ATTACHMENT DOCUMENT
FOR
COUNCIL MEETING

PART B

Tuesday 22 September 2020

Michael Urquhart
GENERAL MANAGER

AGENDA

1. *Rowena Flood Study and Floodplain, Risk Management Study and Plan – Draft Report.*

ROWENA FLOOD STUDY AND FLOODPLAIN RISK MANAGEMENT STUDY AND PLAN

Draft Report

JULY 2020

Rowena Flood Study

Project Number: 190042

Client: Walgett Shire Council

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Date: 9 July 2020

Verified By: Zac Richards

Date	Version	Description
17 December 2019	1	Data collection, model setup, design flood results
16 March 2020	2	Updated based on Council and DPIE feedback
9 July 2020	3	Updated with Floodplain Risk Management Study

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EXECUTIVE SUMMARY

A flood study and floodplain risk management study has been carried out for the town of Rowena in accordance with the NSW Floodplain Management Program. The study uses the record of flooding at the town and the wider region, as a well as a series of hydrologic and hydraulic models, to determine the town's design flood behaviour. The primary outputs of the flood study are description and mapping of a range of design flood events, ranging from frequent to very rare floods. The floodplain risk management study, contained in this joint report with the flood study, assesses flood risk and possible flood risk management measures. The floodplain risk management plan consists of a table presented in this executive summary.

Rowena is located in northern NSW Sydney about 80 km east of Walgett and 100 km west of Moree. The town lies between two floodplains; the Gwydir River to the north and the Namoi River to the south. Historical flood events, including in February 2012, have seen the majority of the town inundated with floodwaters. The source of this flooding has been assessed by the current study.

The study found that while Rowena is in the vicinity of various creeks and rivers with extensive floodplains, the town is not flooded by these watercourses in all but the most extreme flood events. Specifically, neither Thalaba Creek to the north nor Pian Creek to the south flood the town in events up to and including the 1% AEP. The remnant channel of an unnamed creek that approaches the town from the east also does not lead to flooding. A series of hydraulic models using HEC-RAS and TUFLOW were used to analyse all potential sources of flooding, and these are detailed in Section 3.

The analysis concluded that localised rainfall events lead to flooding at Rowena, with the catchment area extending around 3 km to the east of the town. A local hydraulic model was established to assess the flooding due to local rainfall (see Section 3.5) and eight design events were assessed (20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP, as well as PMF). The modelling found that runoff can be trapped in the town area by the railway embankment on the town's western boundary, as reported by various residents of the town. The town's flood behaviour is described in Section 3.5.4.

A flood risk assessment was carried out for the town including hazard mapping, property inundation and economic damages. In a 1% AEP flood the town experiences H1-H3 hazard and widespread inundation, with many properties flood above floor level. The town can also be isolated for days or weeks at a time due to flooding in Gwydir or Namoi River systems. The risk assessment is presented in Section 4.

Flood risk management measures include a variety of structural and non-structural measures. A drainage system and levee for the town was design in 2019. This study assessed the design as well as an additional levee section. The report also considers planning measures and response measures. A summary of the recommended measures is presented in the below floodplain risk management plan.

Table 1: Floodplain risk management plan for Rowena

Measure	Objective	Responsibility	Report Reference
Rowena Road levee with additional eastern section, built to 1% AEP plus freeboard, combined with improved railway cross drainage.	Significantly reduce the severity of flooding by preventing inundation from reaching the town and draining it more efficiently through the railway line.	Council	Section 5.2.3
Adopt updated Flood Planning Area and Flood Planning Level for Rowena	Ensure new development is built above the design flood level.	Council	Section 5.3
Community Flood Education	Improve awareness of flooding in the community and how to respond during a flood	Council and SES	Section 5.4.1
Update Local Flood Plan	Update the plan to contain information on flooding and flood determined by this study	SES	Section 5.4.2
Road Safety Guide Posts	Guide vehicles away from hazardous flooding by marking the road boundaries.	Council	Section 5.4.3

FOREWORD

The New South Wales (NSW) Government's Flood Prone Land Policy aims 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.

Through the NSW Department of Planning, Industry and Environment and the NSW State Emergency Service (SES), the NSW Government provides specialist technical assistance to local government on all flooding, flood risk management, flood emergency management and land-use planning matters.

The Floodplain development manual (NSW Government 2005) assists councils to meet their obligations through a five-stage process resulting in the preparation and implementation of floodplain risk management plans. Image 1 presents the process for plan preparation and implementation.

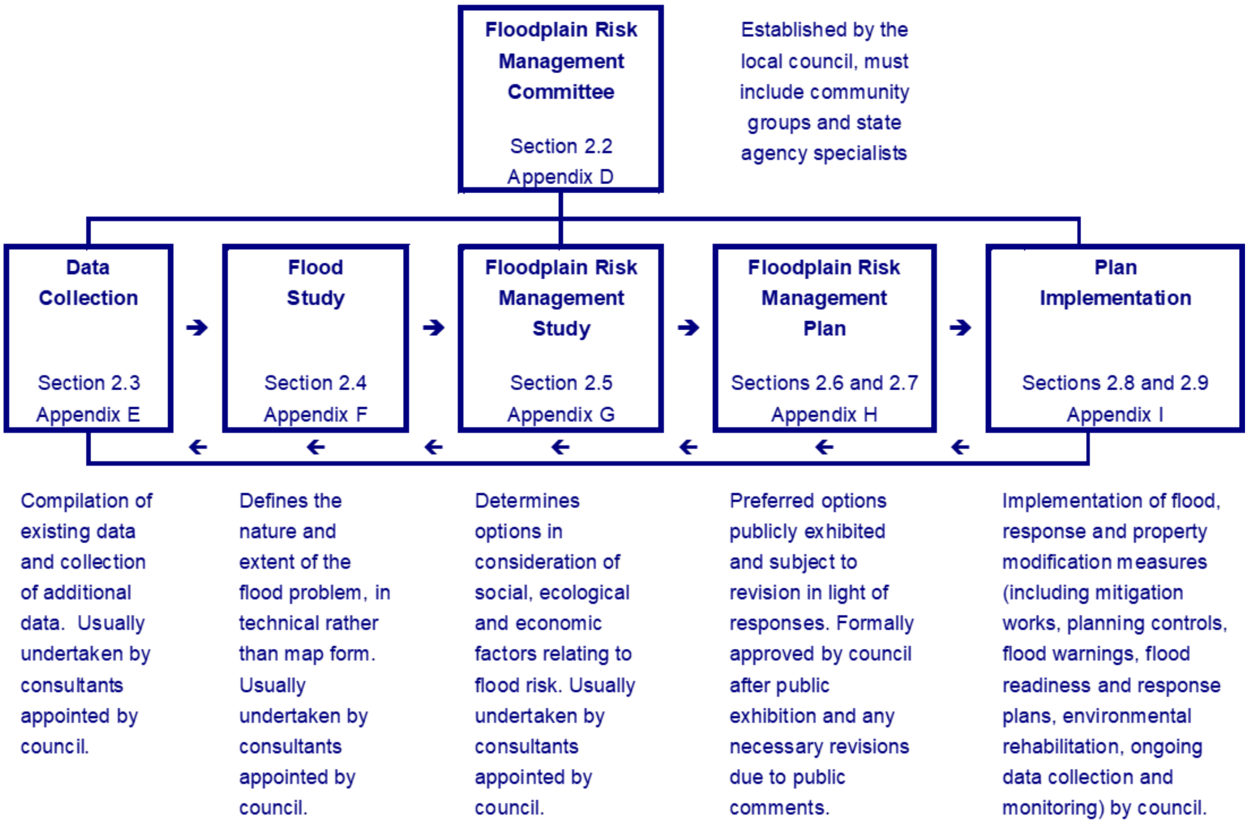


Image 1: The floodplain risk management process in New South Wales (FDM, 2005)

1. INTRODUCTION

Walgett Shire Council (Council) has received financial support from the State Floodplain Management program managed by the Department of Planning, Industry and Environment to undertake a flood investigation of the township of Rowena. GRC Hydro have been engaged by Council to undertake a flood study and floodplain risk management study and plan.

This study composes stages 1 to 4 in the five-stage process outlined in the NSW Government's Floodplain Development Manual (FDM, 2005). These works include:

Data collection – collection of all applicable data to be used for the ensuing stages of the studies;

Flood Study – a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan;

Floodplain Risk Management Study (FRMS) – assess the impacts of floods on the existing and future community and allows the identification of management measures to treat flood risk; and

Floodplain Risk Management Plan (FRMP) – outlines a range of measures, for future implementation, to manage existing, future and residual flood risk effectively and efficiently.

Following the completion of the FRMP, the final stage of the FDM (2005) floodplain management process will involve implementing the findings of the FRMP. Further details of each of these FDM (2005) stages are outlined below.

Data Collection

The collection and collation of data necessary for the completion of the flood and floodplain risk management studies is a fundamental part of the floodplain management process. It is typically begun at the outset of the study, but generally continues throughout the period of the project as data becomes available. The quality and quantity of available data is key to the success of a flood study and FRMS.

Flood Study

A flood study is a comprehensive technical investigation of flood behaviour that provides the main technical foundation for the development of a robust floodplain risk management plan. It aims to provide an understanding of flood behaviour and consequences for a range for flood events. Consideration of the local flood history, flood data is used to assist in the development of hydrologic and hydraulic models which are calibrated and verified to improve confidence in model results.

Floodplain Risk Management Study

A floodplain risk management study increases understanding of the impacts of floods on the existing and future community. It also allows testing and investigating practical, feasible and economic management measures to treat existing, future and residual risk. The floodplain risk management study will provide a basis for informing the development of a floodplain risk management plan.

Floodplain Risk Management Plan

The floodplain risk management plan documents decisions on the management of flood risk into the future. The FRMP uses the findings of a floodplain risk management study, to outline a range of measures to manage existing, future and residual flood risk effectively and efficiently. This includes an itemised list of measures and prioritised implementation strategy.

This report examines Stages 1 and 2 of the 5-step process outlined above. Stages 3 and 4 will be presented in subsequent reports produced as part of the current study.

1.1 STUDY OBJECTIVES

The objective of this study is to improve understanding of flood behaviour, and better inform management of flood risk for Rowena. The study will also provide a sound technical basis for any further flood risk management investigation for the town. Meeting the requirements of the identified end user groups (see Section 1.2), which have been tailored to the context of the flood situation, is a key objective of this study.

The Data Collection and Flood Study stages include:

- Review all available flood related information for the town and its catchments;
- Develop a hydrologic computer model to simulate the rainfall/runoff process for the various rivers, creeks and overland flow paths that contribute to flooding at Rowena;
- Ensure the accuracy of the rainfall/runoff model through calibration to historic events and validation of design flows estimates to flood frequency analysis;
- Develop design flows for each of the watercourses affecting the town for the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP events and the PMF;
- Develop a hydraulic model to simulate flood behaviour at the town
- Ensure the accuracy of the hydraulic model through comparison to historic events;
- Define design flood behaviour for the events described above;
- Undertake sensitivity analysis to investigate potential changes associated with Climate Change and selected model parameters; and
- Assess design event flood hazard, flood function and emergency response classifications.

The FRMS and FRMP objectives include:

- Definition of a Flood Planning Area;
- Providing information to support emergency management activities;
- Providing advice on land-use planning considering flooding and overland flow;
- An assessment of cumulative impact of development;
- The identification and preliminary assessment of management options; and
- Detailed assessment of preferred options; and

- The development of a FRMP which list the recommended measures aimed at managing flood risk for Rowena.

1.2 PROJECT END USERS

The study outputs are suitable to inform decision making for investing in the floodplain; managing flood risk through prevention, preparedness, response and recovery activities; pricing insurance, and informing and educating the community on flood risk and response to floods. Each of these areas has different user groups, whose needs vary. The key end-user groups that this study aims to support are identified in Table 1.

Table 2: Project End Users

Potential End User Group
High-level strategic decision makers
Community
Flood risk management professionals
Engineers involved in designing, constructing and maintaining mitigation works
Emergency management planners
Land-use planners (strategic planning and planning controls)
Hydrologists and meteorologists involved in flood prediction and forecasting
Insurers

2. BACKGROUND

2.1 STUDY AREA

Rowena is located in northern NSW Sydney about 80 km east of Walgett and 100 km west of Moree. The town has a population of between 10 and 20 people[1] and has a post office, primary school and pub. Although small in size, the town serves the surrounding farming area, which is used for agriculture and grazing. The study area, see Figure 1, is approximately 330 ha in size and centred on the town. The region was recently affected by flooding 2011, 2012 and 2016.

Figure 1: Study Area

The town is located on slightly elevated land between Thalaba Creek to the north and Pian Creek to the south. Thalaba Creek is a tributary of the Barwon River, and extends approximately 40 km west of Rowena and at its closest point it is 7.1 km north of Rowena. Pian Creek is 13.5 km to the south of Rowena, and is an anabranch of the Namoi River that re-joins it near Walgett. The catchment area of both creeks is not straightforward to define. In flood events, virtually all channels in the region tend to split into anabranches, with some flowpaths forming in areas that have little to no channel

[1] In the 2016 census, the 'state suburb' of Rowena had a population of 181, while the town itself is recorded as having a population of 23 in the 2016 Development Control Plan. Site visit in September 2019 recorded a current population of 9 residents. The primary school, which serves the surrounding area, had 33 students and five staff in 2012.

definition. For example, previous modelling indicates that Thalaba Creek receives flow from the Gwydir River, its own catchment, and also the Namoi River (see Section 2.3). Determining the sources of flooding at Rowena therefore required considerable analysis, which is described in Section 3. The analysis found that flooding at Rowena does not occur due to breakouts of Pian or Thalaba Creeks, but rather is caused by local rainfall, in virtually all flood events.

2.2 DISCUSSION OF RELEVANT POLICIES, LEGISLATION AND GUIDANCE

2.2.1 Implemented Guidelines and References

Table 3 presents the guidelines, manuals and technical reference documents used for this study. These documents detail best practice in regard to management of flood risk. They cover both best practice about the technical assessment of flood behaviour and flood risk, and, more generally, who has responsibility for managing flood risk and how this management is best achieved in the area.

Table 3: Guidelines and Reference Documents

Reference	Topic
Australian Emergency Management (AEM) Handbook Series, Managing the floodplain: A guide to best practice in flood risk management in Australia – AEM Handbook 7	Best practice
AEM Handbook 7, Technical flood risk management guideline – Flood Hazard	Flood hazard
AEM Handbook 7, Technical flood risk management guideline – Flood Emergency Response Classification	Emergency Response
AEM Handbook 7, Technical flood risk management guideline – Flood risk information to support land-use planning	Land use
AEM Handbook 7, Technical flood risk management guideline – Assessing options and service levels for treating existing risk	Mitigation options and service levels
AEM Handbook 6, National Strategy for Disaster Resilience – community engagement framework	Community engagement
Australian National Committee on Large Dams (ANCOLD) Guidelines	Dam safety
Australian Rainfall & Runoff 2016	Best practice
Section 733 of the Local Government Act, 1993	Flood prone land policy
NSW Government's Floodplain Development Manual (2005)	Flood prone land policy and industry practice
SES requirements from floodplain risk management process	SES requirements
Practical consideration of climate change	Climate change

2.2.2 Review of Council Planning Policy

Walgett Shire Council has a number of policies relating to development of flood prone land in the Local Government Area (LGA). The LGA, which borders Queensland and has an area of approximately 22,000 km^2, includes the towns of Walgett, Lightning Ridge, Collarenebri, Pilliga, Pokataroo, Rowena, Burren Junction, Cryon, Cumborah, Glengarry and Carinda. Centred on Walgett, it also contains the Barwon, Namoi and Mehi Rivers. The relevant council policies are the Local Environmental Plan

(2013), the Development Control Plan (2016) and to a lesser extent, the Rural Residential Land Use Strategy (2015), and these are summarised in the following section.

Local Environmental Plan 2013

The LEP contains standard provisions in Clause 6.2 for flood planning in the LGA. The objectives of the clause are to:

a) minimise flood risk to life and property,
b) allow development that is compatible with a site's flood hazard, including the risks associated with climate change; and
c) to avoid adverse impacts on flood behaviour and the environment.

The clause applies to flood liable land, and there is not a flood planning area map or other further definition to define the location of such land. The clause then contains the standard conditions on development on flood liable land, which are reproduced here:

> *(3) Development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development:*
>
> *(a) is compatible with the flood hazard of the land, and*
>
> *(b) will not significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and*
>
> *(c) incorporates appropriate measures to manage risk to life from flood, and*
>
> *(d) will not significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and*
>
> *(e) is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.*

Development Control Plan 2016

The DCP contains provisions for development in flood prone land in the LGA. Specifically, Section 3.2 gives an overview of flood affected land and then sets out development controls. The overview states that the LGA is "about 85%" of the area is "floodplain land form", and that, in general, flood prone land is considered to be where soils are black (red soil is considered not flood prone). It describes Rowena's flood affectation as follows:

Rowena 23 people	Located on a flood plain, 7.4km south-west of the nearest named watercourse, Thalba Creek.	Anecdotal evidence indicates village area has never been inundated by floodwater. During Feb 2012 the village was isolated by what was considered record flooding of Thalba Creek system.	No

Specific flood controls in the section include:

- The floor of a dwelling house on flood prone land is to be at least 500 mm higher than the historical flood peak for the site

- Residential subdivisions should ensure there is flood free access via vehicle, or if not possible, there should be safe wading access, provided there is not prolonged inundation.
- Development should not "obstruct the movement of floodwater or cause concentration or diversion of floodwaters".
- Construction materials should be flood compatible and the Development Application should demonstrate the structure can withstand the force of floodwaters, including debris and buoyancy.
- For residential development, floor levels of habitable rooms should be above the flood planning level, and where floor levels are below it, there should be any increased risk to the inhabitants. Rebuilding part of a dwelling may be permitted if the building maintains the same footprint and effect on floodwaters.
- For landfilling, a report is required to detail the impact of the proposed fill on adjoining properties, and internal drainage for any proposed levee banks.
- Controls for commercial development and non-residential rural buildings.

Walgett Shire Rural Residential Strategy

The rural residential strategy has the objective of guiding decisions on the development of rural residential land in the LGA. Section 8 of the strategy consists of a constraints analysis, one of which is flooding. Flooding has been classified as either high, medium or low velocity, with 'high' likely to require hydraulic infrastructure, while 'medium' can mitigated at the property level. It describes flood affectation for several areas of rural residential development but no area is in the vicinity of Rowena.

2.2.3 NSW SES Local Flood Plan

The applicable plan is the 'Walgett Shire Local Flood Plan', which covers the town of Rowena. Information specific to the town is currently limited, with description consisting of:

> *"Rowena (Population – about 19) - Rowena may be isolated to the north by flooding in Thalaba Creek and to the south by Pian Creek."*

Other information related to Rowena in the plan is:

- The town's location in the northern part of the shire and so sources their supplies from Brisbane and southern Queensland.
- At a height of 7.00 m at the Collarenebri gauge, road access between Collarenebri and Rowena is cut. There is access for some Rowena residents to Wee Waa via Burren Junction.

2.3 PREVIOUS STUDIES

A number of studies have investigated flooding and floodplain management in the Namoi and Gwydir catchments, in the vicinity of Rowena. These studies and their relevance to the current study are summarised below.

2.3.1 Narrabri Flood Study (WRM Water, 2016)

The study investigated flood behaviour at Narrabri using a flood frequency analysis, a hydrologic model (XP-RAFTS), and a hydraulic model (MIKE-FLOOD). The study produced a range of design flood extents and levels for the town, including the effect of flooding in the Mulgate Creek and Long

Gully catchments. The hydraulic model was calibrated to the floods of February 1955, February 1971 and July 1998. Two other events (December 2004 and February 2012) were used for calibration of the local catchments.

The study provides little information regarding flood behaviour on the Namoi River floodplain downstream of Narrabri. The pertinent information to the current study is therefore the estimated river flow at Narrabri for historical and design events. The design events were determined using a flood frequency analysis (FFA) used a record of 125 years (1890-2015) by reconstructing periods of missing data, as well as censored flows in the 1865-1890 period. Based on findings of previous studies, the FFA assumed that the construction of various dams upstream did not impact flood behaviour or the FFA. The historical and design flows at Narrabri, which are a combination of the Narrabri Creek and Namoi River, are as follows:

- February 1955: 5,335 m^3/s
- February 1971: 3,618 m^3/s
- July 1998: 2,408 m^3/s
- 5% AEP: 2,920 m^3/s
- 1% AEP: 4,860 m^3/s

This information was used to model the 1% AEP flood behaviour in the current study (see Section 3.4).

2.3.2 Floodplain Management Plan for the Lower Namoi Valley Floodplain (NSW DPI Water, 2018)

The document is a state government floodplain management plan for the Lower Namoi, aimed at guiding development on the floodplain via planning processes, to manage flood risk as well as to manage ecological function, cultural assets and economic activities in the area. The plan used a series of five MIKE-FLOOD hydraulic models to map the extent, discharge, velocity and depth-velocity product of two design floods: those of February 1971 (referred to as 4% AEP 'large design flood') and December 2004 (13% AEP, 'small design flood'). The modelled area is the Namoi River from Narrabri to Walgett, including the floodplain to the north but not as far as Rowena (see Figure 2).

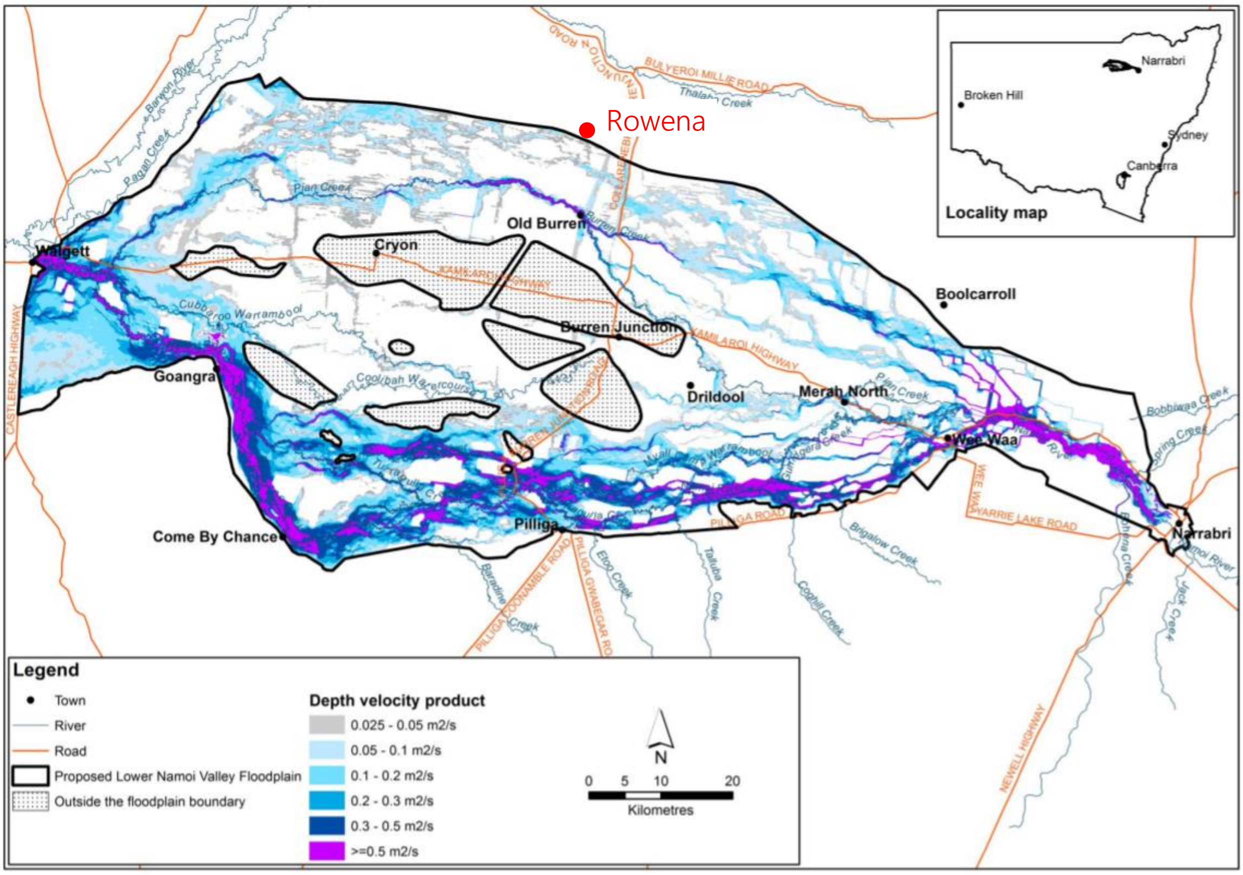


Figure 2: Figure 10 from the Floodplain Management Plan for the Lower Namoi, showing large design flood event with Rowena location added

The study's mapping of creeks and watercourses on the Namoi River floodplain does not conclusively show whether Rowena lies within the floodplain. There are several flowpaths near the northern extent of the modelled area that may continue west and flood Rowena. The modelling indicates that Pian Creek near Old Burren does not have a wide floodplain and while there are flowpaths further north, towards Rowena, they are poorly defined and have relatively little flow.

2.3.3 Floodplain Management Plan for the Gwydir Valley Floodplain (NSW DPI Water, 2015)

This document is a state government floodplain management, similar to the Namoi Plan, for the Gwydir floodplain between Pallamallawa (near Moree) to near Collarenebri. The area includes the Mehi River and various creeks including Thalaba Creek near Rowena. The plan used a series of hydraulic models (MIKE-FLOOD) and hydrologic models (RORB) and flood frequency to map inundation extents and the depth-velocity product of two floods (January 2004, referred to as the 'small design flood' February 2012, referred to as the 'large design flood'). The flood frequency analysis used six different gauges, with the longest record being 67 years, at Gravesend, approximately 50 km upstream of Moree. It is not apparent how the effect of Copeton Dam (completed in 1973) was incorporated in the analysis. The FFA design discharges at Gravesend were not reported but have been read off of the report's figure as approximately 6,370 m^3/s for the 1% AEP and 1,850 m^3/s for the 5% AEP event.

Modelling of the flood behaviour for the February 2012 event (referred to as the 'large design flood') shows the town of Rowena is not flooded by Thalaba Creek flooding. This is further discussed in Section 3).

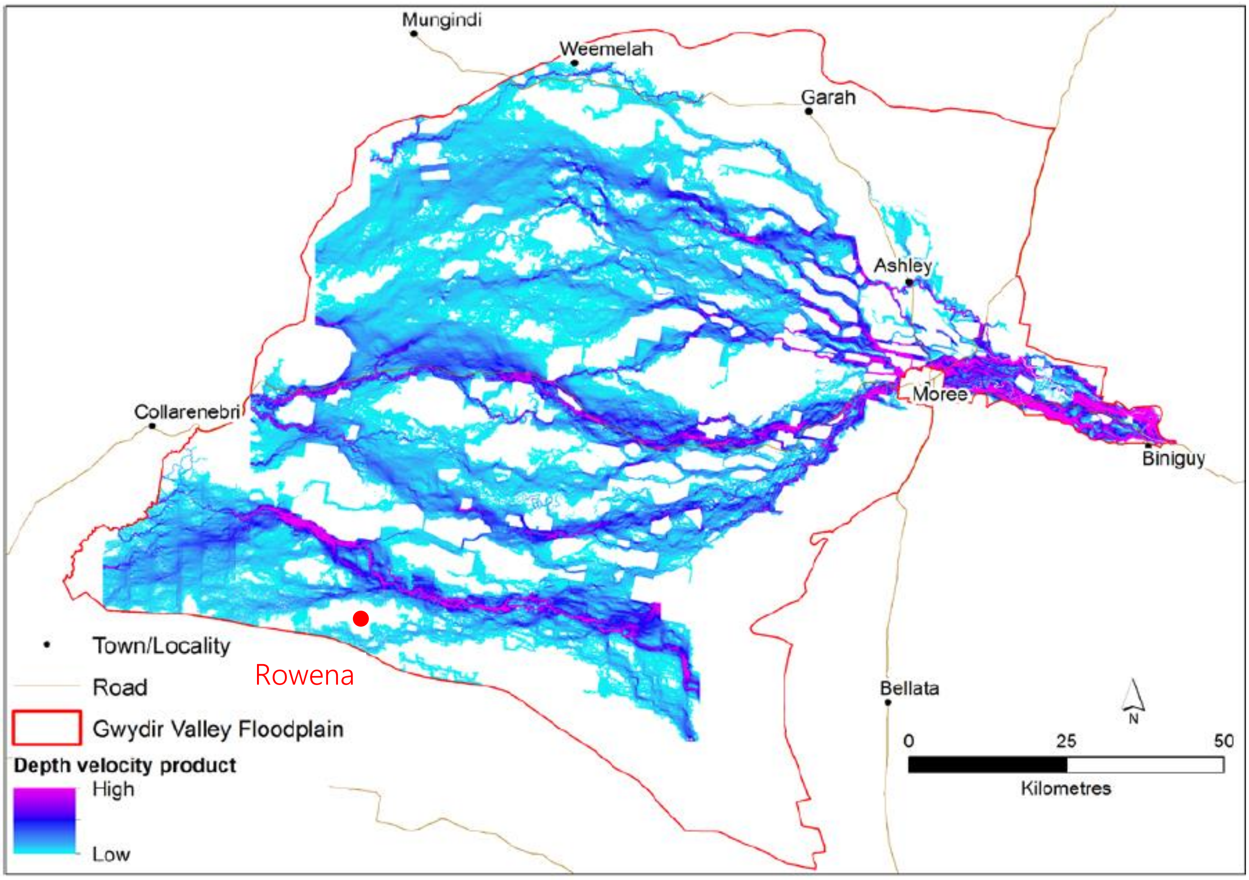


Figure 3: Figure 5 from Gwydir Floodplain Management Plan, showing 'large design flood' with Rowena added

It was not possible to determine the exact model parameters used in the RORB model established for the Thalaba Creek catchment. The reported parameters did not appear to match those modelled, which gave uncertainty to the estimated discharge hydrographs, and meant conservative values were adopted for the current study. Further information is provided in Appendix C.

2.3.4 Drainage Design Rowena (SMK Consultants, 2019)

SMK Consultants produced drainage design plans for Walgett Shire Council in May 2019, based on survey of the town and occurrence of previous flooding. The survey was undertaken by a combination of drone LiDAR and conventional ground survey. The proposed drainage features consisted of a gutter drainage system running south to north on Shaw, Rowena and Middle Streets, which connect to a line discharging to the west on Rowena Road. There was also an earth levee proposed for the north side of Rowena Road, at 155.26 mAHD, approximately 0.5 m higher than Rowena Road. It is understood these features were at least partially constructed in mid-2019.

2.4 DATA COLLECTION

2.4.1 Topographic Data

A number of different topographic data sets were used in investigating flood behaviour. Ground level survey primary consisted of Digital Elevation Models (DEM) derived from LiDAR, available from the government website 'ELVIS – Elevation and Depth – Foundation Spatial Data'. Ground level spot heights for the town of Rowena were available from recent survey. The data is summarised below and the extent of the available data is shown on Figure 4.

1. 5 metre resolution data provided by NSW Government Spatial Services. The 5 metre Digital Elevation Model (DEM) is produced using TIN (Triangular Irregular Network) method of averaging ground heights to formulate a regular grid. The model is not hydrologically enforced. The processed data has been manually edited to achieve ICSM standard category 3 whereby the ground class contains minimal non-ground points such as vegetation, water, bridges, temporary features, jetties etc. This data has a vertical accuracy of (+/-) 0.9 metre on bare open ground (95% Confidence Interval 1.96xRMSE) and horizontal accuracy of (+/-) 1.25 metre (95% Confidence Interval 1.96xRMSE) on bare open ground. Elevation data were captured in 2017.
2. 1 metre resolution data, provided by Geoscience Australia. The LiDAR 2013 with a point density of two points per square metre. The specified accuracies are 0.3 m vertical error and 0.8 m horizontal.
3. Ground survey of the town was carried out in May 2019, by SMK Consultants on behalf of Walgett Shire Council. The data was used as part of the project 'Drainage Design Rowena'.
4. The location of manmade structures on the floodplains upstream of Rowena was taken from the Floodplain Management Plan for the Gwydir Valley Floodplain (see Section 2.3.3). That study reported that these structures are impermeable and should assumed to be higher than any flood level. This was confirmed via inspecting a sample of them in the 1 m LiDAR, which showed them to be 3-4 m high, and visual inspection during the site visit.

The 5 metre data was found to be uniformly higher, on average, than the 1 metre data, and so was adjusted for use in the coarse and refined hydraulic models. Figure 5 shows three sample areas comparing the two datasets. The figure shows that there is not a constant difference, with a variation of between 0.1 and 0.8 m in the areas shown, with most locations around 0.6 m difference. This average difference of 0.6 m was confirmed by taking long sections of relatively flat ground. The 5 m grid was therefore lowered by 0.6 m before being applied to the model. All areas of step-up or step-down between the two data sets were checked that they were not having a significant effect on flood behaviour.

The 5 metre data was also compared to the 2019 survey at Rowena. It was found to generally match the survey except for a constant offset of between 0.2 and 0.4 m. For the local hydraulic model (see Section 3.5) the 5 metre data was lowered by the average difference (0.315 m). In general, the 5 metre data is not ideal for hydraulic modelling but the alternative (new LiDAR survey) was not feasible given the study budget and the limited added value.

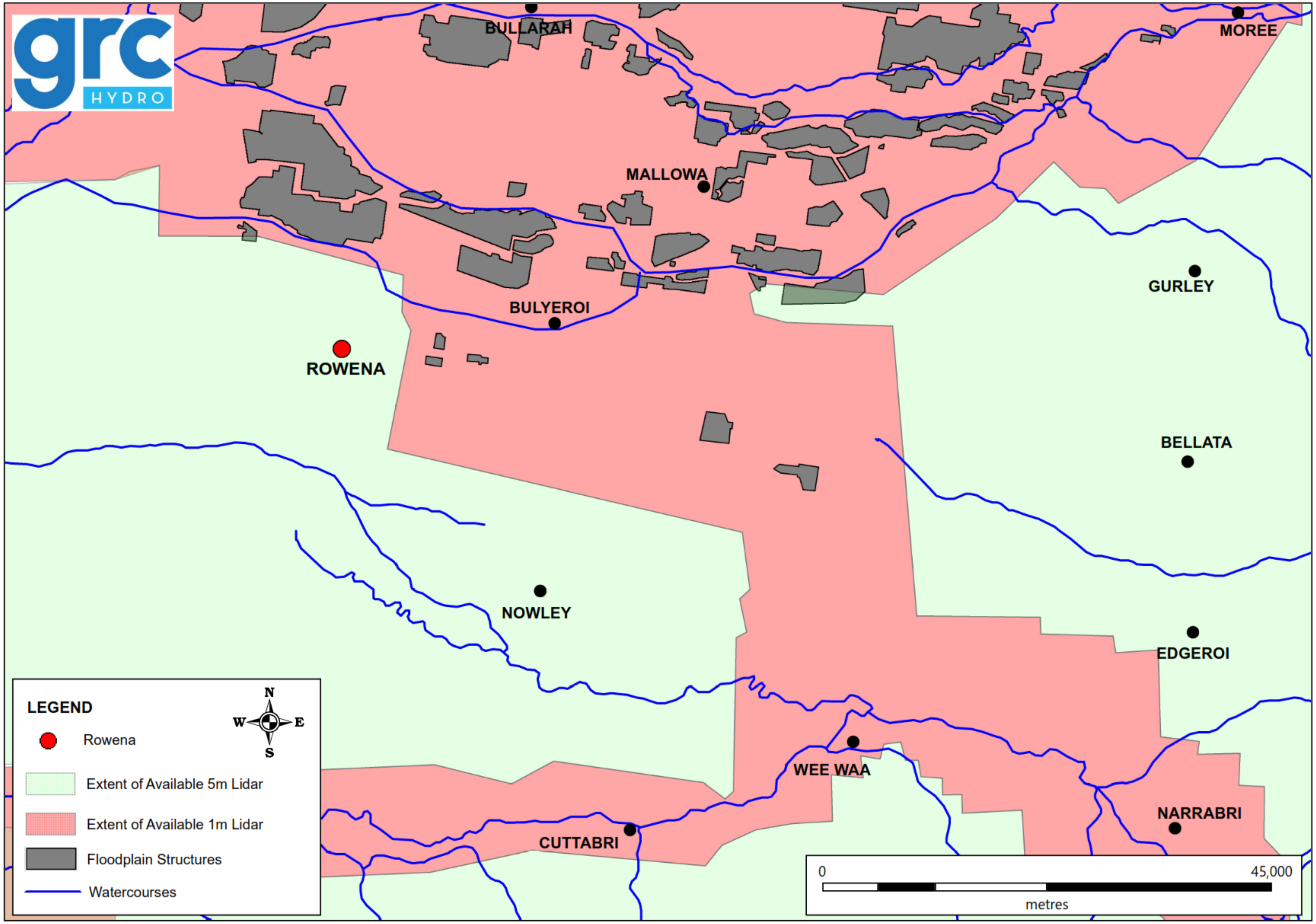


Figure 4: Available Topographic Data

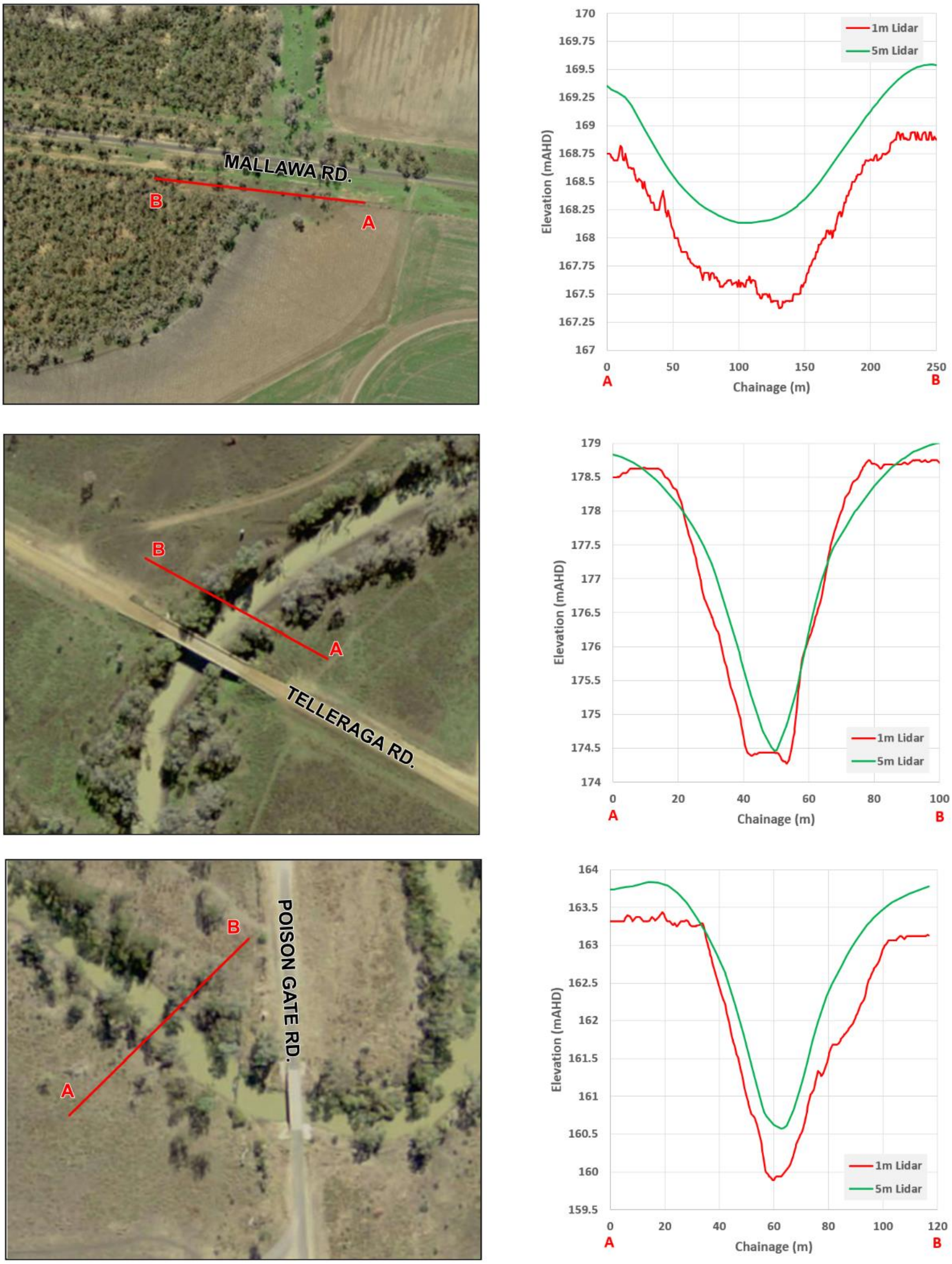


Figure 5: 5m and 1m LiDAR Comparison

2.4.2 Hydrologic Data

The wide scope of the investigation of possible sources of flooding at Rowena meant that a large volume of hydrologic data was collected. This included stream gauge and rainfall data along the Gwydir and Namoi catchments, and records of historical flood events. The data are summarised in the following section.

2.4.2.1 Stream Gauge Data

Stream gauge data is summarised in Table 4 and the location of the gauges is shown on Figure 6.

Table 4: Available Stream Gauge Data

Gauge No.	Gauge Name	Period of Record	Length of Record (years)	Notes
418058	Mehi River at Bronte	1982 to present	37.6	
418068	Mehi River at U/S Ballin Boora Creek	1989 to present	30.6	
418070	Moomin Creek at Moomin Plains	1994 to present	25.4	
418004	Gwydir River at Yarraman Bridge	1929 to present	91.3	Missing record data from 1950 to 1964
418049	Mallawa Creek at Regulator	1986 to present	32.8	
418085	Mehi River D/S Gundare Regulator #2	2002 to present	16.8	
418067	Moomin Creek at Clarendon Bridge (Heathfield)	1988 to present	30.7	
418060	Moomin Creek at Glendello	1984 to present	34.7	
419111	Pian Creek at Old Burren No2	2012 to present	7.0	
419064	Pian Creek at Rossmore	1990 to present	28.9	
419059	Namoi River at downstream Gunidgera weir	1976 to present	43.4	
419061	Gunidgera Creek at downstream Regulator	1975 to present	44.1	
419900	Namoi River at Glencoe	1995 to present	24.2	
419039	Namoi River at Mollee	1972 to present	46.9	
419039A	Namoi River downstream Mollee Weir	1995 to 2011	14.1	
419110	Namoi River at Yarral East	2012 to present	7.1	
419002	Namoi River at Narrabri	1891 to 2011	119.9	Only extreme records reported before 1913. Missing Records from 1995 to 2009.
419003	Narrabri Creek at Narrabri	1891 to present	128.1	Only extreme records reported before 1960.
418002	Mehi River at Moree	1937 to present	82.1	
418037	Mehi River at D/S Combadello Weir	1977 to present	42.2	
418048	Moomin Creek at Combadello Cutting	1982 to present	37.3	
418062	Moomin Creek off take	1992 to 2011	19.2	
418013	Gwydir River at Gravesend road bridge	1955 to present	65.6	Missing record data from 1963 to 1971

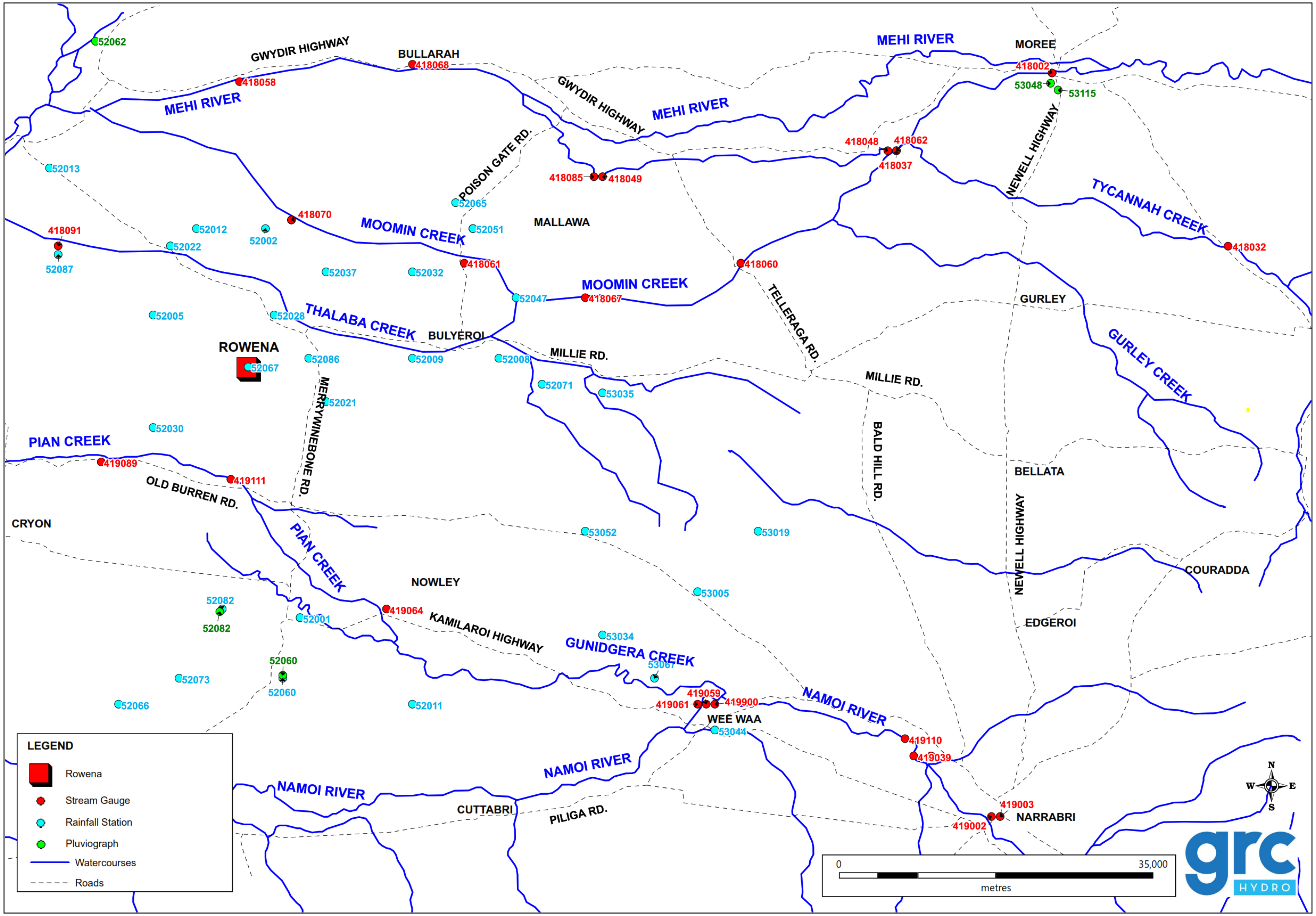


Figure 6: Available Rainfall and Stream Gauge Data

2.4.2.2 *Rainfall Data*

Rainfall data was used to estimate the rainfall for historical events in areas not covered by stream gauges. Available rainfall stations consisted of daily read and pluviograph rainfall gauges. The gauges used are summarised in Table 5 and their location is shown on Figure 6.

Table 5: Available Rainfall Data

Station No.	Station Name	Period of Record	Length of Record (years)	Type
52067	Rowena Post Office	1/11/1968 – 31/08/2019	51	Daily
52086	Rowena (Mayleigh)	01/12/1990 – 31/12/2013	23	Daily
52021	Rowena (Bungara)	01/10/1902 – 27/03/2017	115	Daily
52028	Rowena (Waroonga)	01/08/1898 – 31/08/1990	93	Daily
52082	Burren Junction (Lochmohr)	18/08/1988 – 01/07/19891	1	Pluviograph
52060	Burren Junction (Plain View)	14/09/1966 – 31/12/1970	5	Pluviograph
52062	Collarenebri (Collymongle)	14/09/1966 – 30/11/1975	10	Pluviograph
53048	Moree Comparison	08/04/1964 – 31/07/1995	32	Pluviograph
48031	Collarenebri (Albert St)	02/11/1976 – 31/10/2016	41	Pluviograph
52088	Walgett Airport AWS	10/05/2005 – 30/10/2014	10	Pluviograph
53115	Moree Aero	06/07/1995 – 30/11/2017	23	Pluviograph

2.4.2.3 *Historical Flood Information*

Historical flood information was obtained and collated for use in the model calibration and validation exercise. The information was obtained from a variety of sources including; previous studies and anecdotal evidence provided by local residents as part of the community consultation. Table 6 describes the historical flood information.

Table 6: Historical Flood Information

Source	Flood Event	Description	Notes
Rowena Public School Annual School Report 2012	Nov-2011	"With 2011 ending badly with a very wet harvest for many followed by a minor flood"	Assumed to be November 2011 event
	Feb-2012	"2012 starting so disastrously with the biggest Thalaba creek flood in living memory"	
13 Feb. 2014 Daily Telegraph article – "NSW Drowning in the Dust"	Feb-2012	"[A] farm near Rowena in the state's north west was devastated with floods in February 2012"	Discussion with residents indicate this farm is near Thalaba Creek, several km from Rowena
	Jul-2012	Photo of a house near Rowena flooded, and a car in floodwaters	As above

8 Oct. 2012 Northern Daily Leader article – "Rebuilding lives after flood devastation"	Feb-2012	"floodwaters swept through the North West eight months ago, causing widespread damage and devastation in what was one of the worst floods in at least half a century […] [Rowena] property Rio Park was submerged by floodwaters, isolating them for about four weeks."	Property is same as that in Daily Telegraph article, there is no reference to flooding at the town
	1974	"It was thought to have been the worst flood in that area in about 150 years – the big 1974 flood did not even enter the house at Rio Park"	Indicates that Feb-2012 is the highest flood in 150 years on Thalaba Creek
29 Nov. 2011 ABC article – "A new flood aspect"	Nov-2011	""The floodwaters are receding at last… [at] Rowena where he said he used his dad's surf board to rescue his family chooks.""	Unknown if this is in town or surrounding area
Various other articles were reviewed that described flooding in the region but with no reference to Rowena or the creeks nearby. These include "Moree floods ease as threat moves west" (ABC News, 5 Feb 2012) and "Queensland Premier Anna Bligh declares flood areas disaster zone" (news.com.au, 4 Feb 2012).			
Meeting with two community members on 9 September 2019	Various – February 2012, 1974 and September 2016.	Residents said that flooding in the town is caused by local rainfall, not creek flooding. They explained that when it floods it covers wide areas, with very low velocity and over a long duration (many days), and floodwaters have come up to just below the floorboards in some houses in Rowena. The large round feature south-east of town is referred to as a swamp and fills with water. The paddocks south of the silo, and north of the town also flood. Flooding is likely to be largely the result of culverts through the railway being too high, and possibly too small (the railway borders the west side of Rowena). These culverts are currently being replaced and this may completely resolve the town's flooding issue.	

Meeting with two more community member on 9 September 2019	Various – February 2012, 1974 and September 2016.	The February 2012 event consisted of eight days of flooding in the town. There was a flood in 1974 and water was lapping against the post office building. In that flood, one resident reported that flow came from the north as a breakout from Thalaba Creek that made it's way across a series of paddocks (this could not be verified further). At the time, there was a temporary levee built near the oval in 1974 to protect against the flood. The 'swamp' feature SE of the town can drain into the town once it is full. There was flooding in localised areas of the town due to heavy rainfall on 15 September 2016 Repeated the concerns that railway culverts are causing the flooding issue.	

In summary, there are very few articles describing flooding in town in Rowena, with local residents and the school annual report much richer sources of information. Articles that do refer to Rowena largely relate to properties several kilometres outside the study area, near Thalaba Creek. This information is further analysed in Section 3.2.

2.4.3 Site Visit

The project team conducted a site visit in September 2019, to familiarise with each of the study areas and investigate features of interest. The site visits included photographs of drainage features, watercourses, roads and land usage types. Where possible, features were measured and recorded in GIS. The site visits covered the following features, with photos shown in Figure 7:

- Inspection of Thalaba Creek where Merrywinebone Road crosses it, approximately 17.5 km north-west of the town
- Comparison of roads approaching the town to 5m DEM data.
- Inspection of all drainage features in the town, typical house construction, the railway structure and it's culverts, and the 'swamp' features to the south-east of the town. All features appear to match those recorded by the May 2019 survey.


Thalaba Creek at Merrywinebone Rd, looking south


Looking south-east from south end of Shaw Street


Railway culverts south of Rowena Road, DS side


Railway culverts north of Rowena Road, US side


Recently built on north side of Rowena Road


Roadside drainage on Shaw Street, looking south

Figure 7: Site Visit Photos

3. CURRENT STUDY MODELLING METHODOLOGY

Hydrologic analysis and a hydraulic model were established to investigate the sources of flooding at the town. The study is somewhat unusual in that the town lies on elevated land, approximately 7 km from the nearest watercourse (Thalaba Creek). The modelling was therefore conducted in two stages, firstly, determining the sources of flooding at the town (including modelling), and secondly, model and map design flood behaviour at the town. The investigation used the following process;

1. Establish a coarse hydraulic model of Rowena's upstream area, extending as far west as Moree and Narrabri. Use this model to map the location of all watercourses in the vicinity of Rowena.
2. Establish the location and severity of historical flood events in the town via review available hydrologic data (rainfall and streamflow gauges) and records of flooding.
3. Similarly, compile the dates and relative magnitude of historical flood events on the two floodplains (Namoi and Gwydir) that may cause flooding at Rowena.
4. Combine the record of flooding established in steps 1 and 2 to evaluate each possible source of flooding. This included using a refined, calibrated hydraulic model to model flooding events on Thalaba and Pian Creeks, which used a combination of historical and design flood events.

The following sections (3.1 to 3.4) correspond to each stage of this process.

3.1 Coarse Hydraulic Model

A coarse 2D hydraulic model was established to understand the range of possible sources of flooding at Rowena. Rowena lies between the Gwydir and Namoi river systems, which have areas that do not have defined catchment boundaries, due to the absence of ridges or valleys that typically separate catchments. Generally speaking, this feature of the two catchments begins to occur downstream of Narrabri on the Namoi, and Moree on the Gwydir and has been established in previous studies (Reference 3 and 4). These two towns also have some of the longest stream gauge records in the region and so are a logical location for the upstream boundary of a model.

A hydraulic model with coarse topographic resolution was used to simulate a combination of flood producing rainfall and river flow, to estimate where a) where creeks and other flowpaths exist across the region and b) how these flowpaths interact via anabranches, breakouts and other features. A hydrologic model generally assumes catchment boundaries are clearly defined and so was not appropriate for this exercise. The model was only for investigative purposes and was not used to estimate design flood behaviour for Rowena.

HEC-RAS software was used for the coarse hydraulic model. Background on HEC-RAS modelling software is presented in Appendix B. The software offered several advantages for the coarse model including representation of sub-grid channel conveyance and model run-time. The model setup is shown in Figure 8 and its features are summarised below:

- Model grid: Uses 1 m DEM and adjusted 5 m DEM (see section 2.4.1) with 90 m cell size in most areas and 45 m cell size in some channels (see Figure 8), with a total model area of ~12,840 km^2. The elevation range was approximately 144.7 to 281.2 mAHD.

- Model inflows: 'Rainfall-on-grid' using the recorded rainfall at Rowena Post Office across the entire model domain, combined with inflow boundaries at Gwydir River at Yarraman bridge, Mehi river at Moree, Tycannah Creek at Horseshoe lagoon, Namoi river at Narrabri, Moomin Creek, Millie Creek and Thalaba Creek. The inflows hydrographs were based on recorded hydrographs, except for Thalaba Creek which used the inflows applied for the February 2012 event in Floodplain Management Plan for the Gwydir Valley Floodplain's hydraulic model, derived from its hydrologic model (Reference 4).
- Downstream boundary: A normal-depth boundary type, across entire western boundary of the model.
- Hydraulic roughness: Constant value of 0.05
- Other features: Break lines along all main roads and railways. This aligns the HEC-RAS cell boundaries with the elevated features to ensure they have a continuous elevation in the model domain.

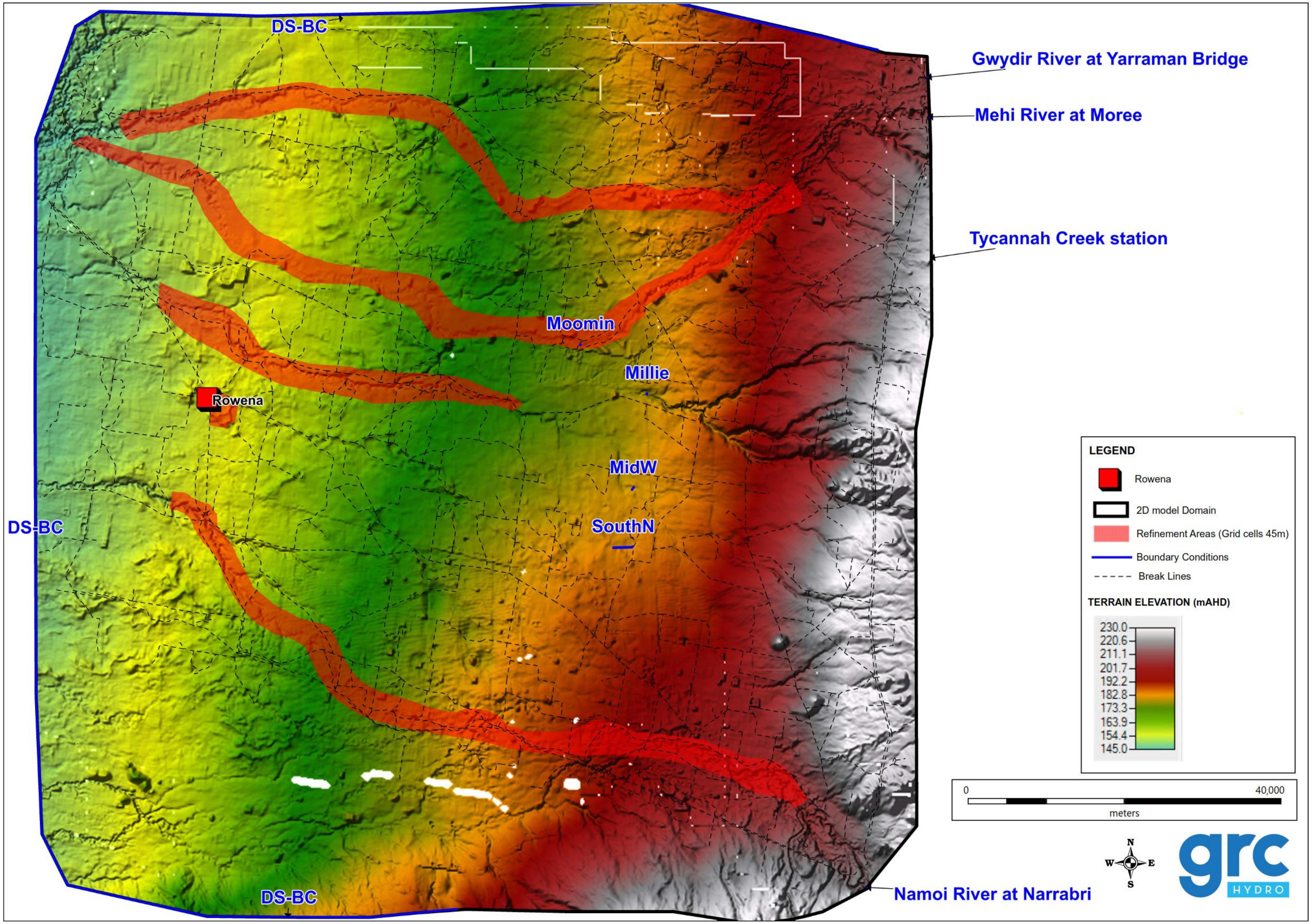


Figure 8: Coarse Hydraulic Model Setup

3.1.1 Model Results

The model was used to simulate the February 2012 flood event, with model inflows consisting of gauged inflows at Gwydir River, Mehi River, Tycannah Creek, Namoi River, estimated inflows at Moomin Creek, Millie Creek and Thalaba Creek from the previous study's hydrologic model (Reference 4), and rainfall on grid across the entire model domain based on the recorded hyetograph at Rowena. To reiterate, these estimated inflows were only used to understand the two objectives defined in the previous section – location of flowpaths and their general interaction – hence the coarse estimates of rainfall.

The peak flood depth for the model simulation is shown in Figure 9, while Figure 10 shows the peak flood depth in the vicinity of Rowena. Figure 9 shows that the model represents all of the named watercourses in the region, including the Namoi, Gwydir and Mehi Rivers, as well as Thalaba, Moomin, Pian and Gunidgera Creek. The model results also show large areas of flow that are breakouts from these watercourses and tend to be guided by man-made features (e.g. roads and agricultural floodplain structures) before joining another watercourse. Thalaba Creek, which passes near the town, receives so10%me flow from a Moomin Creek breakout, as well as rainfall from its own catchment to the east. The unnamed creek east of Rowena tends to receive flow from breakouts from the Namoi River but the channel is discontinuous and at several points stops conveying flow, with it breaking out to the north or south. More significantly, there appears to be a breakout from Thalaba Creek approximately 20 km west of Rowena, near 'Bulyeroi', that passes near Rowena and flows to Pian Creek.

Figure 10 shows the watercourses in the vicinity of Rowena. Specifically, it shows that:

- Thalaba Creek, to the north, has depths of greater than 2 m in its channel and depths of around 0.5 m on its adjacent floodplain, which is around 5 km wide. The floodplain is around 3 km from Rowena at its closest point (marked as 'A' on the figure). The apparent breakout from Thalaba Creek approximately 20 km west of Rowena ('B' on the figure) has depths of around 0.3-0.5 m and passes within 1 km of the town (albeit with shallow depths). It also appears to fill the topographic depression ~2.5 km west of the town ('C' on the figure)
- Unnamed Creek, to the east and south of the town, has depths of less than 1 m in most areas and appears to not function as a watercourse, despite sections of what appear to be channel ('D' on the figure). It does not connect to the Thalaba breakout and does not receive significant runoff from an upstream area. It is therefore highly unlikely that it is linked to flooding at Rowena.
- Pian Creek, to the south, has depths of greater than 2 m in its channel but a confined floodplain in the event, with many dry areas adjacent to the creek. It is more 10 km from Rowena at its closest point ('E' on the figure) and is therefore unlikely that it is linked to flooding at Rowena in small to moderate sized floods. In addition, flood levels in Pian Creek are around 2.5 m lower than the ground level at Rowena.

In summary, coarse hydraulic simulation of the 2012 event shows that there is unlikely to be any form of mainstream flooding at Rowena in this sized flood event, as mainstream flow does not occur near the town. However, the modelling also shows there are three potential sources of flooding (see dot points above) and therefore these warrant investigation for rarer flood events.

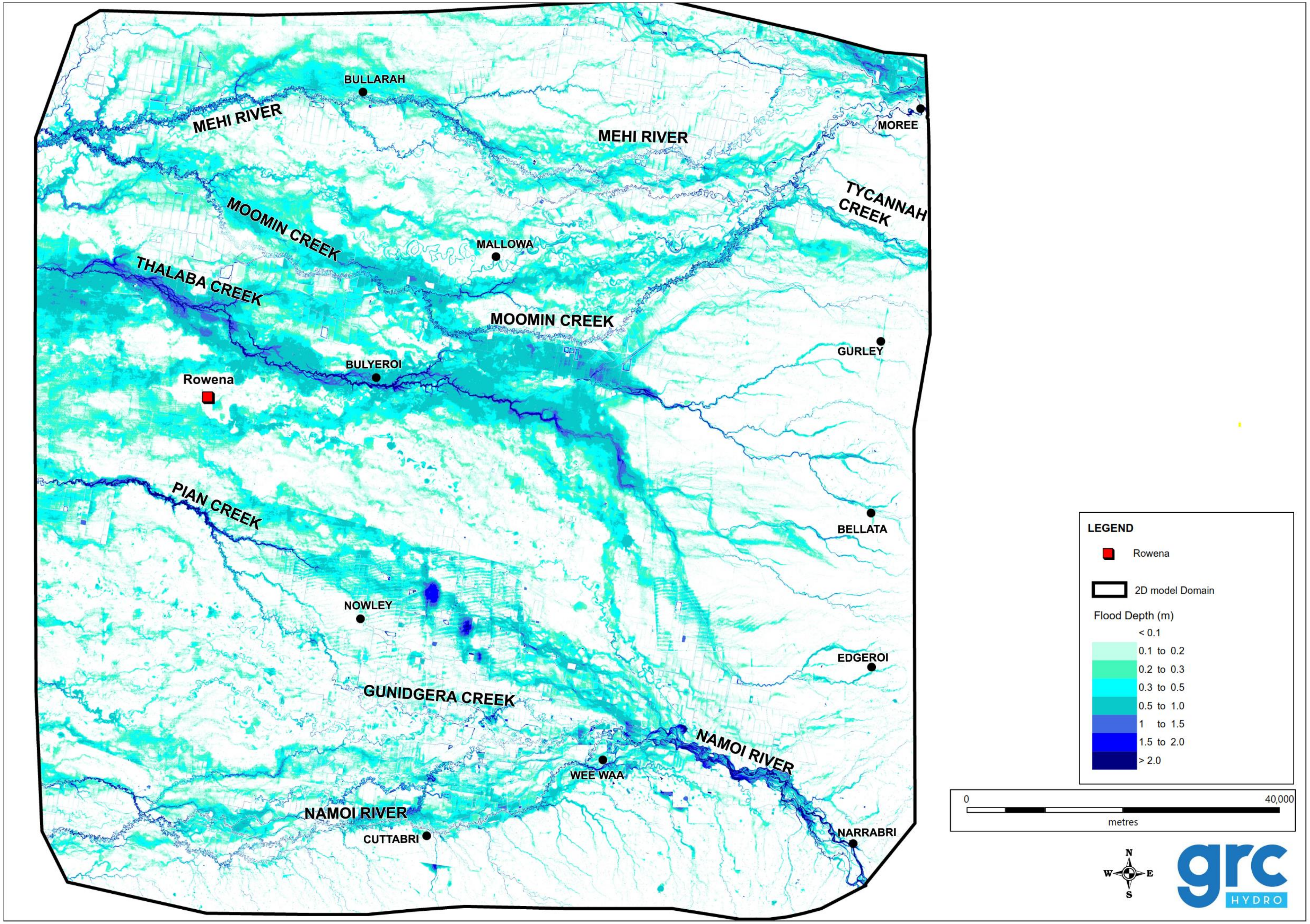


Figure 9: February 2012 HEC-RAS Peak Flood Depth

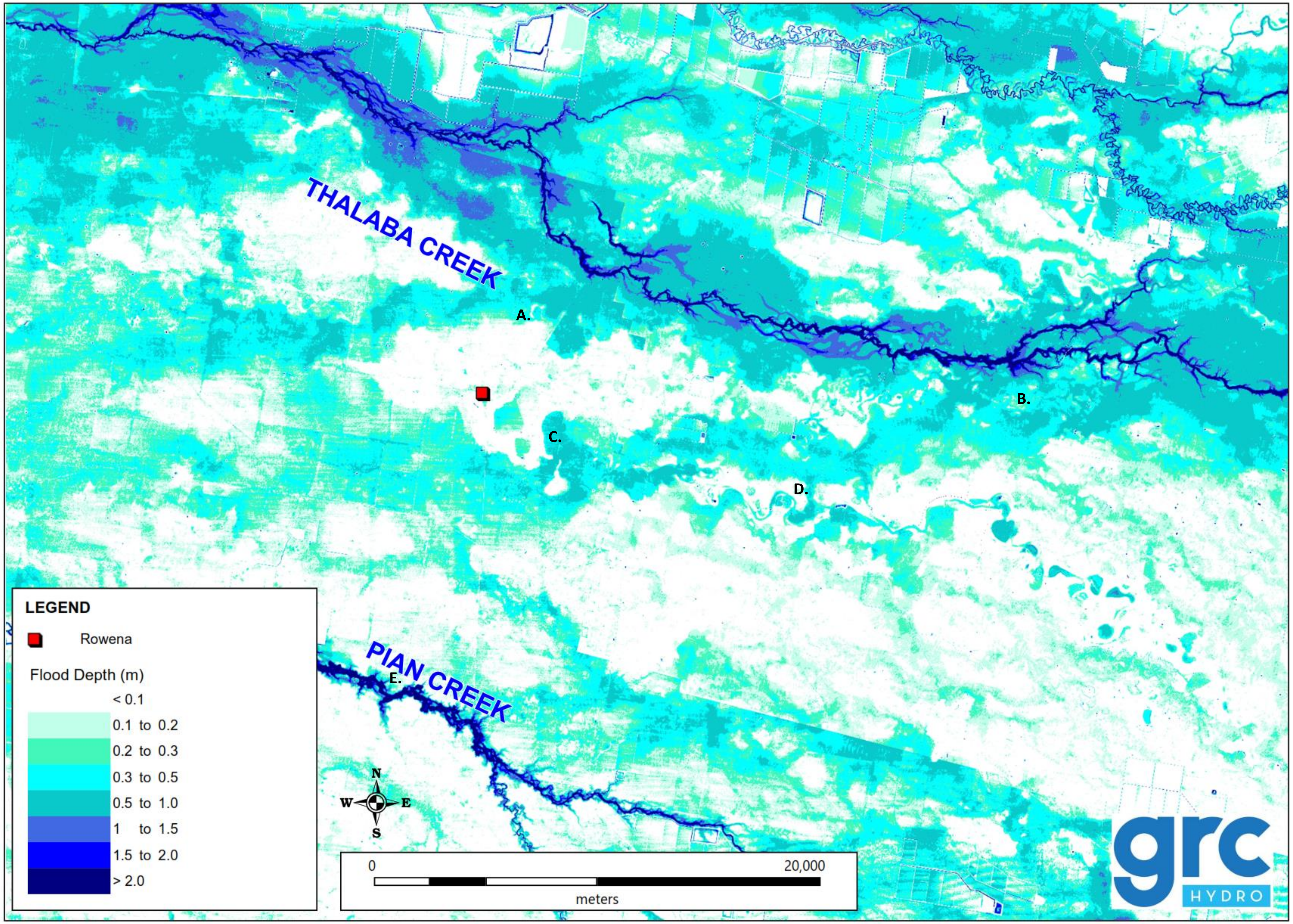


Figure 10: February 2012 HEC-RAS Peak Flood Depth - Rowena Zoom

3.2 Record of Flooding at Rowena

The primary record of flooding at Rowena is media reports and residents' recollections, as no stream gauge exists. There are historical rainfall records for the town and the surrounding area which can be used to supplement reported instances of flooding. The available information is described in Section 0 and the historical events are summarised in Table 7.

Table 7: Summary of Historical Floods at Rowena

Flood Event	Description	Recorded Rainfall	Notes
January 1974	For a property outside of town, the 1974 flood is referred to as a large flood but not as large as 2012. One resident in the town recalled flooding in the town in 1974, including breakout flow from Thalaba Creek flowing south.	303.4mm for 7th - 10th January 1974. Daily maximum of 128.5mm (8th January)	The date of flooding is not known. Moree and the Gwydir floodplain flooded in January, with the peak level at Moree in 9th January. However, Rowena Post Office recorded an exceptionally large rainfall of 128.5 mm on 8th January, the largest recorded daily rainfall at that station. It is therefore very likely that flooding at Rowena in January 1974 was caused, partially if not fully, by localised rainfall.
November 2011	Several reports of flooding but these are related to inundation outside of the town, closer to Thalaba Creek.	106.0mm for 24th - 26th November 2011. Daily maximum of 59.0mm (24th November)	Thalaba Creek peaked on 1st December downstream of the town, at approximately 4.2 m depth at the gauge. There is no record of flooding at the town, but if it did occur, it was likely a result of the rainfall on 24th November.
February 2012	Several reports of flooding within the town (residents) and around the town (media reports). The date of the peak level in Rowena is not known. Both Wee Waa (Namoi floodplain) and Moree (Gwydir floodplain) flooded, along with many other towns.	142.4mm for 28th January -4th February 2012. Daily maximum of 62.6mm (2nd February)	Thalaba Creek peaked on 5th February downstream of the town, at approximately 4.5 m depth at the gauge. So, as with January 1974, rainfall almost certainly contributed to flooding, while creek flow likely did not contribute, based on residents' recollections.
15 September 2016	Residents reported flooding in the town, with large areas of ponding around gutters.	52.0mm recorded the 14th September 2016	There were elevated creek/river levels at some locations in both the Namoi and Gwydir floodplains, however, the significant rainfall recorded at the Post Office combined with the multiple resident accounts indicates this was almost certainly caused exclusively by local rainfall.

The main rainfall stations in the vicinity of Rowena are 'Rowena' (in town), 'Rowena (Bungara) (9 km south-east of town), 'Rowena (Mayleigh)' (7 km east) and 'Rowena (waroonga)' (8 km north). Figure

11 presents the daily rainfall at Rowena from 1968 to present, with the dates of the 25 largest daily totals labelled on the figure. The largest five recorded totals are:

1. 8 January 1974 (128.5 mm)
2. 13 December 1991 (111.0mm)
3. 10 March 2000 (108.0mm)
4. 22 February 1977 (102.0mm)
5. 14 May 1977 (96.6mm)

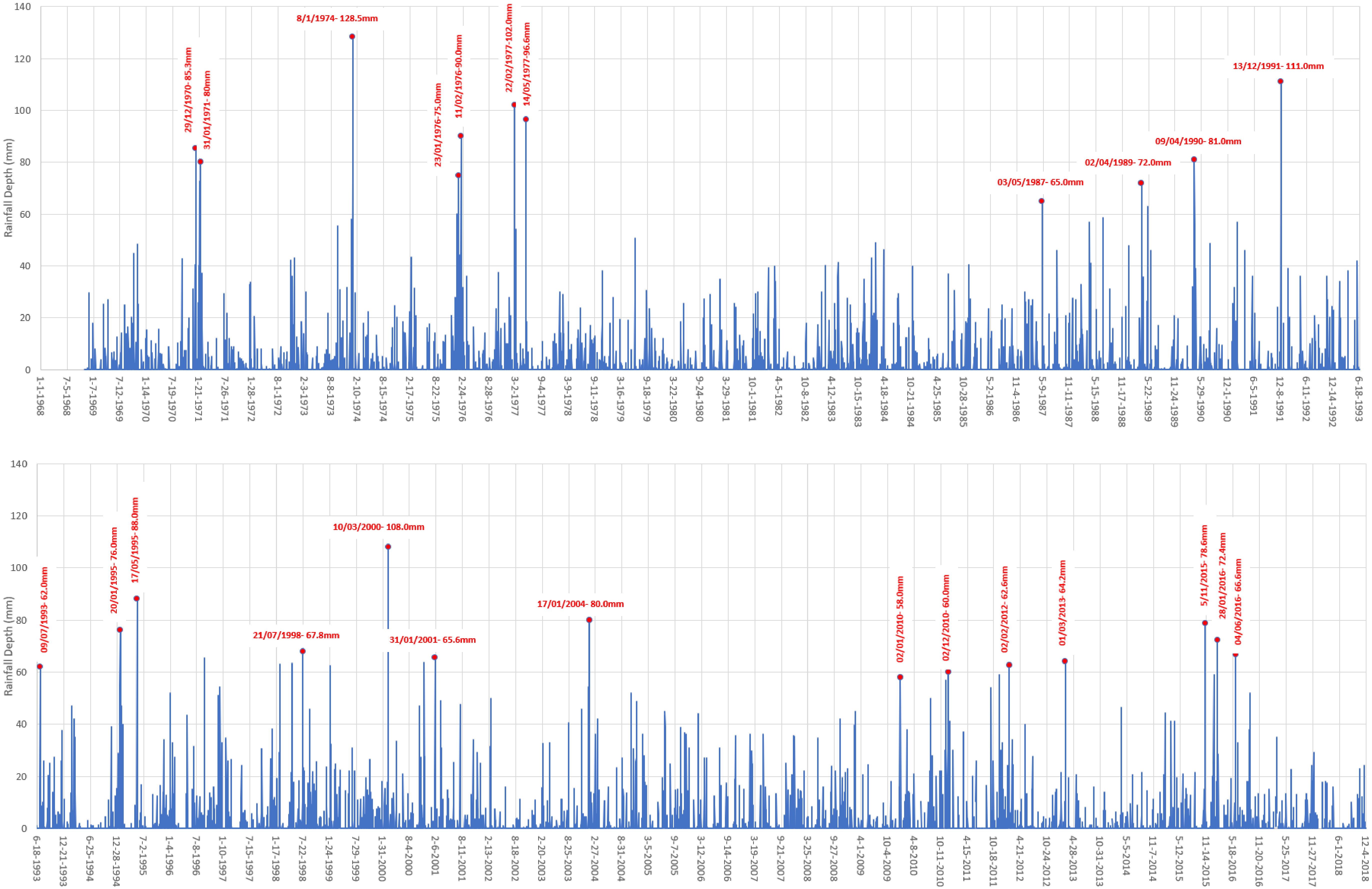


Figure 11: Rowena Post Office rainfall record with high rainfalls labelled

The record of flooding at the town does not suggest creek flooding contributes to inundation experienced at Rowena. There is no recorded flooding event that did not coincide with heavy rainfall at Rowena Post Office. The only evidence of creek flooding is that a resident reported flow coming from Thalaba Creek to the town in the 1974 flood. The final two steps in the investigation are:

a) did floods that occurred on the adjacent floodplains coincide with flooding at Rowena or its nearby creeks; and

b) do larger floods than what has occurred in the past (e.g. 1% AEP flood on both floodplains) affect Rowena, using a refined hydraulic model.

3.3 Record of Flooding in Adjacent Floodplains

The record of flooding in the Gwydir and Namoi River floodplains is well-established with a number of stream gauges with long records, as well as larger towns that experience flooding (Narrabri and Moree). There have also been multiple flood studies that examined the historical record of flooding. Therefore, the record of flooding was established using the available stream gauges and the previous studies. The following sections present information for the largest recorded floods on the two floodplains. The primary question is if these flood events caused, or are linked to, flooding on Pian Creek, Thalaba Creek or the unnamed remnant channel to the east of Rowena.

Table 8 presents a summary of the historical flood events, both in Rowena and in the adjacent floodplains. Green cells indicate a high gauge level, while white cells indicate not flooding and grey are no available data.

Table 8: Record of Flooding in Adjacent Floodplains

Flood Event	Narrabri ('419003' on Namoi River)	Pian Creek '419064' (Namoi anabranch)	Moree ('418002' on Gwydir River)	Moomin Creek '418067' (Gwydir anabranch)	Thalaba Creek ('418091')	Rowena (no gauge)
Average gauge level	205.1 mAHD	164.3 mAHD	198.9 mAHD	167.3 mAHD	0.6 m	
February 1971	213.6 mAHD	No gauge data	208.4 mAHD	No gauge data	No gauge data	No record of flooding
January 1974	213.0 mAHD	No gauge data	No gauge data but 9.3 m depth at '418001' upstream.	No gauge data	No gauge data	Anecdotal evidence of flooding
February 2001	206.3 mAHD	165.5 mAHD	206.7 mAHD	170.2 mAHD	No gauge data	No record of flooding
January 2004	208.1 mAHD	164.7 mAHD	206.0 mAHD	169.1 mAHD	No gauge data	No record of flooding
November 2011	210.4 mAHD	165.7 mAHD	208.1 mAHD	170.2 mAHD	4.2 m	No evidence of flooding in the town

February 2012	211.8 mAHD	No data but 4.1 m depth at '419089' downstream	208.6 mAHD	170.4 mAHD	4.5 m	Anecdotal evidence of flooding
July 2012	No data but 203.2 mAHD at '419039' downstream (5.2 m above normal river level)	165.5 mAHD	202.9 mAHD	169.3 mAHD	4.0 m	No evidence of flooding at the town
September 2016	No data but 203.6 mAHD at '419039' downstream (5.6 m above normal river level)	165.4 mAHD	202.0 mAHD	166.6 mAHD	2.6 m	Flooding at the town (photos and anecdotal)

The table summarises a sample of flood events in the Gwydir and Namoi floodplains in the last 50 years. There are several relationships (or lack of) that can be observed:

- Floods often occur at Moree and Narrabri at the same time, despite being on different rivers, with catchments several hundred kilometres apart.
- Flooding on the Namoi River does not appear to cause flooding on Pian Creek. Results from the coarse model and in the previous study (Reference 3) appear to support this as neither shows a clear flowpath between the creek and the river.
- Flooding on the Gwydir River at Moree appears to cause, or be otherwise linked to, flooding on Moomin Creek, with a general correlation in their observed levels.
- Similarly, there is a correlation between high levels on Thalaba Creek and Moomin Creek
- Many flood events on the two floodplains did not coincide with flooding at Rowena, and those that did coincide had high rainfall events at Rowena (see previous section).

In summary, while different relationships exist, there is little evidence to suggest flooding at Rowena is caused by creek or river flooding, based on the range of events that have occurred in the last 50 years.

3.4 Refined Hydraulic Model

As a result of the conclusions reached by the review of historical events, and the coarse hydraulic model results, a second hydraulic model was setup to evaluate the three possible sources of mainstream flooding at the town (Thalaba Creek, Pian Creek and the unnamed creek to the east and south). The evidence suggested it is unlikely these cause flooding, but a model was needed to confirm that larger flood events (e.g. a 1% AEP flood) did not cause flooding. The refined model used TUFLOW software and was calibrated to the February 2012 flood event. The model setup is shown in Figure 12 and its features are summarised below:

- Model grid: Uses 1 m DEM and adjusted 5 m DEM (see Section 2.4.1) with 30 m model cell size, with total model area of 7,560 km^2. The elevation range was approximately 144.9 to 226.9 mAHD. The model extent was refined by excluding areas that do not contribute flow to one of the three sources of interest, using the coarse hydraulic model results.
- Model inflows: Inflow boundaries at Gwydir River at Yarraman bridge, Mehi river at Moree, Tycannah Creek at Horseshoe lagoon, Namoi river at Narrabri, Moomin Creek, Millie Creek and Thalaba Creek, based on historical and design discharges. These were combined with 'rainfall-on-grid' using either design or historical rainfall across the entire model domain. For design rainfall, a long storm duration (72 hour) and constant intensity were used, as the rainfall was only to simulate wet catchment conditions, and not flooding of the town due to localised rainfall.
- Downstream boundary: Normal-Depth boundary type, across entire western boundary of the model.
- Hydraulic roughness: Constant value of 0.05
- Other features: Floodplain structures blocked out of the 2D domain. Break-lines along the Pokataroo railway, Rowena Road, Camerons Lane and relevant topographic features nearby the project area

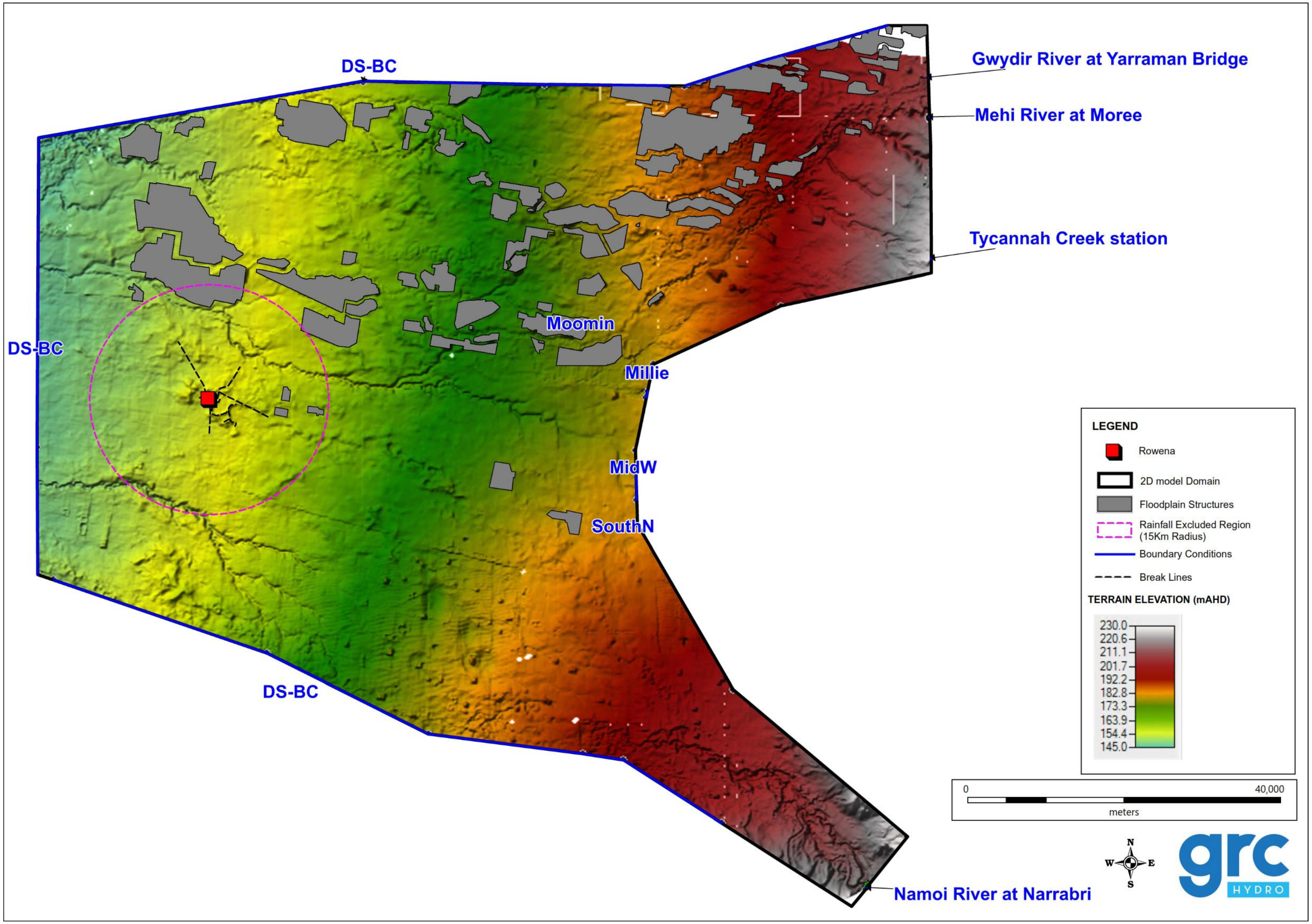


Figure 12: TUFLOW Model Setup

3.4.1 Model Results – February 2012 event

The model was used to simulate the February 2012 flood event, with model inflows consisting of gauged inflows at Gwydir River at Yarramabn Bridge, Mehi River at Moree, Tycannah Creek and Namoi River at Narrabri, estimated inflows at Thalaba and Moomin Creeks, and rainfall on grid across the entire model domain based on the recorded hyetograph at Rowena.

The peak velocity-depth product for the model simulation is shown in Figure 14, which also shows the location of the only stream gauge on Thalaba Creek, which was used for model calibration. Details of the stream gauge (418091, Thalaba Creek at Belarre) were downloaded from the NSW WaterInfo website. The gauge did not have a gauge zero and so modelled flood levels could not be directly compared to observed depths at the gauge. As a workaround, the cross-section from the WaterInfo website was compared to the DEM cross-section, in order to compare the depth of out of bank flooding. Figure 13 below shows the DEM cross-section (left) with the gauge cross-section on the right pane. A more rigorous calibration, for example using a surveyed cross-section at the gauge, is not warranted given the overall accuracy of the 5 m DEM used in the model.

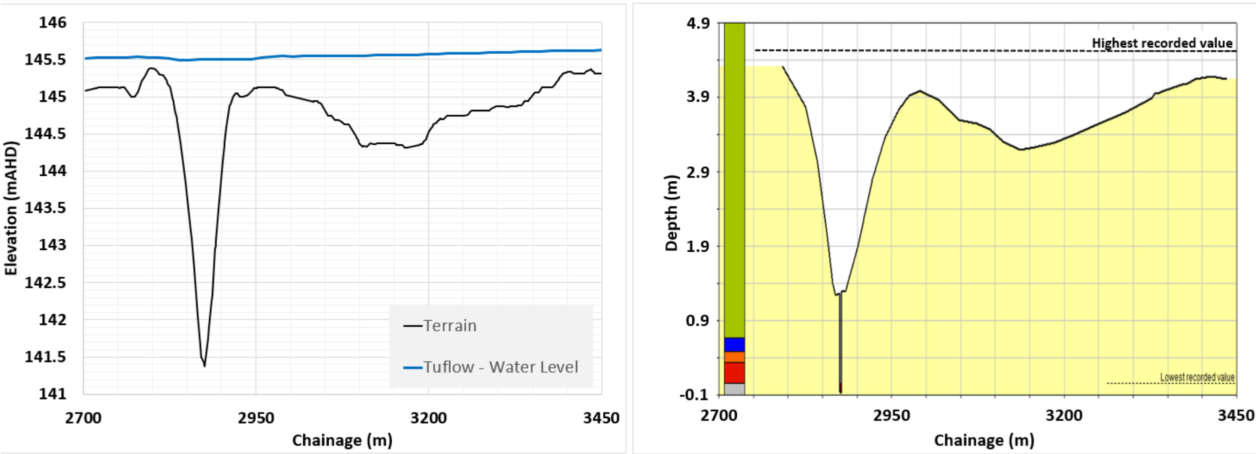


Figure 13: DEM and gauge record cross-sections at Thalaba Creek gauge

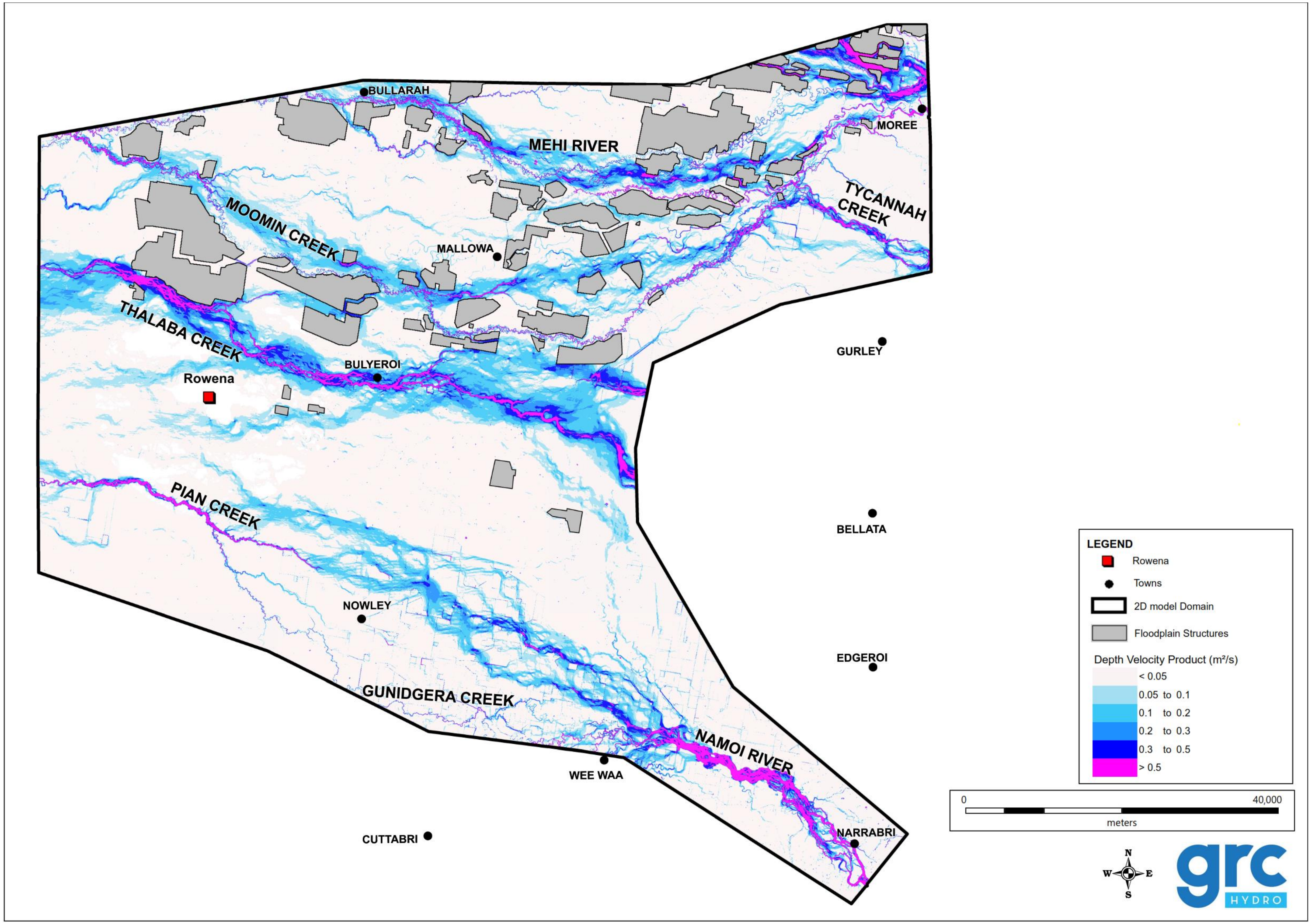


Figure 14: Depth-velocity product 2012 event

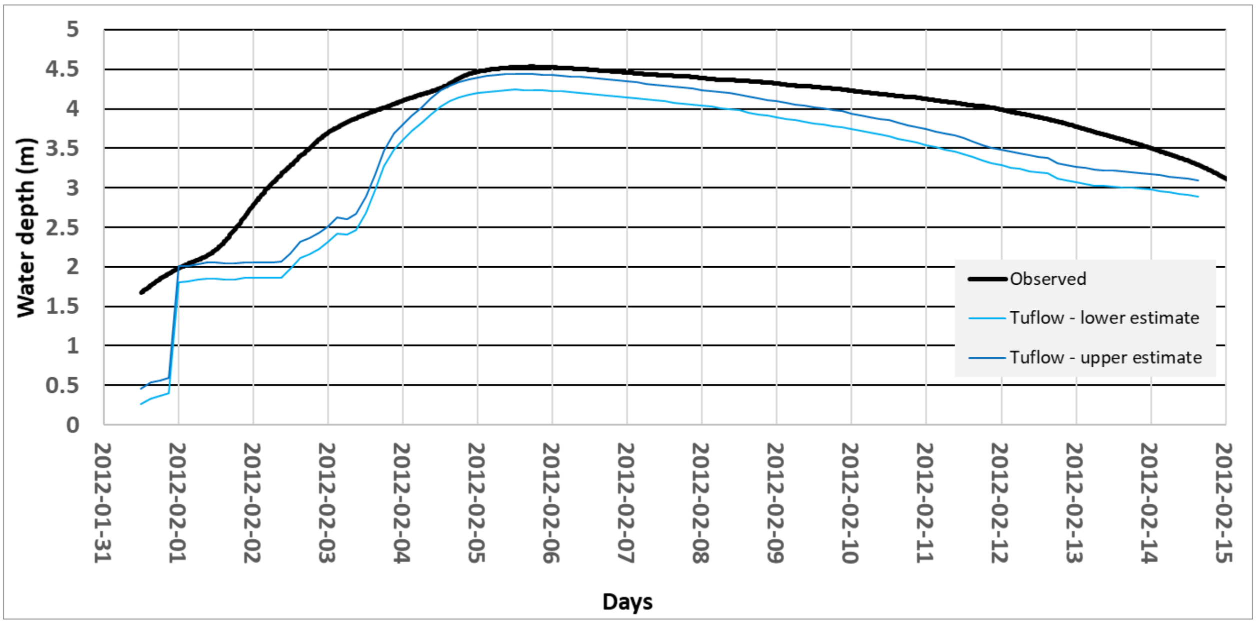


Figure 15: Observed and Modelled Flood Level - Thalaba Creek Gauge

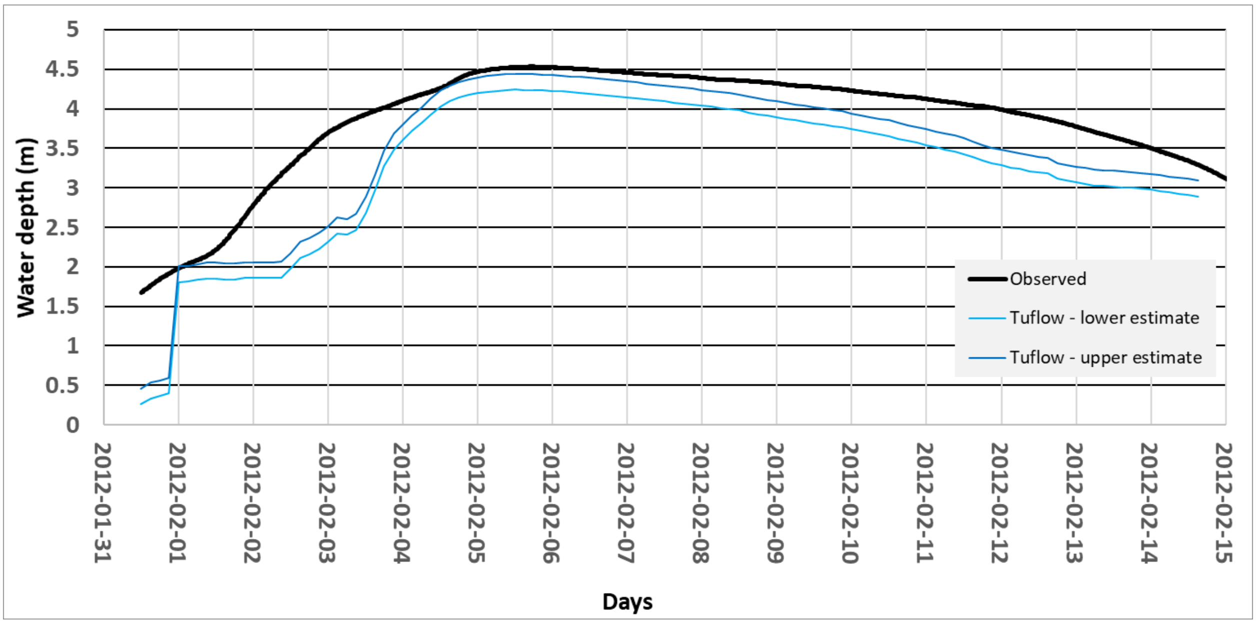


Figure 15 then shows the recorded water level hydrograph at the gauge, and the upper and lower estimate of the model result. The upper and lower estimate are derived from an upper and lower estimate of the gauge zero height in mAHD (using the comparison in Figure 13) – the two levels are from the same TUFLOW simulation. The figure shows that the model generally reproduces the observed level, with a difference of between 0.1 to 0.3 at the peak. While the timing of the peak is well-replicated, the rising limb is steeper in the simulation and suggests the flow from the hydrologic model does not capture the overall volume of runoff, and the rainfall losses should be lower. It is likely the model resolution is also underestimating channel conveyance for low depths of flow. Regardless of the exact reason, the results suggest the model is performing better at higher stages and major flood events. This is important as the town is not flooded in frequent events. Overall, the model was considered suitably accurate to model the general flow behaviour of 1% AEP flooding in the vicinity of the town.

3.4.2 Model Setup – 1% AEP event

The 1% AEP event was modelled to determine if the possible sources of flooding identified in the coarse hydraulic model may cause flooding in a rare flood event. Modelled inflows in the 1% AEP were based on a combination of existing Flood Frequency Analysis (FFA) and the hydrologic model (RORB) established for Reference 4. The inflows consisted of:

- 2,520 m^3/s at Mehi River at Moree and 3,780 m^3/s at Gwydir River at Yarraman Bridge, with the February 2012 event hydrograph shape for both, recorded at those locations. The total flow is based on the FFA completed by Reference 4 for the 'Gwydir @ Gravesend' gauge, with the flow split at Moree based on the recorded in the 2012 event.
- 750 m^3/s at Tycannah Creek, with the February 2012 event hydrograph shape. The flow was taken from the flood frequency analysis available on the BoM stream gauge website.
- 4,859 m3/s at Namoi River at Narrabri, taken from the FFA carried out by Reference 2, with the February 2012 event hydrograph shape recorded at Narrabri.
- 1,457 m^3/s and 361 m^3/s on the Thalaba Creek catchment (respectively at the 'MidW' and 'SouthN' locations (see Figure 12)), using ARR2016 1% AEP rainfall applied to the existing Thalaba Creek RORB model (Reference 4). An ensemble method critical duration analysis was carried out as per ARR2016 and the critical duration was found to be 36 hours. However, the 72 hours duration was found to produce the same mean flow and so it was adopted as it would give greater coincidence with the Namoi and Gwydir hydrographs, and is therefore considered a more conservative estimate. Description of the critical duration analysis is given in Appendix D.
- 1,241 m^3/s at the Millie Creek location. The origin of the 'Millie' inflow in Reference 4's MIKE model is not clear (it does not seem to correspond to a hydrologic model). To be conservative, it was included by taking the 2012 event Tycannah Creek and Millie Creek discharges (559 m^3/s and 926m^3/s) and scaling the Millie Creek inflow by the ratio of the % increase of Tycannah Creek to its 1% AEP estimate (750 m^3/s). The hydrograph shape was based on the recorded hydrograph at the Tycannah Creek gauge in the 2012 flood. The catchment area of Millie Creek, which lies between the Thalaba and Tycannah catchments mapped by Reference 4, is approximately 1,200 km^2, which makes it generally comparable to the neighbouring Tycannah Creek (1,037 km^2).
- A 72 hour duration, 1% AEP rainfall across the model domain except for an exclusion area consisting of a 15 km radius circle centred on Rowena. This is to ensure the flood behaviour at the town is not the result of local rainfall. The rainfall was applied with constant intensity, given the rainfall was primarily to ensure a wet catchment with depressions filled.

These inflows are considered a conservative estimate of 1% AEP flood behaviour. The most conservative components are the 1% AEP inflows for Thalaba Creek, which are based on the reported RORB parameter values that likely overestimate peak flow (see Appendix C for more information) and the more coincident Thalaba Creek duration of 72 hours (compared to 36 hours). In addition, the modelling assumes a 1% AEP flood is simultaneously occurring on the Gwydir and Namoi Rivers, and that 1% AEP rainfall is also occurring across the area. The coincidence of 1% AEP flooding in all watercourses simultaneously is unlikely and the associated AEP would be much rarer than 1% AEP.

3.4.3 Model Results – 1% AEP event

Figure 16 shows the peak flood depth in the 1% AEP in the vicinity of Rowena and Figure 17 shows the depth-velocity product, to indicate where flow is occurring. The results show that the town's area is not flooded to any significant depth. The velocity-depth product shows a very minor flow (the model results indicate a peak of 0.3 m^3/s) that reaches the town but is not sufficient to pond against the railway embankment. The flow across the Thalaba Creek floodplain is in the order of 2,500 m^3/s, but this flow, including the breakout west of Rowena, does not reach the town. There are slightly raised areas of land between Thalaba Creek and Rowena which mean that although the town itself is not particularly high (relative to the Thalaba Creek flood level), flow is diverted away from the town.

Analysis of the upstream flood behaviour indicated that a large majority of the Thalaba Creek flow was from its own catchment and from the neighbouring Millie Creek, with less than 5% of its flow coming from Moomin Creek breakouts and around 20-30% coming from the Namoi River breakout. These results are only indicative as the overall timing and magnitude of the different systems will likely vary significantly between flood events.

Furthermore, sensitivity runs that considered larger possible flows on Thalaba Creek were found to not significantly flood the town. By scaling up the Thalaba Creek inflow to 4,500 m^3/s, the 'swamp' feature immediately southeast of the town filled and eventually spilled some flow into the town, with a depth of 0.2-0.3 m ponding in the town behind the railway embankment. This demonstrates that while there may be some mainstream flood affectation at Rowena in extreme events, there is no change in flood behaviour relative to what has been observed due to local rainfall (e.g. September 2016 or February 2012 events). A model was therefore setup to assess flooding caused by local rainfall (see following section).

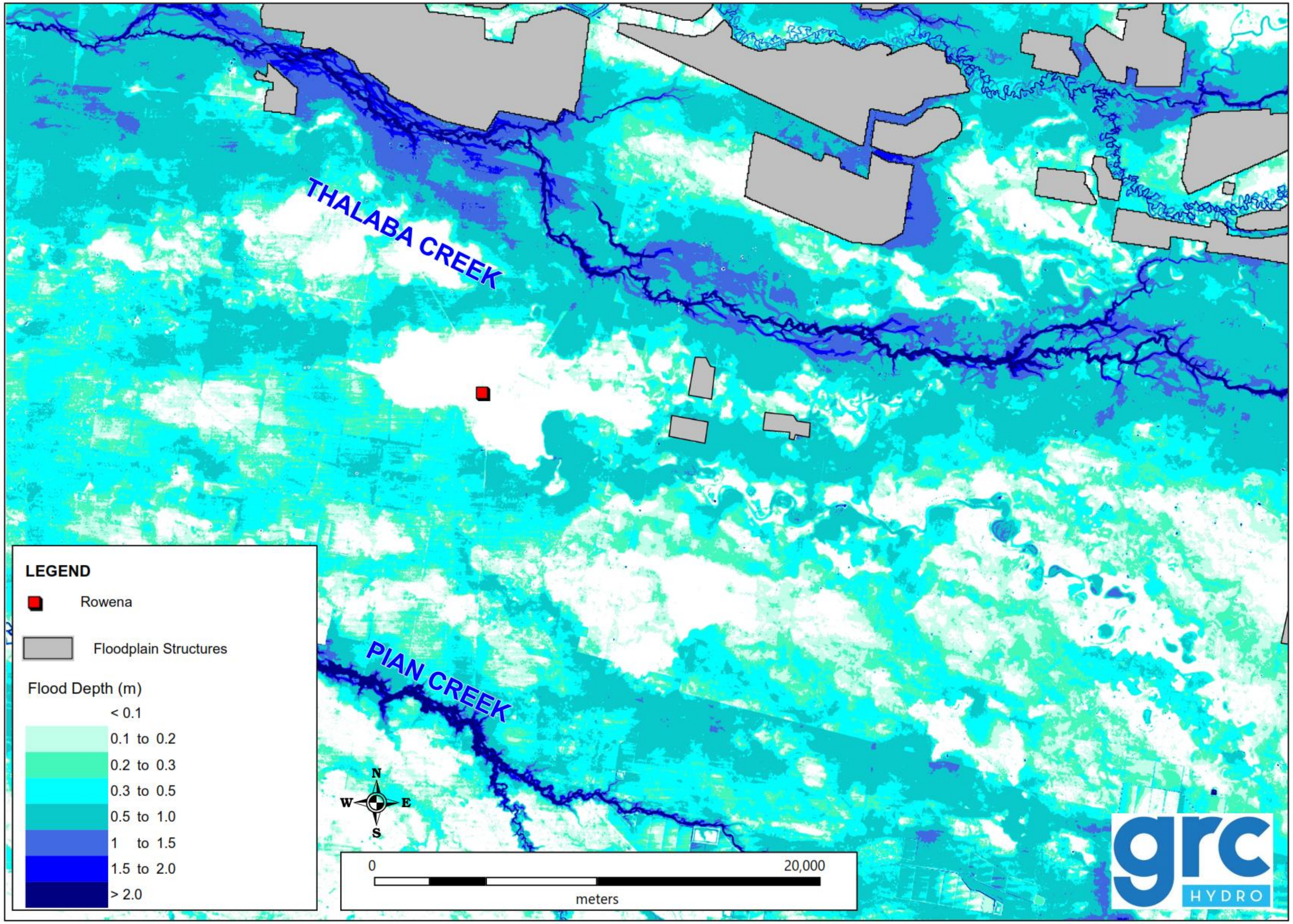


Figure 16: 1% AEP peak flood depth in the vicinity of Rowena (excluding local rainfall flooding)

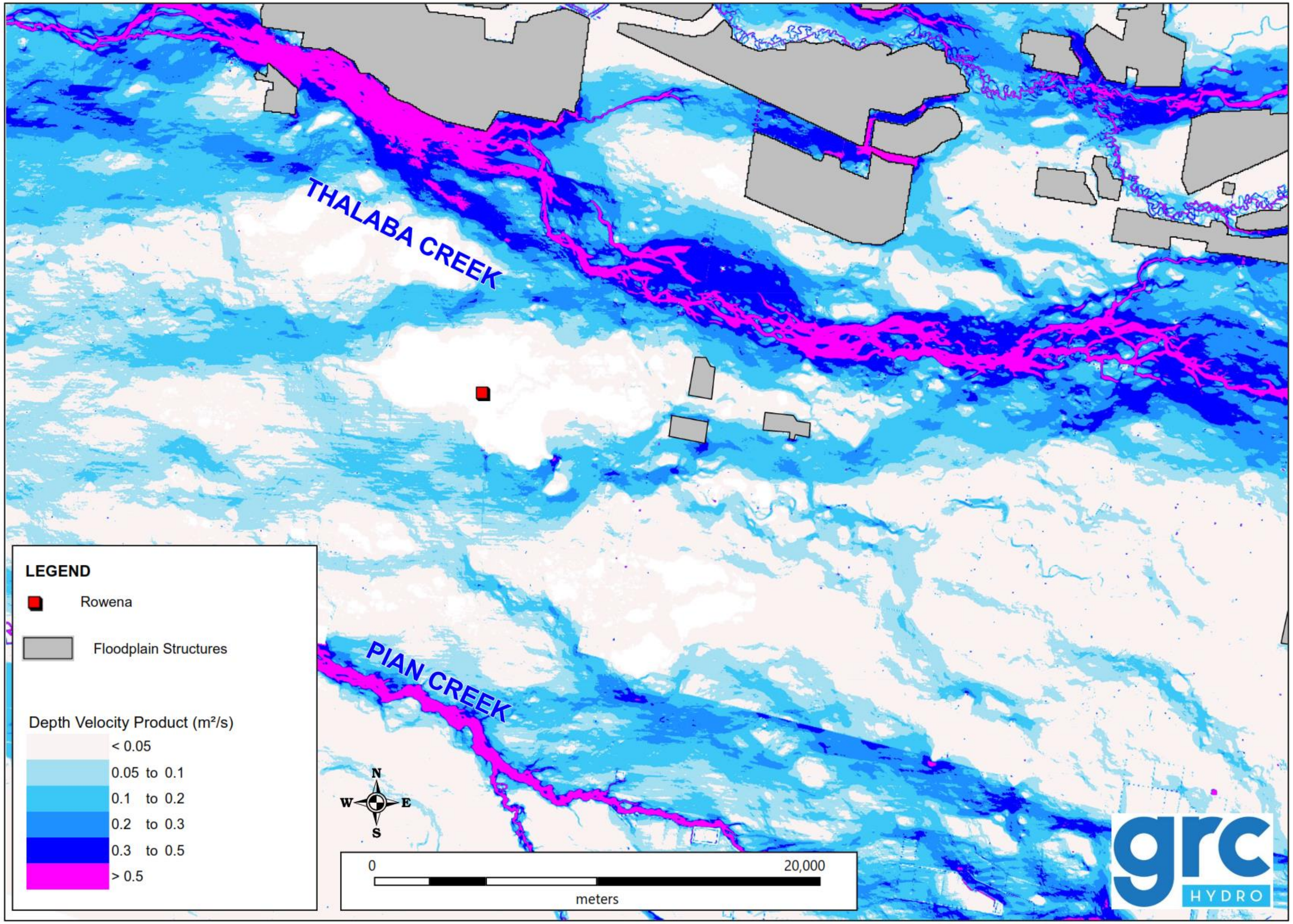


Figure 17: 1% AEP depth-velocity product in the vicinity of Rowena (excluding local rainfall flooding)

3.5 Local Hydraulic Model

A 'local' hydraulic model was established for Rowena, following the finding that no watercourse (including all nearby creeks and rivers) can cause flooding at the town. Given that historical flood events have coincided with heavy localised rainfall (see Section 3.2), the local hydraulic model was used to estimate how rainfall in the vicinity of Rowena can flow towards and then accumulate within the town. The model setup is shown in Figure 18 and its features are summarised below:

- Topographic Data: The 5 m DEM was adjusted based on local survey (see Section 2.4.1 for description of both). The adjustment was made by comparing the DEM and survey levels at each of the survey points, calculating the average difference (0.315 m) and then lowering the 5 m DEM by this value. The difference in the two datasets was generally consistent, between 0.2 and 0.4 m. The survey points were then used to define the road break lines in the model.
- Model grid: The model uses the adjusted 5 m DEM with 6.5 m model cell size, with a total model area of 19 km^2. The elevation range was approximately 155.1 to 157.5 mAHD. The model extent was defined by applying 'direct rainfall' to a larger model extent and then excluding areas that do not contribute any significant flow to the town. During model development, larger model extents of 66 km^2 and 601 km^2 were tested and produced identical flood depths at the town. This confirmed that the adopted model extended sufficiently far 'upstream' of the town. As shown on the model results, the model domain does not contain conventional catchment topographic features such as ridges or watercourses.
- Model inflows: Due to the lack of defined catchment area, subcatchments could not be delineated and therefore a 'direct rainfall' approach was used, where rainfall is applied to each cell in the model domain. Event duration is described in the following section (3.5.1).
    - Rainfall losses: The NSW Office of Environment and Heritage guide to application of ARR2016 in NSW was used to define design rainfall losses. The guide sets out a 5 level hierarchy for defining rainfall losses. In the absence of calibrated losses from a nearby study, and a nearby FFA, the ARR Data Hub initial loss was used with the initial loss burst set by the Probability Neutral Burst Loss (also from Data Hub). Continuing losses were taken from Data Hub (0.0 mm/hour) and multiplied by 0.4. The Data Hub initial loss for the area is 67 mm and the Probability Neutral Burst Initial Loss for the durations of interest was between 29 mm (1% AEP, 24 hour) and 52 mm (10% AEP, 48 hour).
    - Areal Reduction Factor (ARF): The ARF was calculated in accordance with ARR2016. The small catchment area (19 km^2) resulted in an ARF of 0.99 which was rounded to 1.
- Downstream boundary: A stage-discharge (HQ) boundary was set along the western model boundary, with a slope of 0.001.
- Hydraulic roughness: Varied across the model domain, with adopted values shown in Figure 19.

Other features: Model break-lines were applied along the Pokataroo railway, Rowena Road, Camerons Lane and relevant topographic features nearby the project area. Culverts in the town were represented as 1D model elements, with location and dimensions based on the 2019 survey and site inspection.

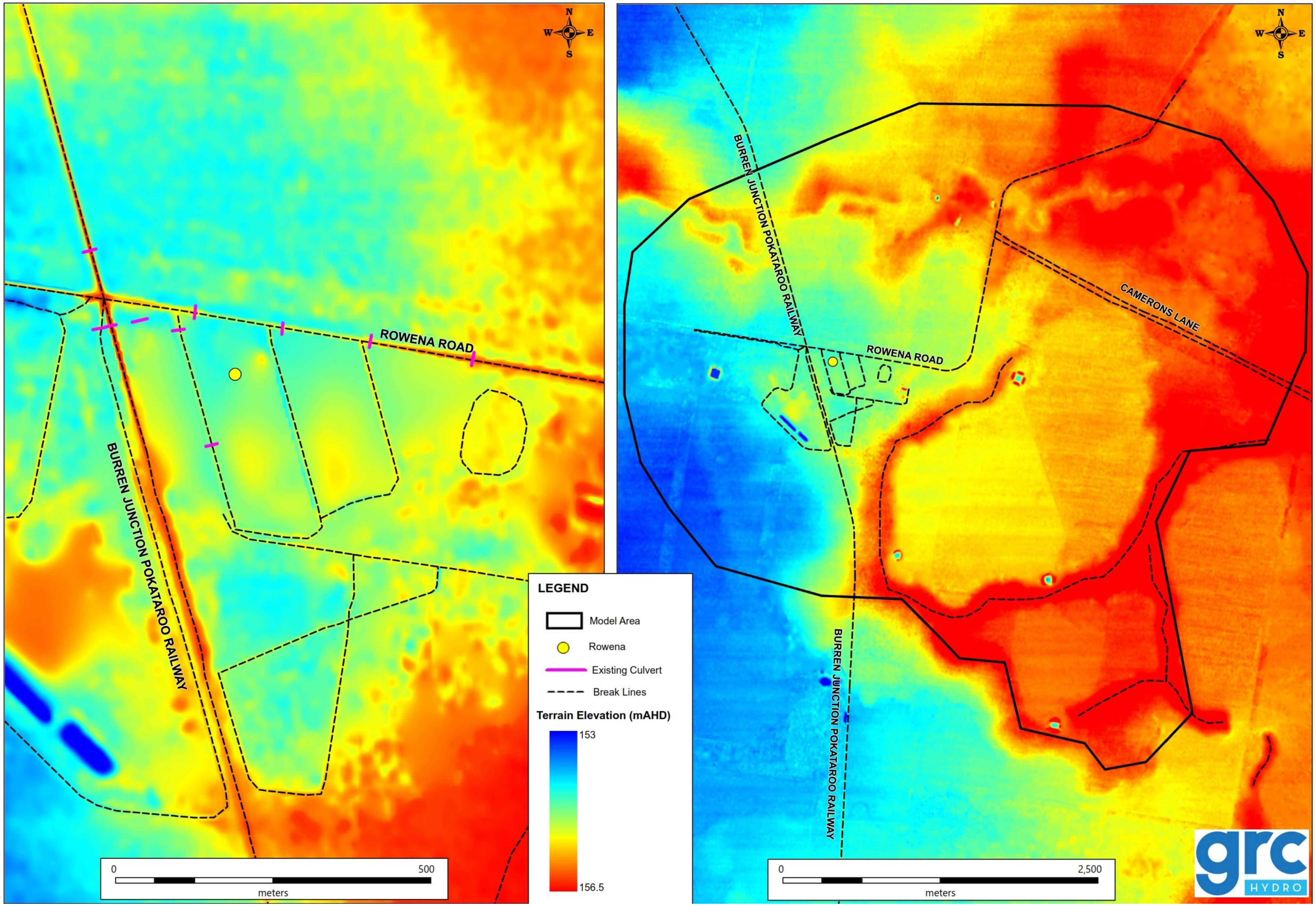


Figure 18: Local Hydraulic Model Setup

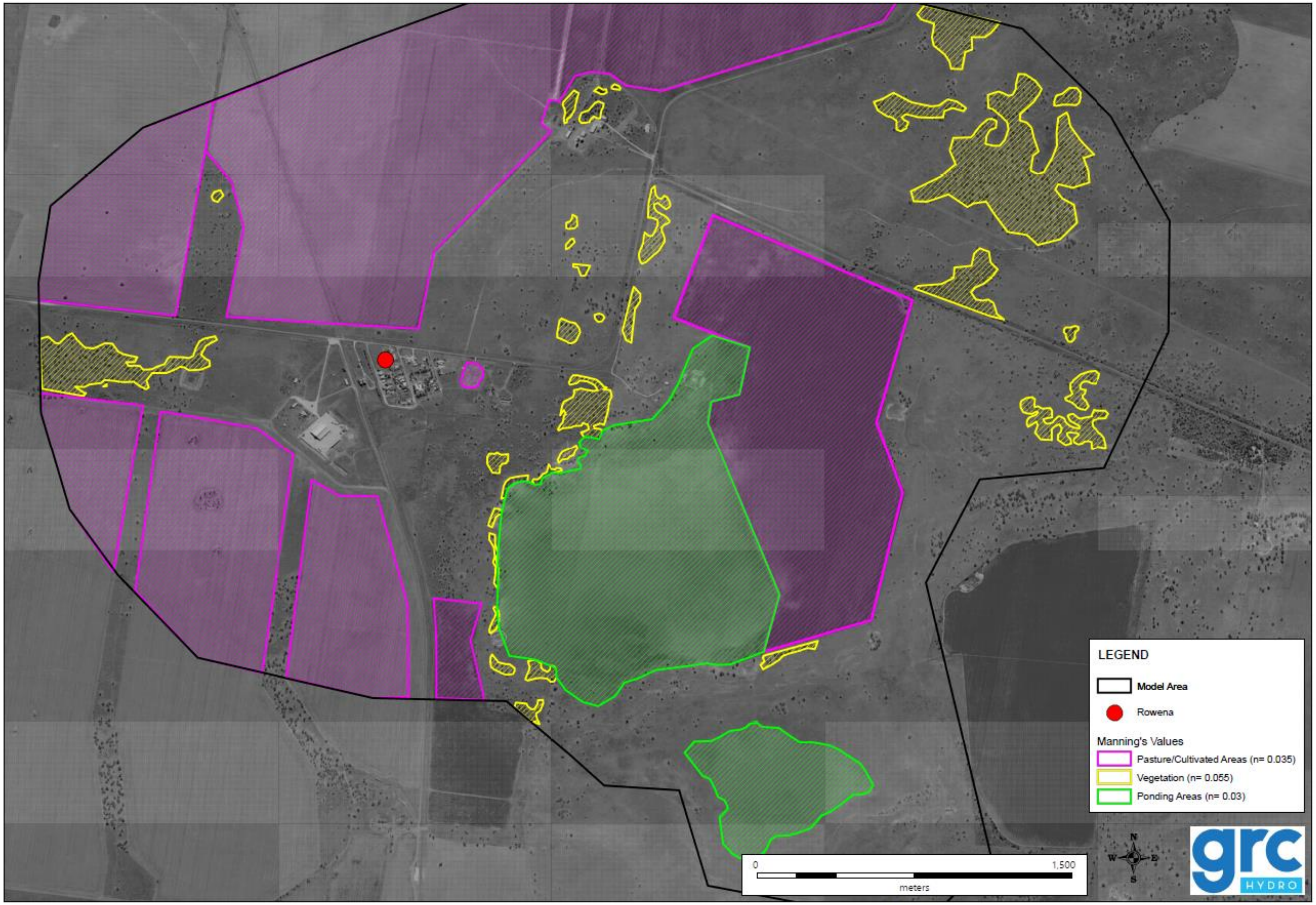


Figure 19: Local Hydraulic Model Manning's n values

3.5.1 Critical Duration and Temporal Pattern

The critical duration and temporal pattern of the design rainfall were determined in accordance with ARR2016. ARR2016 requires ten different temporal patterns to be considered for each storm duration. If possible, a hydrologic model is used to simulate all ten temporal patterns for each duration, for each AEP. For each AEP and duration, ten peak flood levels are produced and the critical duration will have the highest average peak flood level, while the critical storm is that which produces a level just above the average level.

The local model for Rowena required a different approach as sub-catchments could not be delineated, which meant the hydraulic model with direct rainfall was used in lieu of a hydrologic model. To avoid a large number of hydraulic model simulations (over 500 would be necessary), a representative temporal pattern was estimated for each duration and AEP. The following method was used to estimate this single representative temporal pattern. For a set of ten temporal patterns:

1. Rank their peak rainfall depth over a range of sub-durations, and determine their average rank across all sub-durations. Temporal patterns with particularly high or low sub-burst durations are unlikely to produce the final design flood level at a location.
2. By plotting each event's sub-duration depth, determine the gradient of the line that joins each depth and determine which patterns have close to the average slope. Similarly, patterns with particularly high or low gradient are likely to produce outlier results.
3. Based on these two criteria, discard patterns that are outliers (i.e. have a high or low rank, or gradient) and select a temporal pattern that is close to the average for both criteria.

This method was validated by determining the peak flood level for each 'representative' temporal pattern for the range of durations, for the 1% AEP event. The set of ten temporal patterns was then modelled for three durations of interest and the results compared. The results of the validation are shown in Table 9.

Table 9: Flood level in Rowena using single and ensemble of temporal patterns

Duration	Flood Level – Estimated Representative TP	Average Flood Level – 10 Temporal TP	Difference in estimate, and full ensemble
18 hours	155.10 mAHD	155.11 mAHD	0.01 m
24 hours	155.12 mAHD	155.11 mAHD	0.01 m
30 hours	155.11 mAHD	155.12 mAHD	0.01 m

The table shows that the estimated representative temporal pattern is a satisfactory substitute for simulation of the full ensemble as it consistently produces a flood level within 0.01 m of simulation of the full ensemble. Perhaps more importantly, the table shows that Rowena has minimal sensitivity to event duration, with the three durations producing very similar levels (although short durations are unlikely to contain sufficient volume to cause a critical flood depth). This is further described in the model results section (Section 3.5.4).

The results of the critical duration assessment for a range of design events is shown in Figure 20. The figure shows the peak flood depth taken at the town for three design events across different durations. The full range of durations was run for the 1% AEP, and based on its results, a subset of durations (0.5 – 3 days) was run for the other events. The town was found to be not flooded in a 20% AEP event.

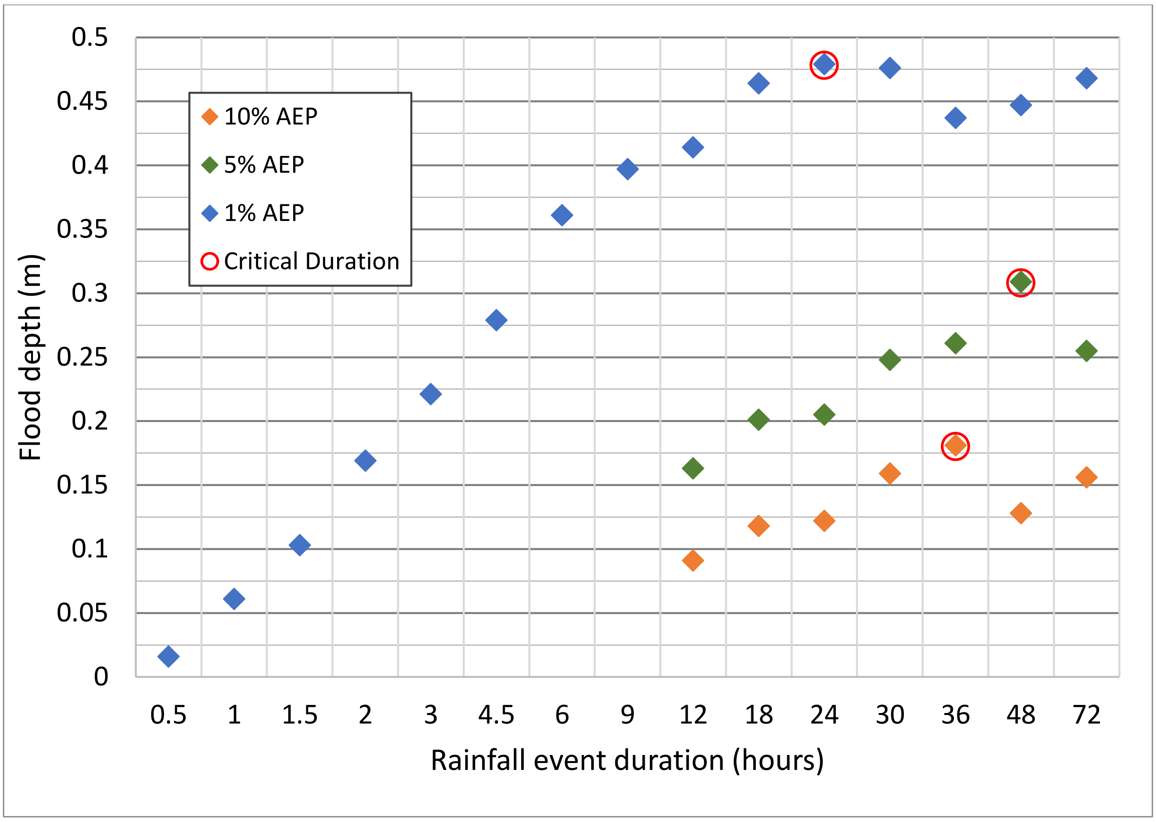


Figure 20: Critical Duration Assessment Results

The figure shows that the critical duration is between 1 and 2 days for the events tested. The critical durations are:

- 10% AEP: 36 hours (1.5 days)
- 5% AEP: 48 hours (2 days)
- 2% AEP : 30 hours (1.25 days)
- 1% AEP: 24 hours (1 day)
- 0.5% AEP : 18 hours (0.75 day)
- 0.2% AEP : 72 hours (3 days)

These durations are relatively long in the context of the catchment size (<15 km^2). The reason for this is that flooding in the town appears to more sensitive to the total volume of runoff, rather than the peak flow rate (as is typically the case). This effect appears to be caused by the railway embankment impounding runoff in the town, which, in simple terms, causes the town to act as a basin. This means that longer rainfall events, which have a much lower rainfall intensity but greater overall rainfall volume, tend to cause flooding in the town. This also means that the temporal pattern is not particularly important, as all temporal patterns produce the same volume of rainfall.

3.5.2 Model Validation

The model was validated using comparison of modelled flood behaviour to historical flood events. As discussed in the previous section, flooding is primarily the result of the volume of rainfall during a storm event. For this reason, validation was undertaken via comparison of the modelled design events and two recent flood events (February 2012 and September 2016). These are summarised below:

- First week of February 2012: 82 mm of rainfall recorded over 3 days (close to 50% AEP) and 134 mm over the wider 7-day period. Flooding is reported to have occurred close to the floor level of the post office (approximately 0.3 m depth of water). Comparing to IFD data for the town, the 3 day depth is close to 50% AEP and the 7 day period is just over the 20% AEP depth.
- 15 September 2016: 52 mm of rainfall recorded over 24 hours. Photos and description of the event showed localised ponding in the town, for example on sides of the road, but no widespread inundation. The average depth of flooding is estimated at <0.1 m across the town. Comparing to IFD data for the town, the 24 hour depth is just less than the 0.5 EY depth.

The comparable design floods to these two events are:

- 10% AEP, 48 hour duration: design rainfall of 130 mm over 48 hours. The model simulation produced a depth of 0.2 m in the vicinity of the Post Office (and across most of the town area). This is similar to the observed flooding in February 2012. It's noted that there was significant rainfall (29 mm over two days) in the week before the February 2012 rainfall event, which likely resulted in a lower initial loss than what was estimated for the design event.
- 20% AEP, 24 hour duration: design rainfall of 88 mm over 24 hours (36 mm greater than what was recorded on 15 September 2016). The model did not show any runoff entering the town area, due to insufficient rainfall volume. Accordingly, the modelled depth at the post office was 0 m. This corresponds well to observed flooding which had isolated areas of localised flooding, likely due to rainfall directly over the town.

Based on these results, the established model is accurate for the purpose of assessing design flood behaviour in the town.

3.5.3 Probable Maximum Flood (PMF)

The PMF is an estimate of the largest possible flood that can occur, based on the estimated Probable Maximum Precipitation (PMP) or other methods. In regional areas with complex hydrology, a flood discharge of three times the 1% AEP flow is often used instead of modelling the PMP. Estimation of the PMF at Rowena is somewhat complicated by the town's proximity to creek/river systems that do not cause flooding in the town in a 1% AEP flood event (separate to the more localised catchment identified at the start of Section 3.5). The potential for inundation arising from an extreme flood on Thalaba Creek has been assessed and is described at the end of Section 3.4.3. The already conservative estimate of Thalaba Creek's 1% AEP flow (1,457 m^3/s) was tripled to 4,500 m^3/s, which resulted in inundation of the town to a depth of 0.2-0.3 m, significantly less than the 1% AEP flood depths from the local hydraulic model (see Section 3.5.4).

The PMF was therefore estimated by simulation of the PMP event occurring over the local catchment. The PMP was estimated via the Generalised Short Duration Method (BOM, 2003). The catchment lies just inside the GSDM zone of 3 hour storm duration. The PMF model results are described in Section 3.5.4.

3.5.4 Model Results

Peak flood behaviour was determined for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP design events, as well as the PMF. The model results show that despite the absence of a watercourse or well-defined catchment area, the town has significant flood liability due to various man-made features which exacerbate ponding of runoff in the town.

The peak flood depth and level for the eight modelled design events is shown on Figure 29 (20% AEP) to Figure 36 (PMF) at the end of this report in Appendix A. The figures shown the model extent, indicating which upstream areas contribute flow to Rowena, and a zoomed extent, showing flooding in the town.

The peak flood depth and level at two locations in the town – outside of the post office and the school – is shown in Table 10. The table shows that depths tend to be greater at the post office, as the north-west of the town is at a slightly lower elevation than the south-east. The table also shows that rarer floods do not tend to produce much greater depths, with only 0.3 m difference between the 10% and 1% AEP. This is to be expected, given the small catchment area and very flat nature of the terrain.

Table 10: Design Peak Flood Depths

Flood Event	Rowena Public School	Post Office
20% AEP	<0.1	<0.1
10% AEP	<0.1	0.2
5% AEP	0.2	0.3
2% AEP	0.3	0.4
1% AEP	0.3	0.5
0.5% AEP	0.4	0.5
0.2% AEP	0.4	0.5
PMF	0.7	0.8

The table and Figure 29 also show that there is no flooding in the 20% AEP event. In this event, the majority of the modelled area has flood depths of less than 5 cm (or 0.05 m), which is shown as transparent on the figure. Two factors have been identified that cause this lack of flooding. Firstly, the initial loss captures almost half of the rainfall depth, which significantly reduces the runoff volume. Secondly, slight undulations in the ground topography means runoff collects in localised low points before it accumulates into more defined flowpaths.

The flow through the two sets of railway culverts, north and south of Rowena Road, is shown in Table 11. The railway was not overtopped in the events modelled. It is also noted that the ballast has been modelled as an impermeable embankment, which is likely a conservative assumption.

Table 11: Peak Culvert Flow in Design Events

Flood Event	Railway culverts south (m^3/s)	Railway culverts north (m^3/s)
20% AEP	0	0
10% AEP	0.6	1.5
5% AEP	1.1	2.3
2% AEP	1.5	3.2
1% AEP	1.6	3.4
0.5% AEP	1.7	3.4
0.2% AEP	1.8	3.4
PMF	2.7	3.7

Discussion of Flood Mechanism

The town's flooding mechanism is demonstrated via comparison of the peak flood level for three design events (10%, 5% and 1% AEP) as shown on Figure 21. The figure shows that the flood level across the town area is very flat (indicated by the uniform colour) while the flood level decreases relatively quickly west of the railway. This flat level, or ponding, is caused by the railway blocking runoff flowing out of the town to the west, save for the limited volume that passes through the railway culverts north and south of Rowena Road. This means that the peak flood level is largely determine by the volume (not intensity) of rainfall, and that flooding in the town will tend to last for several days or longer, depending to what degree the culverts are functioning. The model also showed a long duration of flooding, with approximately 5 days of inundation following the peak of the 1% AEP, 24 hour event. These model results strongly agree with the flood mechanism described by local residents (see Section 0), with regard to both the function of the railway and the long duration of flooding.

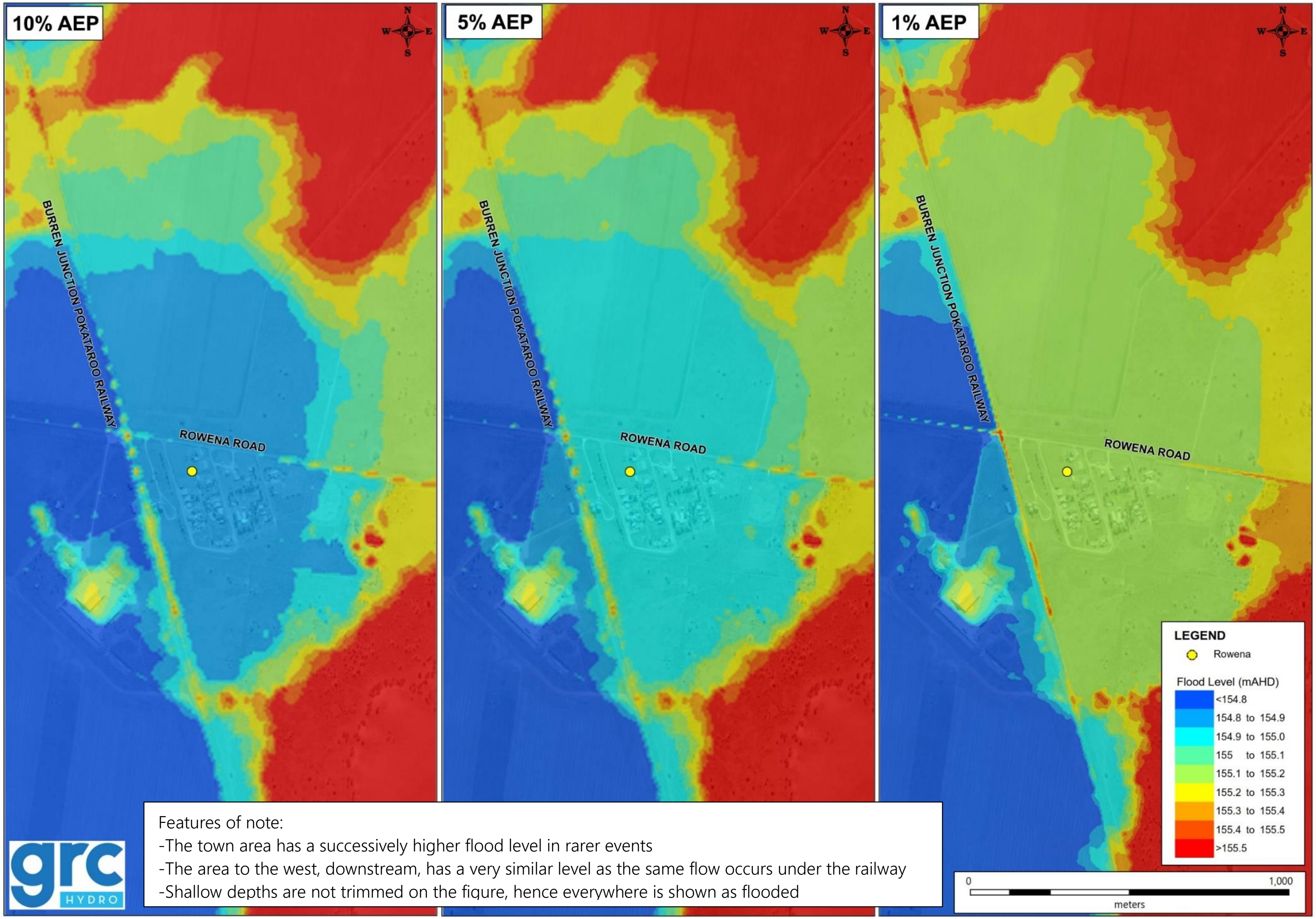


Figure 21: Comparison of Design Flood Level at Rowena

3.6 Flood Study Conclusions

An investigation has been undertaken to determine the sources of flooding at Rowena. Flooding has been observed on several occasions in the past but the vast majority of hydrological and anecdotal data indicates that this is caused by localised rainfall. A series of hydraulic models were established to assess the potential sources of flooding. The ‘coarse’ and ‘refined’ hydraulic models found that there was no significant flooding at the town due to mainstream flooding (some areas had shallow depths of less than 0.1 m) for events up to and including the 1% AEP. In contrast, the ‘local’ hydraulic model found that localised rainfall around the town does cause flooding, and that the railway embankment and other manmade features tend to determine where inundation occurs. The remainder of this report assesses the town’s flood risk and potential risk management options.

4. FLOOD RISK ASSESSMENT

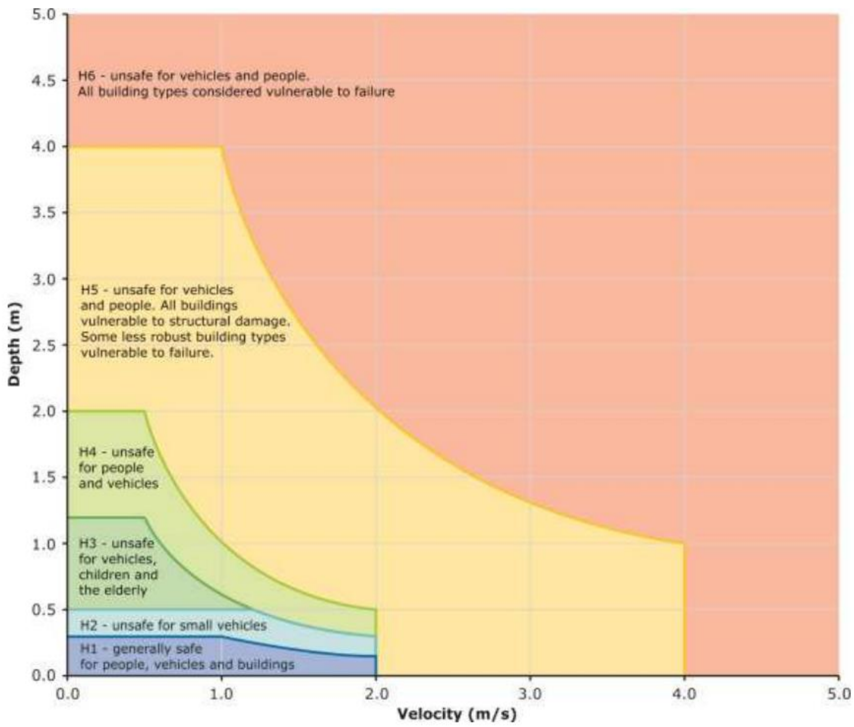
Rowena is affected by two types of flooding – localised, relatively short duration storms that cause widespread inundation of the urban area, and larger floods in the Namoi and Gwydir river systems that cut access roads to the town and can last for weeks at a time. The two types of flooding can also occur simultaneously. Flood risk in the area is related to flooding of properties, damage to vehicles and other assets and prolonged isolation of the town. Despite the widespread inundation, floodwaters pose relatively little direct risk to life as depths and velocities do not correspond to high hazard flow. However, the indirect risks associated with prolonged isolation are significant and have also been considered here. Description of the area’s flood risk has been divided into the following sub-sections:

- Flood Hazard and Flood Function (Section 4.1) describes flood hazard, which relates depth and velocity to risk posed to pedestrians, vehicles and buildings, and also flood function, which divides the floodplain into the categories of flow conveyance, flood storage and flood fringe.
- Impact of Flooding (Section 4.2) describes the consequences of flooding in the town. This section includes mapping of property flooding across the town, flood liability of sensitive land uses, the economic impact of flooding and discussion of isolation of the town due to major riverine flooding.

4.1 Flood Hazard and Flood Function

4.1.1 Flood Hazard

Flood hazard is defined as the threat that the hydraulic characteristics of flooding will pose to human activity. It is calculated based on the flood’s depth and velocity in each model grid cell and then adjusted, if necessary, to incorporate other factors not covered by the depth-velocity calculation. The calculation is based on the Australian Emergency Management Handbook 7 guideline, which considers the threat to types of people (children, adult) and activity (pedestrian, vehicle and within a building). The calculation is presented in the below chart.



As per the chart, there are six categories of flood hazard, specifically:

- 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 vehicles and people. All buildings vulnerable to structural damage. Some less robust building types vulnerable to failure.
- H6 – Unsafe for vehicles and people. All building types considered vulnerable to failure.

Hazard categories for Rowena are presented on Figure 37 to Figure 40, for the 5%, 1% and 0.2% AEP, and the PMF maps. The figures show the following areas of hazard:

- In the 5% AEP, roads and property in the town has mostly H1 and H2 hazard, with some areas of H3 on Rowena Road and the adjacent lots. Outside the town there is mostly H1, with some areas of H2.
- In the 1% AEP, the majority of the town also experience H1-H2 hazard but there are larger areas of H3, with Rowena Road in the town mostly H3 and lots on the north side of the town also largely H3. The north half of Rowena Street also has H3 hazard. The sections of Camerons Lane and Rowena Road just outside the town have H1.
- In the 0.2% AEP, the hazard is largely the same as in the 1% AEP, with slightly higher flood depths in the town corresponding to slightly larger areas of H3 and H2.
- In the PMF, all of the town area has H3 hazard, including Rowena Road as it enters the town. There are no significant areas of H4-H6 hazard.

Areas of hazard not captured by the depth-velocity calculation are described qualitatively in the flood risk section.

4.1.2 Flood Function

Flood function is a processed model output that classifies floodwaters into flow conveyance (previously floodway), flood storage or flood fringe. These categories describe the function of flow in a particular area of the floodplain and are commonly used by town planners to understand flood behaviour in an area of potential development. According to the Australian Emergency Management Handbook 7 (AIDR, 2017), these three categories can be defined as:

Flow Conveyance – the areas where a significant proportion of the floodwaters flow and typically align with defined channels. If these areas are blocked or developed, there will be significant redistribution of flow and increased flood levels across the floodplain. Generally, the flow conveyance is areas of deep and/or fast-moving floodwaters.

Flood Storage – areas where, during a flood, a significant proportion of floodwaters extend into, water is stored and then recedes after a flood. Filling or development in these areas may increase flood levels nearby.

Flood Fringe – areas that make up the remainder of the flood extent. Development in these areas are unlikely to alter flood behaviour in the surrounding area.

There is no prescribed methodology for deriving each category and as such categorisation is typically determined based on past experience and knowledge of the study area. In Rowena, this task is further complicated by the absence of any type of floodplain that was considered when the categories were developed. Specifically, the study area has no channel, or natural topographic features that cause accumulation of overland flow paths. As the area has very little grade, with only a slight slope to the west, the roads and the railway are the main feature that can cause accumulation of flow in a particular area.

Flooding in the study area does not meet the criteria as being flow conveyance or flood storage. There is little to no concentration of flow, which would correspond to a path of relatively high depth or hydraulic hazard, and there are no areas that, if developed, would cause a significant redistribution of flow and increased flood level. While the study area meets some of the criteria of being a flood storage area, it is not the case that filling or development would cause significant increase in flood levels nearby. Simply put, the railway and other raised barriers have a much larger effect on flood levels than filling any residential lot.

The study area is therefore classified as flood fringe in all design flood events. This does not necessarily mean there is low flood risk, rather, that fill or development can occur in any area without significant impact on flood behaviour.

4.2 Impact of Flooding

4.2.1 Property Flooding

Properties in the study area are inundated when floodwaters spread across the town in the 10% AEP and rarer events. The flat topography and lack of watercourse means there are similar depths of inundation across the area. Depths tend to be slightly deeper in the northern half of the town, due to the natural grade of the land.

As part of the economic damages assessment, the flood affectation on a per property level was assessed by comparison of each lot's ground level and habitable floor level to the design flood levels at the property. The comparison is made at a point location on each lot, usually at the visible entry (i.e. front door). The floor level at each lot is an estimate based on visual inspection and not a surveyed level. This assessment allows an overall estimate of where properties are flooded above floor level, as shown on Figure 41, which colour codes each property for the flood event it is first flooded above floor level. As shown on the map, around half of the lots are inundated above floor by the 5% AEP event, with the remainder nearly all inundated in the 1% AEP event.

4.2.2 Sensitive Land Uses and Critical Infrastructure

Critical infrastructure is that which is essential for the safe functioning of a town, while sensitive land uses refers to places such as schools and aged and vulnerable care facilities that are associated with a higher risk to life if flooded. In the study area, there are few such facilities, with the town limited to residential properties, a primary school (Rowena Public School), a handful of commercial properties and some sports facilities. Essential services, for example medical practices, are located in Collarenebri, or further away in Walgett or Moree.

The main critical infrastructure are the access roads to Rowena (see Section 4.2.4) while Rowena Public School is the only sensitive land use. The school has an enrolment of 26 students and serves as a focal point in the community (as per its 2019 annual report). It consists of three adjoining buildings and an outdoor playground. While the floor level is around 0.4 m above the ground, the school grounds are inundated in the 10% AEP and rarer. The main school building abutting Shaw Street is estimated to be first flooded in a PMF event, making it one of the higher buildings in the town. It is considered to be very unlikely that students would be trapped at the school in a flood event, given the available warning time for a flood occurring.

4.2.3 Economic Impact of Flooding

A flood damages assessment is used to quantify the economic impact of flooding on the community. The assessment equates the depth experienced at each property to an economic cost, based on data from historical floods. The absolute flood damages flood value are used solely for the purpose of calculating benefit-cost ratios for proposed management measures and by the state government in prioritising resources.

A flood damages assessment is used to quantify the economic impact of flooding on the community. Generally, a flood damages assessment aggregates the following:

- Direct costs to individual properties such as structural damages or damage to contents;
- Indirect costs to individual properties such as clean-up, disposal or loss of income; and
- Cost of damage to infrastructure.

The flood damages assessment for the current study has been completed in accordance with guidance for estimating residential flood damages from the NSW Department of Environment and Climate Change (now Department of Planning, Industry and Environment). This guideline uses the depth of flooding above ground and floor level to estimate the variation of damage to structures and yards. The absolute flood damages flood value are used solely for the purpose of calculating benefit-cost ratios for proposed mitigation measures and by the state government in prioritising resources. It should also be noted that the same assessment methodology is used for all locations in NSW and has not been modified for this study.

The flood damages for a town or suburb is typically summarised using the Average Annual Damages (AAD), which is an estimate of the average financial cost of flooding due to property damage in any year. The AAD is calculated by scaling down the cost of a flood event based on the likelihood it will happen in a given year.

The flood damages assessment for Rowena estimated an Average Annual Damage of $128,600. This is likely an overestimate of the actual value, however, as described the NSW-wide methodology has been applied to give consistency with other studies. The results of the assessment, including properties flooded above floor per design event, and corresponding cost, is presented in Table 12.

Table 12: Rowena Flood Damages

Event	No. Properties Affected	No. Flooded Above Floor	Total Damages for Event	% Contribution to AAD	Avg. Damage per Flood Affected Property ($)
20% AEP[1]	0	0	$0	0%	$0
10% AEP	22	10[2]	$563,600	22%	$25,600
5% AEP	23	14	$916,500	29%	$39,800
2% AEP	23	22	$1,325,900	26%	$57,600
1% AEP	23	22	$1,489,500	11%	$64,800
0.5% AEP	23	22	$1,525,000	6%	$66,300
0.2% AEP	23	22	$1,610,800	4%	$70,000
PMF	23	23	$1,894,500	3%	$82,400
Average Annual Damages (AAD)			$ 128,600		$ 5,600

1. It was assumed that no damage is occurred in a 20% AEP event, based on recollection of previous floods and the shallow depth of flooding (<0.05 m across the town)
2. This generally matches recollection of previous floods in Section 2.4.2.3., which described many properties having water just below their floorboards. The estimates are quite sensitive, with A small increase in level (~0.1 m) causing an additional ~10 properties to be flooded.

The table shows that most flood events in the town cause around $0.5-1.5 million in damage, with around 10-20 properties flooded above floor. In relatively small floods, there are 10-15 properties flooded above floor, while for the 2% AEP and rarer the number is constant at 22 properties. This indicates there is relatively little scaling between different sized floods, and that as a small town with all buildings at similar ground levels, there is little variation in which areas are flooded. The table also shows that common events (10% and 5% AEP events) account for 50% of the AAD estimate.

4.2.4 Isolation of the Town

Rowena is significantly impacted by isolation during a flood event, which limits people, goods and services entering or leaving the town. The nearest town is Collarenebri around 40 km to the north-west, while Walgett is a further 70 km from Collarenebri. The regional centre is Moree, which is around 160 km to the east. The current study has not assessed flooding of access roads outside the study area, but based on previous floods, there is widespread inundation and closures of highways and access roads, across the region. Records of previous floods, as presented in Section 0, describe rural properties being cut-off for four weeks in the 2012 floods. Further information is provided in the Walgett Shire Local Flood Plan, which states that supplies for Rowena and nearby towns are sourced from Queensland, and that at a height of 7.00 m at the Collarenebri gauge, road access between Collarenebri and Rowena is cut (though there is access for some Rowena residents to Wee Waa via Burren Junction).

Figure 22 provides an overview of access roads to Rowena and their floodplains. Historical record indicates flooding tends to occur simultaneously across multiple river systems, alongside flooding of smaller creeks and flowpaths that may or may not be connected to the river systems. This means that in practice, the severity of flooding and impact on access roads will vary significantly between flood events and there is no guaranteed access route.

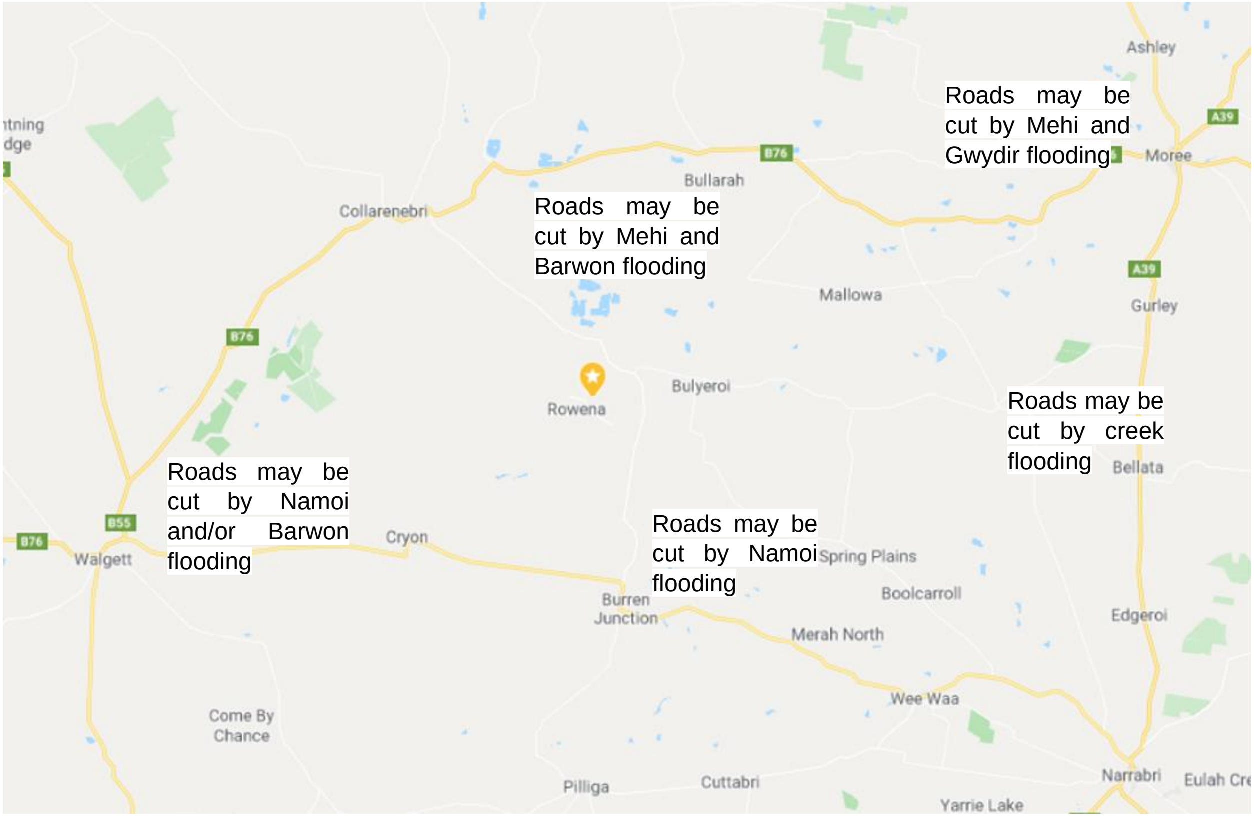


Figure 22: Rowena location relative to different floodplains and access roads

The Local Flood Plan aims to manage the isolation issue by coordinating the provision of emergency food and medical supplies to Rowena and other areas that can become isolated, as well as organising evacuation of isolated areas, during or in advance of a flood occurring. These activities are managed through a communications system (telephone, fax and email between fixed locations, and radio to deployed SES units) and a network of SES units and ancillary services (police, RFS, RMS, Council, etc.).

5. FLOOD RISK MANAGEMENT MEASURES

5.1 Background

Assessment of flood risk management measures is one of the two key outputs of the floodplain risk management study, along with assessment of the Rowena's flood risk. Flood risk management measures are broadly defined as interventions that Council or other stakeholders can implement that will reduce, or otherwise manage, the risk of flooding in the town. There is a wide range of measures that can be used to manage flood risk, from large-scale structural works (e.g. a new levee) to non-structural interventions (e.g. planning control for new development). To determine which are best suited to a particular area, the range of measures is considered and evaluated against the nature of the flood risk. The investigation then determines whether a measure is feasible and ranks the feasible measures for implementation priority. The recommended measures are summarised in the Floodplain Risk Management Plan, including timing, responsibility and indicative costing.

Management measures are chosen from three categories set out in the NSW Floodplain Development Manual (2005), as follows:

1. Property Modification Measures are those that modify existing properties to manage their flood risk. This includes planning-related measures such as minimum floor levels and zoning based on a locality's flood risk. They also include house raising, and in cases of high flood risk, voluntary purchase schemes.
2. Response Modification Measures are those that improve the ability of people to plan for and react to flood events. They often involve emergency services and can be targeted at different phases of a flood, e.g. preparation, warning, response and recovery.
3. Flood Modification Measures are those that change the depth, level, flow or velocity of floodwaters, via structural measures. They are often used to exclude flow from an area (e.g. a levee bank) or to reduce the peak flow (e.g. detention basin).

5.2 Flood Modification Measures

Flood modification measures were developed based on assessment of the town's flood risk as well as via community consultation and discussion with Council. As discussed in this report, flooding in Rowena is strongly influenced by raised topographic features, particularly the railway that runs through the town. As described in Section 2.3.4, drainage features have recently been designed by SMK for the town that may also improve flooding. These measures have been assessed as well as possible additional works. The assessed measures all relate to either railway's cross-drainage or a levee along the north side of the town.

5.2.1 Railway Line Cross-drainage Upgrade

The railway line is currently drained by two sets of culverts, on either side of Rowena Road. Residents have reported that the channel inverts were too high to drain inundation in the town area, in recent flood events and this was confirmed during a site visit. The model also generally confirms this behaviour. Council and residents have also discussed plans to upgrade the culverts by lowering their level. While some drainage improvements have been carried out as part of the SMK plans from May 2019, the railway cross-drainage has not been modified.

The existing culverts cause flooding because they have upstream inverts slightly higher than parts of the town, and because their capacity is exceeded in a large flood. While the invert of the culverts is higher than parts of the town, with the southern set of culverts at 154.48 mAHD (upstream invert), they are generally level with the immediately adjacent land. For the culverts to function more effectively, they would need to be lowered, and a swale or table drain would be needed to drain runoff across the town to the culverts.

The SMK drainage plans from May 2019 (Reference 5 and described in Section 2.3.4) include a table drain to the culverts, and lowering the southern set of culverts to have an invert of 153.885 mAHD at the upstream side (approximately 0.6 m lower than the current invert). This would lower the culverts below the natural ground level and so a very long (~600 m) table drain would be needed on the west side of the railway.

Figure 23 shows the first measure assessed by the current study, which involves lowering the culverts as per the SMK design to have inverts of 153.885 mAHD (south set, the north set is unchanged) and as well as construction of table trains, to drain towards to the culverts (east of the culverts) as well as the long table drain to the west of the railway. The figure shows the impact on existing flood levels in the 1% AEP event.

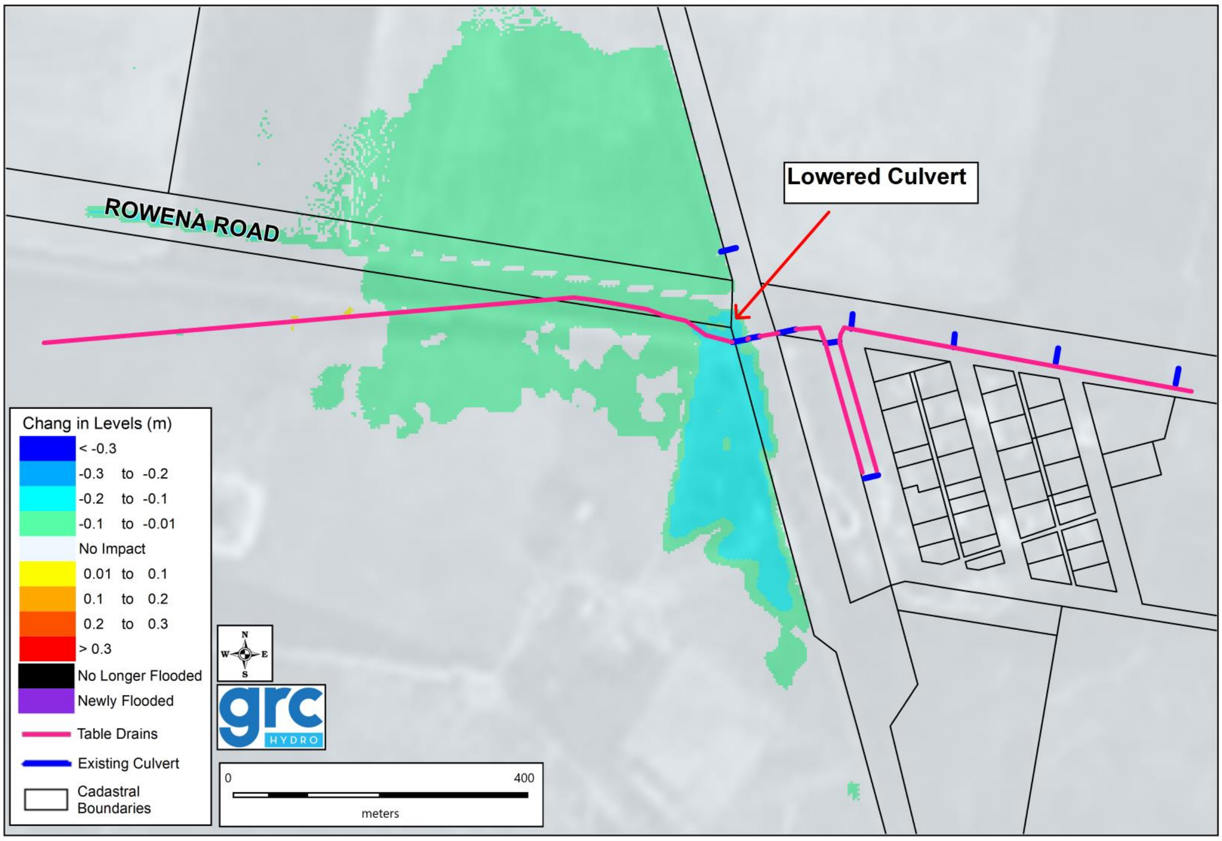


Figure 23: 1% AEP Peak Flood Level Impacts – Railway Line Cross-drainage Upgrade

The figure shows that there is negligible impact due to the measure in the 1% AEP event. In this event, the culverts are completely submerged on both upstream and downstream sides. This means that without a very large increase in their size, the culvert flow will be constrained by the high water level on the downstream side (i.e. downstream controlled) and lowering their invert will not improve flooding in the town. Based on these results, the measure was then also run for a more common event, the 10% AEP event. The results for the 10% AEP are shown in Figure 24.

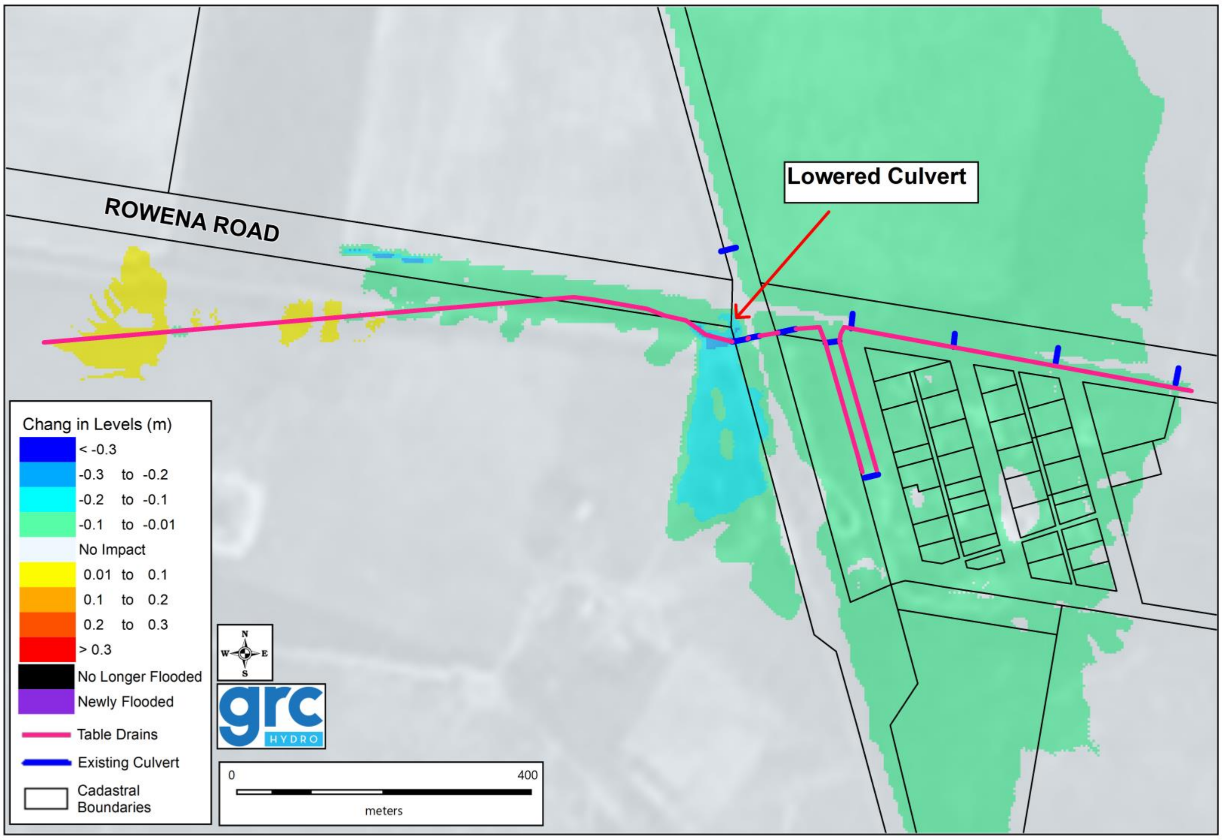


Figure 24: 10% AEP Peak Flood Level Impacts – Railway Line Cross-drainage Upgrade

The green area of reduced flood level in the figure corresponds to a decrease of only 0.01 to 0.03 m, from depths in the existing case of around 0.2 m. The model results have been reviewed and relevant details are as follows:

- The peak flow through the southern set of railway culverts increases from 0.6 m^3/s (existing case) to 1.3 m^3/s (proposed case). This more than doubling of flow indicate lowering the culverts significantly increases their peak flow.
- The culverts discharge significantly more flow when greater depths are experienced in the town. At a depth of around 0.2 m in the proposed case, the culverts discharge 1.3 m^3/s while at around 0.1 this drops to 0.9 m^3/s. In other words, the last 0.1 m of depth in the town is much slower to drain than higher depths.
- The depth at a sample point in the town decreases more quickly, with a depth of > 0.1 m decreasing from 20 hours (existing case) to 13 hours (proposed case).

The results indicate that the lowered culvert and table drains will reduce the duration of flooding but will not significantly alter the peak flood depths, in a 10% AEP event.

5.2.2 Rowena Road Levee Combined with Drainage Upgrade

A levee was built along the north side of Rowena Road in 2019 based on plans designed by SMK Consultants (see Reference 5). The levee runs from the railway embankment, for around 600 m before tying into the road, with a top of bank level of 155.26 mAHD along the levee. This level is based on the design drawings and not work-as-executed drawings or survey. For reference, the railway at its west end is approximately 155.5 MAHD, while the road at the east end is approximately 155.35 mAHD. The levee design was based on description of floodwaters arriving at the town via the field to the north, and aims to divert this flow west, to the north set of railway culverts. This levee has been partially built in September 2019, see photo below.

Figure 25: Section of levee along Rowena Road in September 2019

The hydraulic model established for the current study was used to assess the effect of the levee. The measure was modelled in conjunction with the proposed culverts and table drains as designed by SMK. The impact of the levee on the 1% AEP event is shown on Figure 26.

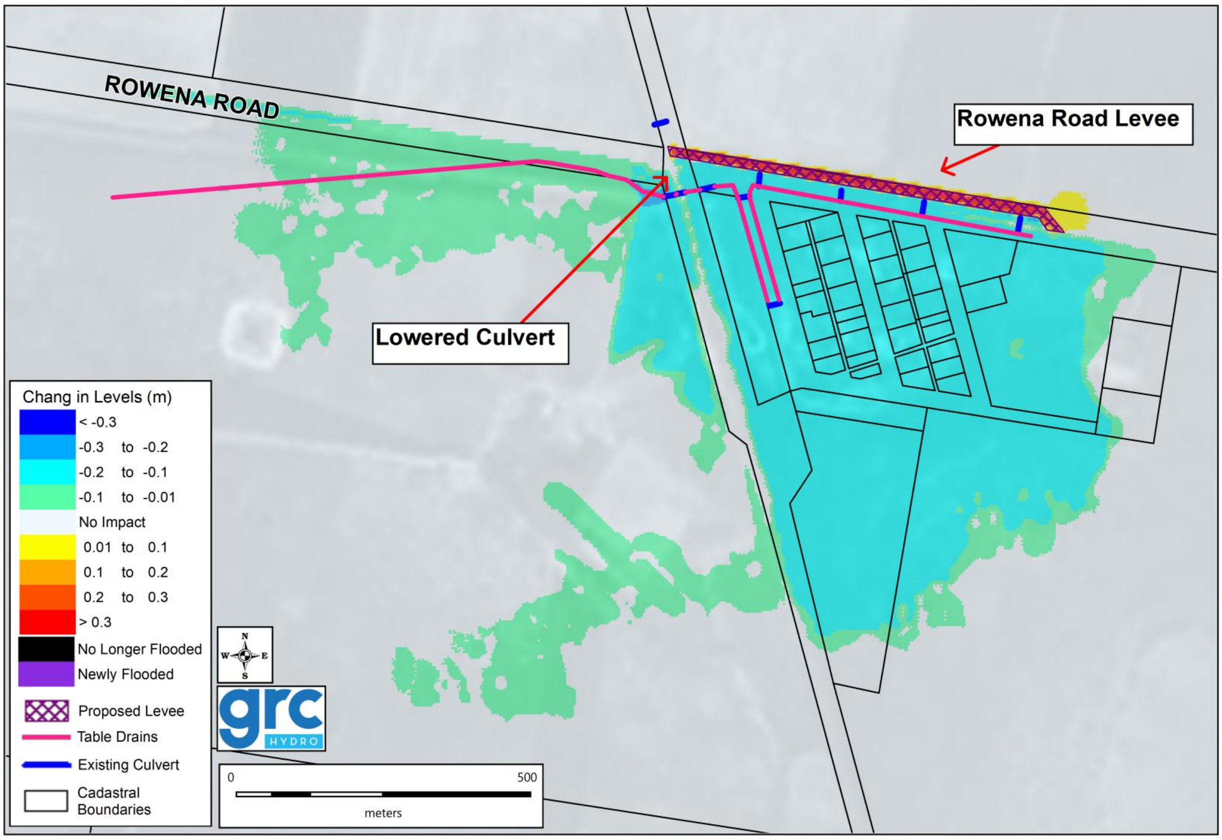


Figure 26: 1% AEP Peak Flood Level Impacts - Rowena Road Levee

The figure shows that the levee is successful in diverting some floodwaters from entering the town, with a decrease of 0.2 m in the 1% AEP across the town. The levee crest level (155.26 mAHD) is slightly above the 1% AEP level in the field north of the town, which is 155.10 mAHD. However, it is noted that at this height the levee has only 0.16 m freeboard and may therefore be overtopped in a 1% AEP event. Secondly, the levee does not prevent flow entering the town south of Rowena Road at the eastern end of the levee.

In conclusion, the SMK drainage plans will provide some benefit with regards to flooding but will not significantly reduce flooding in a 1% AEP event. The function of the drainage in regular rainfall events has not been assessed but it is expected to provide more substantial benefit in such events.

5.2.3 Further Measures

A modified version of the levee design was then assessed to further reduce flooding at the town. The modified levee aims to divert the flowpath that arrives south of Rowena Road, from the east. Figure 27 shows the ground elevations in the town and the location of this flowpath.

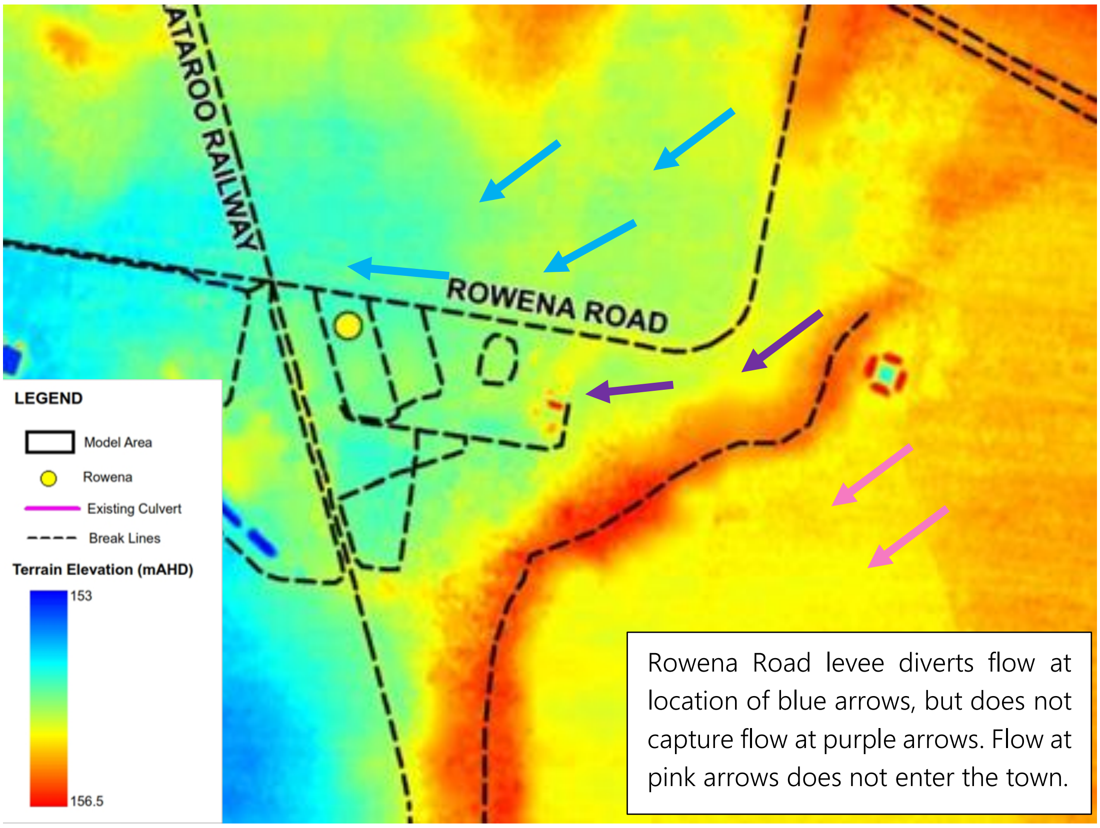


Figure 27: Ground elevation in the vicinity of Rowena

The location of the modified levee and the impact in the 1% AEP event are shown on Figure 28. The figure shows that the additional levee section significantly reduces flooding in the town, with a reduction of around 0.3 m in the 1% AEP peak level. The figure shows that the flow is diverted to the north-east of the town and causes a minor increase in peak flood level. The flood level at the eastern section of the levee is 155.42 mAHD and so the levee crest would be approximately 155.92 mAHD, assuming 0.5 m freeboard. In comparison, Rowena Road is 155.35-45 mAHD between the two levee sections. The road in this section between the levees would need to have a small levee alongside it at approximately 0.5 m above the ground, to provide equal level of protection to the two levee sections at 1% AEP + 0.5 m.

Note that a freeboard of 0.5 m is based on standard freeboard heights in NSW. A freeboard assessment for the levee can be carried out to refine the freeboard estimate.

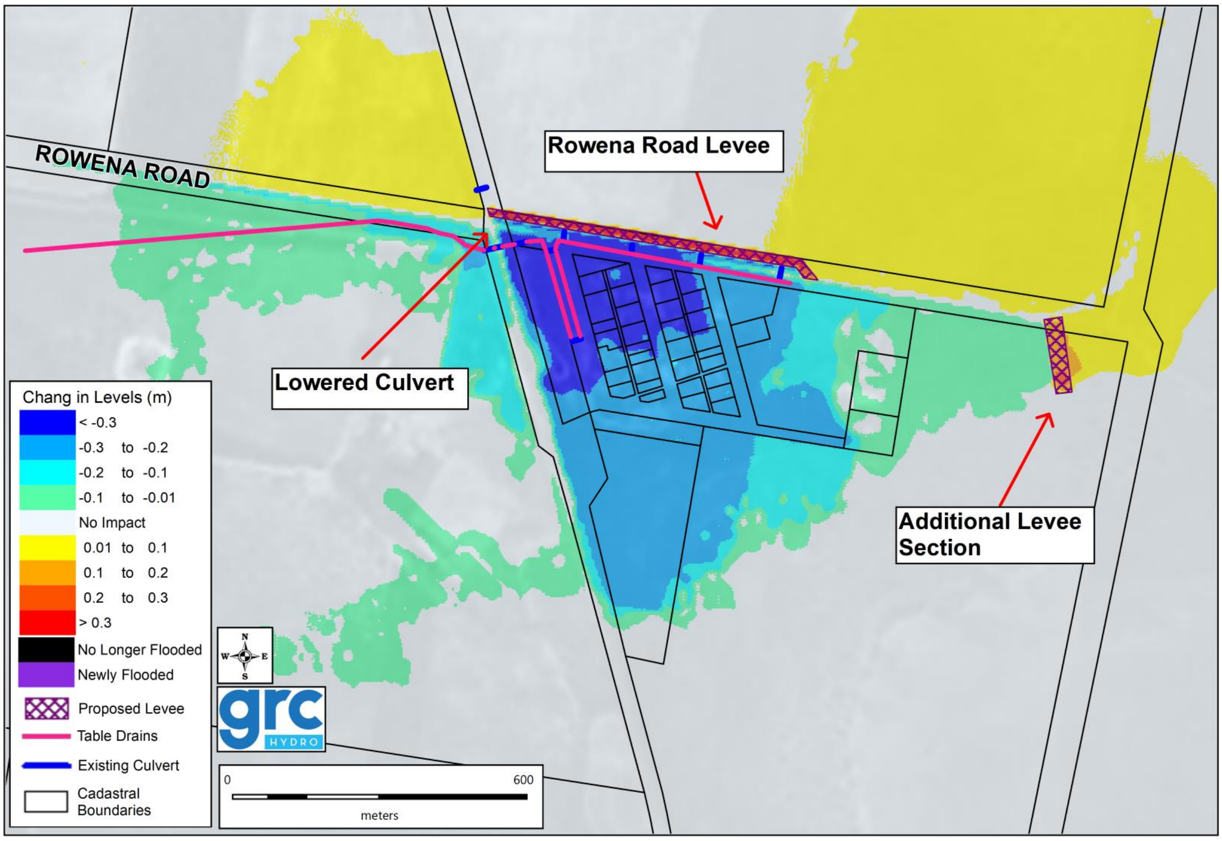


Figure 28: 1% AEP Peak Flood Level Impacts – Additional Rowena Road Levee

As a further sensitivity test, the modified levee design was combined with a doubling of the south set of railway culverts, from 5 to 10 culverts. This measure consisted of the modified levee design, the table drains and the doubled and lowered railway culverts. While increasing the flow rate significantly and reducing the duration of flooding, the peak flood level was only marginally lower (see below). A second sensitivity test was also run that used only the unmodified levee, with no other changes, with the results presented below.

The flood level under different measure has been taken at two points in the centre of town, for a more straightforward comparison of each measure. Point A is between Rowena and Shaw Streets and point B is between Middle and Shaw Streets, just north of the school. A summary of the impact of the measures is provided in the following table, which also includes the duration of flooding above 0.1 m depth at point A, in each scenario.

Table 13: Comparison of possible measures – 1% AEP

	Depth (m) at point A	Depth (m) at point B	Duration that depth >0.1 m at point A
Existing case	0.43	0.32	30 hours
Table drains and lowered culverts [SMK design with no levee]	0.42	0.32	30 hours
As above with Rowena Road levee [SMK design]	0.24	0.13	24 hours
Further measures:			
Table drains, lowered culverts and Rowena road levee with additional eastern levee	0.13	0.02	5 hours
As above with southern culverts doubled	0.11	0.01	2 hours
Rowena Road levee by itself	0.34	0.23	27 hours

The table indicates that the most effective measures are the Rowena Road levee when combined with the table drains/lowered culverts, and the levee with the additional eastern section. These reduce the flooding by around 0.2-0.3 m while other measures have less than 0.1 m reduction. The table indicates that at point B near the school , where there is slightly higher ground, the Rowena Road levee will remove most of the inundation, with a peak of 0.13 m, while at point A, the additional eastern section of levee provides significant benefit. Regarding duration of flooding, doubling the southern railway culverts reduces the duration significantly.

A cost-benefit analysis has been carried out for the third measure in the table ('Table drains, lowered culverts and Rowena road levee with additional eastern levee'). This involved determining the AAD for the option, calculating the reduction in AAD from the existing case, and comparing this to the estimated cost of the works. The results are presented below:

Table 14: Option Cost Estimate

Item	Cost Estimate
Contractor setup and project management	$57,000
Excavation and compaction of fill	$373,000
Lowered railway culverts	$200,000
Total (inc. GST and 20% contingency)	$882,000
Cost estimate is only approximate, for the purposes of economic analysis of the option. Railway culvert works may be	

The option's reduction in Average Annual Damages, the Net Present Value (NPV) of this reduction (assuming 50 year design life and 7% discount rate) and the benefit-cost ratio are presented below.

- Average Annual Damage Reduction: $92,043
- NPV of reduction: $1,359,180
- Cost estimate of option: $882,000
- Benefit-cost ratio: 1.5

The benefit-cost ratio indicates the economic benefit of the option is around 50% more than the cost of the works. However, the estimate is based on a standardised estimate of flood damages which may be less accurate in Rowena than some other areas. The cost estimate of the works may also be revised as part of detailed design, as standard cost estimation handbooks do not include works in a railway. The analysis indicates that in general, the works are likely to be broadly feasible from a benefit-cost perspective.

5.2.4 Recommendations

It is recommended that Council implement the SMK drainage plans, with some modifications. The recommended measure consists of:

- The table drains and culverts shown in the SMK drainage plans, including lowering the culverts under the railway.
- Constructing the Rowena Road levee to a height of 155.6 mAHD, to give it a freeboard of 0.5 m in the 1% AEP event.
- Constructing an additional levee section to the east, as shown in Figure 28. This should be built to the 1% AEP + 0.5 m (155.92 mAHD).
- Constructing a small levee embankment joining the two sections (around 0.5 m high) as the road is currently close to the 1% AEP flood level and so has no freeboard. The road can then be raised by 0.5 m where the levee crosses it.
- As a lower priority measure, double the capacity of the southern set of railway culverts to reduce the duration of flooding in the town.

5.3 Property Modification Measures

Property modification measures are those that directly deal with existing and future development to manage its flood risk. While such measures do not change the flood behaviour itself, over time they can remove dwellings and other buildings from the most hazardous flooding and ensure the remaining flood-prone areas are well-equipped to deal with flooding. Such measures are particularly suited to areas where flood modification measures are either not available or prohibitively expensive. In most cases property modification measures are implemented via Council policies, which can be used to stipulate where and how development can occur in the floodplain.

Property modification measures in the following sub-sections have been assessed for Rowena. Other measures that were considered but not assessed include:

- Rezoning of land would give little benefit as flood risk is largely uniform across the study area
- Voluntary purchase and voluntary house raising were not considered given the low flood risk in most events and the potential for structural measures to significantly improve flooding
- For similar reasons flood proofing of properties was not assessed.

5.3.1 Adopt updated Flood Planning Area for the town

The Flood Planning Area (FPA) defines properties that are subject to flood related development controls and is a key planning tool for managing and mitigating flood risk in an LGA.

Typically an FPA is set out on a map to indicate where it applies. In Rowena, all lots in the study area are subject to flooding, hence the FPA should cover the area modelled in the Local Hydraulic Model. The Flood Planning Level (FPL) is recommended to be set at the 1% AEP flood level plus 0.5 m freeboard. 1% AEP flood levels are shown in Figure 33. The level in the town is 155.1 mAHD, which corresponds to an FPL of 155.6 mAHD. The FPA would therefore be defined as all land below 155.6 mAHD.

Adoption of the FPA can be made in the short-term, while changes to the LEPs and DCPs may take slightly longer (see following measures). Adoption of this Floodplain Risk Management Study and Plan by Council can be used to formally adopt the new planning areas.

5.3.2 Adopt updated Flood Planning Level

The Development Control Plan currently contains controls for new development in flood-prone areas, as summarised in Section 2.2.2. The DCP currently refers to the use of a historical flood in setting design flood levels. It is recommended that this requirement be updated for Rowena to use the 1% AEP flood, which reaches 155.1 mAHD across the town, instead of a historical flood.

5.3.3 Council Policy Amendments

The Local Environment Plan is the overarching policy document that sets requirements for managing flood risk in the LGA. Section 2.2.2 describes the flood planning clause in the LEP. It is considered best practice for LEPs to remove reference to a Flood Planning Area (FPA) map and refer to development below the Flood Planning Level instead, with the FPA map then contained in the DCP or elsewhere. Other councils have also benefitted from a Floodplain Risk Management Clause in the LEP for controls that apply between the FPL and the PMF extent.

However, a revised LEP clause would have minimal utility for Rowena because there is negligible variation in flood risk across the floodplain. Current controls adequately manage the flood for the town and the difficulty and cost of changing the clause is considered to not be worthwhile for Council.

5.4 Response Modification Measures

Response modification measures are those that improve the ability of people to plan for and react to flood events. As described in Section 4, Rowena is affected by flooding in the township, but can also be isolated for days or weeks due to flooding of the adjacent river systems. In the township, flooding generally occurs with minimal warning time but can last several days. In the adjacent floodplains, there is likely to be several days of warning time. It is also noted that flooding in the area will directly or indirectly all residents, and this leads to a high level of awareness of flooding. Response modification measures are therefore focussed on improving general preparedness for a flood event.

Additional warning signage for flooded roads has been considered below. Roads in the study area do not experience H3-H6 hazard flooding in the 1% AEP, however they do experience H2 flooding (hazardous to small cars) and during widespread inundation, a vehicle could veer off the road into deeper waters (i.e. H3 hazard).

Other response modification measures that have been considered but not recommended include:

- Flood prediction and warning system. The Bureau of Meteorology currently issue warnings for heavy rainfall in the region. Because of the uniform flood risk across the town, a more sophisticated warning system would provide minimal benefit.

5.4.1 Community Flood Education

The level of awareness of flooding in a community is an important indicator of how well the community can prepare for, respond to and then recover from a flood event. Beyond general awareness that flood risk exists in a particular town, flood education is most effective when it facilitates resilience to flooding in a community. This encompasses understanding of the types of flood risk, the available warning systems, measures that can be taken in preparation for a flood event, personal safety and protection of assets during a flood, and recovery from a severe flood event. In Rowena, there is generally high awareness of flooding and education should focus on maintaining awareness between floods and improving residents' preparedness.

Materials used in education should consist of:

- information on previous floods including photos
- design flood information as described in the flood risk sections of this report
- SES information on preparing for a flood, common hazards during a flood, and the recovery phase

The range of communication methods adopted should cover different demographics and groups within the community. Available methods include:

- SES and Council stall at local events, with fact sheets, maps and SES staff available to talk to interested residents.
- Flood depth markers showing the height reached by historical floods. These can be attached to telegraph poles or other infrastructure.
- Periodic articles in press and social media, which describe the history of flooding and useful information on the current flood risk, and available resources.

Education packages for primary schools and secondary schools. See https://www.ses.nsw.gov.au/for-schools/ for examples. It is recommended that Council and the SES implement a community flood education program for the town.

5.4.2 Update Local Flood Plan

The measure consists of updating information on flooding in the Walgett Shire Local Flood Plan. The current study cannot offer further information on isolation of the town, though survey of local authorities may provide information for that section.

With regards to flooding in the town itself, a summary of the information presented in Section 4 of this document will suffice. It should also be noted that analysis undertaken during this study concluded that Rowena will not be directly flooded by Pian Creek or Thalaba Creek flooding, although an extreme event (i.e. the PMF) may possibly flood the town to a shallow depth.

5.4.3 Road Safety Guide Posts

The use of road safety guide posts is recommended to guide vehicles during a flood event. In the 1% AEP flood event, all roads experience a maximum of H2 hazard, which is hazardous to small cars. However, road sections in the north half of the town experience H3 hazard on either side of the road, and the road boundaries may not be visible. It's therefore recommended to install road guide posts along the road to demarcate the road boundary and where higher flood risk exists. This is recommended for Rowena Road and the three roads through the town.

6. CONCLUSIONS

A flood study and floodplain risk management study and plan has been carried out for Rowena. The town experiences widespread shallow flooding and can also be isolated for days or weeks during flooding of the creek and river systems to the north and south of the town. Flooding in the town itself is caused by heavy rainfall in the local area to the east. Improved drainage through the town's railway line, and a levee system on the north side of the town have the potential to significantly reduce the occurrence of flooding in the town. It is also recommended that Council implement a flood planning level for development in the town, based on the 1% AEP design flood event. A list of recommended measures is presented in the executive summary and constitutes the draft Floodplain Risk Management Plan.

7. REFERENCES

1. Australian Rainfall and Runoff (ARR2016)
   Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, Commonwealth of Australia, 2016

2. Narrabri Flood Study
   WRM Water for Narrabri Shire Council, 2016

3. Floodplain Management Plan for the Lower Namoi Valley Floodplain
   NSW DPI Water, 2018

4. Floodplain Management Plan for the Gwydir Valley Floodplain
   NSW DPI Water, 2015

5. Drainage Design Rowena
   SMK Consultants for Walgett Shire Council, 2019

Appendix A: Design Flood Behaviour Maps

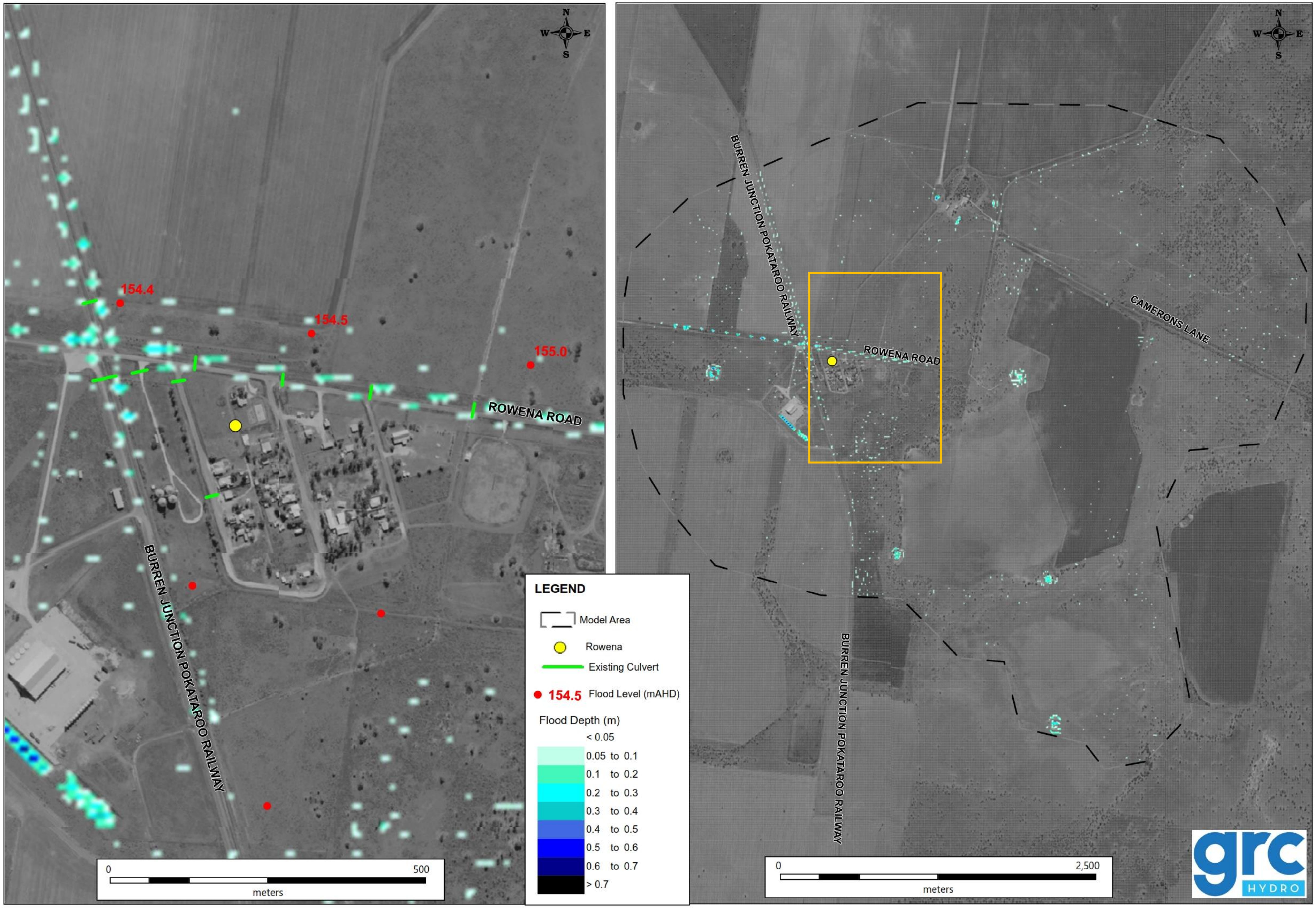


Figure 29: Peak Flood Depth and Level - 20% AEP

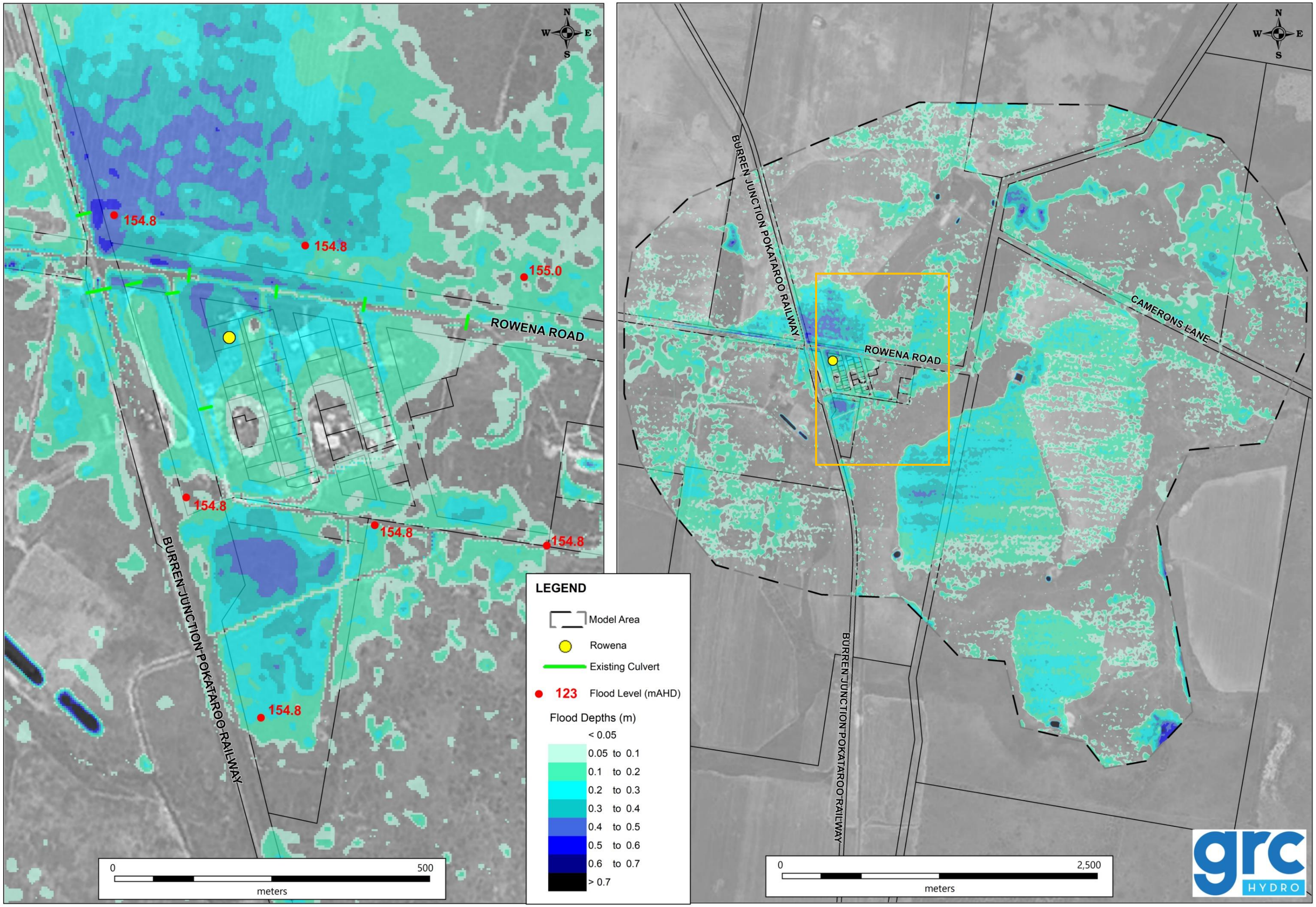


Figure 30: Peak Flood Depth and Level - 10% AEP

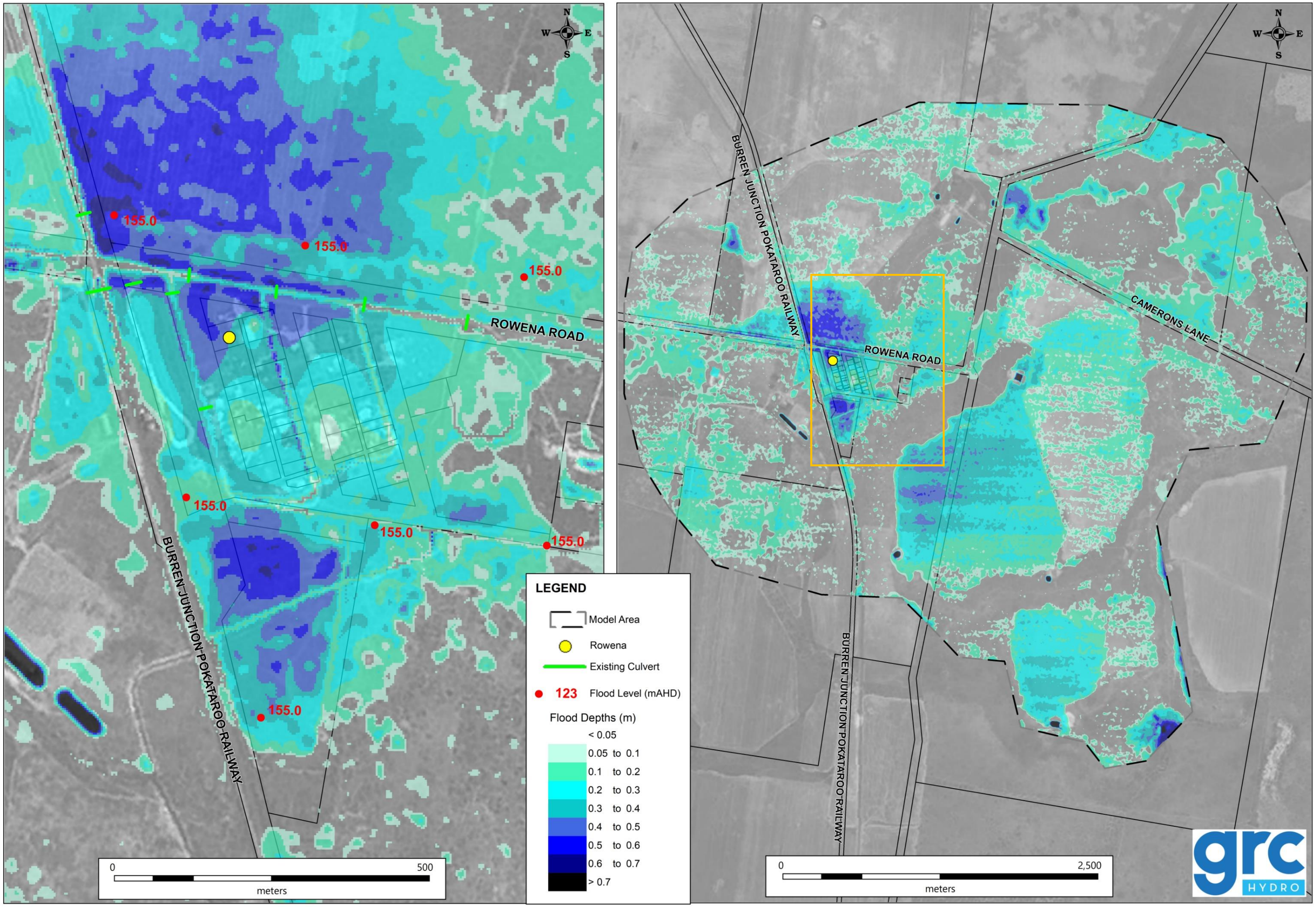


Figure 31: Peak Flood Depth and Level - 5% AEP

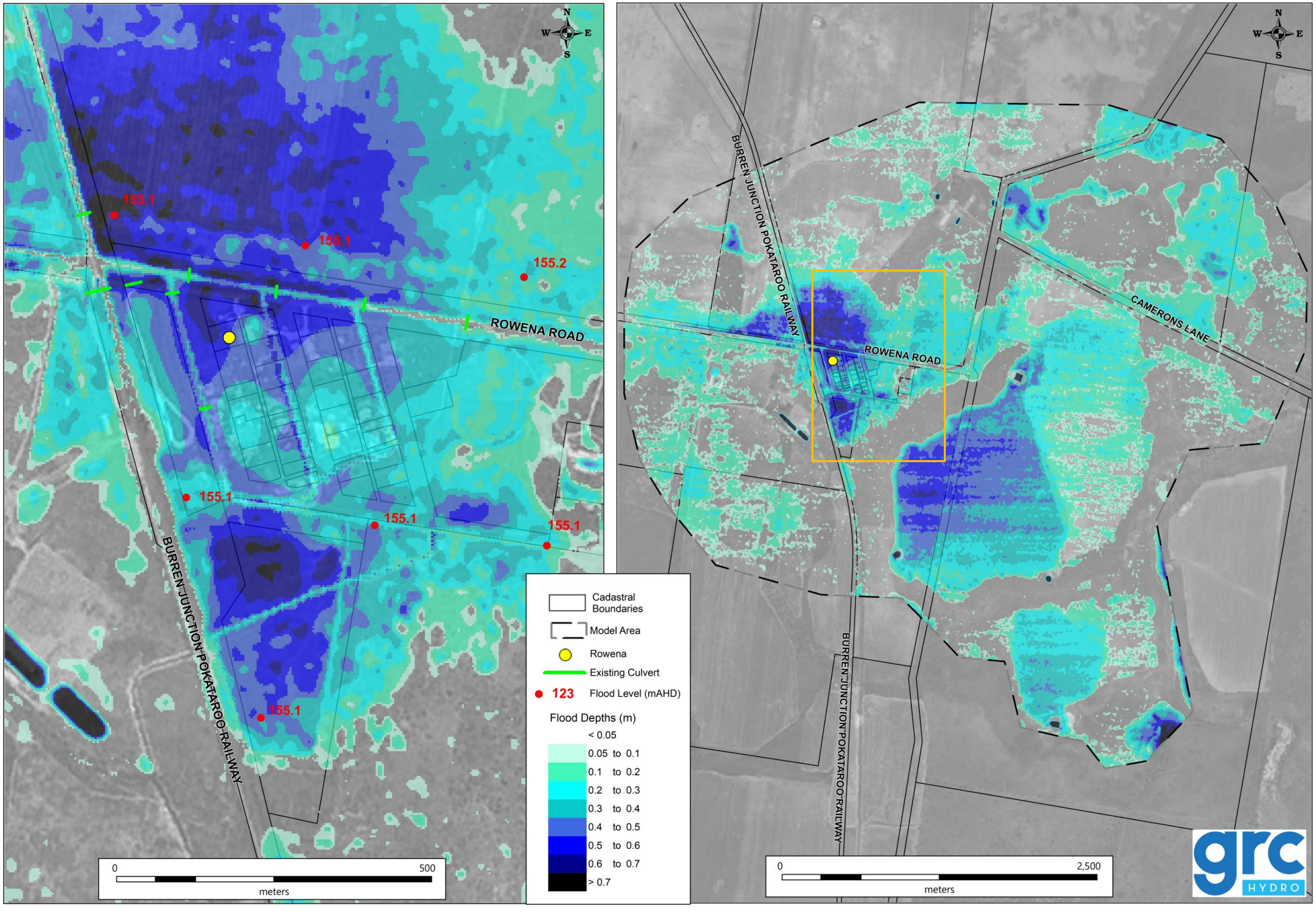


Figure 32: Peak Flood Depth and Level - 2% AEP

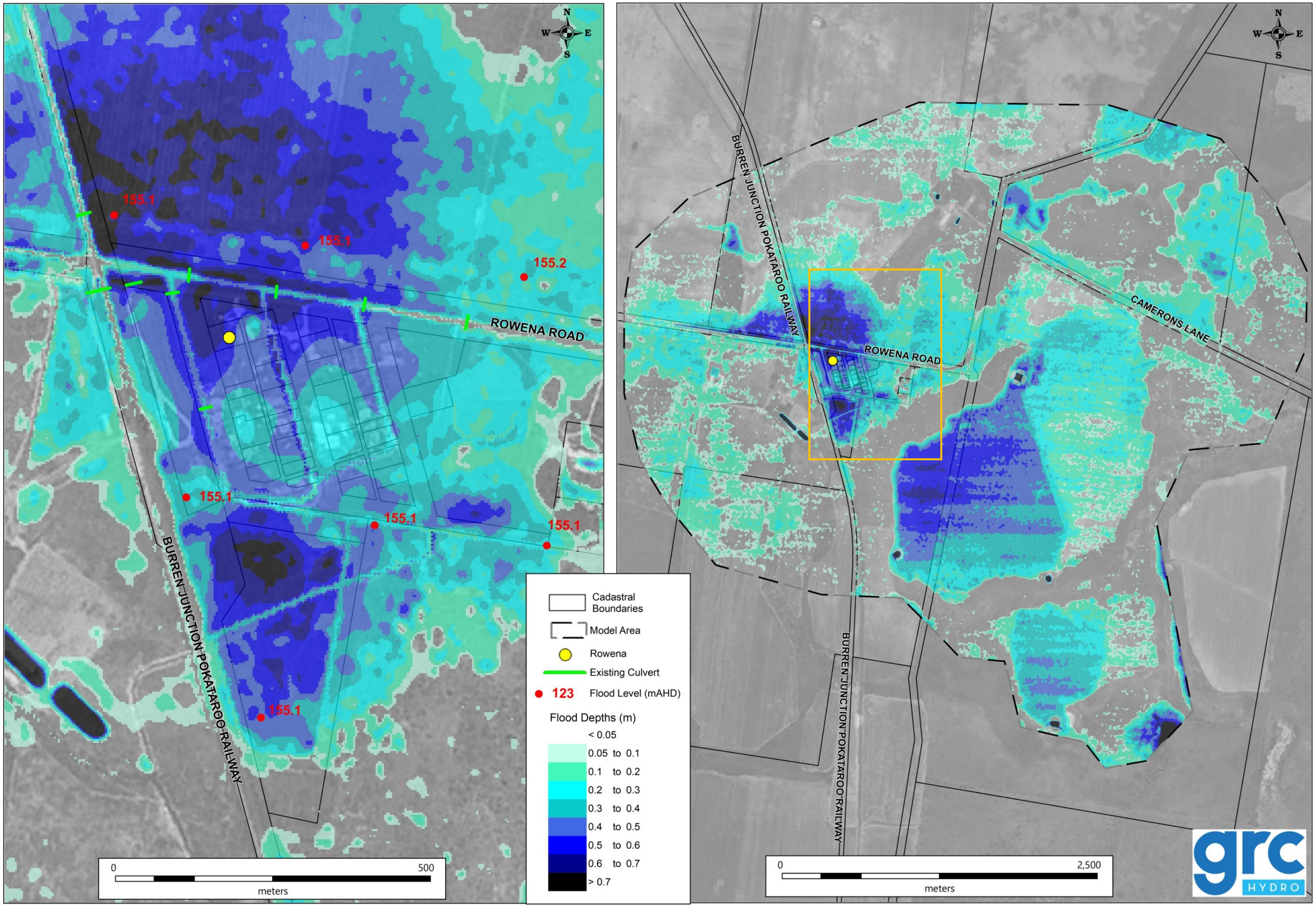


Figure 33: Peak Flood Depth and Level - 1% AEP

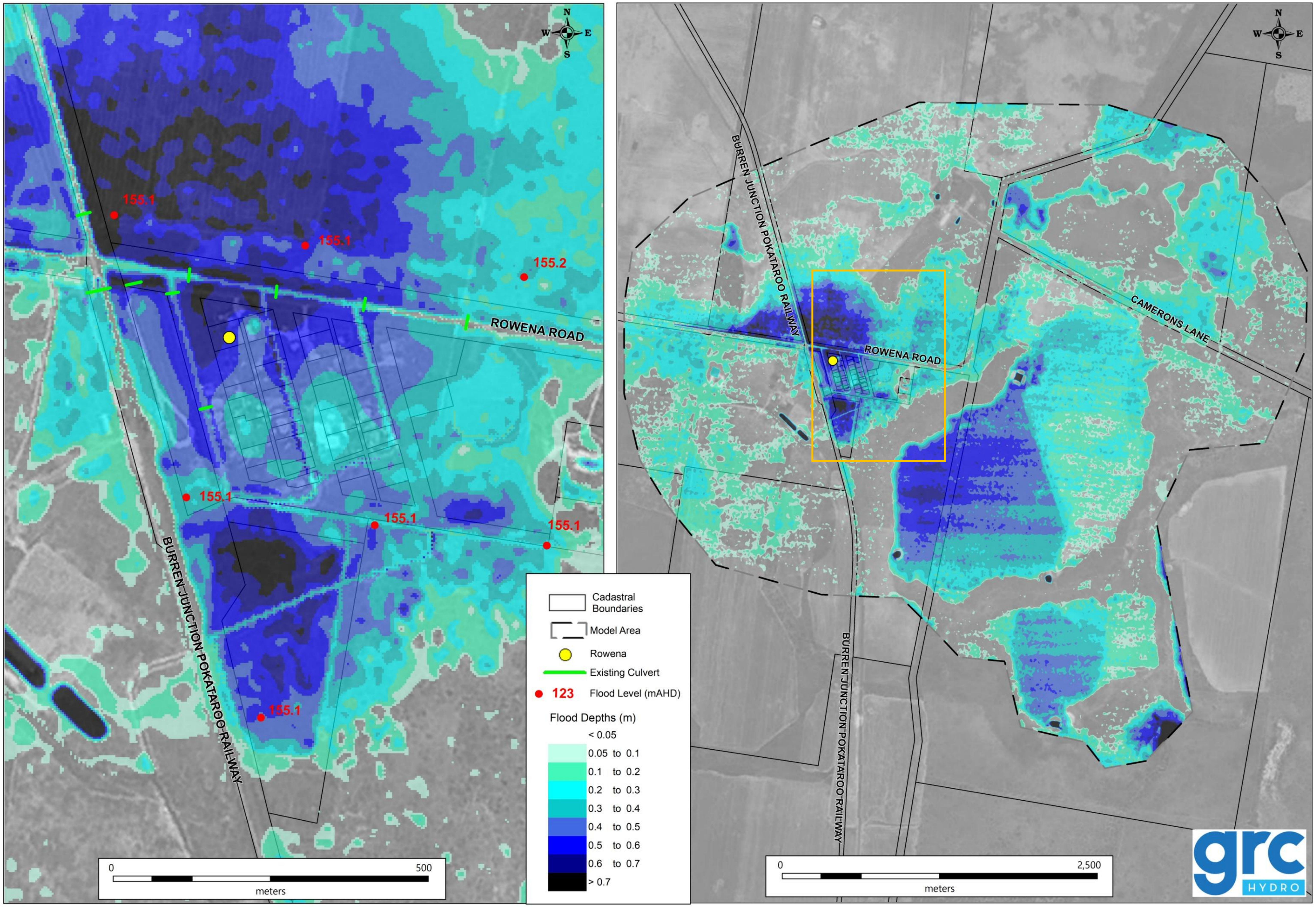


Figure 34: Peak Flood Depth and Level – 0.5% AEP

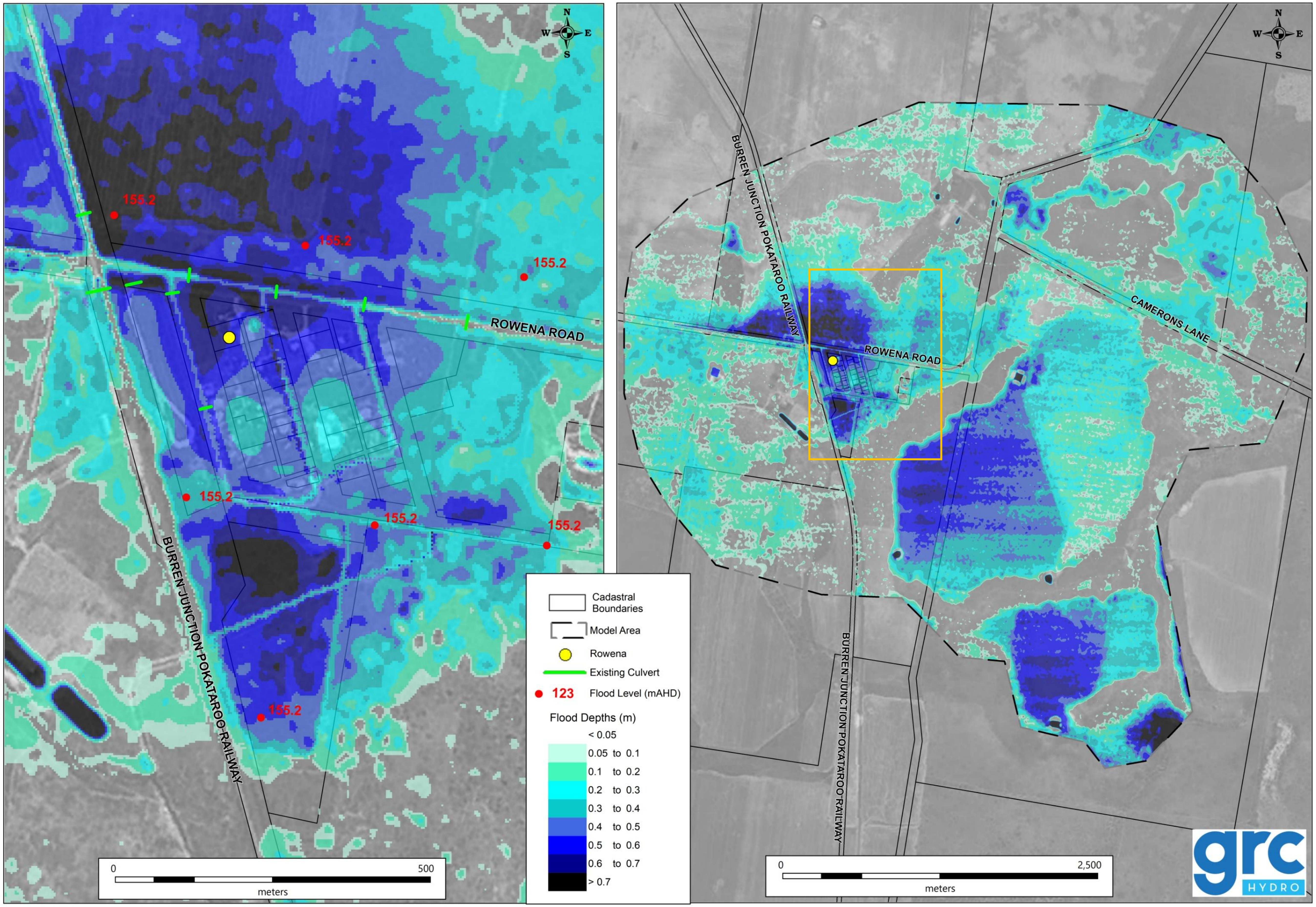


Figure 35: Peak Flood Depth and Level – 0.2% AEP

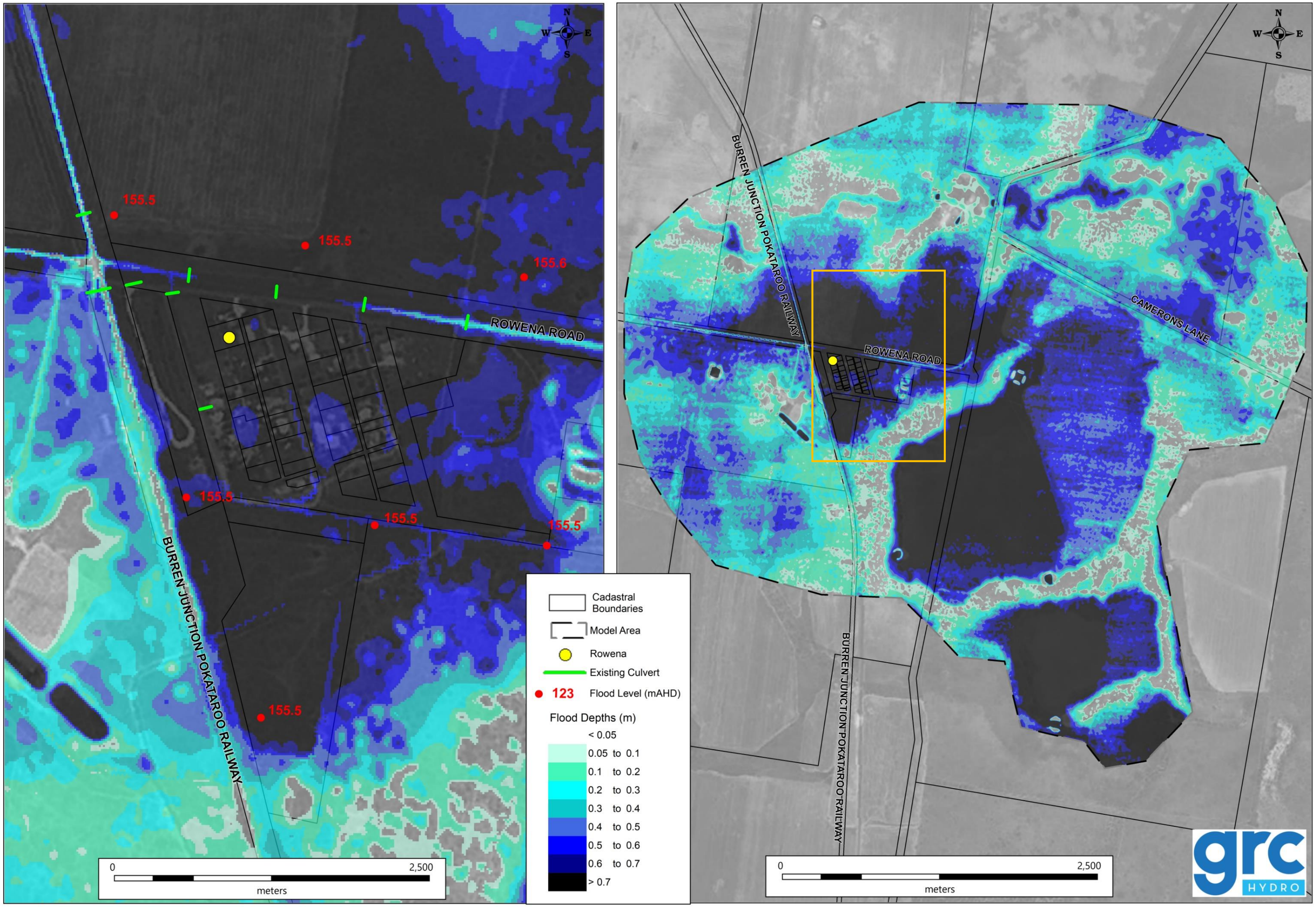


Figure 36: Peak Flood Depth and Level – PMF

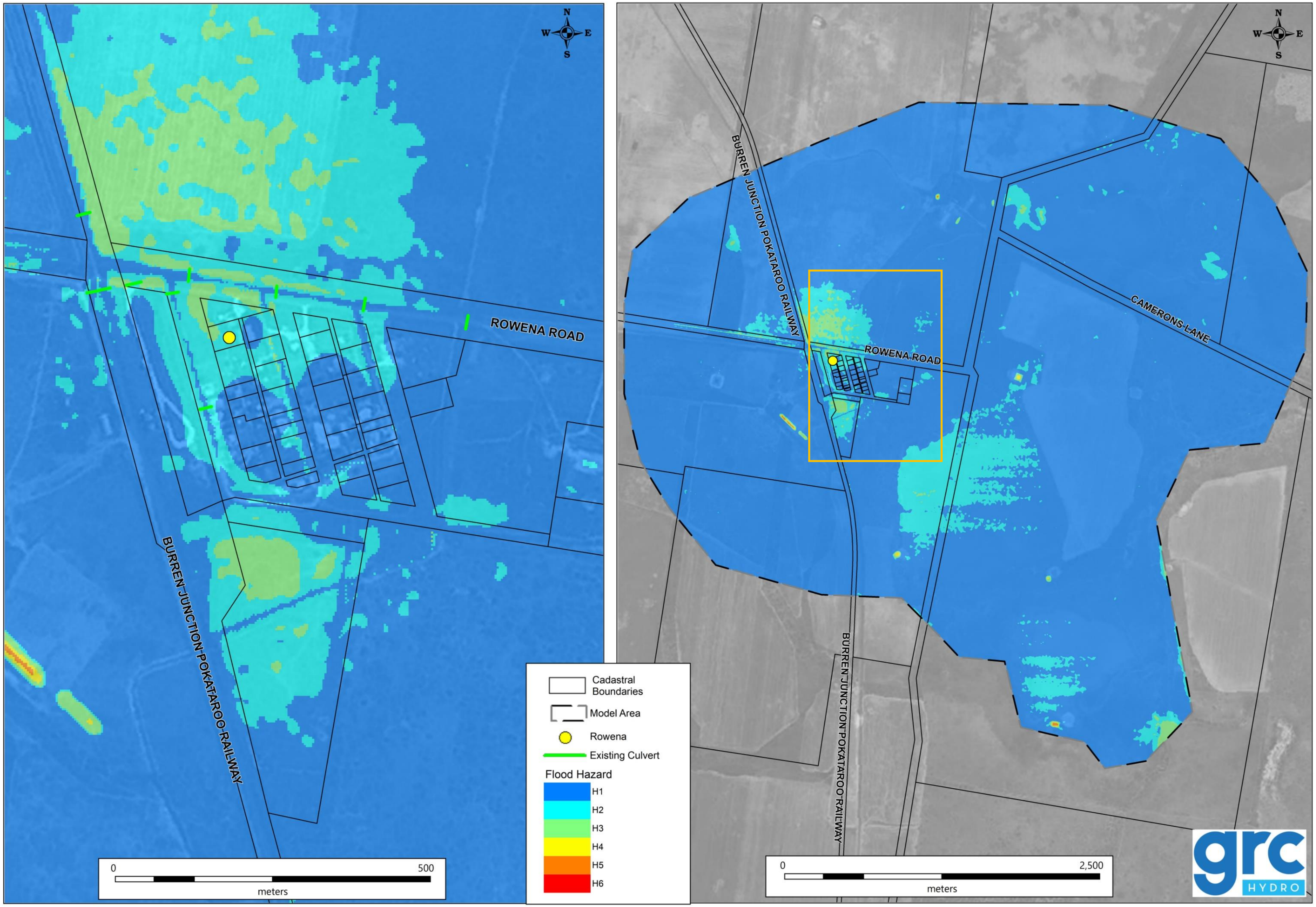


Figure 37: Peak Flood Hazard – 5% AEP

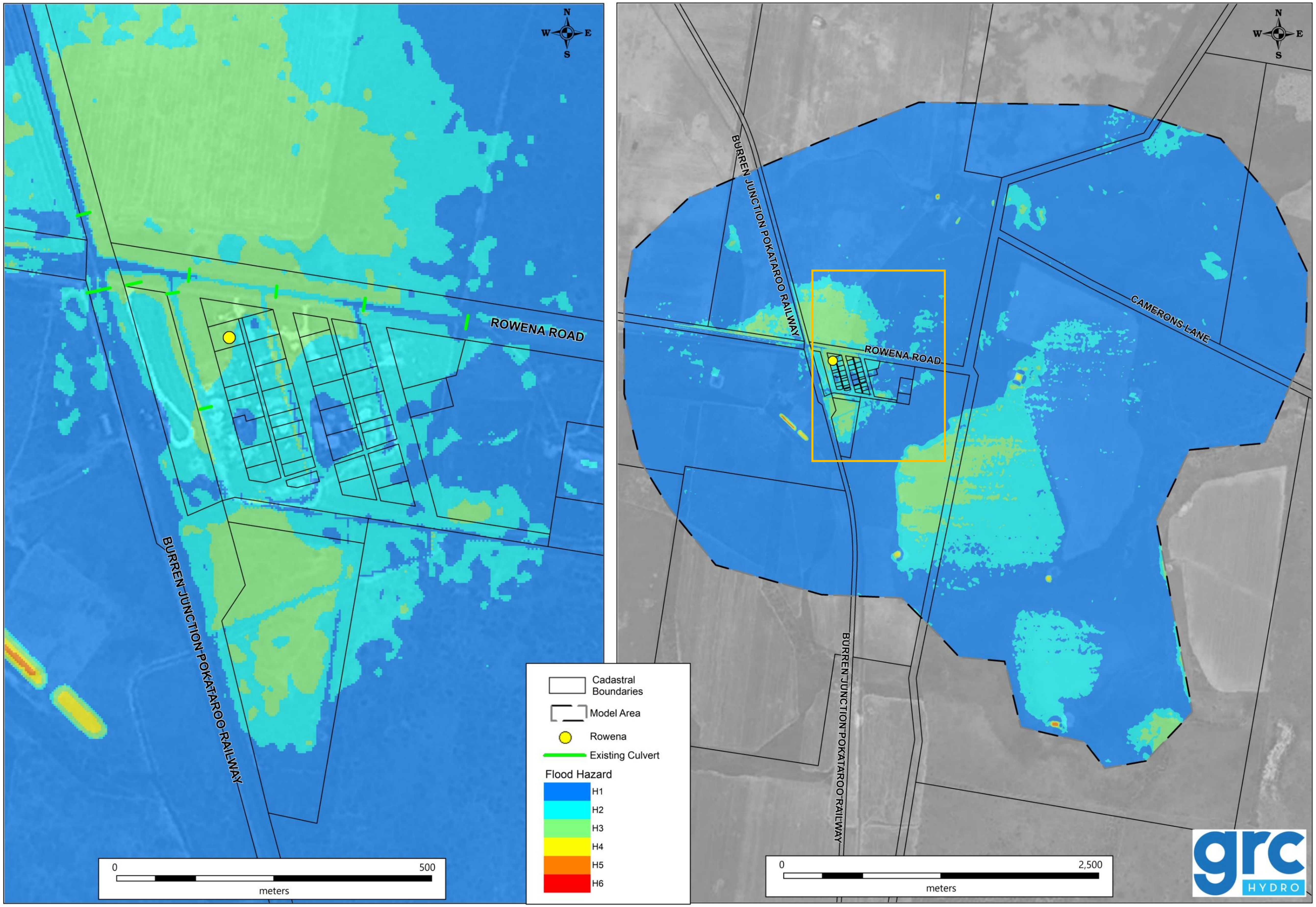


Figure 38: Peak Flood Hazard – 1% AEP

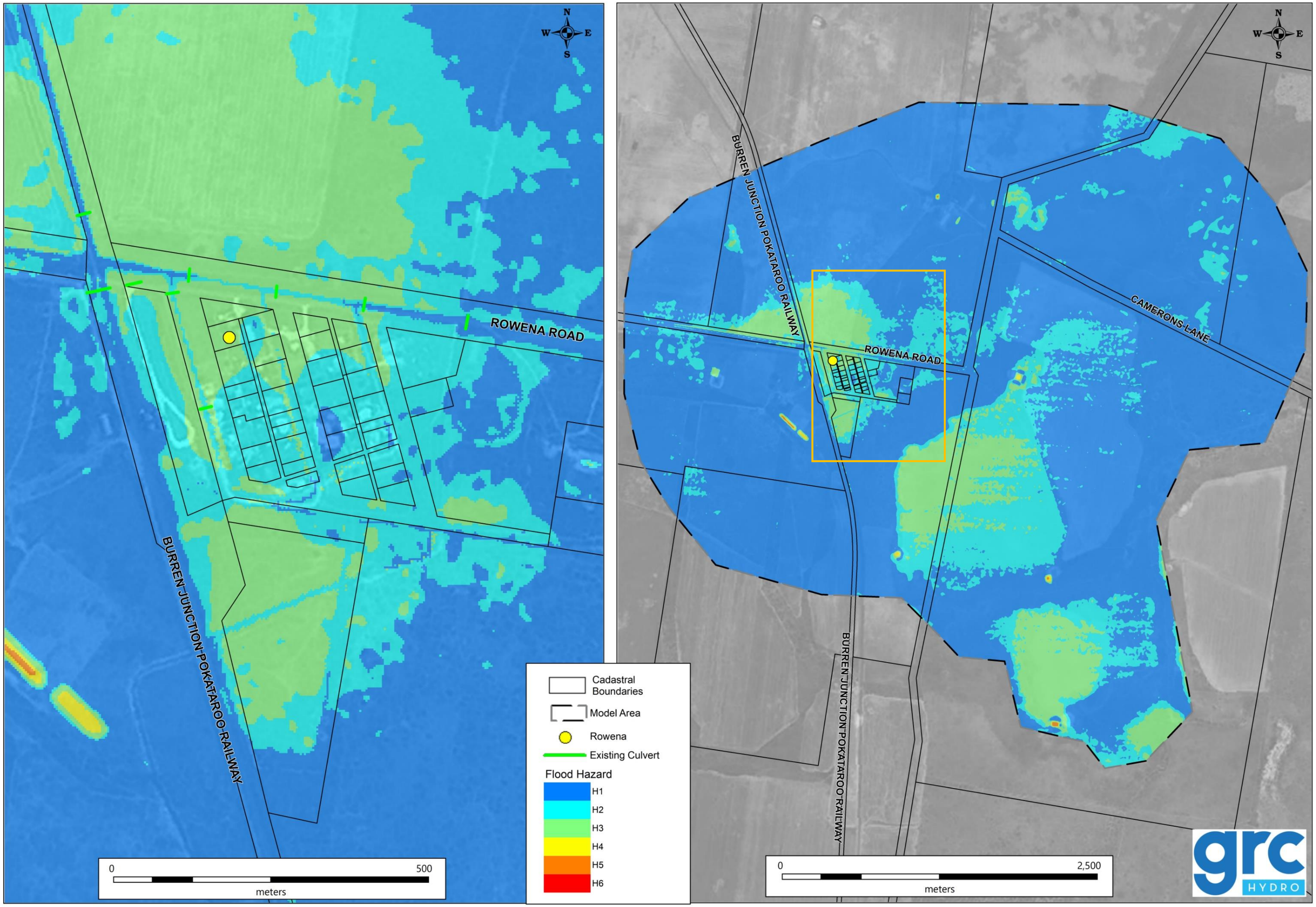


Figure 39: Peak Flood Hazard – 0.2% AEP

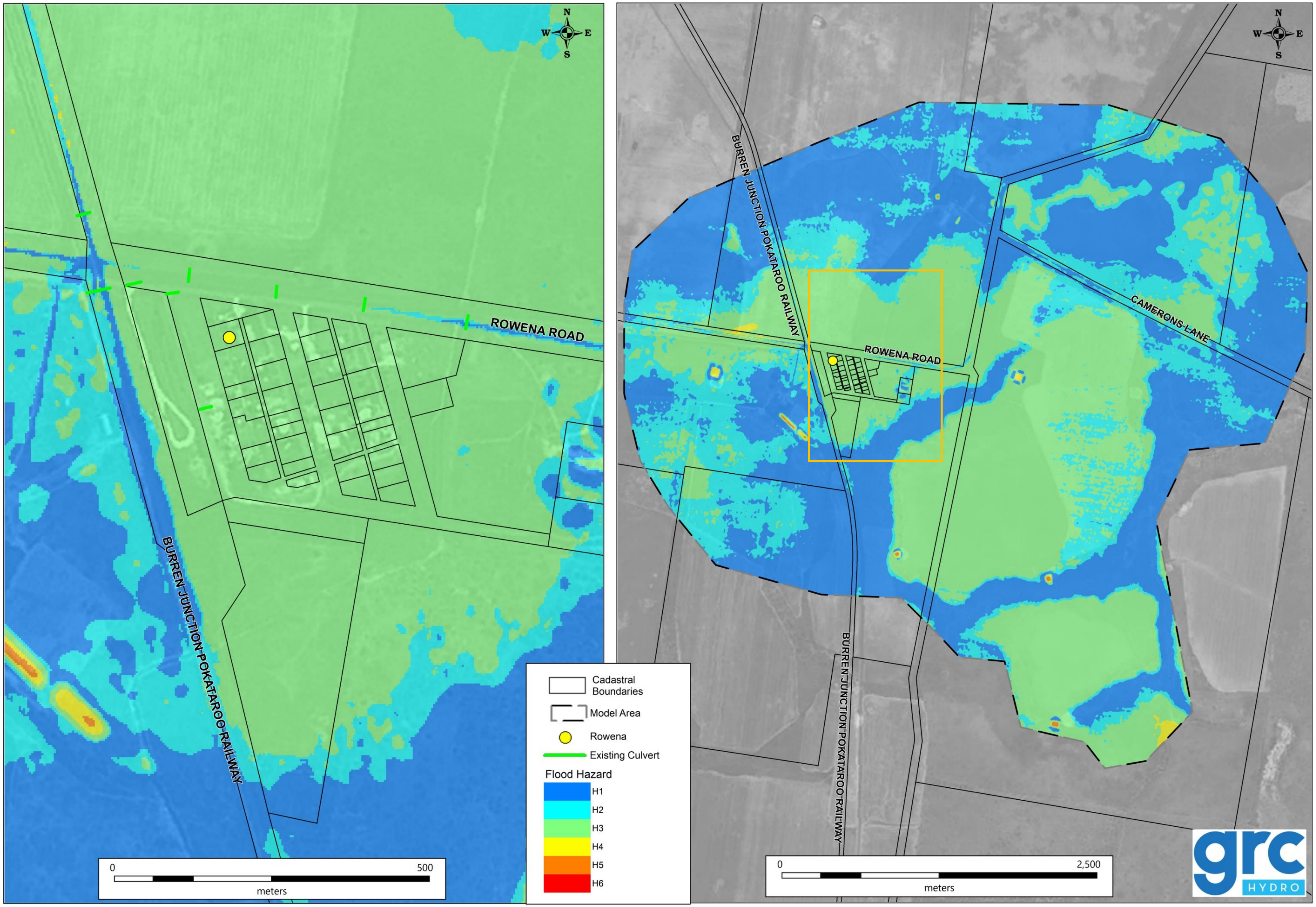


Figure 40: Peak Flood Hazard – PMF

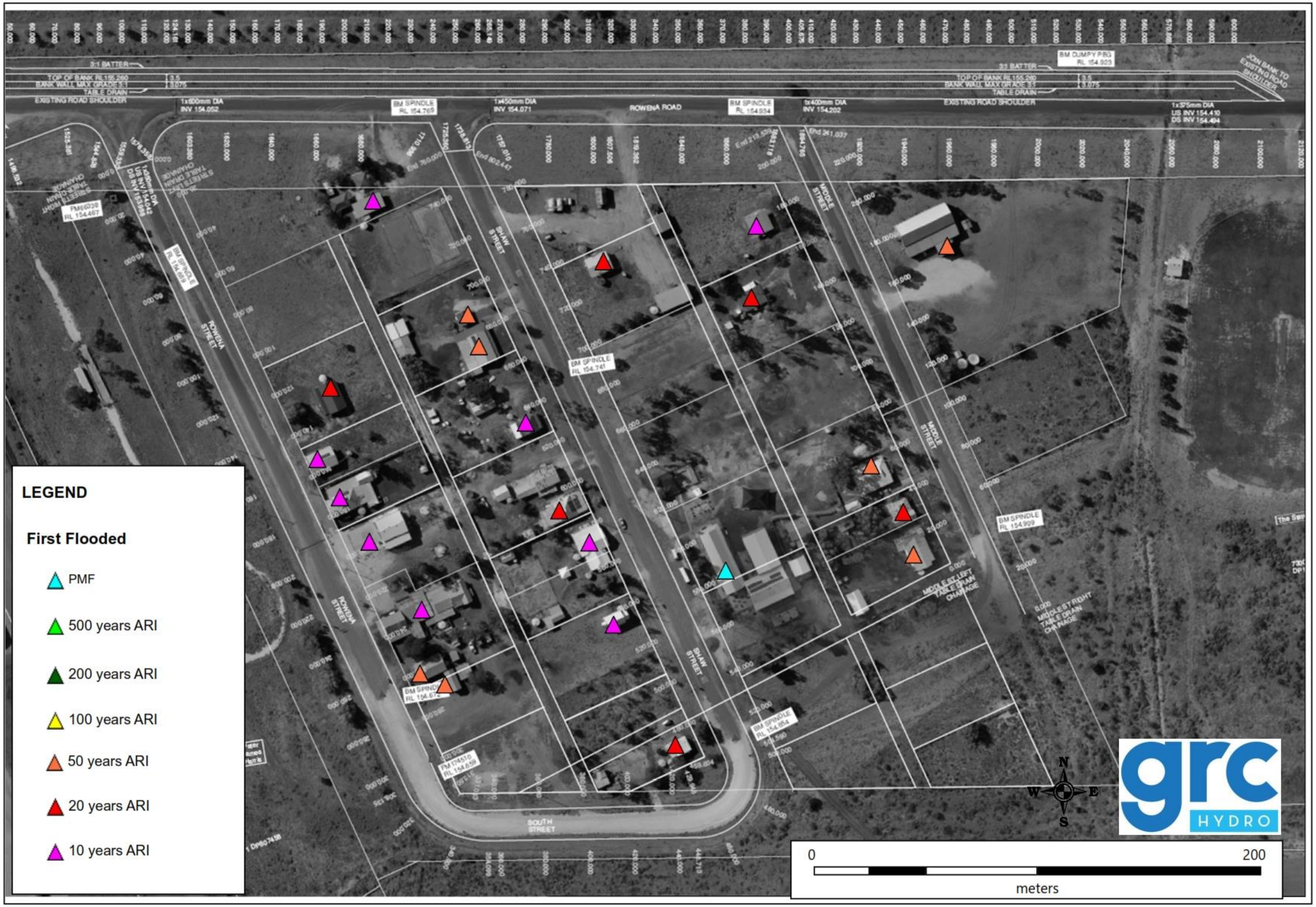


Figure 41: Event First Flooded Above Floor

Appendix B: HEC-RAS Background Information

Hec-Ras is a software developed by the U.S. Army Corps of Engineers and allows to perform one-dimensional steady flow hydraulics, one and two-dimensional unsteady flow hydraulic calculations; quasi unsteady and full unsteady flow sediment transport-mobile bed modelling, water temperature analysis and generalised water quality modelling. For the purpose of this study, the two-dimensional unsteady flow hydraulic calculation engine was used.

The software uses the Shallow Water equations which are the simplified Navier-Stokes equations where incompressible flow, uniform density and hydrostatic pressure are assumed, and the equations are Reynolds averaged so that turbulent motion is approximated using eddy viscosity. It is also assumed that the vertical scale is much smaller than the horizontal length scales. Consequently, the vertical velocity is small, and pressure is hydrostatic leading to the differential form of the Shallow Water equations.

In some shallow flows, the barotropic pressure gradient (gravity) term and the friction terms are the dominant term in the momentum equations and unsteady, advection, and viscous terms can be disregarded. The momentum equation then becomes the two-dimensional form of the Diffusion Wave Approximation. Combining this equation with the mass conservation yields a one equation model, known as Diffusive Wave Approximation of the Shallow Water equations. In this study, the Diffusive Wave approximation was used.

The 2D unsteady flow equations solver uses an Implicit Finite Volume algorithm. The implicit solution algorithm allows for larger computational time steps than explicit methods. The Finite Volume Method provides an increment of the improved stability and robustness over traditional finite difference and finite element techniques. Additionally, the algorithm can handle subcritical, supercritical and mixed flow regimes (flow passing through critical depths, such as hydraulic jump).

The software was designed to use unstructured computational meshes. A structured mesh is treated the same as an unstructured mesh, except that software takes the advantage of cells that are orthogonal to each other (i.e. this simplifies some of the computations required). This means that computational cells can be triangles, squared, rectangles, or irregular polygons up to 8 faces. The mesh can be a mixture of cell shapes and sizes. The outer boundary of the computational mesh is defined with a polygon. The computational cells that form the outer boundary of the mesh can have very detailed multi-points lines that represent the outer face(s) of each cell. The computational mesh does not need to be orthogonal but if mesh is orthogonal the numerical discretization is simplified and more efficient.

Within Hec-Ras, computational cells do not have to have a flat bottom, and cell faces/edges do not have to be a straight line with a single elevation. Instead, each computational cell and cell face is based on the details of the underlying terrain. This type of model is often referred to in the literature as a "high resolution subgrid model" (Casulli, 2008). The term "subgrid" means that it uses the detailed underlying terrain (subgrid) to develop the geometric and hydraulic property tables that represents the cells and the cell faces. Hec-Ras has a 2D flow area pre-processor that processes the cells and cell faces into detailed hydraulic property tables based on the underlying terrain used in the modelling process. The 2D flow area pre-processor computes an elevation -volume relationship based on the detailed terrain data which is in each cell. Therefore, a cell can be partially wet with the correct water volume for the given water surface elevation based on the terrain grid data. Additionally, each computational cell face is evaluated similar to a cross section and is pre-processes in to detailed hydraulic property tables (elevation versus-wetted perimeter, area, roughness, etc…). The flow moving across the face (between cells) is based on this detailed data. This allows the modeler to use larger computational cells, without losing too much of the details of the underlying terrain that governs the movement of the flow. Moreover, the placement of cell faces along the top of controlling terrain features can further improve the hydraulic calculations using fewer cells overall.

Appendix C: Modelled and Reported RORB Parameters in Reference 4

The Floodplain Management Plan for the Gwydir Valley Floodplain (NSW DPI Water, 2015) appears to have discrepancies between its modelled and reported parameters for the Thalaba Creek RORB model. The following information was compared during the current study:

- RORB model files for the Thalaba Creek catchment model (supplied by NSW Department of Planning, Industry and Environment)
- MIKEFlood model files for the Thalaba Creek model (supplied by NSW Department of Planning, Industry and Environment)
- Volume 2: Appendices of the Background Document to the Floodplain Management Plan (available online)
- Gwydir Floodplain Management Plan Flood Modelling Report (supplied by NSW Department of Planning, Industry and Environment)

The Flood Modelling Report states that for the Thalaba Creek RORB model, a value of 70.86 was applied for K_c (the RORB routing parameter), based on calibration of the Tycannah Creek model. A graph shown of the Thalaba Creek RORB model's simulation of the February 2012 event shows a calculated peak discharge of approximately 940 m^3/s (the actual peak was not reported) at the catchment outlet.

Meanwhile, the MIKEFlood model for the same event, which uses inflows from the RORB model, applied inflows upstream from the catchment outlet of 523 m^3/s and 245 m^3/s. It was assumed that these must be from the same RORB model simulation that produced the 940 m^3/s, as there was no indication otherwise. However, there were no result files that showed these three peak discharges, nor were they able to be reproduced.

When the RORB model was run by the current study to reproduce the February 2012 hydrograph results, using the K_c value of 70.86 produced a catchment outlet flow of 1153 m^3/s. As all other model inputs appeared to match, the Kc value was adjusted until it was found that actually a value of 96.38 approximated the reported peak discharge (it corresponded to a peak of 946.6 m^3/s). Using a value of 96.38 produced model inflows of 864 and 133 m^3/s at the hydraulic model inflow locations.

This discrepancy meant that for the current study, the reported K_c value could be used (70.86), or the value that produced the reported results could be (96.38). There was not sufficient information to determine which approach was more accurate. The Kc which produced higher discharge (K_c = 70.86) was therefore chosen to provide a more conservative estimate. For the 2012 event, this produced inflows of 1050 and 167 m^3/s at the hydraulic model inflow locations.

This is likely a conservative estimate of the catchment K_c. There are two comparisons that can be made to the 1% AEP peak discharge produced by the RORB model using ARR2016 rainfall, which produces a peak discharge of 1,493 m^3/s.

- The Flood Frequency Analysis at Gravesend to the north produces a 1% AEP estimate of around 6,300 m^3/s for a catchment area of 11,020 km^2 (the exact value was not reported so the flow was estimated from the FFA chart). The catchment area is approximately 6 times larger than Thalaba Creek (1920 km^2) and the flow is ~4 times larger.

- At Narrabri the FFA estimated a 1% AEP flow of 4,860 m^3/s for an area of 25,400 km^2. The catchment area is approximately 13 times larger than Thalaba Creek and the flow is ~3 times bigger.

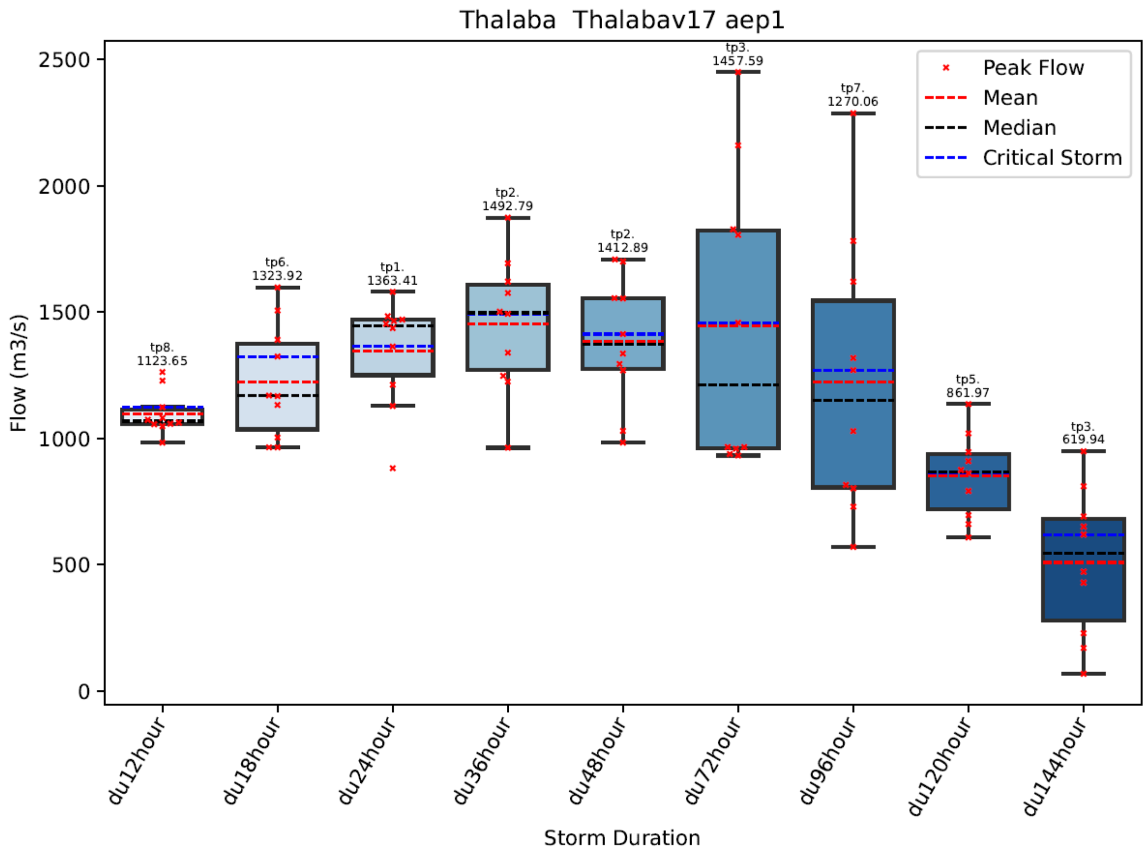
Appendix D: Critical duration analysis

A critical duration analysis was carried out for the RORB model of the Thalaba Creek catchment, as part of the 1% AEP discharge estimate. The analysis was carried out in accordance with ARR2019 and used an ensemble of ten temporal patterns for a range of design event durations to determine the critical duration and the representative storm. The analysis was not previously carried out for the model, as the previous study (Reference 4) only simulated historical flood events.

Ten temporal patterns, downloaded from the ARR 'Datahub' website for the catchment area, were run using the 1% AEP rainfall intensity for the following durations.

- 36 hours (1.5 days)
- 48 hours (2 days)
- 72 hours (3 days)
- 96 hours (4 days)
- 120 hours (5 days)
- 144 hours (6 days)
- 168 hours (7 days)

The analysis found that the critical duration, when using the median discharge, was 36 hours and the critical storm produced a discharge of 1493 m^3/s. The highest discharge was produced by the 72 hour duration (2,456 m^3/s) and that duration produced a similar critical storm discharge (1458 m^3/s) to the 36 hour duration. The 72 hour critical storm was used for the 1% AEP which combined similarly long duration hydrographs from other catchments. The results are shown in the figure below.



Thalaba Thalabav17 aep1
Peak Flow
Mean
Median
Critical Storm
Flow (m3/s)
2500
2000
1500
1000
500
0
tp8.
1123.65
tp6.
1323.92
tp1.
1363.41
tp2.
1492.79
tp2.
1412.89
tp3.
1457.59
tp7.
1270.06
tp5.
861.97
tp3.
619.94
du12hour
du18hour
du24hour
du36hour
du48hour
du72hour
du96hour
du120hour
du144hour
Storm Duration