011	2.8	0	2	0.4	0.8
Total	**212.4**	**267.8**	**191.8**	**427**	**454.5**

Capture of the historic events by the pluviograph stations is summarised below:

- Station 057095 – Tabulam (Muirne): recorded both the February 1976 and January 2011 events. Refer to Appendix A for cumulative rainfall depth plots for these events.
- Station 058081 – Upper Mongogarie (Kimberley): Recorded only part of the February 1976 storm event. Not open for the January 2011 event.
- Station 058192 – Upper Mongogarie (Marangaroo): not open for the February 1976 storm event. Open but did not record the January 2011 event.

Review of the data indicates that the available recorded daily and pluviograph rainfall data is sufficient for the model calibration and verification.

2.5 Stream Gauging Data

Details of relevant stream gauges with significant data present in the vicinity of the study area are summarised in Table 2-5 and location of the gauges are shown in Figure 2-7, along with other gauges without significant data (NSW Office of Water, 2011). Data from these gauges were extracted from PINNEENA (a surface water and groundwater monitoring data base published by the former DPI Water) version 10.2 data base for analysis during the hydrologic assessment. The data covers the February 1976 and January 2011 flood events.

Table 2-5 Stream gauges near Tabulam (Source: GHD, 2015)

Gauge Name and Number	Period of Data	Catchment Area (km^2)	Gauge Datum (m AHD)	Location and direct distance
Clarence River @ Paddys Flat (GS 204051)	1976 – current	2,230	168.883	23.1km upstream
Clarence River @ Tabulam (GS 204002)	1912 – current	4,550	112.299	-
Clarence River @ Baryulgil (GS 204900)	1971 – current	7,490	72.089	34.2km downstream
Timbarra River @ Drake (GS 204046)	1969 - current	1,720	211.852	25.7km south-west. Timbarra River joins Clarence River 2km downstream of Tabulam

2.6 Local Drainage Structures

Stormwater drainage and road cross drainage survey data in Tabulam was provided by Council for use in this study. This data is required for assessment of drainage requirements for flood mitigation (e.g. flood levees) in the village.

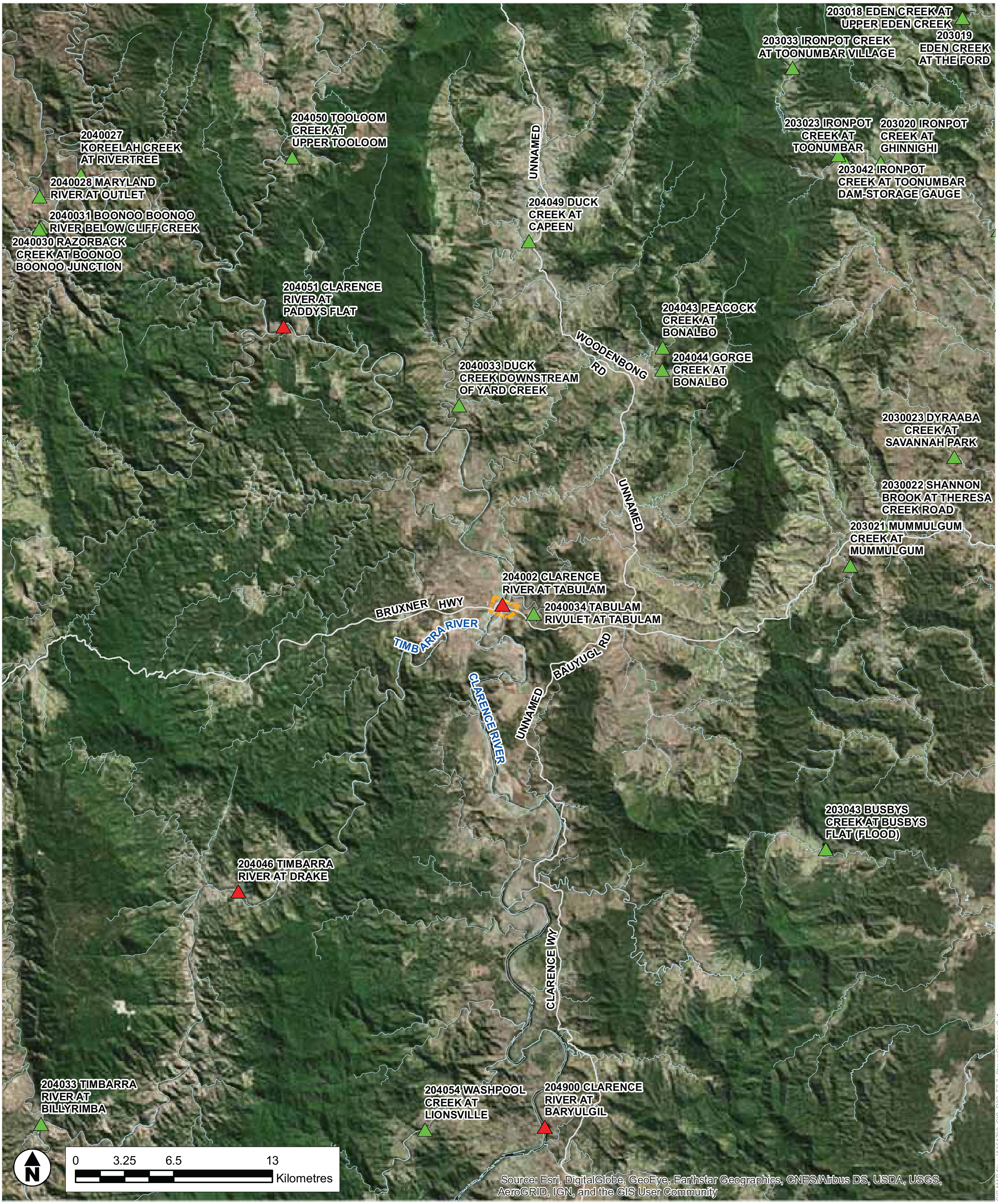
2.7 Additional Data Collected

2.7.1 LiDAR Data and Aerial Photography

Figure 2-5 demonstrates the inaccuracy of the photogrammetry data, hence the collection of LiDAR data was commissioned to fulfil the requirements of the current study's modelling. LiDAR survey was undertaken in April 2018, with the data shown on Figure 2-8 (extent 17km by 9km) with an accuracy of +/- 10cm. Aerial photography was also undertaken at the same time as the LiDAR survey.

2.7.2 Building Floor Levels

Building floor levels of each habitable building in the village were surveyed in April 2018 as a part of this flood study.



Legend

- Stream gauges relevant to the study
- Stream gauges not relevant or no significant data
- Watercourse
- Main Highway

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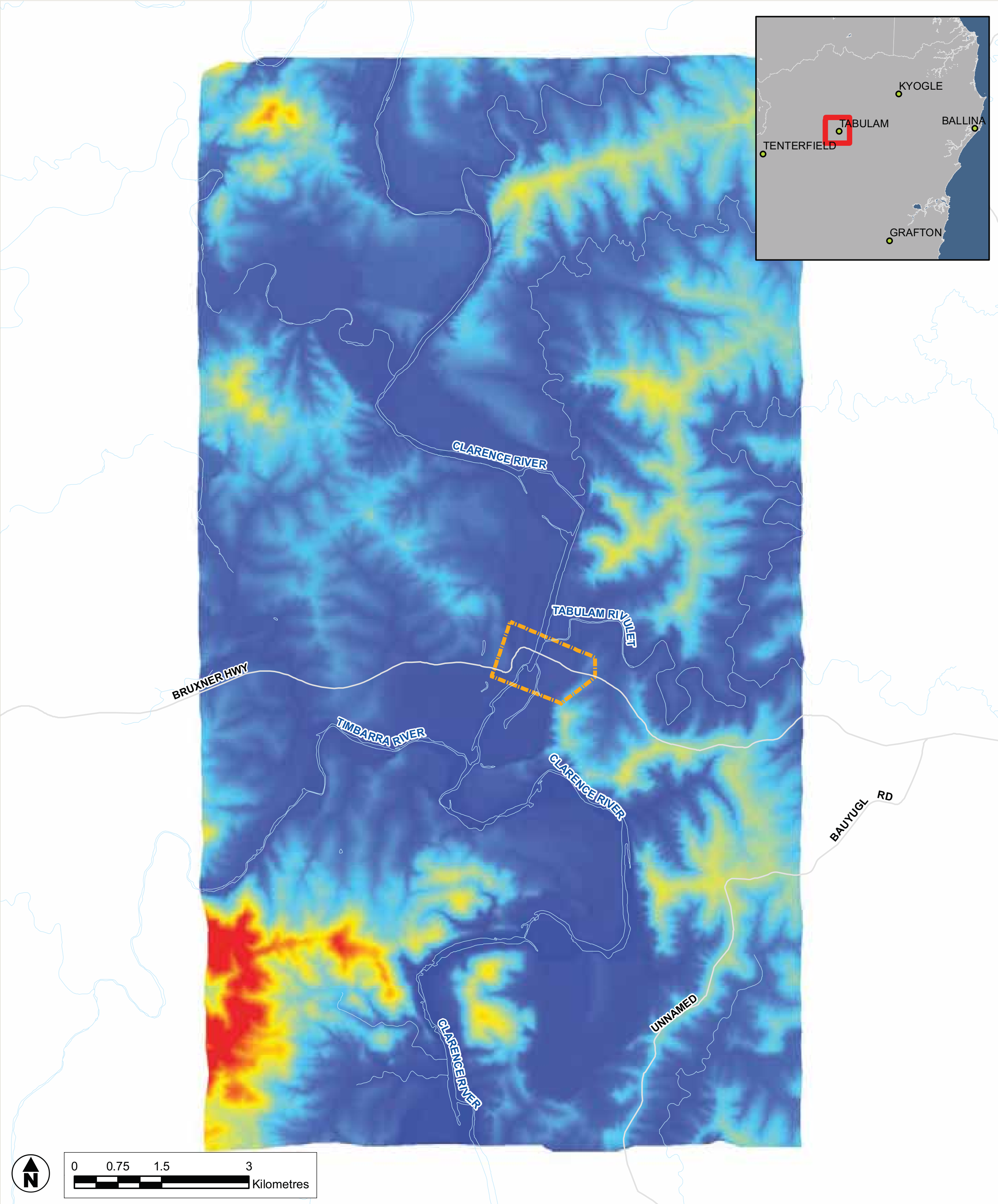
SHEET 1 of 1	GDA 1994 MGA Zone 56		
TITLE	Stream Gauges near Study Area		
PROJECT	Tabulam Floodplain Risk Management Study and Plan		
DRAWN LC	PROJECT # IA164700	MAP # FIGURE 2-7	REV 1 VER 1
CHECK AH	DATE 7/11/2018		



Legend

Ground Elevation
440m AHD
100m AHD

Study Area
Watercourse
Main Highway

A3

SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Collected LiDAR Data

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PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE 2-8	1	1
CHECK AH	DATE 1/11/2018			

2.8 Community Consultation

A number of consultation activities were undertaken to inform and engage the community on the study and request feedback. The consultation undertaken to date is outlined below.

2.8.1 Community Survey

A survey was sent out in the early stages of the study, asking residents for their experiences on previous flooding and opinions on management of the flood risk in Tabulam. The survey was sent out to all households and businesses in the study area. Unfortunately the response rate on the survey was minimal.

2.8.2 Flood Risk Management Committee

A meeting and presentation of the draft flood study was held with the Flood Risk Management Committee (FRMC) for Tabulam in February 2019, which is comprised of Council staff, members of Tabulam SES, OEH representative and community members. The discussion included outlining the development of the flood modelling and estimation of design flooding conditions, and overview discussion on potential flood risk management options.

Further consultation will be undertaken with presentation and discussion of the subsequent floodplain risk management study and plan as a part of this project.

2.8.3 Public Exhibition and Community Information Session for Flood Study

The draft flood study was placed on public exhibition in February/March 2019. The subsequent Draft FRMSP will also be placed on public exhibition following review and comment from the FRMC. Feedback from the community was invited in response to the draft flood study. No submissions were made from the community on the draft flood study.

A community information session was initially scheduled for late February 2019, but was ultimately postposed to the draft FRMS stage to accommodate community bushfire recovery information sessions in the wake of significant bushfires at that time.

3. Catchment Hydrology

3.1 Sources of Flooding

The main source of flooding in the Tabulam is the Clarence River, which conveys runoff from 4,550km^2 catchment area at Tabulam gauge. Significant flood events occurred in 1976 and 2011 in the village which resulted from flooding in the Clarence River. The Tabulam Rivulet may also contribute to flooding in the village during large flood events which have 315km^2 catchment area. The Tabulam Rivulet is located immediately north of the Tabulam village and discharges into Clarence River. The Timbarra River, with a catchment area of 1,720km^2 at the Drake Gauge and approximately 2,000km^2 at its confluence with the Clarence River, may also have back water effect and can contribute to flooding in the village. This river joins with the Clarence River at approximately 2km downstream of the village. In addition, heavy rainfall can cause localised flooding in the village.

3.2 Estimation of Design Flows for Clarence and Timbarra Rivers

Streamflow gauges Clarence River @ Tabulam and Timbarra River @ Drake provide the best source of data for estimation of streamflow for the two rivers for design flood events by undertaking at-site flood frequency analysis. Details on the approach undertaken to estimate inflow for design flood events for the two rivers are discussed in the following paragraphs.

3.3 Review of Stream Gauging and Rating Curve

A review of the rating curve and associated data for each gauge was undertaken to identify any concerns with the rating curve. Details on the stream gauging for the two gauges were provided by WaterNSW and the latest rating table and associated data for the two gauges were downloaded online (https://realtimedata.waternsw.com.au).

3.3.1 Clarence River @ Tabulam

In total, 541 flow gaugings were undertaken at the gauge between 25/4/1917 and 5/6/2018 and the maximum flow (2,665m^3/s) was measured on 21/7/1965 corresponding to a gauge height of 8.75m. A plot of cross section (refer to Figure 3-1) at the gauge shows that a gauge height of 8.75m represents in-bank flow in the main channel of the Clarence River.

All flow gauging data and the current rating curve for the gauge are presented in Figure 3-2. Peak recorded gauge heights and peak rated flows for the flood events of 1976 and 2011 are also presented in Figure 3-2 which shows that estimated peak flows for both events involve huge extrapolation of the rating curve. In addition, the gauge being located downstream of the bridge, recorded data at the gauge are likely to be influenced by the geometry of the bridge. Hence, there is significant uncertainty at the higher end of the rating curve for discharges relevant to significant flood events and associated peak flow rates.

It is also to be noted that the rating curve at the gauge is updated after each significant flood event to account for changes in channel bed form. It is understood that WaterNSW intends to undertake high flow gauging for the site in the near future.

Figure 3-1 Cross Section - Clarence River @ Tabulam (source: https://realtimedata.waternsw.com.au)

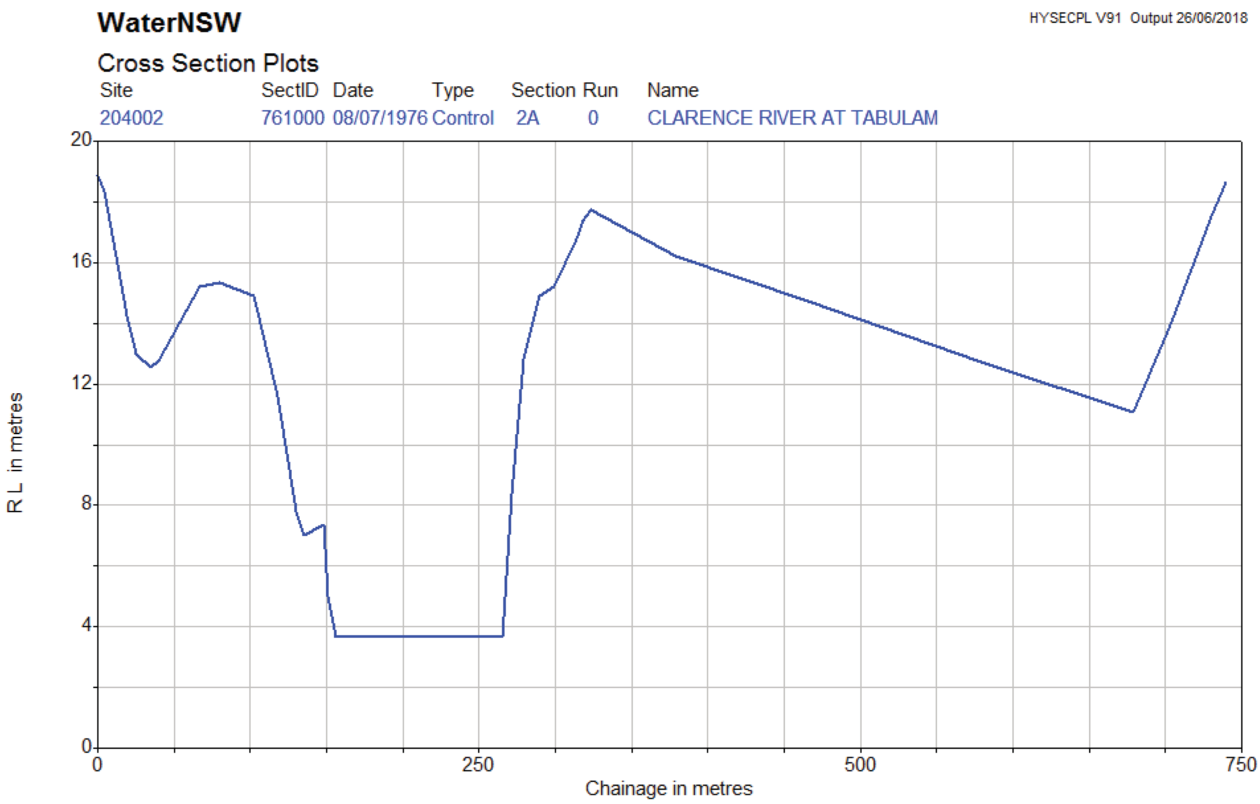
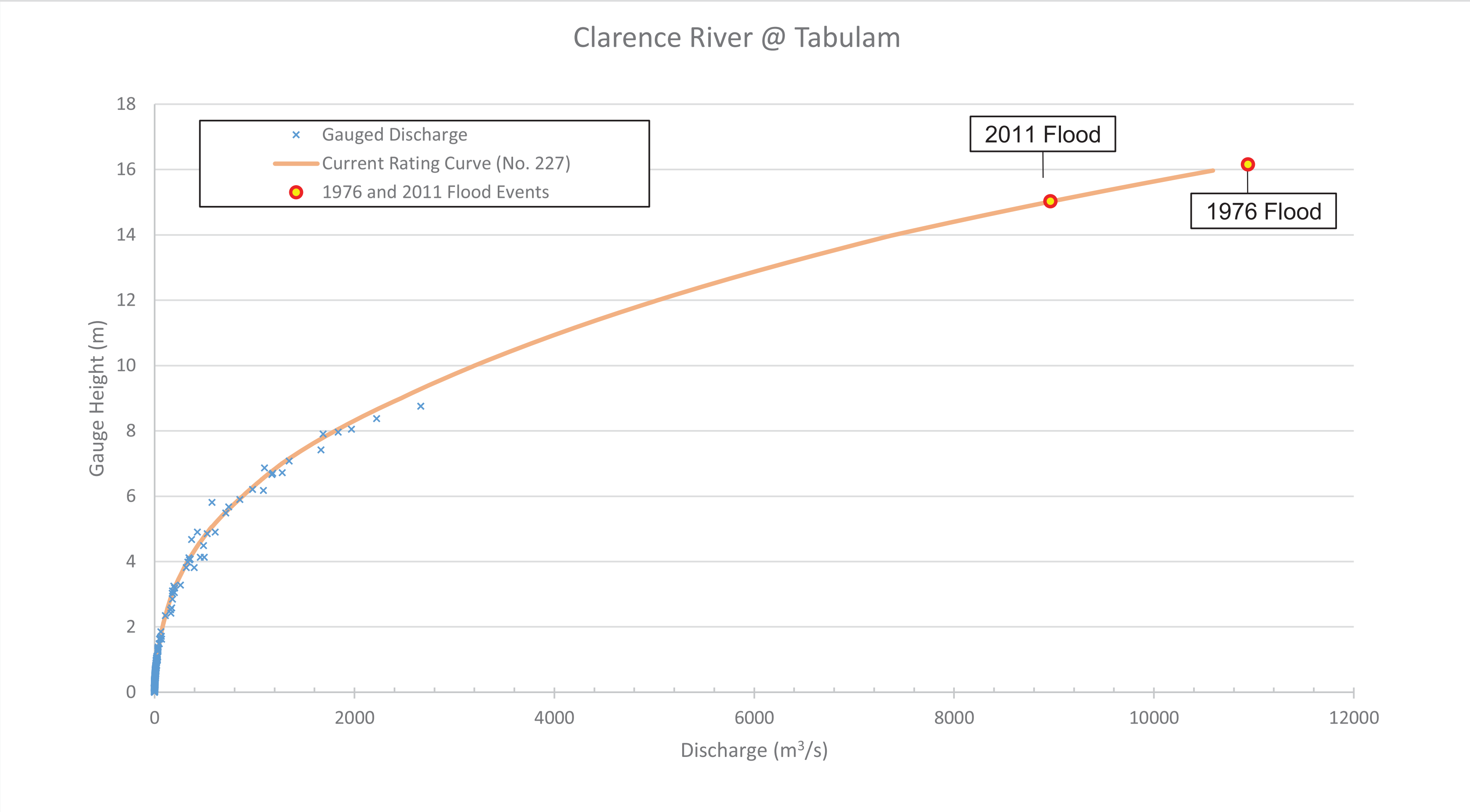


Figure 3-2 Gauged Flows and the Current Rating Curve - Clarence River @ Tabulam (GS 204002). Old gauge location (between old bridge and new bridge)



3.3.2 Timbarra River @ Drake

In total, 258 flow gaugings were undertaken at the gauge between 5/9/1990 and 6/6/2018 and the maximum flow (430m^3/s) was measured on 13/3/1974 corresponding to a gauge height of 2.88m. A plot of cross section (refer to Figure 3-3) at the gauge shows that a gauge height of 2.88m represents in-bank flow in the main channel of the Timbarra River.

All flow gauging data and the current rating curve for the gauge are presented in Figure 3-4. Peak recorded gauge heights and rated peak flows for four largest flood events for the gauge including the flood events of 1976 and 2011 are also presented in Figure 3-4 which shows that estimated peak flows for both events involve huge extrapolation of the rating curve. Hence, there is significant uncertainty at the higher end of the rating curve for discharges relevant to significant flood events and associated peak flow rates. It is also to be noted that the rating curve for the gauge is updated after each significant flood event to account for changes in channel bed form.

Figure 3-3 Cross Section - Timbarra River @ Drake (source: https://realtimedata.waternsw.com.au)

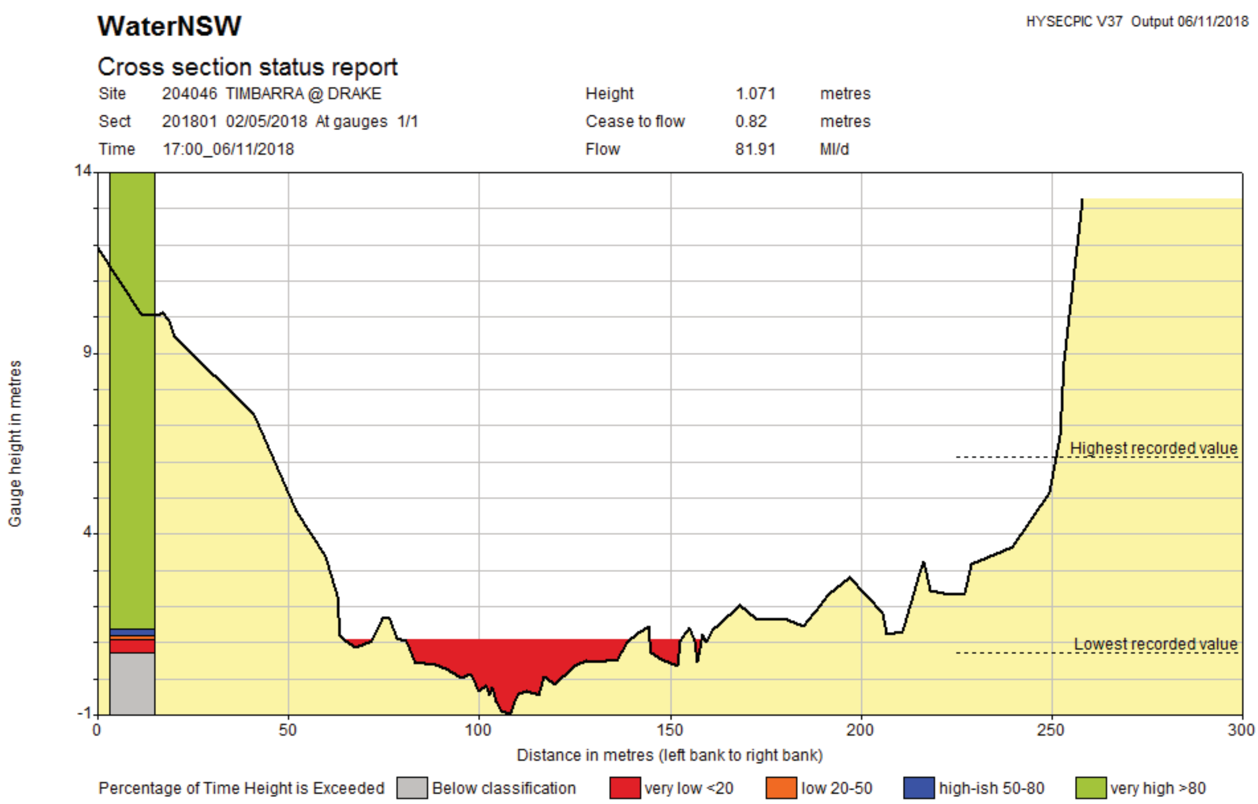
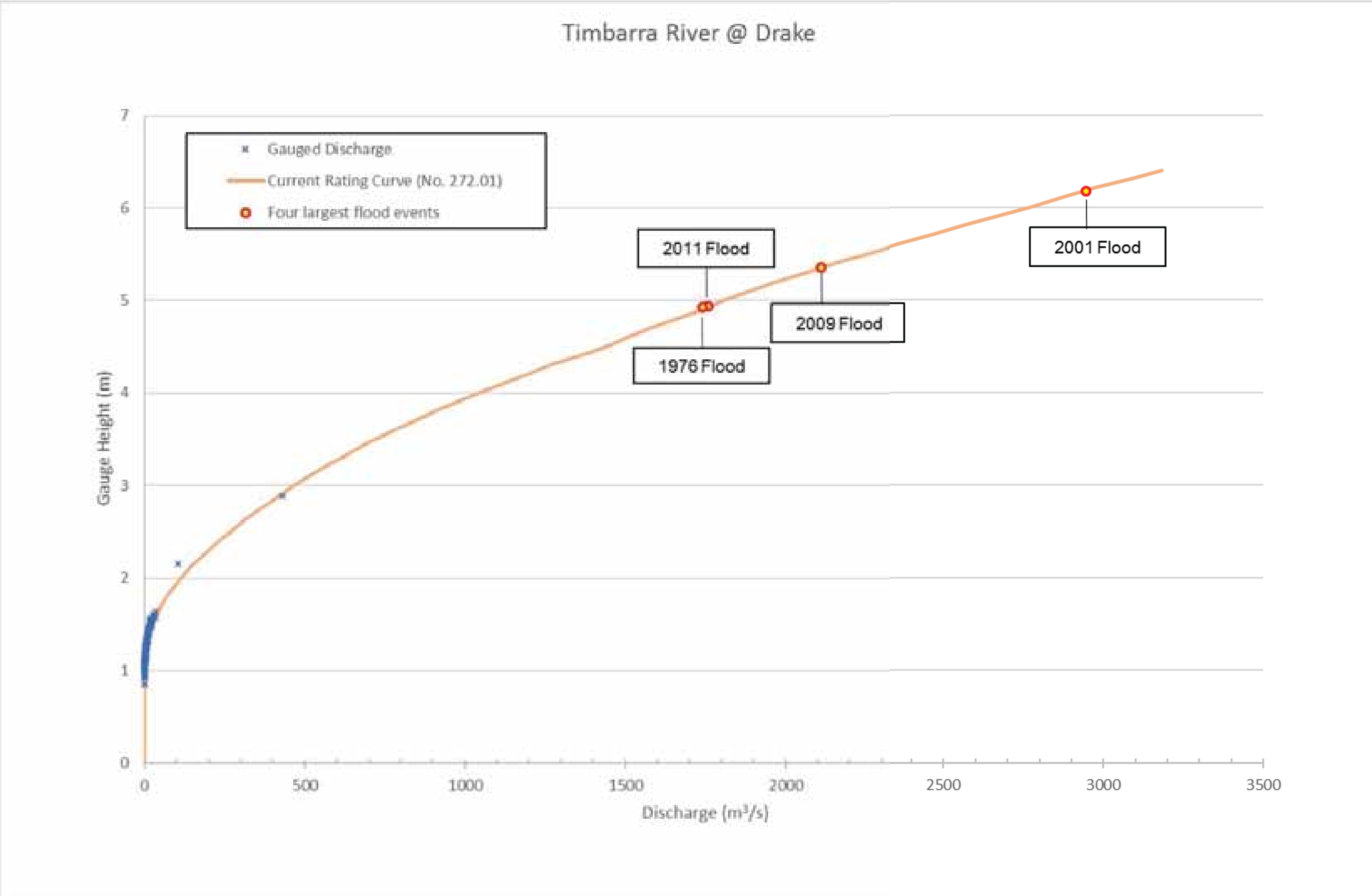


Figure 3-4 Gauged Flows and the Current Rating Curve - Timbarra River @ Drake (GS 204046)



3.4 At-Site Flood Frequency Analysis

A flood frequency analysis (FFA) was undertaken on the annual maximum instantaneous peak flows for Clarence River @ Tabulam (1965 – 2017) and Timbarra River @ Drake (1969 – 2017) gauging stations. TUFLOW FLIKE software was used to fit Log-Pearson III distribution to the annual maxima for each gauge using a Bayesian inference in accordance with ARR 2016 guidelines. The observed and the fitted distribution are shown in Appendix A. Estimated design flows for the two gauging sites are presented in Table 3-1 and compared against flood frequency estimates adopted by GHD (2015a, 2016) for Clarence River @ Tabulam gauge. Table 3-1 shows significant underestimation of peak flows by GHD. This due to the fact that the flood frequency undertaken by GHD was based on annual maximum mean daily flows and GHD fitted Gumbel distribution to the annual maxima. Refer to Section 6.7.1 for further discussion.

Table 3-1 Design Flows based on Flood Frequency Analysis using Log-Pearson III distribution

Event AEP	Clarence River @ Tabulam (GS 204002)		Timbarra River @ Drake (GS 204046)
	This Study	GHD (2015a, 2016)	This Study
20%	3,000	2,100	820
10%	4,900	-	1,400
5%	7,100	5,400	2,100
2%	10,000	6,800	3,400
1%	12,100	7,900	4,600
0.5%	14,200	-	5,900
0.2%	16,800	-	8,100
Extreme (3x 1% AEP)	36,300	-	13,800

Sensitivity of the design flow estimates to adopted flood frequency distribution and approach was undertaken. A Generalised Extreme Value (GEV) distribution and inclusion of the Multiple Grubbs Beck Test were assessed. The Multiple Grubbs Beck Test aims to remove potentially influential low flows from the flood frequency analysis. Refer to Table 3-2. The sensitivity FFA plots are shown in Appendix A.

In summary:

- As noted earlier, Gumbel distribution as adopted in GHD (2015a, 2016) results in lower design flow estimate than LPIII.
- GEV results in significantly higher (5x for the 1% AEP and 1.8x for 5% AEP) than LPIII. There is a poor fit of the annual maximum flows to the GEV distribution.
- Inclusion of Multiple Grubbs Beck Test for both LPIII and GEV distributions result in similar design flow estimates to LPIII (+/- 6%) for the Clarence River at Tabulam gauge. There is no difference with the Multiple Grubbs Beck Test for both LPIII and GEV for the Timbarra River at Drake gauge as there are no outliers identified by the test.

The results validate the adoption of LPIII distribution in the flood frequency analysis for the design flow estimates.

Table 3-2 Sensitivity of Flood Frequency Analysis approach on design flow estimate.

Approach	Clarence River @ Tabulam		Timbarra River @ Drake	
	1% AEP	5% AEP	1% AEP	5% AEP
LPIII (Adopted)	**12,100**	**7,100**	**4,600**	**2,100**
Gumbel (GHD 2015a, 2016)	7,900	5,400	N/A*	N/A*
GEV	67,100	12,700	13,200	3,100
LPIII & Multiple Grubbs Beck Test	12,800	7,000	4,600	2,100
GEV & Multiple Grubbs Beck Test	12,600	6,600	13,200	3,100

* Not estimated by GHD (2015a, 2016).

3.5 Hydrologic Modelling of Tabulam Rivulet

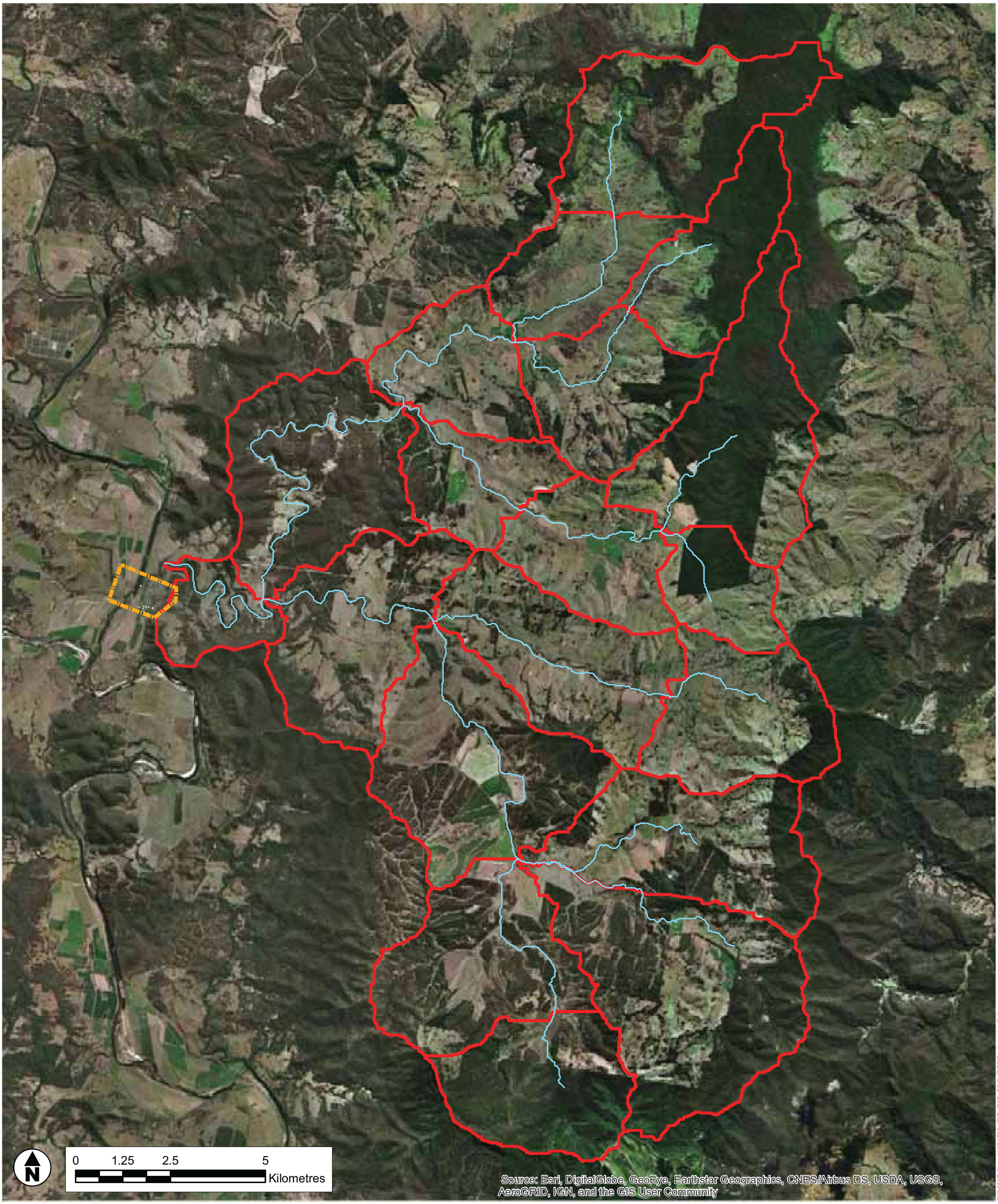
Tabulam Rivulet drains a catchment area of approximately 315 km^2 and no streamflow gauges are located within the catchment area of Tabulam Rivulet. Hence, a hydrology model was required to estimate rainfall runoff generated from the catchment. Details on the development of a hydrologic model for the catchment are discussed in the following sections.

3.5.1 Methodology

The catchment area of Tabulam Rivulet was modelled using RORB (version 6.32), a runoff routing program (Laurenson et al 2010). RORB is one of the most widely used models of its type in Australia, and consequently there is substantial information available on the value of the model parameters for a wide range of catchments. The model has the capability to simulate both linear and non-linear catchment behaviour, and exhibits many desirable modelling features, such as spatially distributed inputs, flexible reservoir-routing options and the ability to model flows at a number of points throughout the catchment.

3.5.2 RORB Model Configuration

Sub-catchments for Tabulam Rivulet were delineated based on the 30m Shuttle Radar Topography Mission (SRTM) DEM, which covers the entire catchment to be modelled. A total of eighteen (18) sub-catchments were delineated to the outlet of Tabulam Rivulet. An outline of the RORB catchments is shown in Figure 3-5. Length flow paths were obtained from the SRTM DEM. The model was developed using MiRORB.



GIS MAP file : IA164700_GIS_R02_F3-5_RORBsubcatch_r2v1

Legend

RORB Sub-Catchment
RORB Flow Path
Study Area

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SHEET 1 of 1 | GDA 1994 MGA Zone 56

TITLE Tabulam Rivulet RORB Model Layout

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE 3-5	1	1
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AH	7/11/2018			

3.5.3 Input Used in the Estimation of Design Flood Events

The adopted value of k_c and m for the RORB model were 16.65 and 0.8 respectively based on ARR 2016.

Design rainfall data was downloaded from the Bureau of Meteorology's DataHub, including ARR 2016 design rainfall depths and temporal patterns relevant to the study area up to and including the 1% AEP event. The data was extracted for the centroid of the catchment for Tabulam Rivulet.

Design rainfall depths for the Probable Maximum Precipitation (PMP) events were derived based on the Generalised Short Duration Method (GSDM) in The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method (BOM, 2003).

ARR 2016 recommendations for rainfall losses based on an initial loss/continuing loss model, with storm loss depths (pre-burst + burst losses) prescribed by the ARR Datahub were adopted for events up to and including the 1% AEP event. ARR Datahub provided an initial storm loss of 48 mm and a continuing loss rate of 3.5 mm/hr for the catchment. An initial rainfall loss of 0 mm and a continuing loss of 1 mm/hr were adopted for the PMP events.

Areal reduction factors and ensembles of 10 temporal patterns from ARR 2016 were adopted for events up to and including the 1% AEP event. In the case of the PMP events, spatial and temporal distribution of rainfall were based on BOM's GSDM.

3.5.4 Results

A range of storm event durations from 1 hour to 7 days was assessed in the RORB model for events up to the 1% AEP event. The peak flows and critical event durations are summarised in Table 3-3. The RORB design flow estimates are also compared to the ARR 2016 Regional Flood Frequency Estimation (RFFE) model results. It is observed that the RORB design flow estimates up to the 1% AEP events are relatively low compared to the RFFE expected quantiles, however, this is a common occurrence encountered in NSW by Jacobs' flood management practitioners. The RORB design flow estimates fall within the 5% and 95% confidence limit bands outputted by RFFE. The estimated design flow for the PMF event is considered high due to the relatively adopted low value of k_c. It is to be noted that ARR 1987 recommended different approaches for calculating values of kc for catchments located east and west of the Great Dividing Range. However, ARR 2016 recommends a uniform approach for calculating values of kc for catchments located in NSW.

In recognition of limitations of RFFE, it is recommended that peak flows estimated by the RORB model for the design events were adopted in this study.

Table 3-3 Design Flows based on RORB Hydrologic Modelling – Tabulam Rivulet

Event AEP	RORB		ARR 2016 RFFE	
	Peak Flow (m^3/s)	Critical Duration	Expected Quantile (m^3/s)	5%/95% Confidence Limits (m^3/s)
20%	330	12 hour	498	212 – 1,180
10%	540	12 hour	792	309 – 2,020
5%	750	12 hour	1170	407 – 3,350
2%	1,010	12 hour	1830	539 – 6,150
1%	1,220	12 hour	2470	639 – 9,360
PMF	9,350	4 hour	N/A	N/A

4. Hydraulics

4.1 Model Selection

A TUFLOW combined one-dimensional (1D) and two-dimensional (2D) hydrodynamic model was developed for this study. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment as it has:

- Capability in representing complex flow patterns on the floodplain, including dispersed overland flows, flows in flow paths and watercourses and flows around buildings.
- Capability in accurately modelling flow behaviour in 1D channel, bridge and culvert structures and interflows with adjacent 2D floodplain areas.
- Capability with 2D modelling of complex bridge structures including bridge hydraulic energy losses.
- Flexibility in representation and modelling of future mitigation works.
- Easy interfacing with GIS and capability to present the flood behaviour in easy-to-understand visual outputs.

The model was developed and run in TUFLOW 2017-09-AC-iDP-w64 in the TUFLOW “Classic” computation scheme.

4.2 Configuration of Hydraulic Model

4.2.1 Extent and Structure

The TUFLOW model is comprised of:

- A 2D domain of the study area surface reflecting the catchment topography, with varying roughness as dictated by land use. The watercourses were modelled in 2D.
- River bathymetry were defined based on bed level data from the previous Tabulam New Bridge Hydraulic Assessment (GHD, 2015a) and Tabulam Bridge Aquatic Habitat Assessment (Hydrosphere Consulting (2015), contained in Tabulam New Bridge Review of Environmental Factors (GHD, 2015b)).
- Bridges were modelled as layered flow constriction objects in TUFLOW.

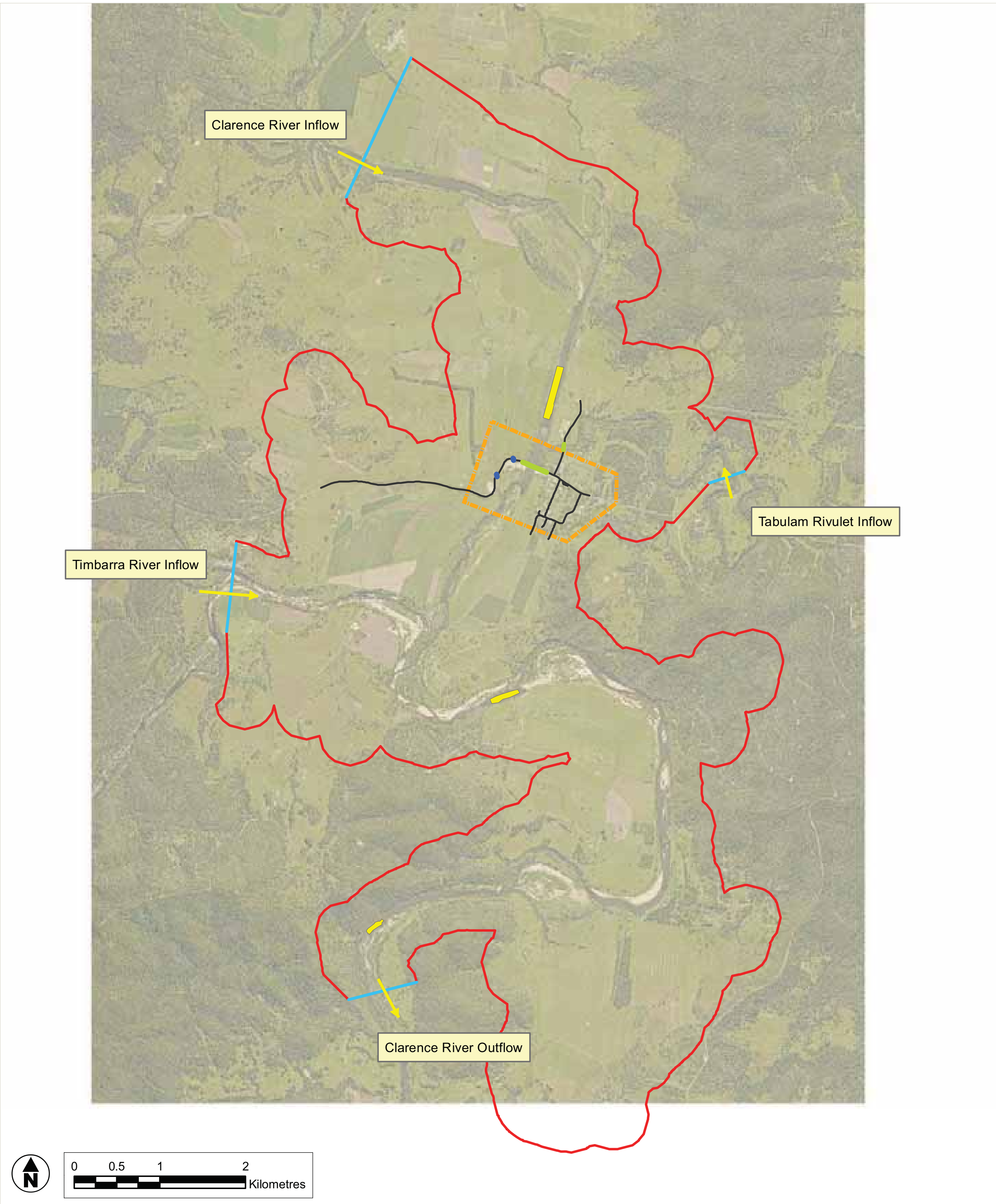
The model extent includes the entire 1.5km^2 study area, in addition to adjoining floodplain areas (40km^2) outside of the study area which is likely to influence on flood behaviour in the study area. Refer to the following sections for details on these features. The locations of various features in the TUFLOW model are shown on Figure 4-1.

4.2.2 Model Topography

The topography of the catchment was represented in the model using a 20m grid. Finer grid resolutions of 10m to 16m were trialled with numerous configurations for the model calibration and for the design events, however, model instabilities were observed in a number of locations with anomalous flood surface variations and flow velocities, rendering these results unreliable. Hence the 20m model grid was retained as greater confidence in the model results was attained.

TUFLOW is based on the shallow water equations and if the depth of flow is excessive for the adopted cell size then the model is likely to be unstable. Given the swift, deep flows with depth of flooding in the main channel of 20m or more in the calibration and design events, it was found to be a significant challenge to run the model with a grid size smaller than 20m.

The overall basis of the topographic grid used in the TUFLOW model is the LiDAR data as described in Section 2.7.1. The LiDAR survey captured the construction works of the Bruxner Highway new bridge, including temporary stockpiles and other features. Hence the model topography was modified as required to remove the effects of these features to represent the pre-development topography.



GIS MAP file : IA164700_GIS_R02_F4-1_TUFLOW_r1v1

Legend

TUFLOW Domain		Road Breakline	
Model Boundary		2D Sandbar	
1D Bridge		Study Area	
2D Bridge			

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SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE TUFLOW Model Configuration

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE 4-1	1	1
CHECK	DATE			
AH	1/11/2018			

4.2.3 Hydraulic Structures

4.2.3.1 Tabulam Bridge and Bruxner Highway Hydraulic Structures

Tabulam Bridge was incorporated in the model as layered flow constriction, representing the influences of the piers, bridge soffit, railings and superstructure. Bridge loss coefficient values were estimated separately for the main channel spans and the floodplain spans due to the different configurations of the bridge piers and trestles in these sections.

The old bridge was represented for the model calibration, with soffit, railing and deck levels extracted from the GHD (2015a) model. Industry standard parameters were initially adopted for the bridge and the parameter values were updated in the model calibration stage. The new bridge was represented for the design event simulations, based on the 80% detailed design bridge details presented in GHD (2015b).

The Clarence River Overflow 1 and 2 Bruxner Highway structures on the western bank of the river were modelled as 1D objects.

4.2.3.2 Stormwater Networks

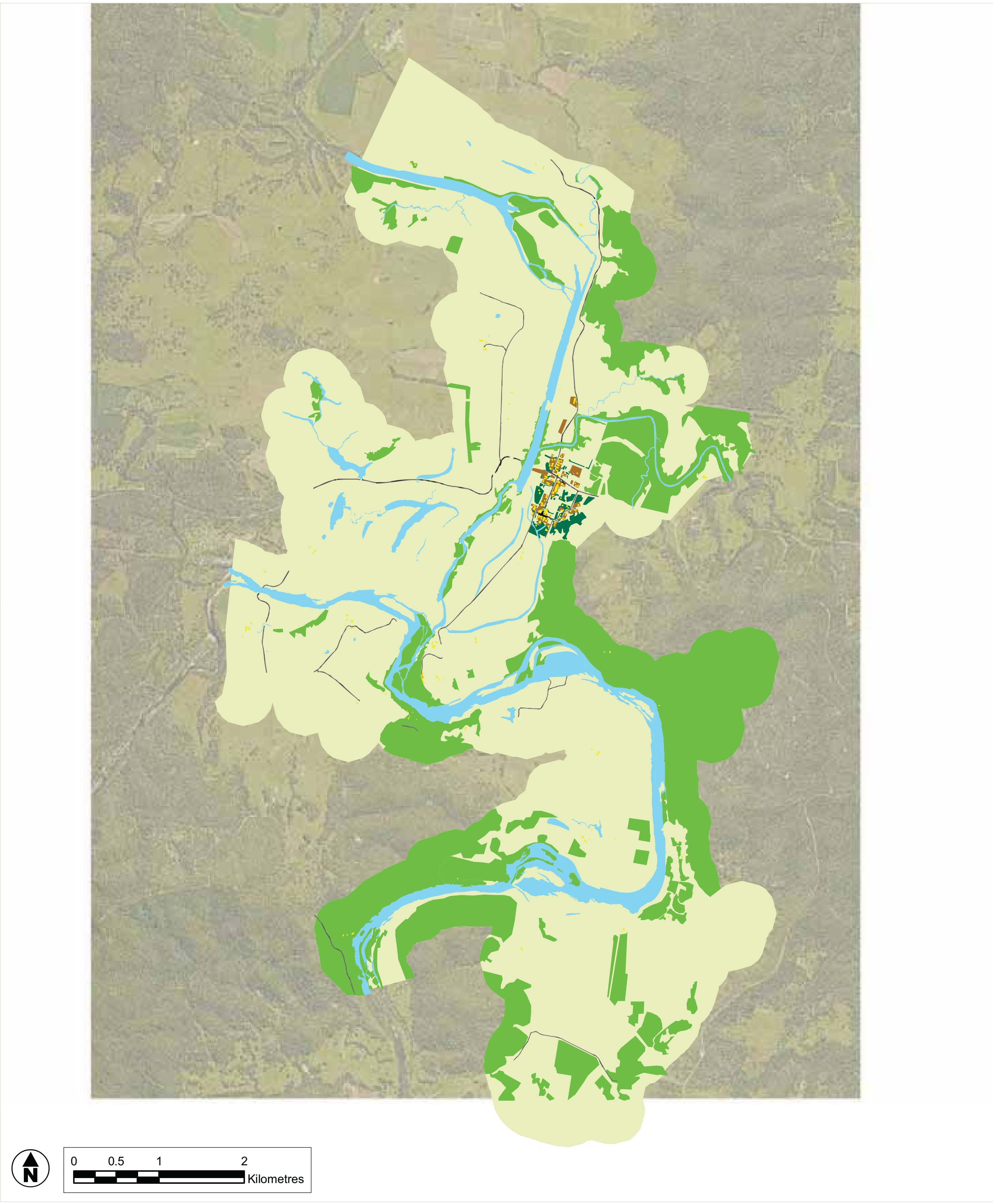
The stormwater structures data in Tabulam village consists of small pipes up to 450mm diameter, according to available Council survey. These structures were considered inconsequential to the hydraulic model calibration to mainstream flooding and hence were not represented in the TUFLOW model at this stage. These structures will impact on local catchment drainage, which will be modelled in the design event and mitigation (e.g. levees) runs, and will therefore be represented in those model scenarios.

4.2.4 Surface Hydraulic Roughness

All parts of the study area within the TUFLOW model were assigned hydraulic roughness values in a "materials layer" according to the dominant ground cover types in the study area, including:

- Rural land use, pasture: n = 0.045
- Village properties, with elevated roughness to represent the effects of fencing: n = 0.1
- Vegetated areas on village properties: n = 0.1
- Vegetated areas in rural properties: n = 0.08
- Paved roads: n = 0.02
- Buildings: n = 0.2
- Watercourse and overland flow paths: n = 0.03

These are based on engineering experience and typical values used in previous flood studies undertaken across NSW by Jacobs and other consultants.



Legend

- Rural - Pasture
- Village Properties
- Village Property Vegetation
- Rural Vegetation
- Roads and Paved
- Buildings
- Watercourse and Overland Flow Path

A3

SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE TUFLOW Hydraulic Roughness

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE 4-2	1	1
CHECK	DATE			
AH	1/11/2018			

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4.3 Boundary Conditions

The model boundaries were set at a sufficient distance away from the area of interest so that the selection of boundary type did no impact on the model results at Tabulam village.

4.3.1 Model Inflows

Inflows were input into the hydraulic model at the upstream model boundaries on the Clarence River, Timbarra River and Tabulam Rivulet. As previously discussed in Section 2.8, Clarence River and Timbarra River inflows are derived from gauged flows for the historic events and from flood frequency analysis for the design events, while the Tabulam Rivulet inflows are derived from RORB hydrologic modelling.

4.3.2 Tailwater Boundary

A tailwater boundary was defined for Clarence River at a location about 14.5 km downstream of Tabulam village to ensure that the overland flood behaviour within the study area was unlikely to be influenced by the adopted tailwater boundary. A normal depth flow condition with assumed water surface slope of 0.2% was adopted in the TUFLOW model, estimated based on the bed slope. TUFLOW automatically generates a water level and flow relationship at the downstream boundary dependent on the input topography and the slope at the boundary location. Sensitivity to the assumed boundary condition was tested for the 1% AEP design flood and is discussed in Section 6.9.

5. Model Calibration and Verification

5.1 Overview

Model calibration was carried out against direct measurements at Tabulam Bridge, which is the only gauging station available within the model area.

Depths of flooding during past flood events given by local residents were collected and used to verify modelled flood depths and flood behaviour as a way of “sanity-checking” the modelling and confirming its reliability. This anecdotal information is generally considered indicative as often only the general location of the observation is usually given, and approximate depths of flooding. Photographs of flooding were also provided which offer more detailed information of the flooding behaviour at specific locations within the village. Consideration is needed on whether the photographs were captured at the peak of the flooding.

The model calibration focussed on only two events selected based on availability and quality of data. The general approach involved running the hydraulic models and comparing the flood depths and flow patterns to reported observations and direct measurements. The model configuration and parameter values were adjusted as necessary with the aim of achieving a satisfactory fit to the observations.

5.2 Selection of Calibration Events

Flooding was reported for numerous individual events occurring over the recent historical times. Two historic events were selected for model calibration and verification based on the number of responses and availability of direct measurements for each event and the magnitude of the storm event. These events included:

- February 1976 – One most significant flood in records. The flood was reported as 1% AEP event by GHD (2015a) but was estimated in the updated FFA this study as a 1.3% (i.e. 1 in 80) AEP event.
- January 2011 – The available gauge record indicates that this was the second largest event. During the 2011 event, a number of houses and their occupants were evacuated.

Characteristics of the selected events are provided in Table 5-1. The 1976 flood level was about 1 m higher than the 2011 flood.

Table 5-1 Characteristics of Calibration Events

Flood Event	Peak Flow at Tabulam gauge. Estimated in this study m^3/s	Peak Flood Level at Tabulam Bridge m AHD	Soffit Level (old bridge) m AHD	Deck Level (old bridge) m AHD	Approximate Event AEP*
Feb 1976	10,942	128.25	127.69	~129	1.3%
Jan 2011	8,965	127.28	127.69	~129	2 – 5%

* Based on FFA conducted in this study.

The 1976 and 2011 flood events are the largest recorded at the Tabulam gauge, with records from 1912 to the present. The third largest flood on record occurred in 1948 which peaked at 125m AHD, approximately 2m lower than the 2011 event. Note that this is a manually-read flood level which may have been lower than the peak flood level. In recent times, floods occurred in 2008, 2009 and 2013 which peaked 3 – 4m lower than the 2011 event. The smaller magnitude of these other floods mean that these were not selected for the model calibration and verification.

5.3 Adopted Parameter Values for Model Calibration

5.3.1 Estimation of Historic Event Model Inflows

Flows in the Clarence River and Timbarra River are the main governing factor which influence the water level at Tabulam gauge. Initially, inflow hydrographs for the two gauges were adopted in the TUFLOW model. The inflow hydrograph for Clarence River @ Tabulam gauge was defined as the upstream boundary for the Clarence River and the inflow hydrograph for Timbarra River @ Drake gauge was used to define the inflow for the Timbarra River. The adopted inflow hydrograph for the Timbarra River was based on scaled up (to account for the increased catchment area at the outlet) inflow hydrograph for Timbarra River @ Drake gauge which was lagged by 5 hours to account for travel time between the gauge and the outlet. A comparison of observed and modelled flood behaviour indicated the need to increase flows in the Clarence River for higher flood levels to account for flood storage and attenuation between the model upstream boundary and the Tabulam gauge. Hence, an iterative approach was adopted in the estimation of inflow hydrograph for the Clarence River for the calibration events. The current rating curve beyond the highest gauged flow was adjusted iteratively to obtain a reasonable agreement between modelled and observed water level hydrographs for the calibration events. This is a valid approach considering the high degree of extrapolation of the current rating curve and influence of the bridge geometry to the peak flood flows estimated at the gauge which is located downstream of the bridge.

Several stages of interpretation of the rating curve and iterative runs of the TUFLOW model were required to derive the river inflows for a satisfactory calibration of the model. The iterative approach also considered varying the lag and timing of flows in the Timbarra River compared to the Clarence River. The adopted model inflows for the TUFLOW model calibration and verification are presented in Figure 5-1 and Figure 5-2 respectively.

Inflows from the Tabulam Rivulet were assumed to be negligible in the model calibration and verification runs. Instead of a separate hydrologic modelling exercise to estimate the historic event flows in the Rivulet, these were assumed to be combined with the Clarence River inflows, with the Clarence River inflows estimated accordingly. For the purposes of the TUFLOW model runs for the calibration and verification, a steady inflow of $10 m^3/s$ was assumed in the Tabulam Rivulet.

Figure 5-1 TUFLOW model inflows – February 1976 calibration event

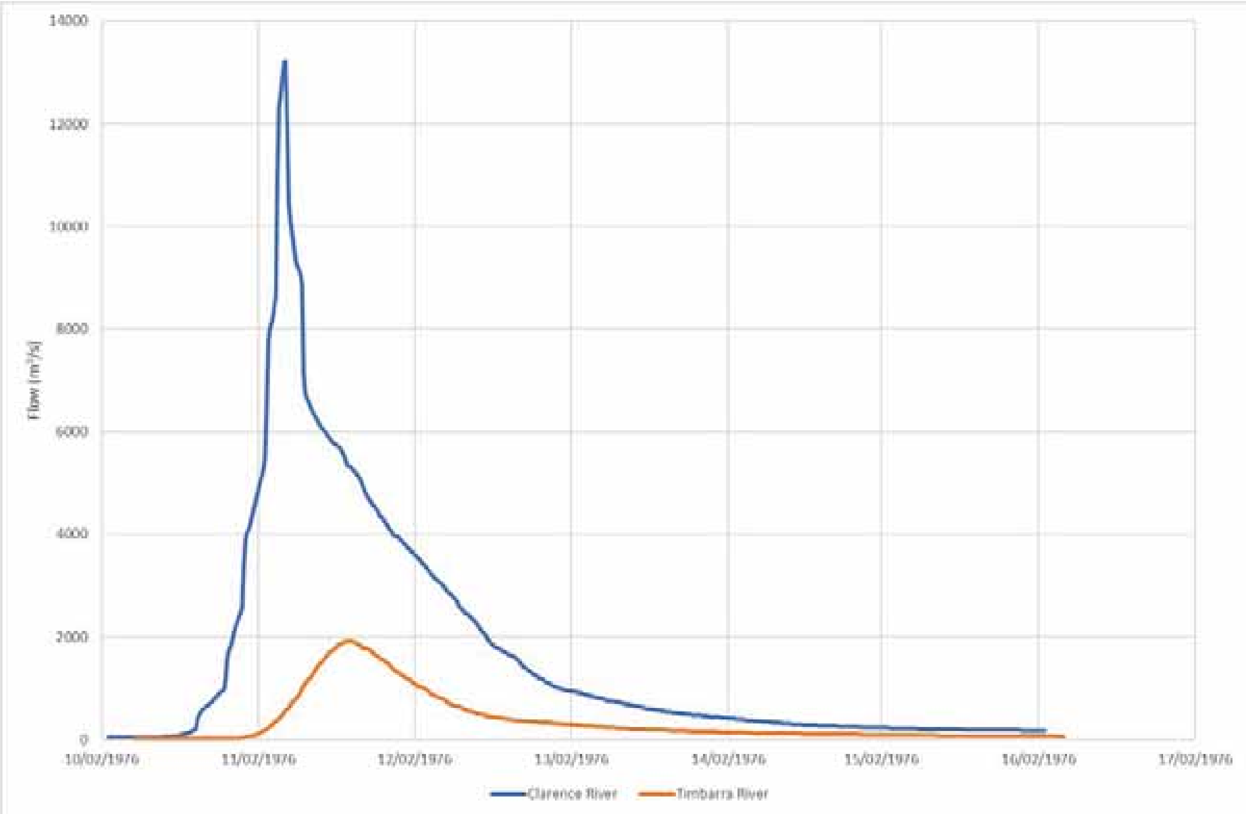
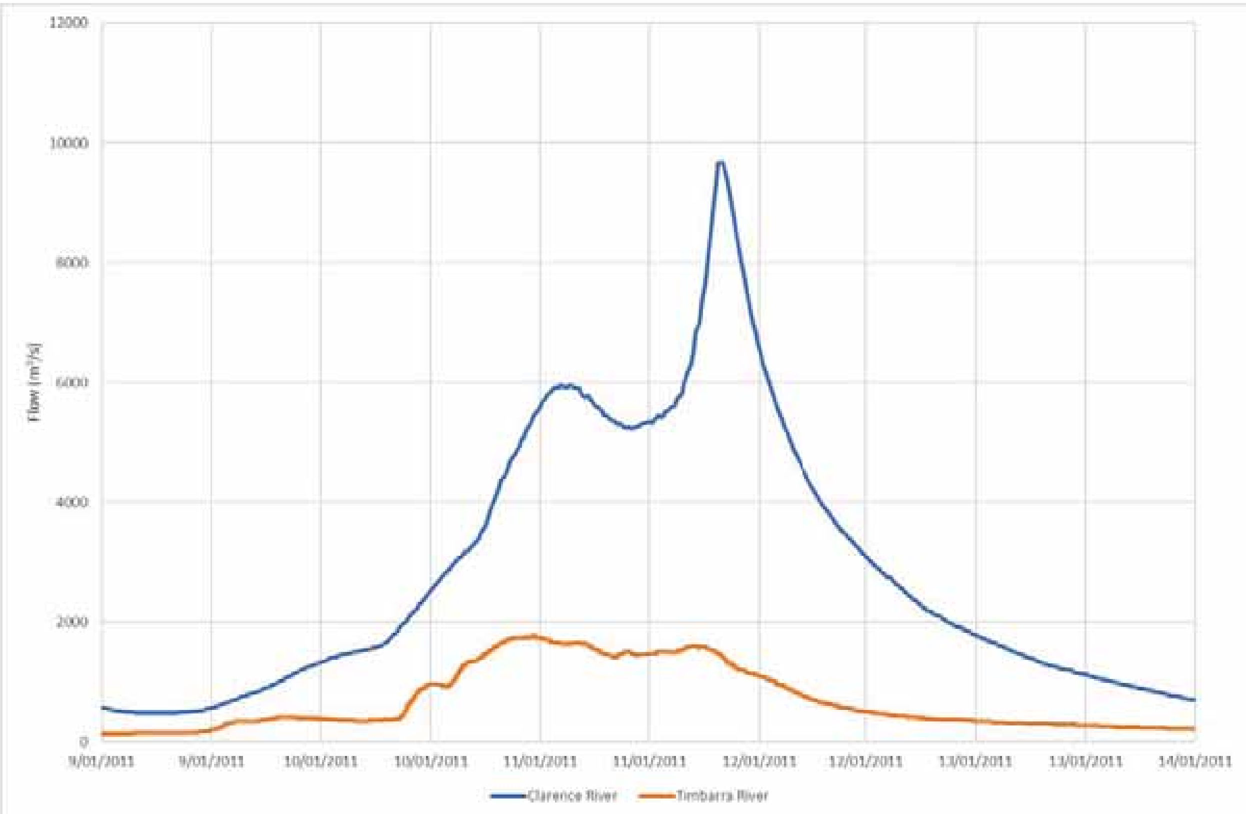


Figure 5-2 TUFLOW model inflows – January 2011 verification event



5.3.2 Blockage of Hydraulic Structures

Guidance on blockage of hydraulic structures was sought from *Australian Rainfall and Runoff Revision Project 11– Blockage of Hydraulic Structures Stage 2* (Engineers Australia, 2013).

A blockage of up to 6% was applied for the piers and trestles of the Tabulam old bridge. Also, 100% and 50% blockages were applied for the bridge deck and bridge hand railing respectively.

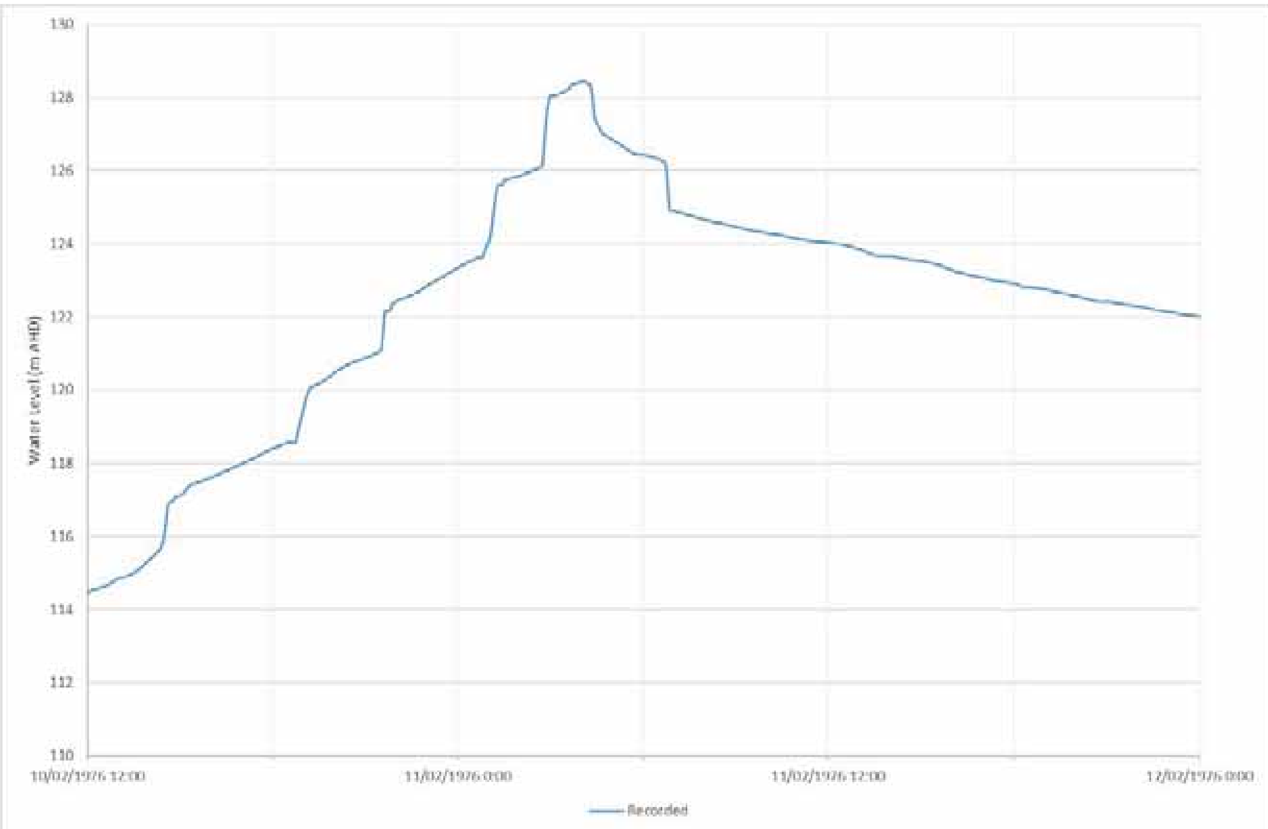
No specific information was obtained on blockage of the Bruxner Highway crossings of the Clarence River Overflows 1 and 2, hence, these were assumed to be fully clear for the purposes of the model calibration.

5.4 Clarifications on Recorded Water Level Data

Detailed review of the recorded water levels at Tabulam Bridge gauge in the February 1976 flood event during the model calibration phase indicated anomalous rates of rise during several periods on the rising limb of the flood. Very sharp rates of rise (up to 2m over 30 minutes) and steps in the water level hydrograph were observed in the data extracted from PINNEENA database, which could not be replicated in the TUFLOW model. Refer to the recorded water level hydrograph on Figure 5-3. Significant effort was made in analysing this data in trying to resolve and explain the apparent flood behaviour indicated by the recorded data.

Clarification was sought from WaterNSW, who administer the river gauging program for inland rivers in NSW. An officer from WaterNSW confirmed that due to instrument failure at the Tabulam gauge, the flood peak for the 1976 event was derived from a Flood Slope Survey and parts of the rising and falling limb of the hydrograph were estimated. WaterNSW is confident of the flood peak level and time from reference to the available raw data and survey information. Based on this advice, the gauge data was not considered to be fully reliable and it was considered satisfactory for the modelling to achieve a general fit to the gauged hydrograph shape, rather than a precise match of the recorded data.

Figure 5-3 Recorded water level hydrograph February 1976 – indicating anomalous steps in hydrograph



5.5 Calibration Results

5.5.1 Comparison to Direct Measurement

Model parameters were adjusted until the TUFLOW model provided a reasonable match to the measured water level Clarence River @ Tabulam gauge. Comparison between recorded and modelled water level for the 1976 and the 2011 events (Figure 5-4 and Figure 5-5 respectively) shows that the TUFLOW model generates a satisfactory fit to the shape of the recorded water level hydrographs. There is a minor lag in the peak of the modelled flood wave of about 1.5 hours in both events which is attributed to the assumed timing of the river inflow when transferred from the gauge location to the upstream model boundary. This is a minor issue and could be resolved by adjusting the timing of the model inflow.

Figure 5-4 Flood Level Hydrographs – Recorded versus Modelled – February 1976 Flood Event

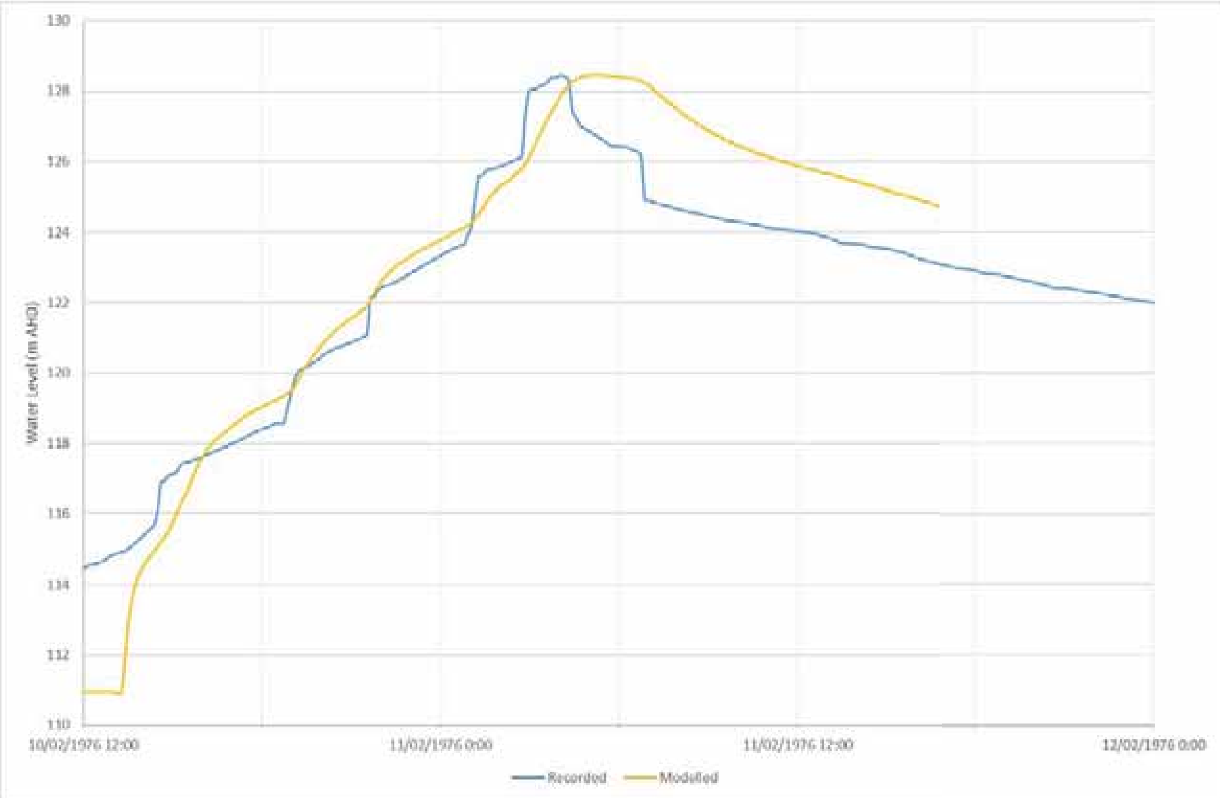
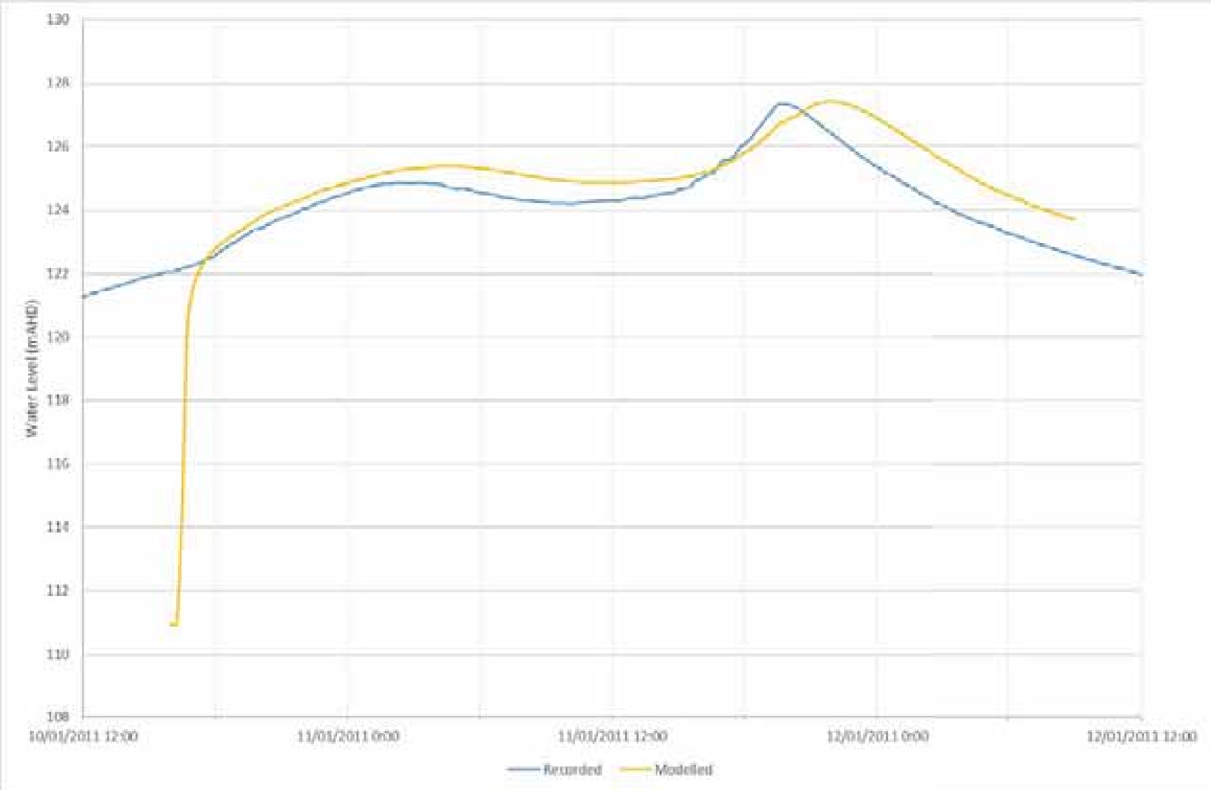


Figure 5-5 Flood Level Hydrographs – Recorded versus Modelled – January 2011 Flood Event



Note that the recorded water levels for the 2011 event at Tabulam gauge, provided by WaterNSW, exhibit a peak flood level at 8pm on 11 January 2011 (Australian Eastern Standard Time), compared to Tabulam SES observed peak at 11:48pm, presumably daylight saving time (i.e. 10:48pm AEST). SES reported that the gauge was washed out (or malfunctioned) during the flood event. It is not known how WaterNSW subsequently developed the water level hydrograph for the gauge, though the peak water level in that data set is similar to that manually observed by Tabulam SES.

The inconsistency in the recorded timing of the peak compared to the SES observation is considered a minor issue and could be rectified by a manual adjustment of the gauge data timing. Doing so would adjust the timing of the model inflow hydrograph and provide a better fit to the SES observed peak timing. The quality of the model calibration is not considered to be compromised by the discrepancy in the flood peak timing, as higher priority is placed on the fit of the hydrograph shape and the match of peak flood levels.

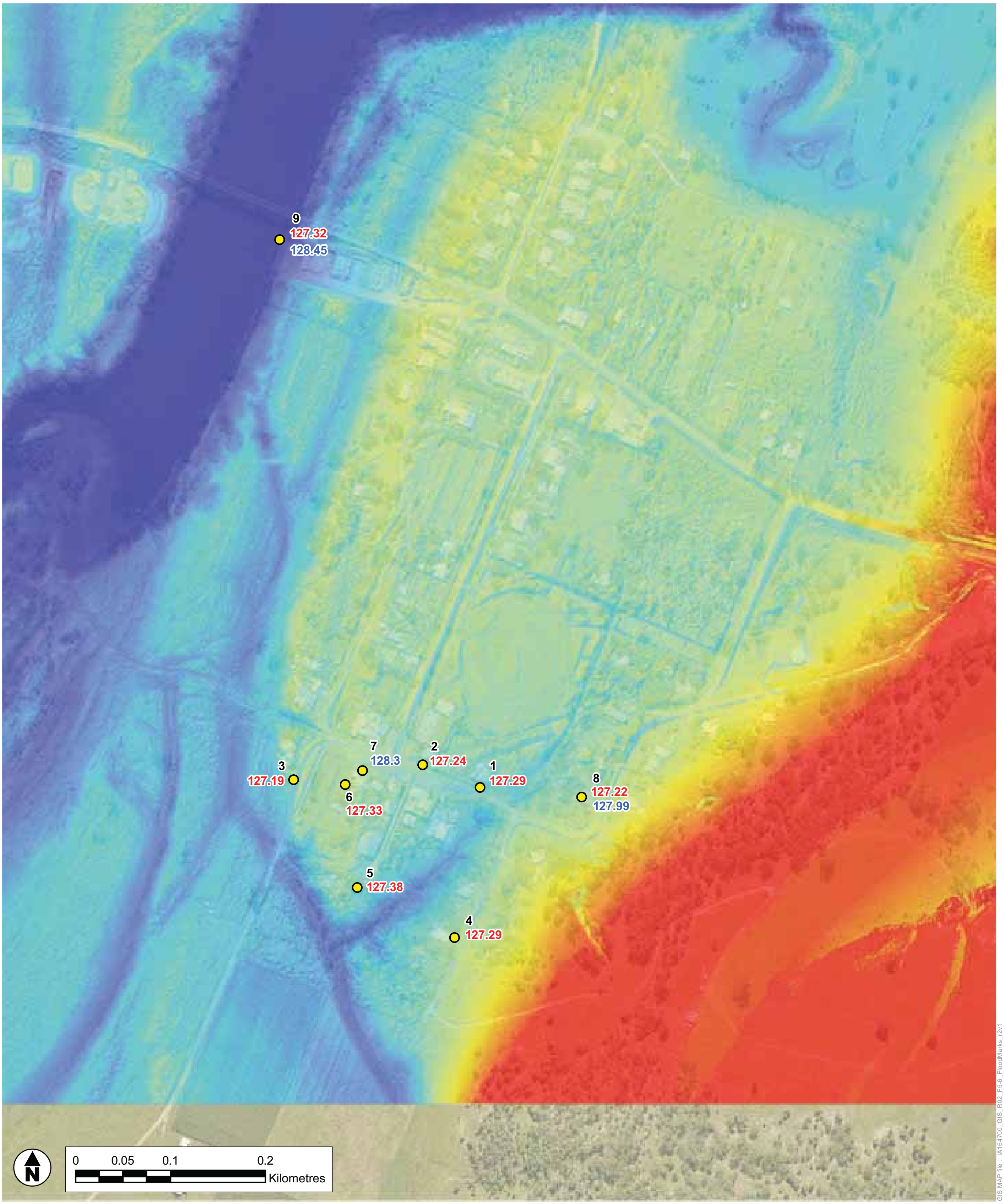
5.5.2 Comparison to Observed Flooding

Flood marks in Tabulam village from the calibration and verification floods were surveyed and reported in Tabulam Flood Information May 2015 (Kyogle Council, 2015). These are mapped on Figure 5-6. It is observed that there is some variability in the flood mark levels within a short distance in the village, such as a 0.14m difference within 50m in the vicinity of Court Street and Racecourse Road. This variability may be attributed in part to local overland flows in the natural gully which runs south from the highway between Clarence Street and Lawrence Street and is not replicated by the TUFLOW model, which focussed on mainstream flooding only. However, the spatial variability of the observed flood levels is not fully consistent with the gully flows as a factor, for example, relatively high flood marks at properties on Court Street are located on high points in the village away from the gullies. Additionally, there is reduction in the flood mark levels with distance upstream along the gully. This potentially suggests backwater flooding from the river up the gully, however, the flood mark on Racecourse Road (ID3, 127.19m AHD) compared with the flood mark on Barnes Street (ID5, 127.38m AHD) disagrees with this hypothesis.

The variability and apparent inconsistency of the flood mark levels could not be satisfactorily explained and hence their reliability was considered low for the purpose of model calibration and verification. The recorded flood levels at the river gauge were used as the primary calibration data as this was considered of high reliability.

The modelled flood levels are compared to the reported flood marks and recorded river levels in Table 5-2. There is a good match to the gauge levels (+/- 0.1m variance), while there is a fair (up to +/- 0.25m) to poor (> +/- 0.25m) fit to the reported flood marks, owing to the unexplained variability of the flood mark levels. A variance of up to +/- 0.25m is considered fair on large riverine systems, which are subject to factors such as wave action and where fine scale features not represented in detail in the hydraulic model may result in localised variances in the water surface.

Overall, the TUFLOW model provides a reasonable match to the observed flood behaviour in the historic events, particularly at the Tabulam gauge. The modelling is considered suitable for estimation of design flood behaviour in the study area.



Legend

Flood Mark ID

Observed Flood Level 2011 (m AHD)

Observed Flood Level 1976 (m AHD)

LiDAR Ground Levels (no scale)

High

Low

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GDA 1994 MGA Zone 56

TITLE Surveyed Flood Marks in Tabulam Village

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE 5-6	1	1
CHECK	DATE			
AH	31/10/2018			

Table 5-2 Comparison of Reported Flood Marks to Modelled Flood Levels

ID	Location	Ground Level (m AHD)	2011 Flood			1976 Flood		
			Observed (m AHD)	Modelled (m AHD)	Difference (m)	Observed (m AHD)	Modelled (m AHD)	Difference (m)
1	23 Court Street	125.33	127.29	127.03	-0.26	N/A	N/A	N/A
2	17-19 Court Street	126.60	127.24	127.04	-0.20	N/A	N/A	N/A
3	2-8 Racecourse Road	126.90	127.19	127.05	-0.14	N/A	N/A	N/A
4	10 Harry Mundine Place	126.01	127.29	127.04	-0.25	N/A	N/A	N/A
5	9 Barnes Street	126.55	127.38	127.04	-0.34	N/A	N/A	N/A
6	Post Office 12-14, Court Street	127.16	127.33	127.05	-0.28	N/A	N/A	N/A
7	Post Office 12-14, Court Street, Front Entrance	127.59	N/A	N/A	-	128.30	128.05	-0.25
8	36-38 Lawrence Street	126.88	127.22	127.04	-0.18	127.99	128.05	0.06
9	Stream Gauge	110.69	127.32	127.41	0.09	128.45	128.44	-0.01

5.5.3 Flood Mapping and Flood Profiles of Calibration and Verification Events

Flood depth and water level contours are mapped on Figure B-1 and Figure B-2 in Appendix B for the 1976 and 2011 flood events, respectively. The peak flood surface profiles are plotted on Figure B-3 for the historic events.

5.6 Sensitivity Testing of Calibration Parameters

A number of scenarios were run with varied model parameters as a part of the model calibration process. These are described in Table 5-3. The differences in model results are compared for the February 1976 flood event on Figure 5-7.

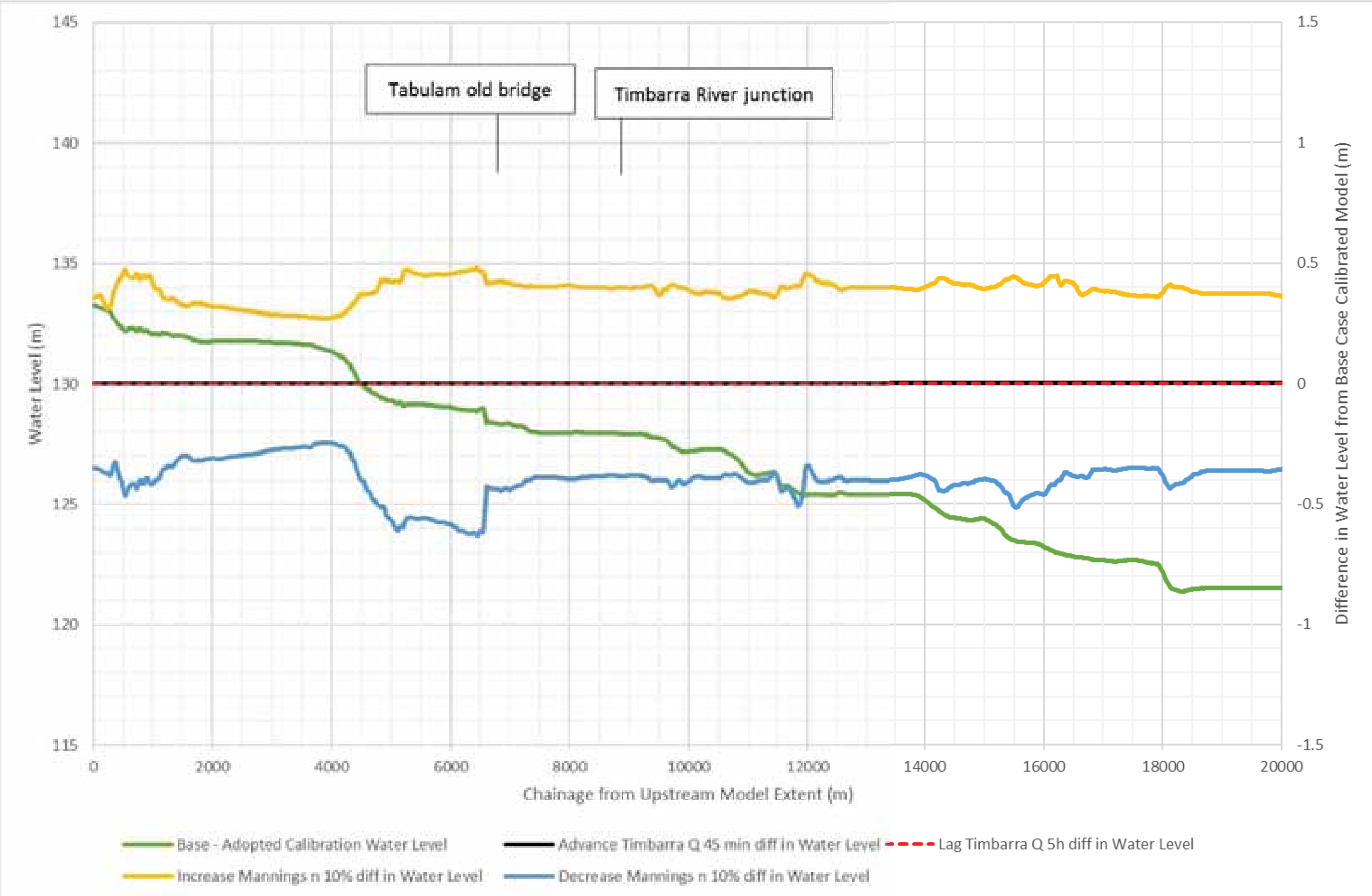
Table 5-3 Sensitivity scenarios in model calibration

Scenario ID	Description	Comments on changes in flood levels (1976 event)
1	Advance Clarence River flows by 45 minutes	Negligible change
2	Lag Timbarra River flows by 5 hours	Negligible change
3	Increase Manning's n 10%	Flood levels increase 0.3 – 0.5m
4	Decrease Manning's n 10%	Flood levels decrease 0.3 – 0.6m

Variation of the timing of the Timbarra River inflows was done within reasonable bounds, based on likely travel times from the Drake gauge to the Clarence River confluence. The adopted variation in Manning's n (+/- 10%) is a typical increment for model sensitivity testing.

Further sensitivity testing was undertaken on the design 1% AEP flood event including change in Manning's n and change in assumed downstream boundary conditions. Refer to Section 6.9.

Figure 5-7 Sensitivity runs water surface profiles



5.7 Model Peer Review

A model peer review was undertaken by Jacobs senior flood modelling practitioners in December 2018. The peer review notes are provided in Appendix E. The flood model development and calibration was found to be generally satisfactory. Queries and review comments were addressed in the design event modelling and in this report.

6. Design Flood Estimation

6.1 Design Flood Model Inflows

The design events of interest to this study include the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP and an extreme flood event (3x 1% AEP flows). Peak flows at the Clarence River and Timbarra River gauges were estimated based on flood frequency analyses as described in Section 3.2. Peak flows estimated for the Timbarra River at Drake gauge were increased by 10% to account for the increased catchment area at outlet of the river. In the case of the Clarence River, peak flows for design flood events estimated at the gauge were scaled up to account for flood storage and flow attenuation due to Tabulam Bridge between the model upstream boundary and the gauge. This was done based on iterative runs of the TUFLOW model in order to achieve a reasonable agreement between the modelled flow and the estimated design flows at the gauge location.

Observed flow hydrographs at the two gauges with closest adopted peak flows for design events were scaled to generate hydrographs for design flood events. The peak flow in the Timbarra River was assumed to occur one hour later than the peak flow in the Clarence River at the TUFLOW model boundaries.

Inflow hydrographs for design flood events for Tabulam Rivulet were estimated using a RORB model as described in Section 3.5.3. Due to the relatively smaller catchment area of Tabulam Rivulet, it was assumed that peak flows in the Rivulet would occur much earlier than the peak flow in the Clarence River.

6.2 Concurrent Flooding

6.2.1 Timbarra River

Annual maximum peak flows in the Clarence River at Tabulam gauge and the corresponding peak flows for the same flood events in the Timbarra River at Drake gauge were analysed (refer to Figure 6-1) to identify any correlation between peak flows in the two rivers. Concurrent flooding in Timbarra River corresponding to the design flood events for the Clarence River was estimated based on the guideline outlined in Book VIII of the Australian Rainfall and Runoff 2016. The adopted concurrent peak flows in the Timbarra River corresponding to design flood events in the Clarence River are shown in Table 6-1.

Figures C-1 to C-9 in Appendix C present the adopted design inflow hydrographs into the TUFLOW model for all flood events assessed.

6.2.2 Tabulam Rivulet

A concurrent flooding analysis for Tabulam Rivulet was undertaken using the same procedure (refer to Section 6.2.1) adopted for the Timbarra River. As Tabulam Rivulet is ungauged, correlation in rainfall between the catchment area of the Clarence River and the catchment area of Tabulam Rivulet was adopted in the estimation of concurrent flooding. The adopted concurrent peak flows in Tabulam Rivulet corresponding to design flood events in the Clarence River are shown in Table 6-1. Figures C-1 to C-9 in Appendix C present the adopted design inflow hydrographs into the TUFLOW model for all flood events assessed.

1% AEP flooding was assumed both in the Clarence River and Timbarra River corresponding to the PMF event for Tabulam Rivulet.

Figure 6-1 Relationship between peak flows in the Clarence River and Timbarra River

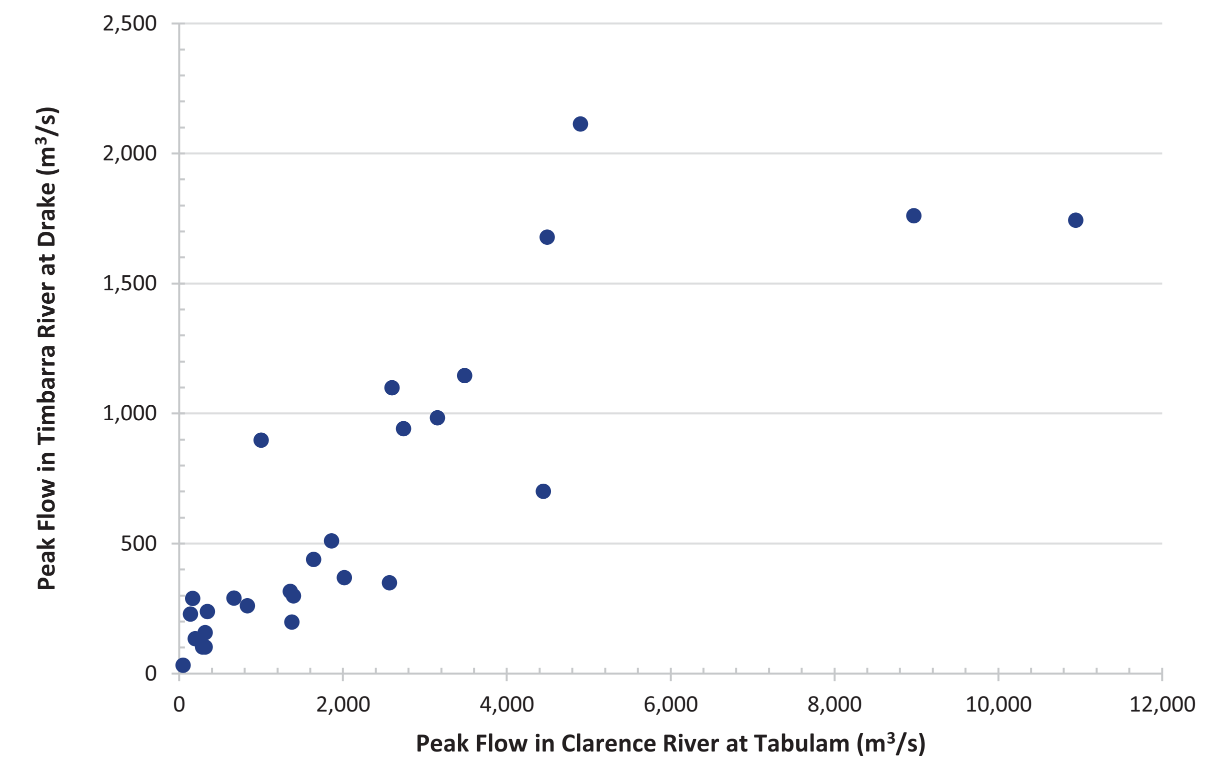


Table 6-1 Adopted Concurrent Flooding in the Timbarra River and Tabulam Rivulet

Design flood event for Clarence River and adopted peak flow*	Peak Flow (m^3/s) in Timbarra River at Outlet	Peak Flow (m^3/s) in Tabulam Rivulet at outlet
20% AEP (3,020 m^3/s)	310	200
10% AEP (4,890 m^3/s)	900	350
5% AEP (7,080 m^3/s)	2,430	410
2% AEP (10,500 m^3/s)	2,920	480
1% AEP (13,550 m^3/s)	3,300	570
0.5% AEP (16,750 m^3/s)	3,700	600
0.2% AEP (21,000 m^3/s)	4,230	790
Extreme (40,660 m^3/s)	5,060	1,260

*peak flow adopted at the upstream boundary of the TUFLOW model

6.3 Assessment of Hydraulic Structures Blockage

Flood debris may get trapped on and against hydraulic structures, reducing the waterway area which results in increased flood levels particularly upstream of the structures. Major rivers such as the Clarence River may have large flood debris including large tree logs, branches and other vegetation, given the large forested areas in the catchment upstream of Tabulam.

The new bridge design (GHD, 2016) has approximately 30m wide spans and 1.4m wide blade piers which do not appear to be particularly prone to catching and accumulating debris. For the purposes of the flood study, it is assumed that there would be a build-up of debris when floodwaters reach the new bridge soffit, and that the soffit would be blocked to a depth of 1m (i.e. bridge soffit level in the model lowered by 1m). The blockage was only applied to the spans over the main channel and not on the overbank spans or overflow crossings. This distribution of blockage is validated by video footage taken during the 2011 flood event and available on Youtube, which showed flows on the overbank areas being relatively slow with little debris, while flows in the main channel section were swift with more debris. A 1m depth of blockage over the main channel spans represents an approximately 5% level of blockage of that section. The overbank spans were assumed to be unblocked. The Clarence River Overflows 1 and 2 crossings and Tabulam Rivulet were also assumed to be unblocked.

6.4 Design Flood Results and Discussion

Mapping and discussion of flood depths and velocities is provided here. Discussion of further details of the flooding within Tabulam village such as flood hazard, flood function, duration of flooding, rates of rise and timing of flooding and cut-off of evacuation routes and emergency classification of communities will be provided in the FRMS.

6.4.1 Flood Mapping and Results

Peak flood levels and depths within the study area for all design events assessed are presented on Figures D-1 to D-8 in Appendix D.

Flow velocities within the study area for all design events assessed are presented on Figures D-9 to D-16 in Appendix D.

Long section water level profiles through the model domain are presented on Figure D-17 in Appendix D.

The peak flood levels at various points in the study area are summarized in Table 6-2. The selected locations are shown on Figure 6-2. Note that the construction of the new bridge necessitated relocation of the Tabulam river gauge from between the new and old bridge to a new location on the downstream side of the new bridge.

Table 6-2 Peak flood levels at selected locations in study area

ID	Event AEP							
	20%	10%	5%	2%	1%	0.5%	0.2%	Extreme
New Gauge Location	122.57	124.21	126.06	128.62	129.29	130.87	132.75	138.99
Old Gauge Location	122.59	124.25	126.10	128.91	129.70	131.45	133.28	138.95
P1	122.60	124.28	126.11	128.95	129.73	131.46	133.25	138.95
P2	-	-	-	128.90	129.69	131.45	133.26	138.93
P3	-	-	-	128.96	129.73	131.38	133.23	138.47
P4	-	-	-	128.97	129.65	131.14	132.99	138.74
P5	-	123.96	125.99	128.49	129.19	130.83	132.74	138.47
P6	-	-	-	128.34	129.07	130.84	132.78	138.54
P7	-	-	-	128.34	129.04	130.75	132.69	138.42
P8	-	-	-	128.33	129.03	130.68	132.58	138.25

* Dash (-) denotes not flooded at that location.

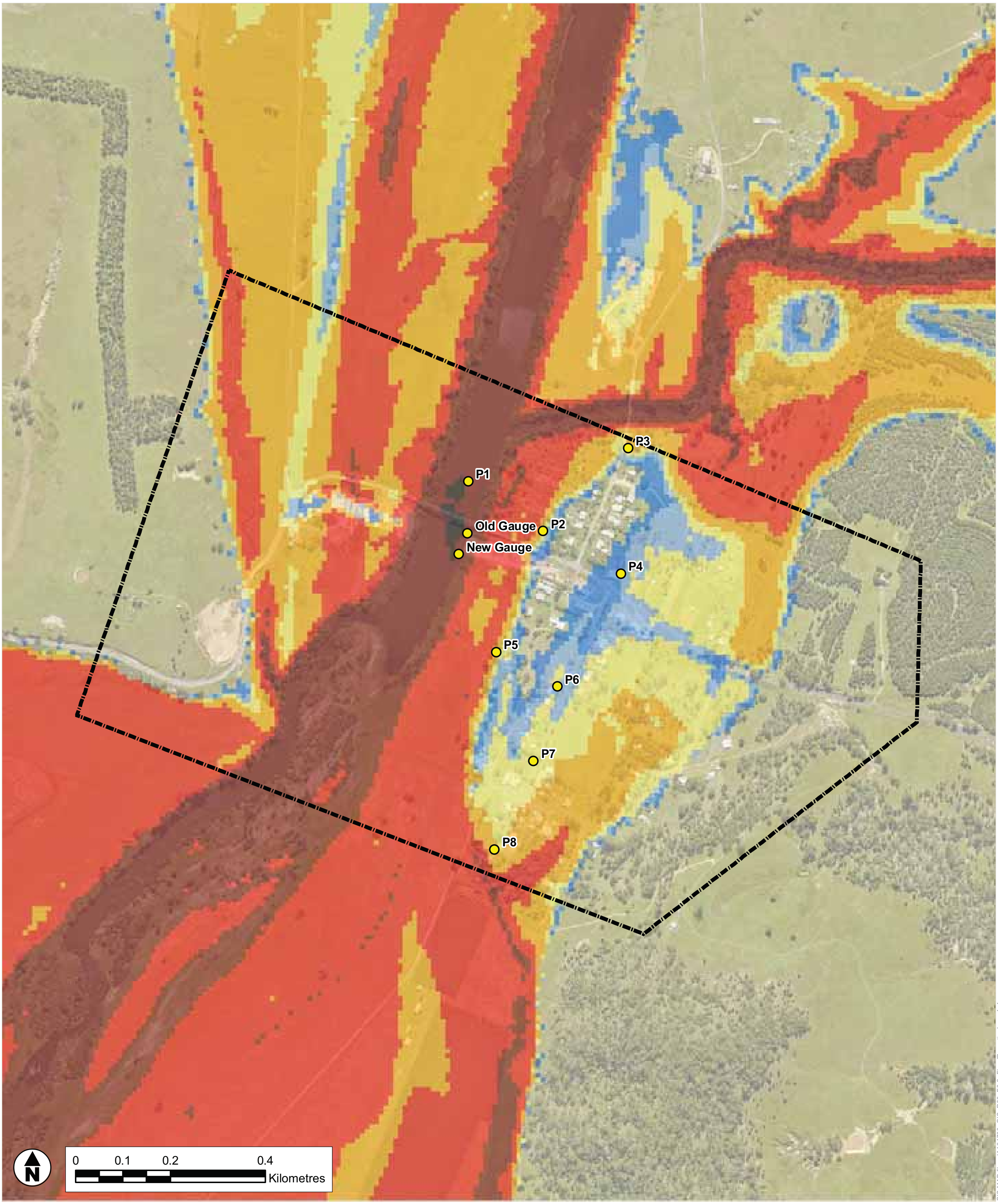
6.4.2 Flood Level Hydrographs and Rate of Rise

Flood level hydrographs at the old gauge location are presented for all design events on Figure D-18 in Appendix D. The flood levels are plotted to AHD and to the old gauge datum. Ground elevations at selected locations are indicated.

Modelled flood rates of rise are summarised in Table 6-3, including the maximum rate of rise and the rate of rise from 120m AHD (approximately start of the flood wave) to peak flood level. The differences in the rate of rise between the design events is attributed to the 1976 flood hydrograph shape, with a faster rate of rise, being adopted for the 1% AEP event and rarer, while the 2011 flood hydrograph shape with a more gentle rate of rise was adopted for up to the 2% AEP event.

Table 6-3 Modelled flood level rates of rise for design events

Design event	Maximum rate of rise (m/hr)	Rate of Rise from start of flood to peak (m/hr)
20% AEP	1.3	0.1
10% AEP	1.9	0.3
5% AEP	1.5	0.2
2% AEP	1.6	0.2
1% AEP	2.8	0.9
0.5% AEP	3.3	0.9
0.2% AEP	3.7	1.0
Extreme Flood Clarence River	3.9	1.1
Extreme Flood Tabulam Rivulet	2.8	1.0



Legend

Flood Level Reporting Location

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- > 20

JACOBS

A3

SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Flood Level Reporting Locations in Tabulam Village

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE 6-2	1	1
CHECK	DATE			
AH	18/01/2019			

6.4.3 Discussion of Flood Behaviour

Observations of flooding behaviour are summarized below.

- Existing dwellings in the village are not impacted in the 20% AEP flood. Flows break out from the river into minor flow paths at and north of Court Street which then flow south and south-east.
- Overall, fringe flooding begins to encroach on some dwellings in the 10% and 5% AEP flood events but there is generally no over floor flooding. There is one property on Harry Mundine Place with overfloor flooding over 0.8m deep.
- The new bridge, with a minimum soffit level of approximately 127.7m AHD on its western side and a maximum soffit level of 129m AHD on the eastern side, is not surcharged in the 5% AEP event (flood level 126.04m AHD). However, the new bridge is surcharged along most of its length in the 2% AEP event (flood level 128.85m AHD).

  Tabulam Rivulet bridge, with deck level of 127.6m AHD, is above the 5% AEP event and submerged to depths of 1.3m in the 2% AEP event.
- Flooding of the village occurs both north and south of the Bruxner Highway in the 2% AEP event, creating a high flood island in the village. Most buildings south of the highway are inundated with approximately half of these with above floor flooding, many with 1m depth above floor and at least one with 3m depth above floor. About half of the buildings north of the highway are inundated, most with above floor flooding, up to 0.7m deep. Flooding in the floodway east of Clarence Street is due to backwater flooding from the Clarence River (south of highway) and from Tabulam Rivulet/Clarence River (north of highway), with low flow velocities in the village (typically less than 0.2m/s, up to 0.5m/s). Velocities on the fringe of the Clarence River are up to 1m/s. The highway is inundated between Clarence Street and Lawrence Street but remains passable for larger vehicles (depths up to 0.4m).
- In the 1% AEP event, flooding is extensive through the village, with many properties affected by flooding of 1 – 3m deep above ground, and a number of properties in the south of the village with 3 – 5m deep flooding above ground. Flow velocities in the floodway are more active with flows from north to south but still relatively low, typically 0.3 – 0.5m. There is a localized area up to 3.5m/s near Lawrence Street where floodwaters overflow the highway and down an embankment into the floodway. Velocities on the fringe of the Clarence River are typically up to 1.5m/s. A high flood island remains in the village in the 1% AEP. The highway is cut off between Clarence Street and Lawrence Street to depths of 1.7m.

  The new bridge, with a minimum soffit level of approximately 127.7m AHD on its western side and a maximum soffit level of 129m AHD on the eastern side, is fully surcharging in the 1% AEP event (flood level 129.7m AHD). Deck levels vary from 129.4 – 130.7m AHD and hence the deck is partly submerged to 0.3m depth, on its western side.
- In the 0.5% AEP event the entire village is inundated with property flooding of 0.5m on the low flood island up to 6.7m on low properties adjoining the floodway. There are several dwellings above the 0.5% AEP flood to the east of Lawrence Street. Flow velocities are typically 0.5 – 1.5m/s in the floodway and along the edge of the main Clarence River flow.

  The new bridge deck is submerged to depths of 0.7 – 2m.
- In the 0.2% AEP event the entire village is fully inundated with property flooding of 1m on the low flood island (i.e. higher land which starts off as an island early in the flood but which then becomes drowned) up to 9m on low properties adjoining the floodway. There are a few dwellings above the 0.5% AEP flood to the east of Lawrence Street. Flow velocities are typically 0.5 – 1.8m/s in the floodway and along the edge of the main Clarence River flow.
- The design extreme event flood is dominated by an extreme flooding event occurring in the Clarence River, with Tabulam Rivulet extreme flood event not being the critical event in any part of the study area. Flood depths in the village range from 8m to 15m. Flow velocities are typically 1.5 – 2.5m/s in the floodway and along the edge of the main Clarence River flow.

6.5 Flood Hazard Mapping

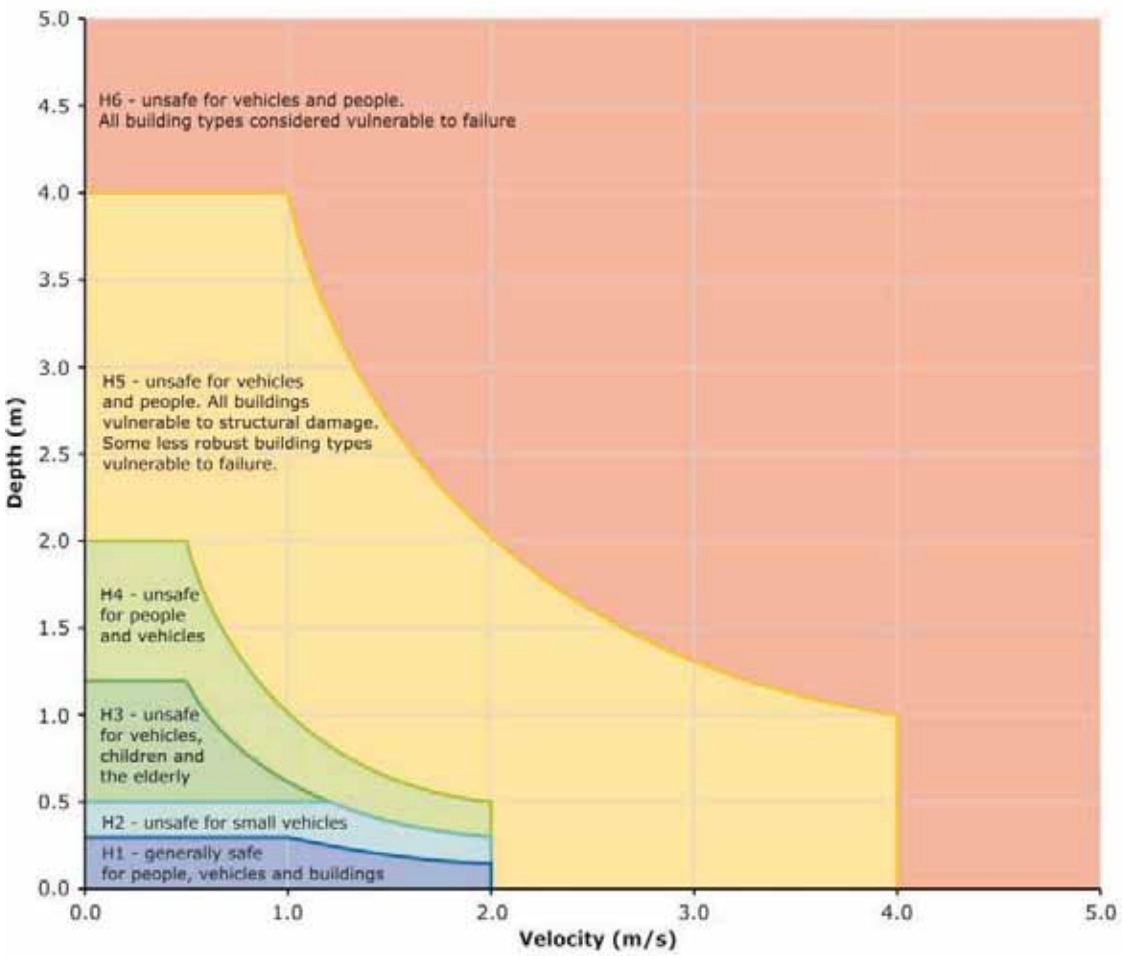
Flood hazard mapping has been prepared which describes the hazard that flooding poses and the vulnerability of the public and assets when interacting with floodwaters. A combined flood hazard classification is presented in *Australian Disaster Resilience Handbook 7. Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (AIDR, 2017a) and *Guideline 7-3 Flood Hazard* (AIDR, 2017b), and is illustrated in Figure 6-3. The flood hazard categories according to the AIDR definition are:

- H1 – Generally safe for people, vehicles and buildings;
- H2 – Unsafe for small vehicles;
- H3 - Unsafe for vehicles, children and the elderly;
- H4 - Unsafe for people and vehicles;
- H5 - Unsafe for people and vehicles. Buildings require special engineering design and construction; and
- H6 – Unsafe for people or vehicles. All buildings types considered vulnerable to failure.

The flood hazard classification is more discrete and provides guidance on flood hazard thresholds to different members of the community (e.g. children and elderly) and different assets (small versus larger vehicles, standard versus specialised engineered buildings). The AIDR flood hazard definition potentially provides a more suitable guideline for assessing flood hazard on the floodplain from an emergency management perspective.

The flood hazard mapping has been prepared for all flood events assessed, from the 20% AEP up to the PMF event, and is presented in Appendix E.

Figure 6-3 General flood hazard vulnerability curves, Australian Institute for Disaster Resilience (AIDR) definition. Reproduced from Figure 6 in *Guideline 7-3: Flood Hazard* (AIDR, 2017b)



The flood hazard in the study area as presented in the mapping is described below.

- Existing dwellings in the village are not impacted in the 20% AEP flood. Overall, fringe flooding begins to encroach on some dwellings in the 10% and 5% AEP flood events with up to H2 flood hazard rating.
- In the 5% AEP event there is one property on Harry Mundine Place affected by up to H4 flood hazard.
- Flooding of the village occurs both north and south of the Bruxner Highway in the 2% AEP event, creating a high flood island in the village. Most buildings south of the highway are inundated with approximately half of these with above floor flooding, with maximum on-property flood hazard ratings ranging from H2 and up to H5. The highway is affected between Clarence Street and Lawrence Street by up to H2 flood hazard but remains passable for larger vehicles (depths up to 0.4m). The highway to the west of the Clarence River is cut at the Clarence Overflow No. 2 crossing, with flood hazard of H5.
- In the 1% AEP event, flooding is extensive through the village, with most properties affected at the dwelling by flood hazard of H3 up to H5. The Bruxner Highway to the east of the village centre is cut between Clarence Street and Lawrence Street by up to H5 flood hazard due to floodway flows from Tabulam Rivulet to the north flowing in a southward direction over the highway. The highway to the west of the Clarence River is cut at the Clarence Overflow No. 2 crossing, with flood hazard of H6. A high flood island remains in the village in the 1% AEP.
- In the 0.5% AEP event the entire village is inundated with flood hazard ratings of H4 to H6.
- In the 0.2% AEP event the entire village is inundated with flood hazard ratings of H5 to H6.
- In design extreme event flood the entire village is inundated with flood hazard ratings of H6.

6.6 Updated Rating Curve

An updated rating curve was derived based on the TUFLOW model results for the new bridge scenario and at the new gauge location downstream of the new bridge. The new bridge has different design aspects and has some impact to flows. This is discussed in Section 6.7.2. Additionally, the gauge location was moved downstream due to construction of the new bridge.

The updated rating curve is compared to the current WaterNSW rating curve (rating curve number 227 which was based on the old bridge) on Figure 6-5. The current rating curve extends to near the 1% AEP design flow estimated in this study. There is reasonable agreement between the updated and current rating curves above the 20% AEP event, noting that the current rating curve is significantly extrapolated above the maximum gauged flow. There is minor variation between the curves for low flows, which is attributed to the absence of detailed bathymetric data in the hydraulic model. It is expected that WaterNSW will update the rating curve to cater for the new gauge location and the new bridge.

Figure 6-4 Updated rating curve based on TUFLOW model results for Clarence River @ Tabulam. New bridge scenario, new gauge location

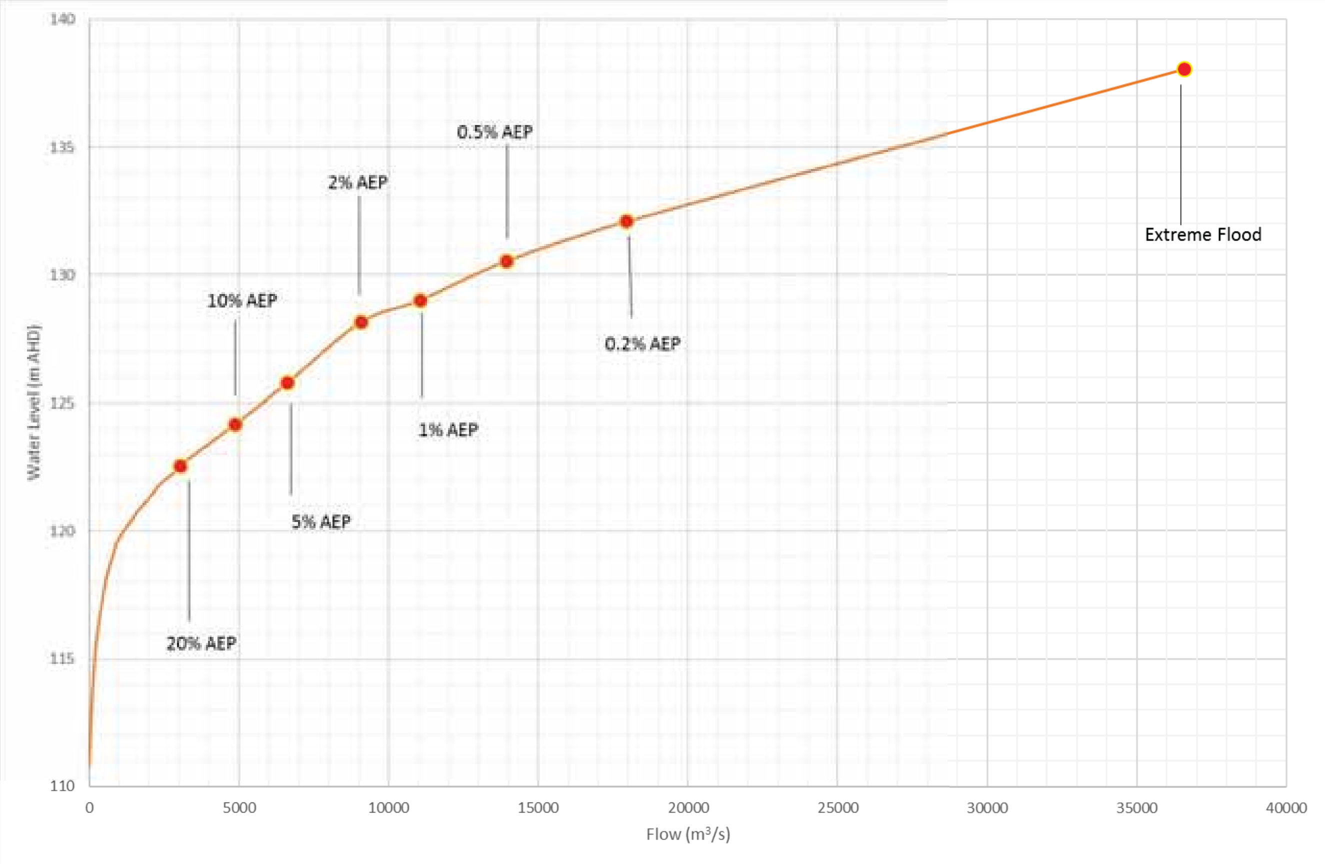
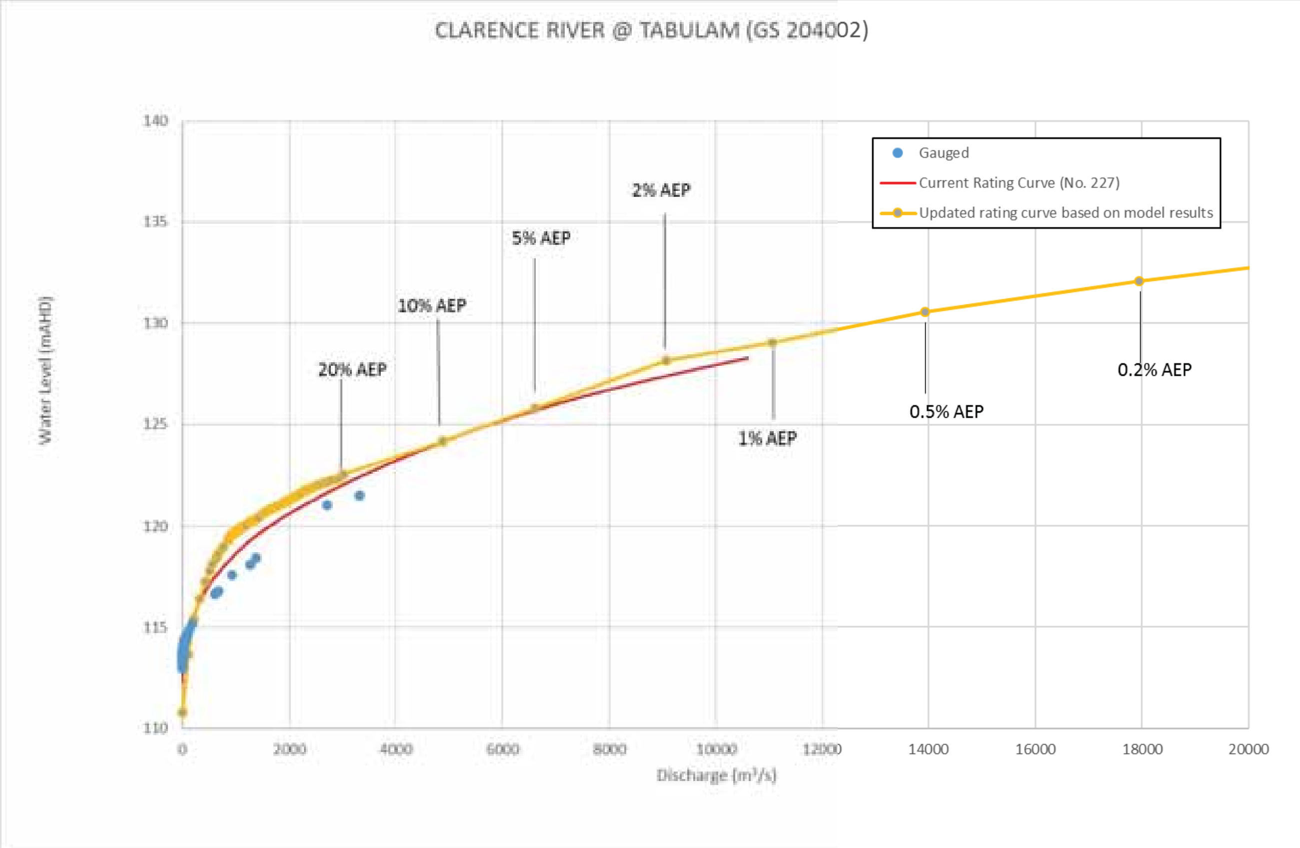


Figure 6-5 Comparison of updated rating curve with current WaterNSW rating curve



6.7 Validation of Flood Modelling

6.7.1 Comparison of Design Flows to Previous Estimates

The Tabulam New Bridge Hydraulic Assessment Supplementary Report (GHD, 2016) estimated a 1% AEP design flow of 7,900m^3/s, which is significantly lower than the estimate made in this study of 12,100m^3/s. It is noted that the GHD FFA was based on fitting a Gumbel distribution to the mean daily data, which is the reason for the lower estimate. In addition, the mean daily flow for the flood event of February 1976 is not considered to be an appropriate approach. The mean daily flows are significantly lower than the *instantaneous flows*, which were adopted in FFA in this study.

Confidence in the current 1% AEP design flow estimate of 12,100m^3/s is taken from the hydraulic model calibration in this study (refer Section 5), where the February 1976 flood event (rated as close to a 1% AEP flood and with a similar flow to the 1% AEP) was run in an extensive hydraulic model and produced a good fit to the recorded flood levels at Tabulam gauge. It is noted that the GHD (2015a) modelling, adopting the lower estimate of 7,900m^3/s, was limited in extent to near the Bruxner Highway bridge crossing with likely high influence of the assumed downstream boundary conditions, and additionally was not calibrated to historic flood levels.

Given these factors, the current design flow estimates and hydraulic modelling in this study are considered more reliable.

6.7.2 Effect of New Bridge versus Old Bridge on Flows

Table 6-4 compares the peak flows in the 1% and 2% AEP events downstream of the existing (old) bridge and new bridge. It indicates that the peak flows downstream of the bridge locations are higher with the new bridge due to the larger waterway area and increased flow conveyance through the bridge.

Table 6-4 Comparison of downstream peak flows with existing (old) bridge and new bridge

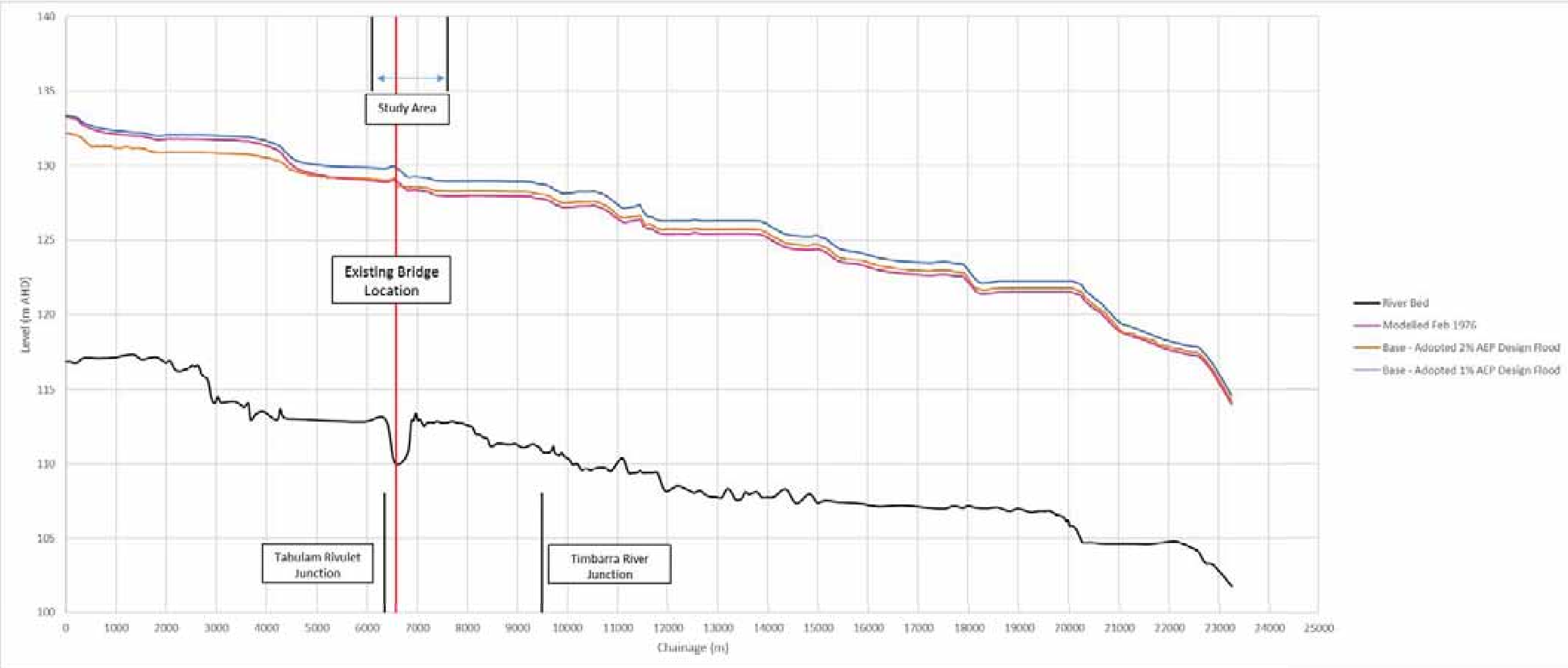
Event AEP	Peak Flow (m^3/s)	
	Existing (Old) Bridge	New Bridge
1%	11,541	11,600
2%	9,438	9,546

6.8 Analysis of Design Flows with Existing (Old) Bridge

The design 1% and 2% AEP flows were run through the calibration model and compared to the simulated 1976 flood profile in Figure 6-6. Bridge details and blockage conditions for the existing (old) bridge and for the model calibration were retained.

Flood levels for the 1976 event at the model upstream boundary are initially similar to the 1% AEP event. The 1976 event is estimated to be a 1.3% (1 in 80) AEP event. The 1976 AEP flood profile drops just upstream of the study area to the 2% AEP, and then drops just below the 2% AEP for the remainder of the model domain down to the model downstream boundary. This is attributed to the adopted peak flows in the Timbarra River for the 1% and 2% AEP events. Adopted peak flows in the Timbarra River for both design flood events are higher than the 1976 flood event.

Figure 6-6 Comparison of peak water surface profiles – Design event and 1976 calibration event – Existing (Old) Bridge



6.9 Sensitivity Testing

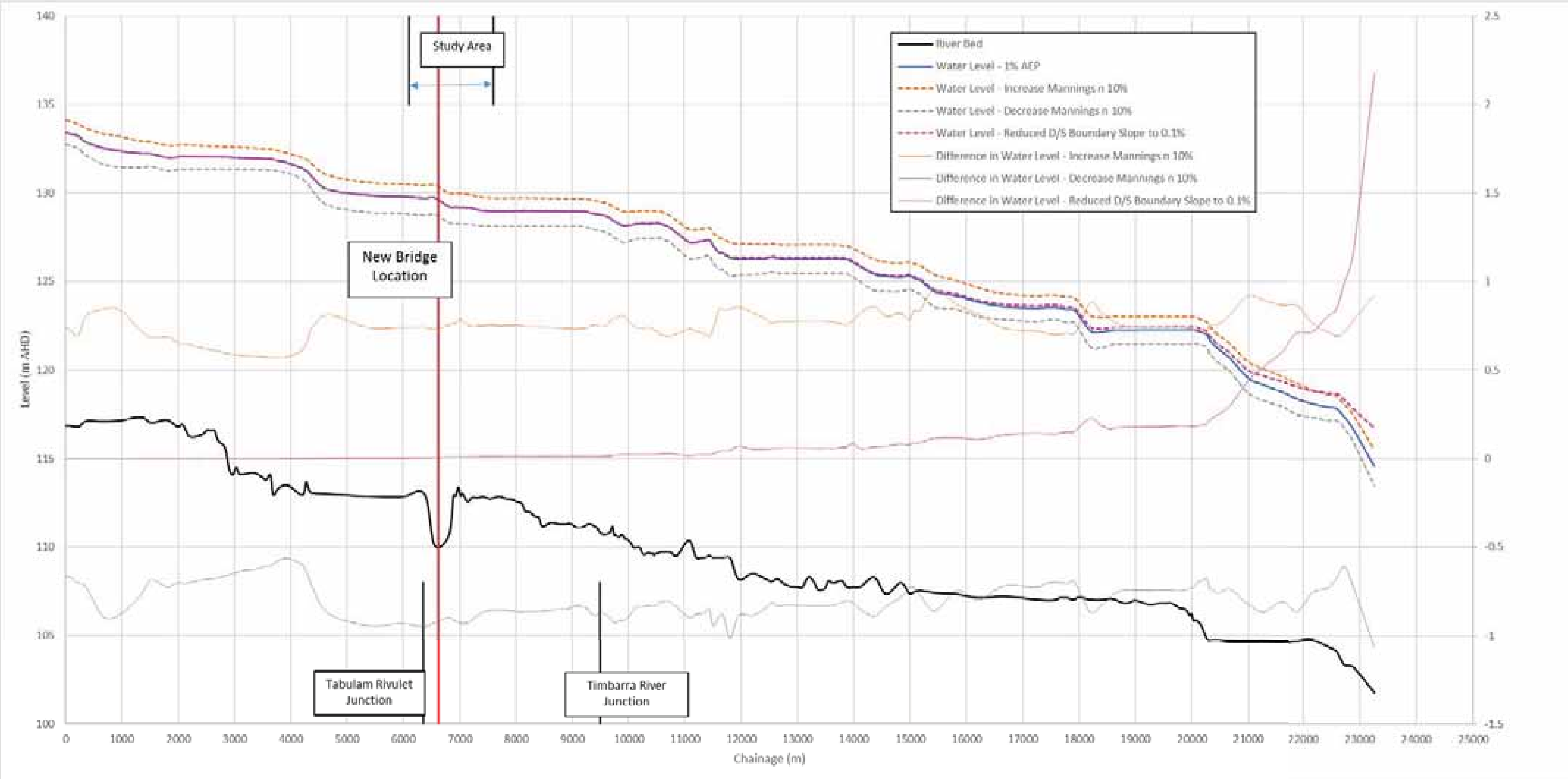
A number of scenarios were run with varied model parameters as a part of the model calibration process. These are described in Table 6-5 and the modelled water surface and water level difference long sections are shown on Figure 6-7. It was observed that reducing the downstream boundary assumed water surface gradient from 0.2% in the design case to 0.1% as a sensitivity resulted in a negligible increase in the peak 1% AEP flood level in the study area.

The change in water level due to +/- 10% in Manning's n is substantial in magnitude, although proportional to the high depth of flooding (approximately 20m). The adopted variation in Manning's n (+/- 10%) is a typical increment for model sensitivity testing.

Table 6-5 Sensitivity scenarios in model calibration

Scenario ID	Description	Comments on changes in flood levels in study area (1% AEP)
1	Reduce downstream boundary assumed water surface gradient to 0.1% (from 0.2% design case)	Negligible (+0.01m)
2	Increase Manning's n 10%	+0.75m
3	Decrease Manning's n 10%	-0.9m

Figure 6-7 Comparison of peak water surface profiles for sensitivity scenarios to design 1% AEP



6.10 Climate Change Assessment

An assessment of the impacts of climate change on flooding in Tabulam was conducted by comparing the design flooding conditions in the 0.5% and 0.2% AEP events to the 1% AEP event. Refer to Table 6-6.

Climate change impacts are often estimated in flood studies based on assessing the change in flood levels to increases in design rainfall depths for the 1% AEP storm event. Comparison of the design rainfall depths at Tabulam indicates that in the existing climate the 0.5% AEP design rainfalls are 11% higher than the 1% AEP design rainfall, and the 0.2% design rainfalls are 27% higher than the 1% AEP design rainfall.

Table 6-6 Comparison of rare flood events model results for indication of potential climate change impact

Event AEP	% increase in design rainfall	Clarence River Flow (m^3/s)	% increase in flow	Flood level increase at new gauge location (m)
1%	-	12,100	-	-
0.5%	11%	14,200	17%	1.6
0.2%	27%	16,800	39%	3.5

ARR 2016 provides interim climate change factors for a range of climate change impact increase scenarios up to the year 2090. For the upper range RCP 8.5 scenario, in the year 2050 and the year 2090 an increase in rainfall depth and intensity of 8.8% and 18.6%, respectively, is predicted. Representative Concentration Pathways (RCP) 8.5 refers to the upper range projection of greenhouse gas concentrations in the atmosphere as adopted by the IPCC in 2014 for the assessment of climate change impacts.

Interpretation of the ARR climate change factors, the BOM design rainfall depths and flood study model results for the 1%, 0.5% and 0.2% AEP events results in the estimated increase in 1% AEP design flood levels for the years 2050 and 2090 as indicated in Table 6-7.

Table 6-7 Estimated climate change impacts on 1% AEP flood level at Tabulam

Year	Increase in rainfall (RCP 8.5 scenario)	Estimated increase in 1% AEP flood level at new gauge location (m)
2050	8.8%	~1.4
2090	18.6%	~2.6

7. Conclusions and Recommendations

7.1 Conclusions

A TUFLOW hydraulic model for the Tabulam study area was developed based on available data from Council and other sources, and topographic and hydraulic structures survey collected during this study. The model was developed with a focus on mainstream flooding originating from runoff from Clarence River, Tabulam Rivulet and Timbarra River. Inflows in the Clarence River and Timbarra River were estimated based on data recorded at stream gauges on the rivers for historic events, and from updated flood frequency analysis (FFA) of stream gauging data for design events. A RORB hydrologic model was developed to estimate design flow hydrographs in the Tabulam Rivulet.

The TUFLOW model was calibrated to the February 1976 and January 2011 flood events based primarily on recorded water levels at the Tabulam gauge in addition to surveyed flood marks in the village collected by Council following the 2011 flood event (including three flood marks from the 1976 event). The flood marks were observed to be markedly variable between adjacent locations. This variability in the flood marks could not be fully explained or resolved in the modelling, and may be due to localised features or contribution of local overland flows in the village, which were not represented in the model calibration as the focus was on the mainstream flooding. The model achieved a good fit (+/- 0.1m variance), while there is a fair (up to +/- 0.25m) to poor (> +/- 0.25m) fit to the reported flood marks, owing to the unexplained variability of the flood mark levels.

Parameter values for the TUFLOW model were adjusted to achieve a satisfactory fit to historic flood observations include model grid size, estimated inflows from the rating curve, hydraulic roughness of the floodplain and watercourse and timing of tributary inflows. An updated flood frequency analysis of recorded gauge data was undertaken to estimate design flows in the Clarence River and Timbarra River, which included a review of stream gauging and the rating curve. This review indicated that estimated peak flows for the largest historic flood events involve huge extrapolation of the rating curve. Hence, there is significant uncertainty at the higher end of the rating curve for discharges relevant to significant flood events and associated peak flow rates.

The updated FFA provides significantly higher design flow estimates than previously estimated by GHD (2015a). The updated FFA was based on fitting the recorded gauge data (instantaneous flow) to a Log Pearson III (LPIII) distribution as per ARR 2016 guidelines, while the previous estimate is based on Gumbel distribution and mean daily (rather than instantaneous) flows. Sensitivity of the FFA to using other statistical methods and tests, including fitting to Generalised Extreme Value distribution and using Multiple Grubbs Beck Test, validated the adoption of LPIII distribution.

Confidence in the current design flow estimates is taken from the hydraulic model calibration in this study using an extensive hydraulic model and which produced a good fit to the recorded flood levels at the Tabulam gauge. The previous studies used a limited extent model with likely high influence of the assumed downstream boundary conditions, and additionally was not calibrated to historic flood levels. Given these factors, the current design flow estimates and hydraulic modelling in this study are considered more reliable.

A range of design flood events including the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events and an Extreme Flood event (3x 1% AEP flows) were simulated to estimate design flood levels in Tabulam Village. The Bruxner Highway new bridge at Tabulam was represented in the design flood estimation. An updated rating curve was prepared based on the design event modelling at the new Tabulam river gauge location, which was moved due to construction of the new bridge. The updated rating curve is in reasonable agreement with the current WaterNSW rating curve (no. 227) above the 20% AEP event.

Flood behaviour in the village is summarised below:

- Overall, fringe flooding begins to encroach on some dwellings in the 10% and 5% AEP floods but there is generally no over floor flooding. There is one property with overfloor flooding over 0.8m deep.
- Flooding of the village occurs both north and south of the Bruxner Highway in the 2% AEP event, creating a high flood island in the village. More than half of the buildings are inundated. The highway is inundated between Clarence Street and Lawrence Street but remains passable for larger vehicles (depths up to

0.4m). The new bridge deck is not overtopped in the 2% AEP event. Tabulam Rivulet bridge is submerged to depths of 1.3m in the 2% AEP.

- In the 1% AEP event, flooding is extensive through the village, with many properties affected by flooding of 1 – 3m deep above ground, and a number of properties in the south of the village with 3 – 5m deep flooding above ground. A high flood island remains in the village in the 1% AEP. The highway is cut off between Clarence Street and Lawrence Street to depths of 1.7m. The new bridge deck is partly submerged to 0.3m depth, on its western side.
- In the 0.5% AEP event the entire village is fully inundated with property flooding of 0.5m on the low flood island up to 6.7m on low properties adjoining the floodway. There are several dwellings above the 0.5% AEP flood to the east of Lawrence Street. The new bridge deck is submerged to depths of 0.7 – 2m.
- The design extreme event flood is dominated by an extreme flooding event occurring in the Clarence River, with Tabulam Rivulet extreme flood event not being the critical event in any part of the study area. Flood depths in the village range from 8m to 15m.

Modelled flood rates of rise were determined to be approximately 1m/hr from start of flood to peak for the 1% AEP design event and rarer.

Flood hazard mapping was prepared from the modelling results and based on hazard classification from the Australian Institute for Disaster Resilience. Description of the flood hazard in the different flood events is summarised below:

- Parts of Tabulam village are affected by low to moderately high (up to H3 rating, localised H4 on low properties) in up to the 5% AEP event.
- In the 2% AEP event, flood-impacted properties are affected by H2 and up to H5 flood hazard rating. The highway is affected between Clarence Street and Lawrence Street by up to H2 flood hazard but remains passable for larger vehicles (depths up to 0.4m). The highway to the west of the Clarence River is cut at the Clarence Overflow No. 2 crossing, with flood hazard of H5.
- In the 1% AEP event, flooding is extensive through the village, with most properties affected at the dwelling by flood hazard of H3 up to H5. The Bruxner Highway is cut between Clarence Street and Lawrence Street by up to H5 flood hazard. The highway to the west of the Clarence River is cut at the Clarence Overflow No. 2 crossing, with flood hazard of H6. A high flood island remains in the village in the 1% AEP.
- In the 0.5% and 0.2% AEP events and the extreme event the entire village is affected by high and extreme flood hazard ratings of H4 up to H6.

The new bridge has higher flow capacity than the existing (old) bridge and was demonstrated in the model to pass greater flows with less backup and attenuation of flows.

Sensitivity of the modelled flood levels to changes in model parameters was assessed. The timing of Timbarra River inflows had negligible influence on peak flood levels in the Clarence River. Reducing the assumed downstream boundary flood surface gradient had negligible impact on flood levels in the study area. Varying the hydraulic roughness by +/- 10% has a substantial impact on peak flood levels in the Clarence River with up to +/- 0.9m change in flood levels in the 1% AEP event.

The impact of climate change on flood levels in the village were assessed based on design rainfall data, modelling results for rare flood events and published ARR 2016 climate change factors. Based on these guidelines the 1% AEP flood level is estimated to increase by approximately 1.4m in the year 2050 and approximately 2.6m in the year 2090.

7.2 Recommendations

It is recommended that Council considers the adoption of this Flood Study and the outputs to guide floodplain management and land use planning in the Tabulam study area. The subsequent Floodplain Risk Management Study should consider the management of flood risk in the study area, which may include the development of flood mitigation strategies.

8. References

- GHD (2015a) Tabulam New Bridge Hydraulic Assessment. Prepared for RMS
- GHD (2015b) Bruxner Highway at Tabulam Review of Environmental Factors. Prepared for RMS
- GHD (2016) Tabulam New Bridge Supplementary Report to Hydraulic Assessment. Prepared for RMS
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9. Acknowledgements

This study was undertaken by Jacobs on behalf of Kyogle Council with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

A number of organisations and individuals have contributed both time and valuable information to this study. The assistance of the following in providing data and/or guidance to the study is gratefully acknowledged:

- Residents of the study area;
- WaterNSW;
- Tabulam Unit of NSW State Emergency Service
- Council officers; and
- NSW Office of Environment and Heritage.

10. Glossary

Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. In this study AEP has been used consistently to define the probability of occurrence of flooding. It is to be noted that design rainfalls used in the estimation of design floods up to and including 100 year ARI (i.e. 1% AEP) events was derived from 1987 Australian Rainfall and Runoff. Hence the flowing relationship between AEP and ARI applies to this study. 20% AEP = 5 year ARI; 10% AEP = 10 year ARI; 5% AEP = 20 year ARI; 2% AEP = 50 year ARI; 1% AEP = 100 year ARI.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long-term average number of years between the occurrences of a flood as big as or larger than the selected event. For example, floods with a discharge as great as or greater than the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
DEM	Digital Elevation Model which represents the terrain.
Development	Is defined in Part 4 of the EP&A Act <u>In fill development</u>: refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. New development: refers to development of a completely different nature to that associated with the former land use. Eg. The urban subdivision of an area previously used for rural purposes. New developments involve re-zoning and typically require major extensions of exiting urban services, such as roads, water supply, sewerage and electric power. Redevelopment: refers to rebuilding in an area. Eg. As urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either re-zoning or major extensions to urban services.
Effective Warning Time	The time available after receiving advise of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The

	effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
Flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
Flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
Flood liable land	Is synonymous with flood prone land (i.e.) land susceptibility to flooding by the PMF event. Note that the term flooding liable land covers the whole floodplain, not just that part below the FPL (see flood planning area)
Floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is flood prone land.
Floodplain risk management options	The measures that might be feasible for the management of particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
Floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually include both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defines objectives.
Flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
Flood planning levels (FPLs)	Are the combination of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "designated flood" or the “flood standard” used in earlier studies.
Flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings and structures subject to flooding, to reduce or eliminate flood damages.
Flood readiness	Readiness is an ability to react within the effective warning time.
Flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. Existing flood risk: the risk a community is exposed to as a result of its location on the floodplain.

	Future flood risk: the risk a community may be exposed to as a result of new development on the floodplain. Continuing flood risk: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
Flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas
Floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
Hazard	A source of potential harm or situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community.
Local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
m AHD	Metres Australian Height Datum (AHD)
m/s	Metres per second. Unit used to describe the velocity of floodwaters.
m^3/s	Cubic metres per second or "cumecs". A unit of measurement of creek or river flows or discharges. It is the rate of flow of water measured in terms of volume per unit time.
Mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
Modification measures	Measures that modify either the flood, the property or the response to flooding.
Overland flow path	The path that floodwaters can follow as they are conveyed towards the main flow channel or if they leave the confines of the main flow channel. Overland flow paths can occur through private property or along roads.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation couplet with the worst flood

	producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
Risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
RORB	RORB is a runoff routing program (Laurenson et al 2010) for estimation of catchment rainfall-runoff and flow hydrographs, and is one of the most widely used models of its type in Australia
Runoff	The amount of rainfall which actually ends up as a streamflow, also known as rainfall excess.
SRTM	Shuttle Radar Topography Mission is an international research effort that obtained terrain data on a near-global scale from 56°S to 60°N to generate a high-resolution digital topographic database of Earth.
Stage	Equivalent to water level (both measured with reference to a specified datum)
TUFLOW	TUFLOW is a computer program which is used to simulate free-surface flow for flood and tidal wave propagation. It provides coupled 1D and 2D hydraulic solutions using a powerful and robust computation. The engine has seamless interfacing with GIS and is widely used across Australia.

Appendix A. Catchment Hydrology

Figure A-1 Cumulative Rainfall for the Storm event of February 1976

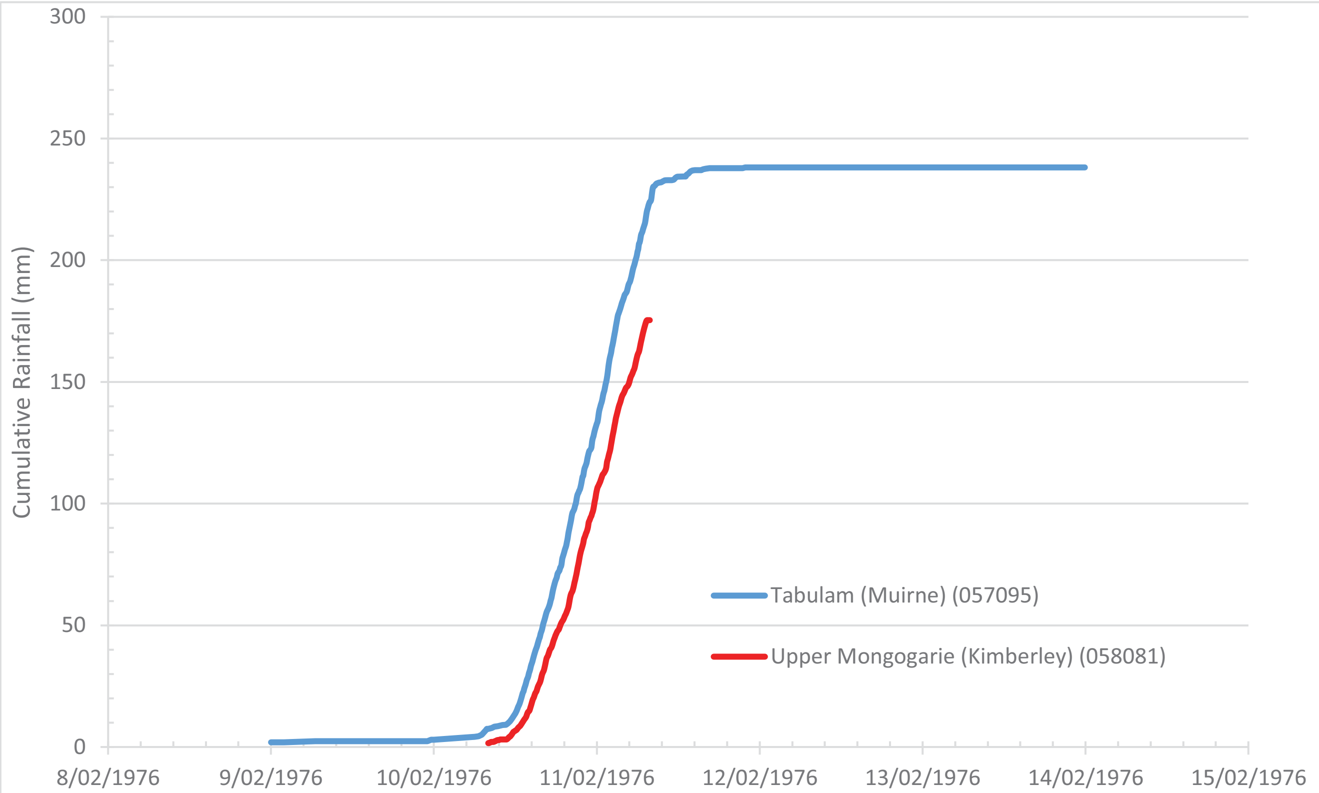


Figure A-2 Cumulative Rainfall for the Storm event of January 2011

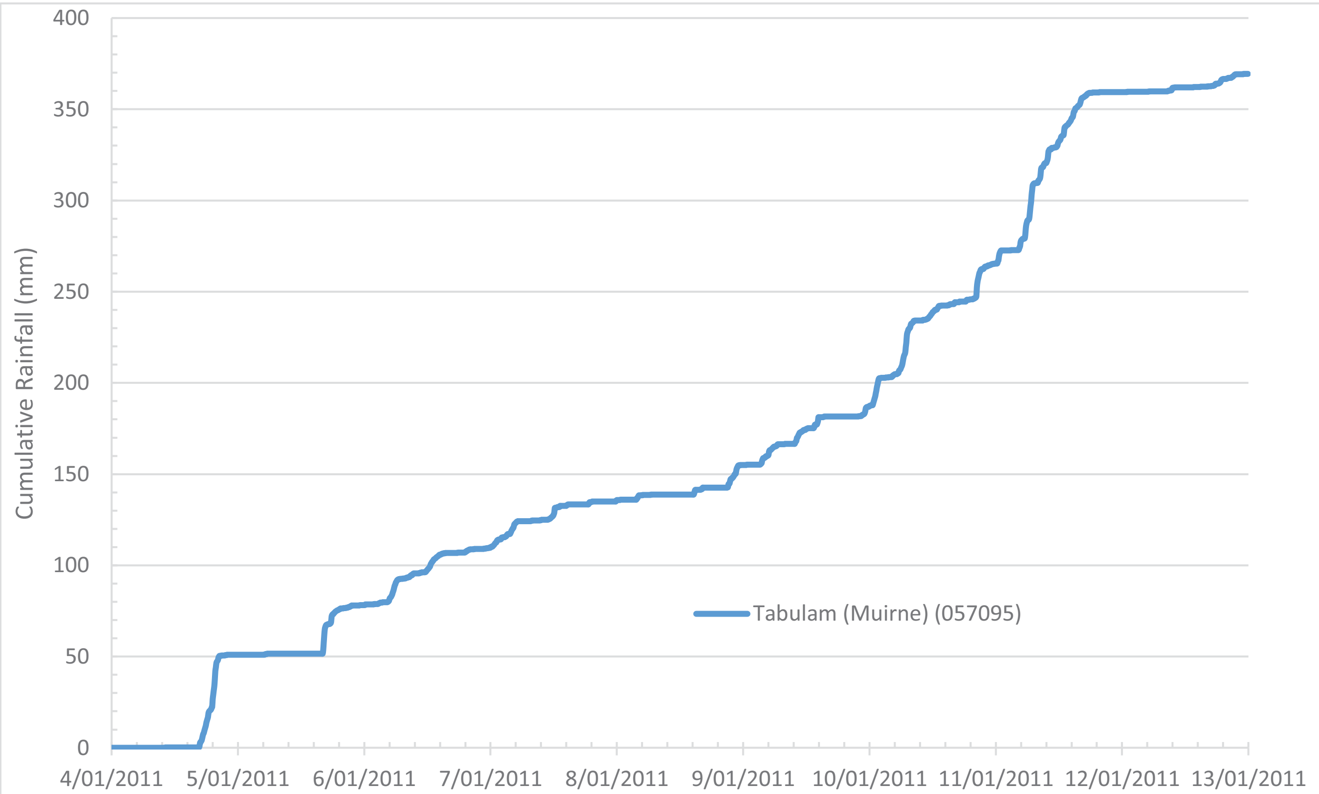


Figure A-3 Adopted Flood Frequency – Clarence River @ Tabulam. Log Pearson III Distribution

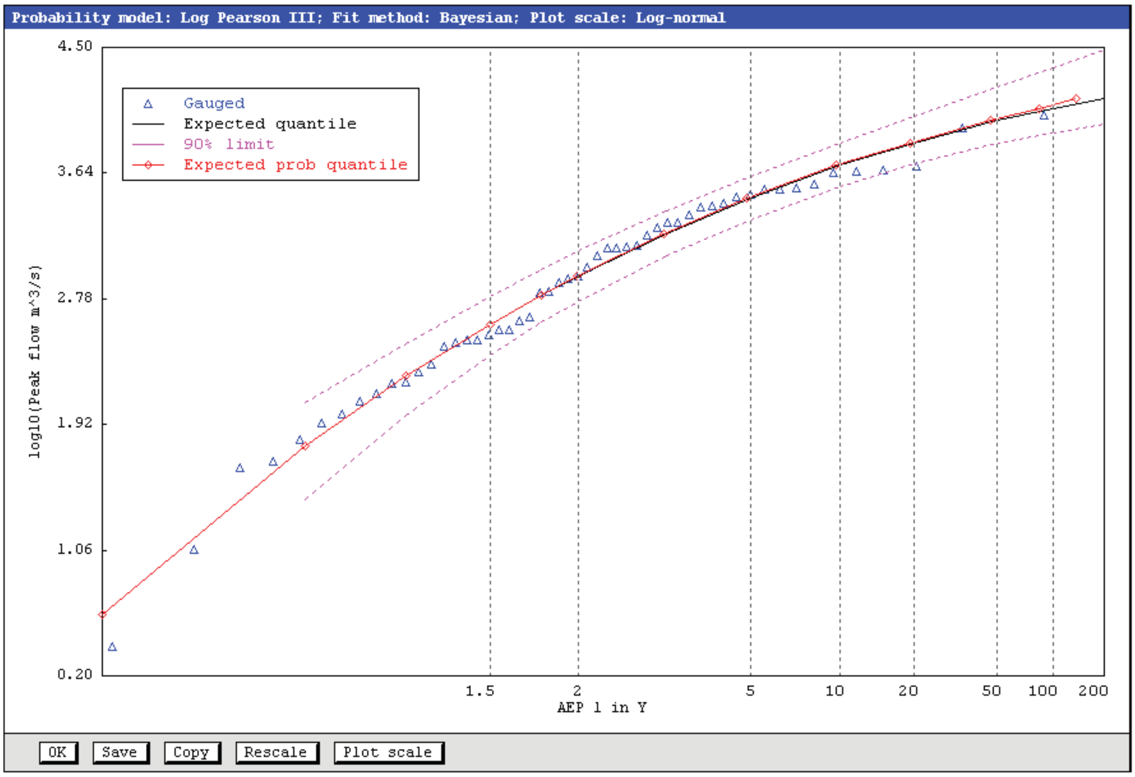


Figure A-4 Adopted Flood Frequency – Timbarra River @ Drake. Log Pearson III Distribution

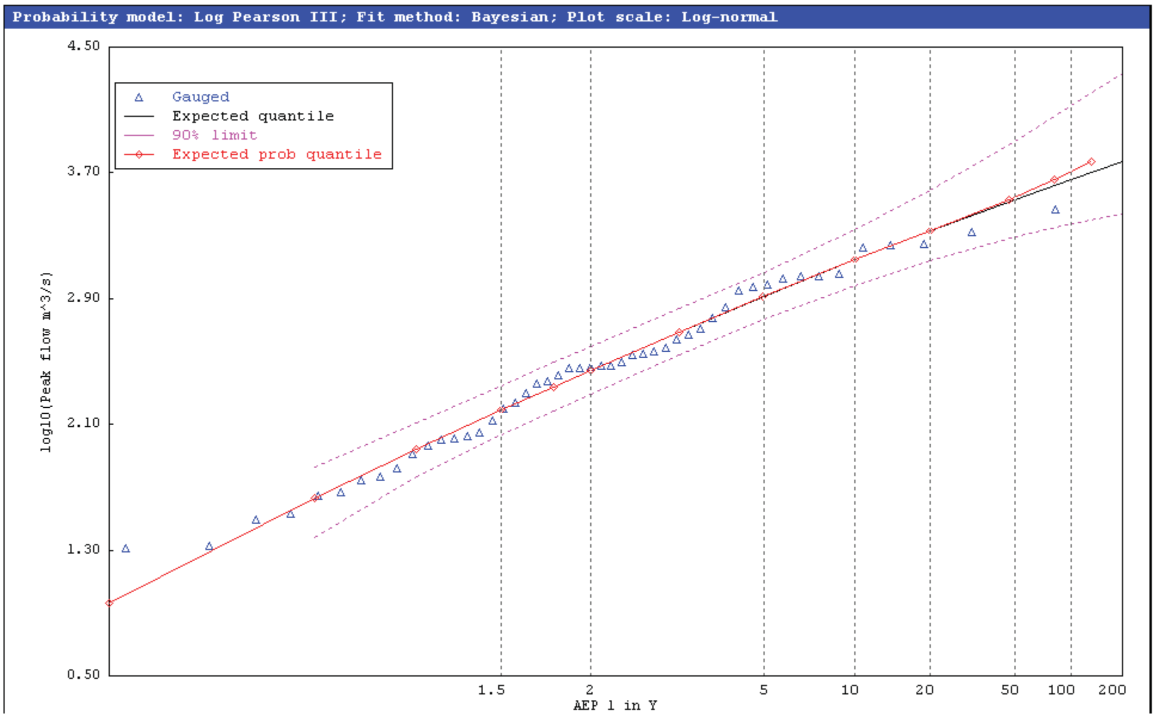


Figure A-5 Sensitivity Flood Frequency – Clarence River @ Tabulam. General Extreme Value Distribution

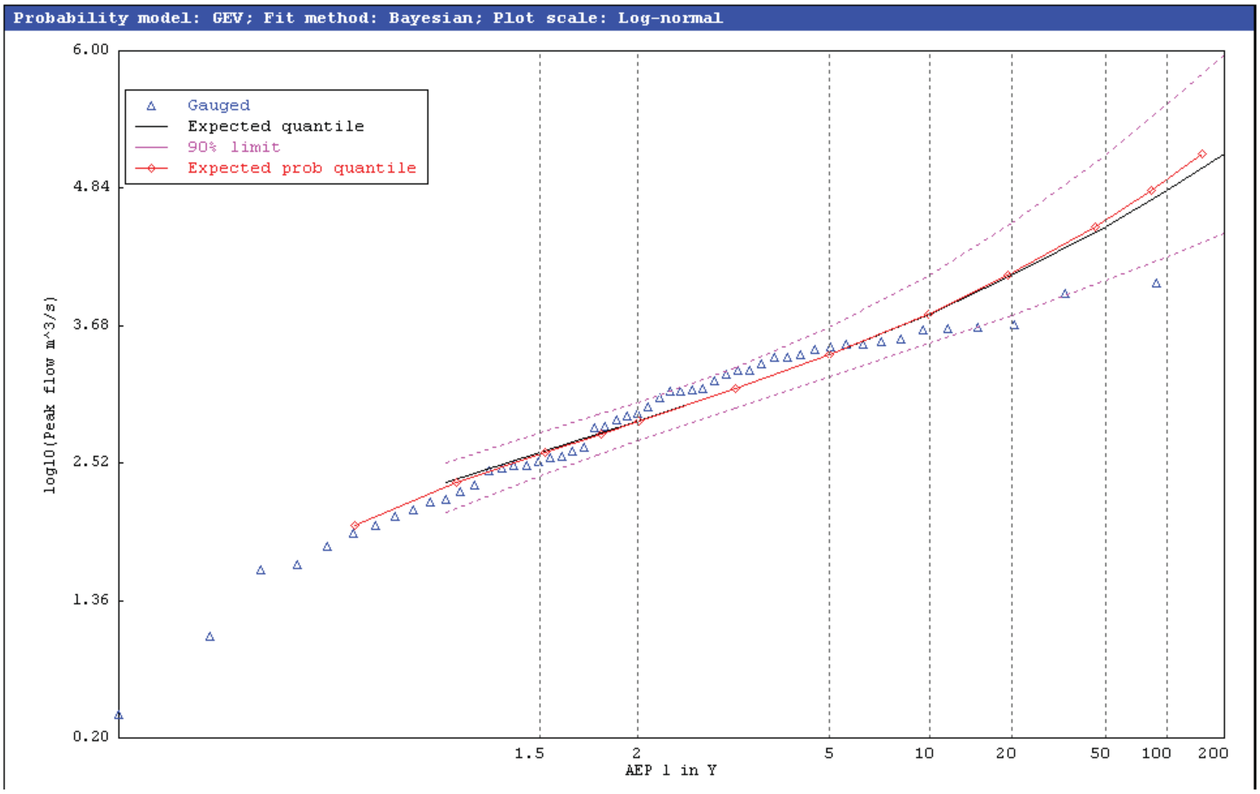


Figure A-6 Sensitivity Flood Frequency – Timbarra River @ Drake. General Extreme Value Distribution

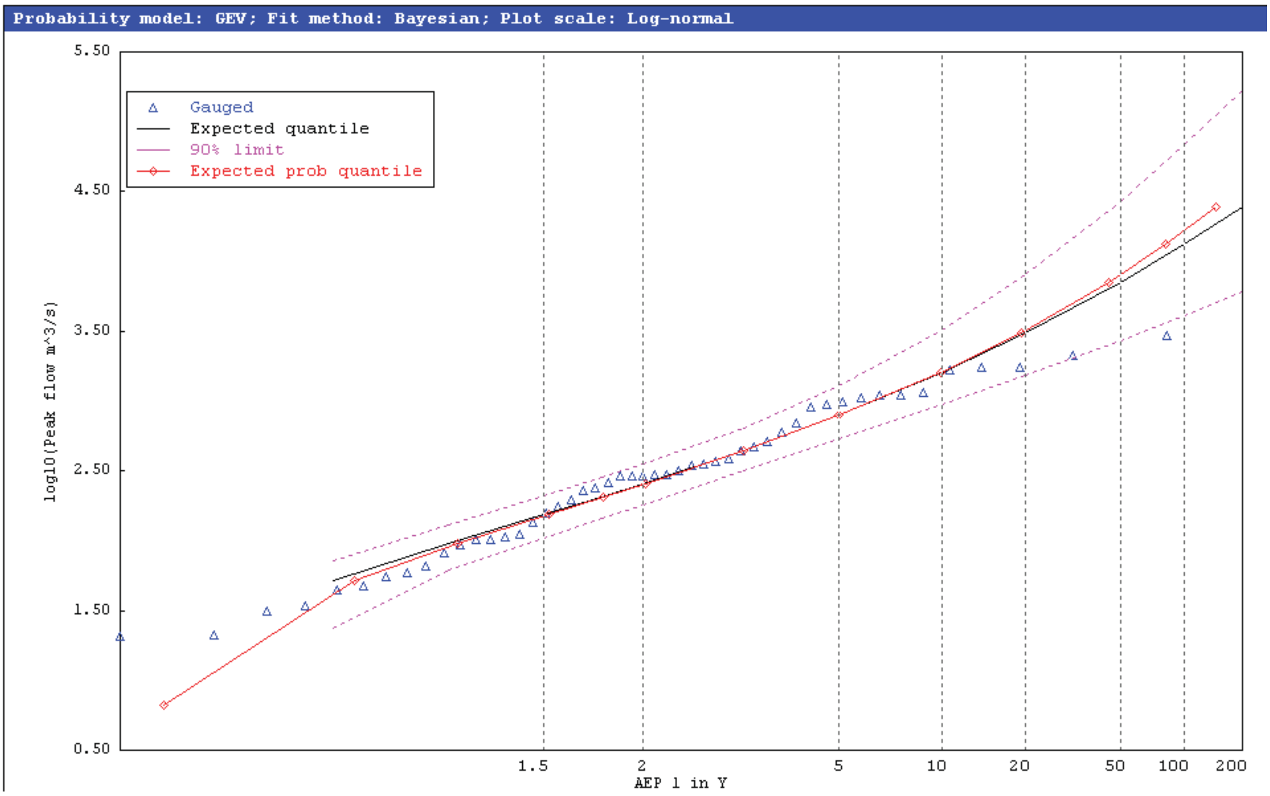


Figure A-7 Sensitivity Flood Frequency – Clarence River @ Tabulam. Log Pearson III Distribution with Multiple Grubbs Beck Test

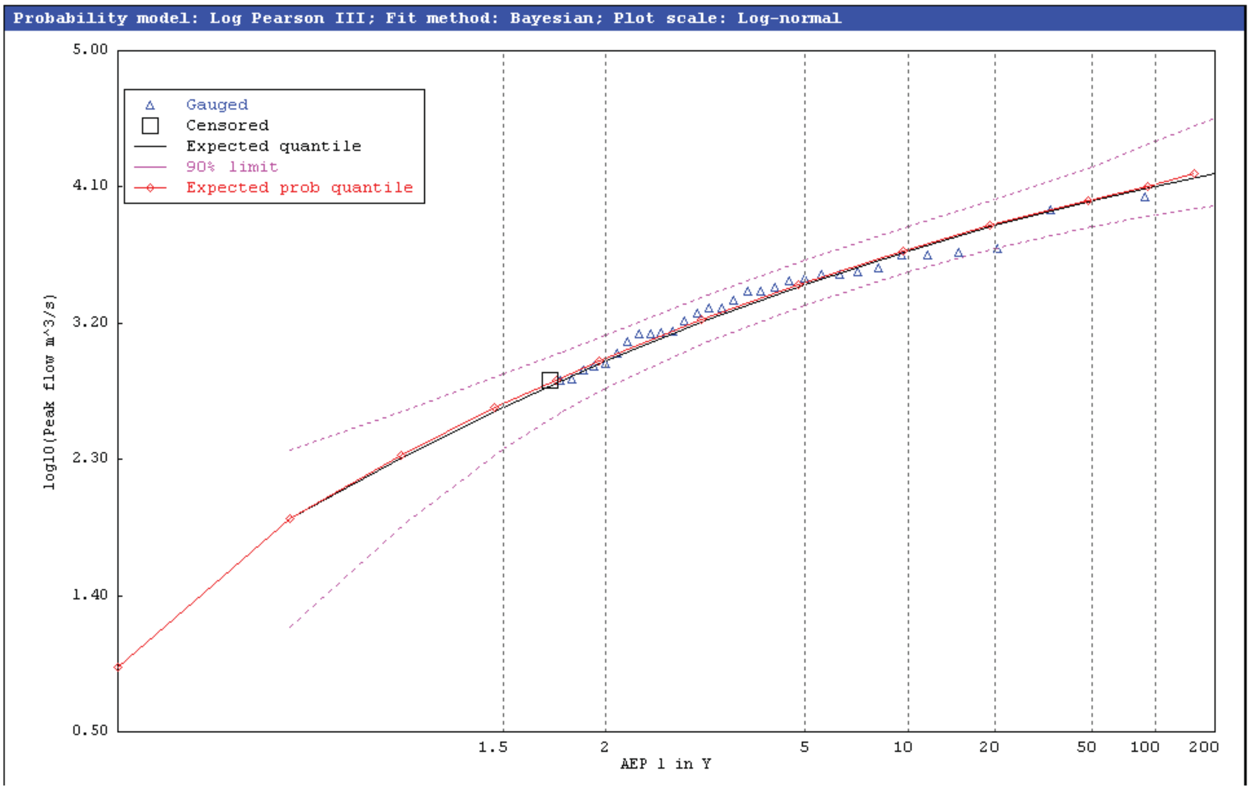


Figure A-8 Sensitivity Flood Frequency – Timbarra River @ Drake. Log Pearson III Distribution with Multiple Grubbs Beck Test

** No change from LPIII analysis. No outliers identified and censored. Refer to Figure A-4.

Figure A-9 Sensitivity Flood Frequency – Clarence River @ Tabulam. General Extreme Value Distribution with Multiple Grubbs Beck Test

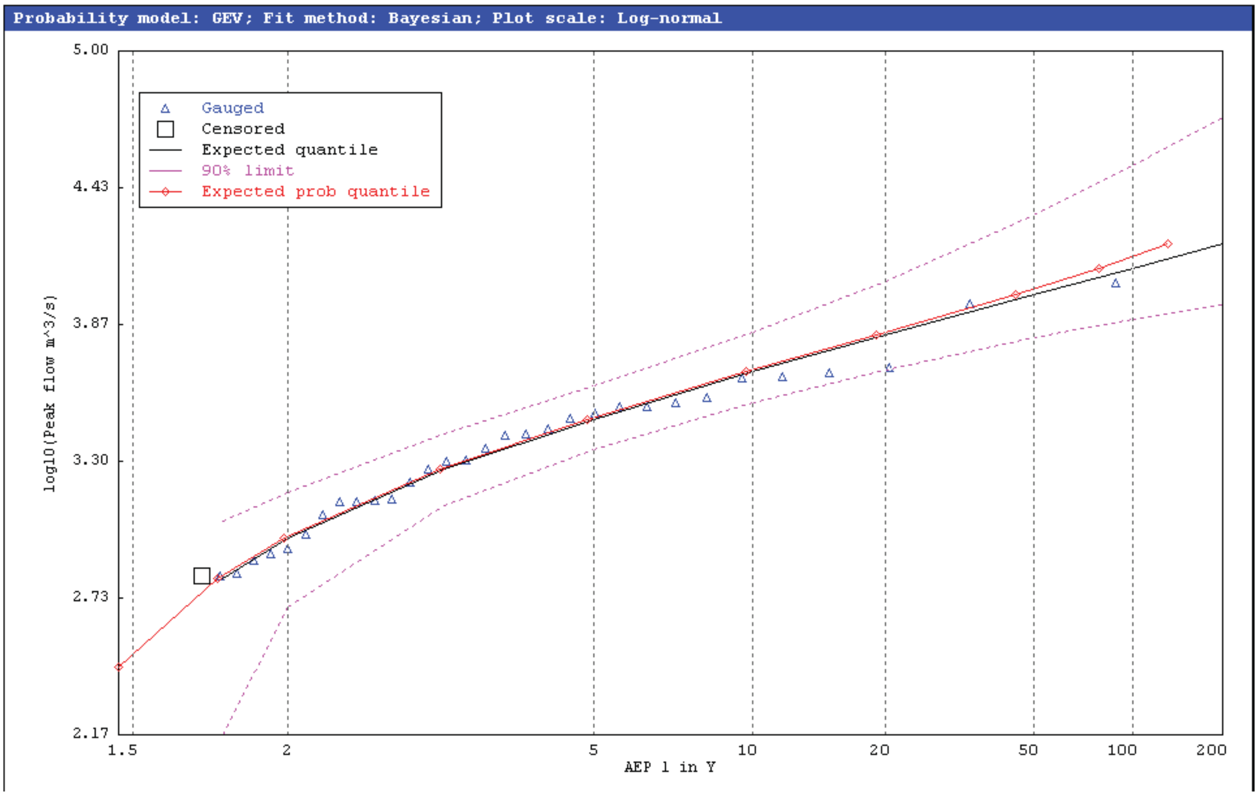
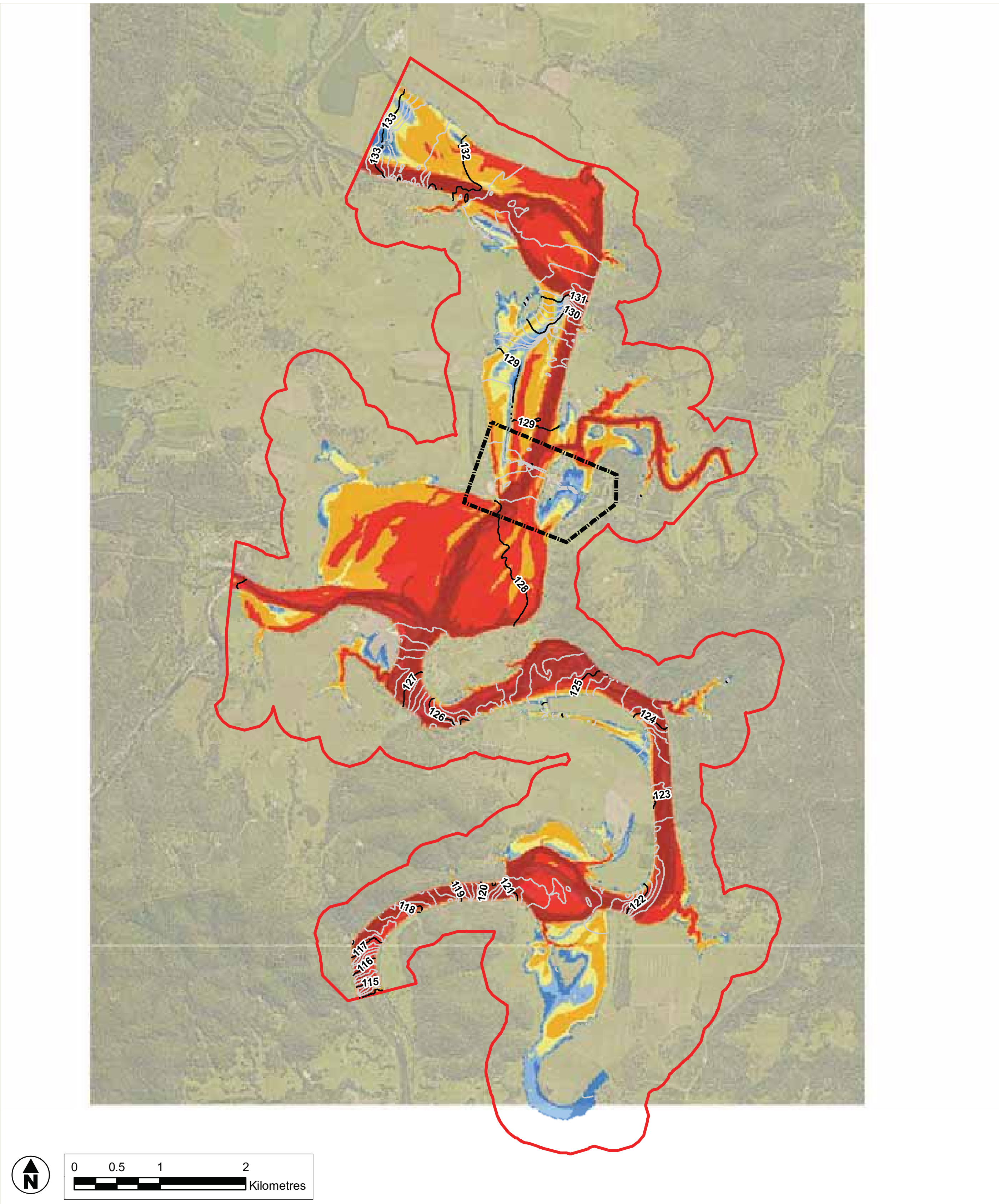


Figure A-10 Sensitivity Flood Frequency – Timbarra River @ Drake. General Extreme Value Distribution with Multiple Grubbs Beck Test

** No change from LPIII analysis. No outliers identified and censored. Refer to Figure A-4.

Appendix B. Calibration Event Flood Mapping



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Limit of Mapping
- Study Area

JACOBS

LIMITATIONS: This mapping is based on data and assumptions identified in the Tabulam Floodplain Risk Management Study and Plan prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

A3

SHEET 1 of 1

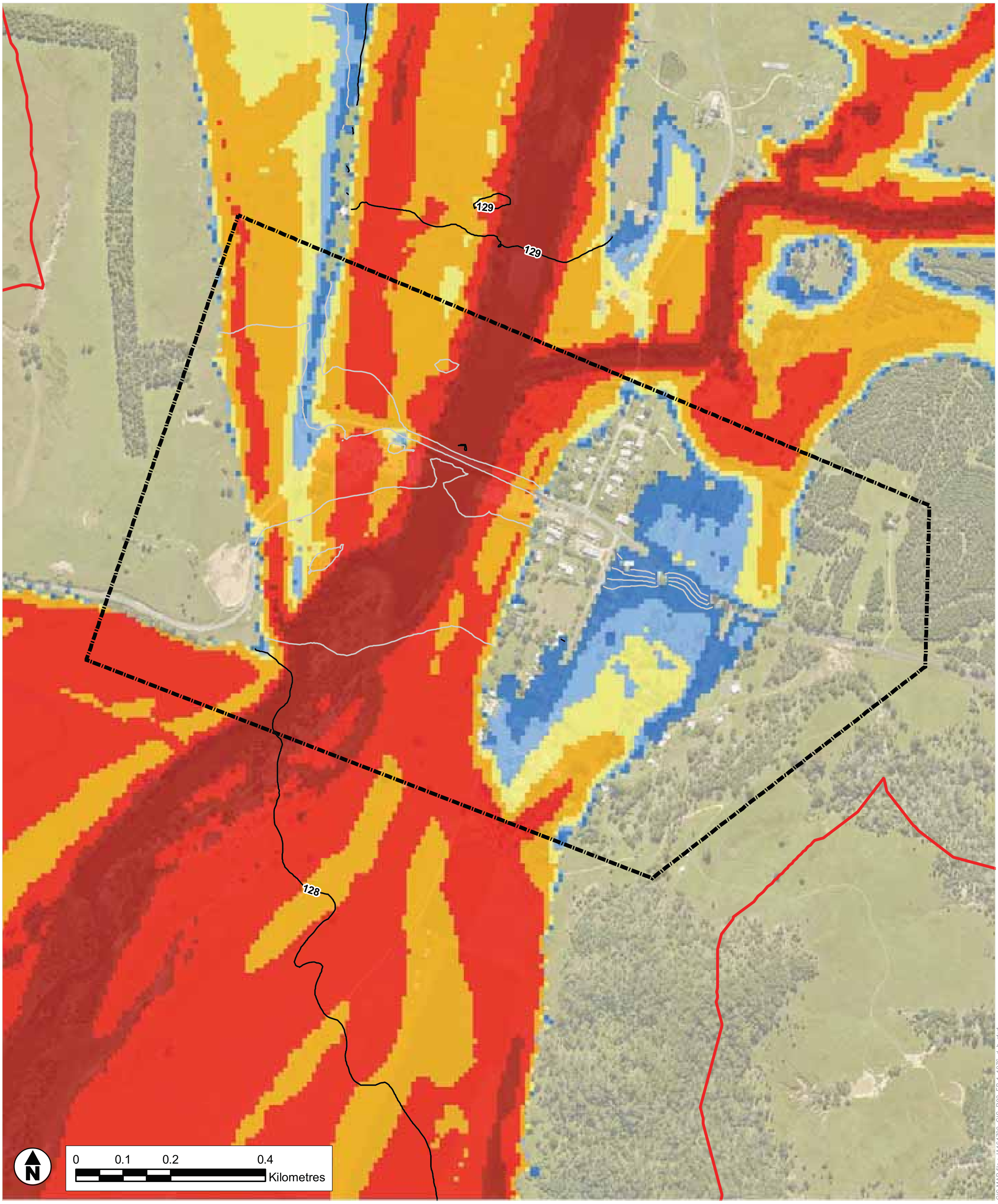
GDA 1994 MGA Zone 56

TITLE Peak Flood Depth and Level February 1976 Calibration

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE B-1	1	1
CHECK	DATE			
AH	1/11/2018			

GIS MAP file : IA164700_GIS_R02_FB-1_1976_d_h_r1v1



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Limit of Mapping
- Study Area

JACOBS

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A3

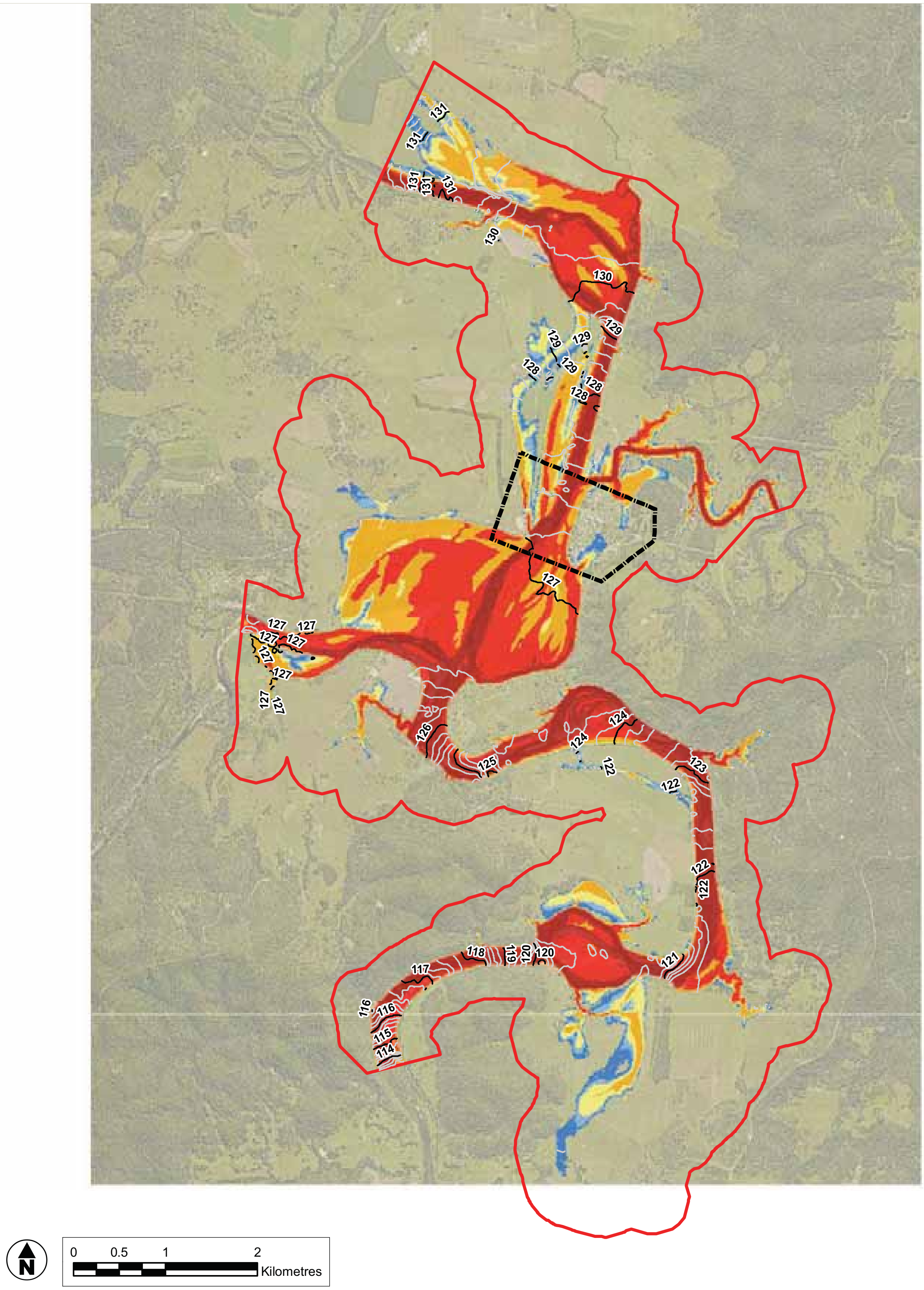
SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Flood Depth and Level
February 1976 Calibration
Tabulam Village Focus

PROJECT Tabulam Floodplain Risk
Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE B-1A	1	1
CHECK	DATE			
AH	1/11/2018			



GIS MAP file : IA164700_GIS_R02_FB-2_2011_d_h_r1v1

Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Limit of Mapping
- Study Area

JACOBS

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A3

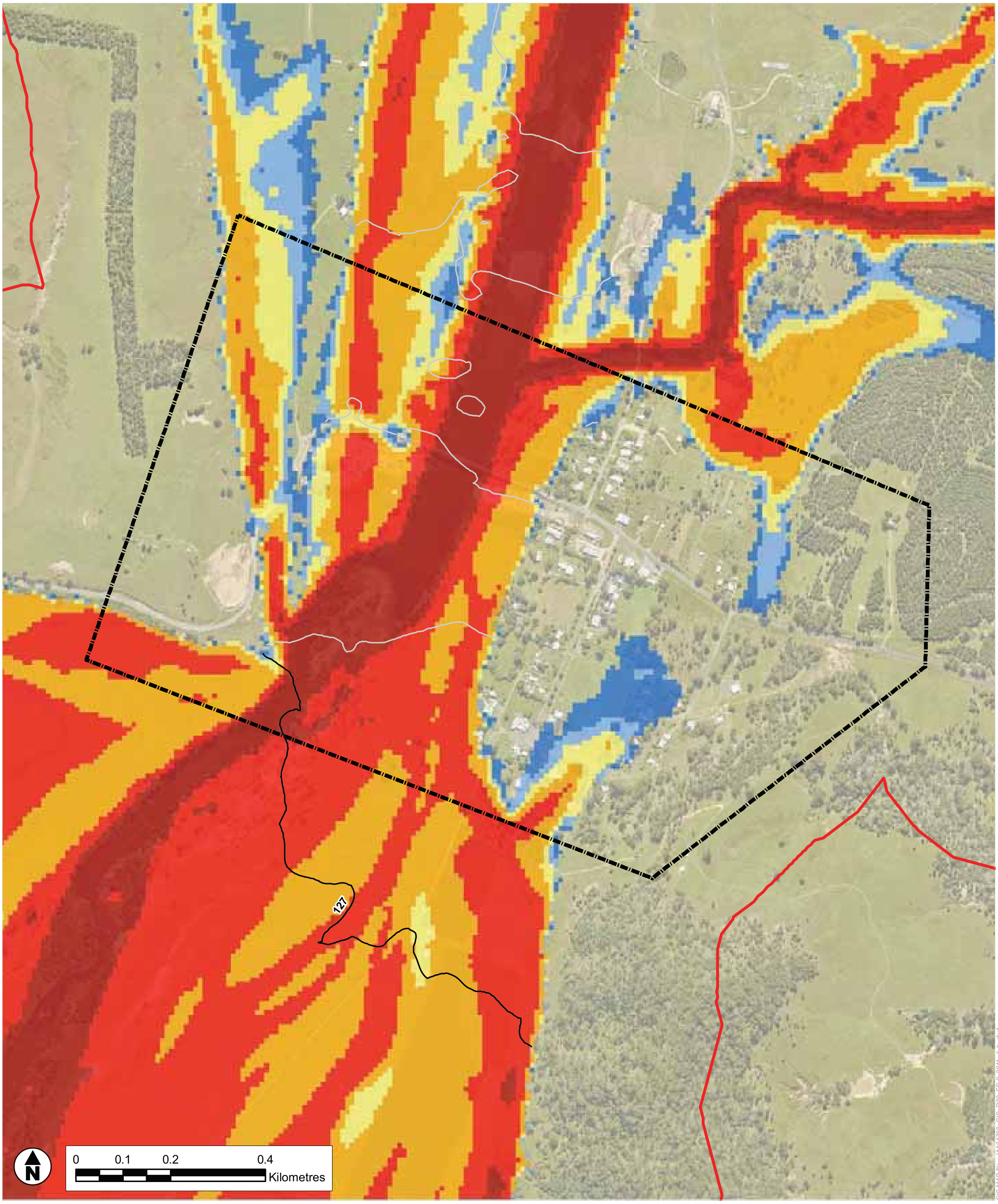
SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Flood Depth and Level January 2011 Verification

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE B-2	1	1
CHECK	DATE			
AH	18/01/2019			



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Limit of Mapping
- Study Area

JACOBS

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A3

SHEET 1 of 1

GDA 1994 MGA Zone 56

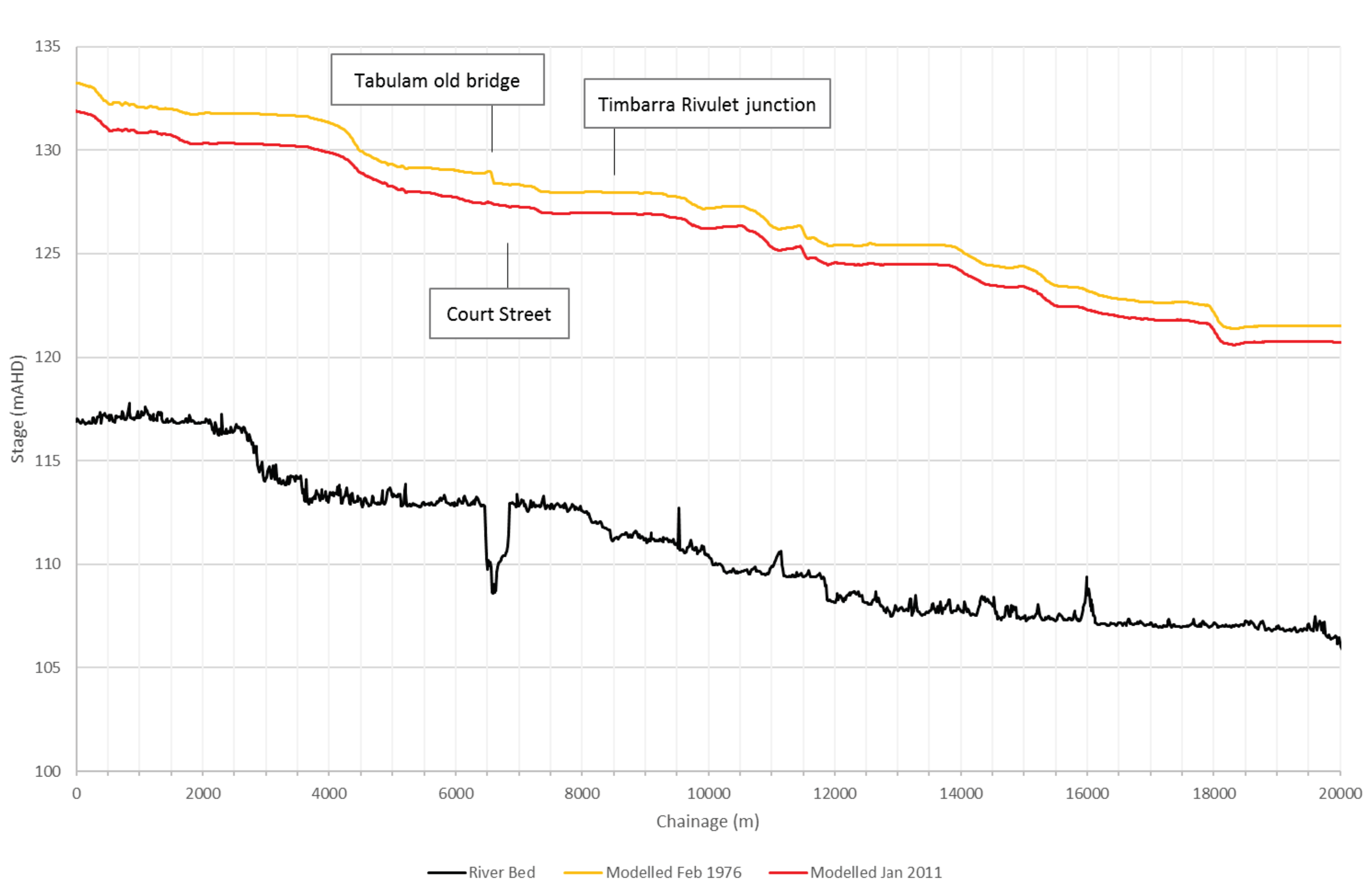
TITLE Peak Flood Depth and Level January 2011 Verification Tabulam Village Focus

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE B-2A	1	1
CHECK	DATE			
AH	18/01/2019			

GIS MAP file : IA164700_GIS_R02_FB-2_2011_d_h_r1v1

Figure B-3 Flood level Profile Plot – February 1976 and January 2011 Event



Appendix C. Design Flood Data

Table C-1 Tabulam Rivulet Catchment IFD Data

Latitude 28.8875° S

Longitude 152.6875° E

Duration	Annual Exceedance Probability									
	1 in x AEP	1 in 5	1 in 10	1 in 20	1 in 50	1 in 100	1 in 200	1 in 500	1 in 1000	1 in 2000
	% AEP	20%	10%	5%	2%	1%	0.5%	0.2%	0.1%	0.05%
1 hour		43.9	51.4	58.7	68.4	75.9	83.9	95.7	105	114
1.5 hour		49.6	58	66.3	77.4	86	95.1	108	119	129
2 hour		54	63.3	72.4	84.8	94.3	104	119	130	142
3 hour		61.2	72	82.7	97.3	109	120	137	150	164
4.5 hour		70.1	83	95.9	114	127	141	161	176	192
6 hour		77.8	92.6	108	128	144	159	182	200	218
9 hour		91.2	109	128	153	174	191	219	241	263
12 hour		103	124	146	175	199	219	251	276	301
18 hour		122	149	176	212	241	266	304	333	364
24 hour		139	169	200	241	274	303	345	379	413
30 hour		152	186	221	266	301	333	379	415	452
36 hour		164	200	238	286	323	358	407	445	483
48 hour		184	223	265	317	357	395	448	488	529
72 hour		210	254	300	356	398	440	497	540	583
96 hour		226	272	319	377	420	465	523	567	612
120 hour		235	283	330	388	432	479	537	582	626
144 hour		241	288	335	395	440	485	544	589	633
168 hour		244	291	337	399	445	488	546	591	635

Figure C-1 Design inflow hydrographs into TUFLOW – 20% AEP event

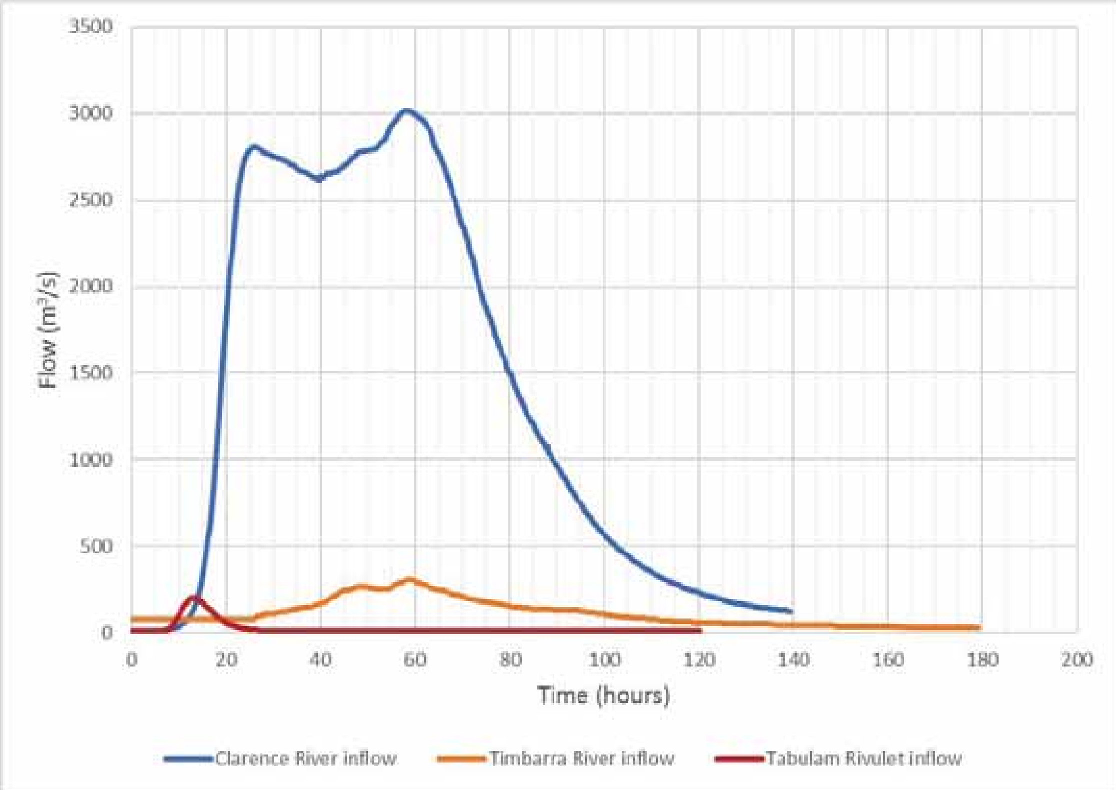


Figure C-2 Design inflow hydrographs into TUFLOW – 10% AEP event

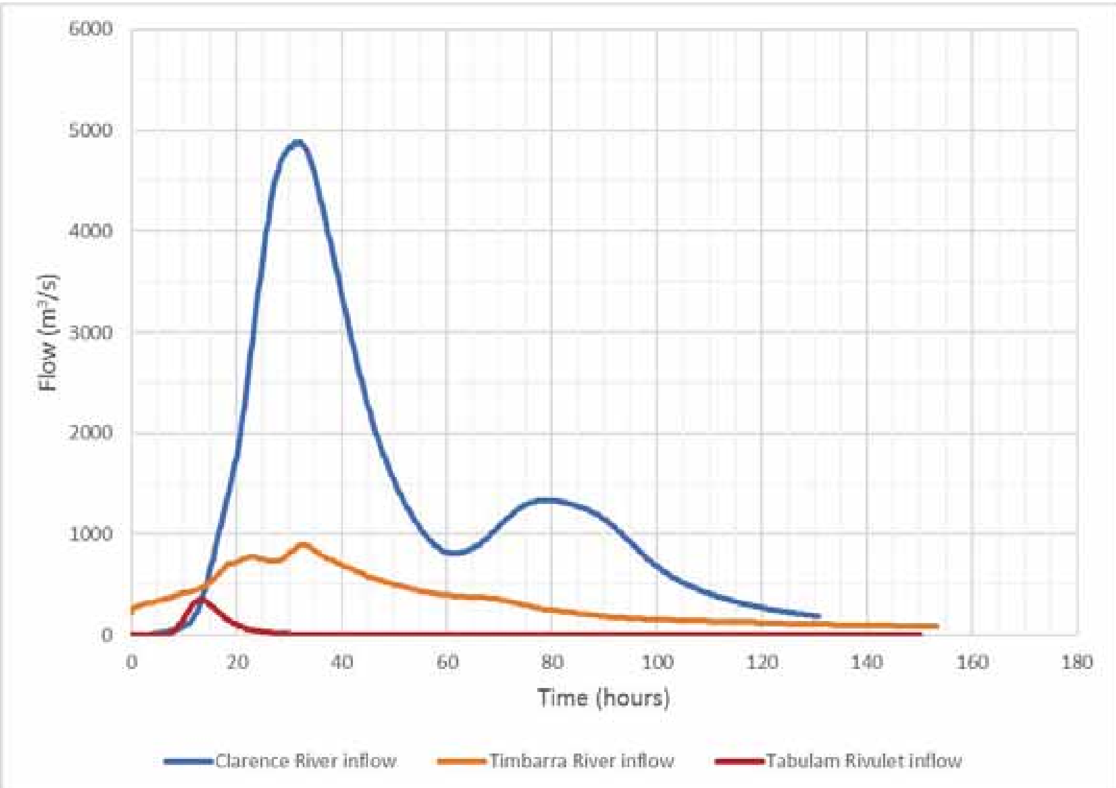


Figure C-3 Design inflow hydrographs into TUFLOW – 5% AEP event

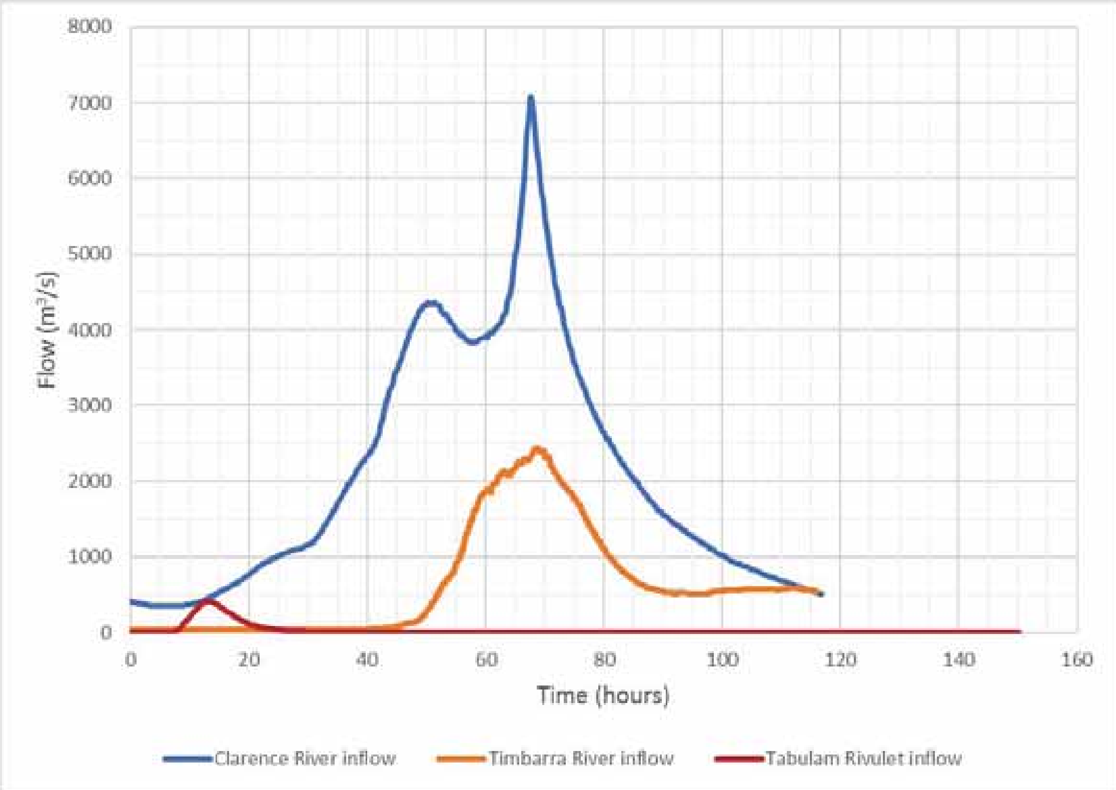


Figure C-4 Design inflow hydrographs into TUFLOW –2% AEP event

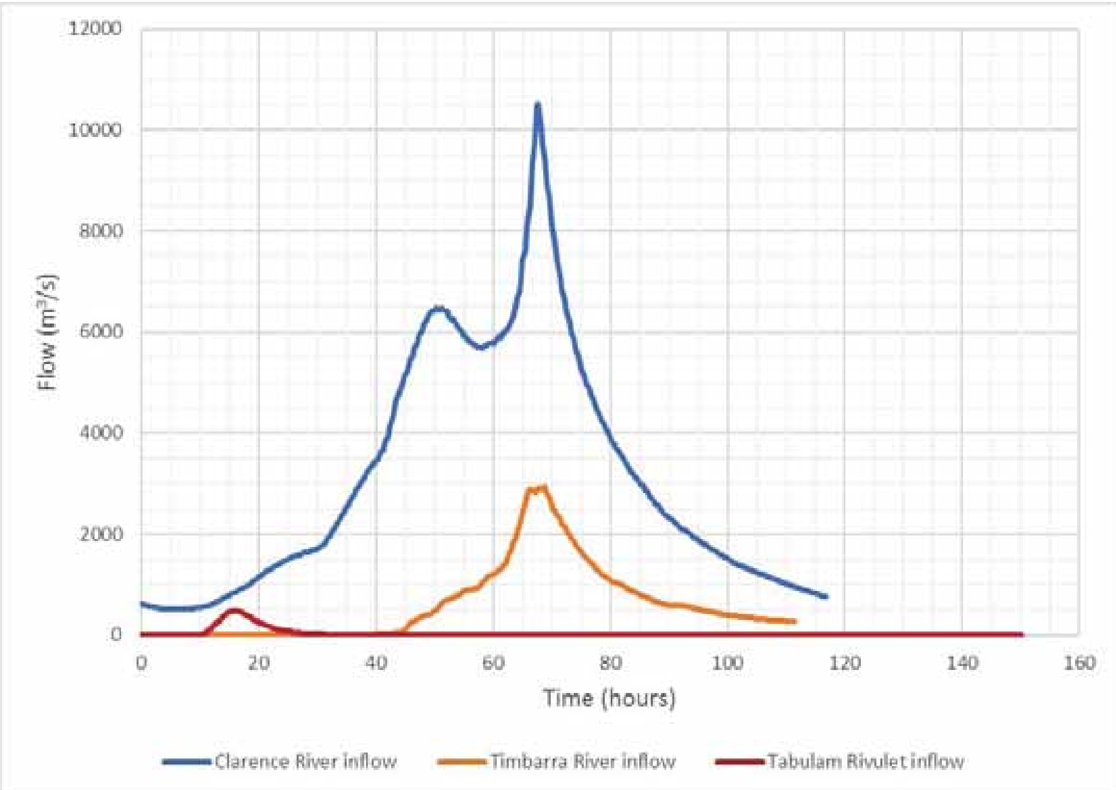


Figure C-5 Design inflow hydrographs into TUFLOW – 1% AEP event

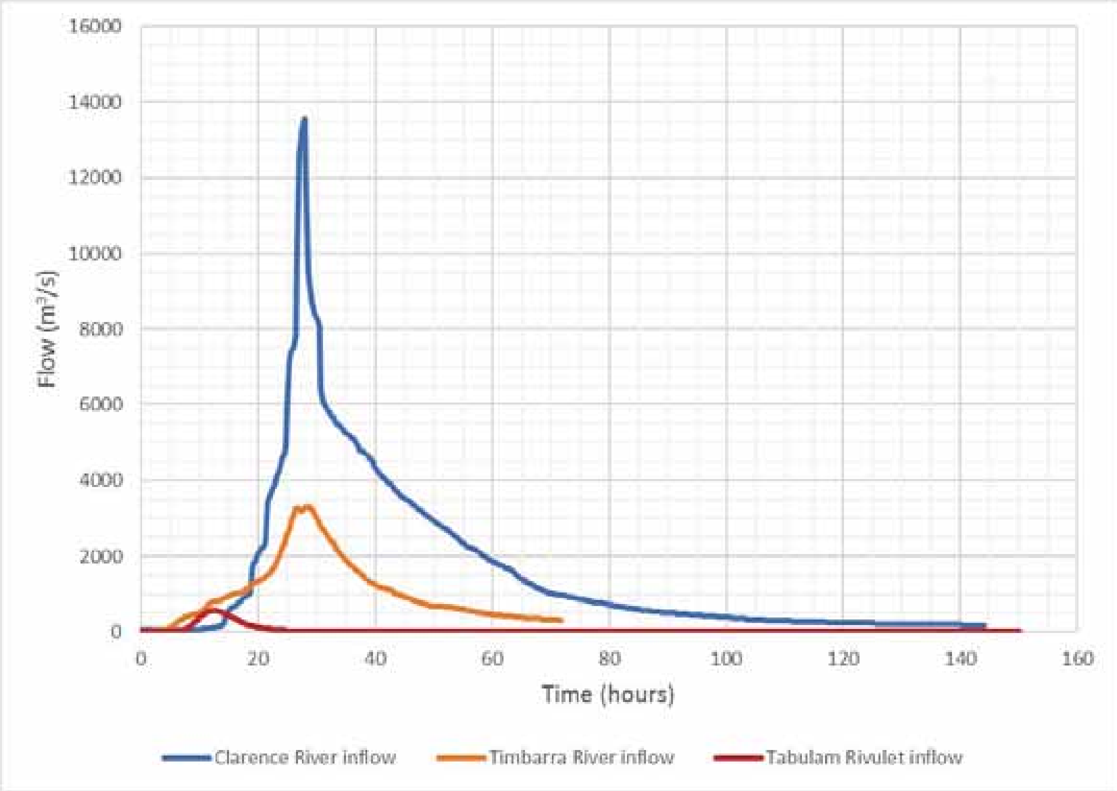


Figure C-6 Design inflow hydrographs into TUFLOW – 0.5% AEP event

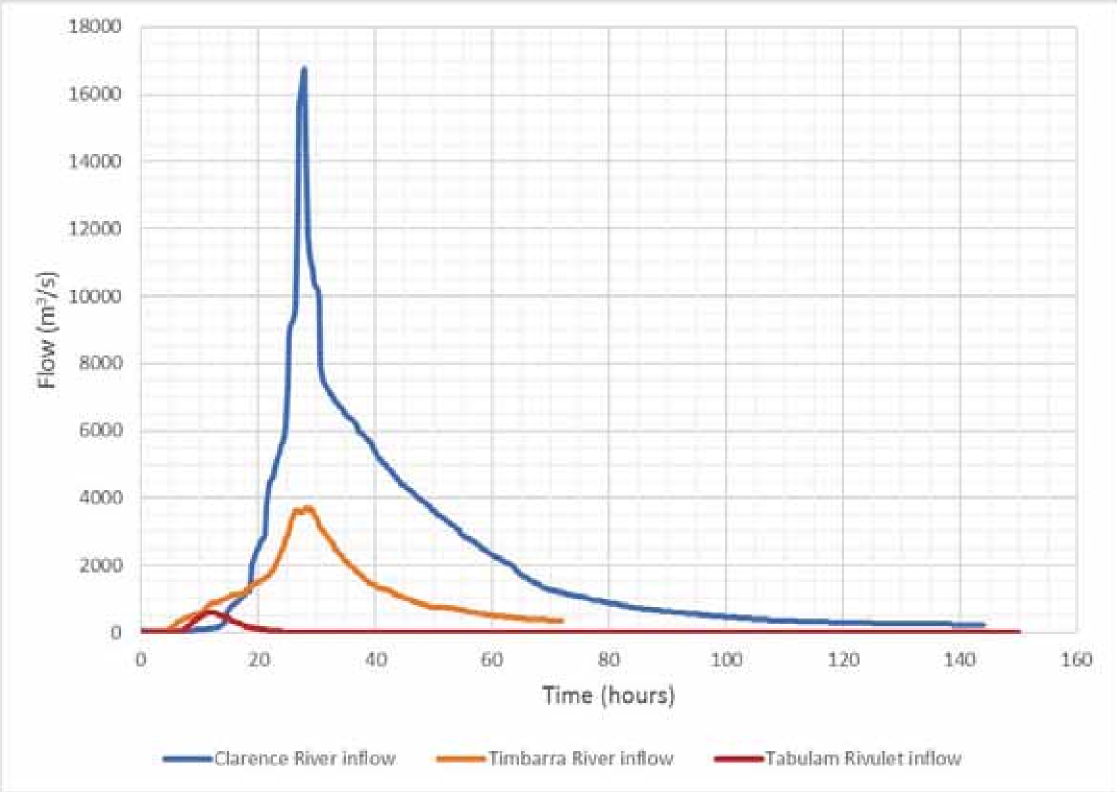


Figure C-7 Design inflow hydrographs into TUFLOW – 0.2% AEP event

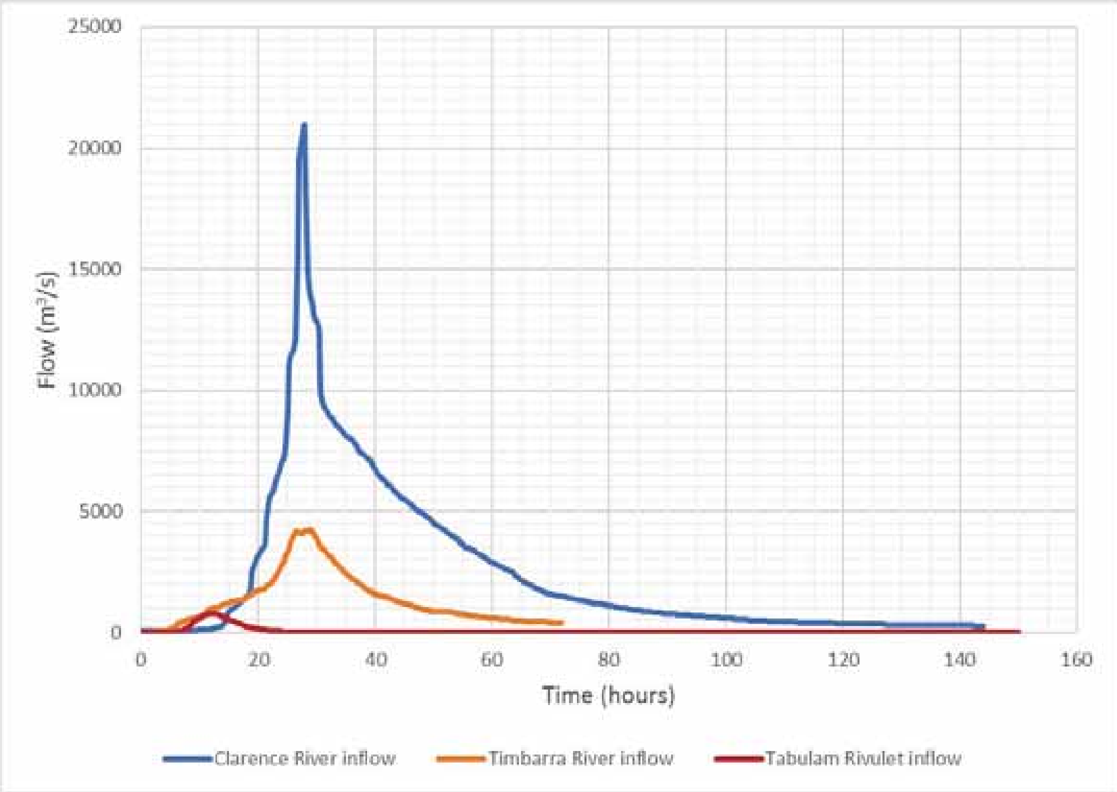


Figure C-8 Design inflow hydrographs into TUFLOW – Clarence River Extreme Event

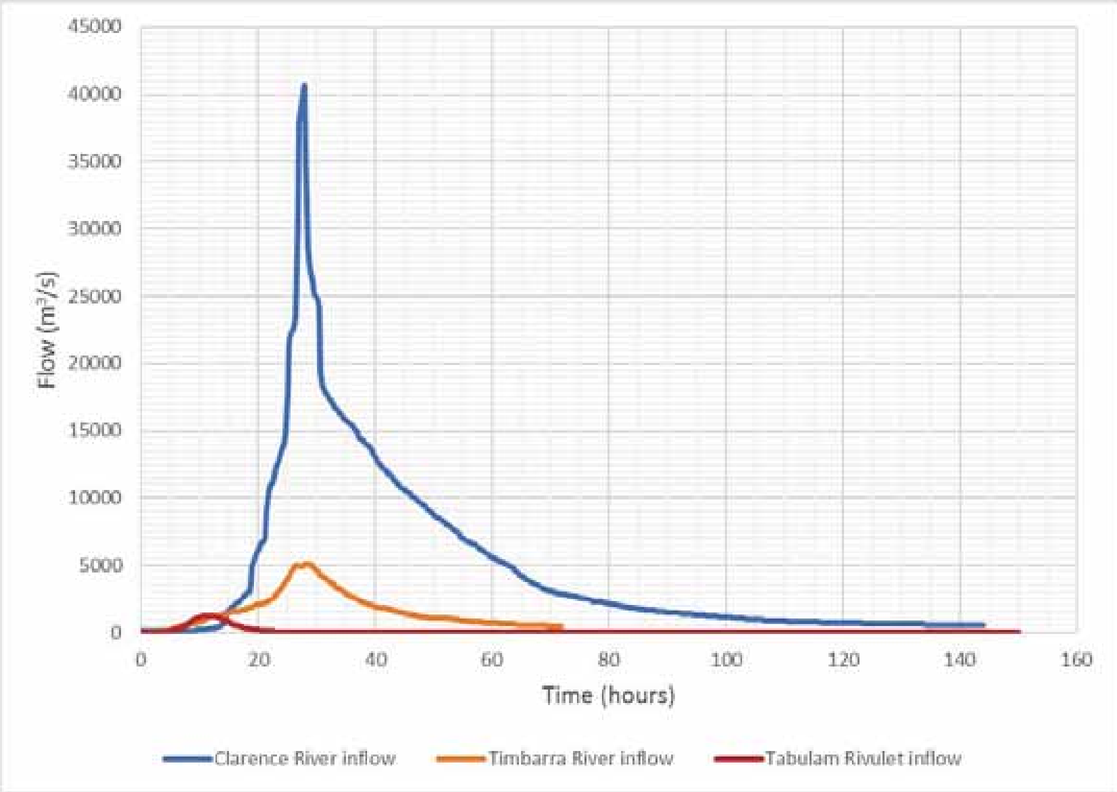
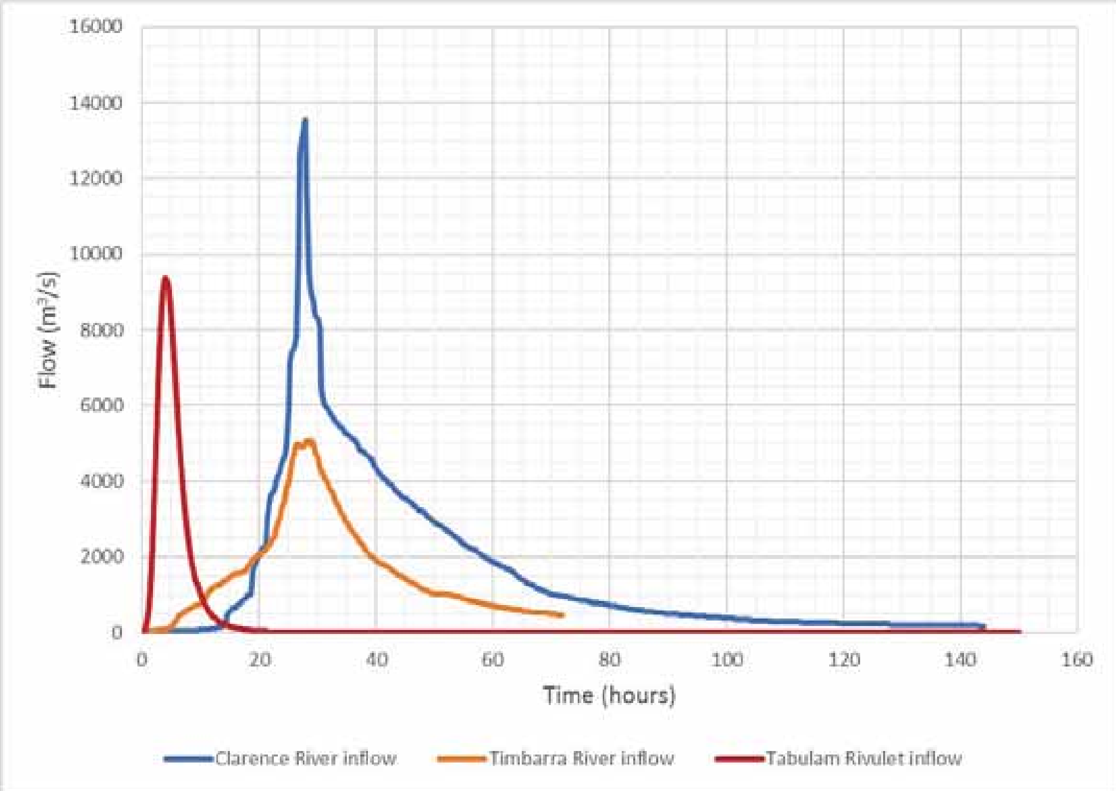
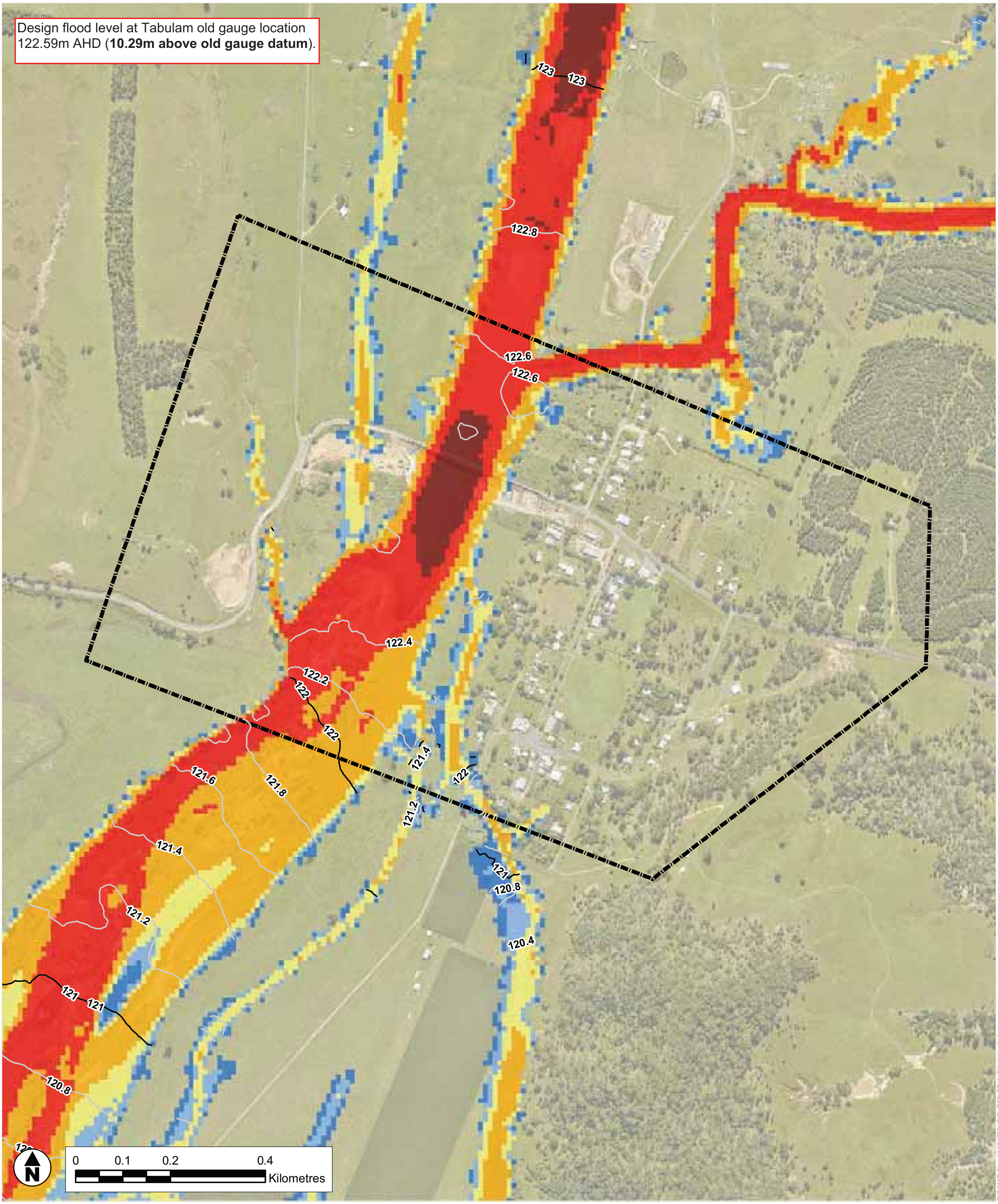


Figure C-9 Design inflow hydrographs into TUFLOW – Tabulam Rivulet Extreme Event



Appendix D. Design Flood Mapping and Results



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 30

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Study Area

JACOBS

LIMITATIONS: This mapping is based on data and assumptions identified in the Tabulam Floodplain Risk Management Study and Plan prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

A3

SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Flood Depth and Level
20% AEP

PROJECT Tabulam Floodplain Risk Management Study and Plan

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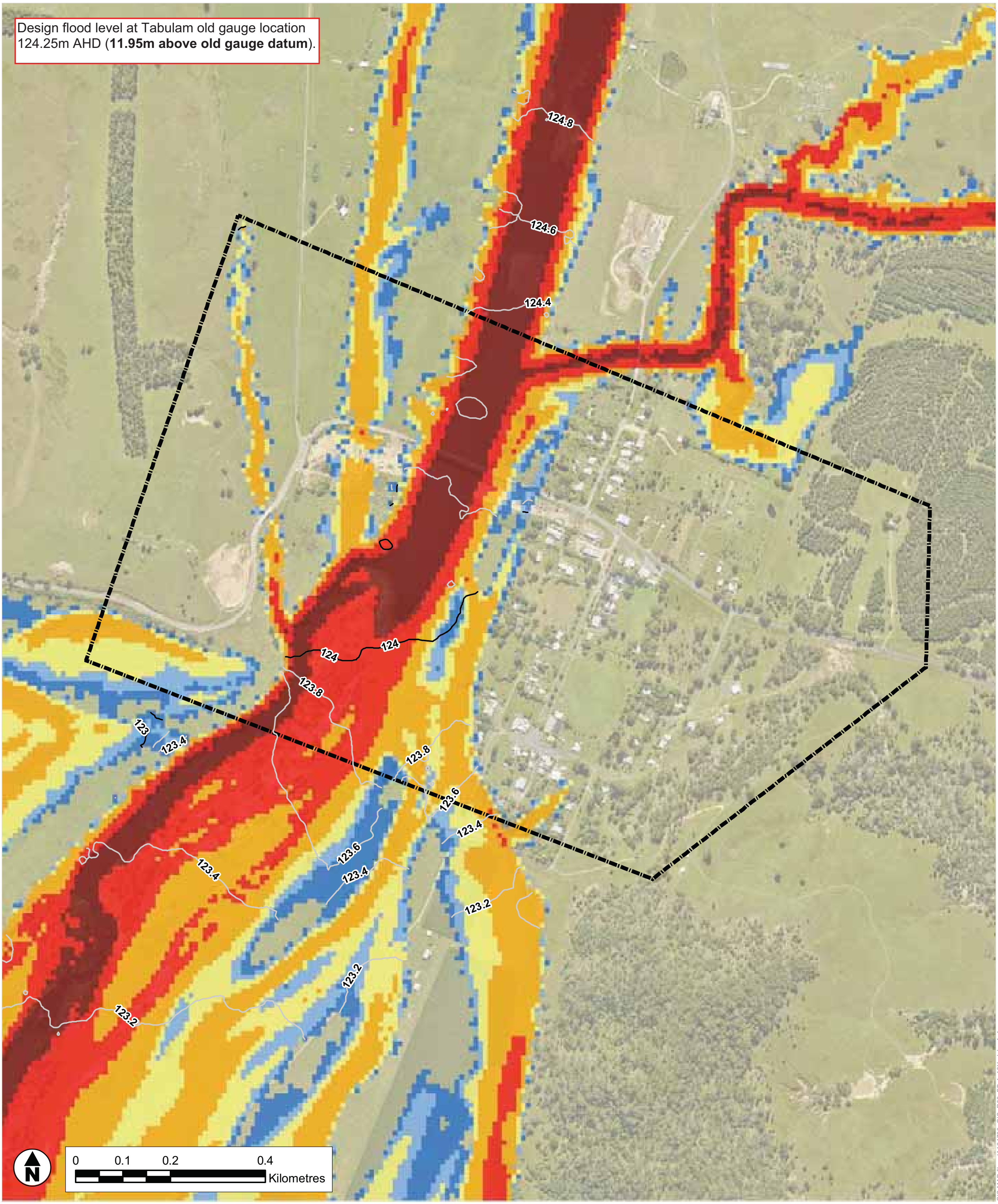
CHECK	DATE			
AH	15/01/2019			



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 30

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Study Area

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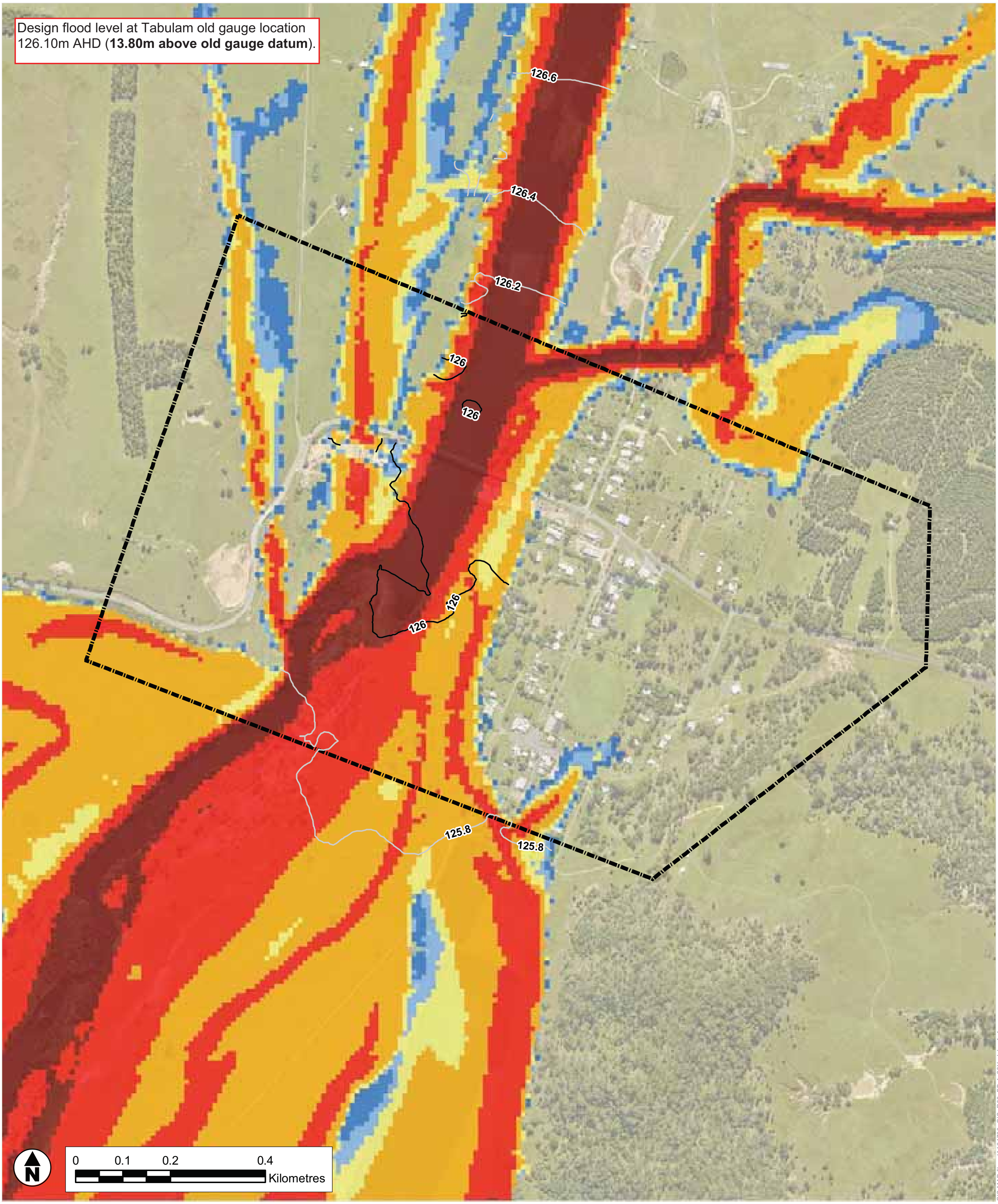
A3

SHEET	1 of 1 — GDA 1994 MGA Zone 56
TITLE	Peak Flood Depth and Level 10% AEP
PROJECT	Tabulam Floodplain Risk Management Study and Plan
DRAWN LC	PROJECT # IA164700
CHECK AH	DATE 15/01/2019
MAP #	FIGURE D-2
REV	1
VER	1



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 30

Flood Level (m AHD) 1m contour

Flood Level (m AHD) 0.2m contour

Study Area

JACOBS

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A3

SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Flood Depth and Level 5% AEP

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE D-3	1	1
CHECK	DATE			
AH	15/01/2019			

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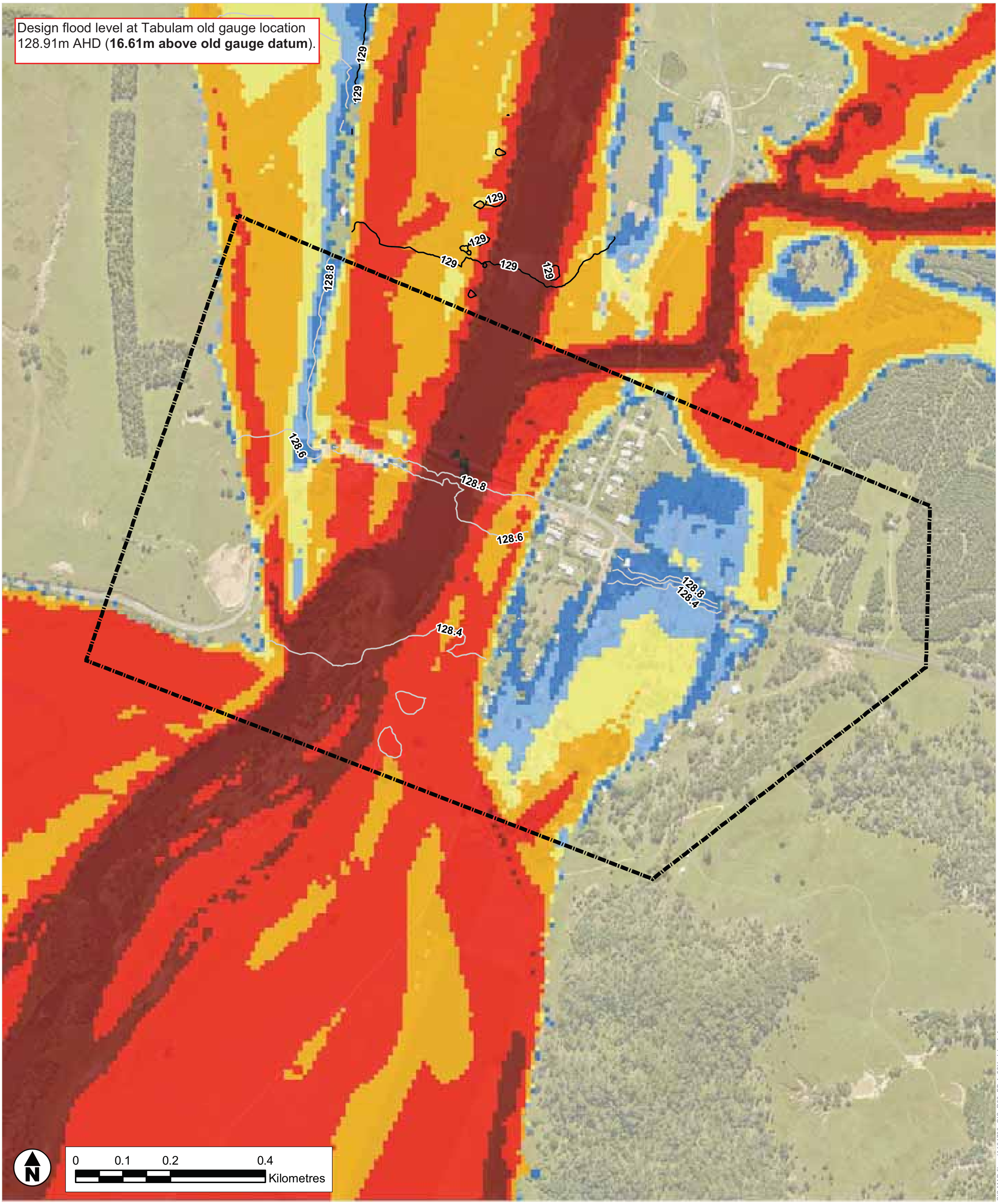

Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 30

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Study Area

JACOBS

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A3

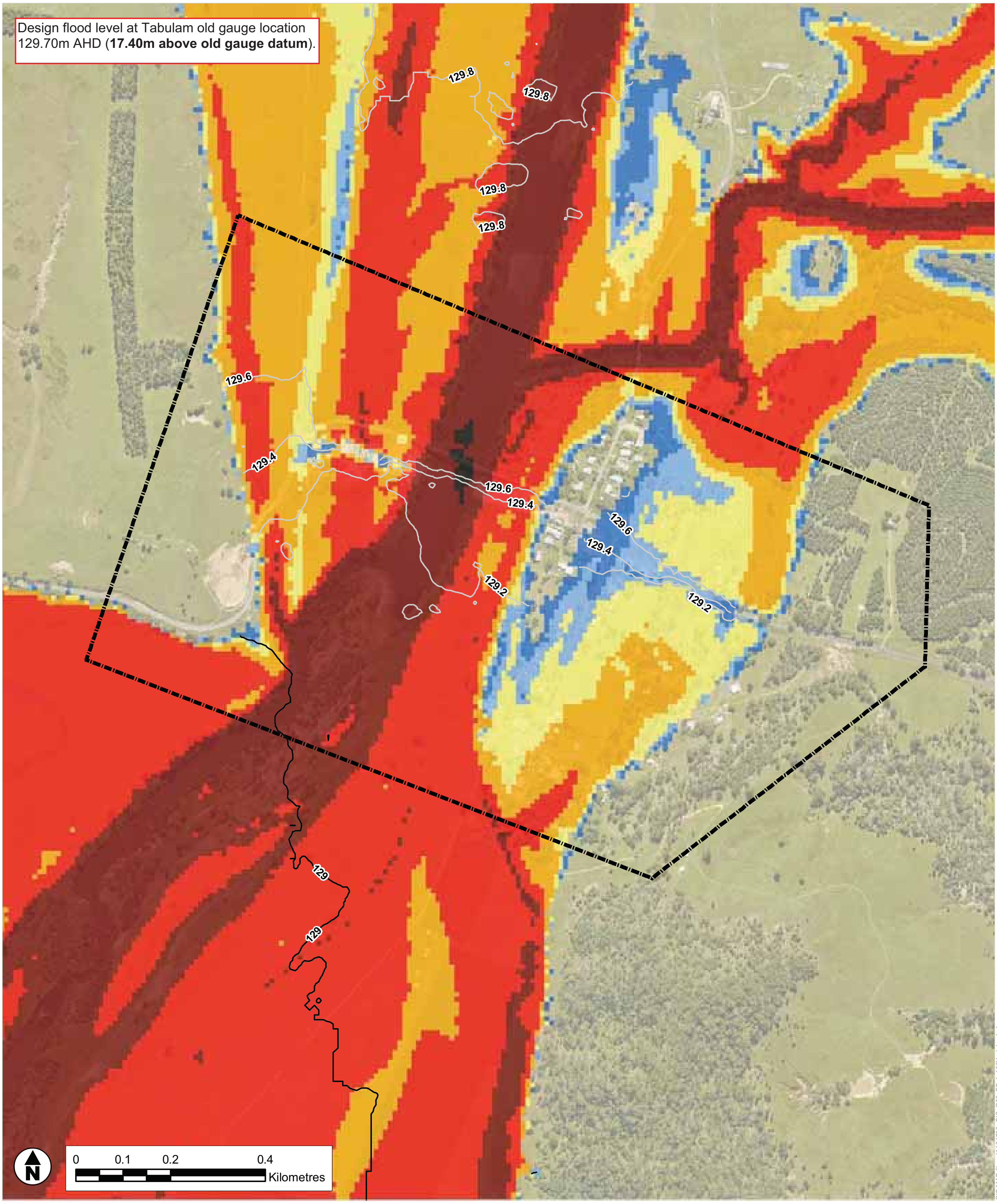
SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Flood Depth and Level
2% AEP

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE D-4	1	1
CHECK	DATE			
AH	15/01/2019			



GIS MAP file : IA164700_GIS_R03_FB-1_100Y_d_h_r1v1

Legend

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	0 - 0.5
	0.5 - 1
	1 - 2
	2 - 5
	5 - 10
	10 - 20
	20 - 30

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Study Area

JACOBS

A3

SHEET	1 of 1	GDA 1994 MGA Zone 56			
TITLE	Peak Flood Depth and Level 1% AEP				
PROJECT	Tabulam Floodplain Risk Management Study and Plan				
DRAWN	PROJECT #	MAP #		REV	VER
LC	IA164700	FIGURE D-5		1	1
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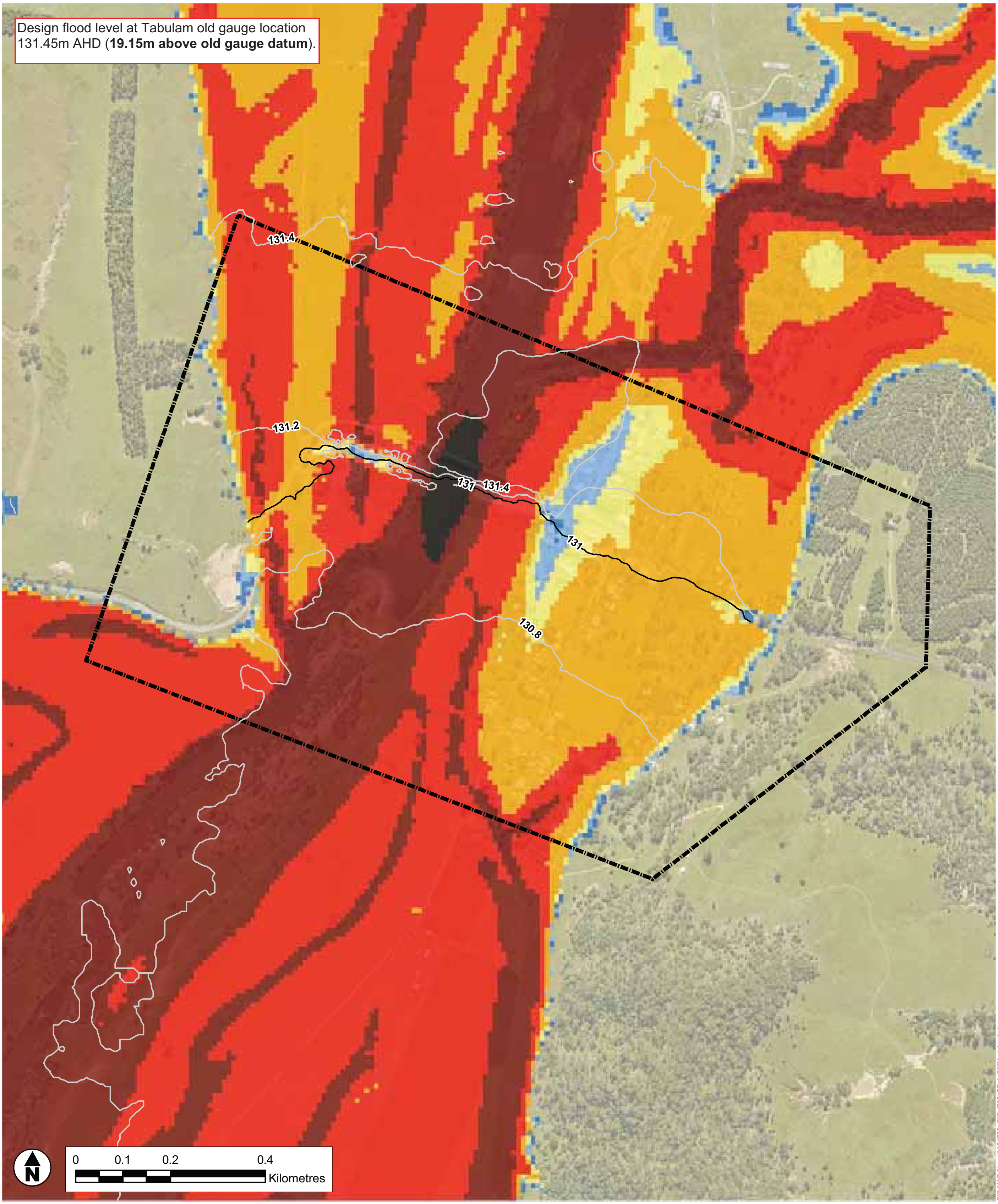
AH	15/01/2019				



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 30

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Study Area

JACOBS

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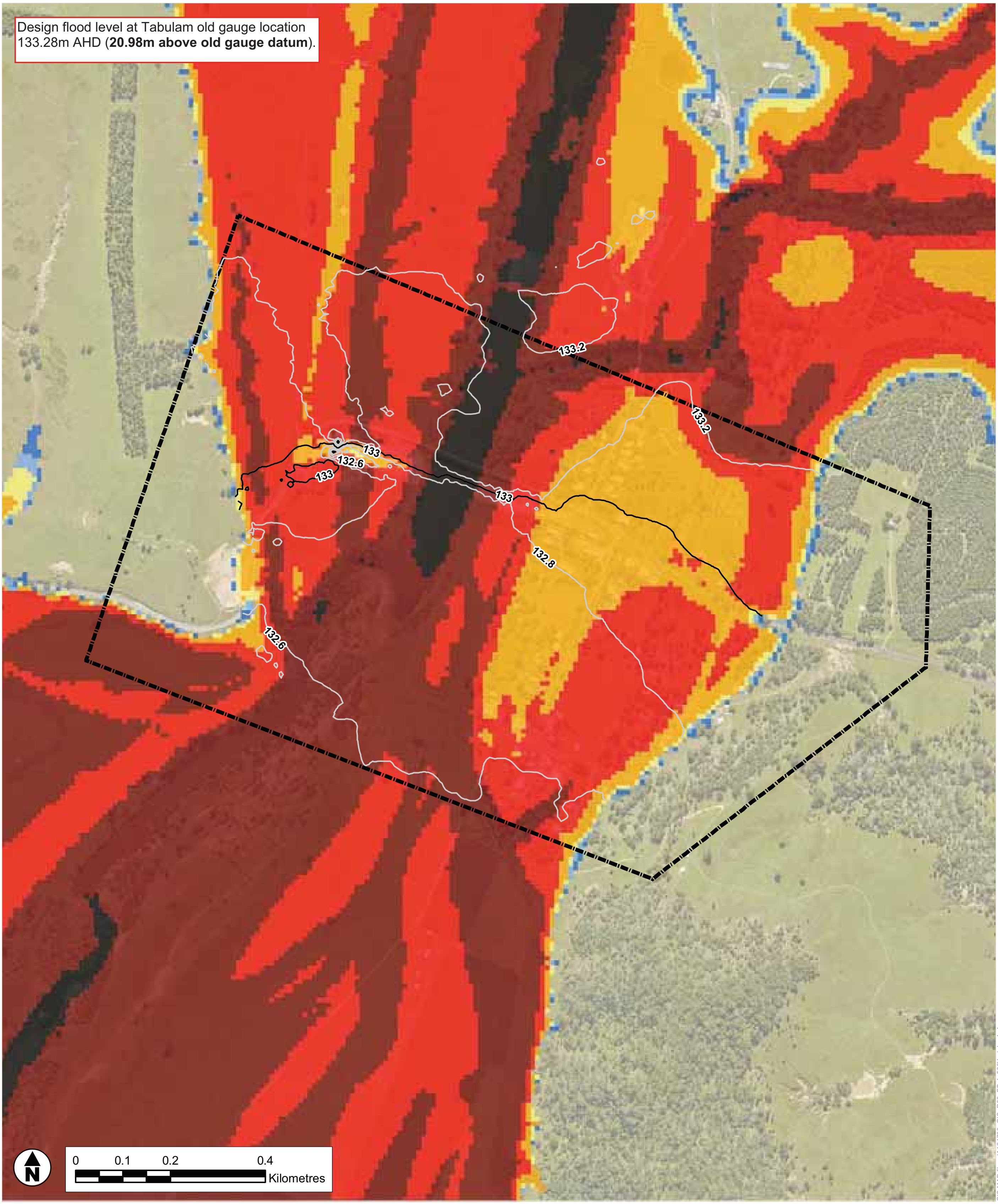
A3

SHEET	1 of 1			GDA 1994 MGA Zone 56		
TITLE	Peak Flood Depth and Level 0.5% AEP					
PROJECT	Tabulam Floodplain Risk Management Study and Plan					
DRAWN	LC	PROJECT #	IA164700	MAP # FIGURE D-6	REV 1	VER 1
CHECK	AH	DATE	15/01/2019			



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 30

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Study Area

JACOBS

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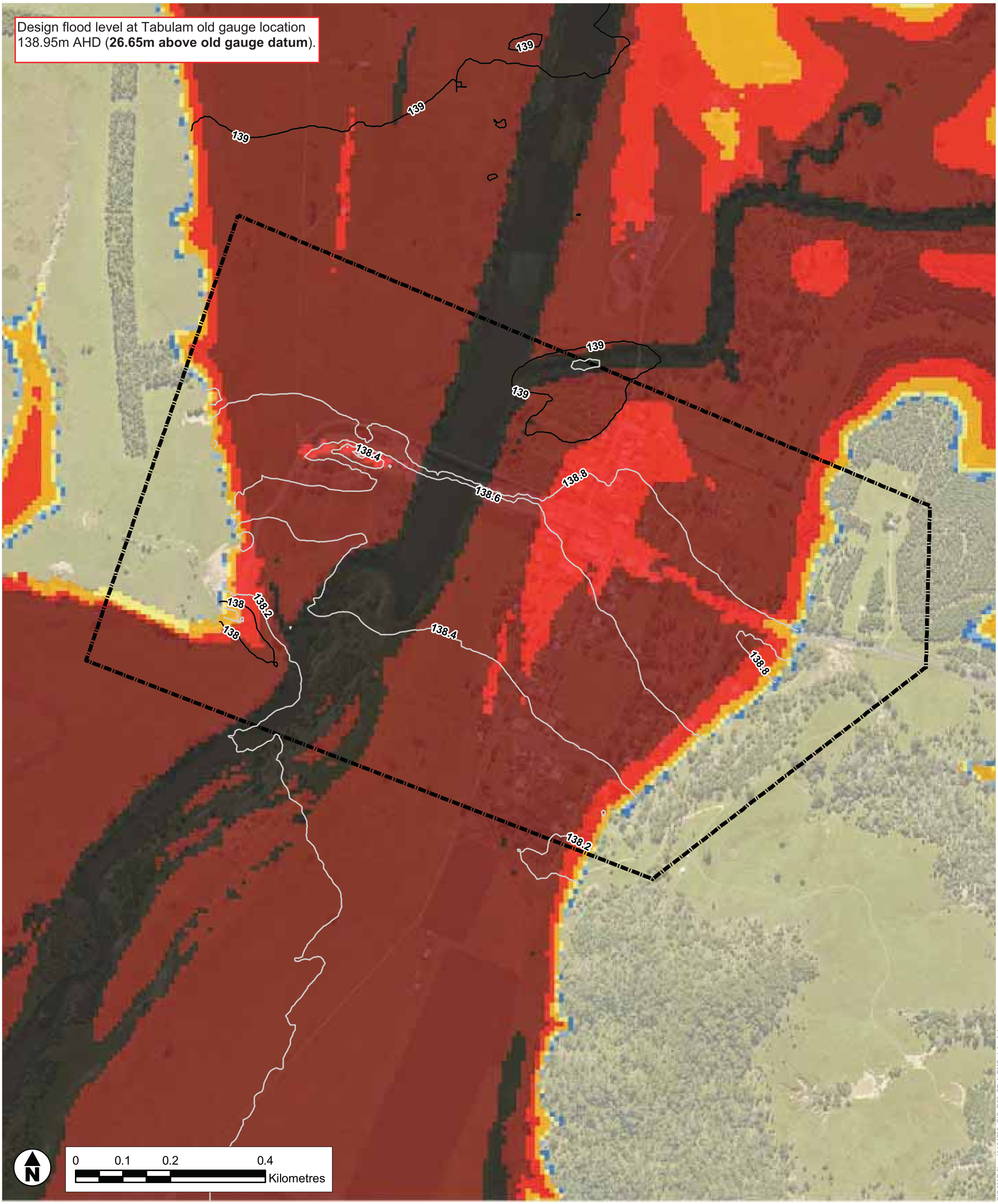
A3

SHEET	1 of 1	GDA 1994 MGA Zone 56			
TITLE	Peak Flood Depth and Level 0.2% AEP				
PROJECT	Tabulam Floodplain Risk Management Study and Plan				
DRAWN LC	PROJECT # IA164700	MAP # FIGURE D-7		REV 1	VER 1
CHECK AH	DATE 15/01/2019				



Legend

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 30

- Flood Level (m AHD) 1m contour
- Flood Level (m AHD) 0.2m contour
- Study Area

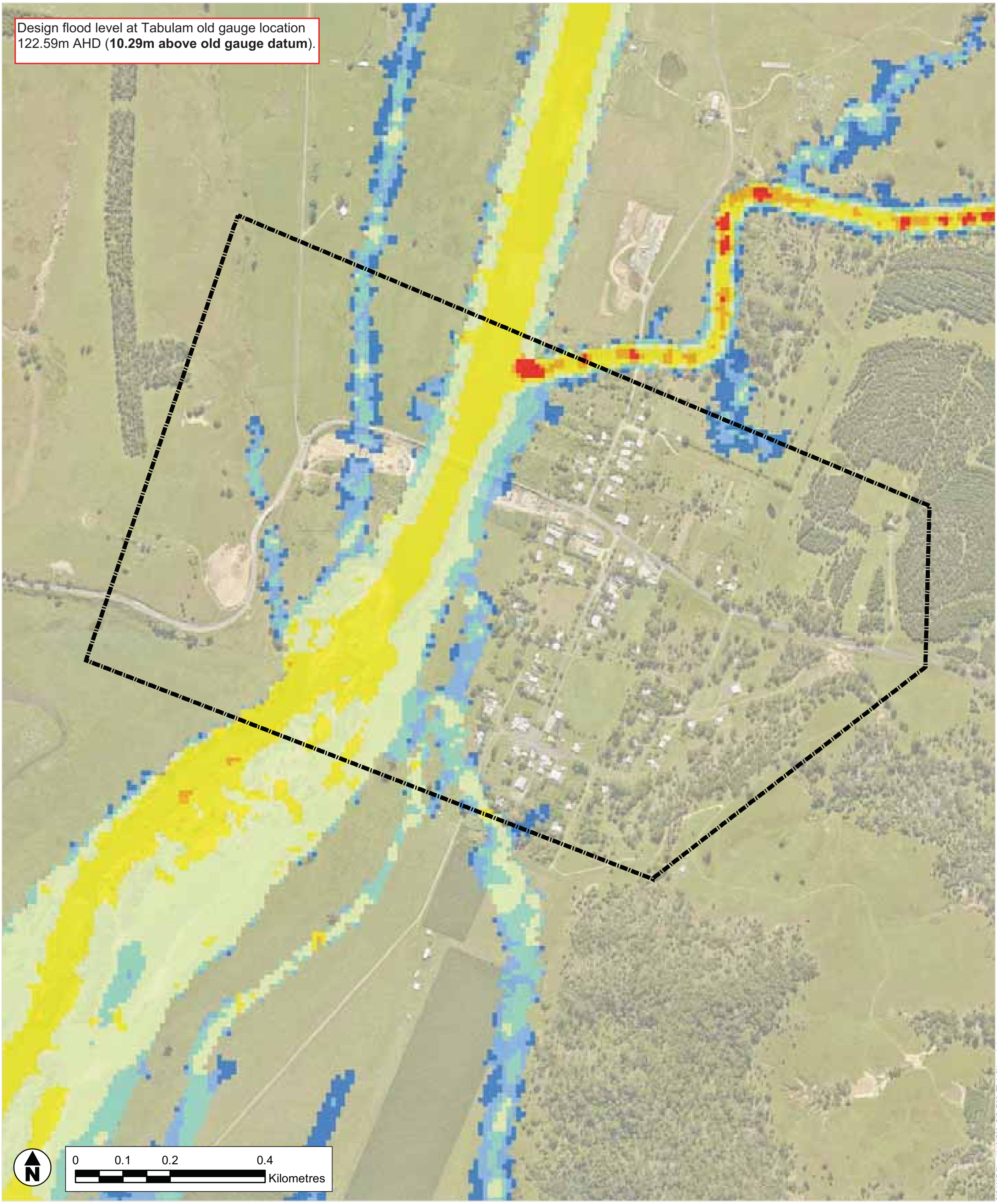
JACOBS

LIMITATIONS: This mapping is based on data and assumptions identified in the Tabulam Floodplain Risk Management Study and Plan prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

A3

SHEET	1 of 1	GDA 1994 MGA Zone 56			
TITLE	Peak Flood Depth and Level Extreme Event				
PROJECT	Tabulam Floodplain Risk Management Study and Plan				
DRAWN LC	PROJECT # IA164700	MAP # FIGURE D-8		REV 1	VER 1
CHECK AH	DATE 18/01/2019				

GIS MAP file : IA164700_GIS_R03_F8-1_PMF_d_h_r1v1



Legend

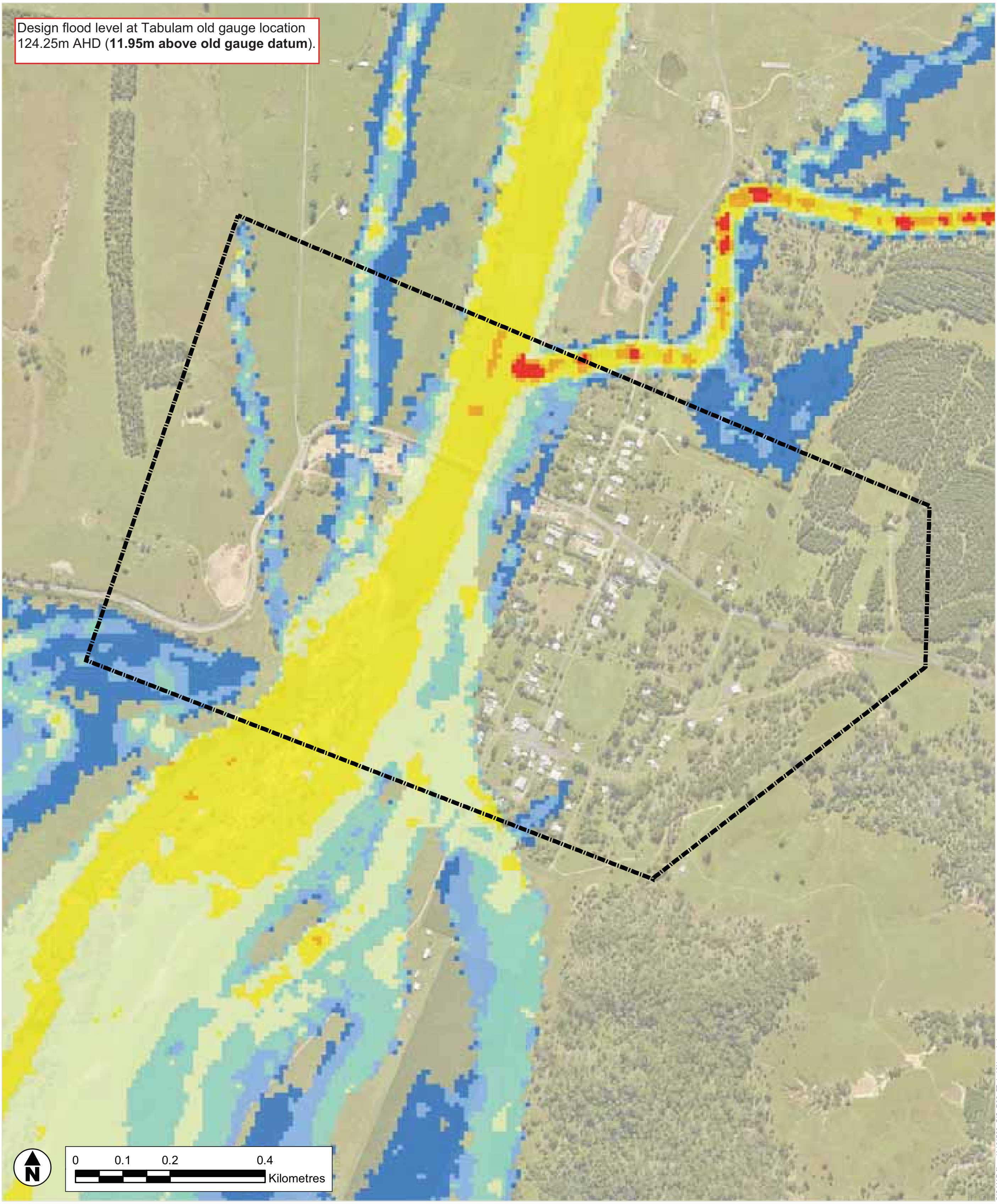
Peak Velocity (m/s)

- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

Study Area

A3

SHEET	1 of 1 — GDA 1994 MGA Zone 56
TITLE	Peak Velocities for 20% AEP
PROJECT	Tabulam Floodplain Risk Management Study and Plan
DRAWN	LC
PROJECT #	IA164700
MAP #	FIGURE D-9
REV	1
VER	1
CHECK	AH
DATE	10/01/2019



GIS MAP file : IA164700_GIS_R03_FB-1_10Y_v_r1v1

Legend

Peak Velocity (m/s)

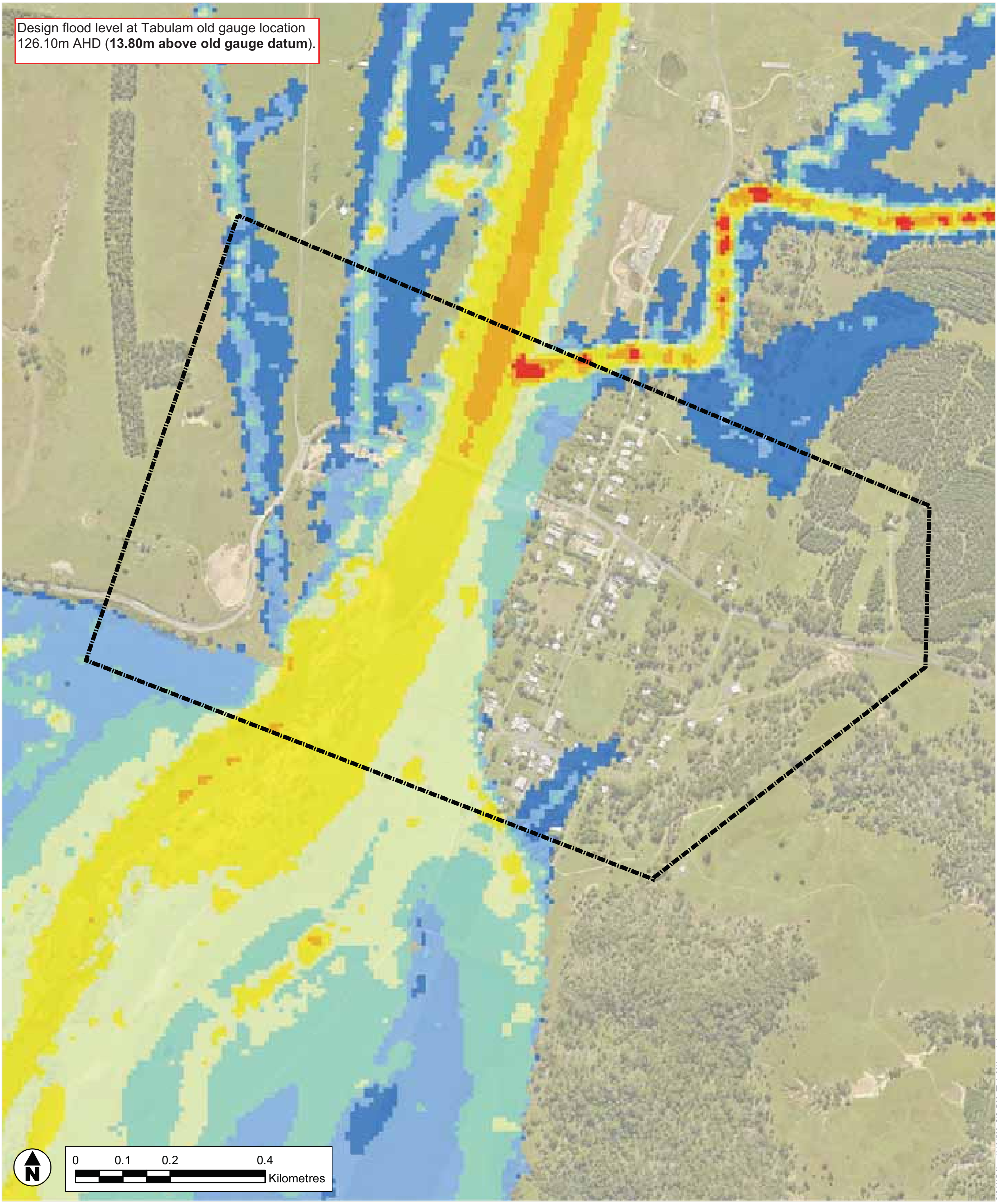
- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

Study Area

LIMITATIONS: This mapping is based on data and assumptions identified in the Tabulam Floodplain Risk Management Study and Plan prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

A3

SHEET	1 of 1	GDA 1994 MGA Zone 56	
TITLE	Peak Velocities for 10% AEP		
PROJECT	Tabulam Floodplain Risk Management Study and Plan		
DRAWN LC	PROJECT # IA164700	MAP # FIGURE D-10	REV 1 VER 1
CHECK AH	DATE 10/01/2019		



Legend

Peak Velocity (m/s)

- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

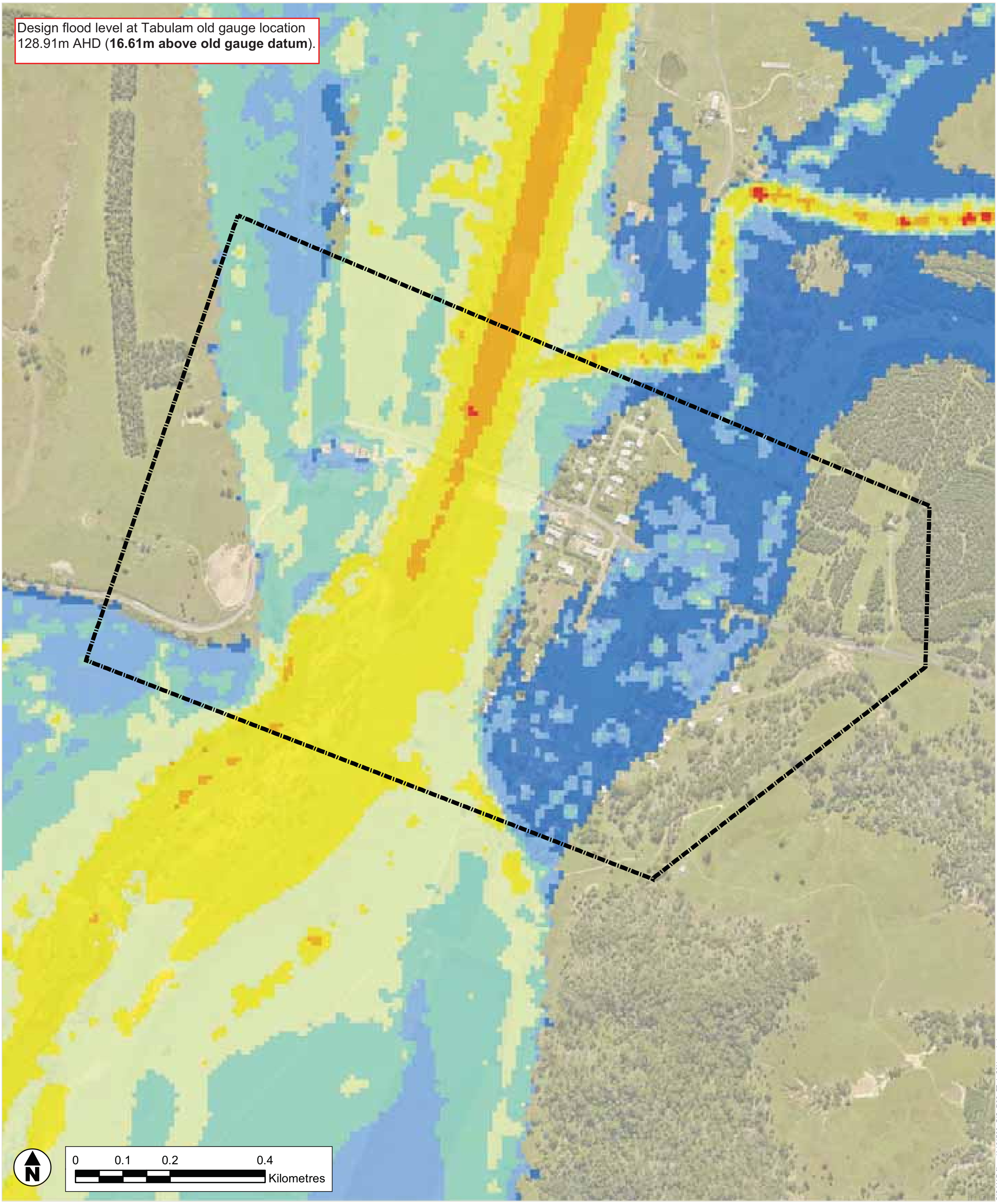
Study Area

JACOBS

LIMITATIONS: This mapping is based on data and assumptions identified in the Tabulam Floodplain Risk Management Study and Plan prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

A3

SHEET	1 of 1	GDA 1994 MGA Zone 56			
TITLE	Peak Velocities for 5% AEP				
PROJECT	Tabulam Floodplain Risk Management Study and Plan				
DRAWN LC	PROJECT # IA164700	MAP # FIGURE D-11		REV 1	VER 1
CHECK AH	DATE 10/01/2019				



GIS MAP file : IA164700_GIS_R03_FB-1_50Y_v_r1v1

Legend

Peak Velocity (m/s)

- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

Study Area

JACOBS

A3

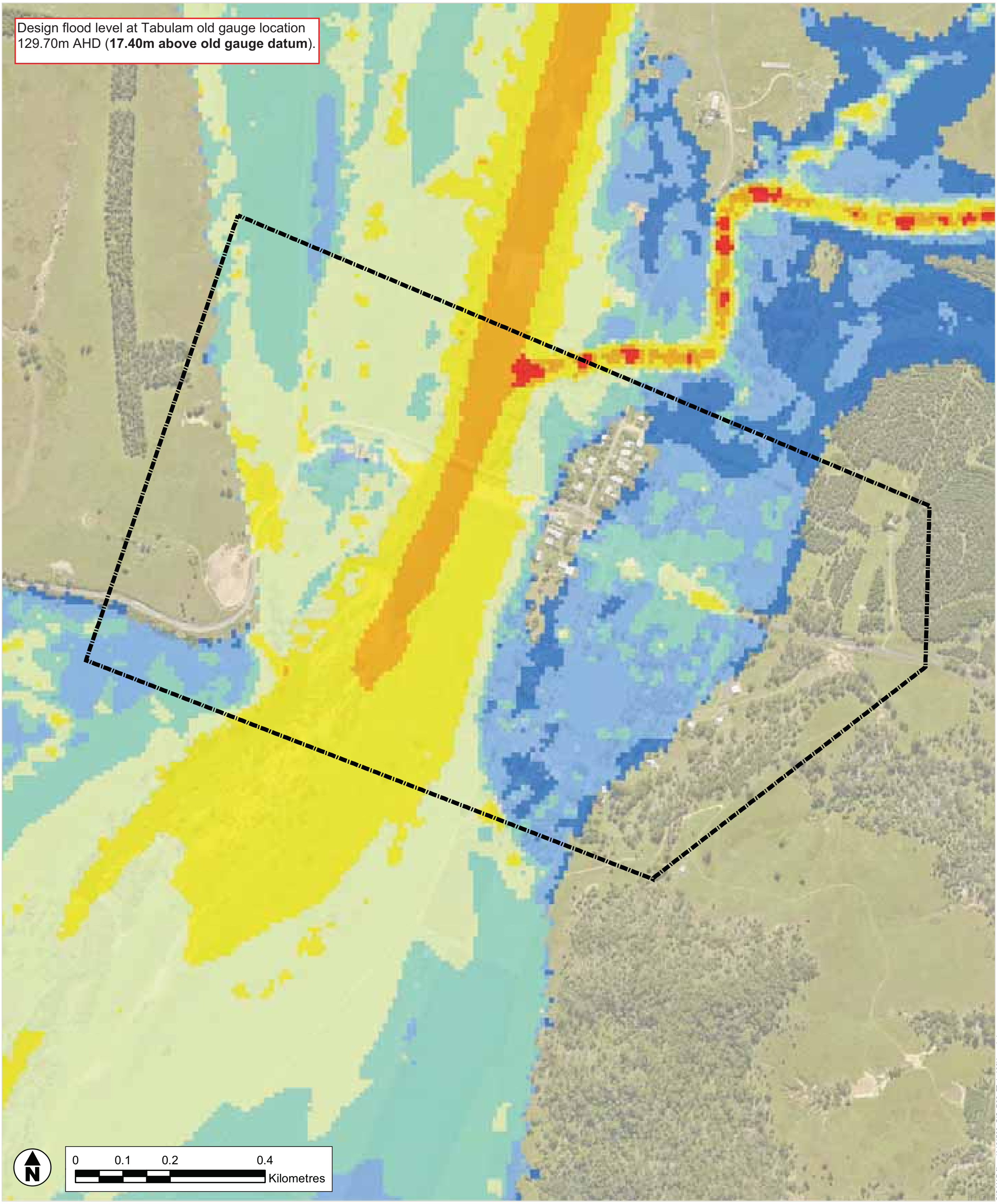
SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Velocities for 2% AEP

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE D-12	1	1
CHECK	DATE			
AH	10/01/2019			



GIS MAP file : IA164700_GIS_R03_FB-1_100Y_v_r1v1

Legend

Peak Velocity (m/s)

- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

Study Area

JACOBS

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A3

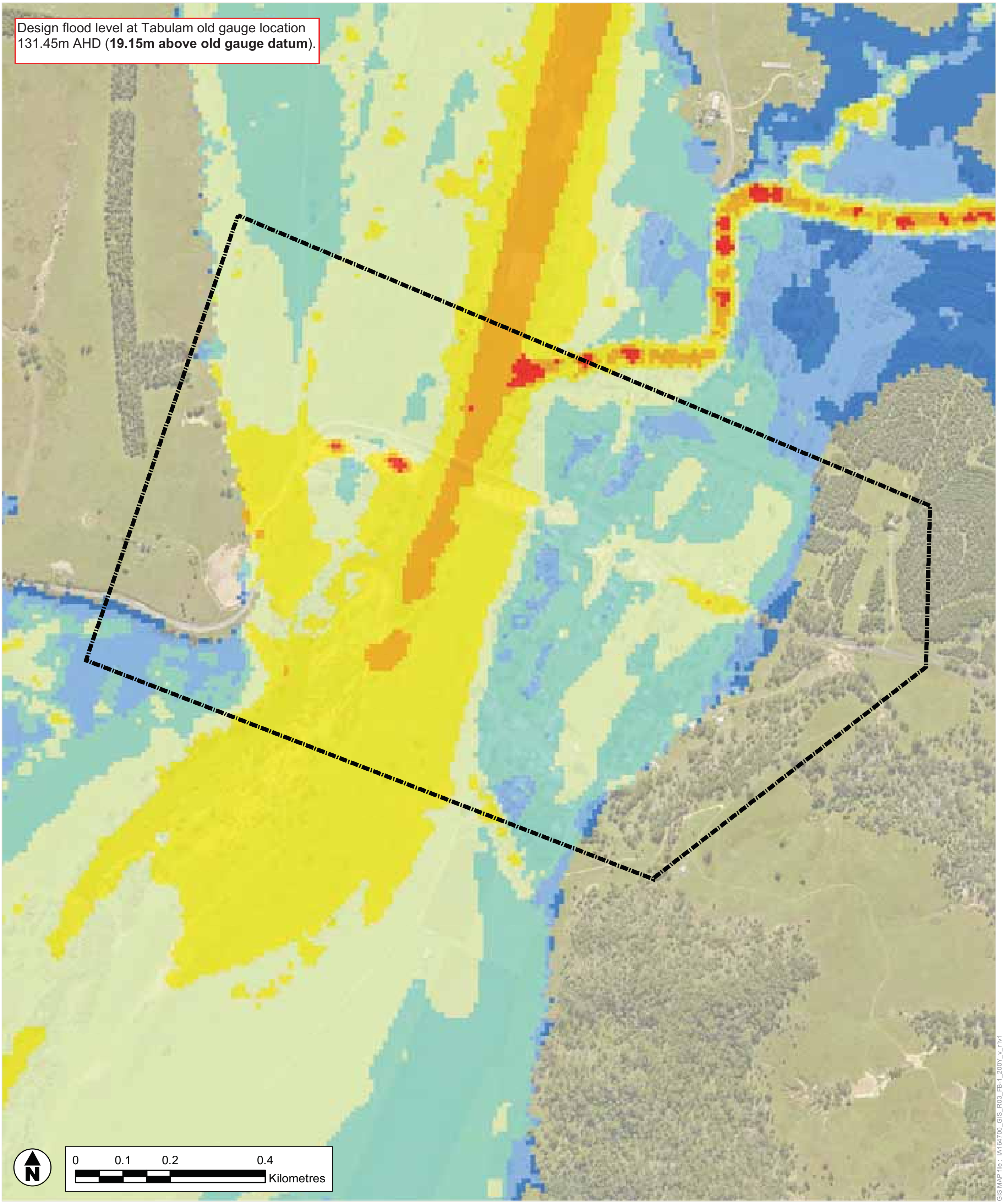
SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Velocities for 1% AEP

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE D-13	1	1
CHECK	DATE			
AH	10/01/2019			



Legend

Peak Velocity (m/s)

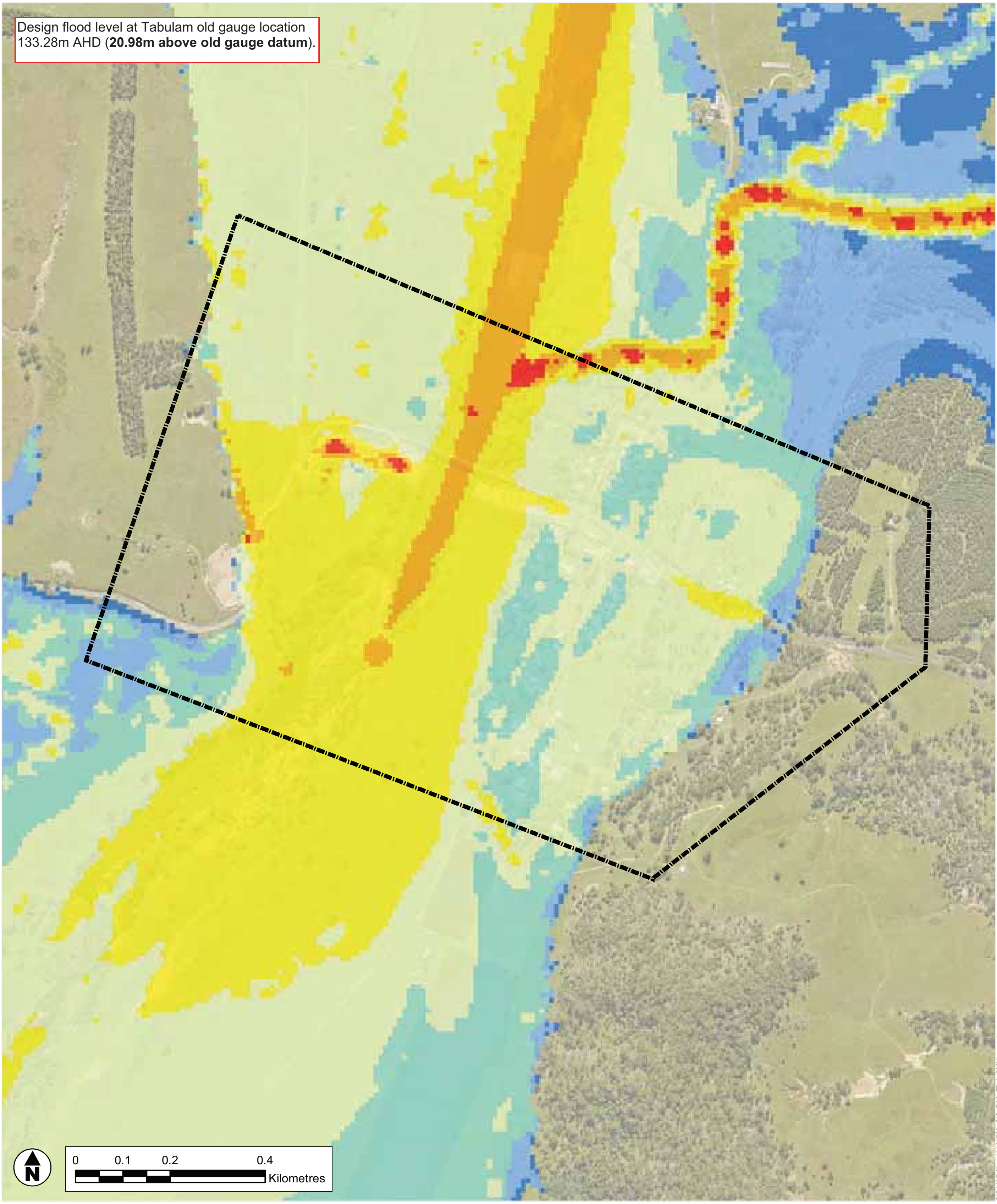
- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

Study Area

LIMITATIONS: This mapping is based on data and assumptions identified in the Tabulam Floodplain Risk Management Study and Plan prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

A3

SHEET	1 of 1	GDA 1994 MGA Zone 56	
TITLE	Peak Velocities for 0.5% AEP		
PROJECT	Tabulam Floodplain Risk Management Study and Plan		
DRAWN LC	PROJECT # IA164700	MAP # FIGURE D-14	REV 1 VER 1
CHECK AH	DATE 10/01/2019		



GIS MAP file : IA164700_GIS_R03_FB-1_500Y_v_r1v1

Legend

Peak Velocity (m/s)

- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

Study Area

LIMITATIONS: This mapping is based on data and assumptions identified in the Tabulam Floodplain Risk Management Study and Plan prepared by Jacobs. Jacobs does not warrant, guarantee or make representations regarding the currency and accuracy ofinformation contained in this map.

A3

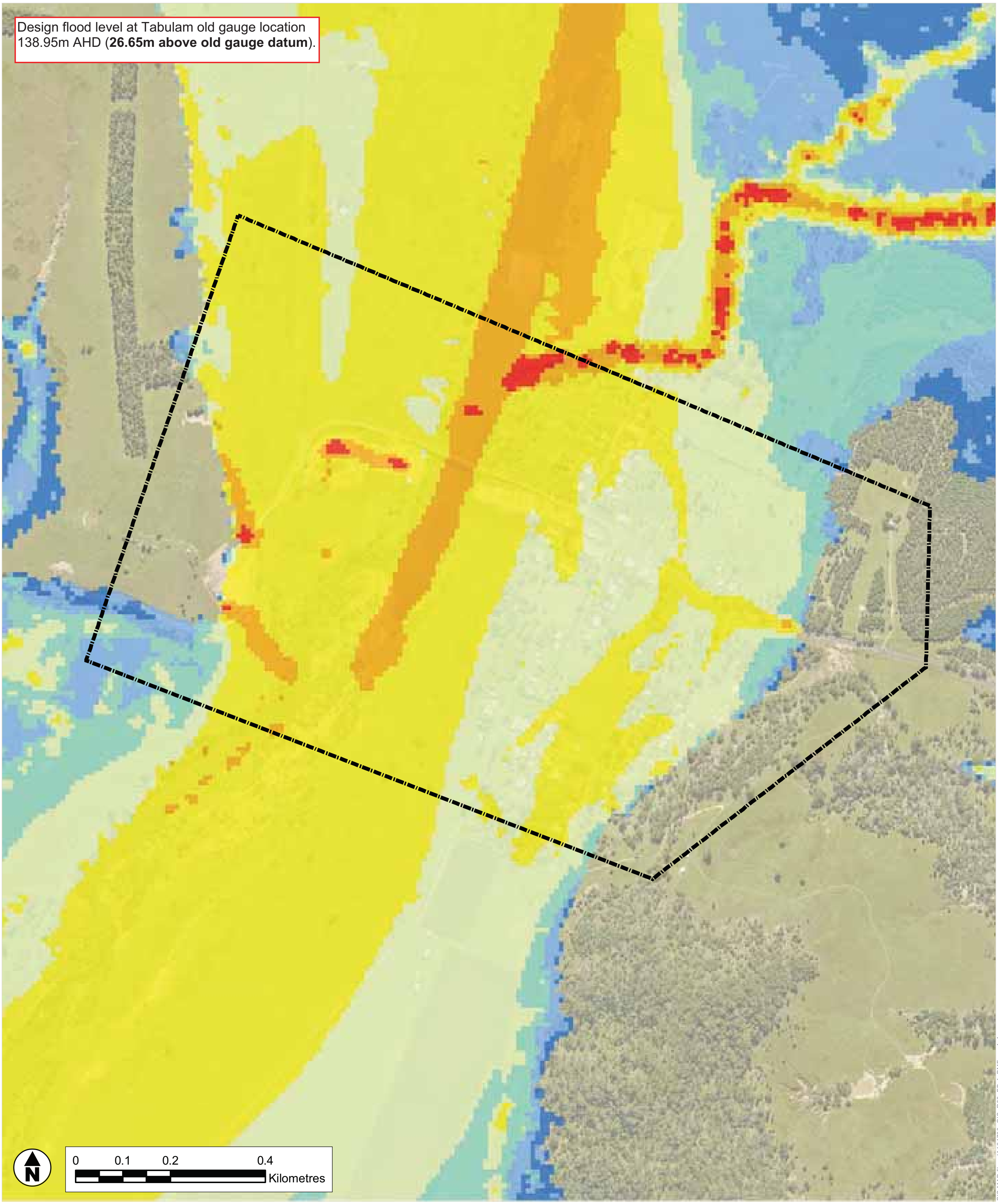
SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Velocities for 0.2% AEP

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE D-15	1	1
CHECK	DATE			
AH	10/01/2019			



GIS MAP file : IA164700_GIS_R03_FB-1_PMF_v_r1v1

Legend

Peak Velocity (m/s)

- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- >6

Study Area

A3

SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Peak Velocities
Extreme Event

PROJECT Tabulam Floodplain Risk
Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE D-16	1	1
CHECK	DATE			
AH	18/01/2019			

Figure D-17 Long section water level profiles along Clarence River for design flood events

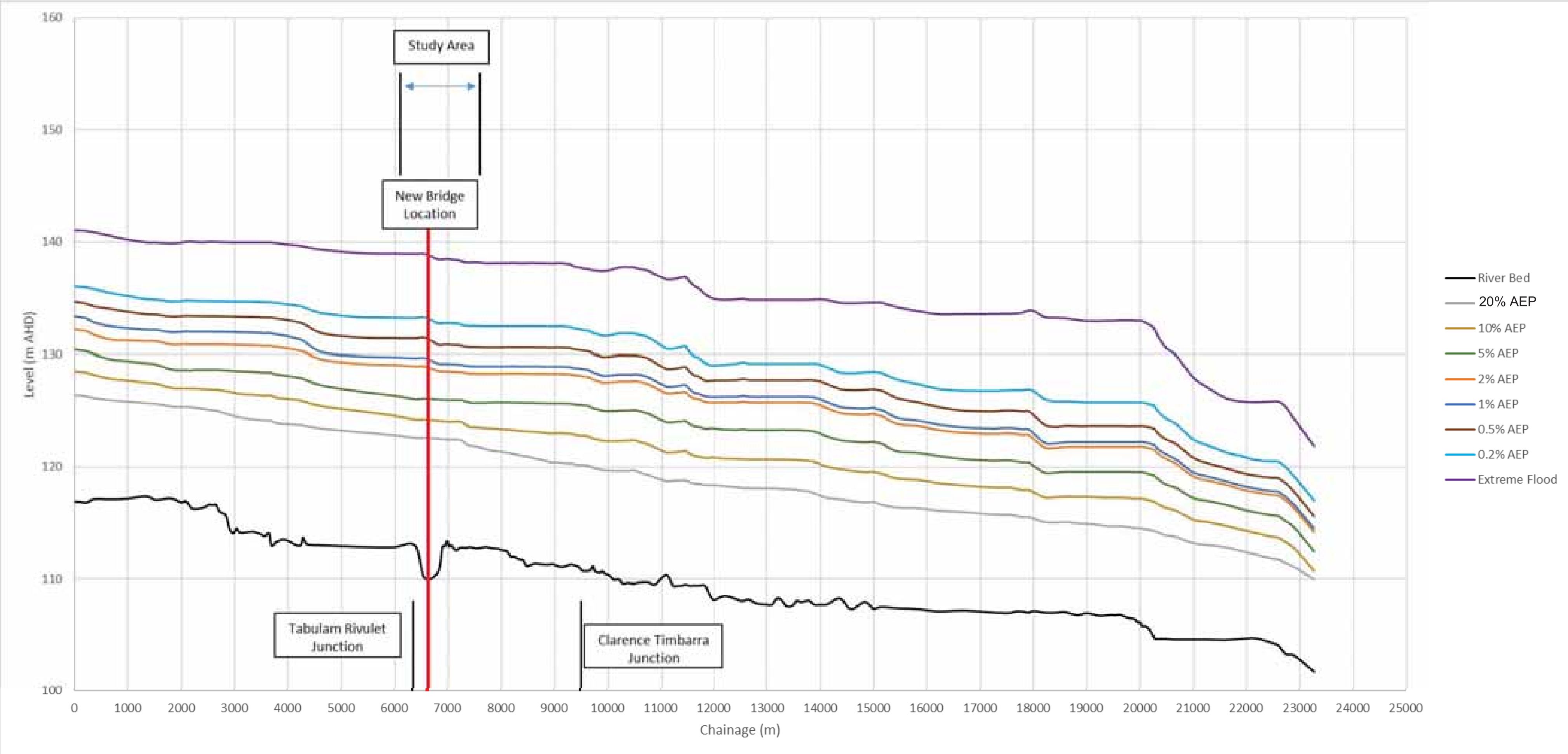
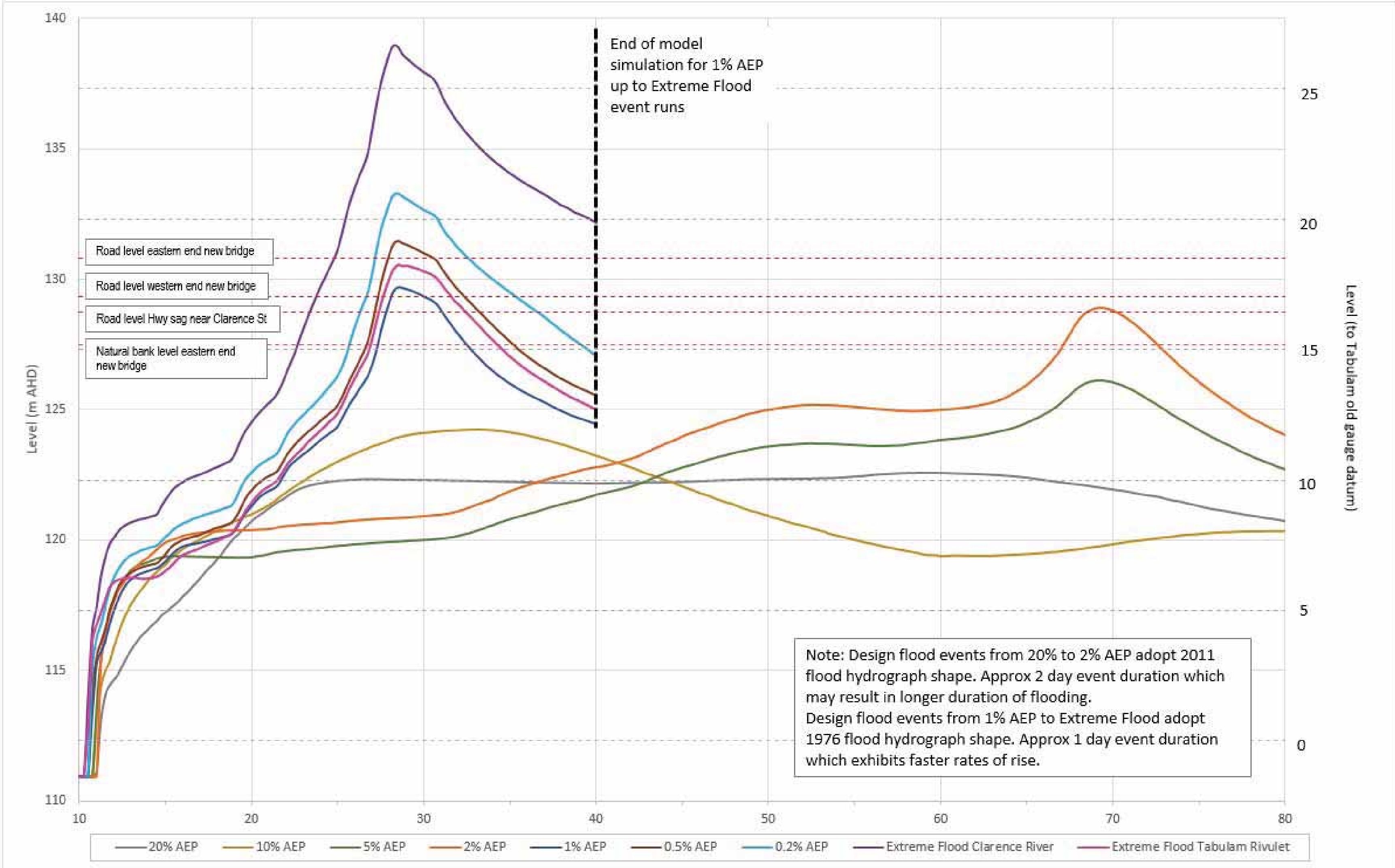
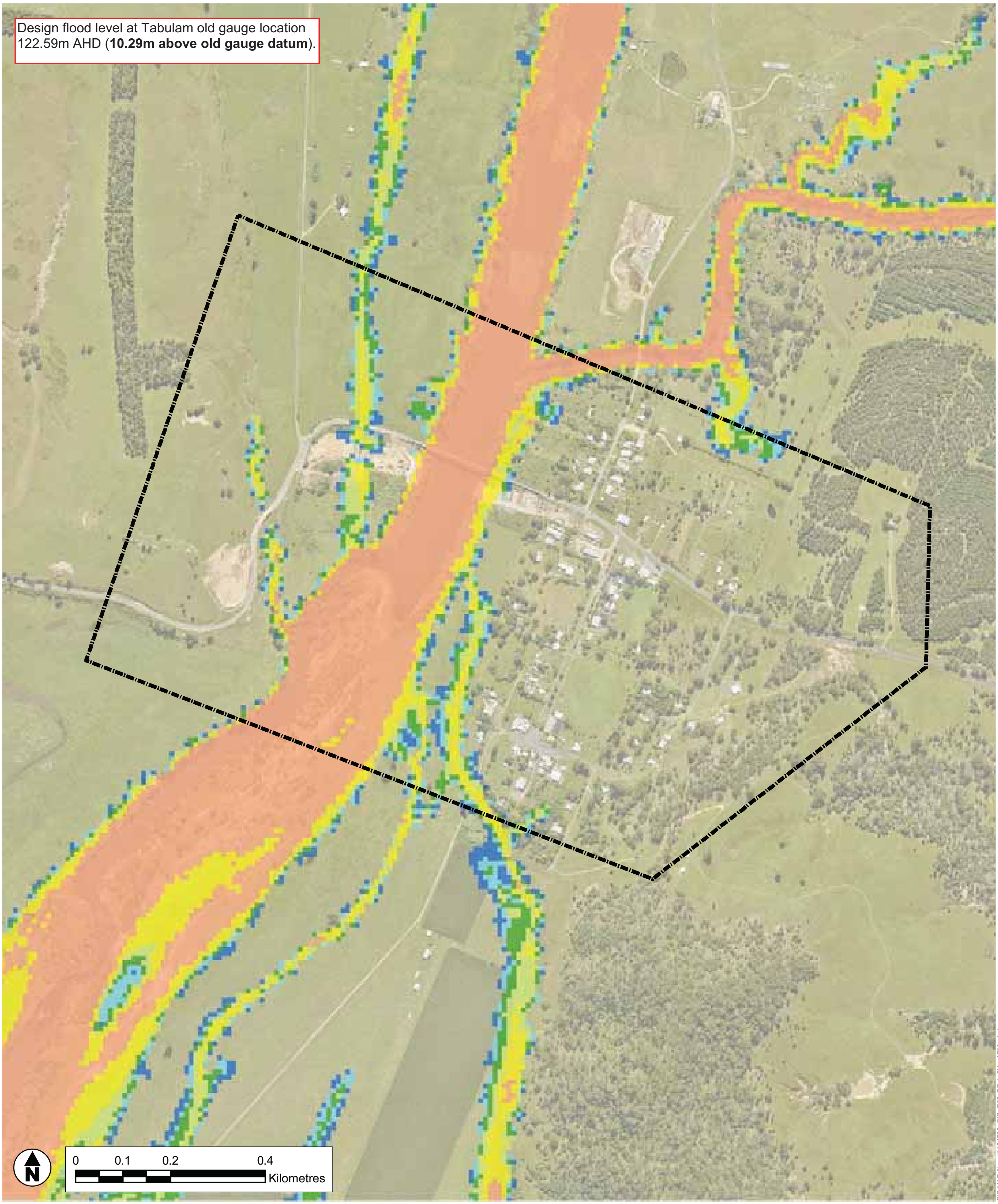


Figure D-18 Flood Level Hydrographs for Design Flood Events at Tabulam Old Gauge Location



Appendix E. Flood Hazard Mapping



GIS MAP file : IA164700_GIS_R03_FE-1_5Y_zAEM_r1v1

Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

JACOBS

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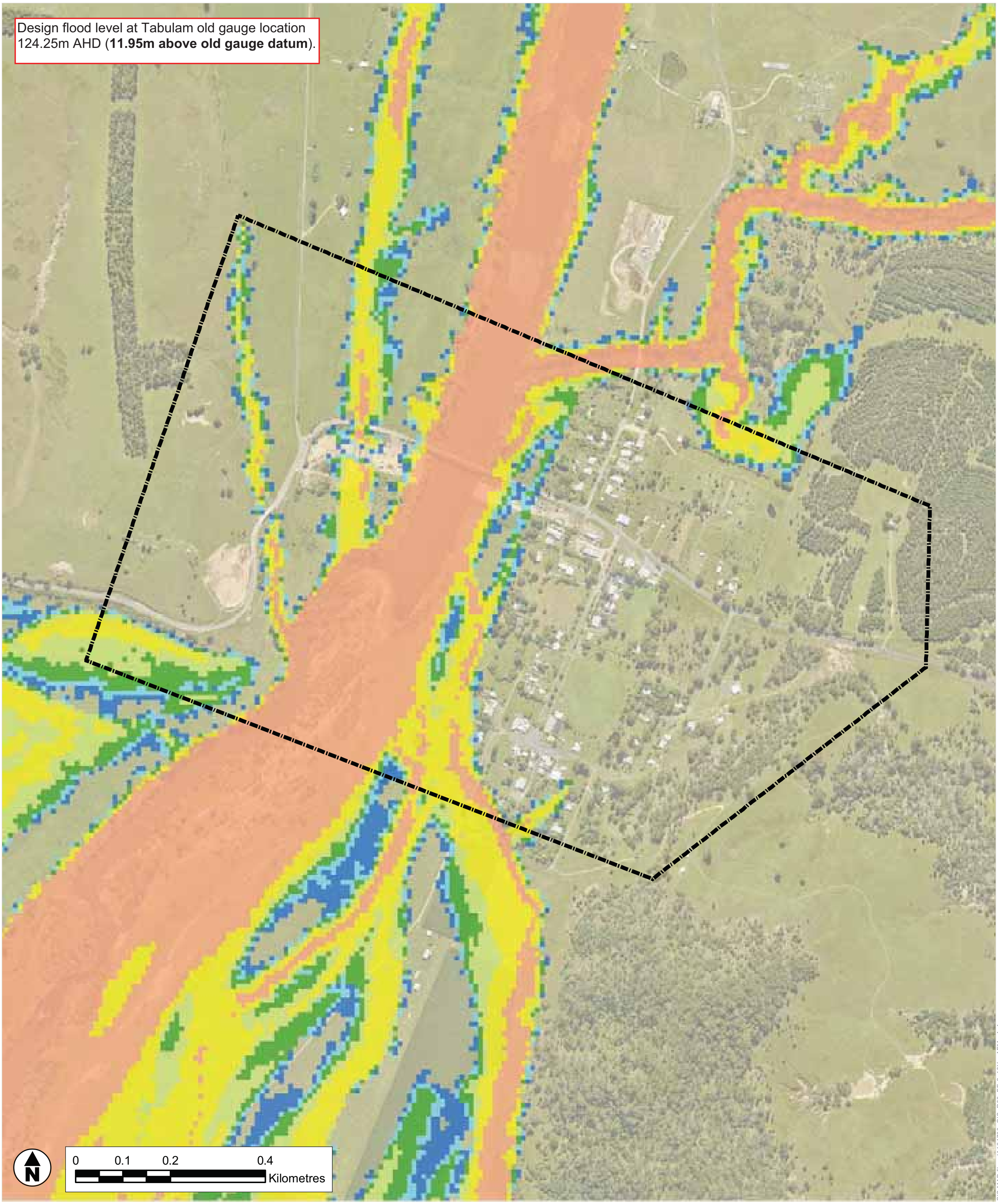
A3

SHEET 1 of 1 GDA 1994 MGA Zone 56

TITLE Provisional Flood Hazard
20% AEP Event
AIDR Categories

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE E-1	1	1
CHECK	DATE			
AH	27/03/2019			



GIS MAP file : IA164700_GIS_R03_FE-2_10Y_zAEM_r1v1

Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

JACOBS

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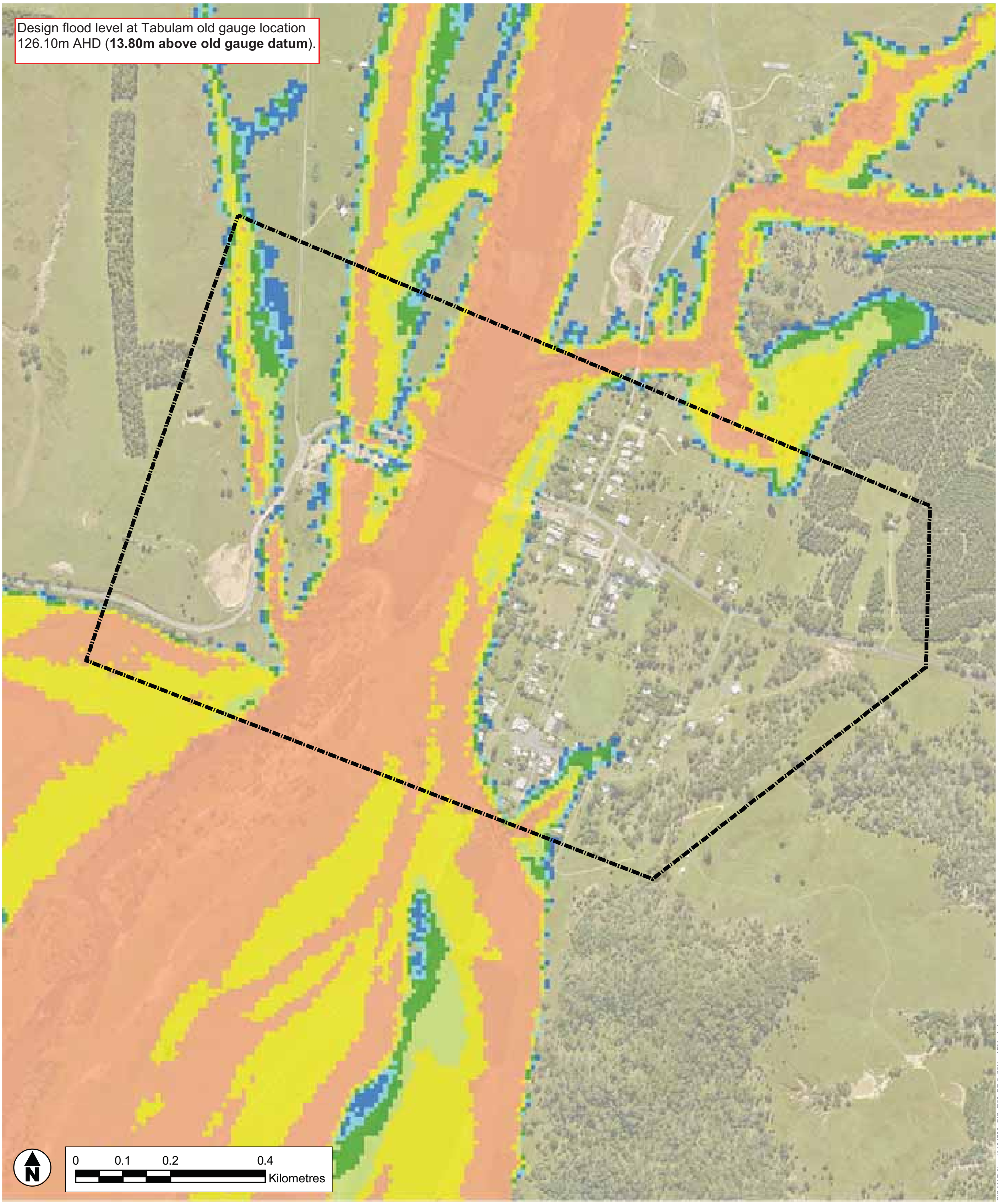
A3

SHEET	1 of 1	GDA 1994 MGA Zone 56	
TITLE	Provisional Flood Hazard 10% AEP Event AIDR Categories		
PROJECT	Tabulam Floodplain Risk Management Study and Plan		
DRAWN LC	PROJECT # IA164700	MAP # FIGURE E-2	REV 1 / VER 1
CHECK AH	DATE 27/03/2019		



Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

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A3

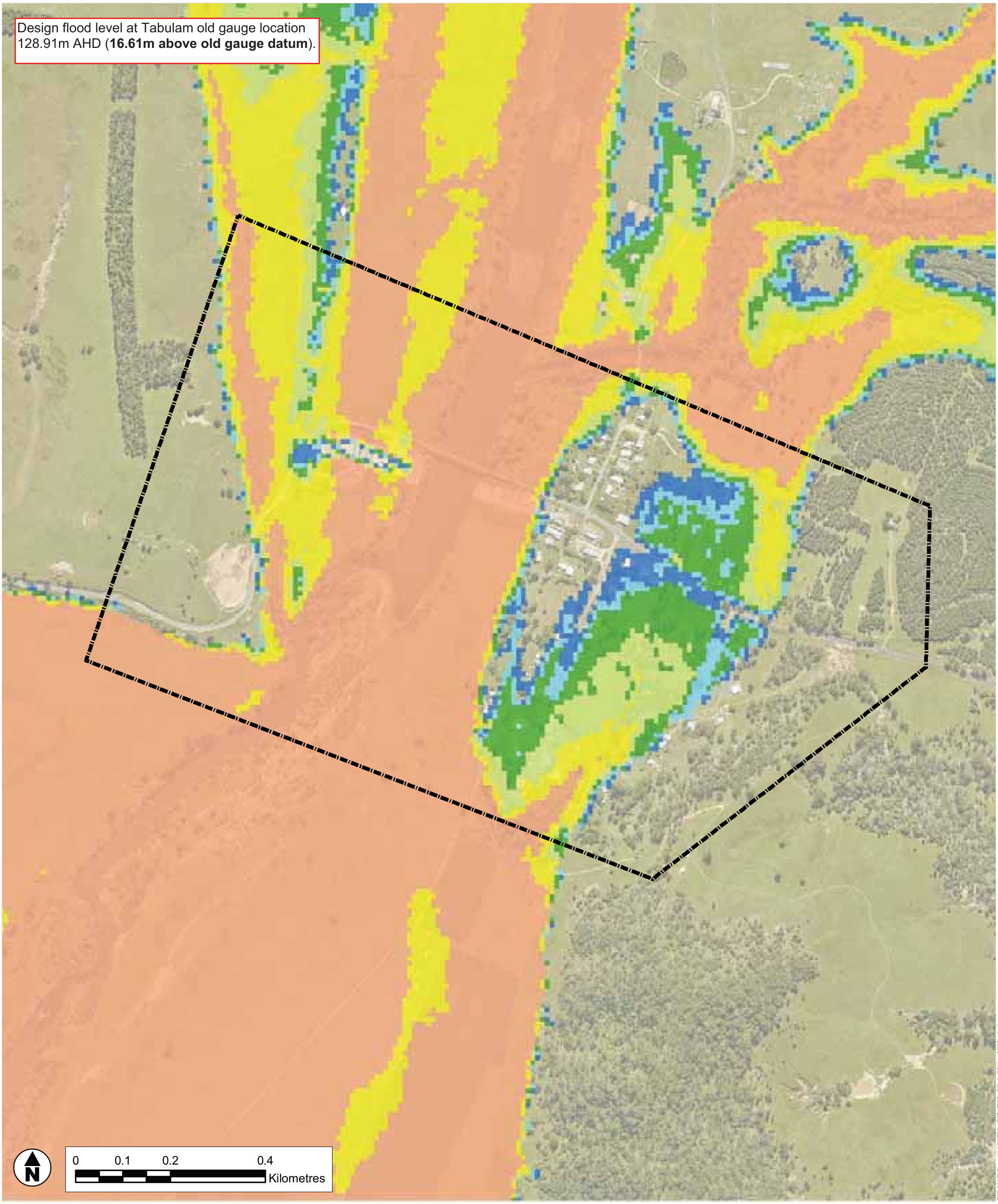
SHEET 1 of 1 | GDA 1994 MGA Zone 56

TITLE: Provisional Flood Hazard
5% AEP Event
AIDR Categories

PROJECT: Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE E-3	1	1
CHECK	DATE			
AH	27/03/2019			

GIS MAP file : IA164700_GIS_R03_FE-3_20Y_zAEM_r1v1



Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

JACOBS

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A3

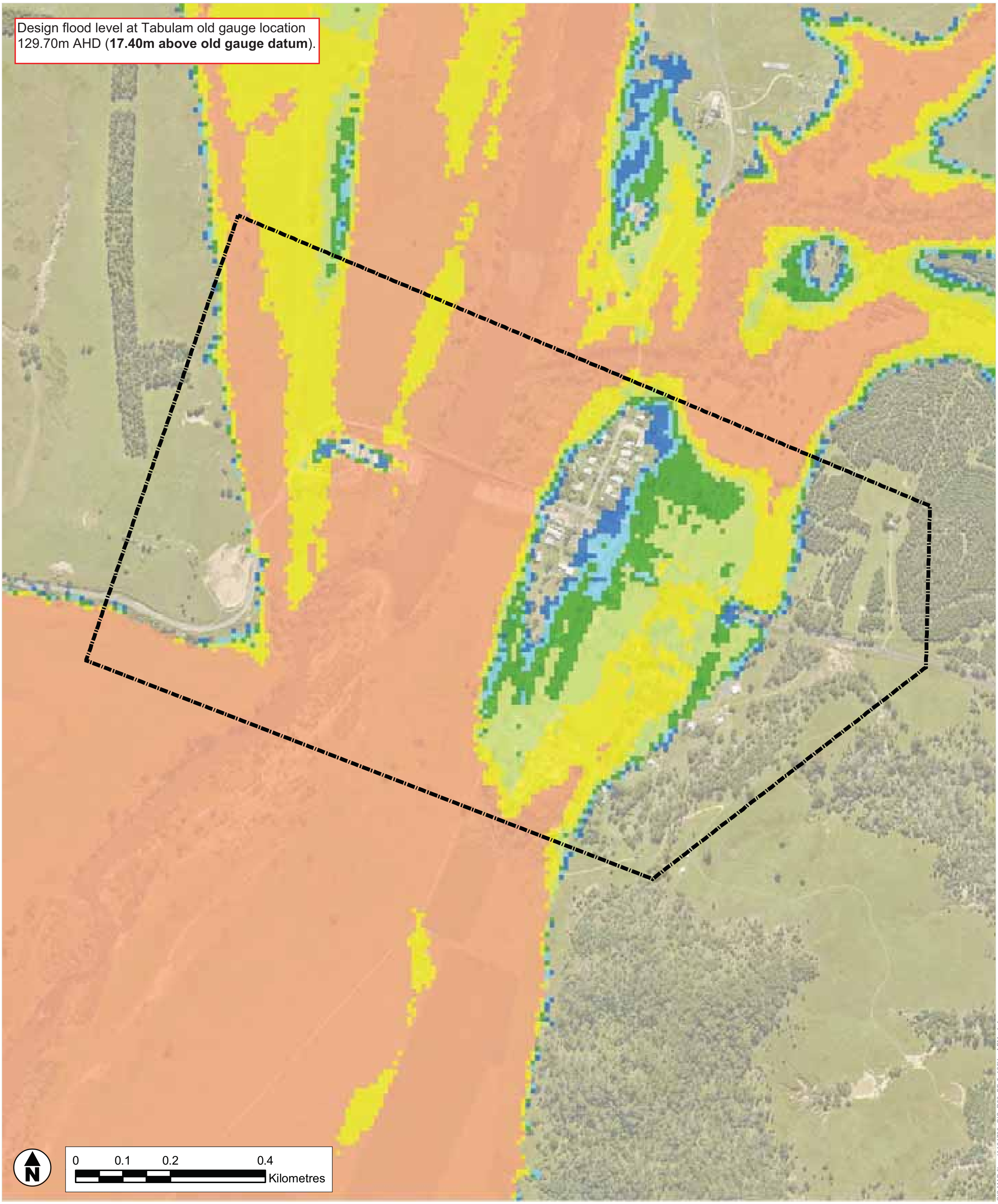
SHEET 1 of 1

GDA 1994 MGA Zone 56

TITLE Provisional Flood Hazard
2% AEP Event
AIDR Categories

PROJECT Tabulam Floodplain Risk Management Study and Plan

DRAWN	PROJECT #	MAP #	REV	VER
LC	IA164700	FIGURE E-4	1	1
CHECK	DATE			
AH	27/03/2019			



GIS MAP file : IA164700_GIS_R03_FE-5_100Y_zAEM_r1v1

Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

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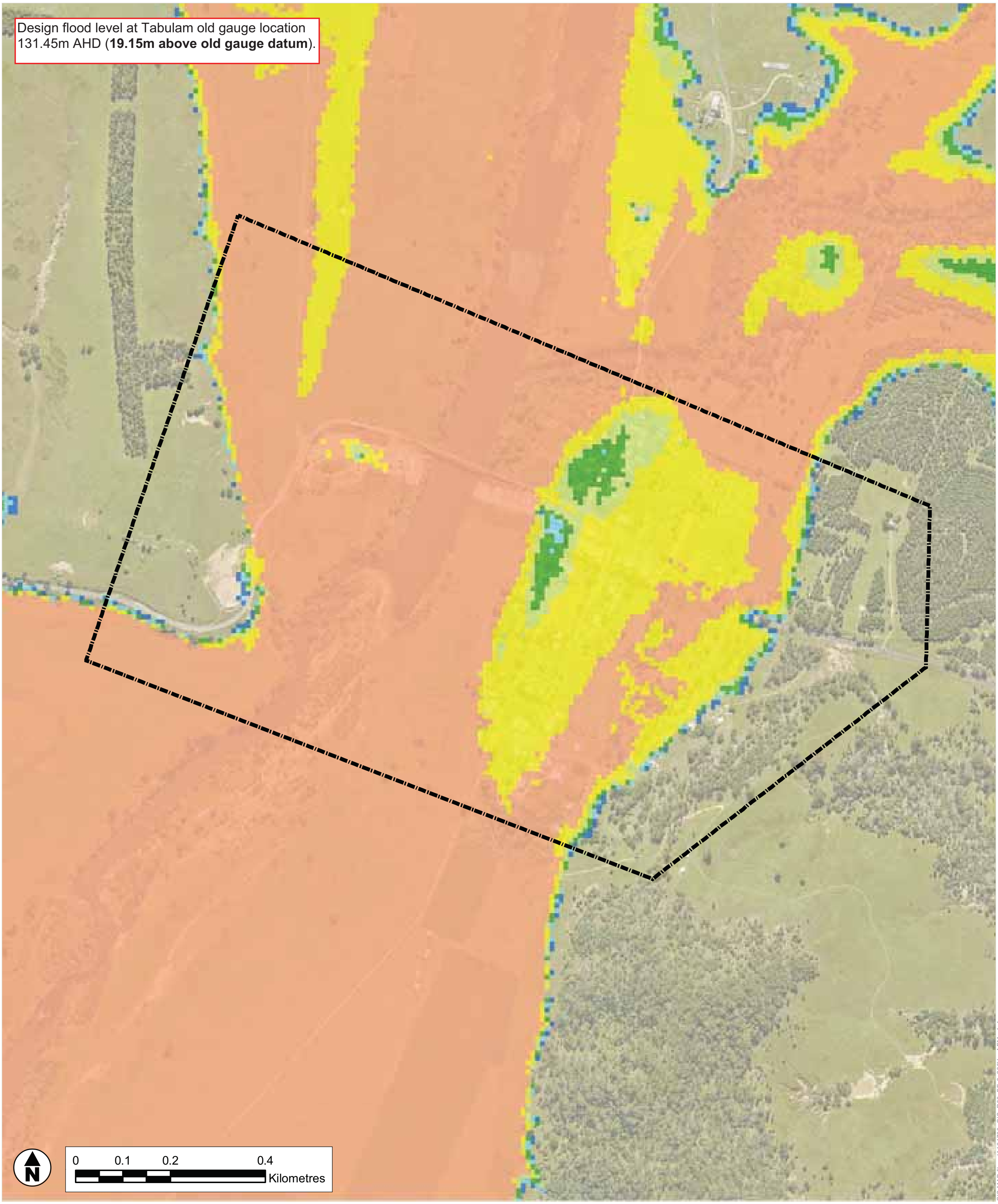
A3

SHEET	1 of 1 — GDA 1994 MGA Zone 56
TITLE	Provisional Flood Hazard 1% AEP Event AIDR Categories
PROJECT	Tabulam Floodplain Risk Management Study and Plan
DRAWN	LC
PROJECT #	IA164700
MAP #	FIGURE E-5
REV	1
VER	1
CHECK	AH
DATE	27/03/2019



GIS MAP file : IA164700_GIS_R03_FE-6_200Y_zAEM_r1v1

Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

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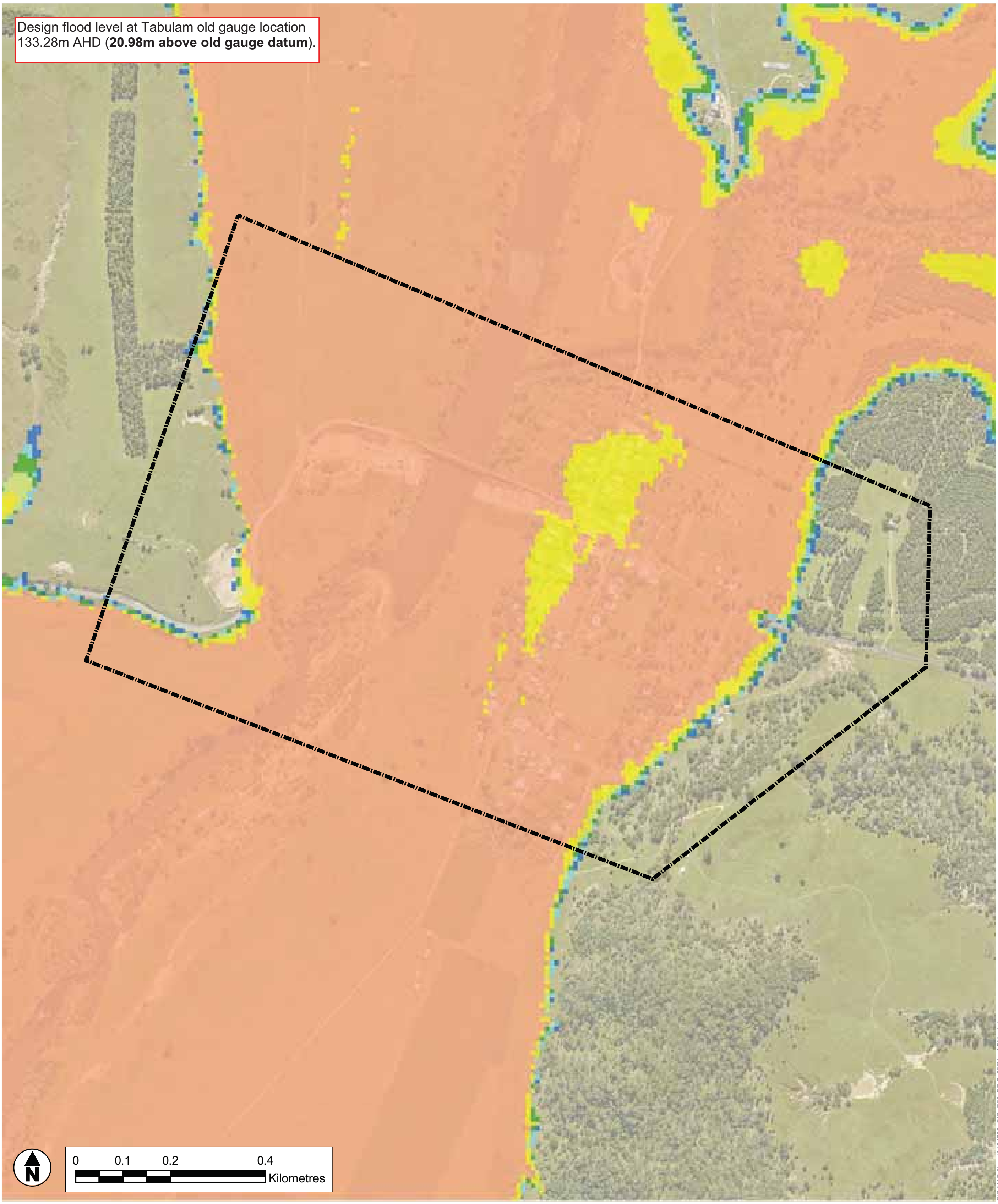
A3

SHEET	1 of 1 — GDA 1994 MGA Zone 56
TITLE	Provisional Flood Hazard 0.5% AEP Event AIDR Categories
PROJECT	Tabulam Floodplain Risk Management Study and Plan
DRAWN	LC
PROJECT #	IA164700
MAP #	FIGURE E-6
REV	1
VER	1
CHECK	AH
DATE	27/03/2019



GIS MAP file : IA164700_GIS_R03_FE-7_500Y_zAEM_r1v1

Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

JACOBS

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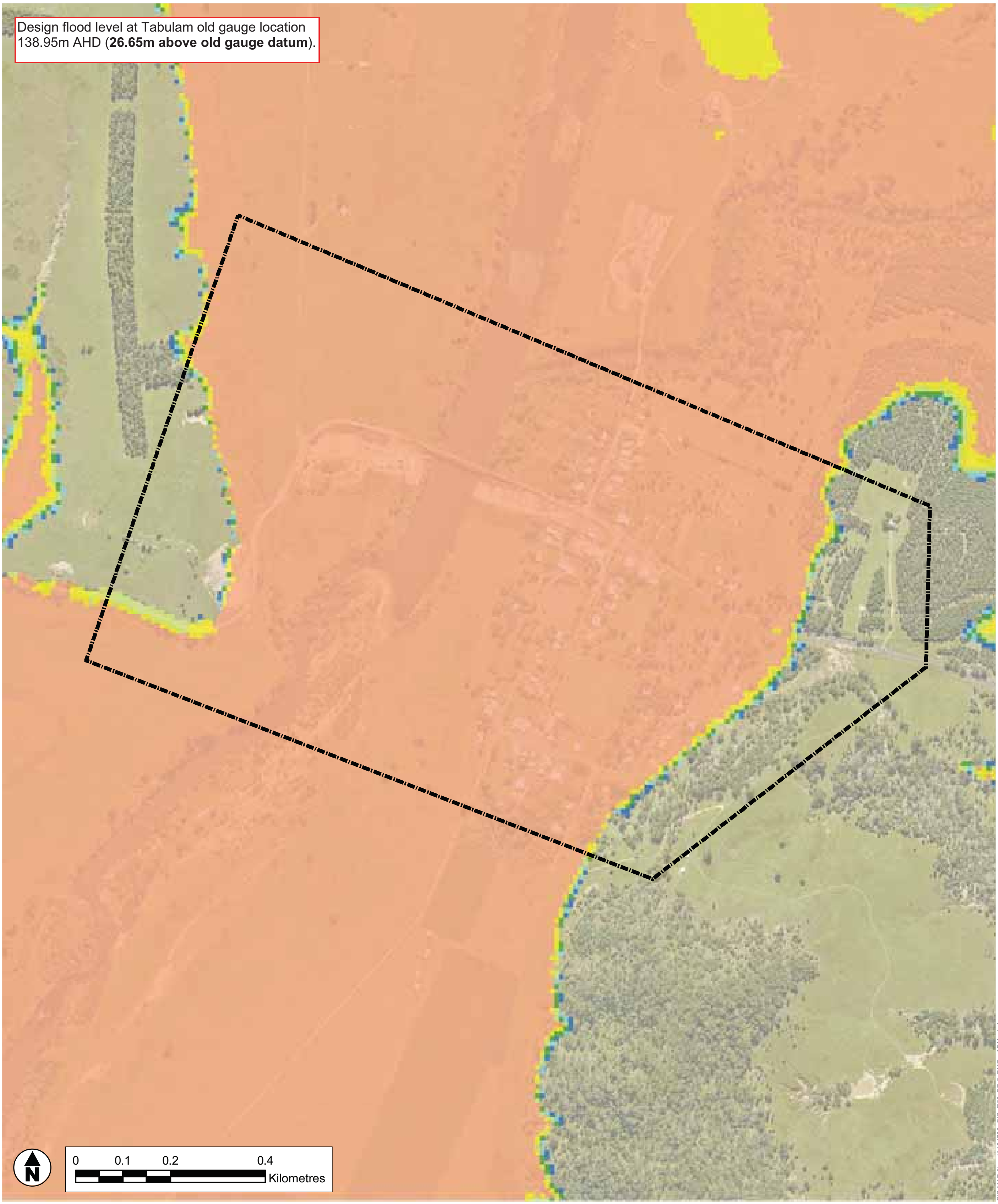
A3

SHEET	1 of 1	GDA 1994 MGA Zone 56		
TITLE	Provisional Flood Hazard 0.2% AEP Event AIDR Categories			
PROJECT	Tabulam Floodplain Risk Management Study and Plan			
DRAWN LC	PROJECT # IA164700	MAP # FIGURE E-7	REV 1	VER 1
CHECK AH	DATE 27/03/2019			



GIS MAP file : IA164700_GIS_R03_FE-8_PMF_zAEM_r1v1

Legend

Hazard Category (AIDR)

Legend - do not remove

- H1 - Generally safe for vehicles, people and buildings.
- H2 - Unsafe for small vehicles.
- H3 - Unsafe for all vehicles, children and the elderly.
- H4 - Unsafe for all people and all vehicles.
- H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
- H6 - Unsafe for Vehicles and people. All building types considered vulnerable to failure.
- Study Area

JACOBS

A3

SHEET	1 of 1 — GDA 1994 MGA Zone 56
TITLE	Provisional Flood Hazard Extreme Event AIDR Categories
PROJECT	Tabulam Floodplain Risk Management Study and Plan
DRAWN	LC
PROJECT #	IA164700
MAP #	FIGURE E-8
REV	1
VER	1
CHECK	AH
DATE	27/03/2019

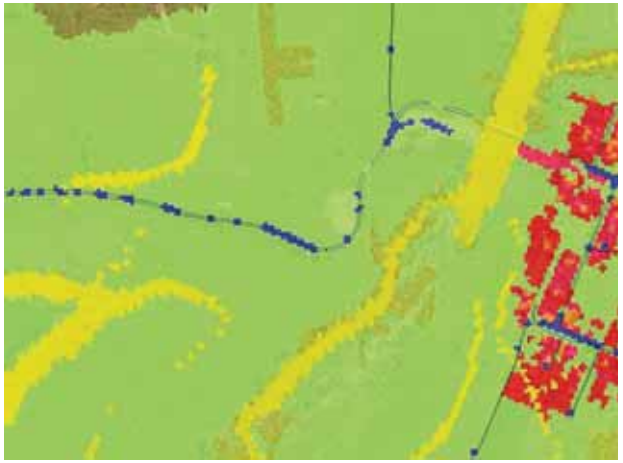
Appendix F. Model Peer Review

Tuflow Model Build and Results Check List

Job Number:	IA164700	**PM:**	Lih Chong
Completed by:	Greg Rogencamp / Shilin Chen	**Date:**	10/12/2018
Model:	TB_DesFlood_~e~_003.tcf TB_Base_Jan2011_20m_034		
Location of Model	J:\IE\Projects\04_Eastern\IA164700\01 Design\JacobsModelling_TUFLOW\Tabulam\DRAFT_TUFLOW		

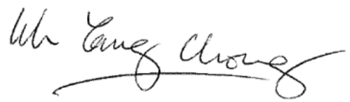
Item	Checker / Review comments	Modeller response	Have all comments been addressed
Focussing Questions			
What is the intended purpose of the flood study?	Investigate existing and future flood risks in the study area		
Have the most appropriate techniques been used?	TUFLOW 2017-09-AC-IDP-W64 used.		
What are the most likely sources of inaccuracy?	Flood gauge for flow estimation Terrain in river (below ALS water level)		
How sensitive are the results to the possible range of inaccuracies?	Flow estimation has by far the largest potential to affect results.	Design flow estimate has been undertaken with careful flood frequency analysis of the available stream gauge data.	Yes
Does the type of model chosen (1D, 2D, 2D/1D, unsteady, steady-state) meet the study needs	Yes	-	Yes
Is the resolution sufficient (2D grid size, 1D XS spacing)	20m. To be changed to 10m as per request from client.	Extensive testing with down to 10m grid was trialled but could not resolve model to produce stable and reliable results. Very deep to 20m and swift flows. Retaining 20m grid	Yes
Is the timestep appropriate?	Timestep is 0.5s for a 20m model – seems too low – should be ok at 2s to 4s.	0.5sec retained but not expected to significantly affect result	Yes
Hydrology			
What hydrology software has been used and is it appropriate ?	None – FFA used. Key issue here is that the calibration process has become circular. The flows were adjusted to meet the gauge levels. This then informed a new rating curve. So, it is hard to call the model calibrated without any independent assessment of flows (eg from rainfall-runoff model). Also, check report – gauge name for smaller river changes from Derek to Drake – looks like the same gauge.	The model inflows were scaled up to account for floodplain storage and flow attenuation for the reach between the upstream boundary and the gauge location, in order to achieve a good match to the flows at the gauge. This is considered an appropriate approach given that there is no stream gauge for flow estimation at the upstream model boundary. A separate hydrologic	Yes

		model would be calibrated/verified to the stream gauge in any case and would not account for the floodplain storage which is evident in the hydraulic model. Gauge name was incorrectly referred to as Derek due to autocorrect – report text has been updated.	
Where is the location of the hydrology review	-	-	
Terrain Representation			
Correct location/orientation and reading of the 2d grid *(2d_dom, 2d_grid checks)*	Oriented to Clarence River – so fine	-	
Upon what was the terrain information based?	LiDar collected in 2018 with +/- 10cm accuracy	-	
Is the accuracy of the terrain data appropriate for the study requirements?	Yes	-	
How sensitive are the model results to terrain inaccuracies?	-	-	
Correct modification to the base data (*2d_zln checks, zsh_zpt_check, DEM_Z.asc).*	Roads modelled as z-line THICK – recommend model as z -line RIDGE THIN Z-shape used to fix bathymetry- ok	Model updated with recommended changes.	Yes
Correct input and reading of hxe and hxi boundary lines i.e at culvert inlets, bank tops, pits *(1d_2d_bc checks)*	Ok	-	
Appropriate distribution of inflows into the 2d domain and reading of data. (i.e. Rain-on-cell / SA / ST)	QT lines – ok	-	
Are there assumptions in the DSBC's that affect modelled flood behaviour? (e.g., HT / HQ)	HQ D/S boundary with slope of 0.002 m/m – looks like it draws down levels a bit too much – actual slope upstream looks more like 0.0007 m/m. Suggest sensitivity test be carried out to show no effect at Tabulam area of interest.	Sensitivity testing has been conducted with d/s slope of 0.001m/m (0.1%) for design 1% AEP and shows low sensitivity and negligible change in flood levels in study area (+0.01m)	Yes
How sensitive are the results to these assumptions?	-	See response above	Yes
Are there joint probability considerations for the rainfall and downstream boundaries?	No	Joint probability not assessed for calibration events as these are based on direct measurement.	Yes

		Joint probability of waterway inflows has been considered for the design flood events.	
Hydraulic Roughness / Losses			
How were the roughness values chosen?	Adopted values fall within the recommended ARR range - ok	-	Yes
Correct input and reading of Bed Resistance values (2d_grid check, DEM_M.asc)	2d_mat_roads layer not read in as a continuous row of cells – no need to fix in coarse model – will be better in fine grid model. (see below. Blue represents roads). 	Model retained as 20m resolution. Effect of narrow road on overall flood behaviour with deep flows not expected to be significant.	Yes
Correct losses applied to landuse in the material layer (particularly in Rain-on-cell)	-	-	
Structures			
Correct input and reading by Tuflow of the 1d network (1d_check) • Channels • Pits / pipes	3 culverts and 2 overflow bridges in 1D	-	
Long section plot of channel / pipes (*1d_check Mi tools*).	-	-	
Bridges • Appropriate loss • Soffits • Weirs • Blockage	Ok	-	Yes

Correct input and sensible head losses through 2d structures (2d_fc checks)	-	-	
Correct input and reading of layer flow constrictions i.e. Bridges or fences (*lfcsh_uvpt_check*) Check total form loss (i.e. 1.56)	Ok.	-	Yes
Outputs			
Has a mass balance simulation been done? What checks have been conducted to confirm external inflows (i.e. XP-RAFTS) have been applied correctly?	Not required as FFA used Internal TUFLOW mass balance is good.	-	Yes
Appropriate PO Lines / points added to cover area of interest and analysis flow paths	-	-	Yes
Grid types required to satisfy the scope of works (i.e. d, h, v, z0, mb1)	-	-	Yes
Appropriate Time Series Output Interval (i.e. enough to capture the peak, but not too many to generate large files)	-	-	Yes
Flood Event Durations			
Have the critical durations been assessed?	NA	-	Yes
Has the hydraulic model been simulated for long enough to capture the maxima?	yes	-	Yes
Simulations			
Do the results make sense ? i.e. Flow paths / location of bank overtopping	OK	-	Yes
How much mass is lost in the model ?	0.01% - ok	-	Yes
Negative depths	0 negative depths	-	Yes
Has a total mass balance been carried out: Rainfall on catchment = Flow out of hydraulic model (net) + Floodwaters retained (net)	-	-	Yes
Are there any fluctuations in the results or any significant head loss over hydraulic structures?	500mm head drop in 500y – bridge overtopped	Considered reasonable for very rare events, high flows	Yes
Mapping			
Does the mapping reflect the results ?	-	Yes	Yes
Does the mapping present the results in a clear manner to the end user ?	-	Yes	Yes
Are any qualifications / comments / caveats required on the mapping ?	-	Yes	Yes

Calibration / Verification (if done)			
Are the historical flood events chosen representative of the design floods of most importance ?	Calibrated to 1976 & verified to 2011 – highest recorded event. But as discussed above, the calibration is circular. There should be some discussion on: • how the 2011 flow estimate could be verified / justified (is there a catchment-wide hydrology model ??) • what is the new rating curve derived from the 2D model and how well does it match the gaugings ? Need to show this new curve as it will form the basis of the FFA which will / has informed the design flows. Ideally, the 2D model rating curve would match well. But it is suspected that the lack of bathymetrical data will affect low flows.	Refer to comment response in Hydrology section above. Updated rating curve based on model result is compared to current rating curve in the report. There is a good match for flows above 10% AEP. As expected the low flows do not have a good match due to absence of detailed bathymetric data in the model.	Yes
How accurate are the recorded flood levels ?	Tabulam gauge – peak and timing accurate, hydrograph not accurate for 1976 Flood marks in the village in 2011 – anecdotal	WaterNSW hydrographer stated there are inaccuracies in the 1976 water level hydrograph due to instrument failure. Refer to discussion in report Section 5.4	Yes
How accurate are the gauged flows ?	Not accurate – flows for 2011 and 1976 extrapolated beyond rating curve until TUFLOW model matched recorded water levels .	The extrapolation is discussed in Section 3.3 of the report.	Yes
Does the model replicate these recorded values to an accuracy commensurate with the study objectives ?	At gauge: 0mm difference in1974, 90mm in 2011 with 1.5h lag – ok Village marks – less than 340mm difference – ok	OK	Yes

Signature of the Modeller		**Date**	15 January 2019
Signature of the Checker / Reviewer		**Date**	11th December 2018