NOBBY

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 150 300 450 600

Metres

1% AEP FLOOD DEPTH RIVERINE & OVERLAND FLOW PATH

Water Depth (m)	
0 - 0.5	Model Extent
0.5 - 1	DirectionFlow
1+	Emergency Services
	School

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\\mapdata\spatialdata\Projects\Spatial Services\Incident Management\114743\114743_NOB_D_AEP1_A3.mxd Author/Date: purvesa 11/02/2015

NOBBY

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 150 300 450 600

Metres

JANUARY 2011 DEPTH RIVERINE & OVERLAND FLOW PATH

Water Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1+

- Model Extent
- DirectionFlow
- Emergency Services
- School

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Flood Studies

TOOWOOMBA REGIONAL COUNCIL

2D Flood Studies Addressing Overland Flow Path Issues for Cooyar, Nobby and Yarraman

February 2015 • *Endorsed on 25 February 2015*

GENERAL NOTE

These reports/documents are a base source of information that will be continually refined over time.

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Work Package 10 – 2D Flood studies addressing overland flowpath issues for Cooyar, Nobby and Yarraman

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Contents

1. Introduction

Sinclair Knight Merz (SKM) was commissioned by Toowoomba Regional Council (Council) to undertake a 2D flood study and overland flow path study for the townships of Nobby, Cooyar and Yarraman – herein referred to as the Studies. These Studies were commissioned as Work Package 10 of the SP051 Toowoomba Flood Studies Project.

This report provides details of the development and validation of the models, the generation of design flood events and the documentation of flooding behaviour and characteristics for the design events. The report consists of the following sections:

- Section 2: Review of Available Data
- Section 3: Model Development
- Section 4: Model Validation
- Section 5: Design Event Hydrology
- Section 6: Design Event Flood Behaviour
- Section 7: Sensitivity Assessment
- Section 8: Climate Change Modelling
- Section 9: Developed Case Modelling
- Section 10: Isolation and Evacuation Assessment
- Section 11: Flood Hazard and Flood Category Mapping Methodology
- Section 12: Conclusions
- Section 13: References

The following supporting information has been provided as an Appendix.

- Appendix A: Hydrologic Analysis
- Appendix B: QRA Flood Frequency Information
- Appendix C: Cooyar Flood Report (BoM)
- Appendix D: XP-RAFTS sub catchment characteristics
- Appendix E: Design Flood Event Mapping – Nobby
- Appendix F: Design Flood Event Mapping – Cooyar
- Appendix G: Design Flood Event Mapping – Yarraman

1.1 Study Objectives

The purpose of the Work Package is to define the nature and extent of flood behaviour, in particular overland flow paths in the townships to enable Council to:

- Develop a Flood Risk Management Study and Plan to address the flood hazards identified in the flood studies; and
- Amend the Toowoomba Regional Planning Scheme to appropriately reflect the flood requirements of State Planning Policy 1/03 and the recommendations of the Queensland Flood Commission of Inquiry (QFCI).

The QFCI recommendations require Councils to obtain flood information where a current or future community could be at risk. As such these Studies focus on providing adequate overlay mapping through the townships focusing on current and potential development areas. The Studies will also support land use and infrastructure planning and provide emergency planning information that will assist Council in its emergency management planning, preparedness and response.

1.2 Approach

For the purpose of this work package, Council has defined overland flowpath flooding as flooding in waterways, overland flow paths (usually ephemeral) as well as constructed stormwater drainage systems that are usually too small to have been assigned a name. The relevance of these overland flowpaths is that they usually traverse through or adjacent to developable land.

The overland flowpath flooding methodology has been defined to cover those areas where an analysis of a local flooding issue is required and is generally associated with a town. The study is typically related to a localised overland flowpath, waterway tributary and /or parts of the local stormwater drainage network where this may exist. The overland flowpath terminology has been used to separate this more localised study from the traditional 1D/2D flood study types.

An overland flowpath study represents a comprehensive flood study approach to provide generally a high level of certainty in estimation of flood risks. While various combinations of hydrologic and hydraulic modelling techniques are available for this approach, the method adopted depends upon the nature of the study area, extent of the stormwater drainage system and associated drainage paths as well as the proposed use of the detailed information.

Cooyar and Nobby were previously investigated as part of the Queensland Reconstruction Authority (QldRA) level 2 flood mapping project (2013). The QldRA project was broad and lacked detailed hydrological modelling and drainage structure details. As such this Work Package seeks to revise this modelling to:

- Provide a more detailed representation of the catchment hydrology; and
- Utilise MIKE by DHI software for the hydraulic modelling to provide consistency with the Toowoomba Flood Studies Project.

The work package also includes development of hydrologic and hydraulic models for the township of Yarraman, which was not assessed as part of the QldRA level 2 flood mapping project.

The approach adopted for each of the work packages was to develop a hydrologic and hydraulic flood model for each town which adequately represents the flood risk for each town, including creek and overland flow paths.

1.3 Background and Flood History

1.3.1 Nobby

Nobby is located about 30 km south of Toowoomba on the road to Clifton and has a district population of 485. The township of Nobby is located on elevated terrain and is therefore not at risk from riverine or creek flooding. However, the town is affected by overland flow from the hills on the eastern side of town. Future development areas within the township are located to the east and west of the railway line. These areas are shown on **Figure 3-1**.

The township was subject to a level 2 assessment by QldRA. However, community consultation undertaken as part of the Toowoomba Flood Scoping Study (SKM, 2013) indicated that the extent of inundation depicted by the QldRA level 2 assessment did not replicate the overland flow paths through the township in January 2011.

Business owners and medium to long-term residents interviewed as part of the Toowoomba Scoping Study (SKM, 2013) indicated that "*Nobby could be affected by numerous overland flow paths which could cause inundation to some slab-on-ground dwellings. A large overland flow path from the west inundates numerous allotments on the western side of Nobby, while overland flow concentrated by the railway line culverts causes nuisance flooding to elevated properties*." A summary of the information collected during community consultation is provided below.

- Stormwater runs off the hills surrounding Nobby and gullies to the west convey the flow
- People have started to build houses closer to the waterway (west of town). The existing houses were centimetres away from being inundated in January 2011.
- In major storm events, the railway line tends to concentrate the flow off Hill and Davenport Streets. This doesn't happen every year – 2 events in 8 years.
- Most houses on stumps, but new houses on slabs which is a concern due to the large amount of the overland flow.
- Flooding is becoming more of an issue as the population becomes more concentrated.
- Kings Creek flooded and cut access to Nobby, and the big bridge at Emuvale nearly got washed away.
- Council needs to be aware of the flow that comes through and change the building laws.
- The Pub didn't get much flooding, water can get around the street corner and continue to floodway to the west of town.
- 6 inches of water flooded over the railway line (2011)
- Jan/Feb 2011 was the most flooding one resident had seen in 10 years, 10th of January was the biggest flood
- Isolation was the biggest issue for Nobby residents.
- In 1914 the old post office was isolated, but this didn't happen in 2011.
- Fast flow was observed in the gully, could be dangerous. Has been too fast for a rescue crew to be able to cross and evacuate people

1.3.2 Cooyar

Cooyar township has developed around Cooyar Creek and Back Creek and has a district population of 300. Cooyar and Back Creek are shown in **Figure 3-2**.The township is located about 65 km north of Toowoomba on the New England Highway. The town has a history of flooding with the largest flood on record occurring in 1988, where it was reported that three buildings were washed away and two lives lost. Much of the township is covered by a QldRA level 2 assessment (SKM, 2012).

The QldRA level 2 assessment noted that a large proportion of the township is located on a delta between the high hazard areas of Cooyar and Back Creek. It was also noted that the primary school was affected by a breakout flow which isolated and then inundated school buildings. The Toowoomba Flood Scoping Studies (SKM, 2013) concluded that "*Cooyar could be significantly affected by flooding from Cooyar and Back Creeks. It is considered that there is a potential population at risk as the town area can be affected by high velocity flow paths and isolation*." There are also significant parcels of land identified as RR2 (Rural Residential 1 ha) and some vacant township land which borders Back Creek.

In general the Toowoomba Flood Scoping Studies (SKM, 2013) found that residents of Cooyar were not highly concerned with flooding with January 2011 having minimal impacts on the town. McDougall Street bridge was overtopped and Cooyar Creek slightly exceeded the creek bank near the pub. However, this occurred numerous times during the 2010 and 2011 wet season. The scoping study reported that "*Residents of Cooyar are not highly concerned with flooding, as all buildings which were washed away in 1988 have not been rebuilt. It was also a common thought that 1988 was a freak storm that won't happen again*."

Consultation with one resident who had lived in Cooyar for 75 years provided the following information. *"The 1988 event occurred during the middle of the night, close to midnight. A large storm in the Bunya Mountains had occurred and Cooyar Creek rose without warning. The first thing which alerted residents to the issue was the sound of truck horns on the highway as they tried to warn of the quickly rising water coming over the bridge on New England Highway. It was very difficult to see as it was the middle of the night. My brother climbed onto the water tank beside his house to try and reach the roof, as the water was rising swiftly. Unfortunately the speed and pressure of the flood water crushed the tank and he was washed away downstream. His house remained. The house across the street had water about 1m up the stump at the rear of the house, but it was a bit hard to see in the dark. The town hall and some other dwelling structures were washed off there stumps and blocked the bridge. There was so much debris which came down with the water. No one could cross any of the bridges as there was so much debris. It was a very short event and the water was gone in a couple of hours. There was no water by daybreak."*

1.3.3 Yarraman

The township of Yarraman is located 120 km north of Toowoomba at the junction of the New England Highway and the D'Aguilar Highway. The township has a population of approximately 1400 people. Yarraman Creek which has its headwaters near the Cooyar Range flows through the southern sections of the township before joining Cooyar Creek. The township also has a number of overland flow paths that drain towards the creek. These flow paths can be seen in **Figure 3-3**.

Business owners and members of the historical society were interviewed as part of the study. It was advised that 2011 was one of the largest floods to affect the locality and caused inundation of a number of businesses and residential properties. The RACQ depot provided the following recollection of the flood event, as published in the South Burnett Historical Trail centenary book and provided to the Yarraman Historical Society.

"*After Yarraman Creek broke its banks, it took 20 minutes for the water to rise 86 centimetres to take everything in its path. Eight foot security fencing held back the water and we moved some possessions before being ripped from the ground. A small tidal wave formed from the bending fence, forcing the water into the house leaving sludge and muck in every crevice.*

Cars were lifted and moved a distance of 200m, left upside down, hooked up in trees and wrapped in fencing and debris. Water tanks were undermined and left lopsided. Gardens were total uprooted and washed away. Gas bottles for the house were ripped off their fittings.

Forcing its way under walls and doors to the workshop shed, the water washed a door open and took spanners and tools and moved welders leaving in places two inches of the gooiest muck I have ever seen. Many metres of road base and blue rock were swept away leaving driveways taken back to bedrock. A Telstra trench dug four years previously appeared to be freshly dug with the cable floating loose.

Boats and trailers tied to posts were pulled to the extreme of their ropes. Large Landcruiser wagons were actually moved about two metres by the water. Water depth marks in these vehicles, parked on a higher part of the yard, were up to the headrests.

Surprisingly two trampolines sitting in the rapid flow of the water were the last things to be taken from the yard. Viewing the camera footage, I was amazed to see a fibreglass boat I had filled with Dirt and made into a garden, floats down the rapids and smash into a fence. – Desley Rutledge."

Both the Yarraman Creek and overland flow paths from the upper catchment to the north of the township create flooding which rises rapidly and without much warning time.

2. Review of Available Data

2.1 Terrain Information

LIDAR (Light Detection and Ranging) survey data of the Yarraman, Cooyar and Nobby townships was collected by Council in 2011/2012. This information was provided to SKM as a 1m grid with a vertical accuracy of +/-0.15 m.

2.2 Rainfall and Streamflow Data

Two historical events were investigated for model validation. To validate the model, rainfall data and recorded flood level data was required. It was found that residents had only recorded sufficient flood level data for the January 2011 event for Yarraman and Nobby. As the waterways in Cooyar were only slightly outside of their banks in the January 2011 event, the residents interviewed had not noted the flood level of this event. As such the 1988 event was used as the validation event for the Cooyar model.

2.2.1 Nobby

In regards to rainfall data, there is a daily gauge present at Nobby (Nobby at Tooth Street (041075)), which is located 0.5 km north of the town. This gauge records rainfall on a daily basis and has a record of 110.7 mm for January 11th, which represents the rainfall that fell between 9 am 10th January and 9 am 11th January 2011. The Nobby historic flooding event of 2011 is believed to have been caused from a flash flood event, much shorter in duration than 24 hours. In order to make use of the Nobby daily data, a pluviographic station nearby was required to determine the temporal pattern of the storm. A pluviometric site at Clifton was investigated, however there was no data available for the event.

As there was no suitable pluviographic gauge data, a comparison of the design temporal pattern and the pluviograph data recorded at the University of Southern Queensland, approximately 30 km from the site was carried out. The USQ data is not publicly available but was provided by the peer reviewer for comparison purposes.

There is no streamflow data available within the Nobby catchment. In lieu of catchment data, a review of local and regional gauges was undertaken to establish whether it was possible to transpose flood peak information from other catchments within the area. This analysis is included in **Appendix A**.

The regional availability of flow gauging data is sparse and the catchments that are currently monitored are much larger than the target catchment network, and have significantly larger floodplains than the target catchments. As no suitable sites with similar area or catchment characteristics were identified, no donor gauges were identified.

2.2.2 Cooyar

Information was collected about the 1988 flood event from the Bureau of Meteorology (BoM), online sources and the previous QldRA flood mapping project. Through a search of rainfall gauges in the upper catchment it was determined that there was no recorded gauge data for the 1988 event which could be used to simulate the event. Therefore the following data collection and review took place.

QldRA provided a flood frequency analysis as part of the Flood Hazard Mapping Project (2013) which concluded that the 1988 event was in the order of a 500 year ARI (average recurrence interval) event. As part of this study, a review of the hydrology was undertaken and compared to determine its accuracy. A copy of the QRA flood frequency data is included in **Appendix B**.

Gauge data for Emu Creek, Cooyar Creek and Brisbane River at Linville was collected and used for the regional flood frequency analysis.

Broad internet searches were carried out to obtain anecdotal information about the 1988 event and its severity. The Bureau of Meteorology (BoM) website provided some information, including the BoM Cooyar February 1988 flood report (BOM, 1990) which detailed the mechanism and intensity of the rainfall experienced during this event. This information is presented in **Appendix C**.

2.2.3 Yarraman

A daily rain gauge is present in Yarraman (Yarraman Post Office), which has recorded a 3-day aggregate depth of 233 mm for the 9th, 10th and 11th of January 2011. There is also another daily gauge in Upper Yarraman, in the middle part of the catchment, which has recorded 103.2 mm of rainfall for the 10th and 108.4 mm of rainfall for the 11th of January 2011. There is also a pluviograph present at the downstream end of the catchment, Yarraman Alert. Two additional pluviographic gauges, Mt Binga and Blackbutt, are located in close proximity to the catchment. The locations of the gauges are shown in **Figure 3-6**.

In regards to flow data, there are no gauges within the catchment. Gauge data from BoM and the Department of Natural Resources and Mines (DNRM) for Emu Creek, Cooyar Creek and Brisbane River at Linville was collected and used to undertake a regional flood frequency analysis. Hydrological analysis of the data has been included as **Appendix A**.

2.3 Historical Flood Levels

As part of these Studies, a site inspection was undertaken of Yarraman and Cooyar (10th September 2013) and Nobby (13th of September 2013) townships.

2.3.1 Nobby

At Nobby, mid-to-long-term residents were able to provide an indication of flood levels and flood behaviour for the January 2011 flood event. Four flood levels were provided and anecdotal evidence about flood behaviour. The anecdotal flood information on the flood behaviour particularly surrounding the railway line was a key input to the model validation.

Council was unable to provide any validation point data for this locality.

2.3.2 Cooyar

For Cooyar, the February 1988 and January 2011 events were considered for data collection to validate the hydrologic and hydraulic model. Unfortunately, no validation data was able to be collected from residents for the 2011 event, as the creeks stayed within their banks and flood levels were not noted. Although the McDougall Street bridge overtopped, recorded levels for the bridge were not able to be obtained. A lack of validation flood levels and gauged rainfall data within the catchment resulted in the 1988 event being the only validation event for Cooyar.

The flood monument in the centre of town provides three levels which were taken from the pub, old post office and model during the 1988 flood.

A description of the flood behaviour for the 1988 event was provided by a long-term resident who had lived in Cooyar for 75 years. Four flood levels were obtained for the 1988 flood event. Three of these levels were located on the flood totem in Memorial Park and one level was for a dwelling on McDougall Street.

Council was unable to provide any validation point data for Cooyar.

The historical flood levels are presented and discussed further in **Section 4**.

Where appropriate, information collected as part of the Toowoomba Flood Scoping Studies (SKM, 2013) was also referenced in these studies.

2.3.3 Yarraman

At Yarraman, creek flood levels for the January 2011 event were recorded by SKM from debris along the creek banks, as well as levels provided by Jetsons Engineering and Yarraman Produce. Yarraman Hotel and Motel provided flood levels from the overland flow paths which affect the centre of town. The level at these points was then confirmed from the LIDAR at each location.

Council was able to provide validation point data collected after the January 2011 event. The data was collected by a Council survey team approximately one month after the event in early February 2011. The data collected included flood debris locations and flood marks, providing information about the extents of the flood and flood levels. The expected accuracy of this type of data would be at best of the order of +/- 500mm. The flood data used in the study was based on the information that was available to Toowoomba Regional Council at the time which may not be accurate or complete.

2.4 Stakeholder Engagement

SKM contacted Emergency Management Queensland (EMQ), State Emergency Service (SES), Queensland Police Service (QPS) (based at Cooyar) and Councillors to determine if they held any information which could be of assistance for the model validation.

Unfortunately these stakeholders were unable to provide any further information which could be used during the validation process. EMQ had tried to source some flood aerial photography, however, was unable to obtain data for the areas of interest. The SES head controller for Cooyar and Yarraman was able to provide some community contacts which were followed up on site. The SES controller for Nobby was previously contacted during the Toowoomba Flood Scoping Studies (SKM, 2013) and this information was used for this project.

The Councillors had been previously contacted in relation to these areas and had directed SKM to contact a previous Councillor who had knowledge of the localities.

The Police Officer stationed at Cooyar was also unable to assist with providing knowledge of the event, as he was posted to the township after the January 2011 flood event.

3. Model Development

3.1 Hydrologic model development

The software package XP-RAFTS v7.0 was used to simulate the hydrology of the Nobby, Cooyar and Yarraman catchment and tributaries.

3.1.1 Hydrologic model characteristics

Details of the hydrological model development for Nobby, Cooyar and Yarraman are provided in the following sections.

3.1.1.1 Nobby

A one-node XP-RAFTS model was created to provide an inflow hydrograph for the Nobby north catchment (which is outside the MIKE rain-on-grid model extent), to provide an inflow hydrograph to simulate the flow from the external catchment. The model sub-catchment areas are shown in **Figure 3-1.**

3.1.1.2 Cooyar and Yarraman

The Yarraman Creek catchment was delineated into 19 small sub-areas, while the Cooyar Creek catchment was delineated into 68 sub-areas. The catchment sub-areas for the Yarraman model varied from approximately 90 ha to 1000 ha depending on their proximity to the area of interest. The sub-catchments in the Cooyar model varied from approximately 20 ha to 1000 ha. The model sub-catchment areas are shown in **Figure 3-1**

Figure 3-2 and **Figure 3-3** for Cooyar and Yarraman respectively.

Each model sub-area is characterised by slope, land use and roughness. Channel routing was used for this model to determine the lag time experienced in each sub-catchment. Local and total hydrographs were extracted from the model.

Equal area slopes were calculated for each catchment, giving a percentage grade of the slope. The slope lengths and flowpaths were measured directly from the Digital Terrain Model (DTM) supplied by Toowoomba Regional Council.

The land use for each sub-area was split between rural and urban land use based on the 2011 aerial photography. The sub-areas were split based on the percent of impervious and pervious land use. Urban areas were assumed to be 40% impervious and 60% pervious as recommended by the Queensland Urban Drainage Manual (2007) for low density residential.

Details of the sub-catchment characteristics are provided in **Appendix D**.

1:25,000 (at A3)

0 200 400 800
Meters

GDA 1994 MGA Zone 56

Legend

- Creeks
- Railway
- Roads
- Catchments
- Hydraulic Model Extent
- Broad Hectare Study Urban
- Cadastre

Elevation (mAHD)

High : 600

Low : 400

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FIGURE 3-1
NOBBY CATCHMENTS

Toowoomba Regional Council

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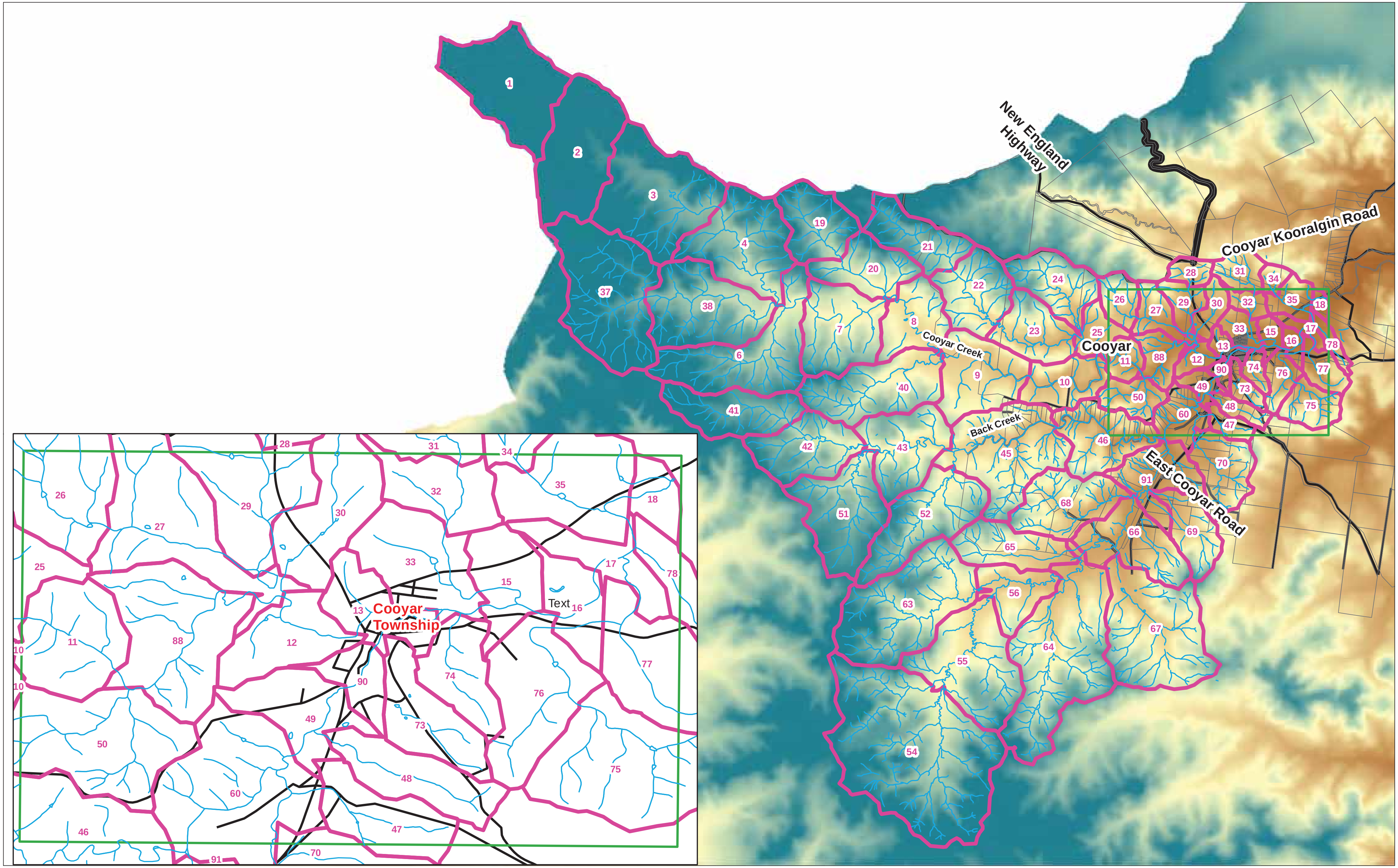
Date Saved: 21/07/2014



1:80,000 (at A3)

0 500 1,000 2,000
Meters

GCS GDA 1994

Legend

- Creeks
- Hydraulic Model Extent
- Catchments
- Cadastre
- Railway
- Roads

Elevation (mAHD)
High : 650
Low : 400

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FIGURE 3-2
COOYAR CATCHMENTS

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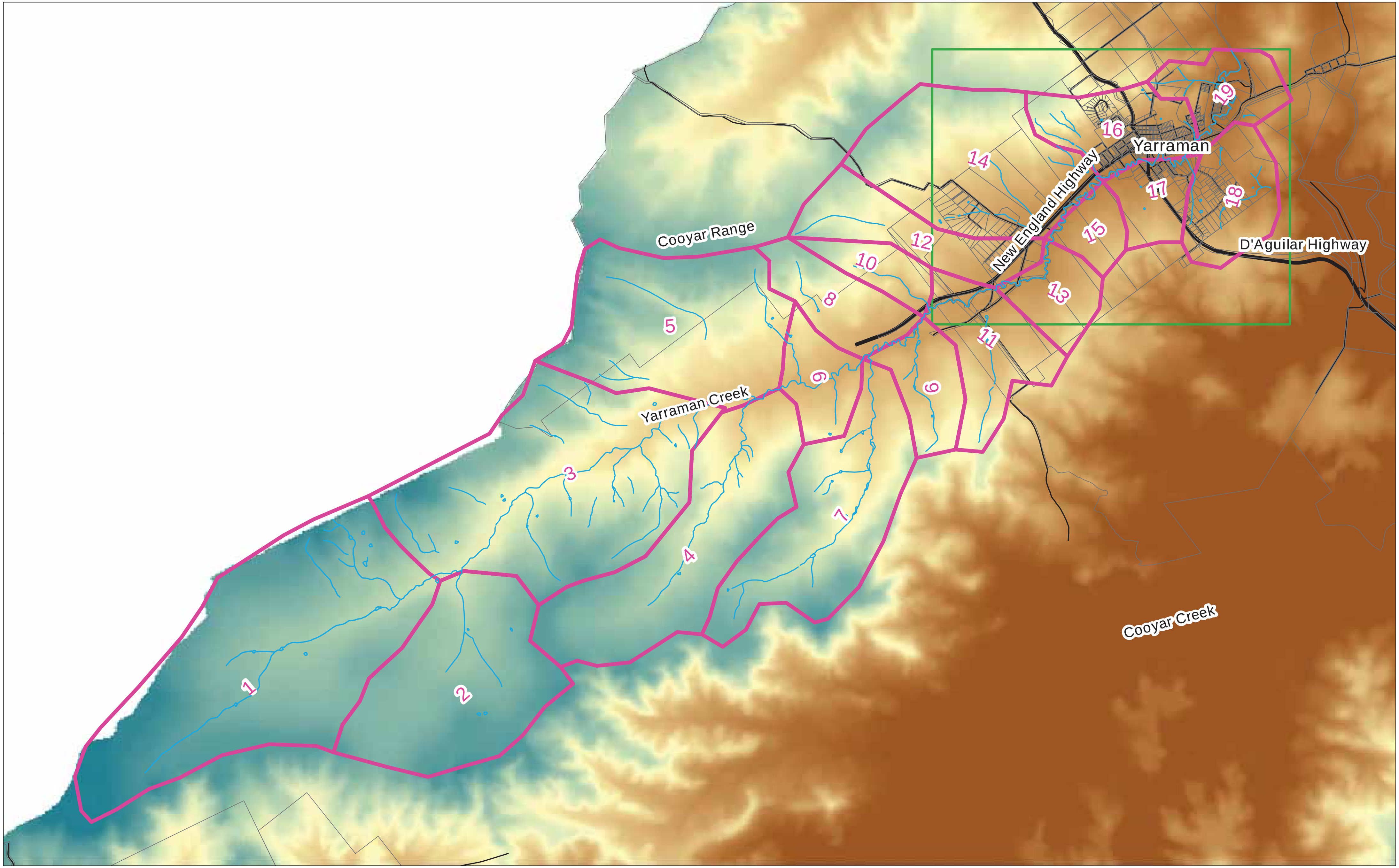
I:\QENV2\Projects\QE06787\Deliverables\Work Package 10\GIS\MXD\Figure3-2-Catchment_Cooyar_RevA.mxd
Date Saved: 12/06/2014



1:50,000 (at A3)

0 370 740 1,480
Meters

GDA 1994 MGA Zone 56

Legend

- Creeks
- Catchments
- Hydraulic Model Extent
- Cadastre
- Railway
- Roads

Elevation (mAHD)
High : 650
Low : 400

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FIGURE 3-3
YARRAMAN CATCHMENTS

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I:\QENV2\Projects\QE06787\Deliverables\Work Package 10\GIS\MXD\Figure3-3-Catchment_Yarraman_RevA.mxd
Date Saved: 25/06/2014

3.1.2 Rainfall

The following rainfall data was used in the modelling for Nobby, Cooyar and Yarraman.

3.1.2.1 Nobby

Suitable pluviograph data representing the 2011 event was not available for Nobby. Therefore a surrogate approach was undertaken by applying design temporal profiles. A 3 hour design temporal pattern consistent with Australian Rainfall and Runoff (AR&R, 2001) guidance was applied. **Figure 3-4** shows a comparison of the design temporal pattern against the recorded rainfall for the 2011 event. This data was recorded by a pluviograph located in University of Southern Queensland (USQ), approximately 30 km from the site. The USQ data is not publicly available but was provided by the peer reviewer from a companion study by WRM/DHI (2013) for comparison purposes. The WRM/DHI Study is the 2D flood study for Westbrook.

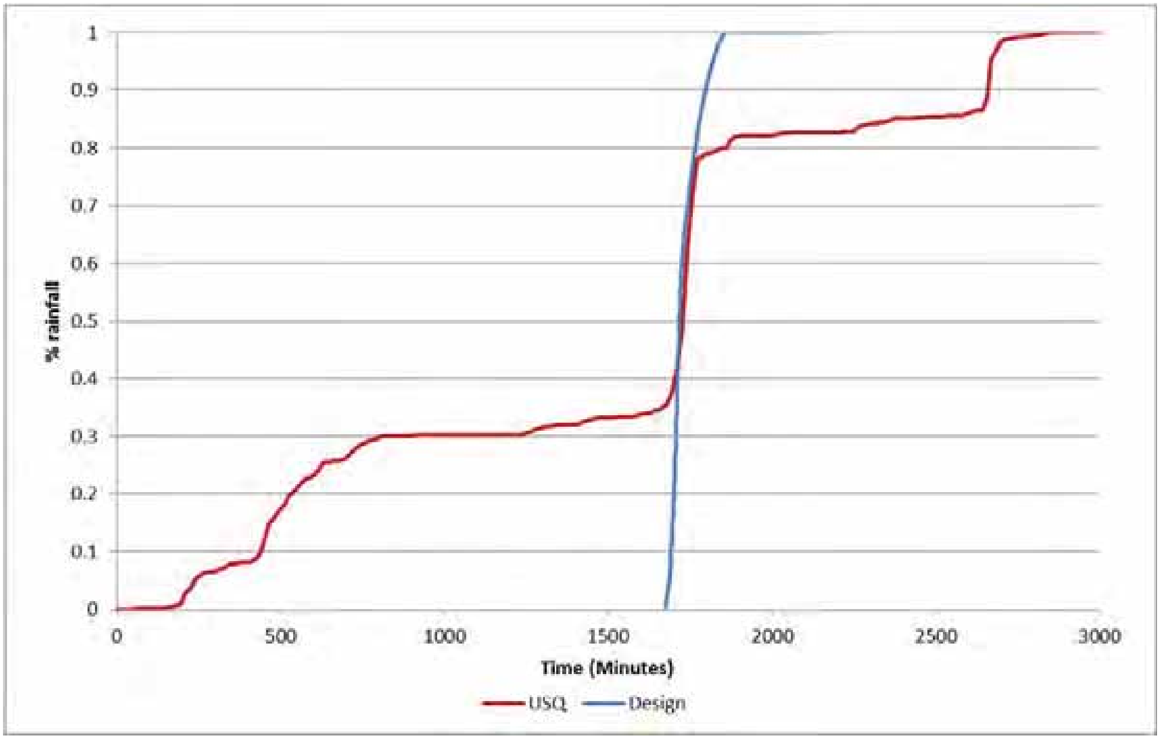

Figure 3-4 : Comparison of design temporal pattern used in the Nobby model and USQ pluviograph data recorded between 09/01/2011 09:00 to 11/01/2011 011:00

3.1.2.2 Cooyar

No rainfall gauge data or radar data was found for the February 1988 historical event. A report was published by BoM in 1990 which outlined the meteorological aspects of the flash flood which affected Cooyar in February 1988. A copy of this report has been included in **Appendix C**.

The report outlined that a significant thunderstorm created rainfall in the upper catchment of approximately 226 mm in a 2.5 hour period. From extrapolation of the BoM Intensity Frequency Curves (IFD), the rainfall exceeded the 500 year ARI point rainfall intensity. The report also outlined that the event was spatially variable and did not cause widespread flooding in the area, with the Cooyar Creek gauge (40km downstream of the township) only registering between a 2 year ARI and 5 year ARI flood event. This demonstrates the lack of rainfall over the whole catchment and the attenuation of the flow as it travelled downstream.

The rainfall temporal pattern from the BoM report including the calculated cumulative rainfall depth in the catchment above Cooyar of 150mm was used in the XP-RAFTS model to simulate the historic event. **Figure 3-5** below shows the rainfall temporal pattern adopted for the historical event.

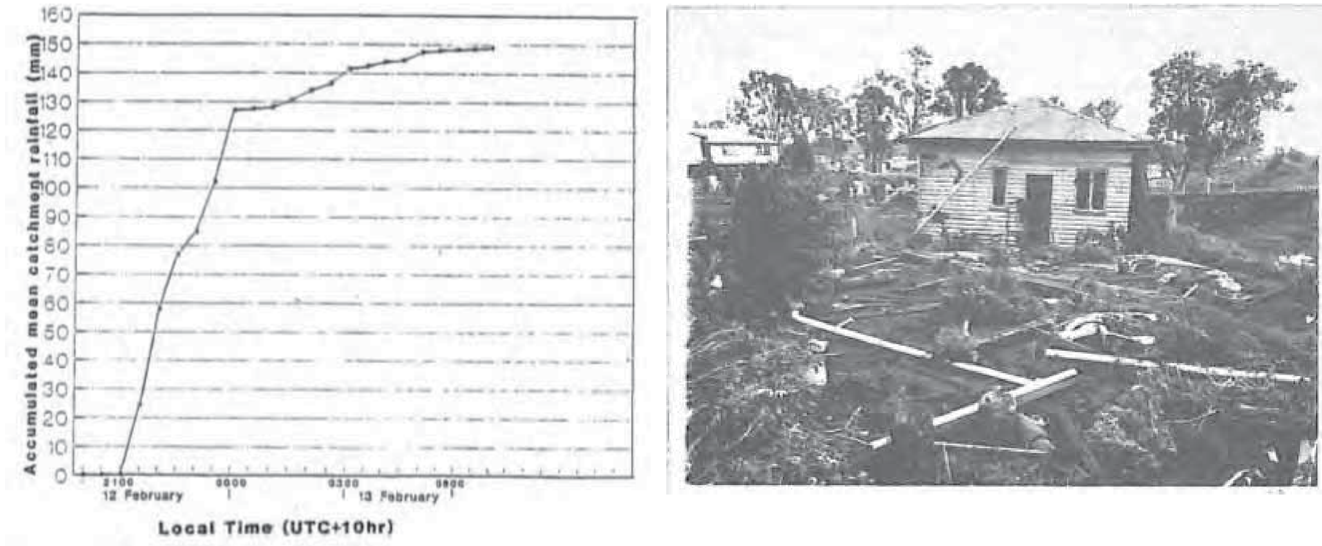

Figure 3-5 : Cooyar temporal pattern for February 1988 event and photo of destruction (BoM, 1990)

3.1.2.3 Yarraman

A number of gauges from within and around the Yarraman catchment were reviewed as part of the investigation of the 2011 event. Those used in the analysis are shown in **Figure 3-6**. A number of rainfall combinations have been investigated, combining the different daily totals and applying areal-weighting based on the proximity to the catchment. In addition, the Blackbutt and Yarraman Alert recorded rainfalls (without manipulation) were also modelled as a sensitivity analysis.

It was determined that the areal-weighted daily totals from Upper Yarraman and Yarraman Alert (AL) pluviograph (checked against the 3-day aggregate for Yarraman Post Office gauge) using the Blackbutt Alert pluviograph temporal pattern was the most appropriate rainfall depth, as the flood flows produced through the hydrologic and hydraulic model produced peak flood levels that matched the validation points within reasonable bounds.

A total depth of 220 mm was adopted for the entire catchment for the 48 hour duration of the 2011 event. This is consistent with the rainfall depths recorded in the various gauges. The 48 hour totals for the event are presented in **Table 3-1**.

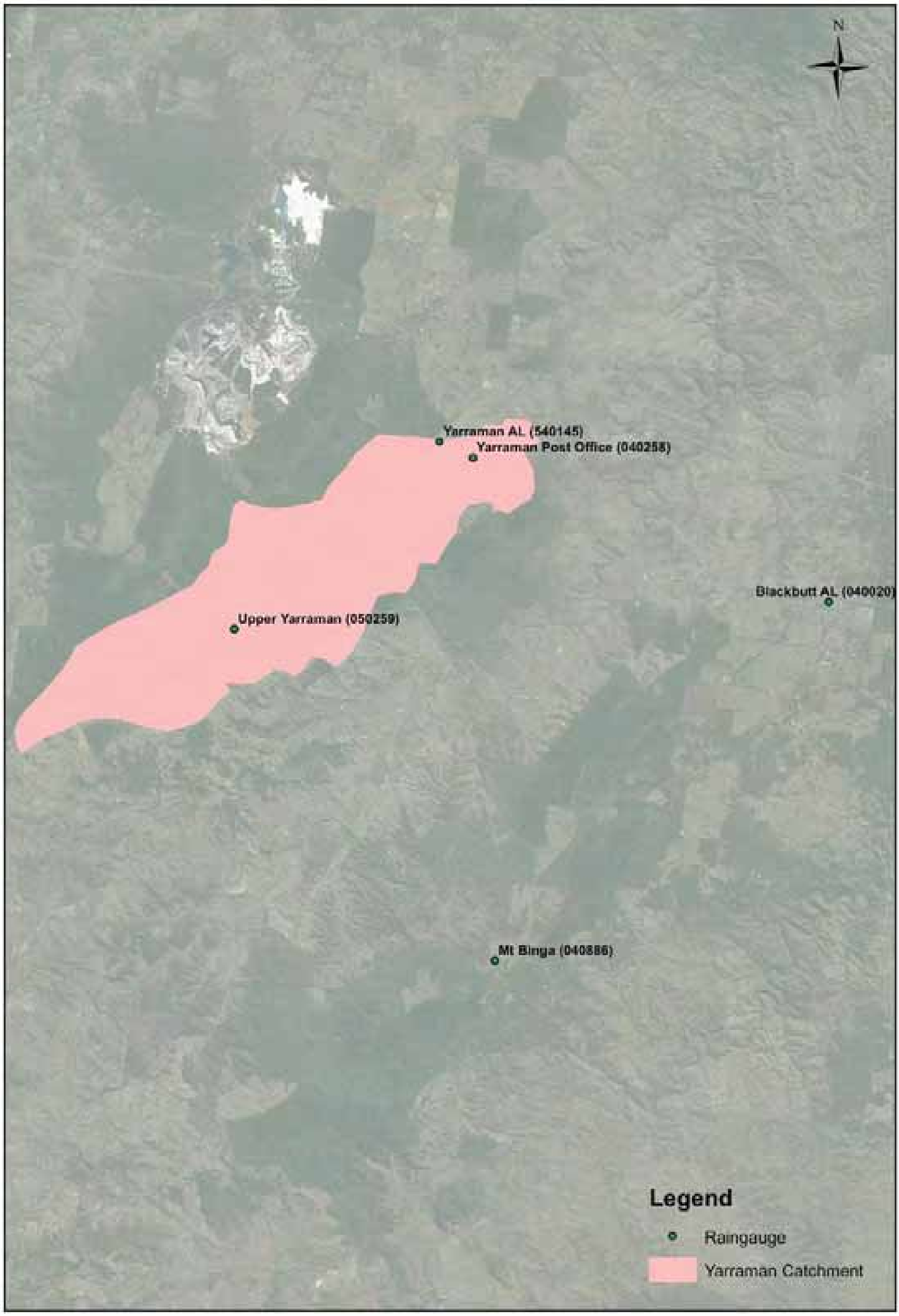

Figure 3-6 : Rainfall gauge locations.

Table 3-1 : Yarraman 2011 event - rain gauges 48 hour totals

Gauge	Rain depth between 09/01/2011-11/01/2011 (09:00 to 09:00- 48 hours)
Yarraman Alert	244 mm
Yarraman Post Office (040258)	233 mm (cumulative for the 8th, 9th and 10th) ,160 mm (cumulative for the 11th and 12th)
Upper Yarraman (040259)	212.2 mm
Blackbutt Alert (040020)	259 mm
Mt Binga (040886)	279 mm (cumulative for the period of 9th-12th (4 days)

The adopted rainfall hyetograph used in the analysis is shown in **Figure 3-7**.

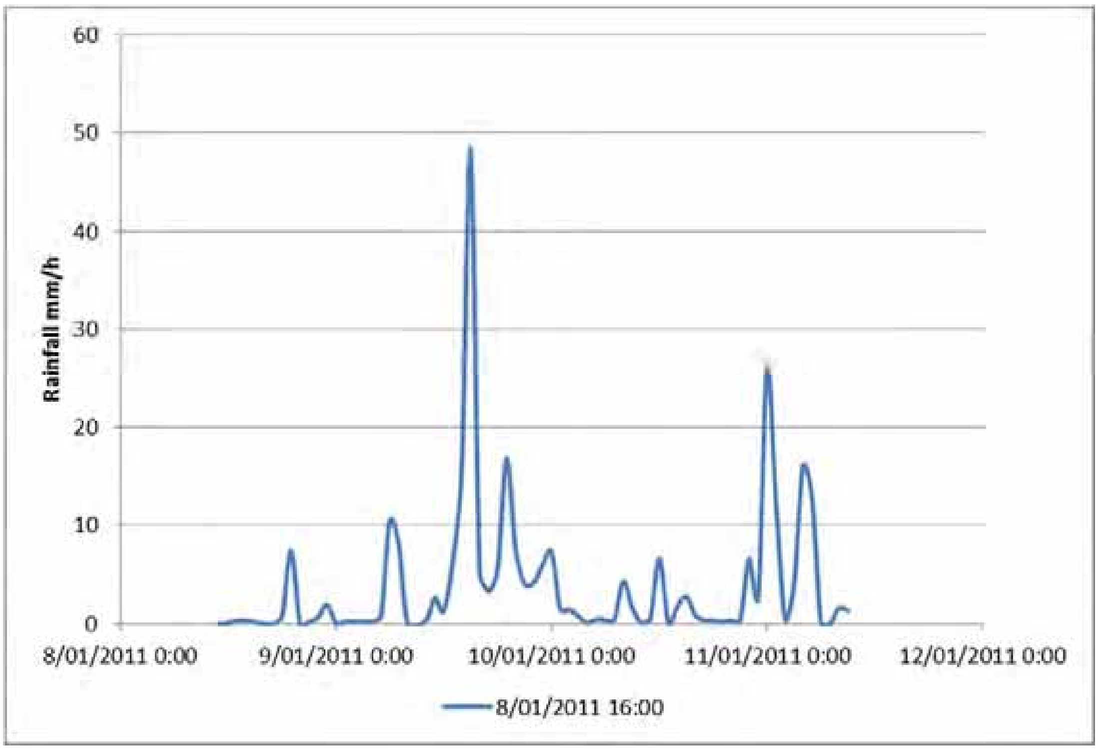

Figure 3-7 : Yarraman rainfall hyetograph – January 2011 event

3.1.3 Manning's 'n' Values

The roughness in XP-RAFTS is represented by Manning's 'n' values. The Manning's 'n' value within each sub-area was based on the land use, as outlined in **Table 3-2** and **Table 3-3** below. The Manning's value was averaged between the values listed in the table depending on the percentage of each type of vegetation and land use contained within the sub-area.

The one-node XP-RAFTS model for Nobby was based on a pervious rural catchment with a Manning's n value of 0.04.

Table 3-2 : XP-Rafts Manning's 'n' values – Yarraman

Land use		Manning's n
Impervious Area		0.095
Pervious Area	Crops/pasture	0.04
	Road	0.025
	Medium Dense Vegetation	0.06
	Dense Vegetation	0.11
	Urban	0.20

Table 3-3 : XP-Rafts Manning's 'n' values – Cooyar

Land use		Manning's n
Impervious Area		0.025 – 0.03
Pervious Area	Crops/pasture	0.04
	Road	0.03
	Medium Dense Vegetation	0.06
	Dense Vegetation	0.08
	Urban	0.03

3.1.4 Loss Parameters

The adopted loss parameters for the XP-RAFTS model were determined through a validation process against the collected historical flood levels. The model initially used link lag data to represent the routing within the catchment, however this proved to be ineffective and the model was changed to a channel routing regime. Using this method, the XP-RAFTS model accounts for catchment routing based on creek cross-sectional area and length. Further refinement occurred through changes to the Manning's n value for the creeks and initial loss values.

The final change to loss parameters was the storage coefficient (B), which enabled an adequate match to the gauged hydrographs.

Based on numerous trials and iterations of parameters as part of the validation process, the parameters in **Table 3-4** to **Table 3-6** were selected.

Table 3-4 : Final RAFTS validation parameters – Nobby 2011 event

Parameter	B	m	Initial Loss (mm)	Continuing Loss (mm/h)
Value	1.1	default	5	2.5

Table 3-5 : Final RAFTS validation parameters – Cooyar 1988 event

Parameter	B	m	Initial Loss (mm)	Continuing Loss (mm/h)
Value	0.6	default	0	1.0

Table 3-6 : Final RAFTS validation parameters – Yarraman 2011 event

Parameter	B	m	Initial Loss (mm)	Continuing Loss (mm/h)
Value	0.7	default	28	3

3.2 Hydraulic Model Development

The MIKEFLOOD package developed by the Danish Hydraulics Institute (DHI) (version 2012) was adopted for these investigations. MIKEFLOOD links the two-dimensional hydraulic modelling package, MIKE21, to the one dimensional hydraulic modelling package MIKE11. This allows for detailed 1-D modelling of specific hydraulic structures inside a 2-D flood model of the river and floodplain.

The MIKE21 model represents the investigation area topography as a terrain grid, with the following parameters input to the model to define flow behaviour:

- Design or historical inflows;
- Terrain roughness (entered as Manning's number M);
- Eddy Viscosity.

3.2.1 Model Area and Terrain Development

The model area was selected based on the extent of LIDAR survey; Council's land use zones and precincts (which were used to identify the potential future development); the likely extent of flooding (to reduce model run times); and the location of model boundaries (to provide model stability). The adopted model areas were confirmed with Council on the 3rd of September 2013 and are illustrated in **Figure 3-8**, **Figure 3-9** and **Figure 3-10** for Nobby, Cooyar and Yarraman respectively.

The 1 m LIDAR data was used to develop a 3 m grid for Nobby and Yarraman and a 5 m grid for Cooyar. The grid cell size was selected based on definition of the major waterways and overland flowpaths and consideration of model run time efficiency. It is noted that the township and future development areas in Cooyar are located along Back and Cooyar Creek and as such the 5 m grid resolution was deemed appropriate to represent the major flow paths through Cooyar. In general the grid cell size provides at least two grid cells within each major flowpath to provide model stability and channel definition.

In addition to this, the following significant linear infrastructure was sampled from the 1 m DEM (Digital Elevation Model) and stamped into the model bathymetry to provide accurate representation of flood control structures.

- Nobby – Nobby Felton Road near the large culvert crossings.
- Cooyar – New England Highway over the bridge structures.
- Yarraman – The elevations of Emmett Street and Barr-Smith Street was interpolated from the 1 m DEM to provide a better representation of the road crest.

3.2.2 Hydrologic Inputs

3.2.2.1 Nobby

A rainfall-on-cell approach was taken to modelling the township of Nobby due to the small local drainage paths. This approach allowed for a better representation of the flooding behaviour due to the interaction between the overland flow and the railway line. Australian Rainfall and Runoff (AR&R, 2001) IFD curves were used to develop intensity in millimetres per hour less the assumed losses. The resultant net rainfall was then applied as a hydrograph to each cell in the model. A one-node XP-RAFTS model was created for the external upstream catchment. The resultant hydrograph was applied as a boundary in the MIKE model, as illustrated in **Figure 3-8**.

A Rational Method analysis was undertaken to check the magnitude of the peak flow at the downstream boundary of the model area.

3.2.2.2 Yarraman and Cooyar

The outputs of the RAFTS hydrologic modelling were used as inflows to the Cooyar and Yarraman hydraulic models. For both models inflows for the major flow paths (catchments upstream of and outside of the hydraulic model domain) were introduced as total inflows at the boundaries illustrated in **Figure 3-9** and **Figure 3-10** for Cooyar and Yarraman respectively.

Inflows for sub-catchments located within the hydraulic model extent were represented as source points and introduced to the model at the centroid of the sub-catchment. At some locations inflows were moved to the nearest gully line or watercourse and or split over several gully lines within the sub-catchment to improve model stability.

For Yarraman two hydraulic models were developed. An initial model was developed, using source points (as described above), that focused on Yarraman Creek flooding (creek flooding model). This model was used for validation and sensitivity testing and the analysis of climate change impacts.

A second model was created for Yarraman using a rainfall-on-cell approach in order to better represent overland flow paths in the study area. This model was used to simulate the 10, 50, 100 and 500 year ARI and PMP design events. To account for rain on the catchment areas outside of the model area the upstream boundary and source points used were based on the RAFTS model for Yarraman. The rainfall depths were obtained for local catchments from the RAFTS model excess rainfall results, which account for rainfall losses. This model was used to assess design flood characteristics and generate the design flood mapping presented in this report.

3.2.3 Critical Durations

To assess the critical duration for each model, a significant number of storm durations were assessed using XP-RAFTS. The most critical storm durations were simulated in MIKE FLOOD.

3.2.3.1 Nobby

For Nobby, the 100 year ARI hydraulic model was run for 1hr, 2hr and 3hr durations. The 1hr and 3hr durations were found to be critical. These storm durations were adopted for all modelled events. **Table 3-7** summarises the critical durations modelled for Nobby, Cooyar and Yarraman. The results of these simulations were enveloped where multiple critical durations were modelled.

3.2.3.2 Cooyar

The Cooyar XP-RAFTS model was run for a range of durations, including the 1hr, 1.5hr, 2hr, 3hr. 6hr and 48hr durations. It was found that the 3hr event was critical in the hydrologic model. A selection of these durations where modelled in the hydraulic model confirmed that the 3hr duration was most critical for the catchment.

3.2.3.3 Yarraman

The Yarraman 100 year ARI hydraulic model (creek flooding model) was run for the 1hr, 2hr, 3hr and 4.5hr durations. The 3hr storm was found to be critical in the main watercourse and the 2hr storm was found to be critical for the overland flowpaths through the town. It was identified that as the flowpaths through the town consisted of shallow sheet flow, there was very little difference in water levels produced by the different storm durations tested.

Smaller events were run for the two critical durations identified for the 100 year ARI event and for a series of longer durations to test if the critical duration increased for the smaller flood events. This was found to be the case only for the 2 year ARI event where the overland flow path critical duration was found to be 6 hrs.

For the larger flood events (200 year ARI and 500 year ARI), the 2hr and 3hr storms were tested and it was found that the 3hr storm was critical in the main watercourse. The 2hr storm gave slightly higher levels in most locations within the overland flowpaths. Shorter duration events were not tested as previous simulations had identified that the water levels in the overland flowpaths were not sensitive to critical duration.

Based on the outcomes of the creek flooding modelling the Yarraman rainfall-on-cell model was tested for 1hr, 2hr and 3hr duration rainfall events for the 100 year ARI flood. It was considered that shorter durations did not need to be tested as the RAFTS model results showed much smaller flows for the 30 minute storm. It was found that the 1hr storm was critical in most overland flow paths, with some of the larger flow paths at the western edge of the model area having a critical duration of 3hrs. The critical duration in the creek was 3hrs as identified in the model of creek flooding. Therefore, the rainfall-on-cell model was run for the 1hr and 3hr durations for the 10, 50, 100 and 500 year ARI floods. As the creek flooding model found that the PMP had a 2hr critical duration in the creek, the PMP event was run for 1hr and 2hr storm durations.

Table 3-7 summarises the critical durations modelled for Nobby, Cooyar and Yarraman. The results of these simulations were enveloped where multiple critical durations were modelled.

Table 3-7 : Critical durations for each model area.

ARI (years)	Nobby Critical Duration (hours)	Cooyar Critical Duration (hours)	Yarraman Creek Flooding Model Critical Duration (hours)	Yarraman Rainfall-on-Cell Model Critical Duration (hours)
2	1, 3	3	2,6	NA
5	1, 3	3	2,3	NA
10	1, 3	3	2,3	1,3
20	1, 3	3	2,3	NA
50	1, 3	3	2,3	1,3
100	1, 3	3	2,3	1,3
200	1, 3	3	2,3	NA
500	1, 3	3	2,3	1,3
PMP	1, 3	3	2	1,2

3.2.4 Manning's n

The Manning's n values were assigned as a grid based on review of aerial photography and value ranges provided in the Queensland Urban Drainage Manual (QUDM, 2007). **Table 3-8** presents the Manning's values assigned for each land use.

Urban blocks were modelled as higher roughness values for Nobby and Yarraman due to the density of housing within the area. As the Cooyar model was to be validated to a 1988 event, when urban blocks were likely to have less development, the Cooyar urban blocks were modelled with a lower roughness value.

Table 3-8 : Manning's n values

Land use	Manning's n
Urban Block (Cooyar)	0.1
Urban Block (Nobby and Yarraman)	0.2
Moderate Dense Vegetation	0.05
Dense Vegetation	0.06
State Forest (Yarraman)	0.11
Cooyar, Back and Yarraman Creek Waterway	0.08
Open Space	0.04
Open Water	0.03
Roads	0.025

3.2.5 Eddy Viscosity

A uniform velocity-based eddy viscosity was applied across the model areas. The selection of eddy viscosity was based on parameters advised by DHI for the model cell size and time step. The eddy viscosity adopted for each model is presented in **Table 3-9**.

Table 3-9 : Eddy Viscosity

Model	Value (m^2/s)
Nobby	0.36
Cooyar	0.5
Yarraman	0.36

Legend

Hydraulic Model Extent	Validation Point	Creeks	Roads	Manning's n: 0.06, 0.03
Model Boundaries	Cross Drainage	Cadastre	Railway	0.2, 0.04, 0.025

TOOWOOMBA REGIONAL COUNCIL

1:18,000 (at A3)

0 125 250 500 Meters

GDA 1994 MGA Zone 56

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FIGURE 3 - 8
NOBBY MODEL EXTENT

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Date Saved: 11/06/2014

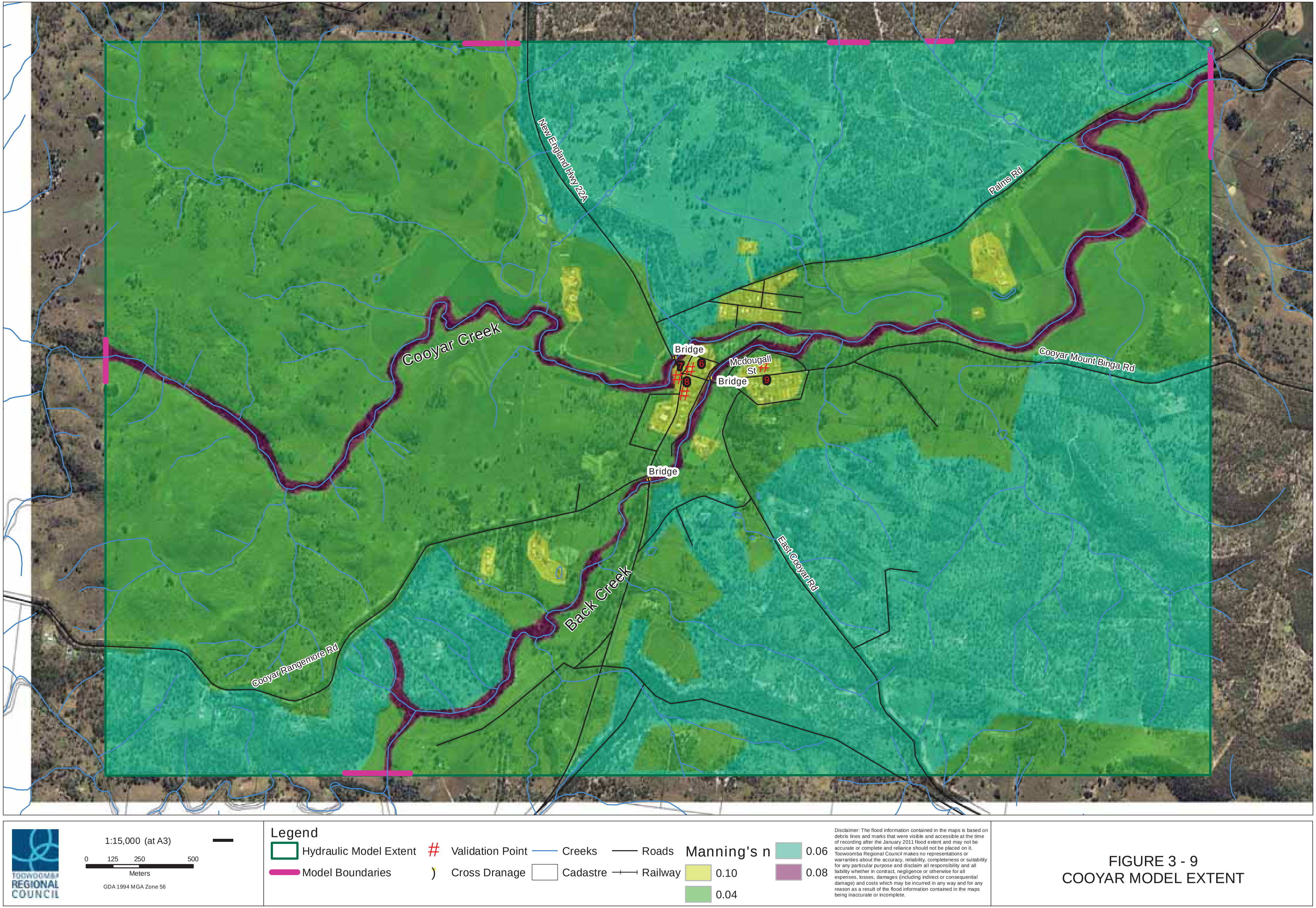

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FIGURE 3 - 9
COOYAR MODEL EXTENT

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Date Saved: 13/03/2014

Legend

- Model Boundaries
- Hydraulic Model Extent
- Road Centrelines
- Cadastre
- Pipe
- Cross Drainage
- Validation Point
- Creeks
- Railway
- Roads

Manning's n

0.025	0.08
0.04	0.11
0.06	0.2

1:16,823 (at A3)

0 120 240 480

Meters

GDA 1994 MGA Zone 56

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FIGURE 3 - 10
YARRAMAN MODEL EXTENT

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3.2.6 Boundary Conditions

The downstream boundary adopted for Yarraman and Cooyar hydraulic models was a fixed tailwater level based on a normal depth calculation for peak inflow of the relevant validation event. The boundary adopted for the Nobby model was set to an initial level approximately 1 m above the natural terrain. The adopted levels are presented in **Table 3-10** below.

Table 3-10 : Downstream boundary conditions for validation event.

Model	Water Level (mAHD)
Nobby	454.0
Cooyar	425.0
Yarraman	418.3

The Nobby model's primary downstream boundary is located 1.7 km downstream of the town and potential development area. The ground levels at the boundary are approximately 17 m lower than the levels within the area of interest. As such the model boundary conditions are considered to have minimal influence over predicted flood levels in the area of interest. Additional model boundaries were utilised where surface runoff around the edges of the model boundary was collecting near the model extent boundary. These boundaries were created using a fixed water level boundary approximately 100mm above natural terrain.

The Yarraman model's downstream boundary is located 2.6 km downstream of the town and potential development area. The ground levels at the boundary are approximately 12 m lower than the levels within the area of interest. As such the model boundary conditions are considered to have minimal influence over predicted levels in the area of interest.

The Cooyar model downstream boundary is located 3.1 km downstream of the town and potential development area. However, while ground levels at the boundary are 6 m lower than the levels within the area of interest they are only 2 m below the level within the Creek. Therefore there was the potential for the adopted downstream model boundary to influence the results within the area of interest. While a constant water level was adopted for the 1988 event to provide model stability, design event modelling of more frequent ARI's used a QH relationship.

Figure 3-8, **Figure 3-9** and **Figure 3-10** illustrate the locations of the adopted model boundaries for Nobby, Cooyar and Yarraman respectively.

3.2.7 Hydraulic Structures

3.2.7.1 Nobby

A site visit to Nobby was undertaken on the 13th of September 2013 and structure details were noted. These structures have been represented in the hydraulic model through one-dimensional hydraulic MIKE 11 links. A summary of the structures is provided in **Table 3-11** below and photographs of some of the key structures are presented in **Figure 3-11** to **Figure 3-14**. Invert levels and culvert lengths/ bridge widths for all structures were extracted from the LIDAR data.

Table 3-11 : Nobby model structure details

Structure ID	Crossing	Structure	Upstream RL (m AHD)	Downstream RL (m AHD)	Pipe length (m)
46	Felton-Clifton Road (approx. 200m west of Langsdort Rd)	4 x 750 RCP	466.03	465.2	10
39	Felton-Clifton Road between Langsdort and Rickert Rd	3 x 2100 x 1700 + 2 x 1800 x 1700 RCBC	463.98	462.4	10
40	Felton-Clifton Road approx 120m east of Rickert Road	4 x 750 RCP	465.59	465.23	10
37	Felton-Clifton Road near Rickert Road Junction	3 x 1800 x 1200 RCBC	465.17	464.64	10
36	Tooth Street at Norfolk Street Junction	1 x 450 RCP	479.6	478.86	10
35	Tooth Street at McGreever Street Junction	1 x 400 RCP	479.89	479.08	8
28	Greenmount-Nobby Road – 1.2km north of Davenport St	2x 1200x600 RCBC	498.35	497.84	6
26	Greenmount-Nobby Road –600m north of Davenport St	1 x 900 RCP	492.27	492.04	6
25	Greenmount-Nobby Road –285m north of Davenport St	1x 900 RCP	491.96	490.8	6
23	At Nobby Connection Rd – 290m north of Davenport St	1x 370 RCP	490.46	489.54	13
18	Northern side of Commerford/Tooth St intersection	1x 400 RCP	489.15	488.6	12
34	Tooth/Free Street intersection	1x 450 RCP	485.11	484.54	7
16	Southern side of Commerford/Tooth St intersection	1 x 370 RCP	484.93	484.07	13
22	Railway Crossing Culvert - 1	3x 430 Corrugated pipe	486.5	486.4	6
21	Railway Crossing Culvert- 2	1x 450 Corrugated pipe	486.06	485.64	6
20	Railway Crossing Culvert - 3	1x 435 corrugated pipe	486	485.68	6
30	Fett Road– 285m south of railway crossing	1x 375 RCP	483.36	483.29	8
33	Nobby Connection - Tooth St. South of memorial	2x 500 RCP	482.02	481.98	8
38	Railway Crossing at Nobby Connection Rd	4x 1200x600 RCP	483.39	483.11	6
31	Railway culvert upstream of McGeever St	1 x 900 RCP	481.07	479.65	6
28	Greenmount-Nobby Rd	1 x 1200x600 RCBC	498.64	498.61	6

Figure 3-11 : Railway Culverts Greenmount-Nobby Road –285 m north of Davenport Street

Figure 3-12 : Culverts at railway crossing

Figure 3-13 : Culverts under Felton-Clifton Road

Figure 3-14 : Culverts under Felton-Clifton Road with upstream weir

3.2.7.2 Cooyar

A site inspection was undertaken of Cooyar (10th September 2013) and three major structures were identified within the model area. Details and measurements of the deck thickness, pier dimensions, handrail heights, bridge length and width were taken during the site visit. Following this, Council, supplied survey details of these bridges which was checked with the site measurements for consistency. A summary of the structures is provided in **Table 3-12**. Photographs of the structures are presented in **Figure 3-15** to **Figure 3-17**. Invert levels and culvert lengths/ bridge widths for all structures were extracted from the LIDAR data.

The bridges were all modelled as 1D elements in the MIKEFLOOD model. Both crossings of the New England Highway were represented as culverts with geometry based on the cross-section database to represent the area under the bridge. The McDougall Street Bridge was represented as a culvert with an irregular width to represent the bridge geometry. The bridges were modelled as culverts to improve model stability, and a Manning's n reflective of the roughness of the creek was applied.

Table 3-12 : Cooyar crossing details

Crossing	Structure	Upstream RL (m AHD)	Downstream RL (m AHD)	Pipe length (m)
Back Creek Crossing of New England Highway	Bridge	430.31	430.29	6.5
McDougall St Bridge (Back Creek)	2 x Semi-circular culverts. 6m wide/4m high	430.03	428.31	12
Cooyar Creek Crossing of New England Highway	Bridge	429.01	428.65	6.5

Figure 3-15 : Bridge on New England Highway – Cooyar Creek

Figure 3-16 : Culverts under McDougall Street

Figure 3-17 : Bridge New England Highway – Back Creek

3.2.7.3 Yarraman

As part of these Studies, a site inspection was undertaken of Yarraman (10th September 2013) and several major structures were identified within the model area. The main bridge located on the D'Aguilar Highway is pictured in **Figure 3-18**. Invert levels and culvert lengths/ bridge widths for all structures were extracted from the LIDAR data.

The bridges were all modelled as 1D elements within the MikeFLOOD model. All structures were modelled as culverts in order to improve model stability. **Table 3-13** below outlines the details of the structures modelled.

Table 3-13 : Yarraman Structure Details

Crossing	Structure	Upstream RL (m AHD)	Downstream RL (m AHD)	Pipe Length (m)
D'Aguilar Highway	Bridge	431.064	431.060	20
Upper Yarraman Road	2 x 1850 RCP	451.95	451.92	15
Holmes Road	2 x 450 RCP	449.65	449.1	15
New England Highway near Yarraman-Tarong Road	6 x 800 RCP	446.85	446.13	20
Emmert Street	3 x 900 RCP	433.15	431.94	20
Toomy Street	1 x 1430 and 2 x 1530 RCP Modelled as 3 x 1480 RCP)	430.49	430.26	20
Stormwater Drain (Davis to Barr-Smith Street)	1 x 500 RCP	434.95	434.08	15
Barr- Smith Street	Modelled as (3 x 2.33 x 2.17 RCBC)	425.3	425.3	15
Millar Street	1 x 900	446.78	434.25	400
Yarraman Weir	Weir	Represented in bathymetry from LiDAR (Approx 15 m wide by 1.8 m high)		

Figure 3-18 : Bridge D'Aguilar Highway– Yarraman Creek

Figure 3-19 Yarraman Weir

4. Model Validation

The results of the hydrologic and hydraulic modelling are presented in **Sections 4.1**, **4.2** and **4.3**.

4.1 Nobby

4.1.1 Validation of Hydrology

No suitable donor gauges were identified to enable a flood frequency analysis for Nobby. Therefore, two alternative methods were investigated to provide validation that the model was producing peak discharges consistent with the selected ARI event.

The first method was the Rational Method, which is a widely used method for the calculation of peak flows from small catchments. This is a simplistic method and the peak discharge is the product of a runoff coefficient, rainfall intensity, and catchment area. The applicability of the Rational Method is restricted to small catchments.

The second method is the quantile regression technique, developed by L. B. Palmen and W.D. Weeks (2011). This methodology has used all suitable streamflow data available for the state. It therefore has a good foundation and it is believed that it has a superior performance than the Rational Method. Two parameters are used in the estimation of the design flows, being the 72 hour 50 year ARI design rainfall and catchment area. The design rainfall data are shown in **Appendix A**.

Catchments were delineated using a client supplied Digital Elevation Model (DEM), 2012 aerial photography and a 1 in 25000 drainage polyline supplied by the Queensland Geographical Information Service (QGIS).

Table 4-1 presents the estimated design peak flows from the quantile regression technique and the Rational Method. For the 1 in 200 and 500 year ARI event, the flood frequency curve was extrapolated using a log linear extrapolation method. The flows derived are indicative and subject to significant uncertainty due to the inherent uncertainty of estimating flows for ungauged catchments and also the extrapolation beyond the 100 year ARI event.

Table 4-1 : Estimated Design Peak Flows – Nobby

Palmen & Weeks	**ARI (year) flows (m^3/s)**							
Location	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**
Nobby_watercourse	1.2	4.5	8.3	13.4	22.0	30.1	43.8	59.4
Nobby_SW_flow	0.3	1.3	2.6	4.2	7.1	9.9	12.4	17.1
Nobby 3	0.3	1.4	2.7	4.5	7.6	10.6	14.5	19.9
Nobby North	1.1	4.2	7.8	12.5	20.5	28.2	38.0	51.3
Nobby West	3.4	12.3	21.7	34.4	55.1	74.2	100.2	135.3
Rational method	**ARI (year) flows (m^3/s)**							
Location	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**
Nobby_watercourse	8.9	11.0	12.2	15.8	20.5	24.1		
Nobby_SW_flow	1.9	2.3	2.6	3.3	4.3	4.9		
Nobby 3	2.7	3.4	3.8	4.8	6.3	7.4		

The results from both methods are generally comparable. The quantile regression technique is considered to have a superior performance for rural catchments in Queensland, and is therefore particularly relevant for the Nobby locality. As the model is a rainfall-on-cell approach, the downstream model boundary flows will be validated against the flows presented by both the Rational Method and quantile regression method for completeness.

Direct rainfall on grid was applied to the hydraulic model. An initial loss of 5 mm and continuing loss of 2.5 mm/h was applied for the validation event. The low initial loss value was selected to represent a catchment with saturated antecedent conditions as it is understood that there was a significant amount of rainfall in the period leading up to the 2011 event in Nobby.

4.1.2 Validation of Hydraulic Model

The Nobby results were validated to within 30 mm of the historical levels provided. One of the Nobby residents reported that the January 2011 flood occurred on the afternoon of the 10th January 2011. This was the event that caused substantial runoff flooding through the town. However, flooding over Commerford Road occurred on and off for a period of 4 days starting on the 9th of January 2011.

The flood behaviour predicted by the hydraulic model is consistent with that observed by the Nobby residents interviewed for this study. In particular the model demonstrates:

- There are a number of gullies to the west of Nobby that convey flood flows into the town
- Flow is concentrated at the railway line
- Flow overtops the railway line by approximately 200 mm (6 inches reported by one resident).
- A number of streets are cut, depicting the isolation hazard described by the residents

The predicted flood levels validated to within 30 mm of the validation points available for the January 2011 event. This performance is provided for a peak flow that approximates the 500 year ARI, the estimated ARI of the January 2011 event. The model is therefore considered an appropriate representation of the historical event for the purposes of defining a flood overlay code for Council’s Planning Scheme.

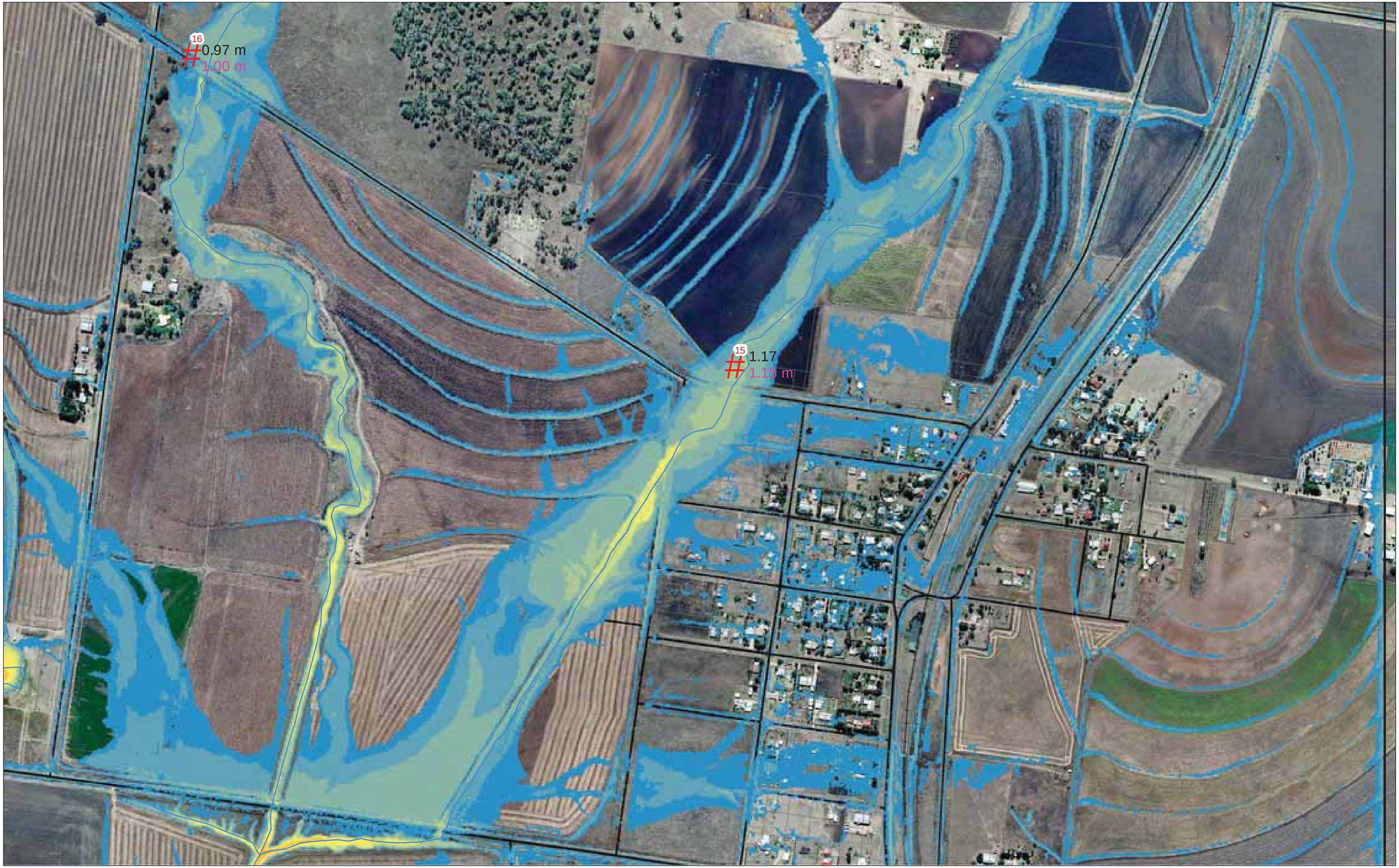
The peak discharge used to validate the hydraulic model to the 500 year ARI event was compared to the results of a rational method calculation. It is noted that this is an indicative estimate using extrapolated rainfall from the IFD BoM curve (ARR 1987). The result of the calculation is tabulated below in **Table 4-2**.

Table 4-2 : Comparison of Rational Method and model results

Parameters	At model outlet
C500	.59
I	70.46 mm/hr
A	1554 ha
Discharge: Rational Method	179.6 m^3/s
Discharge: Model Simulated	168.6 m^3/s

The assessment identified that the peak discharge at the model outlet was only about 9% less than the peak discharge determined by the Rational Method.

The modelled results are presented in **Figure 4-1** and **Figure 4-2**.



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1:6,000 (at A3)

0 50 100 200

Meters

GDA 1994 MGA Zone 56

Legend

#	Validation Point
Modelled Flood Depth (m)	Creeks
Observed Flood Depth (m)	Model Boundaries
	Hydraulic Model Extent
	Cadastre
	Railway
	Roads

Depth (m)

< 0.1	1.0 - 1.5	3.0 - 3.5	> 5.0
0.1- 0.25	1.5 - 2	3.5 - 4	
0.25 - 0.5	2.0 - 2.5	4.0 - 4.5	
0.5 - 1	2.5 - 3	4.5 - 5	

Disclaimer: The flood information contained in the maps is based on debris lines and marks that were visible and accessible at the time of recording after the January 2011 flood extent and may not be accurate or complete and reliance should not be placed on it. Toowoomba Regional Council makes no representations or warranties about the accuracy, reliability, completeness or suitability for any particular purpose and disclaim all responsibility and all liability whether in contract, negligence or otherwise for all expenses, losses, damages (including indirect or consequential damage) and costs which may be incurred in any way and for any reason as a result of the flood information contained in the maps being inaccurate or incomplete.

FIGURE 4 - 1
NOBBY FLOOD BEHAVIOUR
2011 FLOOD EVENT

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Date Saved: 11/06/2014

1:18,000 (at A3)

0 125 250 500
Meters

GDA 1994 MGA Zone 56

Legend

#	Validation Point
	Creeks
	Model Boundaries
	Hydraulic Model Extent

Depth (m)

< 0.1	1.0 - 1.5	3.0 - 3.5	> 5.0
0.1- 0.25	1.5 - 2	3.5 - 4	Cadastre
0.25 - 0.5	2.0 - 2.5	4.0 - 4.5	Railway
0.5 - 1	2.5 - 3	4.5 - 5	Roads

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FIGURE 4 - 2
NOBBY MODEL RESULT
2011 FLOOD EVENT

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4.2 Cooyar

4.2.1 Validation of Hydrologic Model

Accounts of the 1988 flood described fast flowing floodwaters and rapid water level rise in the middle of the night. Several houses were washed away as depicted in **Figure 4-3**.

The BoM reports prepared after the flood estimated the magnitude of the event to be in the order of 1 in 500 years ARI. To simulate the 1988 flood, the rainfall documented in the Cooyar BoM report (BOM, 1990) was applied to the XP-RAFTS hydrologic model. Modelling of the event produced an estimated peak flow just downstream of the township of 1023 m^3/s.

Due to the paucity of rainfall, pluviograph and streamflow gauges in and around the catchment above Cooyar a regional flood frequency analysis was also undertaken to aid in model validation. Details of this analysis are provided in **Appendix A**. The 1988 flood peak flow estimated by the XP-RAFTS model correlates well with the 500 year ARI flow estimated by the regional flood frequency analysis of 1113 m^3/s.

To further aid model validation a series of design event rainfalls from 2 year ARI to 500 year ARI was applied to the XP-RAFTS model and peak flow estimates generated.

Table 4-3 provides a comparison of the peak discharges generated by the hydrologic model and the flood frequency analysis.

Table 4-3 : Comparison of FFA and hydrologic model outputs for Cooyar

ARI (year)	Flood frequency analysis peak flow at Cooyar (m^3/s)	XP-RAFTS design events peak flow at Cooyar (m^3/s)	Difference (%)
2	88	87	-1.1
5	183	196	+6.6
10	270	267	-1.1
20	372	373	+0.2
50	535	523	-2.2
100	681	640	-6.4
200	850	710	-17
500	1113	800	-29

A comparison of the results presented in **Table 4-3** demonstrates that the XP-RAFTS model has been adequately validated to the 1988 event and the range of design events flows determined by the regional flood frequency analysis.

However, it is noted that for events rarer than the 100 year ARI event the regional flood frequency analysis is estimating peak flows greater than the peak flows generated by design rainfall. It is considered that this variation is due to the reliability of the regional flood frequency analysis for these larger events. This variation is further discussed in **Appendix A**.

4.2.2 Validation of Hydraulic Model

The Cooyar model was validated to the 1988 historical event. Records from the historical event were limited to three records on the monument in the centre of town that serves as a flood totem for the 1988 event. The monument provides flood levels representative to those recorded at the Cooyar Hotel, old post office and motel. An additional validation point was provided by a resident of Cooyar on a property downstream at McDougall Street, this level was noted as a low-confidence level with the resident reporting that the flood came approximately halfway up the house stumps (~1 m).

Figure 4-3 : Cooyar Post-Flood 1988 (photo on wall of Cooyar Hotel)

The modelled levels at the war memorial and Cooyar Hotel are within 200 mm of the historical levels. The most significant difference in the modelled and observed flood levels was at the Old Post Office. A summary of the performance of the model to meet the validation points is given in **Table 4-4**. The motel is located only 50 m upstream of the post office, however the difference in the observed flood heights between the motel and post office is 700 mm. A review of the 1 m DEM through this area indicated no significant obstructions to account for this hydraulic gradient. Therefore, assuming that the DEM is largely representative of the terrain through the area in 1988 it is considered likely that the level report at the motel would have been driven by local effects such as blockages. A sensitivity analysis was undertaken to examine the impact of blockages on the model. All bridges in the model were modelled as 100% blocked to identify the upper limit of the model sensitivity. Blockages increased flood levels at the post office by approximately 600 mm, providing a modelled flood level that closely matched the observed flood level. Similarly blockages on the New England Highway Bridge increased modelled flood levels at the hotel to within 400 mm of the observed flood levels. The results indicate that the model is sensitive to blockages.

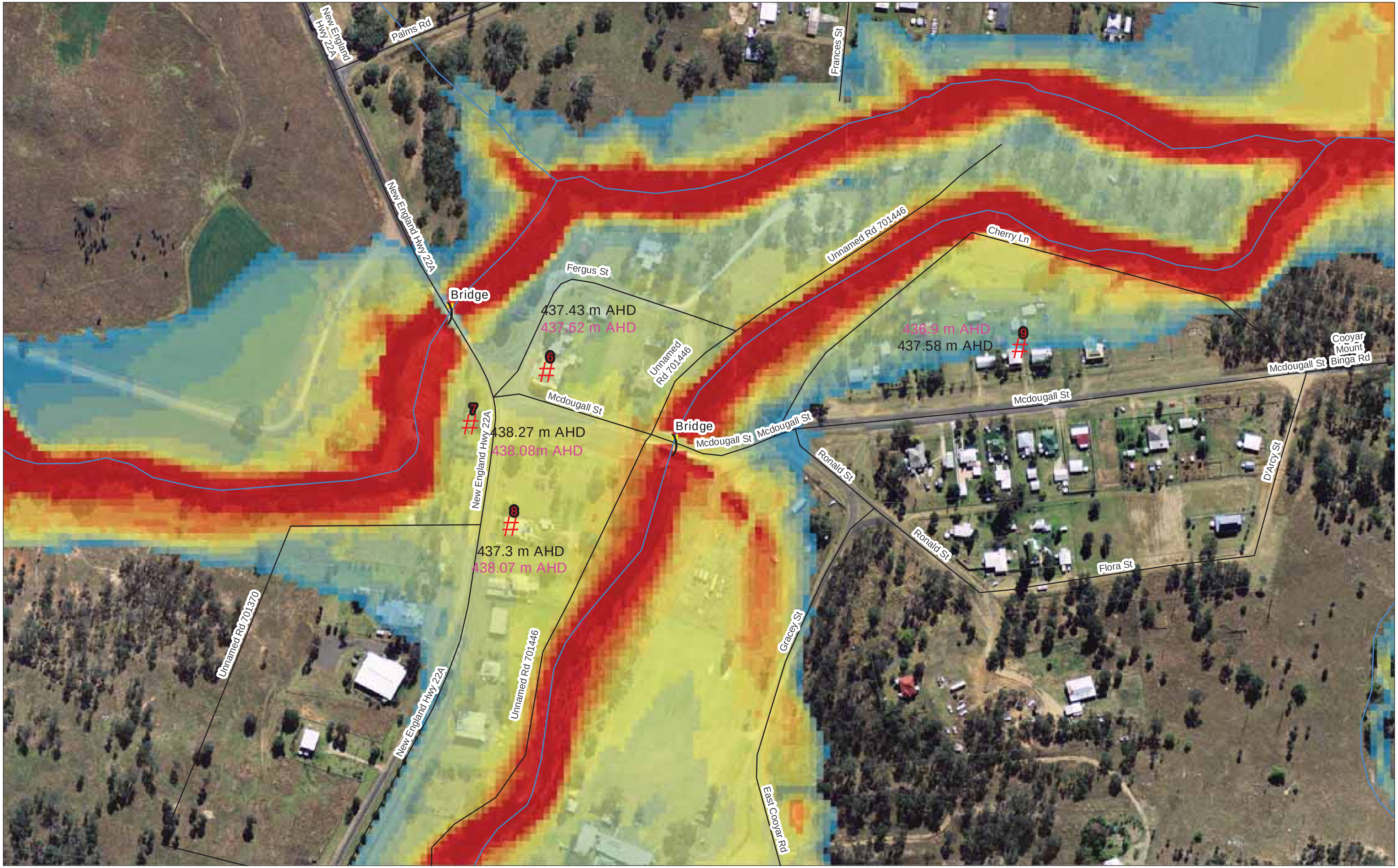
Table 4-4 Cooyar model validation – February 1988

Validation point location	Validation level (m AHD)	Modelled 1988 flood level (m AHD)	Difference (m)
6: Cooyar Hotel	437.43	437.62	-0.19
7: War Memorial	438.27	438.08	0.19
8: Old post office	437.3	438.07	-0.77
9: SKM observed flood level – McDougall St	436.9	437.58	-0.68

The passage of time can result in a number of changes to a catchment. A sensitivity assessment on the assumed hydraulic roughness was undertaken to assess the model sensitivity to increased vegetation within a catchment. A change in Manning's n from 0.04 to 0.05 increased the modelled results by approximately 100 mm. The analysis revealed that the model was only moderately sensitive to the Manning's n parameter.

The lack of model sensitivity to other hydraulic modelling parameters and the conservatism in the calibration of the hydrologic modelling to the FFA indicates that the reason for the discrepancy in the model validation is most likely due to unknowns associated with the model hydrology and size of the 1988 event. While the model provides a moderate validation to the observed flood levels it is considered to provide a reasonable representation of the flow behaviour and is therefore suitable for design flood modelling. It is however recommended that the 1988 historical flood levels and the risks associated with an event of a similar frequency are considered in the assessment of flood risks and flood risk management.

Figure 4-4 and **Figure 4-5** depicts the flood behaviour for the 1988 validation event with 100% blockage of structures applied.



Legend

Observed Level (mAHD)

Modelled Level (mAHD)

Cross Drainage, Validation Point, Creeks, Roads, Railway, Cadastre

Depth (m)				
< 0.1	0.25 - 0.5	1.5 - 2	3.0 - 3.5	4.5 - 5
0.1- 0.25	0.5 - 1	2.0 - 2.5	3.5 - 4	> 5.0
	1.0 - 1.5	2.5 - 3	4.0 - 4.5	

1:2,500 (at A3)

0 25 50 100 Meters

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FIGURE 4 - 4
COOYAR MODEL BEHAVIOUR
1988 FLOOD EVENT

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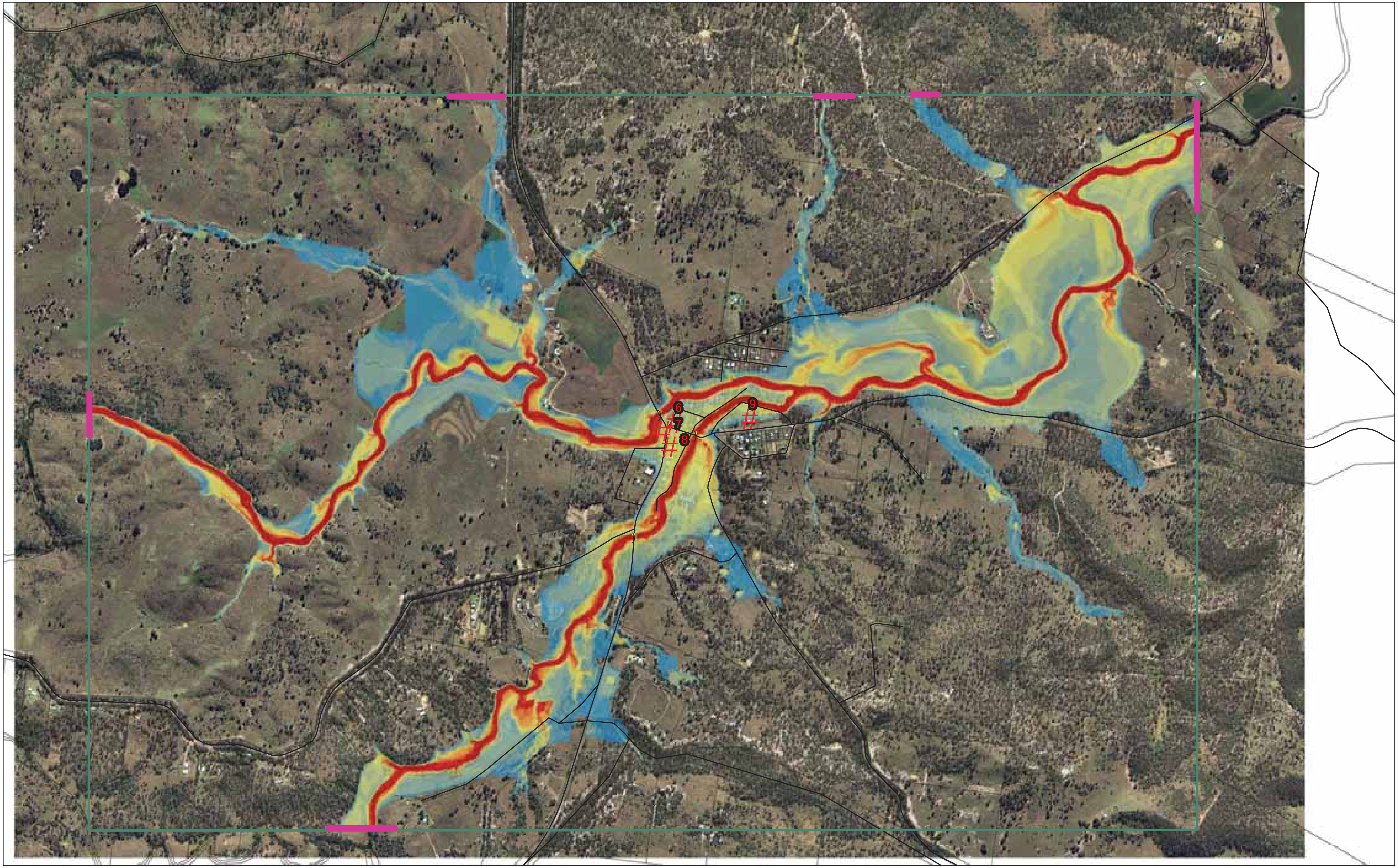

1:15,890 (at A3)

0 170 340 680
Meters

GDA 1994 MGA Zone 56

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Legend

) Cross Drainage	Roads	Depth (m)	0.25 - 0.5	1.5 - 2	3.0 - 3.5	4.5 - 5
# Validation Point	Railway	< 0.1	0.5 - 1	2.0 - 2.5	3.5 - 4	> 5.0
	Cadastre	0.1- 0.25	1.0 - 1.5	2.5 - 3	4.0 - 4.5	

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FIGURE 4 - 5
COOYAR MODEL RESULT
1988 FLOOD EVENT

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4.3 Yarraman

4.3.1 Validation of Hydrologic Model

The developed temporal pattern for the January 2011 event in the Yarraman catchment was entered into the XP-RAFTS model. The resulting hydrograph had a peak discharge of 343 m^3/s which was between the 1 in 50 and 100 year ARI peak discharge estimated by the regional flood frequency analysis.

Cooyar Creek and Linville recorded events in the order of 75 to 100 year ARI events. The hydrologic model provides consistent results with the recorded gauge data. The radar images of the event are shown below in **Figure 4-6**.

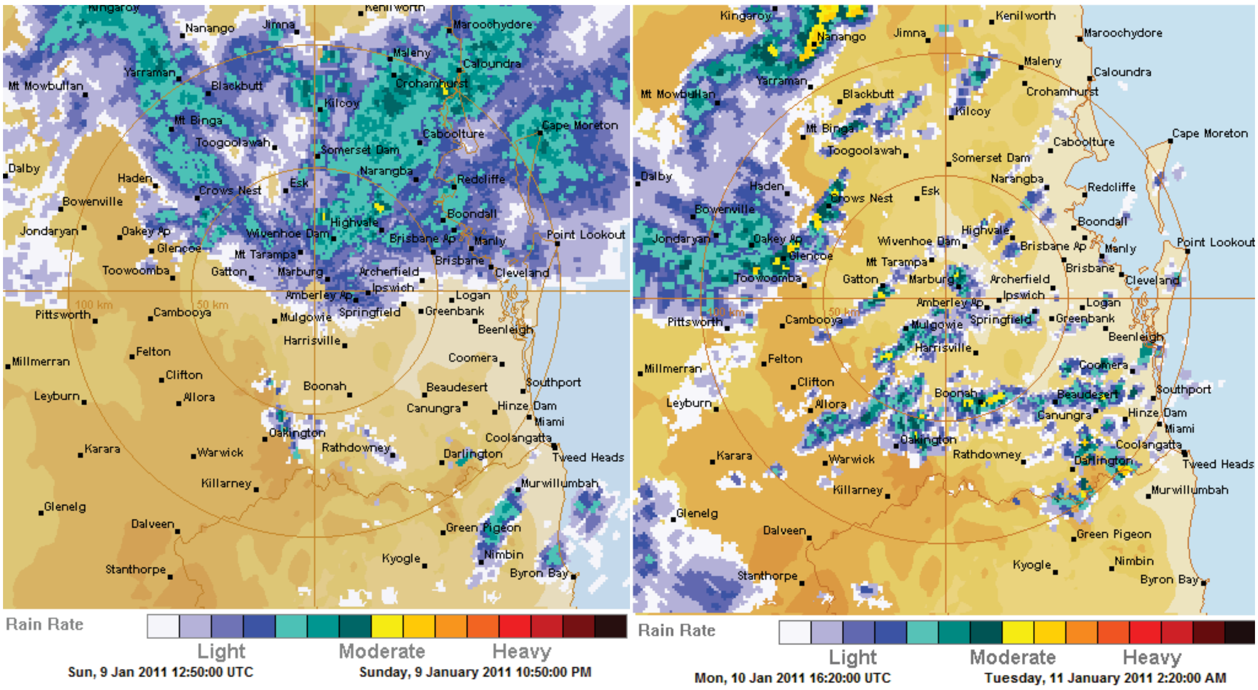


Figure 4-6 : Radar images associated with the flood event in Yarraman, January 2011

Table 4-5 provides a comparison of the results of the flood frequency analysis and the hydrologic model outputs using design event rainfall. A comparison of these results demonstrates that the XP-RAFTS model appropriately represents the peak flow for design events and therefore is appropriately validated.

Table 4-5 : Comparison of FFA and hydrologic model outputs for Yarraman

ARI (year)	Flood frequency analysis peak flow at Yarraman (m^3/s)	XP-RAFTS design event peak flow at Yarraman (m^3/s)	Difference (%)
2	49	56	11
5	102	108	7
10	151	152	1
20	208	215	3
50	299	298	0
100	381	370	-3

Additional detail and discussion of the hydrologic analysis which was undertaken is presented in **Appendix A**.

4.3.2 Validation of Hydraulic Model

The Yarraman Mike Flood models were developed to investigate flooding in the Yarraman township and future development areas. Flooding in the town is characterised by significant overland flow, as well as flooding from Yarraman Creek, which breaks its banks and contributes to flooding south of Margaret Street. The most densely developed areas, north of Margaret Street, are subject to flooding due to overland flow from the north. Community members have observed flow travelling down local roads including Norman Street and George Street to inundate houses and businesses.

The creek flooding model has been validated through comparison with levels observed during the January 2011 flood event in Yarraman, which is believed to have an ARI of between 50 and 100 years. The validation data used was obtained from two sources; TRC supplied information and data that was collected by SKM during a site visit on 10th of September 2013.

The TRC supplied data was collected by a Council survey team approximately one month after the event in early February 2011. The data collected included flood debris locations and flood marks. The data provided information about the extents of the flood and flood levels. This data became available following initial validation of the model to the data collected by SKM.

Seven flood levels (recorded and anecdotal) were derived from the SKM site visit. Five of these levels are within the Yarraman township, with one point to the far north-east (Yarraman Creek Weir) and one to the far south-west on Holmes Road.

Two flood levels were collected along Margaret Street in locations understood to have been flooded by overland flow from the north in January 2011. The first is the Yarraman Hotel Motel (14 Margaret Street), where residents reported approximately 400 mm of floodwater depth on the property. The modelling results show a maximum depth on this property of around 275 mm during the modelled 2011 event. It is likely that the historical flood levels (taken on the upstream side of the property) were affected by local afflux due to the building. This would give higher flood levels on the upstream side of the building than the downstream side. This building is not represented in the flood model, so the afflux is not depicted.

The second flood level collected along Margaret Street was at the bowls club (28 Margaret Street). A flood level of approximately 442 mAHD was reported at this location, along with the observation that the bowling green ‘filled’ with floodwater. The cross section presented in **Figure 4-7** (taken north-south across the bowling green) demonstrates that this was represented in the model. The flood level along the front of the buildings on this property reached a level of 441.95 mAHD during the modelled 2011 validation event, which corresponds closely with the observed level.

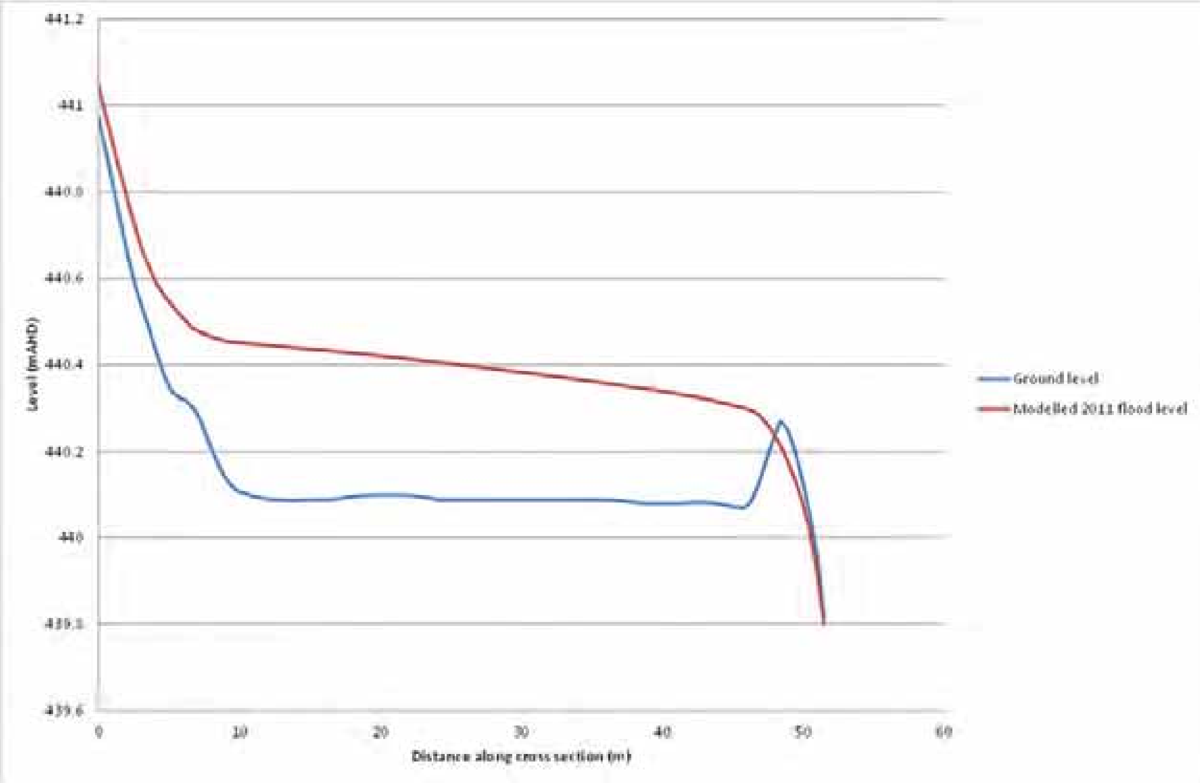


Figure 4-7 : Yarraman Bowls Club green cross section

Two flood levels were collected along Emmet Street south of Margaret Street, where flooding is dominated by flow exceeding the capacity of Yarraman Creek. The two properties are next door to each other, with the buildings located less than 20 m apart. However, the two flood levels collected vary by 650 mm. This indicates that one of the levels may not be accurate. The level on the northern property is expected to be more accurate as it was recorded on a shed wall following the January 2011 flood event rather than derived from anecdotal information.

The level recorded on the northern property on Emmett Road recorded during January 2011 was 436.2 m AHD. The MikeFlood model result in this location is 436.51 m AHD.

A fifth flood level was collected further downstream on Barr-Smith Street. This flood level was estimated from flood debris in trees at 429.8 mAHD. The modelled flood level at this location is 431.0 mAHD. As this validation point is based on anecdotal information only, this is considered an acceptable result.

The sixth historical flood level considered in the validation of the MikeFlood model was taken at the crossing over Holmes Road, approximately 2 km south-west of the Yarraman town centre or 3.5 km upstream along Yarraman Creek (see adjacent figure). Flood debris observed in a tree beside the creek indicated a flood depth of 1.8 m over the concrete causeway at the crossing, which was estimated to translate to a level of 451.8 mAHD. This is significantly lower than the flood levels modelled in this area, which are in the order of 453.45 mAHD. The discrepancy could be due to the debris being associated with the smaller 2013 flood event in Yarraman, rather than the January 2011 flood. Additionally, the debris became caught in a fork between branches of a tree. This suggests that it may have fallen into the fork rather than remaining at the peak flood level.

The level taken at the Yarraman Weir validation point was collected from debris on a fence beside the weir. The debris was found on the upper strands of a wire fence and therefore may have under-estimated the flood depth experienced. Alternatively, the debris mark could have also been due to flooding since the January 2011 event.

A comparison of the TRC captured validation data and the modelled flood surface indicated that in the majority of the locations the model was representing the general extents of the 2011 event. The model generally predicted flood levels higher than the levels captured. However given that a large proportion of the levels appear to be associated with debris levels recorded at flood extents (and it is understood that the capture of the data did not include verification of locations through consultation with residents) this result is consistent with expected flood behaviour. These types of flood marks are often impacted by the recession of a flood with debris being deposited at levels lower than the peak level as the flood recedes. The expected accuracy of these types of flood marks would be at best of the order of +/- 500mm. The comparison of the TRC data levels and the modelled levels indicated that the model was within or close to the +/- 500mm tolerance at almost 50 percent of points. There was no clear trend in model performance against this data and given the uncertainty of the reliability of this data, the performance of the model was considered to be representative of the characteristics of the creek flood plain.

The following table presents the modelling results at the validation points available for the January 2011 event.

a le 4 6 Validation point perfor ance

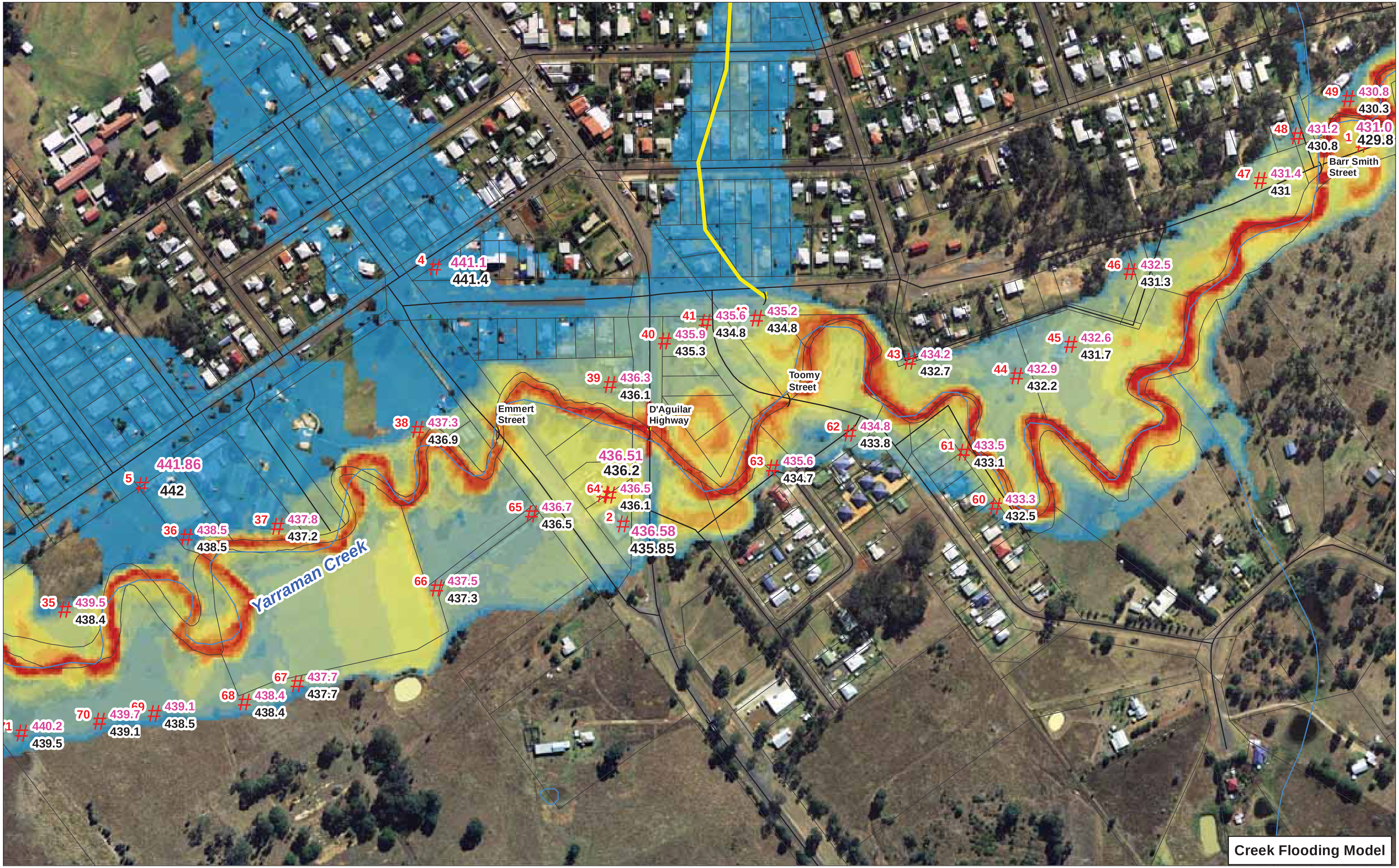
Validation point location	Validation level (m AHD)	Modelled 2011 flood level (m AHD)	Difference (m)
Source: SKM Site Visit			
1: Barr-Smith St - Debris	429.8	431.0	1.2
2: Emmett St - Produce Store	436.85	436.58	-0.27
3: Emmett St - Jetson Engineering	436.2	436.51	0.31
4: Yarraman Hotel Motel (Margaret St)	441.4	441.1	-0.3
5: Lawn bowls club (Margaret St)	442	441.86	-0.14
6: Holmes Rd - debris	451.8	453.45	1.65
7. Yarraman Weir	421.55	422.5	0.95
Source: TRC Data Capture			
8.	455.31	456.12	0.81
9.	454.72	455.35	0.63
10.	453.91	455.06	1.15
11.	456.10	456.74	0.64
12.	452.92	453.44	0.54
13.	452.29	453.08	0.79
14.	451.47	452.65	1.18
15.	447.28	448.02	0.74

Validation point location	Validation level (m AHD)	Modelled 2011 flood level (m AHD)	Difference (m)
16.	448.53	Not Flooded	n/a
17.	448.26	447.97	-0.29
18.	446.90	447.13	0.23
19.	446.36	446.65	0.29
20.	444.78	445.59	0.81
21.	444.53	445.06	0.53
22.	444.30	445.07	0.77
23.	444.03	444.87	0.84
24.	443.31	444.45	1.14
25.	443.41	444.34	0.93
26.	443.37	444.08	0.71
27.	443.26	443.85	0.59
28.	442.62	442.83	0.21
29.	442.26	442.30	0.04
30.	441.59	441.79	0.20
31.	441.43	441.65	0.22
32.	440.22	440.59	0.37
33.	440.21	440.58	0.37
34.	439.36	440.37	1.01
35.	438.45	439.48	1.03
36.	438.54	438.52	-0.02
37.	437.24	437.75	0.51
38.	436.95	437.27	0.32
39.	436.07	436.32	0.25
40.	435.33	435.90	0.57
41.	434.83	435.57	0.74
42.	434.75	435.24	0.49
43.	432.75	434.24	1.49
44.	432.20	432.92	0.72
45.	431.72	432.56	0.84
46.	431.33	432.46	1.13
47.	430.97	431.39	0.42
48.	430.77	431.15	0.38
49.	430.28	430.79	0.51
50.	428.39	428.75	0.36
51.	426.93	427.19	0.26
52.	426.09	426.42	0.33

Validation point location	Validation level (m AHD)	Modelled 2011 flood level (m AHD)	Difference (m)
53.	425.67	426.13	0.46
54.	425.53	425.70	0.17
55.	425.18	425.42	0.24
56.	423.16	424.11	0.95
57.	427.62	428.08	0.46
58.	429.19	429.76	0.57
59.	430.31	430.81	0.50
60.	432.49	433.29	0.80
61.	433.07	433.46	0.39
62.	433.77	434.81	1.04
63.	434.71	435.59	0.88
64.	436.08	436.48	0.40
65.	436.46	436.73	0.27
66.	437.26	437.47	0.21
67.	437.65	437.71	0.06
68.	438.39	438.39	0.00
69.	438.52	439.08	0.56
70.	439.13	439.72	0.59
71.	439.54	440.16	0.62
72.	439.77	440.70	0.93

Figure 4-8 and **Figure 4-9** depicts the flood behaviour in Yarraman in the 2011 flood event.

The performance of the Yarraman rainfall-on-cell model was confirmed by comparing results from this model with results from the validated creek flooding model using the 100 year ARI design event. This process is discussed further in **Section 6**.



1:3,532 (at A3)

0 20 40 80
Meters

GDA 1994 MGA Zone 56

Legend

Modelled Level (m AHD)
Observed Level (m AHD)

- Validation Point
- Cross Drainage
- Pipe
- Creeks
- Railway
- Roads

Depth (m)

- < 0.1
- 0.1- 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- > 5.0

Disclaimer: The flood information contained in the maps is based on debris lines and marks that were visible and accessible at the time of recording after the January 2011 flood extent and may not be accurate or complete and reliance should not be placed on it. Toowoomba Regional Council makes no representations or warranties about the accuracy, reliability, completeness or suitability for any particular purpose and disclaim all responsibility and all liability whether in contract, negligence or otherwise for all expenses, losses, damages (including indirect or consequential damage) and costs which may be incurred in any way and for any reason as a result of the flood information contained in the maps being inaccurate or incomplete.

FIGURE 4 - 8
YARRAMAN MODEL BEHAVIOUR 2011 FLOOD EVENT

Disclaimer: Whilst all due care has been taken in the preparation of the plan and all information (the Plan and all information is referred to as "Plan information"), the accuracy of the Plan Information cannot be guaranteed. The Plan Information is provided as a guide and should not be relied upon in anyway whatsoever. Toowoomba Regional Council takes no responsibility for inaccuracies in the Plan Information and is not liable under any circumstances for any loss or damage whatsoever or howsoever caused arising directly or indirectly in connection with its use. The recipient must verify the Plan Information on site. Please refer any discrepancies to Toowoomba Regional Council - Information, Communications & Technology. No part of the Plan Information should be reproduced without the permission of the Coordinator GIS - ICT Branch, or other delegated representative of Council (131872).

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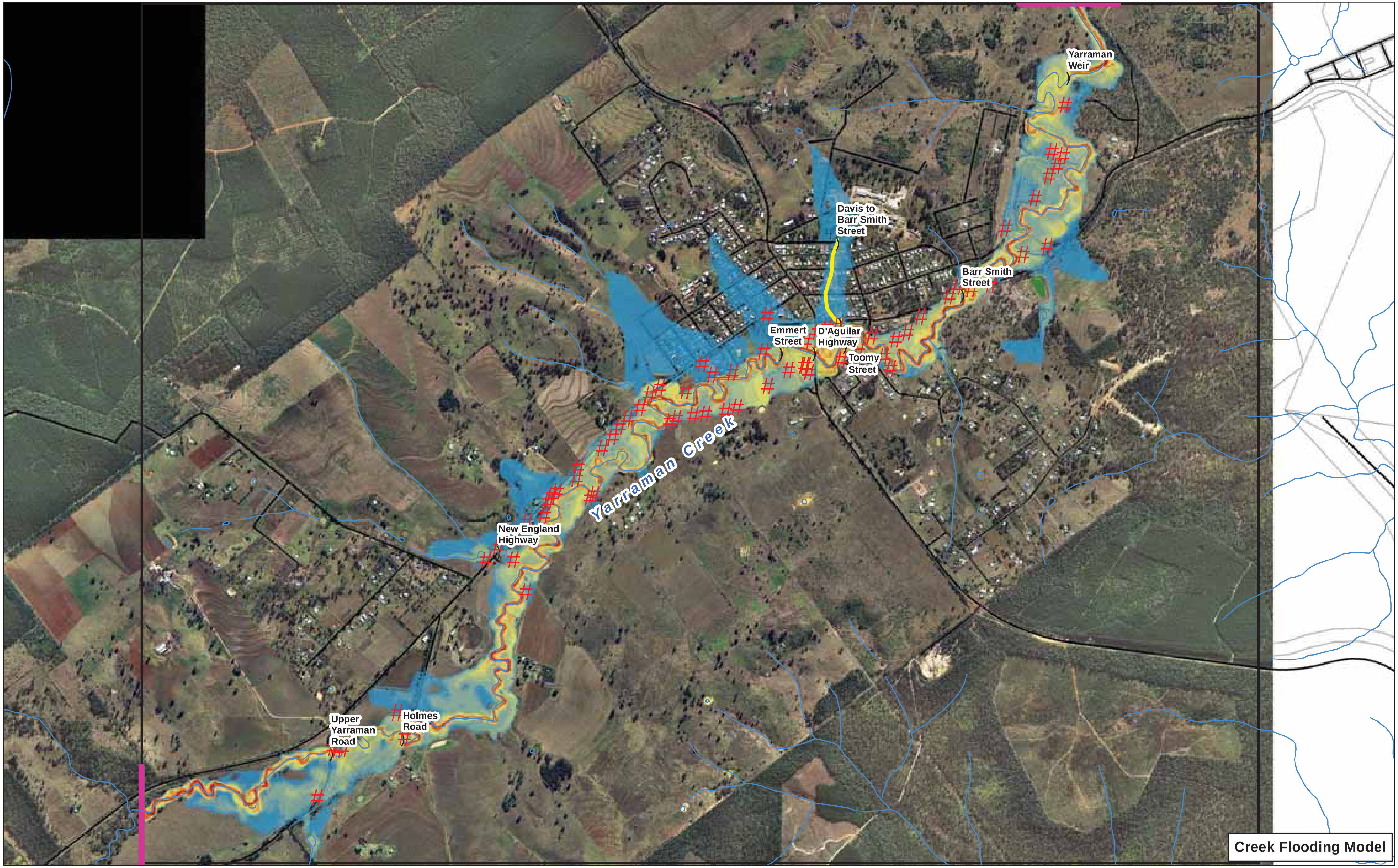
Date Saved: 13/02/2015



Legend

- TRC SURVEY Yarraman Valid Flood Levels Jan 2011_ptz
- Hydraulic Model Extent
- Model Boundaries
- Cadastre
- Pipe
- Cross Drainage
- Validation Point
- Creeks
- Roads
- Railway

Depth (m)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 2
- 2.0 - 2.5
- 2.5 - 3
- 3.0 - 3.5
- 3.5 - 4
- 4.0 - 4.5
- 4.5 - 5
- > 5.0

Disclaimer: The flood information contained in the maps is based on debris lines and marks that were visible and accessible at the time f recording after the January 2011 flood event and may not be accurate or complete. Reliance should not be placed on it. Toowoomba Regional Council makes no representations or warranties about the accuracy, reliability, completeness or suitability for any particular purpose and disclaim all responsibility and all liability (whether in contract, negligence or otherwise for all expenses, losses, damages (including indirect or consequential damage) and costs which may be incurred in any way and for any reason as a result of the flood information contained in the maps being inaccurate or incomplete.

1:16,000 (at A3)

0 125 250 500
Meters

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

FIGURE 4 - 9
YARRAMAN MODEL RESULT
2011 FLOOD EVENT

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Date Saved: 13/02/2015

5. Design Event Hydrology

5.1 Nobby

The design event flood modelling for Nobby used the method of rainfall on grid applying Intensity Frequency Duration (IFD) data specified in *"Australian Rainfall and Runoff Book II'* (AR&R, 1987). The rainfall depth for each event was combined with Zone 2 AR&R temporal patterns and applied over the delineated catchment. Given the small size of the catchments associated with Nobby the application of Areal Reduction Factors was not required. The design rainfall depths used for Nobby are presented in **Table 5-1**.

Table 5-1 : Nobby Design Rainfall Depths

	Design Rainfall depth (mm)							
Duration	**2 year ARI**	**5 year ARI**	**10 year ARI**	**20 year ARI**	**50 year ARI**	**100 year ARI**	**200 year ARI**	**500 year ARI**
1Hr	33.7	40.7	45.0	51.1	59.4	65.8	74.7	85.8
2Hrs	41.8	50.4	55.6	63.2	73.2	81.2	92.0	105.8
3Hrs	36.6	46.5	56.1	62.1	70.5	81.6	102.6	117.9
6Hrs	43.6	55.2	67.2	73.8	84.0	97.8	123.0	141.3
12Hrs	52.0	66.0	80.5	89.4	102.0	119.2	149.8	172.2

Initial and continuing losses were applied to the rainfall depths used in the MIKEFLOOD model. Note that the initial loss for the design events was higher than the initial loss applied to the validation event rainfall. This is because it is understood that there was a large amount of rain in the period leading up to the 2011 flood event in Nobby. Therefore, the loss applied reflected a catchment with saturated antecedent conditions. This assumption was not considered applicable to the design event modelling, where a more standard initial loss of 20 mm was applied. The adopted rainfall losses based on land type are presented in **Table 5-2**.

Table 5-2 : Adopted loss rates

Land type	**Loss type**	**Rainfall loss (mm)**
Pervious	Initial	20
	Continuing	2.5
Impervious	Initial	0
	Continuing	0

The rainfall excess applied to the MIKEFLOOD rain-on-grid model is provided in **Table 5-3**.

Table 5-3 : Nobby Design Rainfall Excess Depths

Duration	Design Rainfall depth (mm)							
	2 year ARI	5 year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI
1Hr	12.1	19.2	23.5	29.5	37.7	44.2	52.5	64.1
3Hrs	20.2	29.8	35.9	44.3	54.8	63.8	75.8	91.2

The Probable Maximum Precipitation (PMP) was estimated using the Generalised Short-Duration Method (GSDM). The analysis assumed 100% of the catchment was rough. A moisture adjustment factor of 0.83 and an elevation adjustment factor of 1 were also applied. The calculated PMP depths are presented in **Table 5-4**.

Table 5-4 : PMP depths for Nobby

Duration (hours)	1	2	3	4	5	6
PMP Depth (mm)	420	640	770	880	970	1030

As detailed in Section 3.1.1.1, an XP-RAFTS model was used to generate flows from the most northern catchment which is external to the Nobby model area. Discharges from the external catchment were generated by the XP-RAFTS model for the two storm durations identified as critical (60 minute and 180 minute) which are presented in **Table 5-4**.

Table 5-5 External catchment flows from Nobby XP-RAFTS model

ARI	60 minute duration peak flow (m^3/s)	180 minute duration peak flow (m^3/s)
2	3.21	4.89
5	6.04	7.94
10	7.82	9.65
20	10.75	12.51
50	15.07	15.62
100	18.69	18.75
200	23.32	23.10
500	29.74	28.88
PMP	284.00	223.20

5.2 Cooyar

The design event flood modelling for Cooyar was based on IFD data from AR&R, 1987.

Design storms greater than 100 year ARI were developed by applying the growth factors derived from the relationships between the 50 year to 500 year ARI CRC-Forge rainfall intensities and the relevant AR&R rainfall intensities. The CRC Forge rainfall intensities used to determine the growth factors were estimated using GIS IFD data available with the CRC-Forge IFD application. This method was used to avoid any discontinuities between the AR&R IFD and the CRC-Forge rainfall intensities.

From these IFDs, design rainfall depths were calculated for a range of ARIs and durations. The rainfall depth for each event was combined with Zone 3 AR&R temporal patterns.

Areal Reduction Factors (ARFs) were applied to point rainfall depths to convert them to catchment estimates. An ARF factor of between 0.81 and 0.85 was applied depending on the critical duration. The same approach was adopted for the 500 year ARI rainfall, to achieve a consistent approach. The ARF estimation followed the recommended approach set out in "Project 2, Collation and Review of Areal Reduction Factors from Applications of the CRC-Forge Method in Australia Final Report P2/S2/012", AR&R April 2013.

A summary of the adopted design rainfall totals is provided in **Table 5-6**.

Table 5-6 : Cooyar catchment design rainfall depths

Duration	Design Rainfall (mm)								ARF
	2 year ARI	5year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI	
1Hr	28.0	34.8	39.0	44.9	52.9	59.3	63.5	68.1	0.75
2Hrs	36.2	44.6	49.9	57.3	67.3	75.0	80.3	86.1	0.79
3Hrs	41.2	50.5	56.1	64.1	75.1	83.7	89.5	96.0	0.81
6Hrs	50.6	61.7	67.8	77.5	90.2	99.9	106.9	114.7	0.85
12Hrs	62.7	76.8	85.2	97.1	112.7	125.5	134.3	144.1	0.89

The losses adopted and applied to the design rainfalls in the Cooyar XP-RAFTS model are presented in **Table 5-7**.

Table 5-7 : Cooyar design losses

Land type	Loss type	Rainfall loss (mm)
Pervious	Initial	30
	Continuing	1.5
Impervious	Initial	0
	Continuing	0

PMP estimates were derived for the Cooyar catchment using the GSDM methodology. The parameters used in the PMP estimation are presented in **Table 5-8**.

Table 5-8: PMP parameters - Cooyar catchment

	Cooyar
Proportion rough	100%
Proportion smooth	0%
Moisture Adjustment Factor	0.83
Elevation Adjustment Factor	1

The calculated PMP depths for the Cooyar catchment are presented in **Table 5-9**.

Table 5-9: PMP depths – Cooyar

Duration (hours)		1	2	3	4	5	6
PMP depth (mm)	**Cooyar**	290	440	540	600	660	700

5.3 Yarraman

The design event flood modelling for Yarraman was based on IFD data from AR&R, 1987.

Design storms greater than 100 year ARI were developed by applying the growth factors derived from the relationships between the 50 year to 500 year ARI CRC-Forge rainfall intensities and the relevant AR&R rainfall intensities. The CRC Forge rainfall intensities used to determine the growth factors were estimated using GIS IFD data available with the CRC-Forge IFD application. This method was used to avoid any discontinuities between the AR&R IFD and the CRC-Forge rainfall intensities.

From these IFDs, design rainfall depths were calculated for a range of ARIs and durations. The rainfall depth for each event was combined with Zone 3 AR&R temporal patterns.

Areal Reduction Factors (ARFs) were applied to point rainfall depths to convert them to catchment estimates. An ARF factor of between 0.81 and 0.85 was applied depending on the critical duration. The same approach was adopted for the 500 year ARI rainfall, to achieve a consistent approach. The ARF estimation followed the recommended approach set out in “Project 2, Collation and Review of Areal Reduction Factors from Applications of the CRC-Forge Method in Australia Final Report P2/S2/012”, AR&R April 2013.

Given the relatively small size of the local catchments in the rainfall-on-cell model area; areal reduction factors were not applied to the direct rainfall on the model area as it was considered that the unmodified point rainfall would be applicable to these small catchments. However, the upstream inflows from catchments outside the model area maintained the same areal reduction factor as the creek flooding model.

Table 5-10 shows the design rainfall depths and areal reduction factors adopted for Yarraman catchment.

Table 5-10: Yarraman catchment design rainfall depths and ARF

Duration	Design Rainfall (mm)								ARF
	2 year ARI	5year ARI	10 year ARI	20 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI	
1Hr	31.2	39.0	43.8	50.5	59.6	66.8	74.2	84.3	0.81
2Hrs	39.5	49.4	55.6	64.0	75.6	84.9	94.2	107.0	0.84
3Hrs	44.2	55.5	62.4	71.9	85.0	95.3	105.9	120.4	0.86
6Hrs	53.0	66.3	74.8	86.4	102.4	115.1	127.5	144.9	0.88
12Hrs	64.9	82.0	92.9	107.7	128.0	144.4	159.4	181.2	0.91

The losses for Yarraman were selected based on the Flood Frequency Analysis. It was found that using an initial loss of 28 mm and continuing loss of 3 mm gave the closest match between the RAFTS results and the Flood Frequency Analysis. **Table 5-11** shows the losses adopted for the Yarraman model.

Table 5-11 : Yarraman design losses

Land type	Loss type	Rainfall loss (mm)
Pervious	Initial	28
	Continuing	3
Impervious	Initial	0
	Continuing	0

PMP estimates were derived for the Yarraman catchment using the GSDM methodology. The parameters used in the PMP estimation are presented in **Table 5-12**.

Table 5-12: PMP parameters - Yarraman catchment

	Yarraman
Proportion rough	100%
Proportion smooth	0%
Moisture Adjustment Factor	0.83
Elevation Adjustment Factor	1

The calculated PMP depths for the Yarraman catchment are presented in **Table 5-13**.

Table 5-13: PMP depths –Yarraman

Duration (hours)		**1**	**2**	**3**	**4**	**5**	**6**
PMP depth (mm)	**Yarraman**	320	480	580	660	720	770

6. Design Event Flood Behaviour

6.1 Nobby

Design flood events from 2 year through to 500 year ARI have been modelled in this investigation. Flooding in Nobby from local runoff can be significant. Properties at the lower end of Commerford, Brodie and Murton Streets are the worst affected with depths of up to 2 metres in the modelled 10 year ARI flood. Limited dwellings are constructed in this area. However a significant number of vacant allotments created as part of historic subdivisions are inundated during frequent events.

The flooding extent does not alter significantly for events greater than 10 year ARI. However, the depth of flooding does increase.

Two main flow paths exist, both intersecting Commerford Street/ Mt Kent Boundary Road. These flow paths are considered to exhibit significant to extreme flood hazard. An additional three flow paths intersect the township, with flow traversing south of Commerford Street, near Free Street and between Norfolk Street and McGeever Street. These flow paths are considered low hazard in the modelled 100 year ARI flood event. It is considered that these flow paths could cause nuisance flooding to the residential properties located in these areas.

Because the hydraulic model for Nobby used rainfall on cell input boundaries, it was considered appropriate to check the flow at the downstream boundary against a Rational Method calculation for a selection of modelled flood events. **Table 6-1** shows the parameters used in the Rational Method calculations.

Table 6-1 Rational Method parameters

Parameter	Value
Catchment area (ha)	1082.9
C_{10}	0.49
I_{10} (mm/h)	45.0
C_{50}	0.56
I_{50} (mm/h)	59.8
C_{100}	0.59
I_{100} (mm/h)	65.8

Table 6-2 shows the comparison. The Rational Method is understood to generally overestimate flows from a catchment, so the difference is considered acceptable.

Table 6-2 Comparison of Rational Method and modelled flows at downstream boundary

Event	Rational Method flow (m^3/s)	Flow at downstream model boundary (m^3/s)	Difference
10 year ARI, 60 minute	66.4	48.9	26 %
50 year ARI, 60 minute	100.8	86.7	14 %
100 year ARI, 60 minute	116.9	106.8	8.6 %

6.2 Cooyar

The modelled 100 year ARI event has a similar extent to that of the 50 year ARI event.

The modelled 100 year ARI flood shows rapid rise in the creek with the first major breakout occurring to the north of the township through farmland. A breakout occurs on the northern and southern side of the Cooyar State Primary School before isolating the school buildings. This is important to note as the school is the most vulnerable to isolation, and once the school buildings are surrounded, persons may not be able to evacuate.

Modelling indicated that approximately two hours elapse from when flows start to increase in the level in Back Creek to the breakout starting to surround the school. Access to the school is cut half an hour after the break out of the creek occurs.

The modelled 100 year ARI flood identified that the dwellings along Munro Street are affected by moderate hazard flooding. It is also important to note that the creek alongside Cooyar State Primary School is affected by extreme hazard in the modelled 100 year ARI flood event. There appears to be an extreme hazard breakout flow to the east which isolates the school buildings.

The 500 year ARI modelled flood event inundates all properties between Cooyar Creek and Back Creek with approximately two metres of flood water. This creates a significant hazard for these properties.

6.3 Yarraman

As described in **Section 3** two hydraulic models were developed for Yarraman. An initial model was developed focusing on Yarraman Creek flooding (creek flooding model). This model was validated to the January 2011 event. A second rainfall-on-cell model was developed in order to better represent the overland flow paths in the study area. The performance of the Yarraman rainfall-on-cell model was confirmed by comparing results from this model with results from the validated creek flooding model using the 100 year ARI design event, as presented in **Table 6-3.**

Table 6-3 Comparison of rainfall-on-cell model and creek flooding model outputs (100 year ARI event)

Validation point	Validated creek flooding model (m AHD)	Rainfall-on-cell model (m AHD)	Difference (m)
1	430.85	430.95	0.10
2	436.43	436.46	0.03
3	436.37	436.39	0.02
4	441.06	441.04	-0.02
5	441.78	441.81	0.03
6	453.26	453.31	0.05
7	422.4	422.47	0.07

The rainfall-on-cell model was then used to determine the flood behaviour in Yarraman for the other design events.

The Yarraman township consists of urban residential and commercial properties localised around the intersection of the D'Aguilar Hwy and New England Highway. Yarraman Creek is fairly confined, with Barr-Smith Street being the point of confluence between the local and creek flooding.

The township is generally elevated above the Yarraman Creek floodplain. Significant overland flow paths exist between Davies St and the creek, down McDougall Street (which originates from Rosalie Drive), and down

George Street and Ann Street. Most overland flow through the town is classified as low hazard during a 100 year ARI event. However, John Street, Pine Street and the D'Aguilar Highway (where it crosses the creek) were all shown as being affected by extreme hazard flooding in the 100 year ARI flood event. Properties were inundated by low hazard floodwaters only. To the east of the town centre in the vicinity of Thomsett Street a breakout from the creek was identified that follows the street in the 100 year ARI flood event. The flood hazard identified in this area was identified as extreme.

Outside the town centre proper the rain-on-cell modelling identified a number of minor flowpaths throughout the modelled area. The majority of these flowpaths are in rural areas. To the south of the town centre in the vicinity of Doith and Smith Streets, for the 100 year ARI flood event, the flowpaths generally exhibited low hazard flooding conditions except in areas where farm dams had been constructed resulting in some incidents of significant hazard being identified.

Yarraman Creek has a confined floodplain and the flood extent does not alter greatly between the modelled flood events. In the 10 year ARI flood event, numerous properties are affected by shallow overland flow that is considered unlikely to cause nuisance. Some vacant allotments along the eastern end of Barr-Smith Street are inundated to depths of 1-1.5 metres. In addition, vacant allotments on McNeil Street, Thomsett Street and Noyes Street are affected in the modelled 10 year ARI event.

The most flood prone allotments are those bordered by Emmett Street, Barr-Smith Street and Park Drive. These properties are affected by flood water in excess of 1 metre in the modelled 100 year ARI event. The vacant allotments on McNeil Street, Thomsett Street and Noyes Street are also affected in the modelled 100 year ARI event with depths varying from 0.5 metres to 2.5 metres.

7. Sensitivity Assessment

The hydraulic modelling was assessed for sensitivity to flow (m^3/s) and land roughness values. As prescribed by the brief, +/- 30% flow, +/-30% increase in roughness and 50% blockage was applied to the 100 year ARI hydraulic models for Cooyar, Nobby and Yarraman (creek flooding model). The change in flood level was identified at each validation point. A summary of the results are shown below in **Table 7-1** to **Table 7-3**.

Table 7-1 : Sensitivity testing results - impacts on flood levels – Nobby

Validation point	30% increase in flow (m AHD)	30% decrease in flow (m AHD)	30% increase in roughness (m AHD)	30% decrease in roughness (m AHD)	50% blockage (m AHD)
15	474.90	474.60	474.80	474.70	474.75
16	482.72	Not Flooded	482.68	482.66	482.67

Table 7-2 : Sensitivity testing results - impacts on flood levels - Cooyar

Validation point	30% increase in flow (m AHD)	30% decrease in flow (m AHD)	30% increase in roughness (m AHD)	30% decrease in roughness (m AHD)	50% blockage (m AHD)
6	436.40	Not flooded	436.26	435.99	436.75
7	436.48	Not flooded	436.35	436.07	437.22
8	436.58	Not flooded	436.45	436.08	437.00
9	435.75	435.75	435.75	435.75	435.75

Table 7-3 : Sensitivity testing results - impacts on flood levels - Yarraman

Validation point	30% increase in flow (m AHD)	30% decrease in flow (m AHD)	30% increase in roughness (m AHD)	30% decrease in roughness (m AHD)	50% blockage (m AHD)
1	431.19	430.45	431.05	430.64	430.85
2	436.69	436.01	436.59	436.2	436.43
3	436.64	435.96	436.54	436.15	436.38
4	441.08	441.03	441.08	441.03	441.06
5	441.79	441.76	441.79	441.76	441.78
6	453.54	452.89	453.41	453.11	453.25
7	422.44	422.22	422.70	422.10	422.83

The sensitivity analysis concluded that the Yarraman and Cooyar models were both most sensitive to flow, with increases in flow directly relating to increases in observed flood levels. All models were generally insensitive to changes in Manning's n. The sensitivity analysis concluded that the Yarraman and Nobby models were generally insensitive to blockages. The sensitivity analysis found that the Cooyar model was moderately sensitive to blockages. However, the resulting change in flood extent, illustrated in **Appendix F**, is generally located outside of developed areas.

8. Climate Change Modelling

Three climate change scenarios were applied to the 1 in 100, 1 in 200 and 500 year ARI design events to investigate the potential impacts of climate change. The scenarios considered were as follows:

- Year 2050 – 10% increase in rainfall (CC1)
- Year 2070 – 15% increase in rainfall (CC2)
- Year 2100 – 20% increase in rainfall (CC3)

The following sections discuss the results of this modelling. The reporting nodes at which the impacts on flood levels were determined are shown in **Figure 8-1** to **Figure 8-3**.

8.1 Nobby

The climate change scenarios for Nobby did not significantly impact flood behaviour beyond the relatively small increases in flood levels that would be expected with the increase in rainfall. Some properties on Davenport Street that were already flooded or on the edge of the flood extent were shown to experience increased flooding in the climate change scenarios. A summary of the impact of climate change on 100 year ARI flood levels taken at five reporting nodes throughout the model area are given below in **Table 8-1.**

Table 8-1: Climate Change impacts on 100 year ARI flood levels - Nobby.

Location	100 year ARI Base Case (m AHD)	100 year ARI CC1 (m AHD)	100 year ARI CC2 (m AHD)	100 year ARI CC3 (m AHD)
1	466.82	466.87	466.89	466.91
2	482.72	482.75	482.76	482.78
3	466.34	466.36	466.37	466.38
4	474.63	474.67	474.69	474.71
5	478.45	478.49	478.49	478.49

8.2 Cooyar

The climate change scenarios for Cooyar had some impact on flood behaviour, particularly in the larger events. The width of the flowpath through farmland to the west of the town increased quite significantly in the 500 year climate change events. However, the flood extent through the town centre remained relatively unchanged. The Evacuation Centre and Police Station remained dry in all modelled climate change events. The flood extent downstream of the town widened, but no additional residences were inundated. A summary of the impact of climate change on 100 year ARI flood levels taken at three reporting nodes throughout the model area are given below in **Table 8-2.**

Table 8-2: Climate Change impacts on 100 year ARI flood levels - Cooyar.

Location	100 year ARI Base Case (m AHD)	100 year ARI CC1 (m AHD)	100 year ARI CC2 (m AHD)	100 year ARI CC3 (m AHD)
1	436.27	436.49	436.58	436.67
2	435.19	435.53	435.77	435.99
3	432.5	432.72	432.83	432.92

8.3 Yarraman

The climate change scenarios for Yarraman, tested in the creek flooding model, did not significantly impact flood behaviour beyond the increases in flood levels that would be expected with the increase in rainfall. The flood extent through the town remained similar. The impact of climate change was greater in the main channel than the overland flowpaths and the larger flood events showed a greater change in flood extent. A summary of the impact of climate change on 100 year ARI flood levels taken at three reporting nodes based on the creek flooding model are given below in **Table 8-3**.

Table 8-3: Climate Change impacts on 100 year ARI flood levels - Yarraman.

Location	100 year ARI Base Case (m AHD)	100 year ARI CC1 (m AHD)	100 year ARI CC2 (m AHD)	100 year ARI CC3 (m AHD)
1	441.77	441.78	441.79	441.79
2	436.4	436.54	436.63	436.72
3	431.61	431.83	431.94	432.04

1:18,000 (at A3)

0 125 250 500

Meters

GDA 1994 MGA Zone 56

Legend

- Reporting Nodes
- Creeks
- Hydraulic Model Extent
- Cadastre
- Railway
- Roads

Disclaimer: The flood information contained in the maps is based on debris lines and marks that were visible and accessible at the time of recording after the January 2011 flood extent and may not be accurate or complete and reliance should not be placed on it. Toowoomba Regional Council makes no representations or warranties about the accuracy, reliability, completeness or suitability for any particular purpose and disclaim all responsibility and all liability whether in contract, negligence or otherwise for all expenses, losses, damages (including indirect or consequential damage) and costs which may be incurred in any way and for any reason as a result of the flood information contained in the maps being inaccurate or incomplete.

FIGURE 8 - 1
NOBBY
REPORTING NODE LOCATIONS

Disclaimer: Whilst all due care has been taken in the preparation of the plan and all information (the Plan and all information is referred to as "Plan information"), the accuracy of the Plan Information cannot be guaranteed. The Plan Information is provided as a guide and should not be relied upon in anyway whatsoever. Toowoomba Regional Council takes no responsibility for inaccuracies in the Plan Information and is not liable under any circumstances for any loss or damage whatsoever or howsoever caused arising directly or indirectly in connection with its use. The recipient must verify the Plan Information on site. Please refer any discrepancies to Toowoomba Regional Council - Information, Communications & Technology. No part of the Plan Information should be reproduced without the permission of the Coordinator GIS - ICT Branch, or other delegated representative of Council (131872).

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Date Saved: 15/05/2014

1:2,500 (at A3)

0 25 50 100

Meters

GDA 1994 MGA Zone 56

Legend

Reporting Nodes
Creeks
Roads
Railway
Cadastre

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FIGURE 8 -2
COOYAR
REPORTING LOCATION NODES

Disclaimer: Whilst all due care has been taken in the preparation of the plan and all information (the Plan and all information is referred to as "Plan information"), the accuracy of the Plan Information cannot be guaranteed. The Plan Information is provided as a guide and should not be relied upon in anyway whatsoever. Toowoomba Regional Council takes no responsibility for inaccuracies in the Plan Information and is not liable under any circumstances for any loss or damage whatsoever or howsoever caused arising directly or indirectly in connection with its use. The recipient must verify the Plan Information on site. Please refer any discrepancies to Toowoomba Regional Council - Information, Communications & Technology. No part of the Plan Information should be reproduced without the permission of the Coordinator GIS - ICT Branch, or other delegated representative of Council (131872).

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Date Saved: 8/07/2014

1:8,447 (at A3)

0 65 130 260
Meters

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Reporting Nodes
- Hydraulic Model Extent
- Model Boundaries
- Cadastre
- Creeks
- Roads
- Railway

Disclaimer: The flood information contained in the maps is based on debris lines and marks that were visible and accessible at the time f recording after the January 2011 flood extent and may not be accurate or complete and reliance should not be placed on it. Toowoomba Regional Council makes no representations or warranties about the accuracy, reliability, completeness or suitability for any particular purpose and disclaim all responsibility and all liability whether in contract, negligence or otherwise for all expenses, losses, damages (including indirect or consequential damage) and costs which may be incurred in any way and for any reason as a result of the flood information contained in the maps being inaccurate or incomplete.

FIGURE 8 - 3
YARRAMAN
REPORTING NODE LOCATIONS

Disclaimer: Whilst all due care has been taken in the preparation of the plan and all information (the Plan and all information is referred to as "Plan information"), the accuracy of the Plan Information cannot be guaranteed. The Plan Information is provided as a guide and should not be relied upon in anyway whatsoever. Toowoomba Regional Council takes no responsibility for inaccuracies in the Plan Information and is not liable under any circumstances for any loss or damage whatsoever or howsoever caused arising directly or indirectly in connection with its use. The recipient must verify the Plan Information on site. Please refer any discrepancies to Toowoomba Regional Council - Information, Communications & Technology. No part of the Plan Information should be reproduced without the permission of the Coordinator GIS - ICT Branch, or other delegated representative of Council (131872).

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Date Saved: 15/05/2014

9. Developed Case Modelling

9.1 Nobby

The file provided by TRC titled *Broad_Hectare_Study_Urban* was used to identify potential development areas in Nobby. Seven polygons with a total area of approximately 16 hectares were assigned as development precincts. A comparison of the developed areas evident on the aerial photography used to define land use in the existing case scenario and the potential development polygons identified that 67% of the potential development area had been utilised. As such an additional area of 5.3 hectares was identified as future development.

The Mannings *n* in the hydraulic model was changed from 0.04 to 0.2 in the areas that were previously modelled as crops/pasture but identified as future development areas. A comparison of flood levels for the base case and developed case for the 100 year ARI event, at the reporting nodes illustrated on **Figure 8-1,** are shown in **Table 9-1**.

Table 9-1: Developed Case impacts on 100 year ARI flood levels - Nobby.

Location	100 year ARI Base Case (m AHD)	100 year ARI Developed Case (m AHD)
1	466.82	466.82
2	482.72	482.72
3	466.34	466.34
4	474.63	474.63
5	478.45	478.45

The results presented in the table illustrate that the proposed future development will not impact 100 year ARI flood levels.

9.2 Cooyar

The file provided by TRC titled *Broad_Hectare_Study_Urban* was also used to identify potential development areas in Cooyar. A comparison of the developed areas evident on the aerial photography used to define land use in the existing case scenario and the potential development areas identified in the *Broad_Hectare_Study_Urban* file identified that there was no additional future development precincts within the Cooyar model area.

9.3 Yarraman

The file provided by TRC titled *Broad_Hectare_Study_Urban* was used to identify potential development areas in Yarraman. The main areas of future development include an area of approximately 9.7ha along the D'Aguilar Highway (south of Yarraman Creek), and an accumulative of 3ha along Barr-Smith Street, John Street and Jane Street.

Five polygons with a total area of approximately 12.6 hectares were assigned as development precincts. A comparison of the developed areas evident on the aerial photography used to define land use in the existing case scenario and the potential development polygons identified that only 9% of the potential development area had been utilised. As such an additional area of 11.5 hectares was identified as future development. The majority of this area is located to the south west of the town centre outside the Yarraman Creek floodplain bounded by the D'Aguilar Highway to the south-west and the rear of rural residential blocks fronting Doith Street and Park Drive to the north-east.

The Mannings *n* and Impervious Fraction in the XP-RAFTS model were changed from the crops/pasture values (Mannings *n* = 0.04, Impervious Fraction = 0) to the urban values (Mannings *n* = 0.2, Impervious Fraction = 0.4).

The Mannings *n* in the hydraulic model was changed from 0.04 to 0.2 in the areas that were previously modelled as crops/pasture but identified as future development areas. A comparison of flood levels for the base case and developed case for the 100 year ARI event (creek flooding model), at the reporting nodes illustrated on **Figure 8-3,** are shown in **Table 9-2**.

Table 9-2: Developed Case impacts on 100 year ARI flood levels Yarraman.

Location	100 year ARI Base Case (m AHD)	100 year ARI Developed Case (m AHD)
1	441.77	441.77
2	436.40	436.33
3	431.61	431.62

The results presented in the table illustrate that the proposed future development will result in a small reduction in levels associated with Yarraman Creek just upstream of the D'Aguilar Highway (point 2) and a small increase in levels just upstream of Barr-Smith Street.

The slight changes in flood levels are due to the decrease in pervious area and increase in Manning's *n* modelled in areas proposed for future development. These changes can increase flood levels due to the higher Manning's *n* and larger flows resulting from an increase in impervious area. However, peak flood levels can also be reduced by these changes if the timing of flows is affected and the runoff peaks from different catchments become less coincident. This is expected to be the case at point 2.

The rainfall-on-cell modelling identified a potential overland flow path through the D'Aguilar Highway block draining north towards Park Drive. In the 100 year ARI event flow depths of the order of 100mm to 200mm were identified across the block. It is suggested that any development of this block needs to consider how this flow is managed through the site and also how the development of the block may affect flooding characteristics downstream of the site.

10. Isolation and Evacuation Assessment

10.1 Nobby

The township of Nobby is located on undulating land. Although the township is located above the floodplain of major creeks and river systems, the township is affected by overland flow and flooding of smaller gully systems.

Within the study area, modelling has shown that some township residential allotments are affected by overland flow paths or contain local gullies which convey flow at depth and with velocity. The Rural Fire Brigade is the only emergency service provided in Nobby and is not affected by overland flow.

Although some properties are affected by overland flow within Nobby, most of these allotments are currently vacant. Of those dwellings which are currently affected, evacuation of the allotment to higher ground could occur as adjacent roadways or allotments are not affected by flood.

Nobby itself may become isolated from other townships due to flooding of the Condamine River and Kings Creek. The extent of this flooding was not investigated as part of this study. Clifton is the nearest town centre with additional emergency services. However flooding of Kings Creek may prevent passage to the township.

10.2 Cooyar

The township of Cooyar is located at the confluence of Back Creek and Cooyar Creek. Most of the township is located on elevated land. However, residential allotments in the centre of town located between the two creek systems are at a significant flood risk.

Flooding in Cooyar is dominated by Cooyar, and Back Creeks, within a fairly well defined floodplain. Several houses and businesses are located within the floodplain and subject to flooding. Dwellings along Munro Street, McDougall and the Cooyar State Primary School are the most vulnerable.

In the 50 year ARI flood or larger event, a breakout flow to the east of the school isolates the school buildings. This is important to note, as the floodwater circles the school buildings before inundating the whole site as the floodwaters rise further. This needs to be noted for evacuation planning as the school is the most vulnerable and isolated portion of the Cooyar township.

Properties along New England Highway are also significantly affected. Evacuation of these properties can occur as depths increase from the rear of the property with New England Highway having less depth. Easy access can occur to the Evacuation Centre. Some properties which are located near the Cooyar Pub and memorial hall are affected by greater depths and would need to evacuate prior to the flood significantly inundating their property.

Cooyar becomes isolated as Back Creek and Cooyar Creek inundate the New England Highway, preventing traffic movements to neighbouring centres. In addition, flooding of McDougall Street bridge can also isolate a number of residential properties and the Police Station.

The Evacuation Hall and Police Station are not inundated for events up to the 500 year ARI event. However, the Rural Fire Brigade is affected by events 5 year ARI and rarer.

10.3 Yarraman

The township of Yarraman is located on undulating land. Although a majority of the township is located above the floodplain of Yarraman Creek, the township is affected by overland flow and flooding of smaller gully systems.

Within the study area, modelling has shown that some township residential allotments are affected by overland flow paths. The evacuation hall, SES facility and the ambulance station sites are affected by overland flow during a 10 year ARI event.

Properties located on the northern side of Barr-Smith Street may be affected by overland flow that may cause damage to property. However, as the flood hazard is low on most properties even in a PMP event, limited evacuation may be required. Some properties north of the evacuation centre may experience significant flood hazard in very rare events. Care should still be taken at properties classified as experiencing low flood hazard, as localised effects of flow traversing around structures may create unsafe situations where people could be washed off their feet.

The areas south of Barr-Smith Street that are affected by Yarraman Creek flooding are subjected to significant to extreme flood hazard. A number of residential properties located on the floodplain to the east of the D'Aguilar Highway and in the Thomsett Street area are impacted. These properties are located within hazardous flow areas and evacuation of these properties would need to occur during an event. As the critical duration of the creek is approximately 3 hours, evacuation would need to occur early in the event.

No notable 'islands' surrounded by flooding of a significant depth were identified in the township. However, due to significant road flooding that is hazardous in some locations, access is likely to be an issue for some residents during flood events. It is not thought that this will result in significant risk to residents as the duration of flooding in Yarraman is likely to be short. This means that access issues will only be experienced over a short period of time.

Yarraman is divided into two as Yarraman Creek floods and cuts the D'Aguilar Highway. The closest major centre to Yarraman is Nanango which is located within South Burnett Shire. Council may wish to speak to South Burnett Regional Council in regard to utilising emergency resources during an event.

11. Flood Hazard and Flood Category Mapping Methodology

11.1 Flood Hazard Mapping

The flood hazard criteria used in the flood hazard maps is based on Schedule 4 on page 45 in the Queensland Reconstruction Authority's *Planning for stronger, more resilient floodplains Part 2 – Measures to support floodplain management in future planning schemes*.

(see http://www.qldreconstruction.org.au/u/lib/cms2/resilient-floodplains-part2-full.pdf).

The flood hazard criteria has been prepared for use in preparing flood investigations (level 2), and planning evaluations based on latest available engineering guidance. In the absence of other more appropriate flood hazard definitions, the criteria below may be used.

The basis of the flood hazard criterion is the relationship between flood depth and flood velocity. The depth of flow is multiplied by the velocity of the flood flow and is used to understand how hazardous the flow is to life and property. For instance, flood water which is 1.5 metres deep, with a very small velocity may be less hazardous than a flow at 0.5 metres with a high velocity which could sweep persons off their feet.

The "Low Hazard" category was mainly based on the *ARR Revision Project 10: Appropriate Safety Criteria for People Stage 1 Report*. A proper understanding of what is meant by Low Hazard can be gained by reviewing these reports. For example, it is noted in the *ARR Revision Project 10: Appropriate Safety Criteria for People* that for the Low Hazard category -

> '*Stability uncompromised for persons within laboratory test program at these flows (to maximum flow depth of 0.5 m for children and 1.2 m for adults and a maximum velocity of 3.0 ms-1 at shallow depths).*'

It is further noted that 'loss of stability could occur in lower flows when adverse conditions are encountered including:

- **Bottom conditions**: uneven, slippery, obstacles;
- **Flow conditions**: floating debris, low temperature, poor visibility, unsteady and flow aeration;
- **Human subject**: standing or moving, experience and training, clothing and footwear, physical attributes additional to height and mass including muscular development and/or disability, psychological factors;
- **Others**: strong wind, poor lighting, definition of stability limit (i.e. felling unsafe or complete loss of footing).'

There are also caveats on the criteria for stability of vehicles. It should be noted that the low flow criteria applies to large 4WD vehicles. Small passenger vehicles may not be safe in this category.

It should be noted that the QldRA flood hazard criteria are only interim guidelines and local authorities may wish to use a different criteria based on local experience. One alternative is given in Appendix J of *Floodplain Management in Australia: best practice principles and guidelines SCARM Report 73*

(see http://www.publish.csiro.au/Books/download.cfm?ID=2260).

The mapping outputs of this study are found in, **Appendix E**, **Appendix F and Appendix G** of this report.

11.2 Hydraulic Category Mapping

As outlined in Section 3 (Mapping requirements and standards) of the project brief, hydraulic category mapping is required to be carried out for each township.

The parameters which define floodway, flood storage and flood fringe are provided below.

- Floodway
  - Velocity-depth product > 0.5 m^2/s or
  - Velocity ≥ 1 m/s
- Flood storage
  - Velocity-depth product < 0.5 m^2/s and
  - Depth ≥ 0.5 m
- Flood fringe
  - Velocity-depth product < 0.5 m^2/s and
  - Depth ≤ 0.5 m

It should be noted that where small areas of flood storage are completely surrounded by a large area of floodway, the flood storage was redefined as floodway and vice versa. In addition, in locations where the category area is small (less than 1 km^2), it was integrated into the nearby category.

12. Conclusions

The overland flow path study for Nobby provides a representation of the flood behaviour of overland flow paths that resulted in significant flooding in the January 2011 event. The modelling of the historic event was generally validated to within 300 mm of the observed flood levels identified by residents of Nobby, with the largest differences thought to be due to the local effects of buildings and fences. This performance is considered to be appropriate given the uncertainty associated with the model inputs. Importantly, the models are generally consistent with the flood behaviour described by the Nobby residents. The modelling is therefore considered to provide an appropriate basis for a flood overlay code for Council's Planning Scheme and floodplain risk management.

The model simulating creek flooding in Yarraman showed good model correlation (generally within 300 mm) to the validation levels collected as part of this study and of the order of 500mm to validation levels collected by TRC in 2011, with some discrepancies believed to result from localised effects of structures and the reliability of survey method employed in 2011. The uncertain reliability of data captured by TRC in 2011 meant that it was difficult to improve the validation of the model using this data. The flood behaviour shown by the Yarraman creek flooding model is generally consistent with the experiences of residents in 2011. The Yarraman rainfall-on-cell model provided a more detailed depiction of overland flow paths within the model area. The results of the rainfall-on-cell model were found to be consistent with those of the creek flooding model.

If not in place already it is suggested that TRC establish clear protocols around the capture of flood extents and flood levels to improve the reliability of future captured data. These protocols should consider elements such as consistent control of the survey exercise, confirmation of flood marks at least by experienced hydraulic modellers/engineers or through consultation with residents, photographs of flood marks, identification of the level of confidence associated with the flood mark, and the capture of flood depth as well as levels and extents.

The Cooyar model results provide an appropriate representation of the 1988 flood, with levels validated to within 0.2 to 0.7 m of the observed flood levels and flood behaviour generally consistent with recollections of the Cooyar residents. It is therefore considered that the model assumptions required to assess the design events are appropriate.

It is considered that Cooyar has the highest flood risk to existing properties. The isolation and flood behaviour surrounding the school should be investigated in future flood risk management studies.

Both Nobby and Yarraman have a significant number of vacant allotments which are presumably a result of historical subdivisions. Many of these allotments are flood prone and adequate building controls should be exercised in these areas to prevent persons to be affected by unacceptable levels of flood risk.

Nobby, Yarraman and Cooyar catchments are all responsive catchments with critical durations of up to 3 hours. It is therefore considered that appropriate disaster management measures should be investigated in the flood risk management phase to improve each community's resilience to flood events.

13. References

- Sinclair Knight Merz, 2013, *Toowoomba Flood Scoping Study.*
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- *2D Flood Study for Westbrook Creek Toowoomba.* (WRM/DHI, 2013)
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- Insurance Council of Australia, 2011, *The Nature and Causes of Flooding in Toowoomba – 10 January 2011*, http://www.insurancecouncil.com.au/assets/report/toowoomba%20hydrology%20report.pdf

Appendix A. Hydrologic Analysis

Appendix B. QRA Flood Frequency Information

The following information was provided by QRA for Cooyar. No report accompanied the excel spreadsheet of data. The data has been summarized below.

Cooyar Town Design Flood Estimates

Annual Exceedence Probability (%)	Peak Discharge - Total (cumecs)	Peak Discharge - Cooyar Ck (cumecs)	Peak Discharge - Logyard and Back Ck (cumecs)
10	NA	NA	NA
5	407	191	217
2	649	304	345
1	853	399	454
0.5	1069	500	569
0.2	1400	655	745

Note - Use this data with extreme caution and use in conjunction with the report:

1 These estimates of flows and levels could change as a result of more detailed flood modelling and/or measurements during higher flood events.

2 Scaled flows at NRM gauge 143015B by factor of 0.36

3 The flood event of 1988 has an estimated AEP of 0.2 %.

Cooyar Flood Frequency Analysis NRM Gauge Station 143015B

Annual Exceedence Probability (%)	Peak Discharge (cumecs)	Monte Carlo 90% quantile probability limits		Peak Level (m Gauge Datum)	Peak Level (m AHD)
10	730	480	1200	6.2	167.3
5	1100	730	2000	7.3	168.3
2	1800	1100	3800	9.0	170.0
1	2400	1400	5800	10.2	171.3
0.5	3000	1600	8500	>10.7	>171.7
0.2	3900	2000	13000	>10.7	>171.7

Within gauged values

Based on theoretical data ie extrapolated rating curve

BoM Gauge Station 540044

BoM Flood Classification Level Minor (5 m) Moderate (6.5 m) Major (8 m)
Minor
Moderate
Major
Major
Major
Major

BoM gauge Zero 158.88 m STATE

12.2 km AMTD BOM Gauge, 13.3km AMTD NRM Gauge

Note - Use this data with extreme caution and use in conjunction with the report:

1 These estimates of flows and levels could change as a result of more detailed flood modelling and/or measurements during higher flood events.

2 The levels only apply at the location of the gauging station

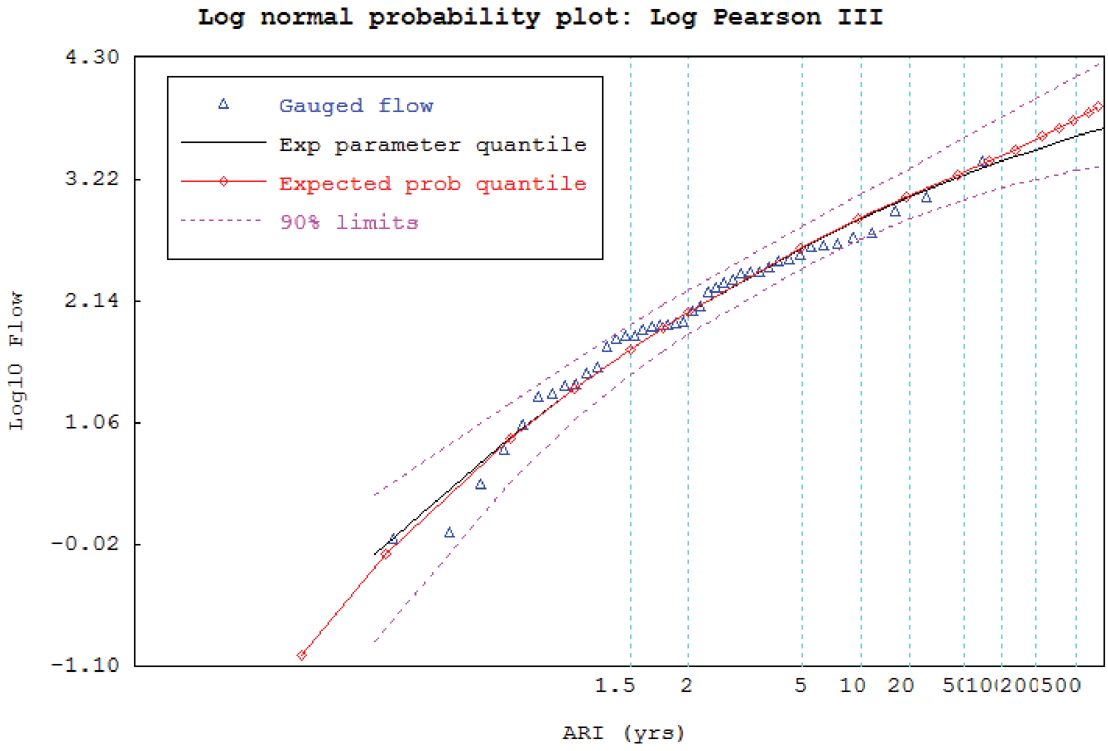
3 The highest gauging was 185 cumecs, so flows exceeding 185 cumecs were estimated using an extrapolated rating curve.

4 Peak Levels are to the gauge datum Gauge Zero at 161.03 m AHD

5 The flood event of 2011 has an estimated AEP of 1.0%.

Annual Exceedence Probability (%)	Peak Discharge (cumecs)	Monte Carlo 90% quantile probability limits		Peak Level (m Gauge Datum)		New ARR using tc	New ARR Using 2I50	Rational	Palmen & Weeks	FFA by Area	FFA by Area^0.7
10	731	480	1199	6.2							206
5	1140	727	2043	7.3		482	246	576	320	187	322
2	1794	1085	3796	9.0		836	417	733	474	294	506
1	2365	1361	5756	10.2		1267	606	812	604	388	667
0.5	2993	1629	8464	>10.7							844
0.2	3894	1953	13256	>10.7							1099

FLIKE FFA Results			
Annual Exceedence Probability (1 in Y years)	Peak Discharge (ML/day)	Monte Carlo 90% quantile probability limits	
10	63143	41446	103588
20	98480	62813	176483
50	155030	93776	327986
100	204369	117594	497335
200	258565	140718	731257
500	336447	168719	1145358
1000	399187	187638	1573582



The following information was provided by QRA for Nobby. No report accompanied the excel spreadsheet of data. The data has been summarized below.

Note Catchment Area aprox 8 km2 compared with 516 km2 at 422334A

Nobby Design Flood Estimates

Annual Exceedence Probability (%)	Peak Discharge (cumecs) A	Peak Discharge (cumecs) B	Peak Discharge (cumecs) C	Peak Discharge (cumecs) D
10	NA	NA	NA	NA
5	16	19	10	6
2	26	30	16	9
1	35	42	22	13
0.5	46	54	29	17
0.2	60	71	38	22

Note - Use this data with extreme caution and use in conjunction with the report:

1 These estimates of flows and levels could change as a result of more detailed flood modelling and/or measurements during higher flood events.

2 Flows estimated by Regional Method (Palmen and Weeks ,2011)

3 The flood event of 2011 has an estimated AEP of 1.3%.

Flood Frequency Analysis NRM G/stn 422334a

Annual Exceedence Probability (%)	Peak Discharge (cumecs)	Monte Carlo 90% quantile probability limits		Peak Level (m Gauge Datum)	Peak Level (m AHD)	BoM Flood Classification Level Minor (4 m) Moderate (4.5 m) Major (5 m)
10	440	310	640	6.9	428.7	Major
5	640	440	1100	7.6	429.4	Major
2	930	590	2000	8.3	430.1	Major
1	1200	680	3100	>8.49	>430.3	Major
0.5	1400	760	4600	>8.49	>430.3	Major
0.2	1800	840	7500	>8.49	>430.3	Major

BoM G/stn 041518

Within gauged values

Based on theoretical data ie extrapolated rating curve

BoM gauge Zero
421.787m AHD
at 18.5 km AMTD

Note - Use this data with extreme caution -:

1 The highest gauging was 110.4 cumecs, so flows exceeding 110.4 cumecs were estimated using an extrapolated rating curve.

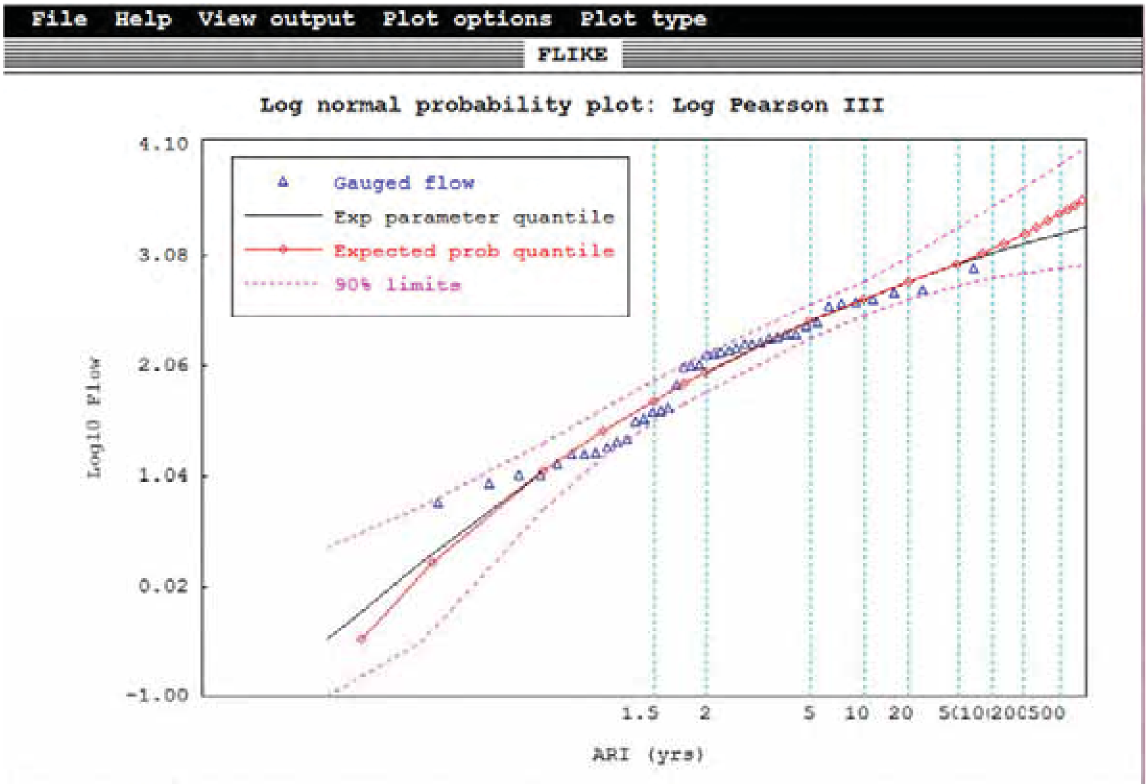
2 These estimates of flows and levels could change as a result of more detailed flood modelling and/or measurements during higher flood events.

3 Peak Levels are to the gauge datum Gauge Zero at 421.8m AHD

4 The levels only apply at the location of the gauging station

The flood event of 2011 has an estimated AEP of 1.3%.

Catchment	Catchment	Method	Peak Flow (m^3/s)			t_c
			20 year ARI	50 year AR	100 year ARI	
1a	Nobby - Sub Area A	Palmen ar	15.9	25.9	35.4	1.1
		New ARR	46	86	124	
		New ARR	4.5	10.2	18.3	
1b	Nobby - Sub Area B	Palmen ar	18.7	30.4	41.5	1.2
		New ARR	49	87	130	
		New ARR	5.7	12.7	22.6	
1c	Nobby - Sub Area C	Palmen ar	9.7	16.1	22.2	0.9
		New ARR	26	49	76	
		New ARR	2.2	5.3	9.8	
1d	Nobby - Sub Area D	Palmen ar	5.5	9.2	12.9	0.6
		New ARR	14	27	41	
		New ARR	1	2.4	4.7	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Log normal probability plot: Log Pearson III
Gauged flow
Exp parameter quantile
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Log10 Flow
1.5
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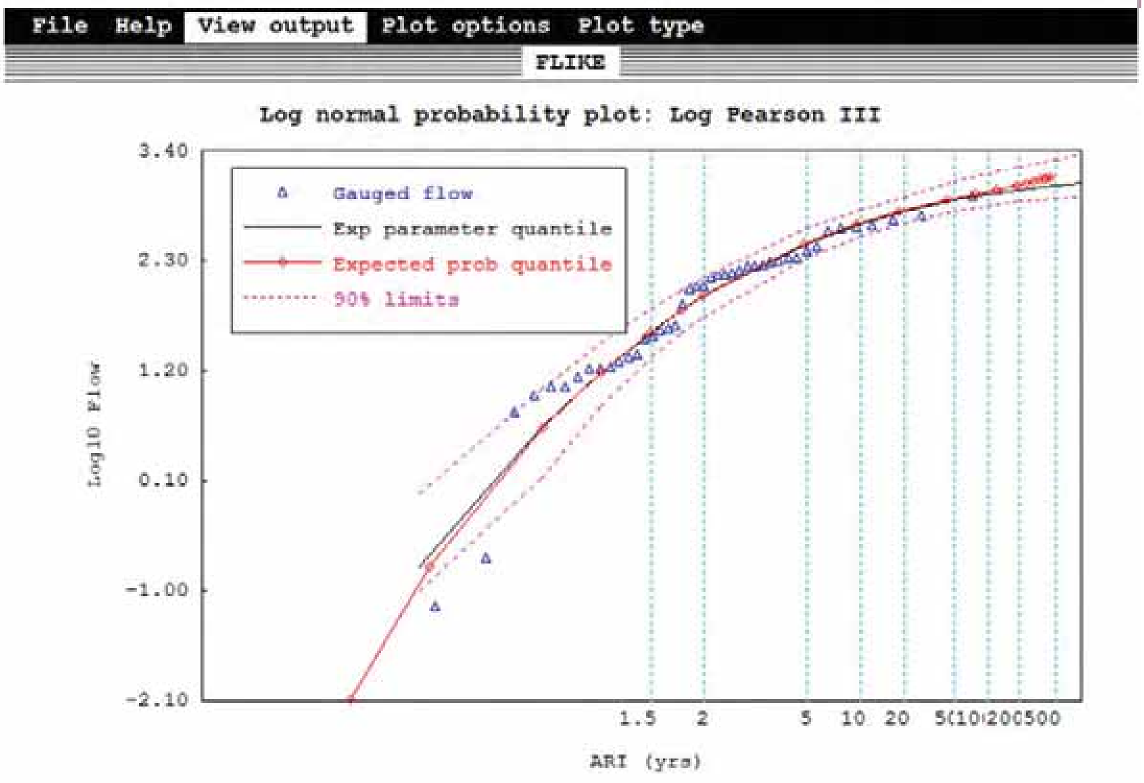
ARI (yrs)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Log10 Flow
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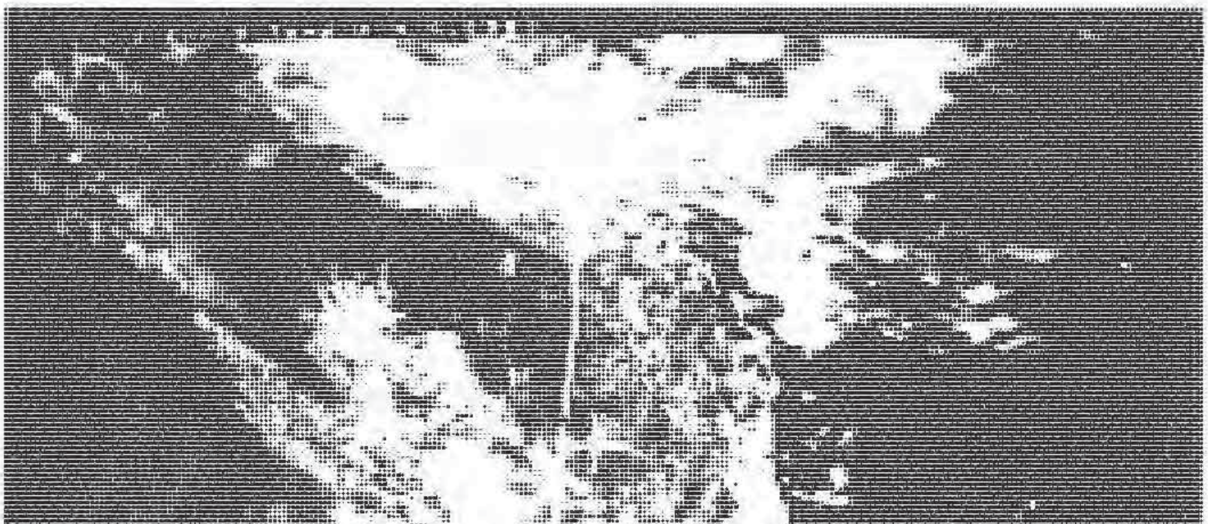
ARI (yrs)

Appendix C. Cooyar Flood Report (BoM)

BUREAU OF METEOROLOGY
DEPARTMENT OF THE ARTS, SPORT,
THE ENVIRONMENT, TOURISM AND TERRITORIES

REPORT ON THE COOYAR FLASH FLOOD

FEBRUARY 1988



October 1990

Published by the Bureau of Meteorology 1990

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CONTENTS

APPENDIXES

TABLES

FIGURES

FIGURES (contd)

THE COOYAR FLASH FLOOD OF FEBRUARY 1988

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Severe Weather Section
Brisbane Regional Office

ABSTRACT

Within the constraints of the available data, an investigation was conducted into meteorological aspects of a flash flood event which devastated the village of Cooyar, some 130 kilometres west-northwest of Brisbane. The event occurred around 1400 UTC 12 February 1988 (midnight local time). Torrential thunderstorm rain fell in the catchment area above the village in the 4 or so hours before midnight.

The aim of the study was to document meteorological conditions surrounding the event and attempt to identify possible focussing mechanisms which concentrated such exceptionally high rainfall in a relatively small area. At the time several features generally associated with flash flood events were in evidence. To complete the analysis, rainfall data was examined from both a spatial and temporal perspective.

INTRODUCTION

During the late evening of 12 February 1988, thunderstorm activity brought torrential rain to the Cooyar Creek catchment. This deluge caused rapid rises in the Cooyar, Logyard and Back Creeks which merge behind the village of Cooyar. Water to a depth of 2 metres is reported to have swept through Cooyar around midnight destroying at least 3 houses, the local shop and the town hall. One person was confirmed drowned while another is presumed drowned. Shortly after the event, the Queensland State Government declared Cooyar a disaster area. Some appreciation of the damage wrought by the surge of water can be obtained from the various scenes in Fig. 1.

Figure 2 is a location map showing Cooyar, elevation contours and place names used in the text. The Cooyar Creek catchment is situated in the northwest corner of the Brisbane River catchment and is bounded by the Main Divide to the west, by the Cooyar Range to the northwest and by the Blackbutt Range to the southeast. The catchment area is approximately 156 square kilometres.

Rainfall isohyets for the 24-hour period from 2200 UTC 11 February to 2200 UTC 12 February 1988 are displayed in Fig. 3. The highest verifiable totals were 249 mm and 246 mm at 2 recording sites on 'Vincentvale' station. 'Trevanna' station which is nearby registered 240 mm. Between 8 pm and midnight (local time) the rainfall was observed by local residents to be at its most intense.

In this paper, the synoptic-scale evolution surrounding the event is described together with commentary on atmospheric stability. Further, the role of satellite and radar imagery in monitoring development is discussed. Vertical motion and the sub-synoptic scale environment are then examined in some detail. Features common to flash floods are later identified and parallels drawn with the Cooyar event.

Fig. 1(a) Cooyar destruction.

Fig. 1(b) Damaged house Cooyar.

Fig. 1(c) Demolished house, Cooyar.

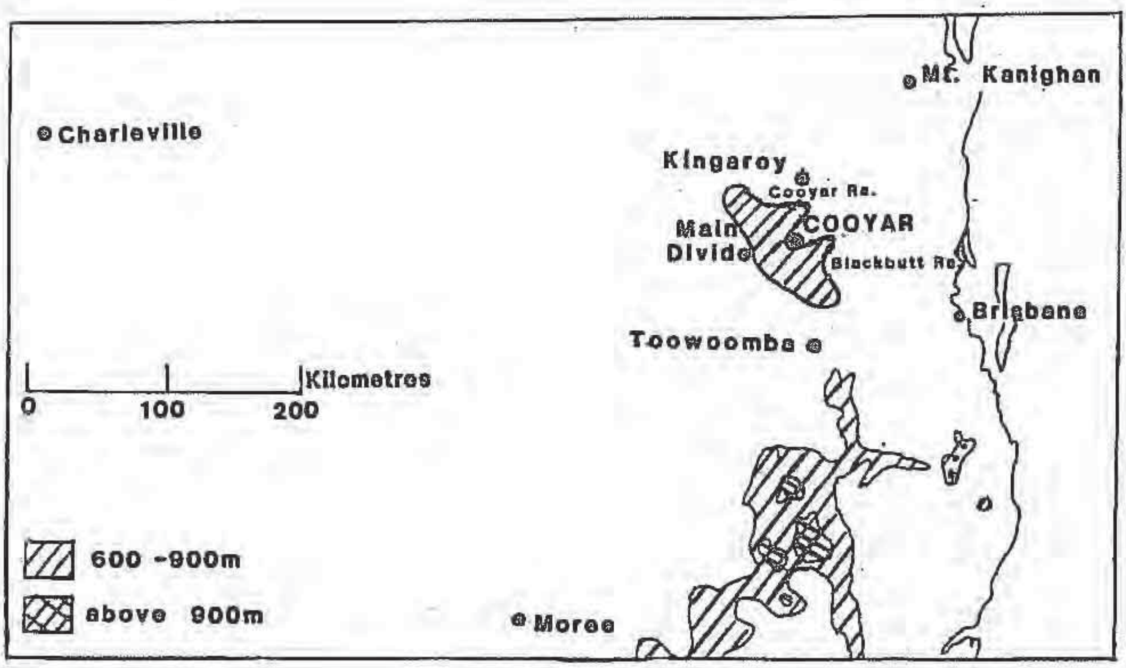


Fig. 2 Location map.

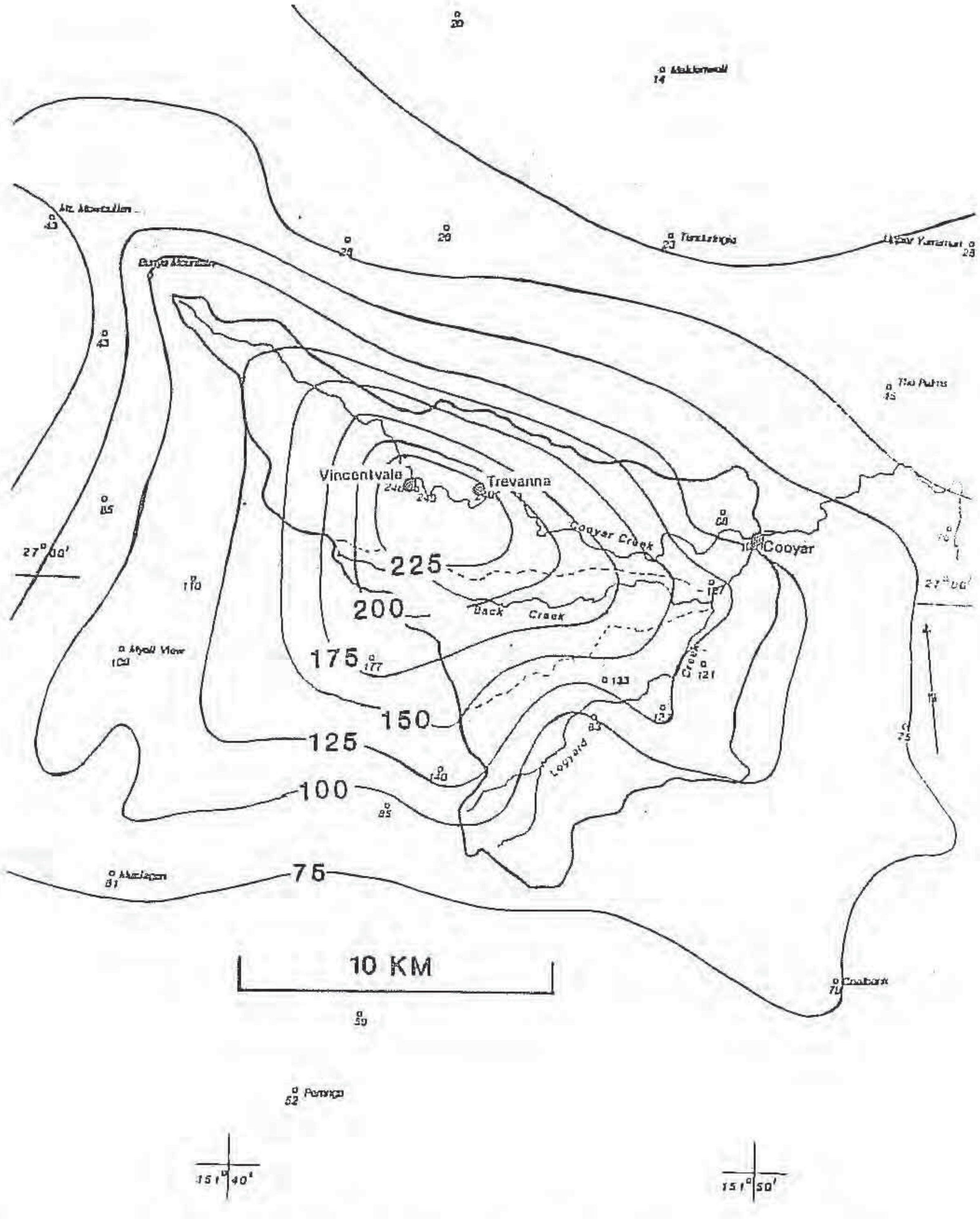


Fig. 3 Rainfall isohyets for period 2200 UTC 11 February 1988 to 2200 UTC 12 February 1988 (millimetres).

Results from a 'Probable Maximum Precipitation' analysis for the catchment are provided and a 'Design Rainfall Intensity' display interpreted. Lastly and in brief, the performance of the Bureau's operational Finest model at that time is evaluated.

SYNOPTIC-SCALE CONSIDERATIONS

In Fig. 4 a sequence of mean sea level (MSL) analyses is presented with superimposed 1000-500 hPa thickness contours spanning the period 0000 UTC 11 February to 0000 UTC 13 February 1988. Synoptic features include an intense slow-moving depression in the Tasman Sea and a low pressure area associated with a weakening thermal trough moving northeastward through New South Wales. At the same time, a high in the Southern Ocean was travelling eastward towards Tasmania. The pressure pattern at 0000 UTC 12 February 1988 points to synoptic-scale confluence existing over inland parts to the west of Brisbane.

Sequences of streamlines at 6-hourly intervals for 4 levels from 850 hPa to 250 hPa are produced in Fig. 5. The following features relevant to the event at Cooyar are noted:

850 hPa A confluent zone on the eastern flank of an area of inflow moved towards Cooyar (denoted by the dark circle) and became quasi-stationary over inland southeast Queensland.

700 hPa A ridge east of a major trough was located over Cooyar and moved slowly east to be oriented along the coast by the end of the period. This ridge is considered crucial to the observed rainfall distribution and is discussed in more detail later.

500 hPa A major trough dominated the middle levels and extended into northwest Australia. However a smaller scale trough with a tilt towards the northeast and located to the near west of Cooyar evolved during the period.

250 hPa Likely influences are difficult to diagnose. The lack of data to the east of Cooyar makes calculations of upper divergence unreliable. Using the barotropic vorticity equation (Palmen and Newton 1969) upper divergence zones can be approximately defined by areas of cyclonic vorticity advection. Cooyar lay east of a 250 hPa trough so that changes in flow curvature would contribute to cyclonic vorticity advection. However an obstacle is determining whether the local wind speed maximum is located north or south of Cooyar at 0400 UTC and 1000 UTC 12 February 1988. This would be critical in calculating the contribution to cyclonic vorticity advection by changes in horizontal wind shear.

SATELLITE IMAGERY

Very little cloud existed over southeast Queensland during the morning of 12 February 1988 (not shown) with the effect of the approaching middle-level system yet to be felt. The evolution and scale of the precipitation area is best illustrated by a sequence of visible and enhanced infrared geostationary meteorological satellite (GMS) imagery (Fig. 6).

A mass of (cold) high cloud over southeast Queensland can be seen to spread from convective cells. In Figs 6 (c) and 6 (d), temperatures colder than about -40°C (delineating the higher cloud tops) are shaded black. This temperature value corresponds to a height of about 10 km. The relative decrease in extent of high

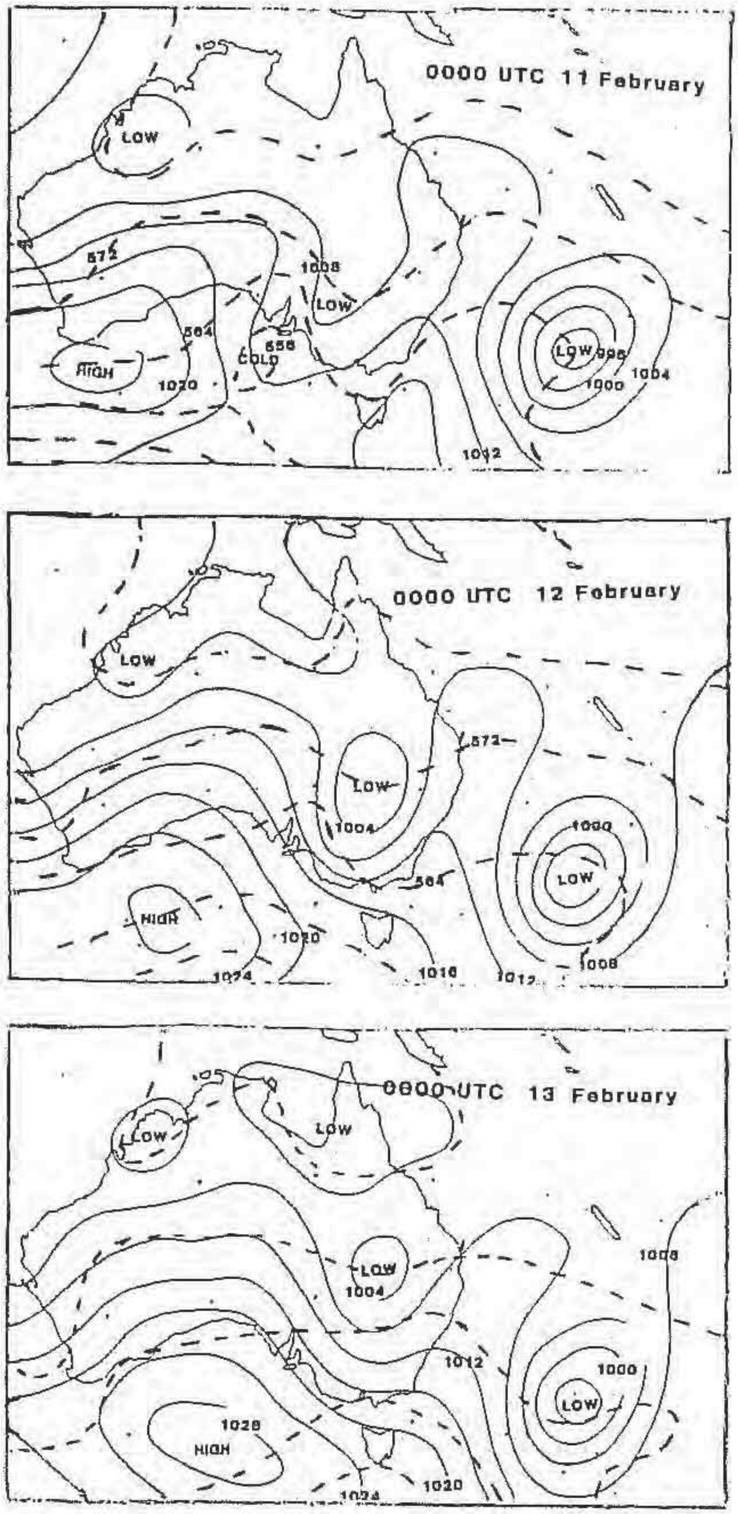


Fig. 4 MSL analyses with superimposed 1000-500 hPa thickness contours.

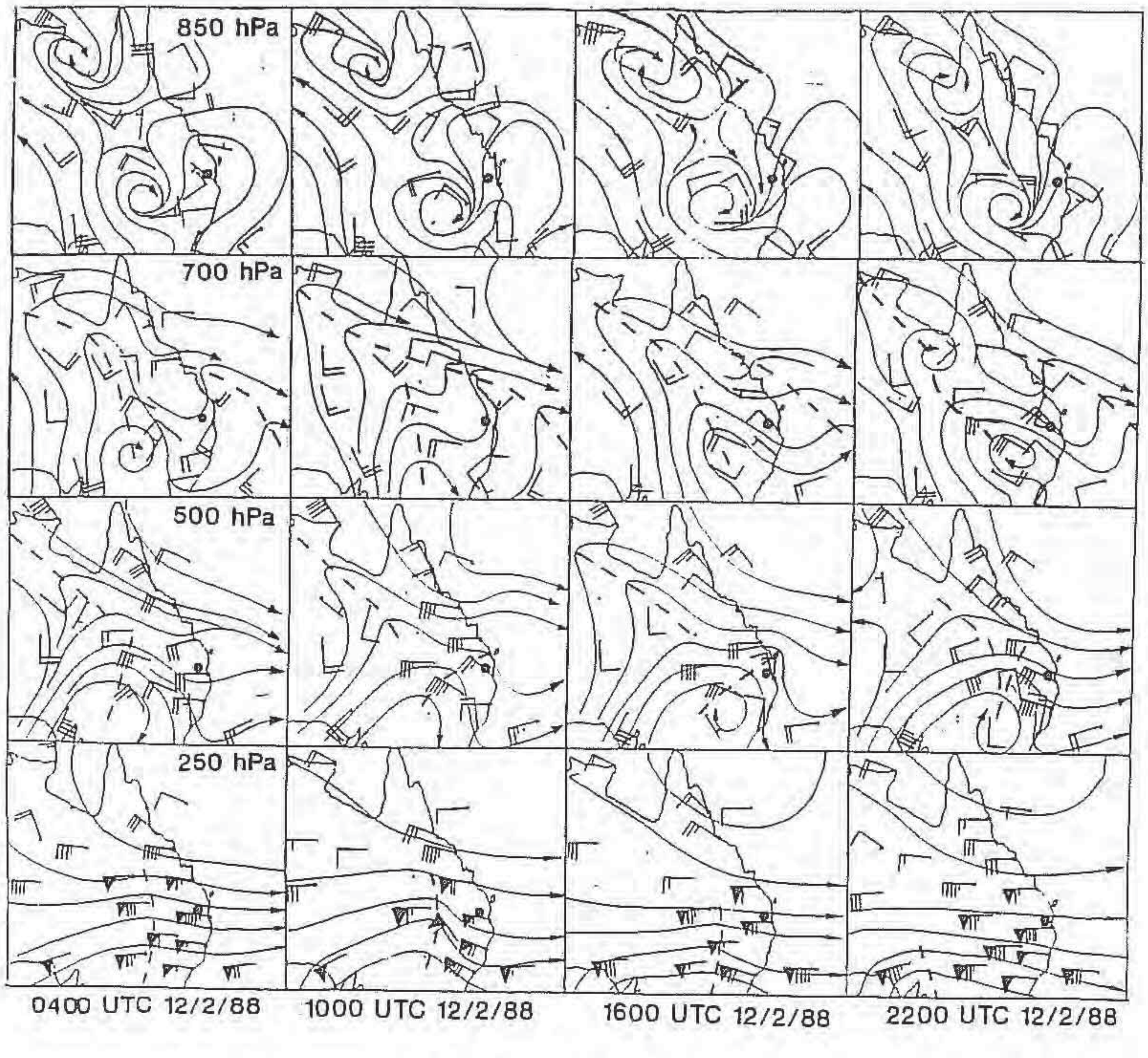


Fig. 5 Sequence of streamlines at 850, 700, 500 and 250 hPa for period 0400 UTC to 2200 UTC 12 February 1988.

Flags, barbs and half barbs on the wind photo represent 25 m/s, 5 m/s and 2.5 m/s respectively.

Fig. 6(a) Visible wavelengths GMS-3. Satellite photograph 0300 UTC 12 February 1988.

Fig. 6(b) Visible wavelengths GMS-3. Satellite photograph 0600 UTC 12 February 1988.

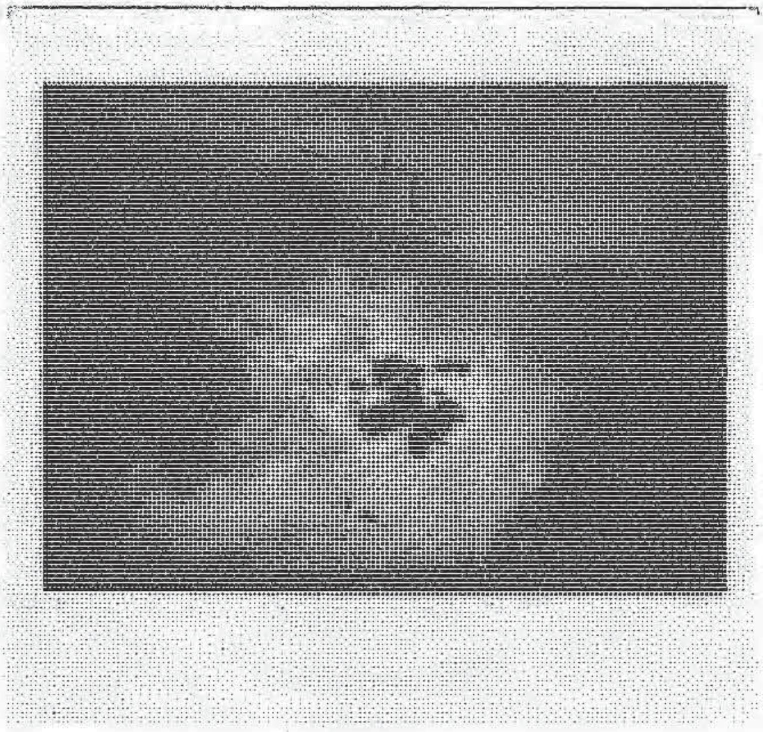


Fig. 6(c) Infrared wavelengths GMS-3. Enhanced satellite photograph 0900 UTC 12 February 1988.

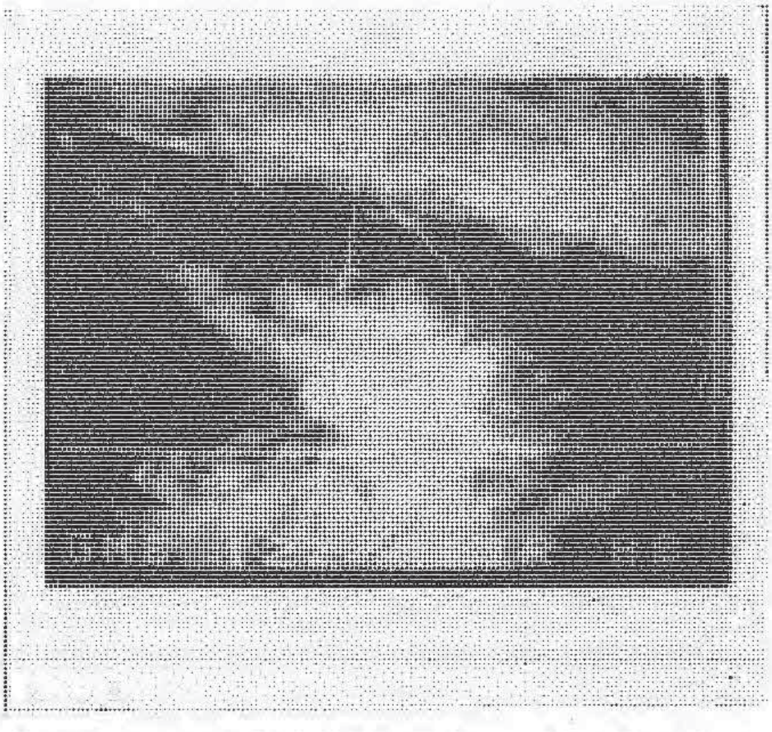


Fig. 6(d) Infrared wavelengths GMS-3. Enhanced satellite photograph 1200 UTC 12 February 1988.

cloud - equivalent to a reduction in mean depth of the convective complex - between 0900 UTC and 1200 UTC 12 February 1988 is clearly visible.

About 0900 UTC, Toowoomba experienced a severe thunderstorm with 4 cm diameter hail and a 33 mm downpour. Note that the heavy rain around Cooyar occurred several hours later. Many who experienced heavy rain reported hearing occasional thunder. It is worth noting that the high cloud mass south of latitude 30 degrees had little significant precipitation associated with it.

ATMOSPHERIC STABILITY

The first evidence of convection on satellite imagery appeared between the upper-air observing stations of Charleville and Moree just before noon on 12 February 1988. From the 0100 UTC synoptic reports, the dry-bulb temperature in the area was around 34°C and the dew-point near 18°C. If these values are applied to the 2200 UTC 11 February 1988 radiosonde traces in Figs 7(a) and (b), parcel theory would support convective cell development to an elevation of almost 11 km (neglecting entrainment).

The main convective cells initially developed in the broad confluence zone referred to earlier. Respective stability indices for Charleville, Moree and Brisbane at 2200 UTC 11 February 1988 are listed in Table 1. Also included are 'scattered thunderstorm' threshold values for the various indices. The indices at Charleville in particular are indicative of scattered thunderstorm activity.

Table 1. Stability indices at 2200 UTC 11 February 1988

	Brisbane	Moree	Charleville	Threshold
Showalter Index	04	03	-01	0
Whiting Index	10	23	39	35
Total - Totals Index	40	45	48	48

RADAR RECORDS

Radar observations were available from both Brisbane and Mt Kanighan throughout the episode. During the time the catchment area was being inundated, the precipitation consisted of rain from stratiform cloud with heavier falls from embedded thunderstorm cells. Skies had generally cleared around Cooyar by 2200 UTC 12 February 1988.

Brisbane weather watch radar reports have been manually plotted and displayed in Fig. 8. At 0930 UTC strong cellular echoes were evident just west and southwest of Cooyar with a large broken area of precipitation extending well to the south. Later at 1115 UTC a much smaller area of precipitation could be seen just south of Cooyar with a convective cell over the catchment region.

Figure 9 is a representation of Mount Kanighan digitised radar imagery for 1150 UTC (35 minutes after Fig. 8). A cellular echo (stippled for clarity) is now much closer to Cooyar representing a cell velocity of about 45 km/h towards the east-northeast. Although the ambient middle-level flow was westerly, thunderstorms in the southeast of the state are regularly observed to track to the

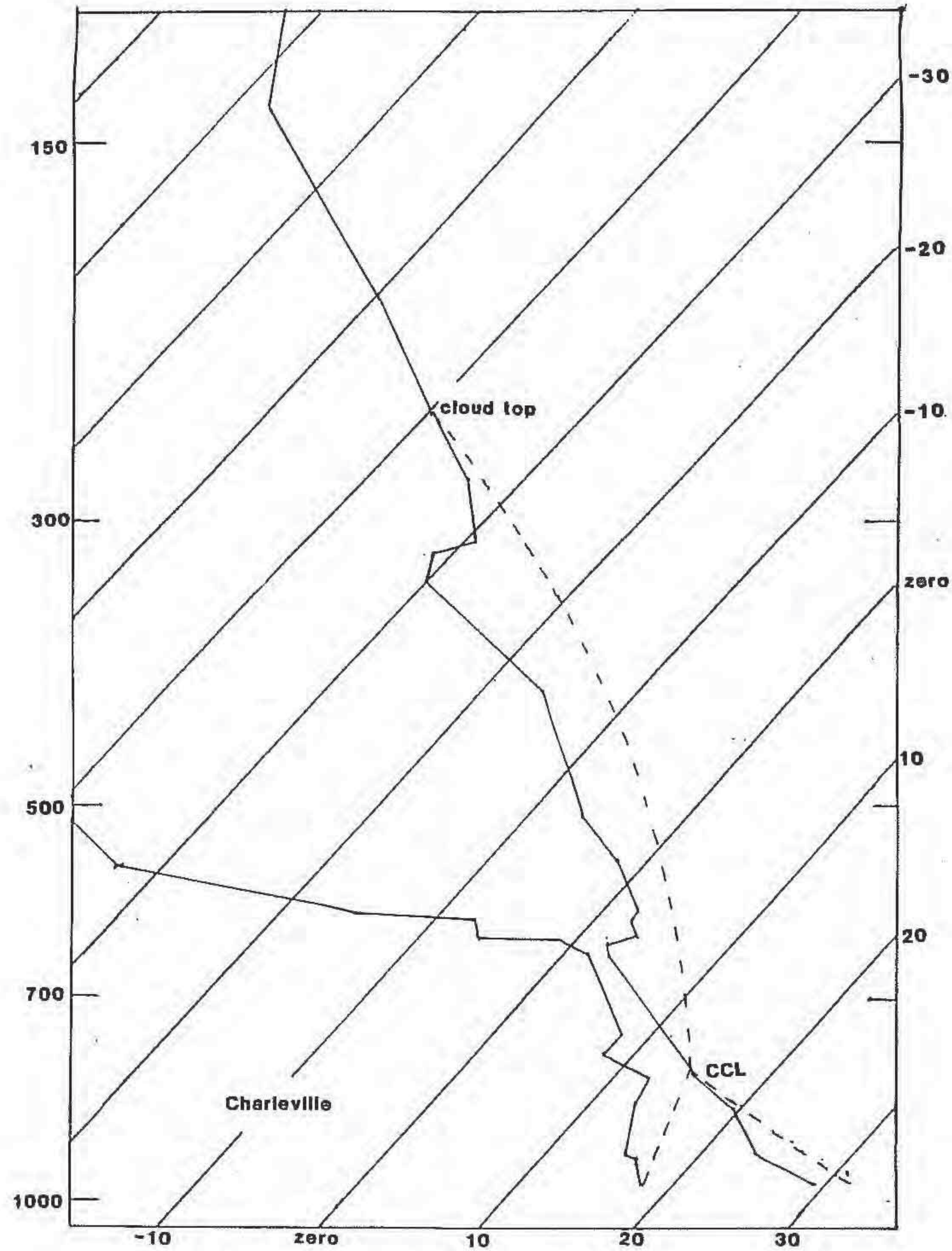


Fig. 7(a) Vertical temperature (°C) and dew-point (°C) sounding for 2200 UTC 11 February 1988 at Charleville.

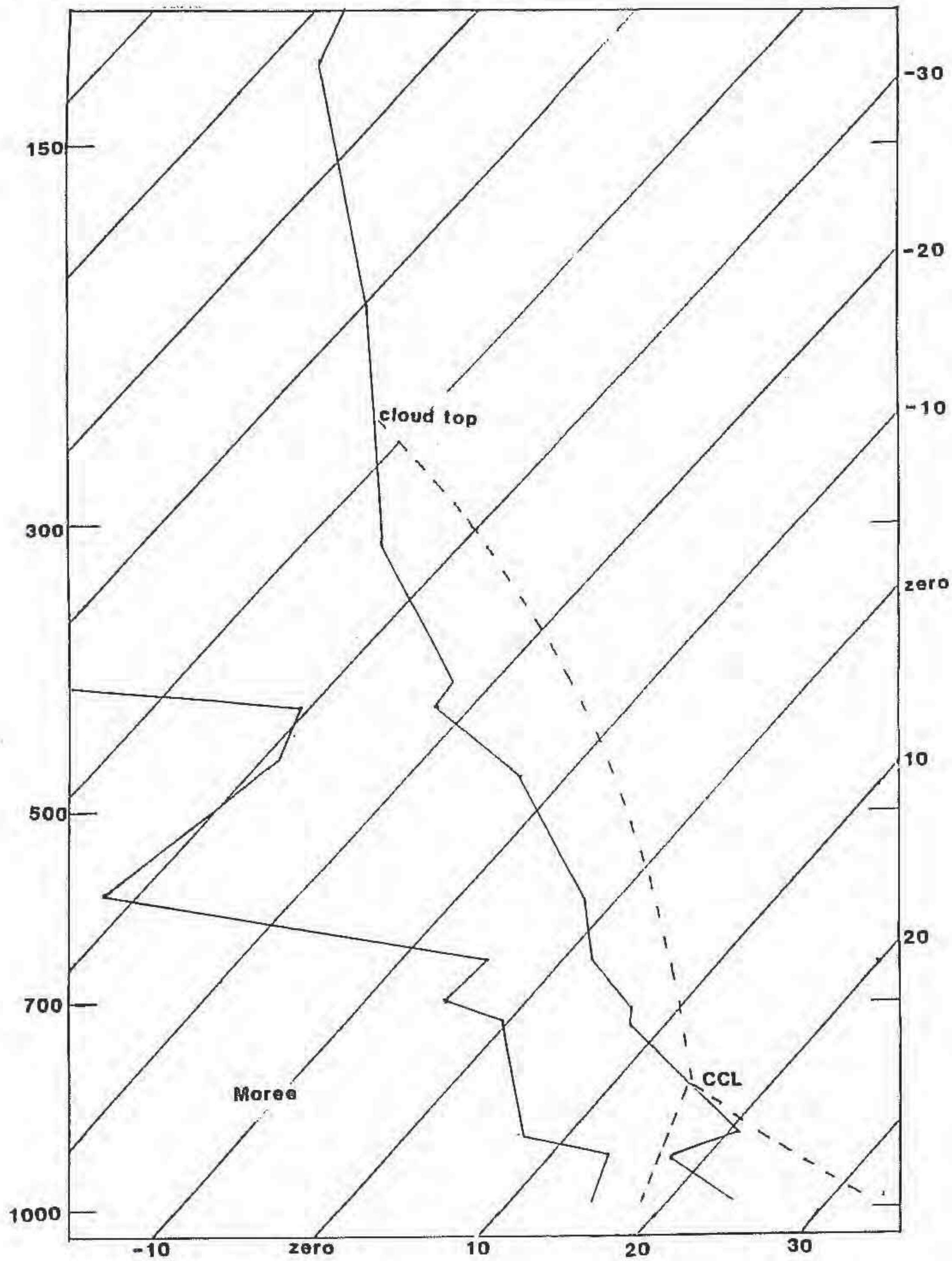


Fig. 7(b) Vertical temperature (°C) and dew-point (°C) sounding for 2200 UTC 11 February 1988 atMoree.

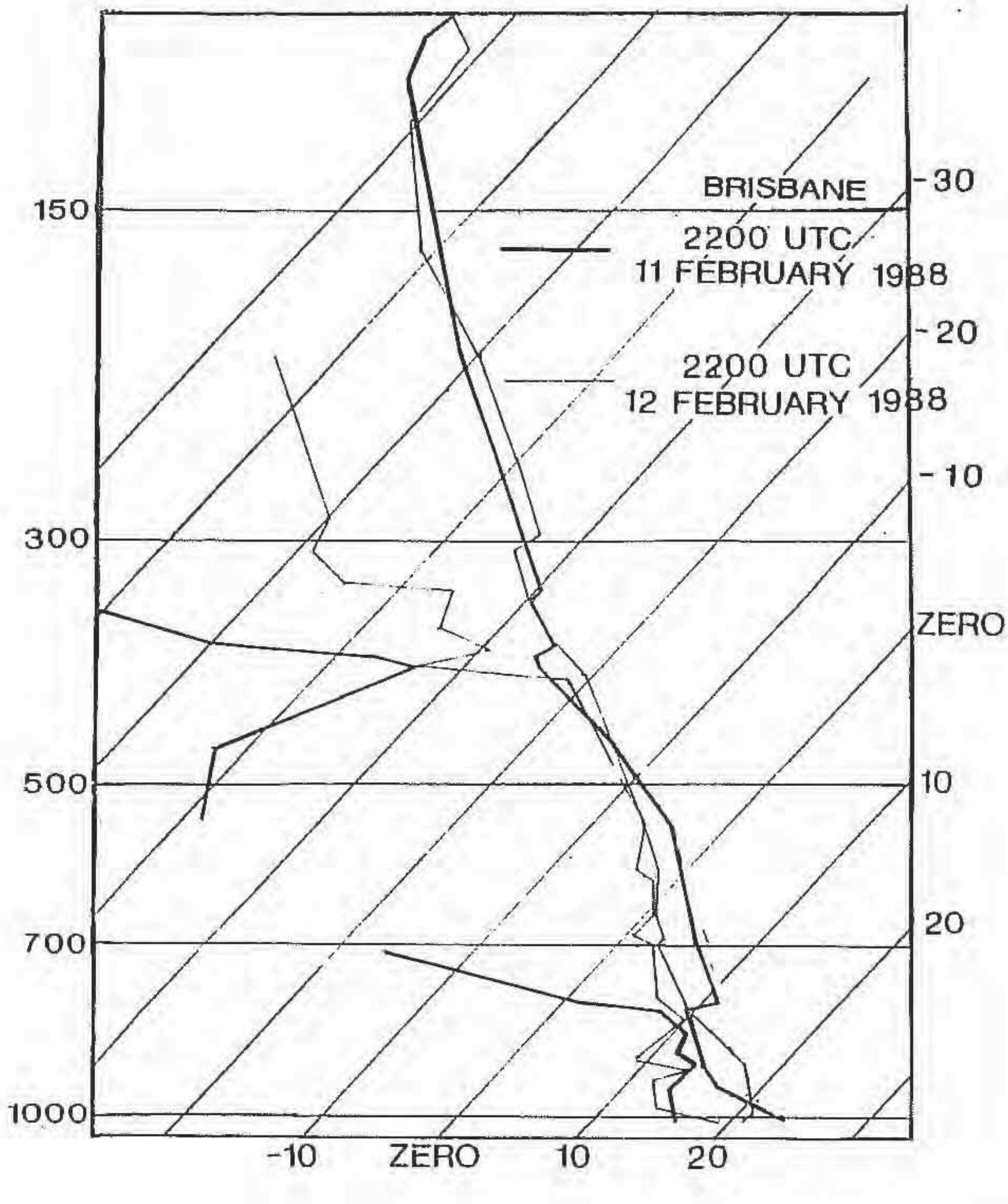


Fig. 7(c) Vertical temperature (°C) and dew-point (°C) sounding for 2200 UTC 11 February 1988and 12 February 1988 at Brisbane.

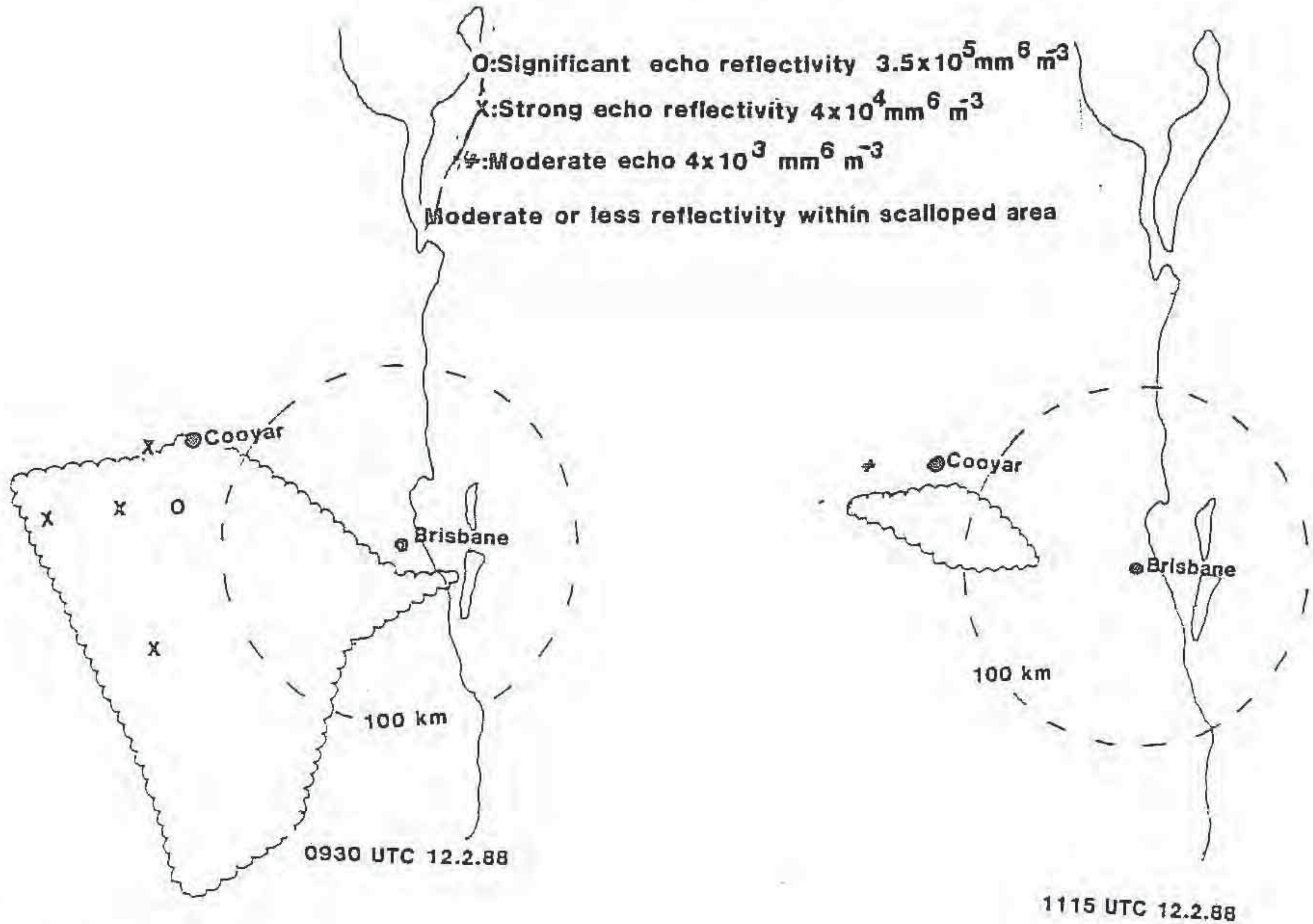


Fig. 8 Plotted radar reports from Brisbane.

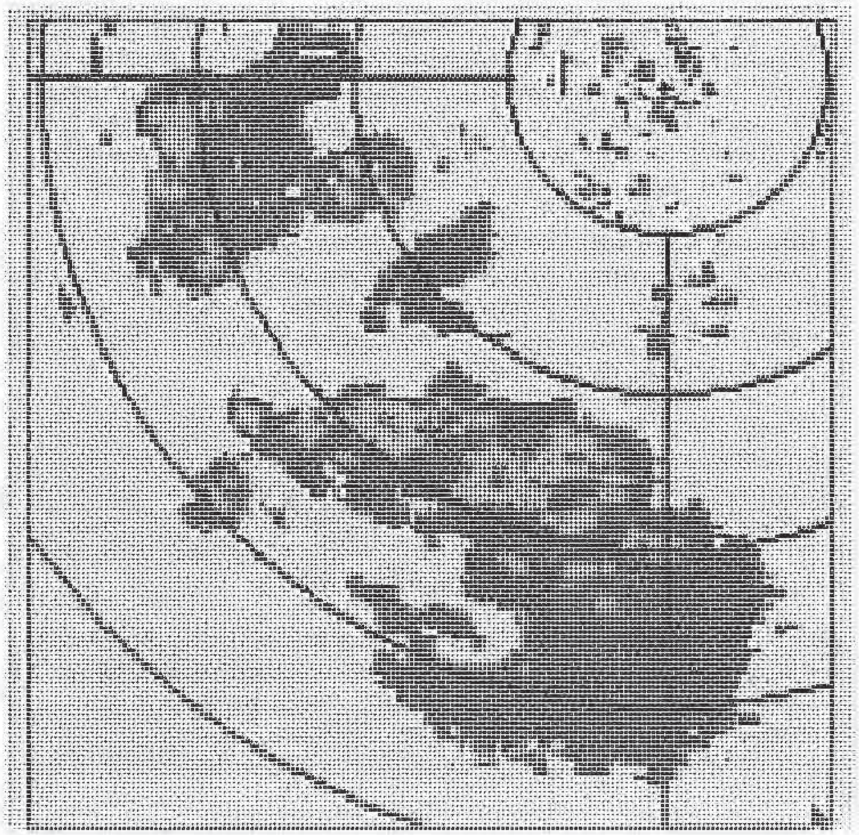


Fig. 9 Digitised radar imagery at 1150 UTC 12 February 1988, from Mt. Kanighan radar. Range rings at 50 km intervals and cross marks location of Cooyar.

left of the mean flow. Note that the scales for Figs 8 and 9 are quite different. From subsequent radar data the general rain area remained roughly orientated northwest-southeast through Cooyar until at least 1800 UTC the next morning.

Radar data suggests a multicellular convective complex became anchored over the catchment. Individual thunderstorm cells did track towards Cooyar and then dissipate after passing out of the rain band and moving off the eastern escarpment of the Great Divide. It is interesting to note that Kingaroy, some 50 km north of Cooyar, received only 3 mm of rain during the entire period.

VERTICAL MOTION

From quasi-geostrophic theory (Trenberth 1978), up-motion exists in the presence of advection of cyclonic vorticity by the thermal wind. In Fig. 10, the 850 hPa relative vorticity field (from the operational numerical model) has been superimposed upon the 850 hPa temperature distribution. Although quasi-geostrophic theory is more applicable at a slightly greater height, the inference can be drawn that up-motion was occurring in the lower troposphere over inland southeast Queensland in the 12 hours to 1200 UTC 12 February 1988.

To further identify mechanisms forcing uplift at lower levels of the atmosphere isentropic charts were constructed. Essentially, these charts represent material surfaces for dry abiabatic processes. In Fig. 11 the 303 K surface is shown with isobars and plotted wind vectors for 2200 UTC 11 February 1988 (before the main cloud mass developed).

Warm advection and up-motion is implied in a channel between Charleville and Brisbane where the orientation of the wind vectors suggest the air trajectory would rise approximately 100 hPa if the pressure pattern was not moving eastward. The pressure distribution on the same surface 24 hours later (again Fig. 11) indicates little movement in the pattern and only slight intensification in the pressure gradient (and hence temperature gradient).

Ascending air and warm air advection west of Brisbane probably played an important role in the development of the mesoscale convective complex. Doswell (1985) cited strong low-level warm advection as the dominant synoptic scale feature associated with similar multicellular convective complexes in the U.S.A. In this case, boundary-layer heating was most likely essential to the convective processes.

SUBSYNOPTIC-SCALE PARAMETERS

A major forecasting difficulty in Queensland is whether or not thunderstorms will develop over southeast coastal districts. It is not uncommon in summer for cumulonimbus clouds, extending up to 15 km or more, to collapse after descending off the ranges to the lower equivalent potential temperature (Theta E) region along the coastal plains.

Local research isolates two parameters as being strongly associated with the collapse of such storms. A detailed investigation is being carried out by this section into 200 storm events during a ten-year period in the area broadly covered by the regional MSL analysis in Fig. 12. Another study by J. N. Butler of the Brisbane Airport Meteorological Office (unpublished) covered a different ten-year period.

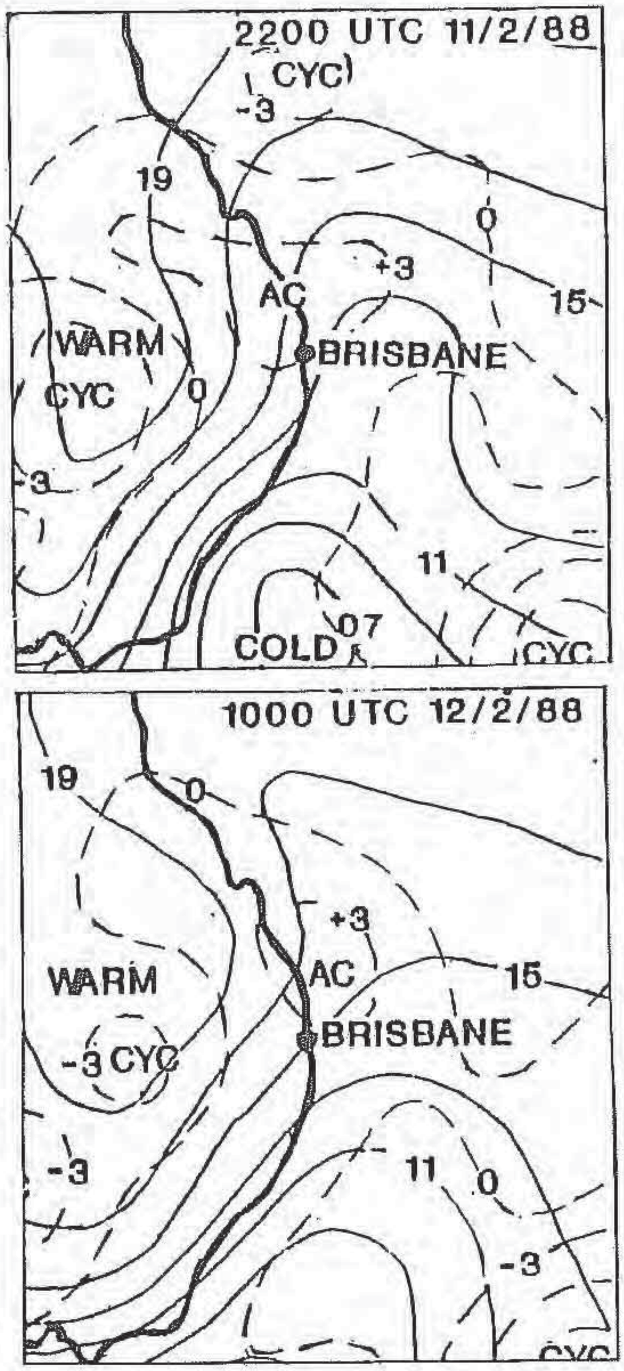
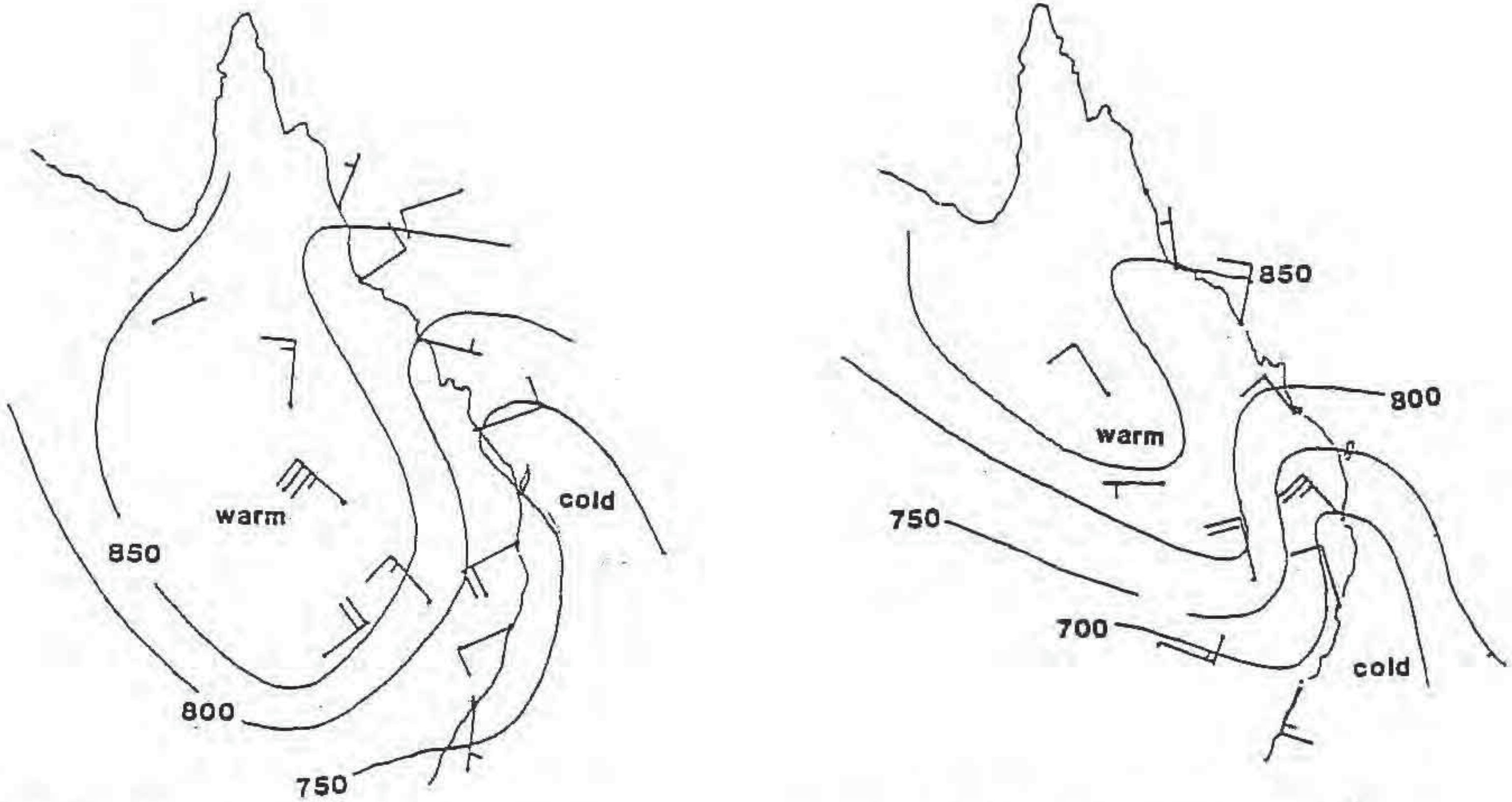


Fig. 10 850 hPa analyses for 2200 UTC 11 February 1988 and 1000 UTC 12 February 1988. Full lines temperature in degrees celsius. Dashed lines vorticity in $sec^{-1} \times 10^{-5}$.



2200 UTC 11 FEBRUARY 1988 | 2200 UTC 12 FEBRUARY 1988

Fig. 11 Pressure (hPa) analyses on the 303K isentropic surface. Wind plotting convention as in Fig. 5.

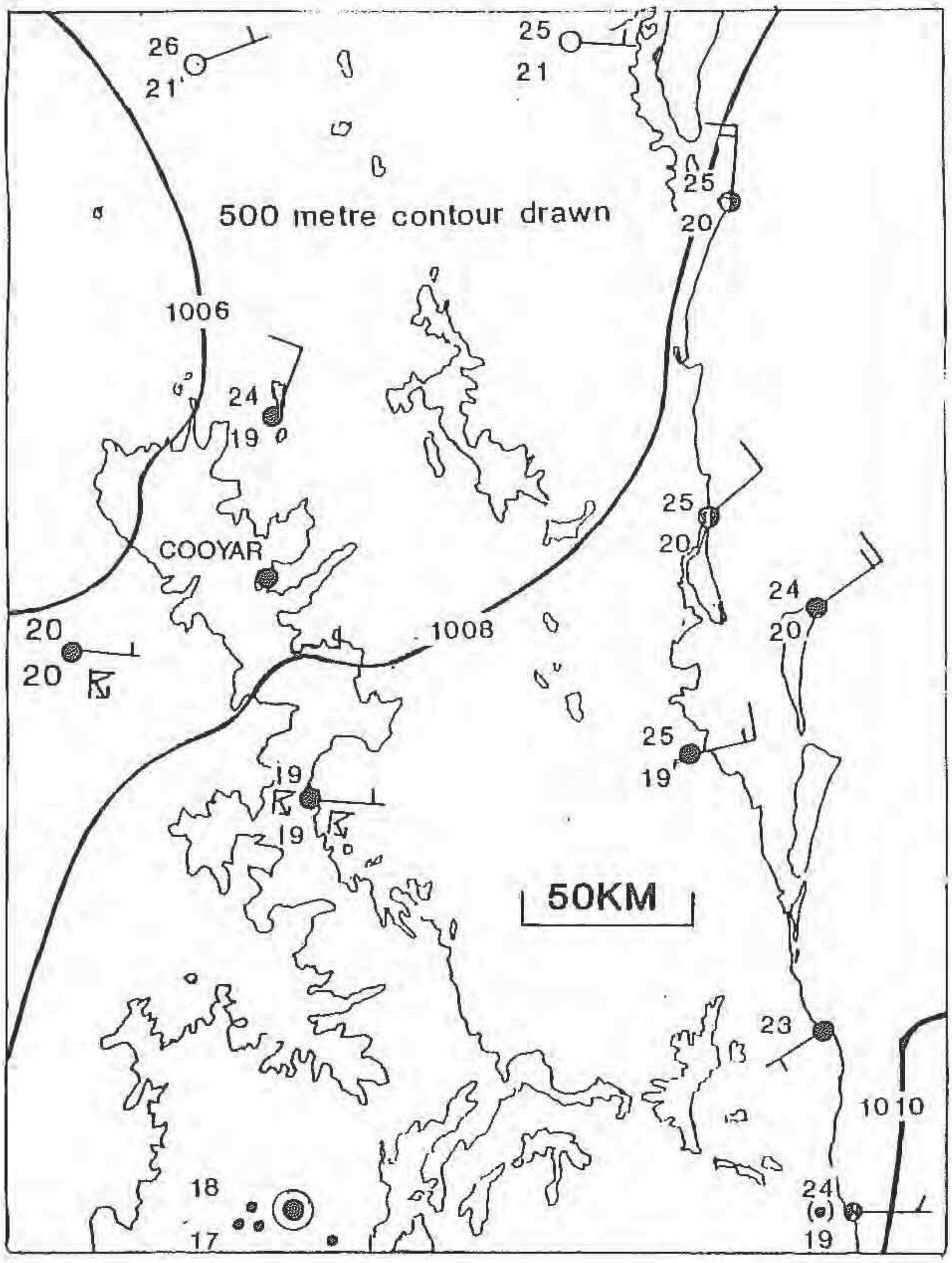


Fig. 12 Regional MSL analysis for 1100 UTC 12 February 1988.

Parameter 1: Vertical Wind Structure
If storms which arrive on strong cold fronts are neglected, there exists a favorable vertical wind structure for the advection of storms off the ranges to the coast. This structure consists of backing winds with height (warm air advection) from northerly to northwesterly near 900 hPa up to west-northwesterly to west-southwesterly winds at 700 hPa.

Parameter 2: Coastal Theta E
The other important parameter is the coastal Theta E ahead of the approaching storms. It has been found that in many cases when storms collapsed the observed coastal temperatures were less than the convective temperature at the same time. This convective temperature can be calculated graphically from the coastal temperatures and dewpoints at the time of collapse and the morning radiosonde trace.

A schematic vertical cross-section (Fig. 13) of the path of the convective complex which deluged Cooyar shows upslope motion to the top of the Great Divide. East of the Divide where the cells dissipated there is a sudden drop in elevation to the Brisbane River Valley.

A time section of the upper winds at Brisbane (Fig. 14(a)) shows the effects of the 700 hPa ridging mentioned earlier. At 0400 UTC and 1000 UTC 12 February 1988, south-southwesterly to southwesterly winds were observed in a layer centred at 700 hPa. At 900 hPa the winds were almost from the opposite direction and represented a vertical wind structure not conducive to tbe advection of storms off the ranges. It should he noted that by 2200 UTC warm advection predominated in the lower balf of the troposphere as the ridge moved seawards. About this time the rain hand which had previously remained quasi-stationary along the ranges had almost reached Brisbane.

A vertical temperature profile to represent the region just east of the Great Divide near Cooyar (Fig. 14(b)) at the time of the heavy rain was constructed from radiosonde and upper wind data at Brisbane. Details of its derivation is provided in Appendix 1.

The nearest observation to Cooyar east of the Divide at the time of the heavy rain was Kingaroy which is the station just north of Cooyar in Fig. 12. This station's temperature and dew-point were used to calculate the lifted condensation level in Fig. 14(b). It can be seen that a mechanism would need to be present to produce uplift to 850 hPa so that convective cloud could develop east of the Divide. As mentioned above little rain was recorded at Kingaroy during the event.

Therefore it appears that dynamic and thermodynamic factors combined to ensure that the convective complex could not propagate off the Great Divide. At the same time a low-level confluent (and presumably convergent) zone remained quasi-stationary in the general area to initiate redevelopment of cells.

FEATURES COMMON TO FLASH FLOOD EVENTS

Maddox et al. (1979) studied 151 flash floods and noted 8 features common to most of the events. These features with comment on their applicability to the Cooyar event are now presented:

(1) Flash floods were associated with convective storms.

- Certainly the case at Cooyar.

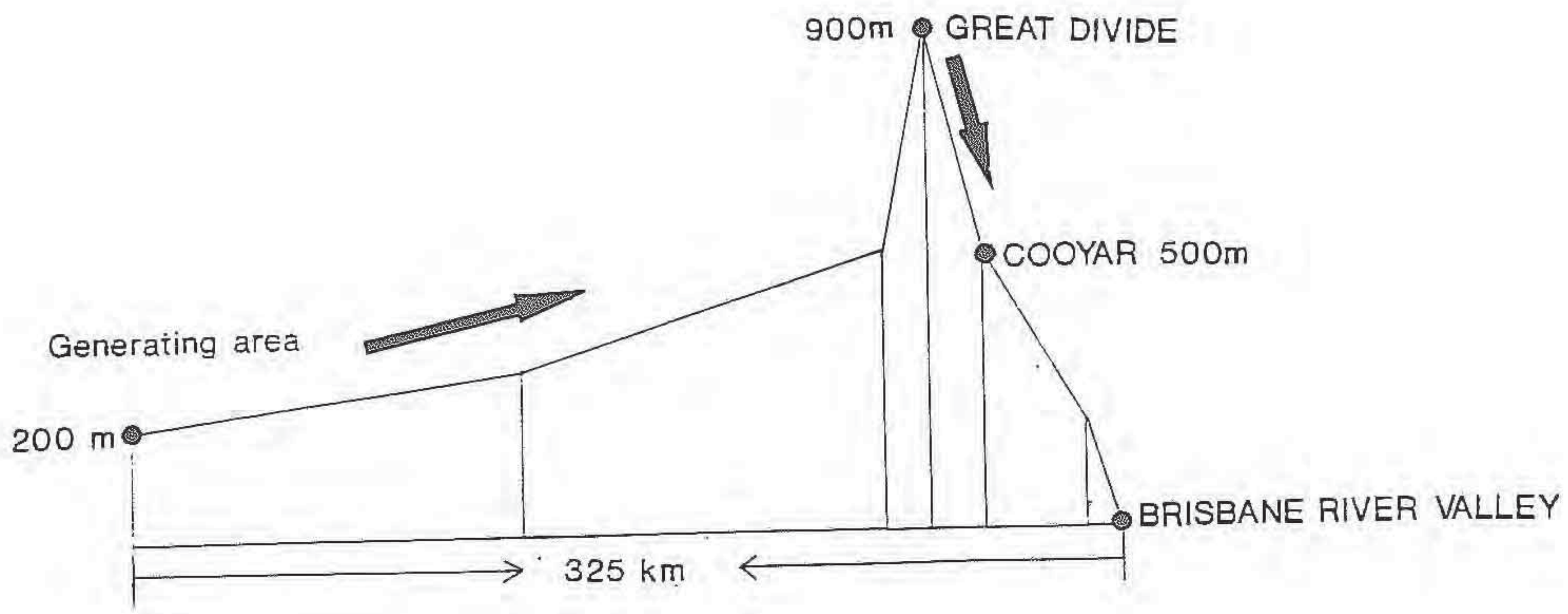


Fig. 13 Vertical cross-section of path of convective complex on 12 February 1988.

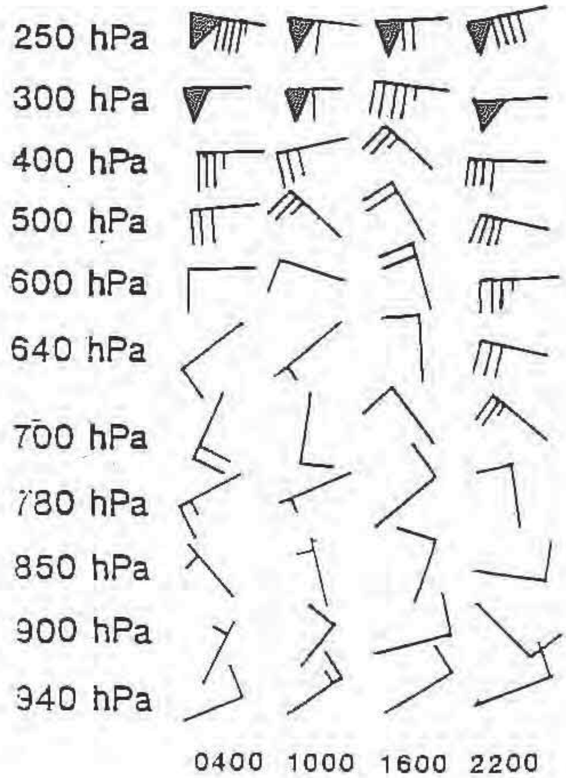


Fig. 14(a) Upper winds Brisbane 12 February 1988 (UTC). Wind plotting convention as in Fig. 5.

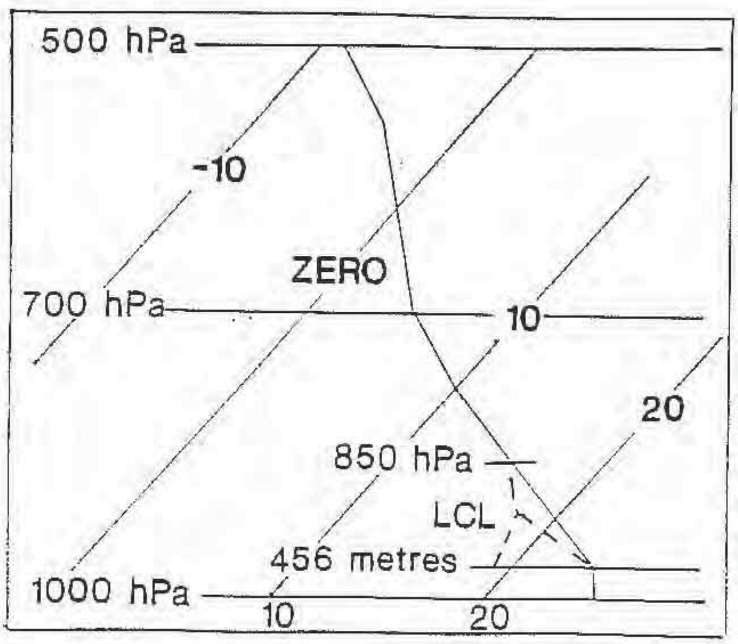


Fig. 14(b) Vertical temperature (°C) 1100 UTC 12 February 1988 near Kingaroy.

(2) Storms occurred in the regions with high surface dew-point temperatures.

- Prior to convective development, surface dew-points were in the 17/20C range which is quite high for inland parts of southeast Queensland.

(3) Relatively high moisture content was present through a deep tropospheric layer.

- From Fig. 7, the respective radiosonde traces are not particularly moist, so this condition was probably not so relevant to the Cooyar event.

(4) Weak to moderate vertical shear of the horizontal wind was present through the cloud depth layer.

- The closest rawinsonde station to Cooyar is Brisbane. About the time of the heavy rain (1200 UTC), the vertical wind shear there was generally weak to at least 400 hPa (Table 2). The relationship of vertical wind shear to precipitation efficiency is discussed in a later section.

(5) Convective storms and/or cells repeatedly form and move over the same region.

- Evidence presented earlier leaves little doubt that this was the case. As noted by Doswell (1985), it is often the succession of moving cells, passing over the same area at about the same heavily-precipitating stage in their life cycle (the so-called 'train effect'), that creates the high localised rainfalls seen in flash floods.

Table 2. Upper winds (m/s) at Brisbane Airport 1000 UTC 12 February 1988

200 hPa	270	44	600 hPa	290	5
250 hPa	280	31	700 hPa	195	6
300 hPa	270	31	800 hPa	245	2
400 hPa	260	16	850 hPa	345	2
500 hPa	315	12	900 hPa	040	6

Vertical Shears

800 to 300 hPa	$3.3 \times 10^{-3}\ s^{-1}$
800 to 400 hPa	$2.0 \times 10^{-3}\ s^{-1}$

(6) A weak mid-tropospheric mesoscale trough helped trigger and focus the storms.

- At 1000 UTC 12 February 1988, a 500 hPa trough and cyclonic curvature were being analysed west of Brisbane (Fig. 5). Whereas the cyclonic curvature had not been an identifiable feature prior to that time, the major trough near Charleville had been evident for some 24 hours.

(7) The storm area was very near the mid-tropospheric large scale ridge position.

- The analyses for 1000 UTC 12 February 1988 (Fig. 5) confirms the presence of a ridge, especially at 700 hPa. In contrast to the Cooyar area, thunderstorm cells entering this region soon collapsed in the rather benign setting. Other factors obviously contributed to the collapse as shown earlier.

(8) Storms often occurred during the night-time hours.

- Needless to say, the heavier rain in this case fell during the night.

Upslope air flow over topography was noted as an important mechanism in some events (Caracena and Fritsch 1983). Moreover, Doswell (1985) defines the role of topography as being one of providing a fixed source of lift which, under the right circumstances, produces the propagation required to make systems quasi-stationary.

The location of Cooyar in relation to the surrounding ranges would ensure that moist low-level northeast winds supplied plentiful moisture for convective development. The regional MSL chart for 1000 UTC 12 February 1988 shows the moist northeast airflow into the Cooyar region (Fig. 12).

RAINFALL ANALYSES

Intensity-frequency-duration (IFD) curves for Cooyar were prepared by the Hydrology Branch Bureau of Meteorology (Fig. 15 (a)). These IFD curves are based on a generalised analysis of rainfall data and derived by using the nearest computer grid-point to the location of the station. At 'Vincentvale' station, 220 mm was registered in a 2 1/2 hour period between 1100 UTC and 1330 UTC. This is well in excess of the rainfall corresponding to a 100 year average recurrence interval (ARI) and could approach a 500 year ARI for 'point' rainfall.

The mean catchment rainfall for the 24 hours to 2200 UTC 12 February 1988 was estimated at 149.1 mm. The temporal pattern appearing as Fig. 15 (b) was constructed, based on the Maclagan pluviograph record and the 'Vincentvale' rainfall reports. For the most intense rainfall period (1100 UTC to 1400 UTC), the mean catchment rainfall for Cooyar Creek to Cooyar village is estimated to be 126 mm.

For durations up to 6 hours and areas up to 1000 square kilometres, probable maximum precipitation (PMP) is estimated using the method detailed in Bureau of Meteorology 1984 [1]. This technique had been modified following the extraordinary flash flood near Dapto in New South Wales in February 1984 (Shepherd and Colquhoun 1985). The method can be directly applied to the Cooyar event as most of the rain fell in a 3 to 4-hour window and the catchment size is approximately 156 square kilometres. PMP estimates for the Cooyar Creek catchment are listed in Table 3. In broad terms, these values exceed by a factor of 3 to 4 the average rainfall rates recorded on this occasion.

Foote and Fankhauser (1973) demonstrated that precipitation efficiency in thunderstorms is (crudely) inversely proportional to vertical wind shear through the principal cloud-bearing layer. With a shear value of about $1.5 \times 10^{-3}\ s^{-1}$, the precipitation efficiency was shown to be close to 100 per cent. At 1000 UTC 12 February 1988 the vertical wind shear between 800 and 400 hPa at Brisbane was $2.0 \times 10^{-3}\ s^{-1}$. Although not conducive to maximum efficiency, the comparatively

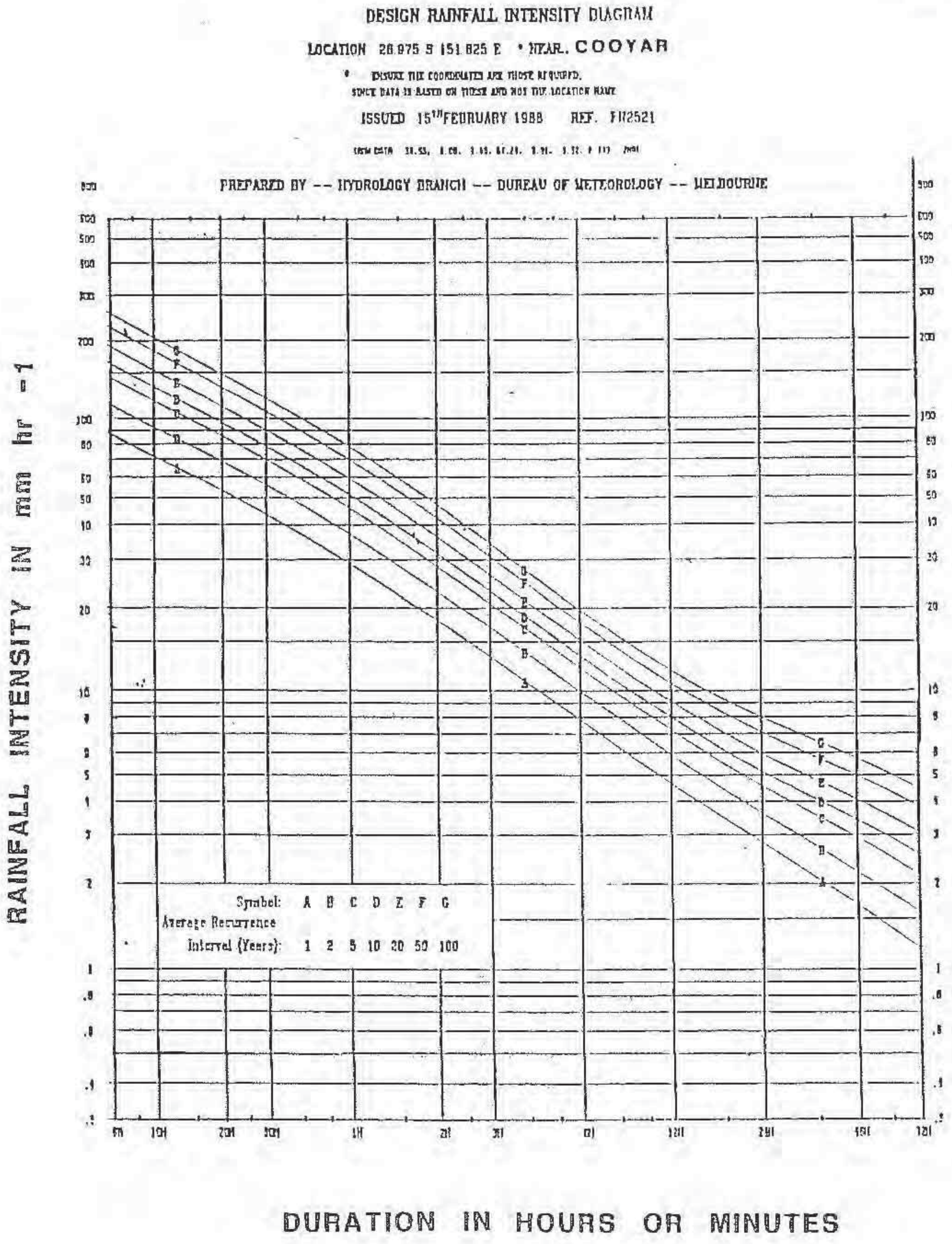


Fig. 15(a) Design rainfall intensity diagram for Cooyar.

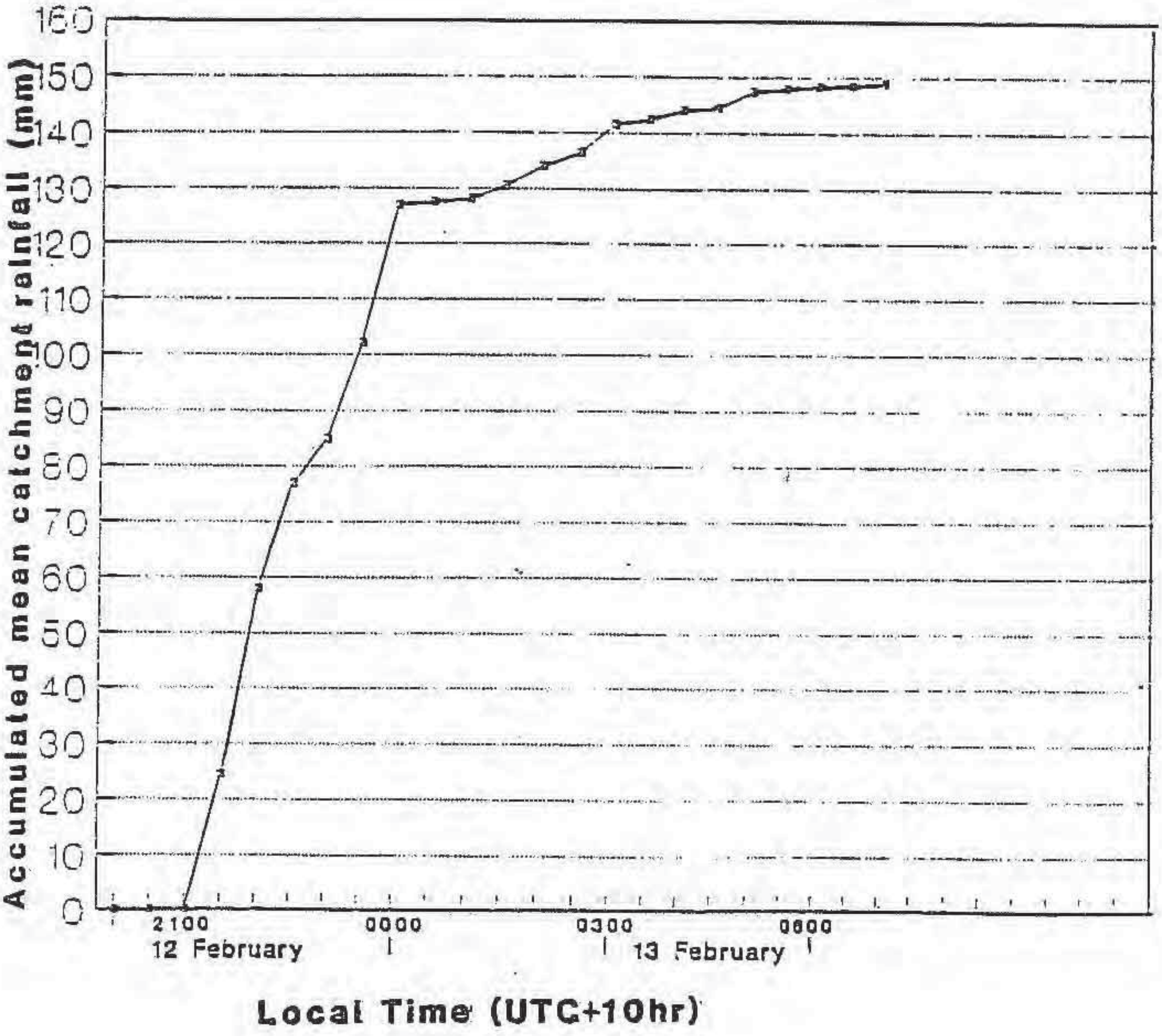


Fig. 15(b) Cooyar Creek to Cooyar estimated temporal pattern 12-13 February 1988.

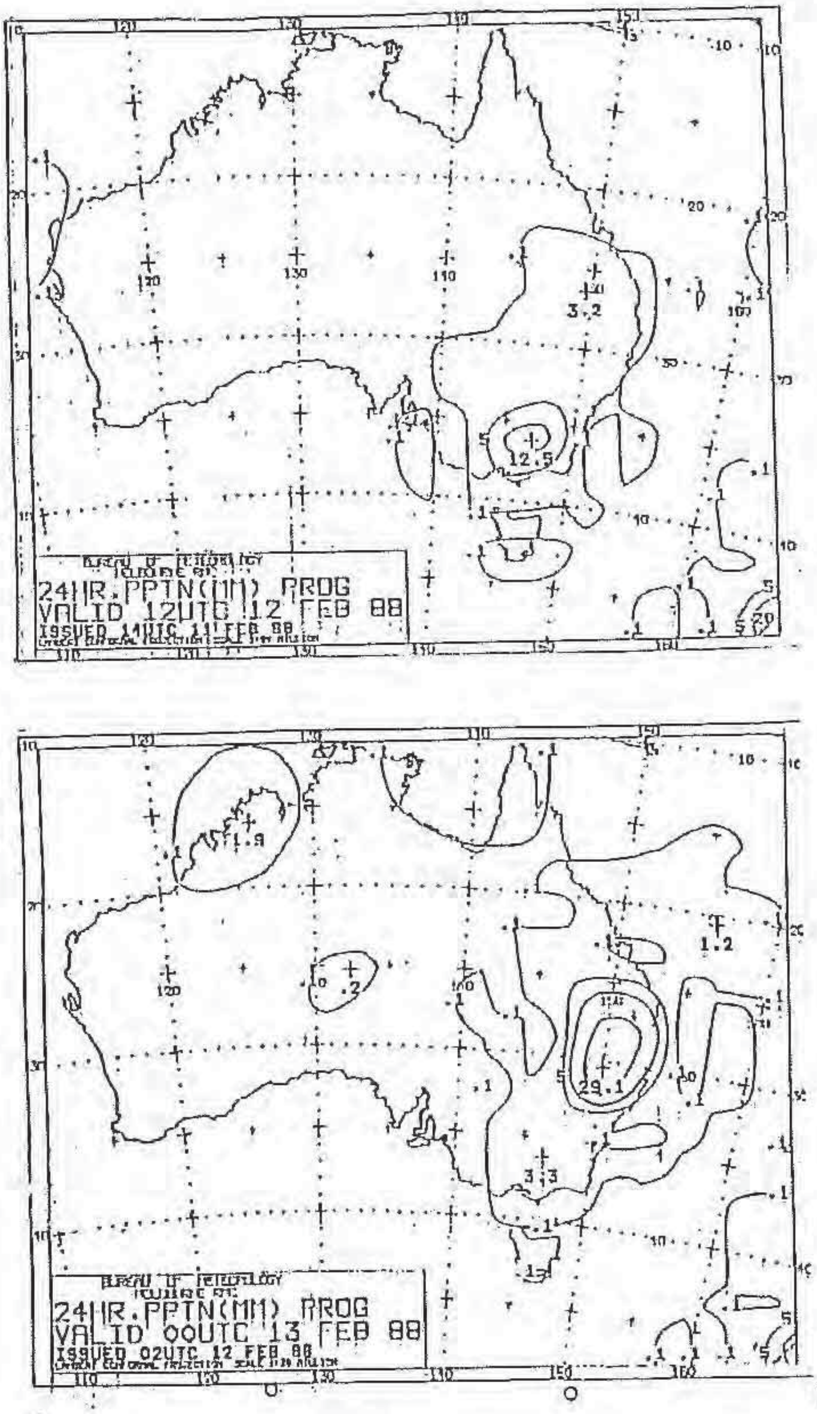


Fig. 16 24-hour precipitation prognoses.

600/400 hPa shear				
700/500 hPa shear	Colder to west	Colder to west	Colder to west	Near thermal trough
850/600 hPa shear	Warmer to west	Near thermal ridge	Warmer to east	Warmer to east
900/700 hPa shear	Warmer to west	Warmer to west	Warmer to east	Warmer to east
	120400	121000	121600	122200

Fig 17 Time section of vertical wind shears at Brisbane 0400 UTC to 2200 UTC on 12 February 1988.

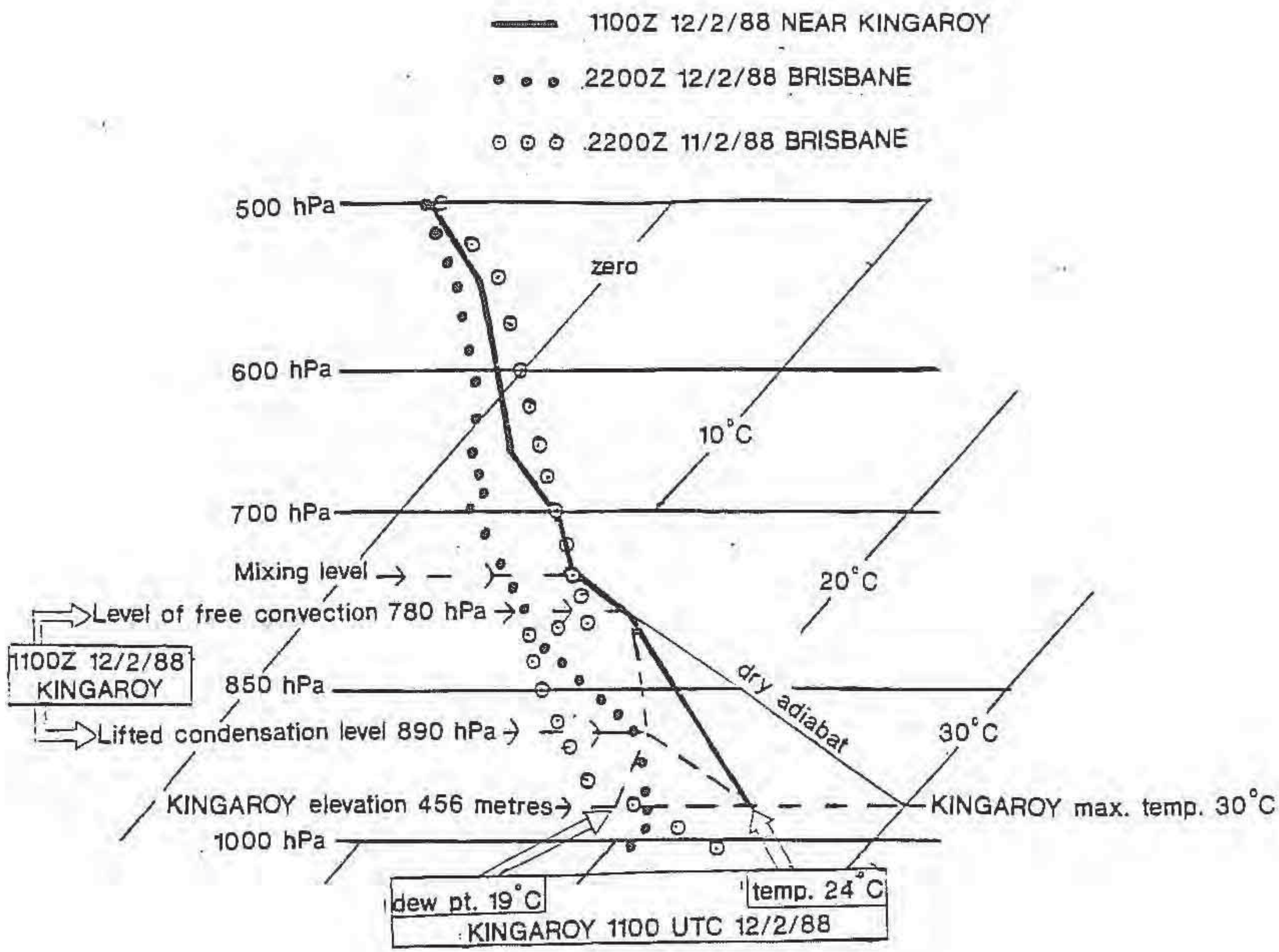


Fig. 18 Derivation of temperature profile near Cooyar/Kingaroy.

weak vertical shear would have contributed to the exceptional rainfall rates observed.

Numerical precipitation prognoses (from the Finest model) are received in the Brisbane Regional Forecast Centre at 12-hourly intervals. Included as Fig. 16 are the 24 hour total precipitation prognoses for both 1200 UTC 12 February 1988 and 0000 UTC 13 February 1988. Rainfall is forecast for southeast Queensland with a 29.1 mm maximum somewhat southwest of Cooyar on the 0000 UTC display. To convert this 'areal' (22500 square kilometres) forecast to a 'point' value, a factor of 4 is appropriately applied (Bureau of Meteorology 1984 [2]). Even 116 mm is significantly less than the 240 mm plus which fell during that night.

Table 3 . PMP for Cooyar Creek catchment

15min	30min	1hr	2hrs	3hrs	4hrs
120mm	180mm	280mm	360mm	410mm	460mm

CONCLUSION

The problem of establishing a flash flood threat is very similar to determining the likelihood of a severe thunderstorm. Various meteorological processes interact on several scales of motion to produce heavy rain in a particular area. As Maddox et al state 'Data indicate that, as in severe thunderstorm situations, marginal values of one important parameter may be compensated by more intense values of another parameter.'

Any attempt at this time to construct a logical decision tree for flash flood forecasting would be thwarted by the scarcity of reliable meteorological data on the sub-synoptic scale. Nevertheless, certain quantifiable features have been identified as common to many flash flood events and these should receive due consideration in the forecast and warning process.

As the range of numerical diagnoses and prognoses available to the forecaster is enlarged and the resolution of the model is reduced, there will likely be a commensurate increase in understanding of focussing mechanisms for heavy thunderstorm rains. Also the pending installation of a surface mesonet in southeast Queensland should provide researchers with high quality data on a sufficiently small scale to perform detailed analyses and design theoretical models.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Dr Lance Leslie and David Pike at BMRC for providing a large range of numerical products. Rainfall statistics were largely compiled by the Queensland Hydrology Section. Other officers assisting in the preparation of the paper were Peter Fletcher, David Shivas and Nirmala Deo. Lyn Maddock typed the manuscript.

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APPENDIX

CONSTRUCTION OF A VERTICAL TEMPERATURE PROFILE NEAR COOYAR

With reference to Fig. 7(c), in the 24 hours from 2200 UTC 11 February to 2200 UTC 12 February 1988, the temperature at Brisbane warmed at low-levels and cooled significantly between 800 hPa and 450 hPa. In Fig. 17 the vertical wind shears at various levels in the 24 hour period were plotted to investigate these temperature changes. A low-level thermal ridge passed through Brisbane between 1000 UTC and 1600 UTC while near 700 hPa a thermal ridge was evident in the Brisbane area at 1000 UTC.

This thermal ridge extended down to somewhere between 780 hPa and 850 hPa as this was the level at 0400 UTC and 1000 UTC the winds changed direction with height to produce the southwesterly shear observed east of the thermal ridge. The maximum temperature reached 30 degrees at Kingaroy on 12 February 1988 so that the mixing level would have been above the top of the inversion at 790 hPa observed on the Brisbane radiosonde trace at 2200 UTC 11 February 1988. Therefore the layer below the inversion would have been heated during the day by convective mixing of surface heating while the top of the inversion was heated by the approach of the thermal ridge.

Refer to Fig. 18. The temperature trace taken to represent the area east of the Great Divide at 1100 UTC 12 February 1988 was drawn from the temperature at 790 hPa (top of inversion) that morning on the Brisbane trace to 24 degrees at an elevation of 456 m. This last level is the elevation of Kingaroy and the temperature was the actual recording at 1100 UTC 12 February 1988. At the top of this layer the environmental temperatures were probably warmer and the lapse rate less than plotted. This would make the trace even more stable and would not destroy the reasoning presented above.

The thermal trough producing the cooling arrived at Brisbane at 600 hPa at the end of the 24 hour period. Above about 700 hPa cooling was occurring for most of the 24 hour period so that here a linear interpolation was applied to arrive at the constructed trace.

ppendi . P R F u catc ent c aracteri tic

Appendix D RAFTS Parameters

Nobby

Node	*Subcatchment*	*Area (ha)*	*Mannings n (m)*	*Percentage impervious (%)*	*Slope (%)*
node1	1	230	0.04	5	2.17

Cooyar

Node	*Subcatchment*	*Area (ha)*	*Mannings n (m)*	*Percentage impervious (%)*	*Slope (%)*
node1	1	512.20	0.05	0	4.08
node2	1	496.70	0.05	0	1.78
node3	1	591.90	0.05	0	1.29
node4	1	443.90	0.05	0	1.28
node6	1	497.50	0.05	0	1.37
node7	1	356.10	0.05	0	0.85
node8	1	228.20	0.05	0	0.87
node9	1	331.90	0.05	0	0.56
node10	1	196.40	0.055	0	0.77
node11	1	73.05	0.044	0	0.90
Dummy7	1	0.00	0.002	0	0.00
node13	1	39.84	0.044	0	0.19
	2	7.03	0.025	0	0.19
node15	1	43.62	0.0496	0	0.30
	2	0.44	0.03	0	0.30
node16	1	35.48	0.0468	0	0.33
	2	0.36	0.03	0	0.33
node17	1	37.58	0.0462	0	0.46
node18	1	21.24	0.0482	0	0.24
node20	1	237.00	0.05	0	2.32
node21	1	289.00	0.05	0	3.64
node22	1	266.90	0.05	0	1.78
node23	1	224.90	0.052	0	1.55
node24	1	236.40	0.052	0	4.08
node26	1	98.51	0.044	0	5.46
node27	1	108.40	0.042	0	1.35
node28	1	57.57	0.042	0	4.50
node29	1	84.37	0.046	0	1.55
node30	1	71.97	0.052	0	2.99
	2	0.73	0.03	0	2.99
node31	1	91.89	0.052	0	3.14
node32	1	48.75	0.057	0	1.79
node33	1	64.76	0.0516	0	1.88
	2	0.65	0.03	0	1.88
node34	1	36.42	0.054	0	7.48
node35	1	84.42	0.059	0	1.47
node37	1	640.20	0.05	0	4.36
node40	1	396.60	0.05	0	2.27
node41	1	291.20	0.05	0	3.07
node42	1	301.80	0.06	0	1.52
node45	1	475.10	0.052	0	0.87
node46	1	281.85	0.0594	0	0.87

	2	2.85	0.03	0	0.87
node47	1	55.74	0.054	0	3.73
node48	1	55.38	0.056	0	3.96
node49	1	122.46	0.0496	0	0.29
	2	1.24	0.03	0	0.29
node50	1	115.90	0.041	0	2.80
node51	1	405.40	0.049	0	2.89
node52	1	426.00	0.049	0	2.81
node54	1	1183.74	0.0504	0	2.43
	2	11.96	0.03	0	2.43
node55	1	494.50	0.044	0	1.06
node56	1	191.17	0.0434	0	0.99
	2	1.93	0.03	0	0.99
node60	1	122.46	0.0536	0	0.31
	2	1.24	0.03	0	0.31
node63	1	611.90	0.05	0	2.52
node64	1	761.70	0.044	0	2.09
node65	1	235.90	0.046	0	2.44
node67	1	576.68	0.0456	0	1.80
	2	11.96	0.03	0	1.80
node68	1	300.50	0.056	0	2.41
node69	1	184.80	0.046	0	3.03
node70	1	226.70	0.058	0	1.80
node73	1	51.97	0.057	0	3.78
node74	1	43.14	0.055	0	4.62
node75	1	119.50	0.059	0	2.84
node76	1	82.31	0.055	0	2.05
node78	1	41.99	0.05	0	2.86
node38	1	455.60	0.05	0	1.35
node19	1	254.30	0.05	0	2.16
node25	1	99.96	0.046	0	0.79
node88	1	105.30	0.044	0	0.49
node12	1	51.46	0.0442	0	0.43
node90	1	24.52	0.0432	0	0.44
	2	0.50	0.03	0	0.44
node77	1	89.05	0.054	0	2.48
node43	1	323.60	0.05	0	1.21
node66	1	306.50	0.0456	0	0.60
	2	3.10	0.03	0	0.60
node91	1	233.94	0.05	0	0.50
	2	2.36	0.03	0	0.50

Yarraman

Existing

Node	*Subcatchment*	*Area (ha)*	*Mannings n (m)*	*Percentage impervious (%)*	*Slope (%)*
1	1	1157.58	0.0421	0	1.47
	2	10.16	0.0421	100	1.47
4	1	647.03	0.0404	0	2.52
5	1	646.69	0.0811	0	3.71
	2	2.99	0.0811	100	3.71

2	1	626.57	0.0403	0	2.14
3	1	1025.81	0.0464	0	1.67
	2	12.98	0.0464	100	1.67
7	1	553.57	0.0587	0	2.56
10	1	105.27	0.0749	0	4.57
	2	0.45	0.0749	100	4.57
8	1	195.86	0.0951	0	3.80
	2	1.92	0.0951	100	3.80
9	1	162.35	0.0603	0	3.47
11	1	262.78	0.0535	0	2.61
	2	2.60	0.0535	100	2.61
12	1	245.37	0.081	0	2.39
	2	5.65	0.081	100	2.39
14	1	560.07	0.0782	0	3.45
	2	4.12	0.0782	100	3.45
13	1	140.72	0.0428	0	3.20
	2	0.21	0.0428	100	3.20
15	1	89.91	0.0423	0	3.28
	2	0.52	0.0423	100	3.28
6	1	151.06	0.0398	0	2.64
	2	1.88	0.0398	100	2.64
16	1	188.67	0.0926	0	3.81
	2	41.22	0.0926	100	3.81
17	1	118.30	0.0533	0	1.46
	2	6.04	0.0533	100	1.46
18	1	204.17	0.0873	0	1.45
	2	15.18	0.0873	100	1.45
19	1	169.80	0.0451	0	1.49
	2	1.92	0.0451	100	1.49

Developed

Node	*Subcatchment*	*Area (ha)*	*Mannings n (m)*	*Percentage impervious (%)*	*Slope (%)*
1	1	1157.58	0.0421	0	1.46839704
	2	10.16	0.0421	100	1.46839704
4	1	647.03	0.0404	0	2.5178676
5	1	646.69	0.0811	0	3.71417821
	2	2.99	0.0811	100	3.71417821
2	1	626.57	0.0403	0	2.14007363
3	1	1025.81	0.0464	0	1.67294116
	2	12.98	0.0464	100	1.67294116
7	1	553.57	0.0587	0	2.55889938
10	1	105.27	0.0749	0	4.57068771
	2	0.45	0.0749	100	4.57068771
8	1	195.86	0.0951	0	3.79955694
	2	1.92	0.0951	100	3.79955694
9	1	162.35	0.0603	0	3.4652063
11	1	262.78	0.0535	0	2.60638176
	2	2.60	0.0535	100	2.60638176
12	1	245.37	0.081	0	2.39106913
	2	5.65	0.081	100	2.39106913

14	1	560.07	0.0782	0	3.45077919
	2	4.12	0.0782	100	3.45077919
13	1	140.72	0.0428	0	3.19938691
	2	0.21	0.0428	100	3.19938691
15	1	89.91	0.0423	0	3.2781631
	2	0.52	0.0423	100	3.2781631
6	1	151.06	0.0398	0	2.6355878
	2	1.88	0.0398	100	2.6355878
16	1	187.94	0.0938	0	3.80974168
	2	41.96	0.0938	100	3.80974168
17	1	114.41	0.0659	0	1.45556925
	2	9.94	0.0659	100	1.45556925
18	1	204.17	0.0873	0	1.45285445
	2	15.18	0.0873	100	1.45285445
19	1	169.80	0.0451	0	1.48550626
	2	1.92	0.0451	100	1.48550626

Appendix E. Design Flood Event Mapping – Nobby

TOOWOOMBA REGIONAL COUNCIL

1:8,000 (at A3)

0 50 100 200
Metres

GDA 1994 MGA Zone 56

Legend

Validation Points	Model Extent
Emergency Locations	Peak Depth (m)
Cadastre	< 0.1
Road Centreline	0.1- 0.25

0.25 - 0.5	2.5 - 3.0	> 5.0
0.5 - 1.0	3.0 - 3.5	
1.0 - 1.5	3.5 - 4.0	
1.5 - 2.0	4.0 - 4.5	
2.0 - 2.5	4.5 - 5.0	

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SP 051 Flood Studies
Work Package 10 - Nobby
2011 Validation Event Peak Depth

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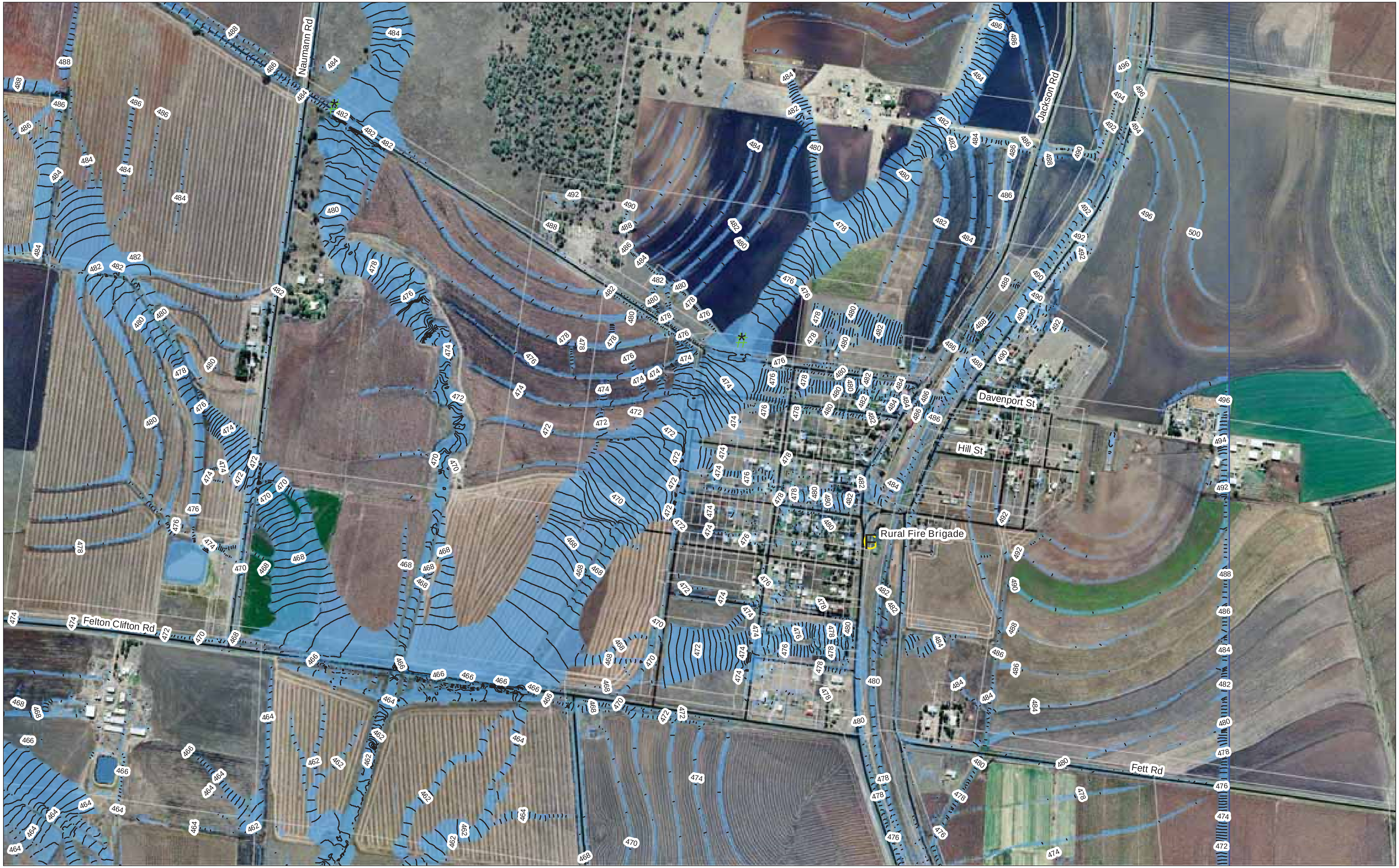

1:8,000 (at A3)

0 50 100 200

Metres

GDA 1994 MGA Zone 56

Legend

- Validation Points
- Emergency Locations
- Cadastre
- Road Centreline
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
2011 Validation Event Peak Water Level

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TOOWOOMBA REGIONAL COUNCIL

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

- < 0.1
- 0.1- 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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SP 051 Flood Studies
Work Package 10 - Nobby
10 Year ARI Event Peak Depth

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0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
10 Year ARI Event Peak Water Level

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1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

Emergency Locations	Model Extent	0.25 - 0.5	2.5 - 3.0	> 5.0
Cadastre	Peak Depth (m)	0.5 - 1.0	3.0 - 3.5	
Road Centreline	< 0.1	1.0 - 1.5	3.5 - 4.0	
Model Boundaries	0.1- 0.25	1.5 - 2.0	4.0 - 4.5	
		2.0 - 2.5	4.5 - 5.0	

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SP 051 Flood Studies
Work Package 10 - Nobby
50 Year ARI Event Peak Depth

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1:17,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
50 Year ARI Event Peak Water Level

TOOWOOMBA REGIONAL COUNCIL

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Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Velocity Vectors

Peak Depth (m)

< 0.1	0.1- 0.25	2.0 - 2.5	4.5 - 5.0
	0.25 - 0.5	2.5 - 3.0	> 5.0
	0.5 - 1.0	3.0 - 3.5	
	1.0 - 1.5	3.5 - 4.0	
	1.5 - 2.0	4.0 - 4.5	

TOOWOOMBA REGIONAL COUNCIL

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

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SP 051 Flood Studies
Work Package 10 - Nobby
100 Year ARI Event Peak Depth

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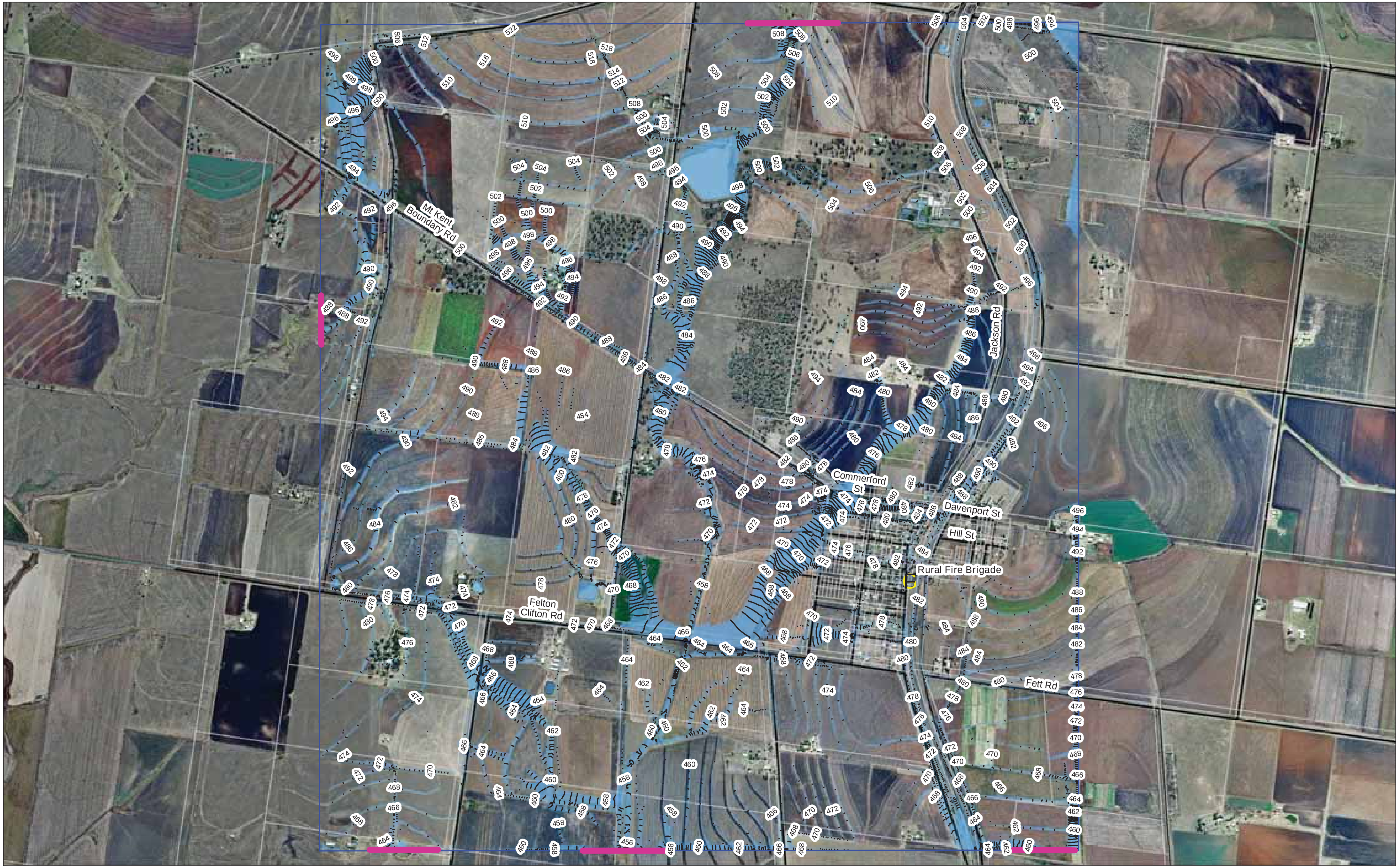
Date Saved: 12/05/2014

SP 051 Flood Studies
Work Package 10 - Nobby
100 Year ARI Event Peak Water Level



1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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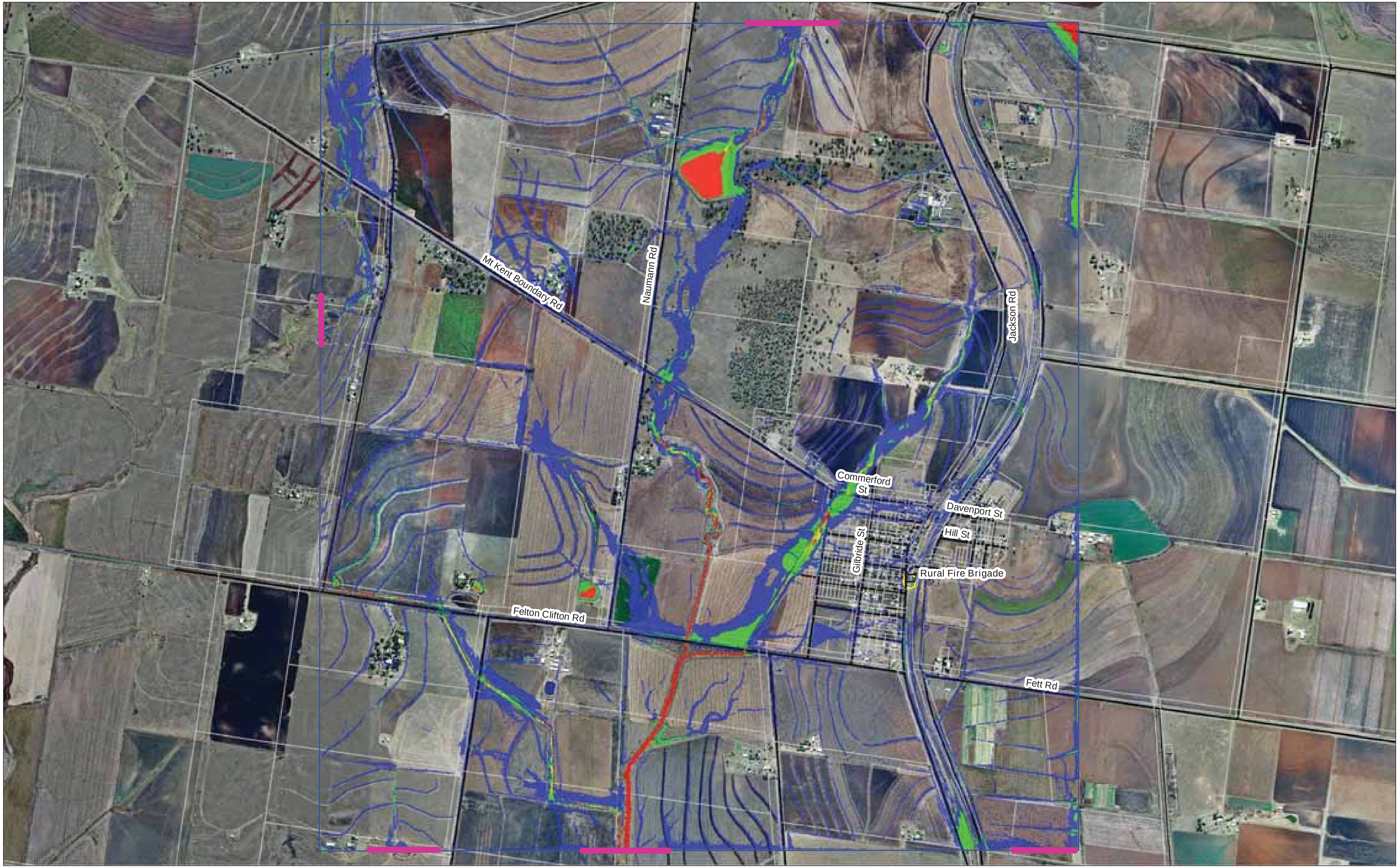

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Hazard Categories
  - Low
  - Significant
  - High
  - Extreme

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SP 051 Flood Studies
Work Package 10 - Nobby
100 Year ARI Event Peak Hazard

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Date Saved: 16/06/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Flood Category
  - Floodway
  - Flood Fringe

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SP 051 Flood Studies
Work Package 10 - Nobby
100 Year ARI Event Flood Category

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Date Saved: 14/05/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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SP 051 Flood Studies
Work Package 10 - Nobby
500 Year ARI Event Peak Depth

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Date Saved: 12/05/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
500 Year ARI Event Peak Water Level

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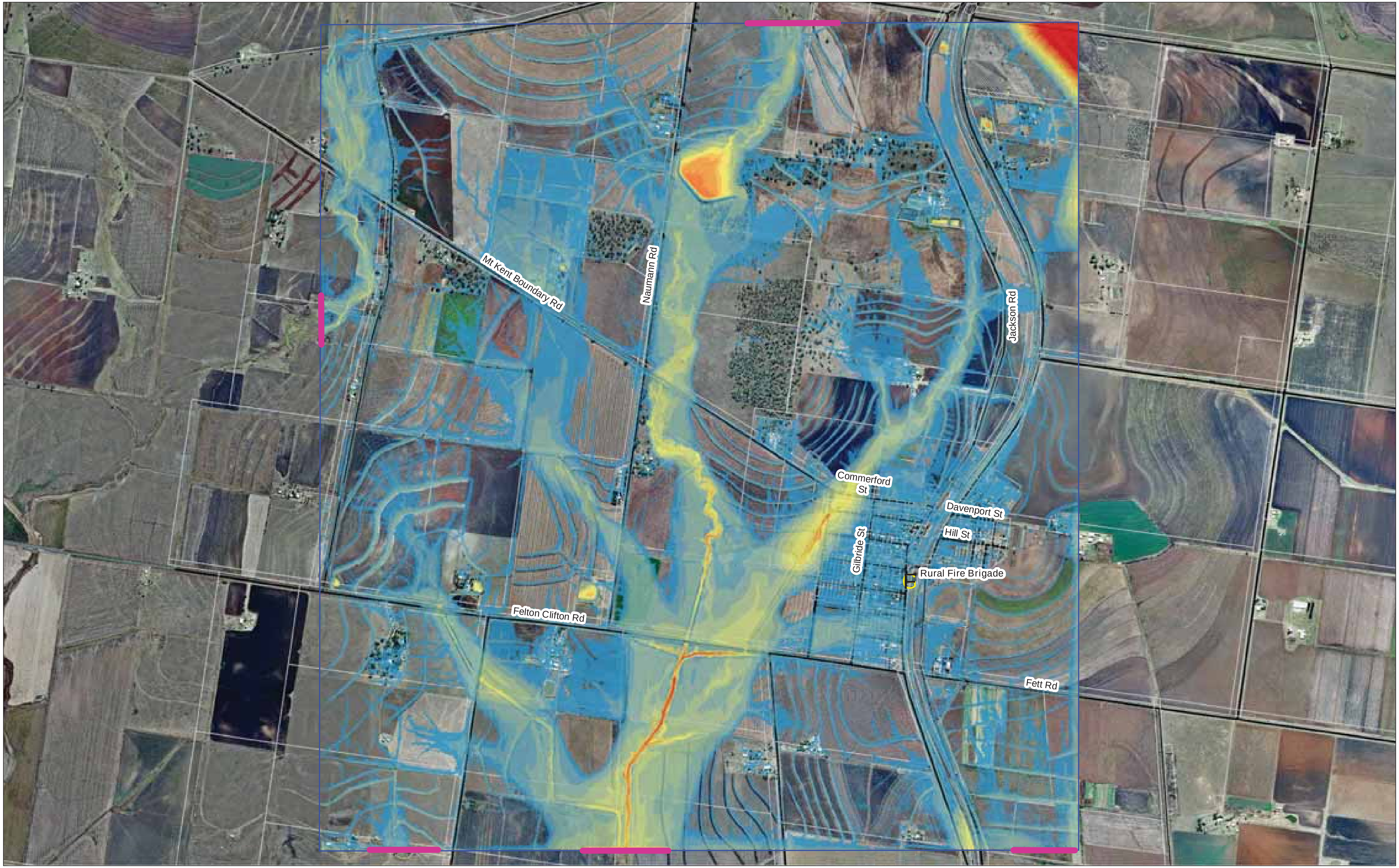

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

< 0.1	0.25 - 0.5	2.5 - 3.0	> 5.0
0.1- 0.25	0.5 - 1.0	3.0 - 3.5	
	1.0 - 1.5	3.5 - 4.0	
	1.5 - 2.0	4.0 - 4.5	
	2.0 - 2.5	4.5 - 5.0	

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SP 051 Flood Studies
Work Package 10 - Nobby
PMP Event Peak Depth

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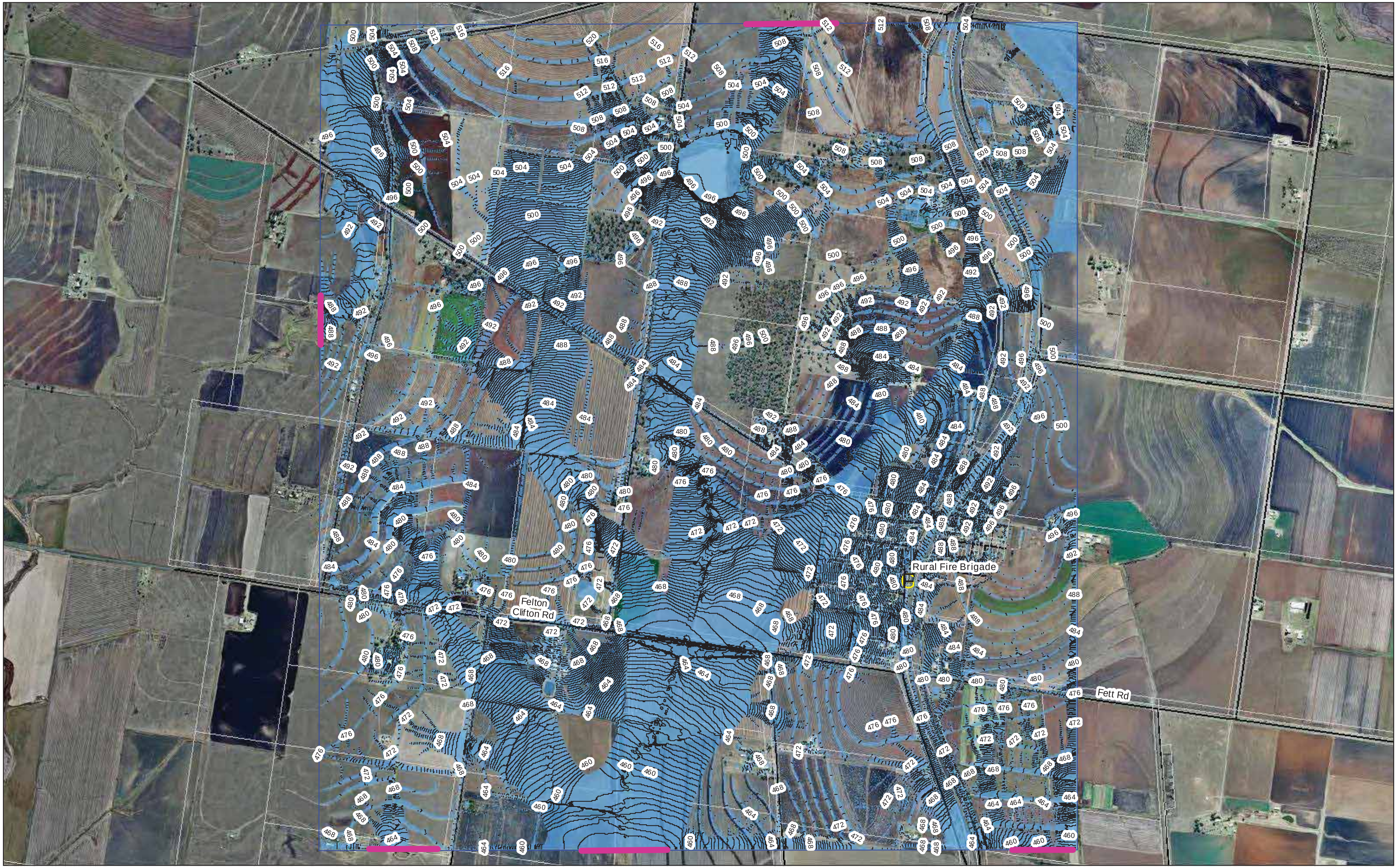

TOOWOOMBA REGIONAL COUNCIL

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
PMP Event Peak Water Level

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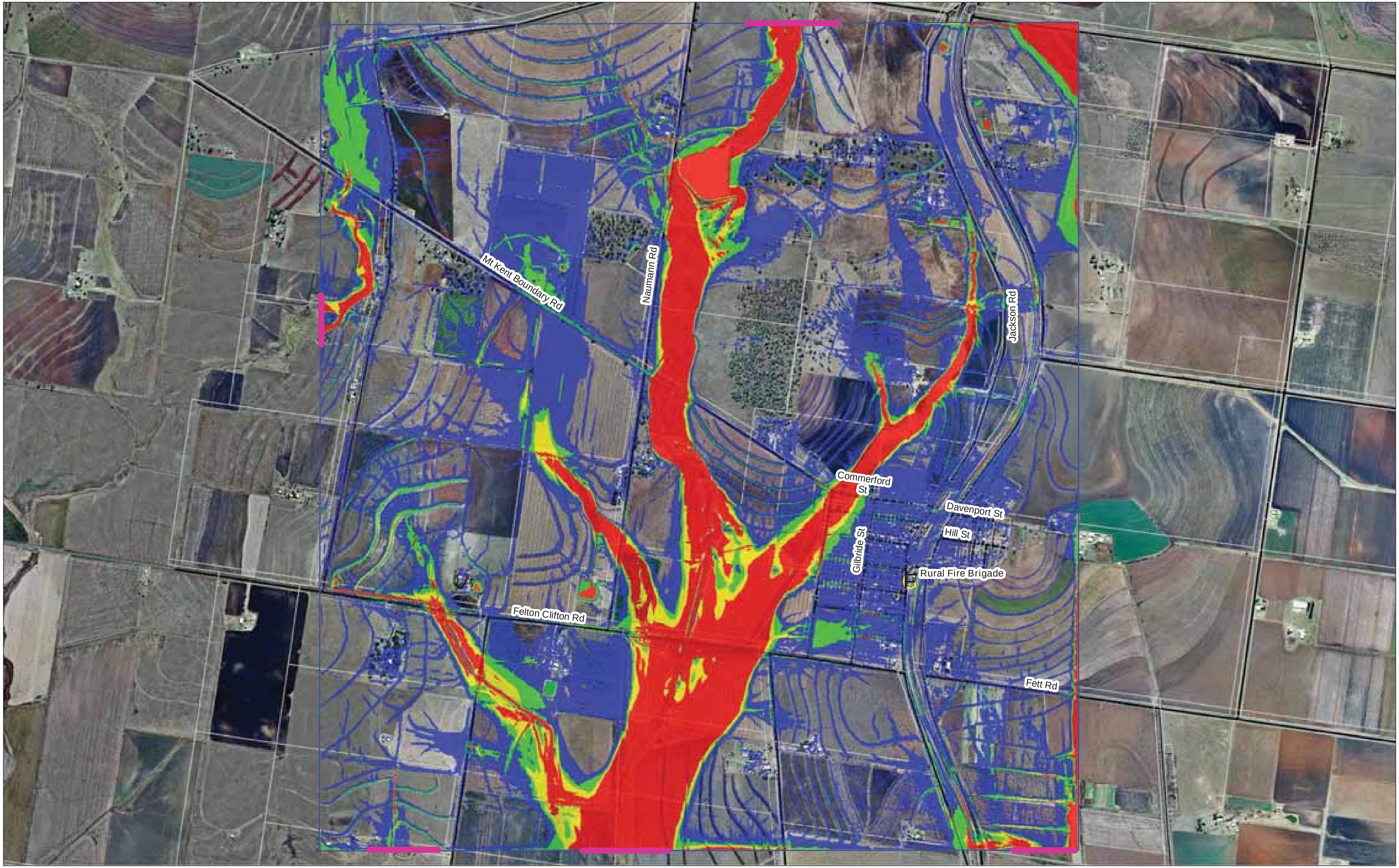

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Hazard Categories
  - Low
  - Significant
  - High
  - Extreme

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SP 051 Flood Studies
Work Package 10 - Nobby
PMP Event Peak Hazard

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Date Saved: 16/06/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Flood Category
- Floodway
- Flood Fringe

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SP 051 Flood Studies
Work Package 10 - Nobby
PMP Event Flood Category

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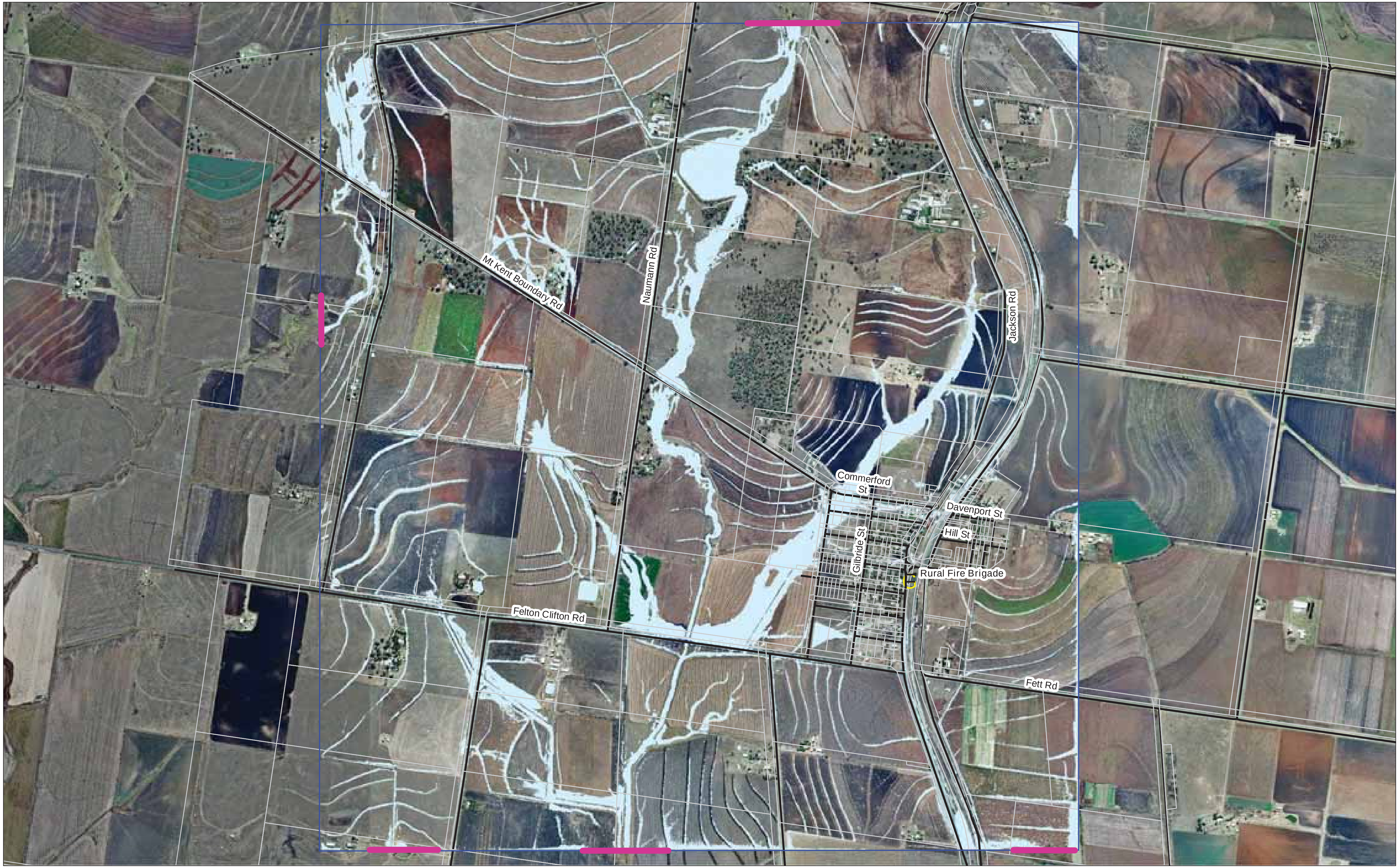

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Flood Extent (Base Case)
- Flood Extent (50% Blockage)

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SP 051 Flood Studies
Work Package 10 - Nobby
Model Sensitivity to Structure Blockage
100 Year ARI Event Peak Flood Level

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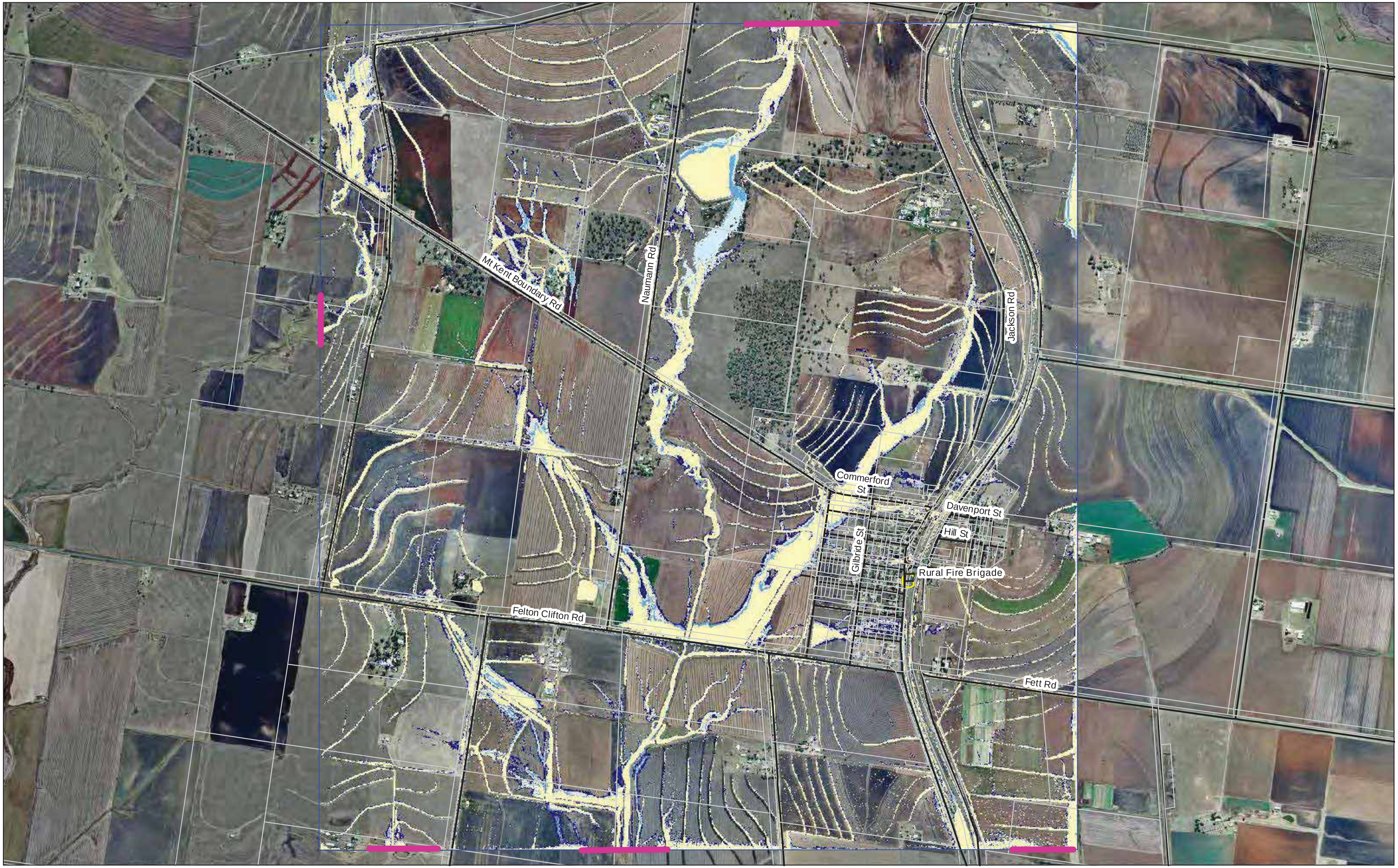
Date Saved: 12/05/2014



TOOWOOMBA REGIONAL COUNCIL

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Flood Extent (Base Case)
- Flood Extent (+30% Rain)
- Flood Extent (-30% Rain)
- Flood Extent (+30% Roughness)
- Flood Extent (-30% Roughness)

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SP 051 Flood Studies
Work Package 10 - Nobby
Model Sensitivity to Roughness and Rain
100 Year ARI Event Peak Flood Extent

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Date Saved: 25/06/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend
- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 1 (+10%)
100 Year ARI Event Peak Water Level

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Date Saved: 14/05/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 2 (+15%)
100 Year ARI Event Peak Water Level

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Date Saved: 14/05/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 3 (+20%)
100 Year ARI Event Peak Water Level

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Date Saved: 14/05/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 1 (+10%)
200 Year ARI Event Peak Water Level

Toowoomba Regional Council

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Date Saved: 14/05/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 2 (+15%)
200 Year ARI Event Peak Water Level

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0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 3 (+20%)
200 Year ARI Event Peak Water Level

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1:17,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 1 (+10%)
500 Year ARI Event Peak Water Level

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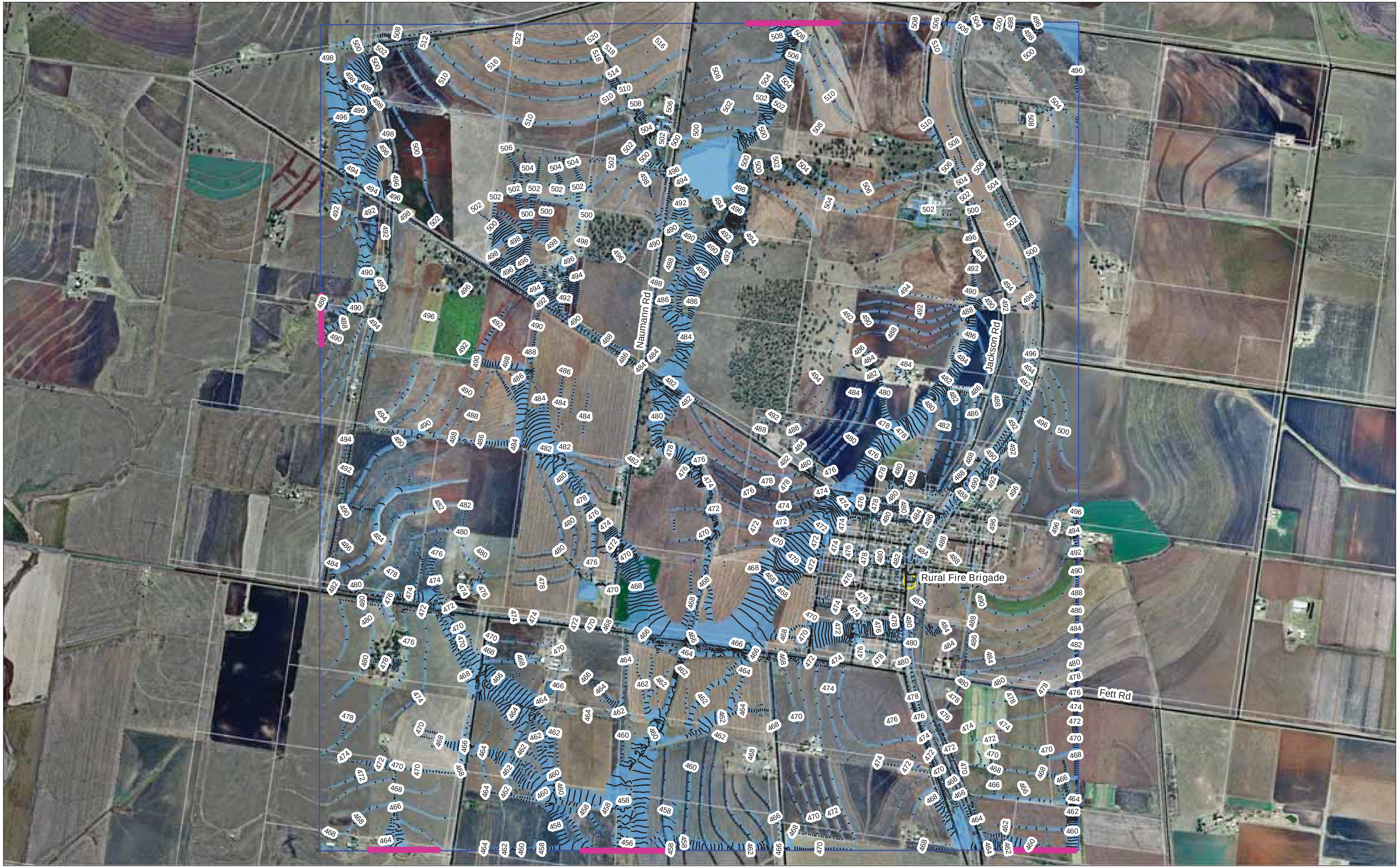

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 2 (+15%)
500 Year ARI Event Peak Water Level

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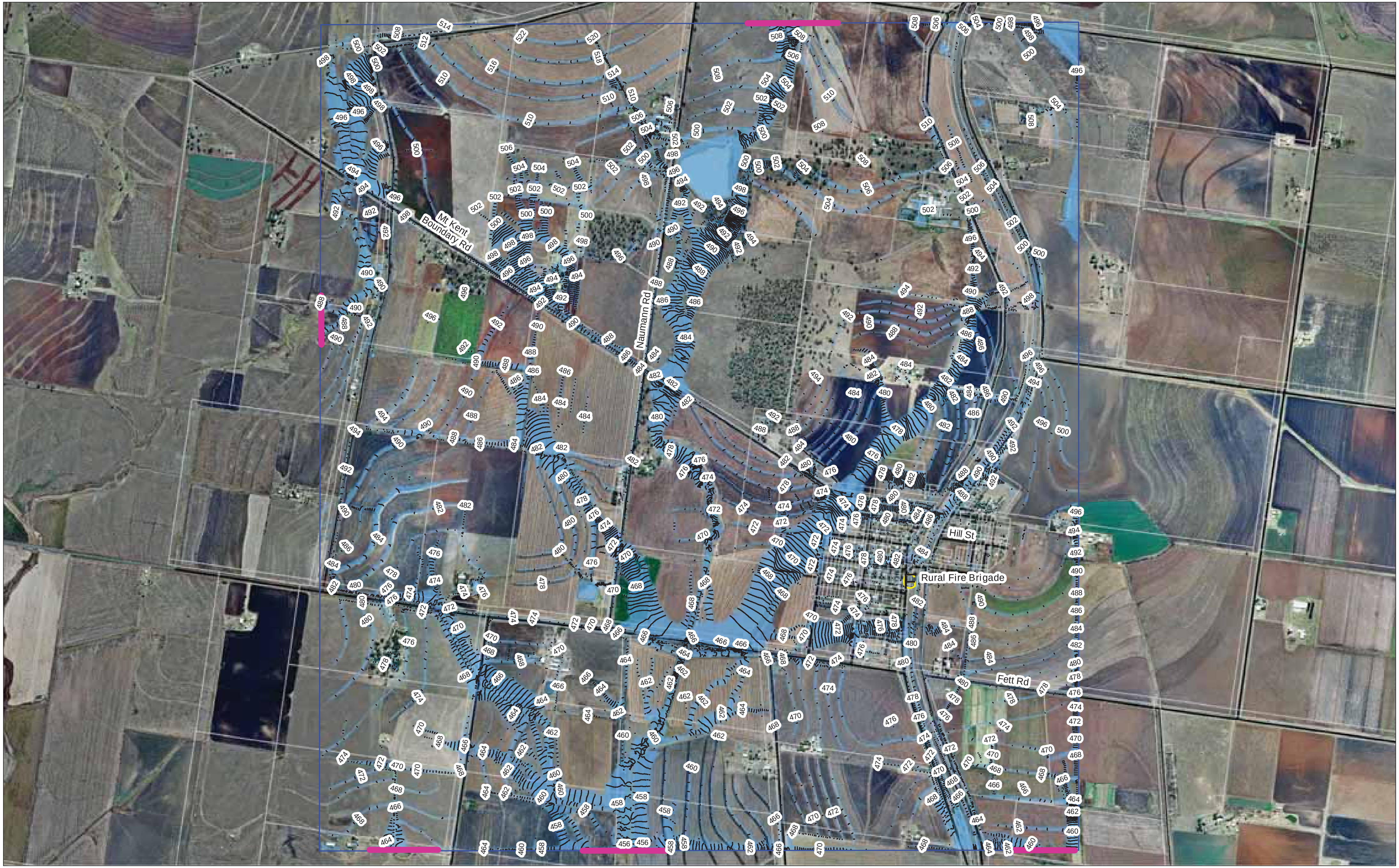

1:17,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Nobby
Climate Change Scenario 3 (+20%)
500 Year ARI Event Peak Water Level

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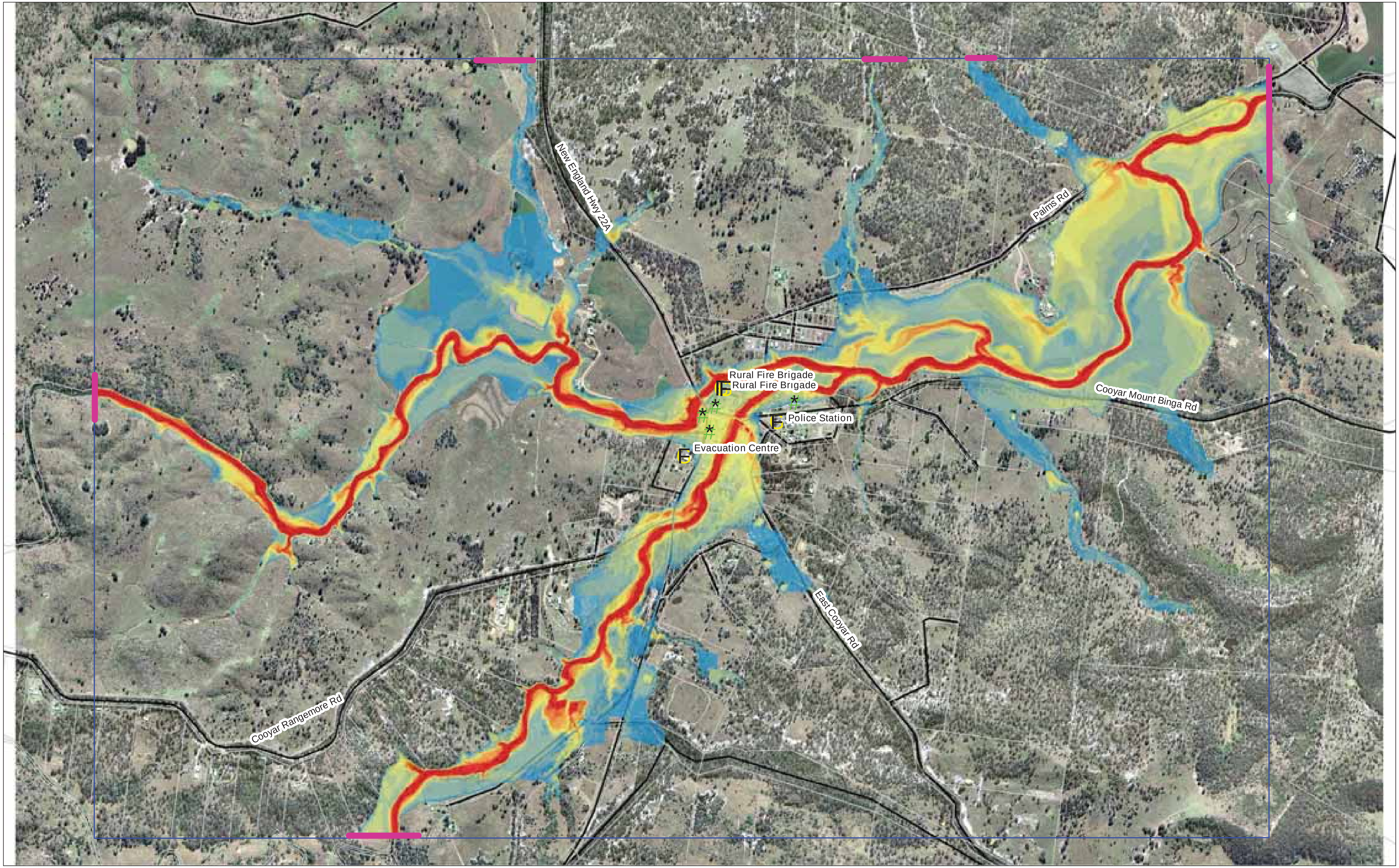
Appendix F. Design Flood Event Mapping – Cooyar



TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Validation Points
- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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SP 051 Flood Studies
Work Package 10 - Cooyar
1988 Validation Event Peak Depth

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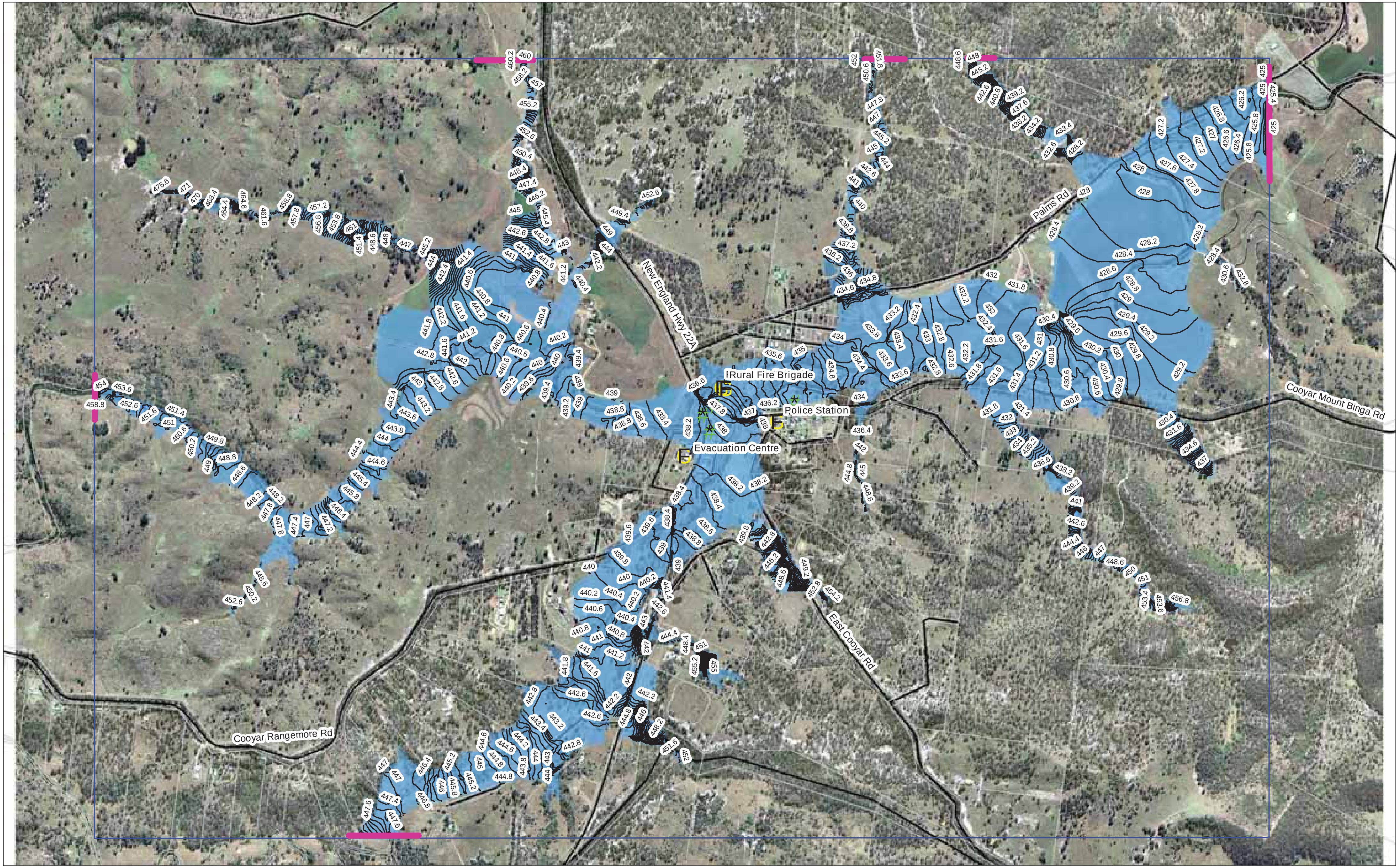

1:15,000 (at A3)

0 125 250 500 Metres

GDA 1994 MGA Zone 56

Legend

- Validation Points
- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
1988 Validation Event Peak Water Level

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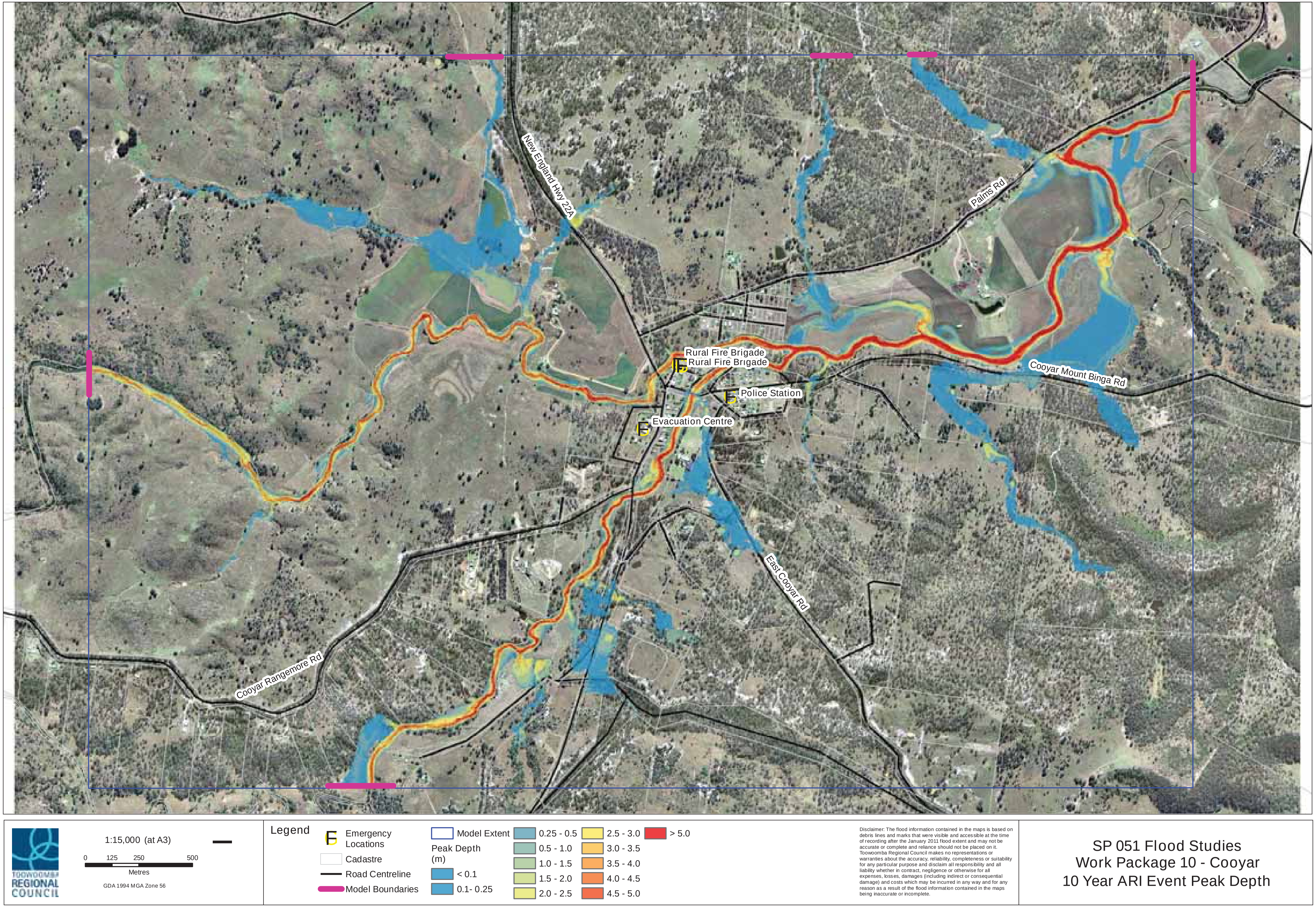

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SP 051 Flood Studies
Work Package 10 - Cooyar
10 Year ARI Event Peak Depth

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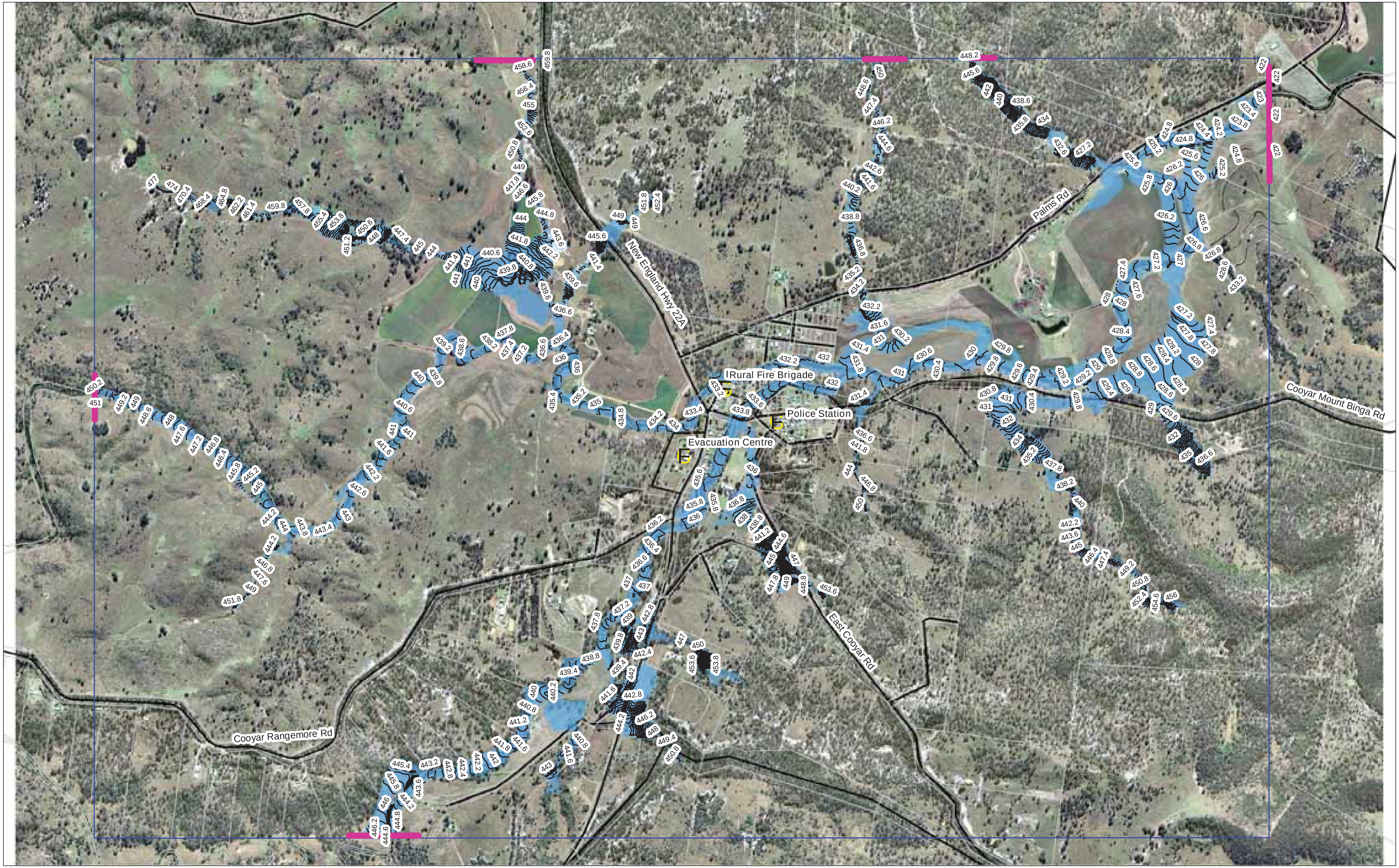

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
10 Year ARI Event Peak Water Level

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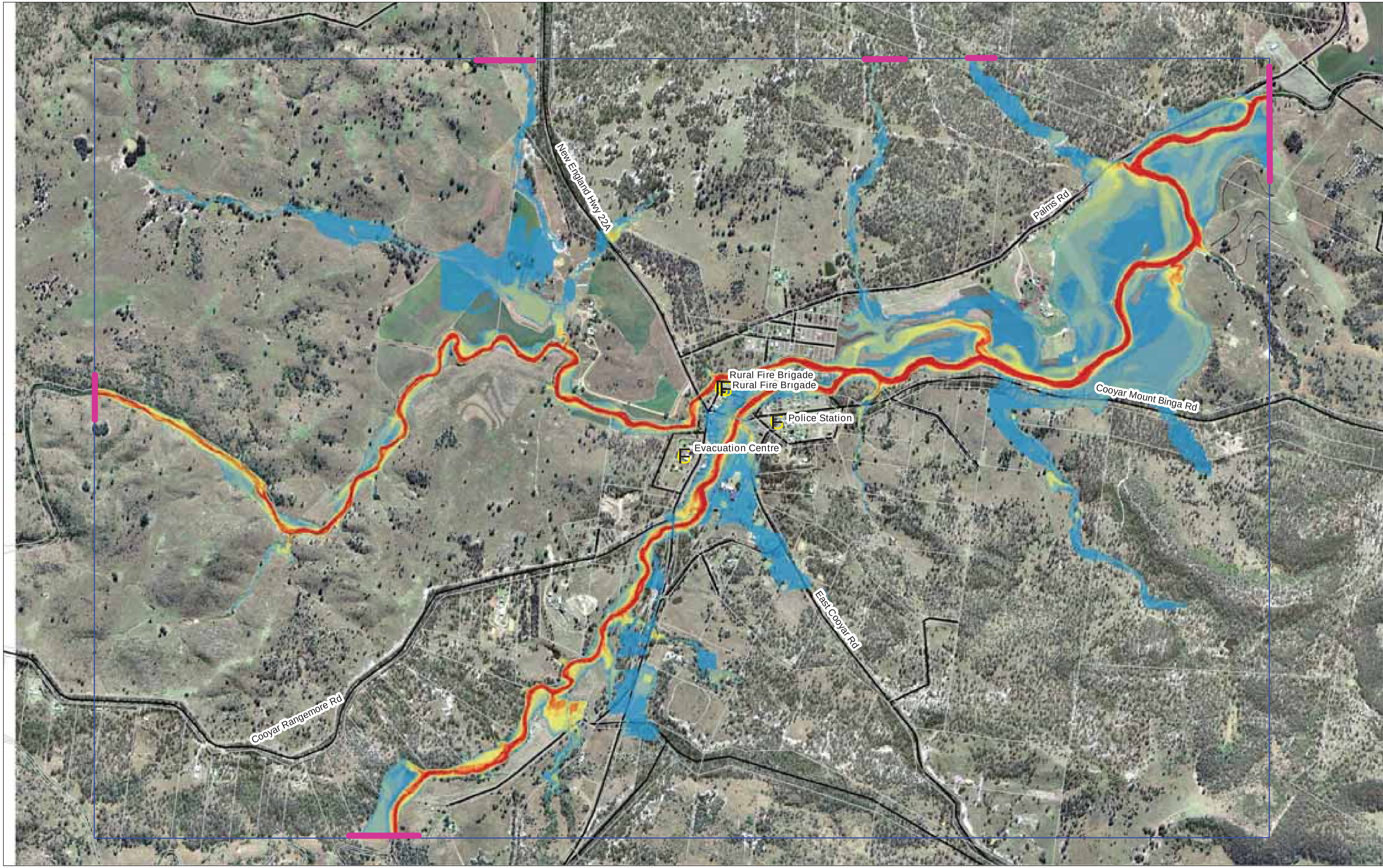

1:15,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

- < 0.1
- 0.1- 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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SP 051 Flood Studies
Work Package 10 - Cooyar
50 Year ARI Event Peak Depth

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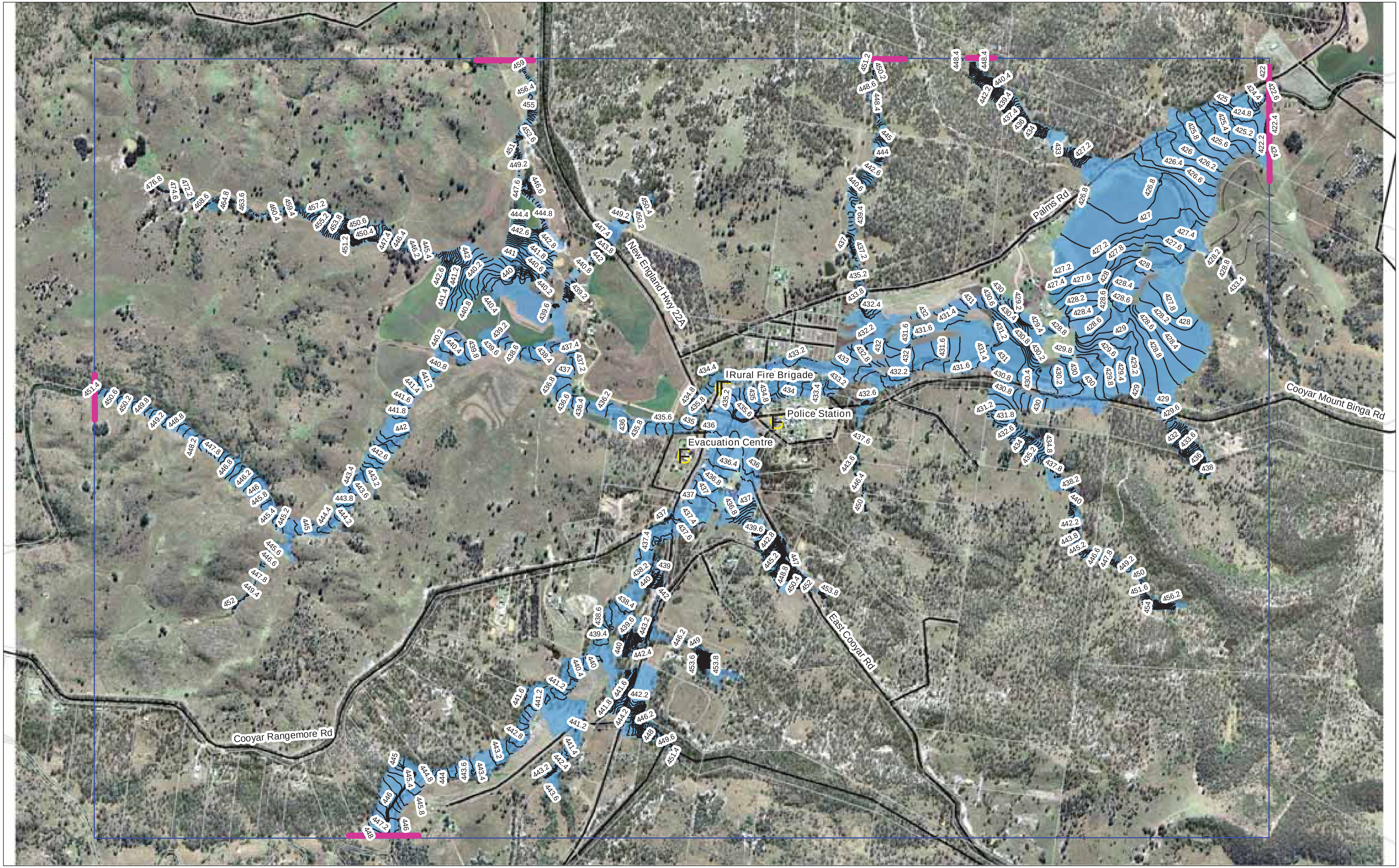

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0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
50 Year ARI Event Peak Water Level

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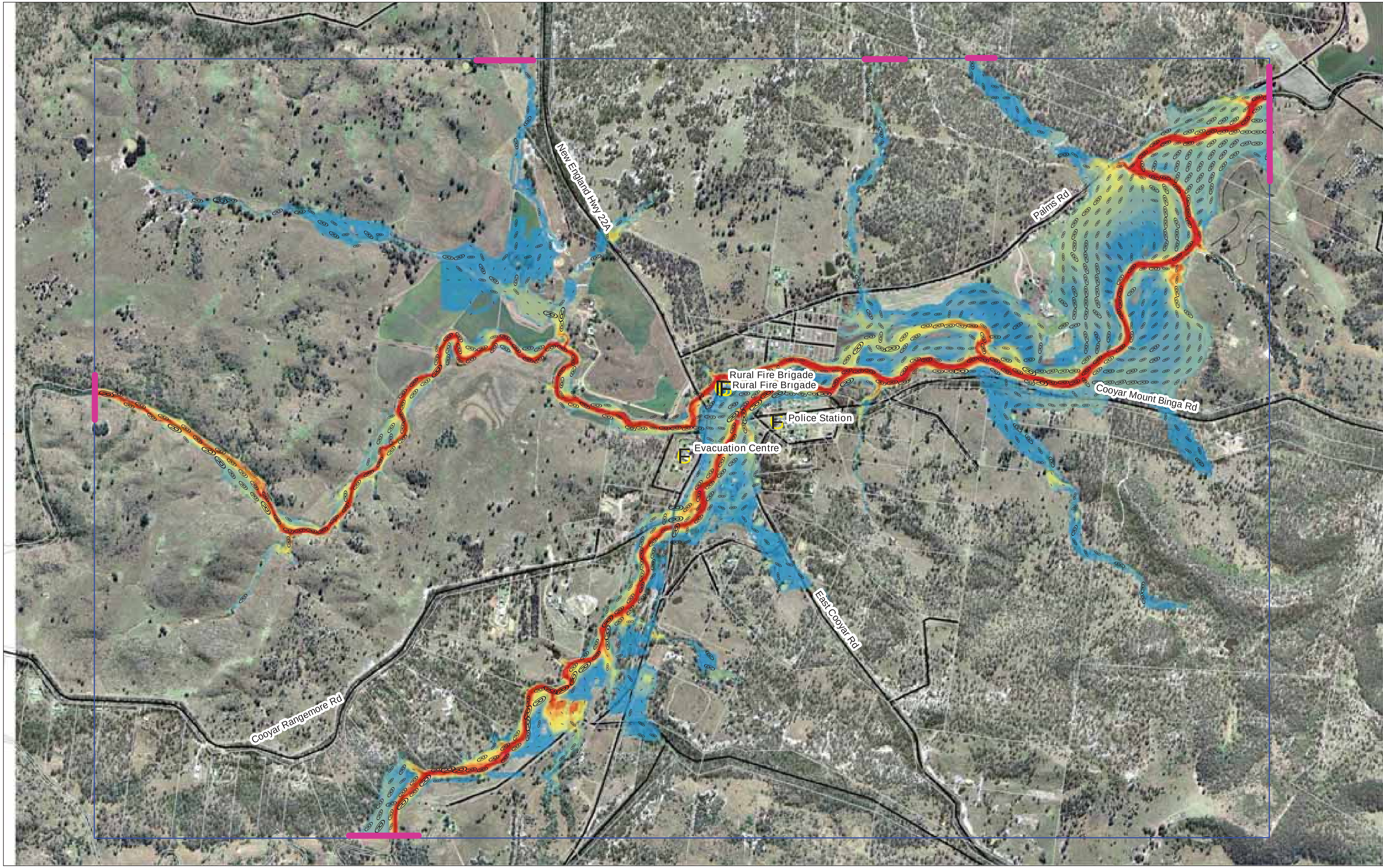

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Velocity Vectors

Peak Depth (m)

- < 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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SP 051 Flood Studies
Work Package 10 - Cooyar
100 Year ARI Event Peak Depth

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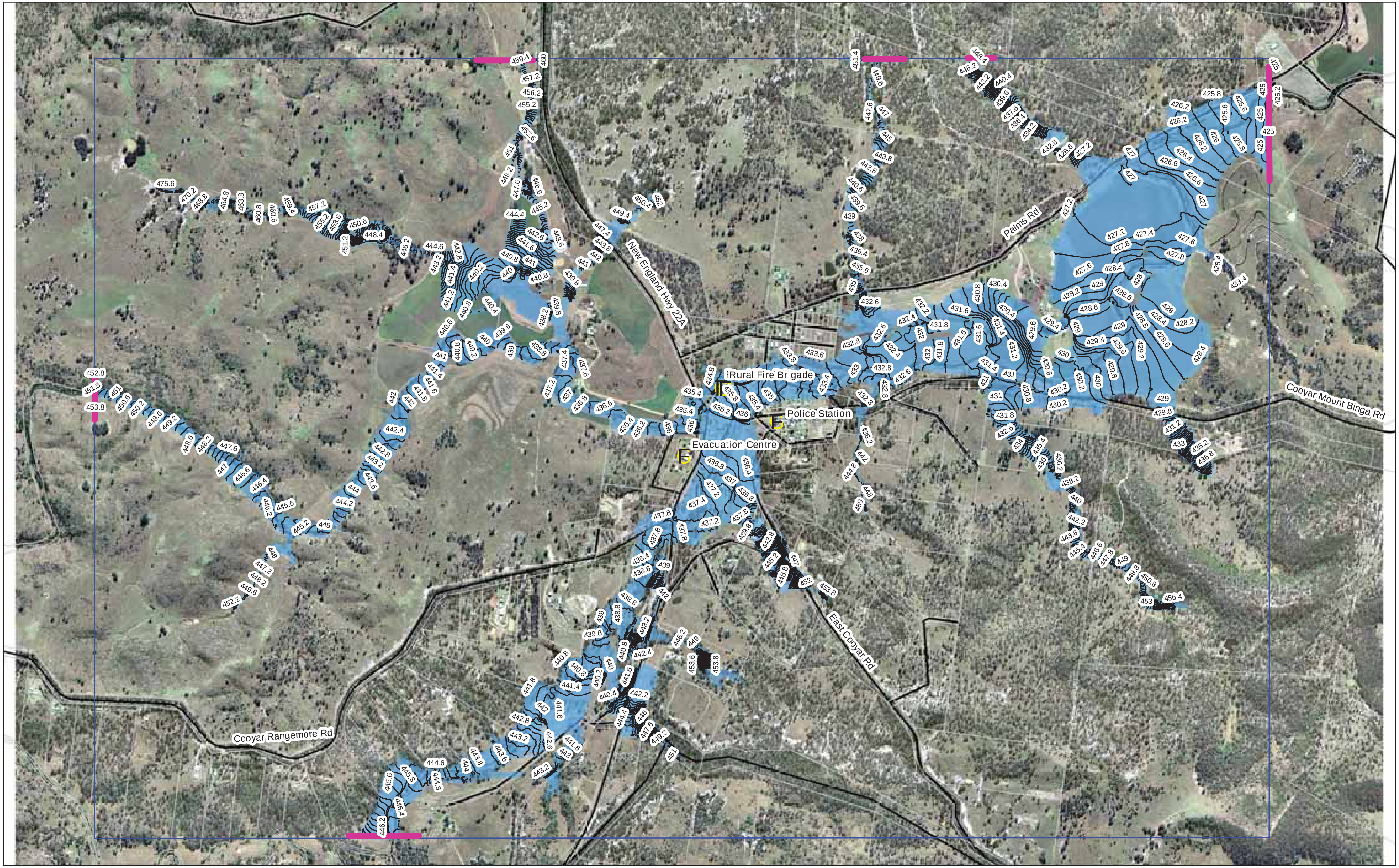

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
100 Year ARI Event Peak Water Level

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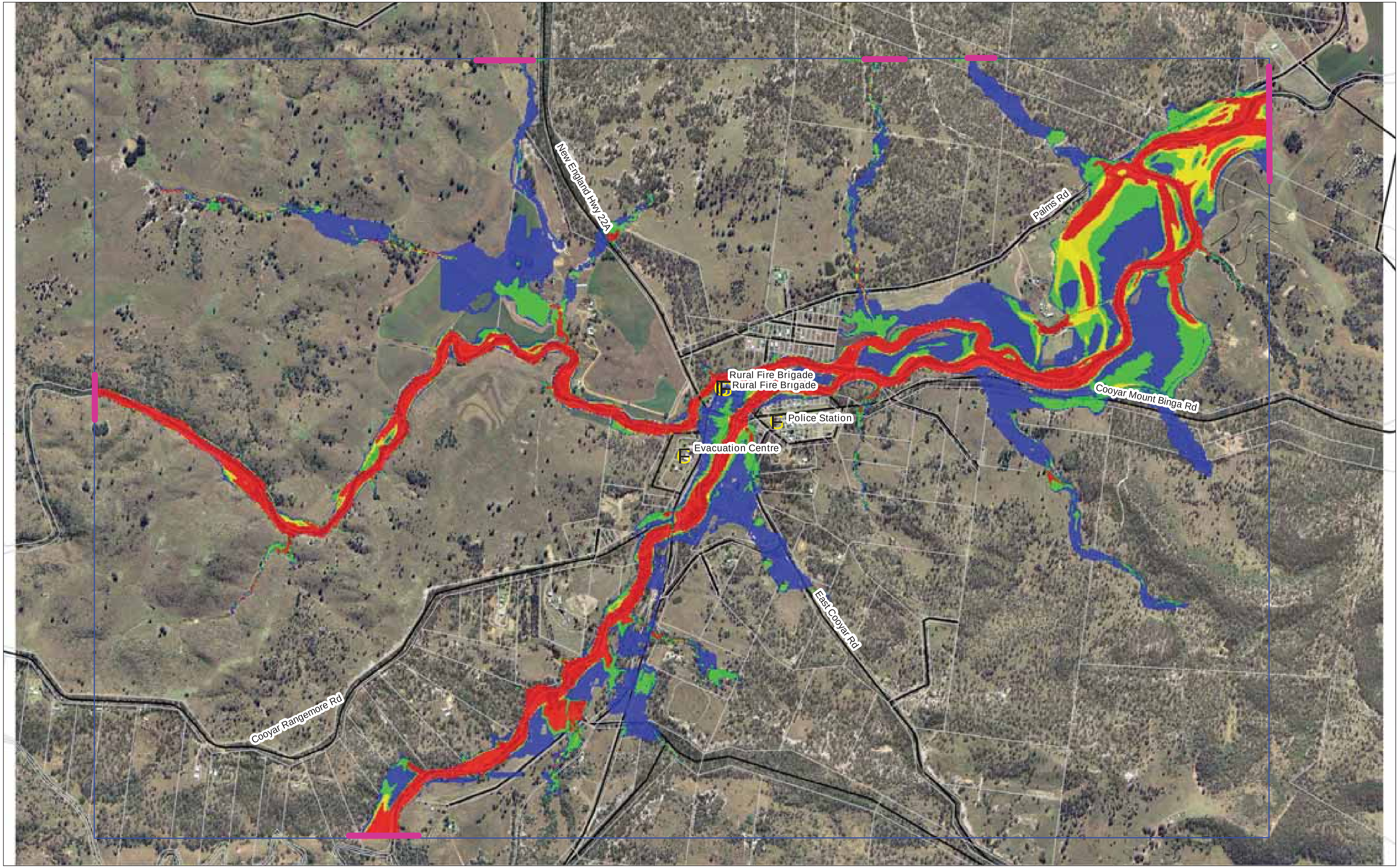

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

Emergency Locations

Cadastre

Road Centreline

Model Boundaries

Model Extent

Hazard Categories

Low

Significant

High

Extreme

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SP 051 Flood Studies
Work Package 10 - Cooyar
100 Year ARI Event Peak Hazard

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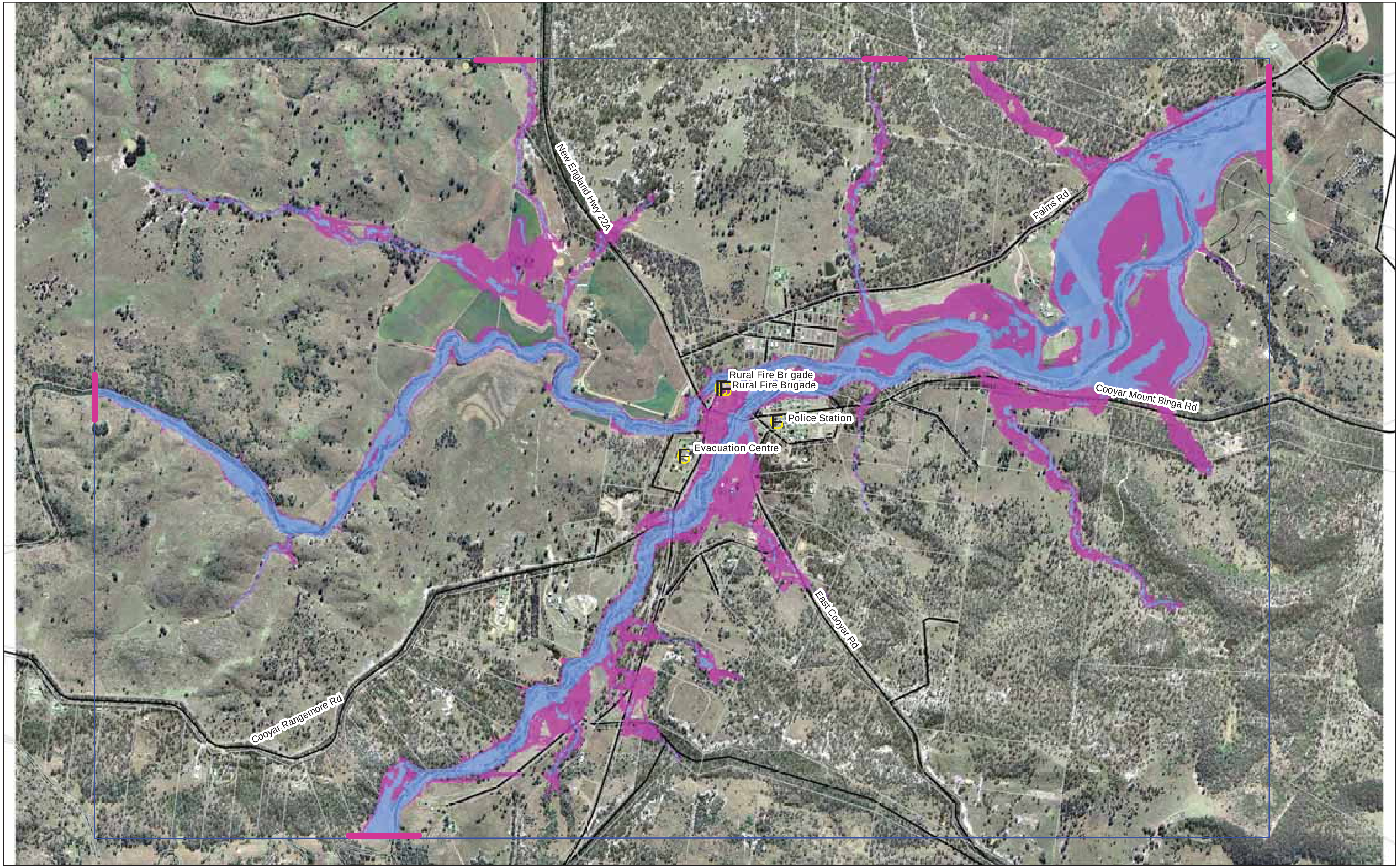

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Flood Category

- Floodway
- Flood Fringe

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SP 051 Flood Studies
Work Package 10 - Cooyar
100 Year ARI Event Flood Category

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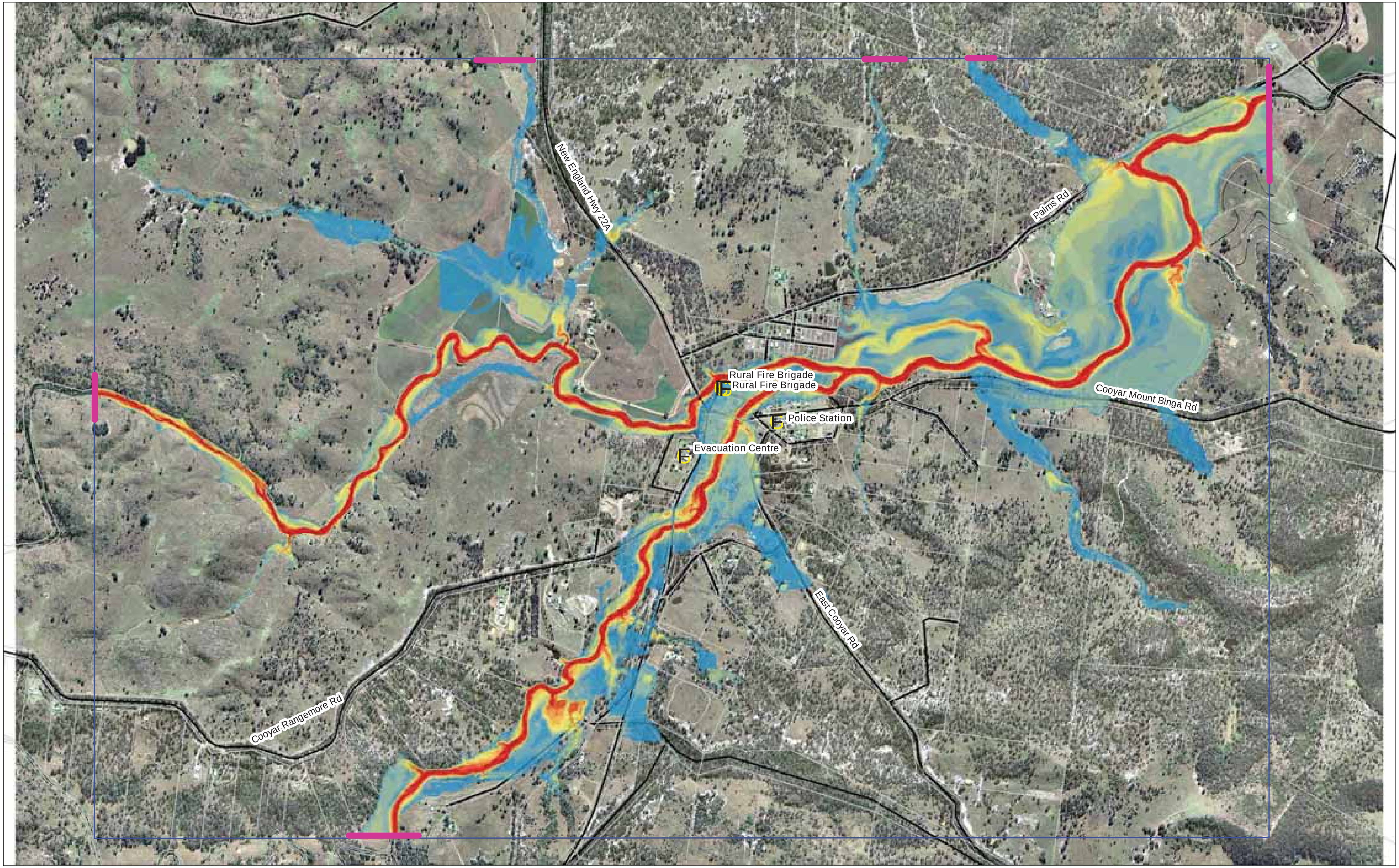

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

- < 0.1
- 0.1- 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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SP 051 Flood Studies
Work Package 10 - Cooyar
500 Year ARI Event Peak Depth

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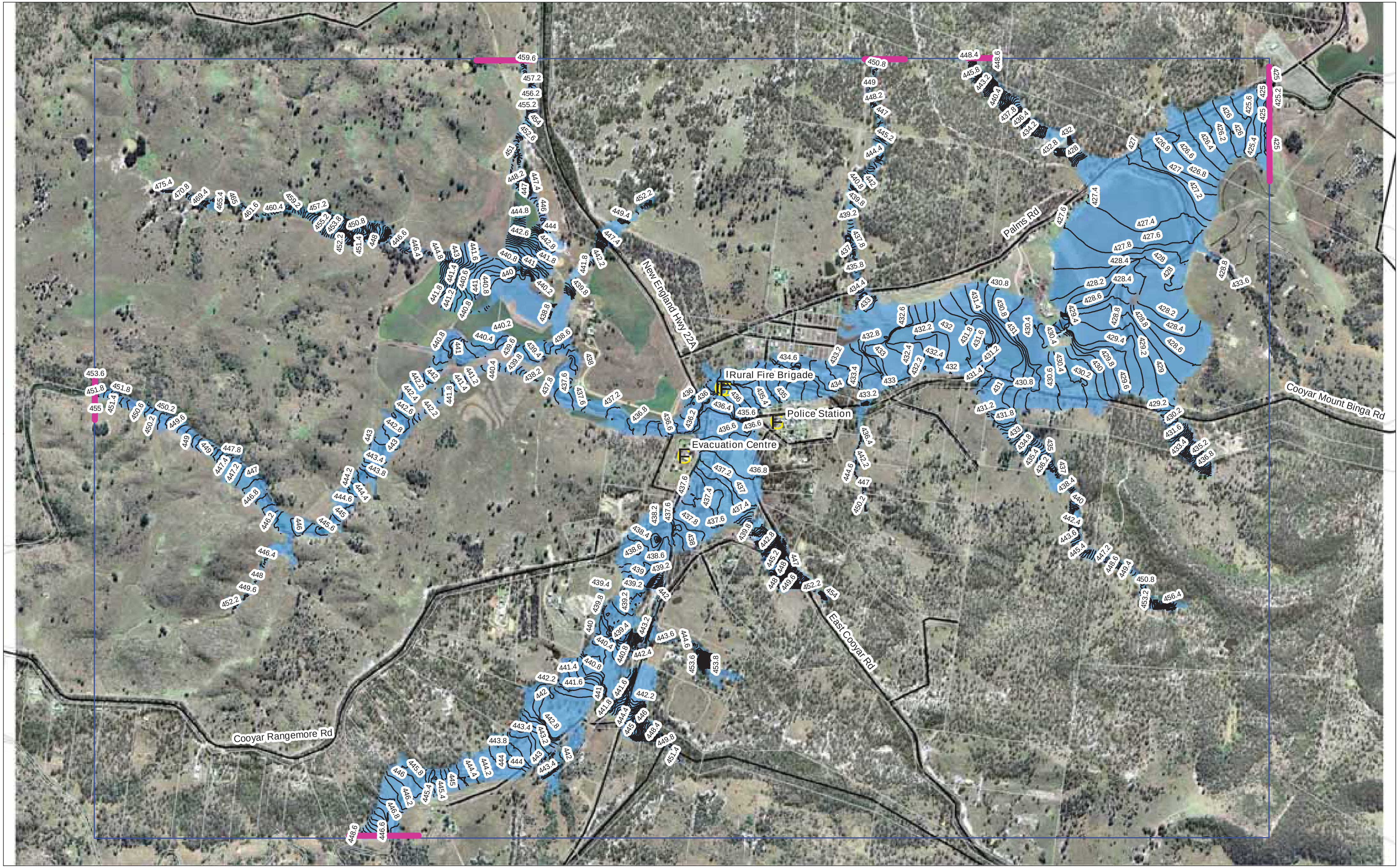

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
500 Year ARI Event Peak Water Level

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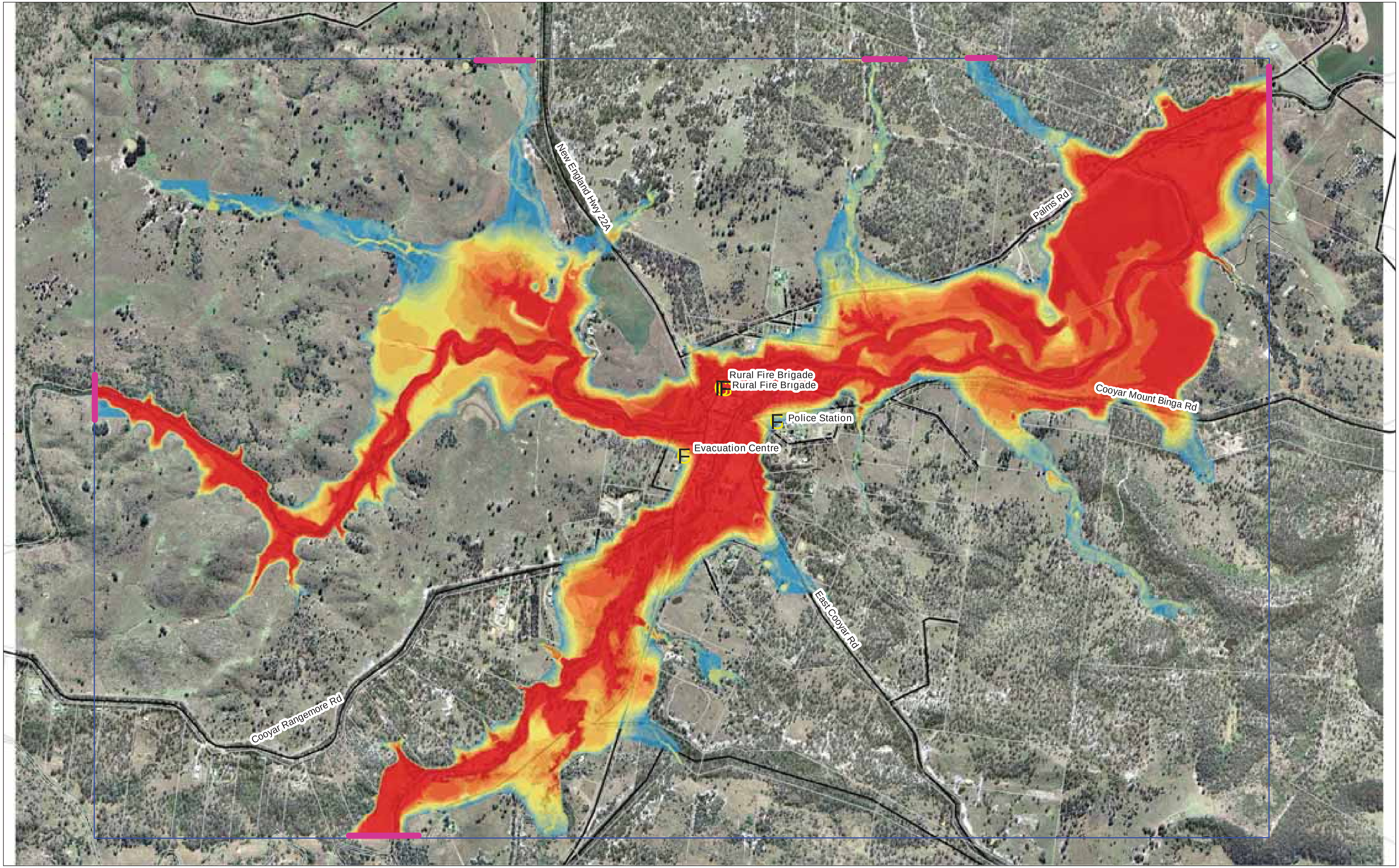

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

Emergency Locations	Model Extent
Cadastre	Peak Depth (m)
Road Centreline	< 0.1
Model Boundaries	0.1- 0.25

0.25 - 0.5	2.5 - 3.0	> 5.0
0.5 - 1.0	3.0 - 3.5	
1.0 - 1.5	3.5 - 4.0	
1.5 - 2.0	4.0 - 4.5	
2.0 - 2.5	4.5 - 5.0	

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SP 051 Flood Studies
Work Package 10 - Cooyar
PMP Event Peak Depth

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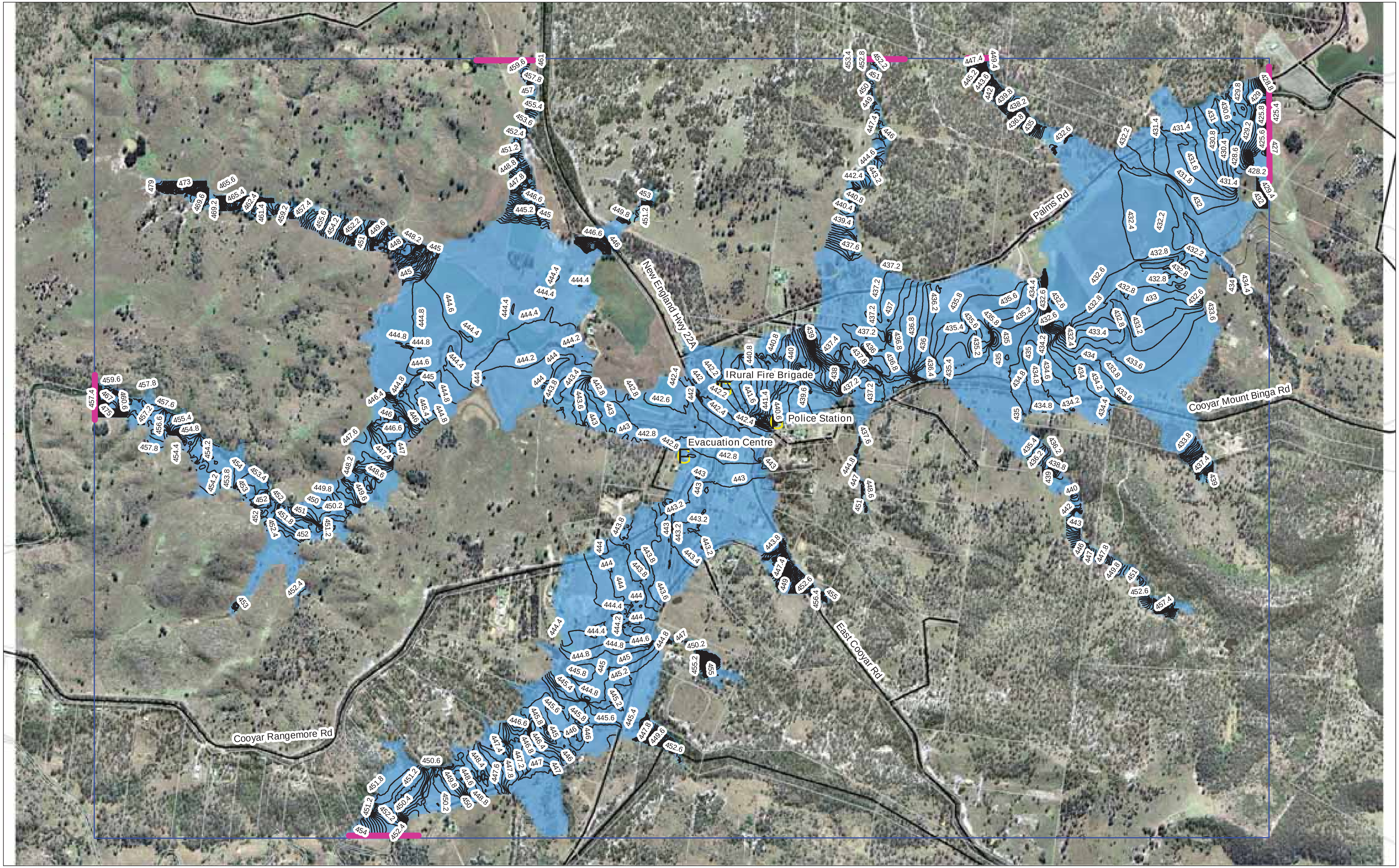

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

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SP 051 Flood Studies
Work Package 10 - Cooyar
PMP Event Peak Water Level

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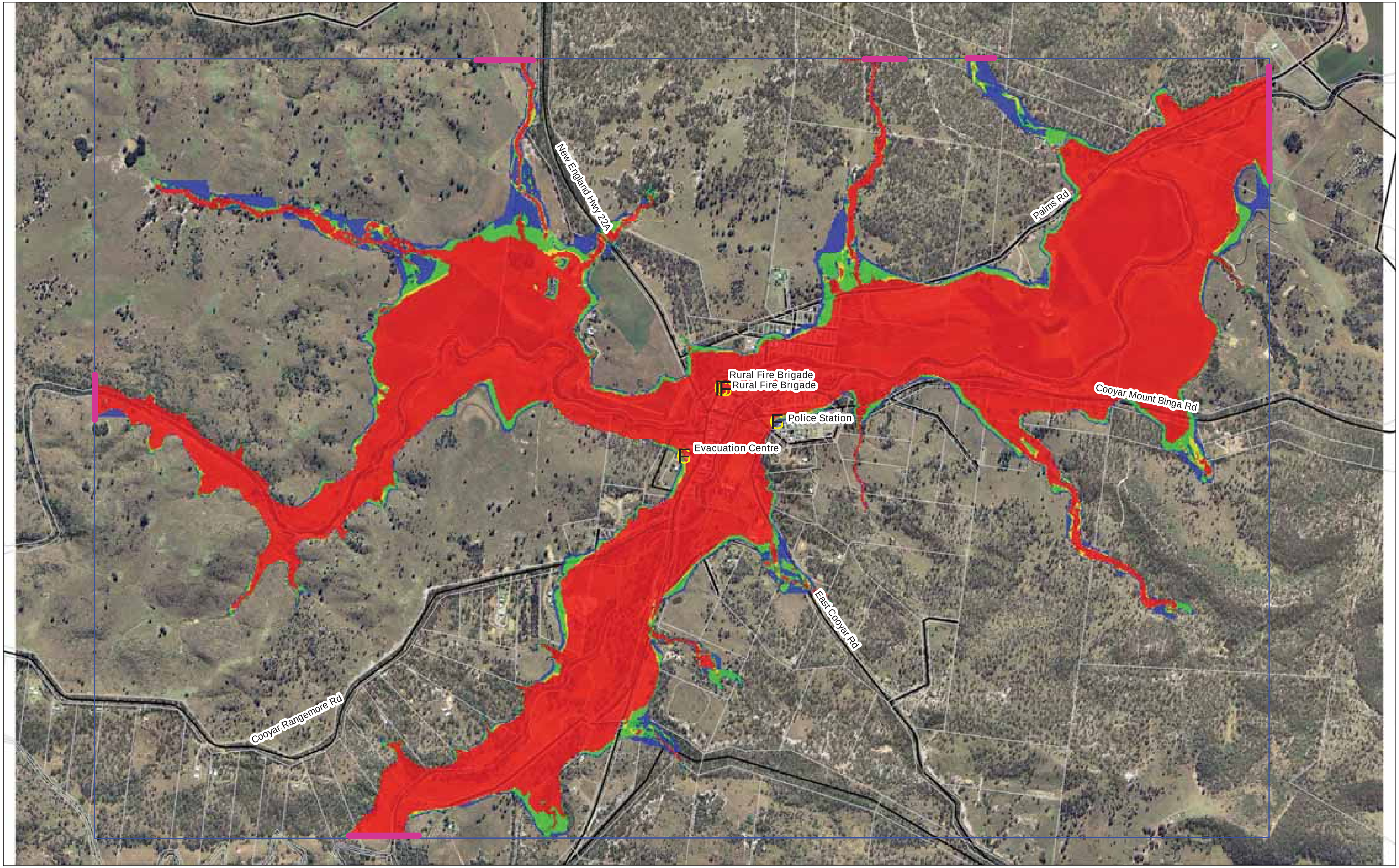

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Hazard Categories
  - Low
  - Significant
  - High
  - Extreme

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SP 051 Flood Studies
Work Package 10 - Cooyar
PMP Event Peak Hazard

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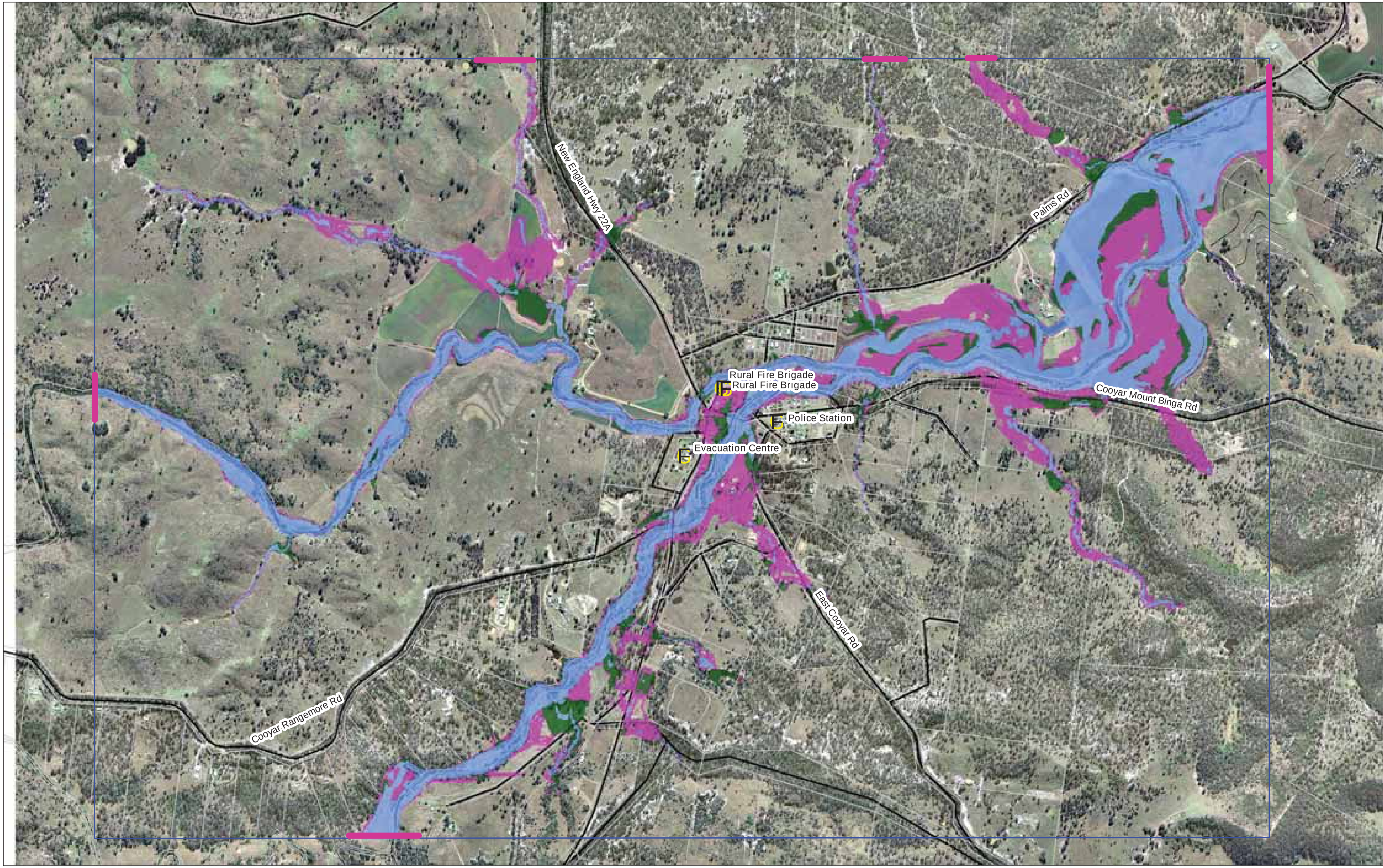

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Flood Category
- Floodway
- Flood Storage
- Flood Fringe

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SP 051 Flood Studies
Work Package 10 - Cooyar
PMP Event Flood Category

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Date Saved: 19/03/2014

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Flood Extent (Base Case)
- Flood Extent (50% Blockage)

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SP 051 Flood Studies
Work Package 10 - Cooyar
Model Sensitivity to Structure Blockage
100 Year ARI Event Peak Flood Level

TOOWOOMBA REGIONAL COUNCIL

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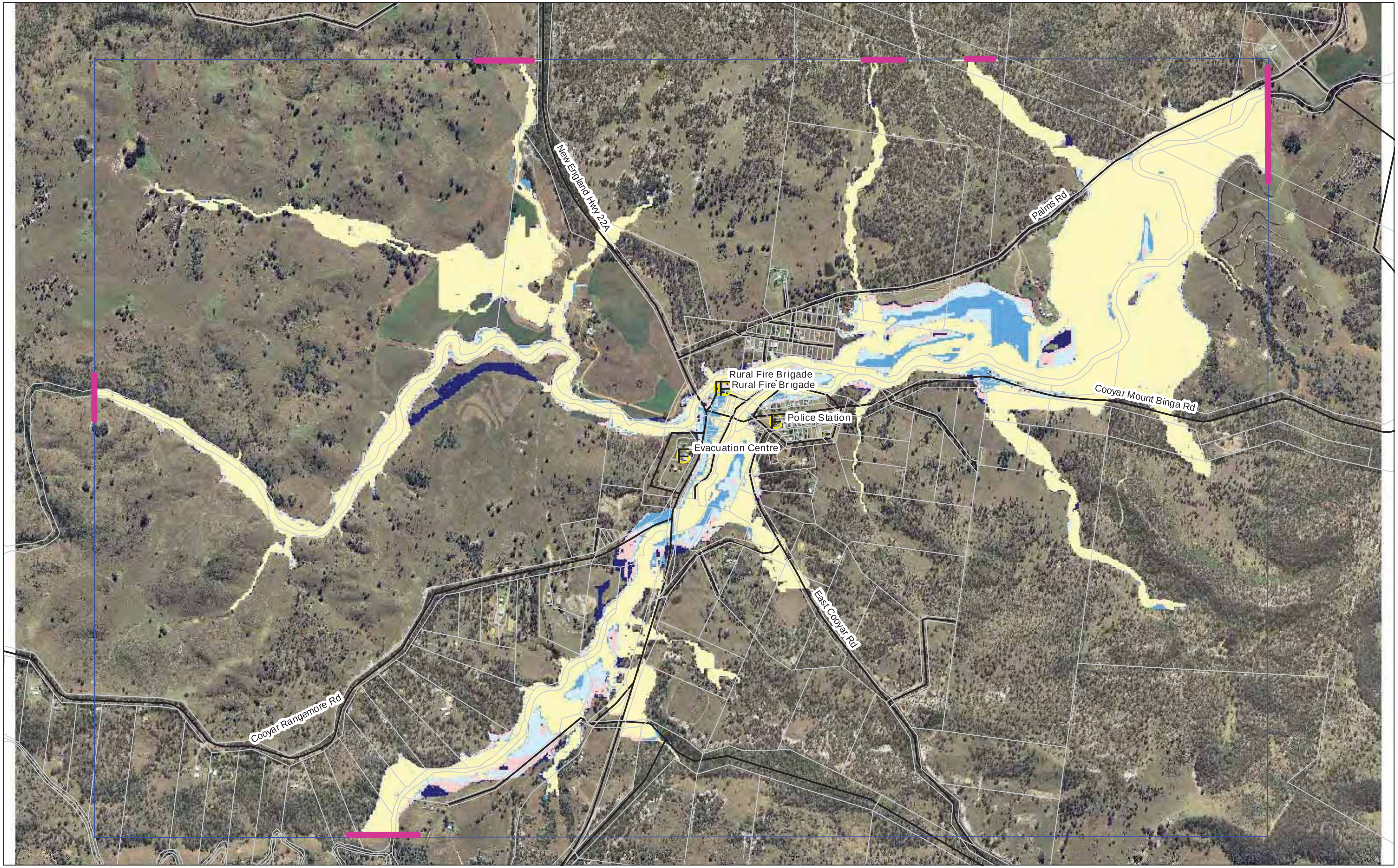

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Flood Extent (Base Case)
- Flood Extent (+30% Flow)
- Flood Extent (-30% Flow)
- Flood Extent (+30% Roughness)
- Flood Extent (-30% Roughness)

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SP 051 Flood Studies
Work Package 10 - Cooyar
Model Sensitivity to Roughness and Flow
100 Year ARI Event Peak Flood Extent

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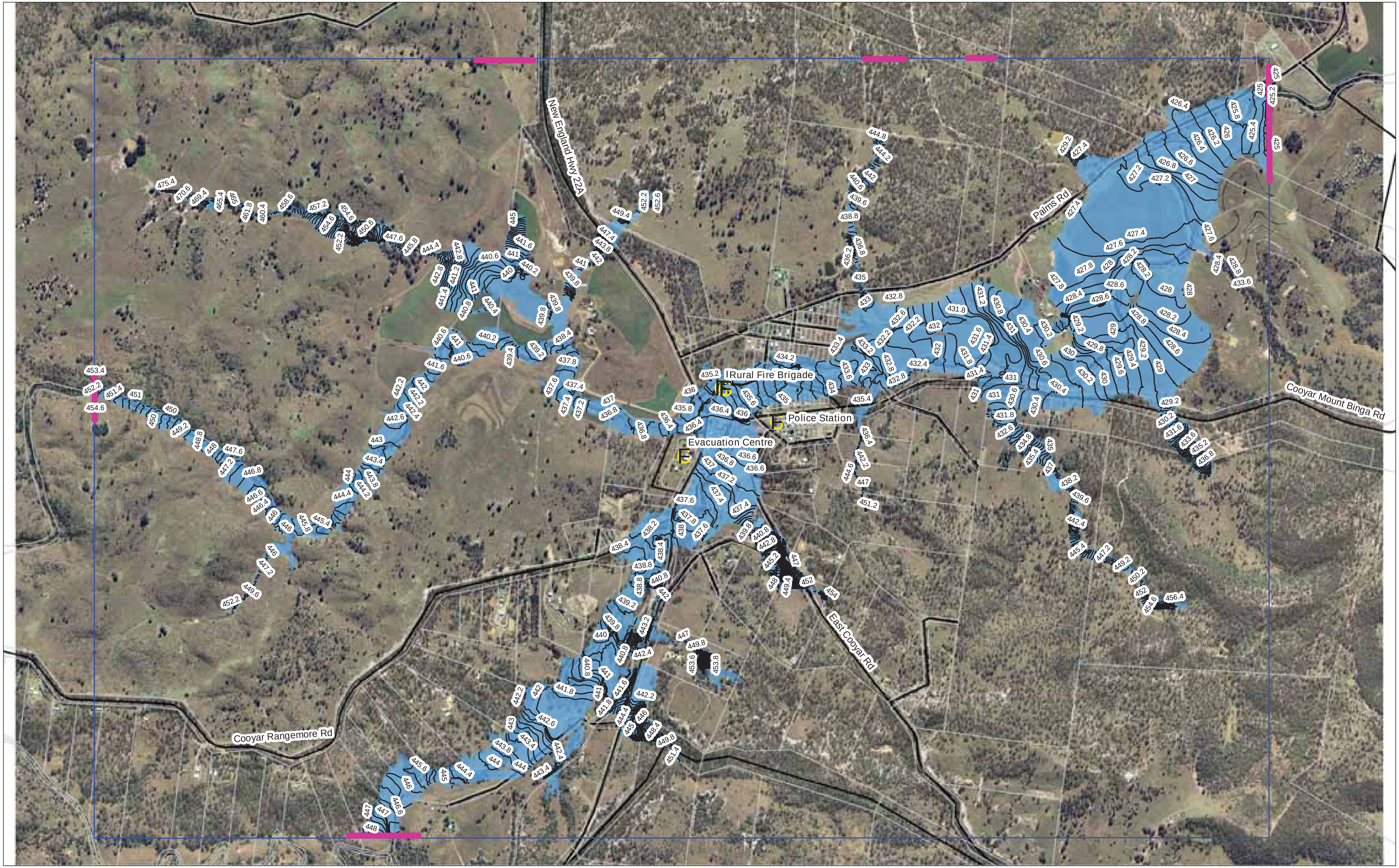

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 1 (+10%)
100 Year ARI Event Peak Water Level

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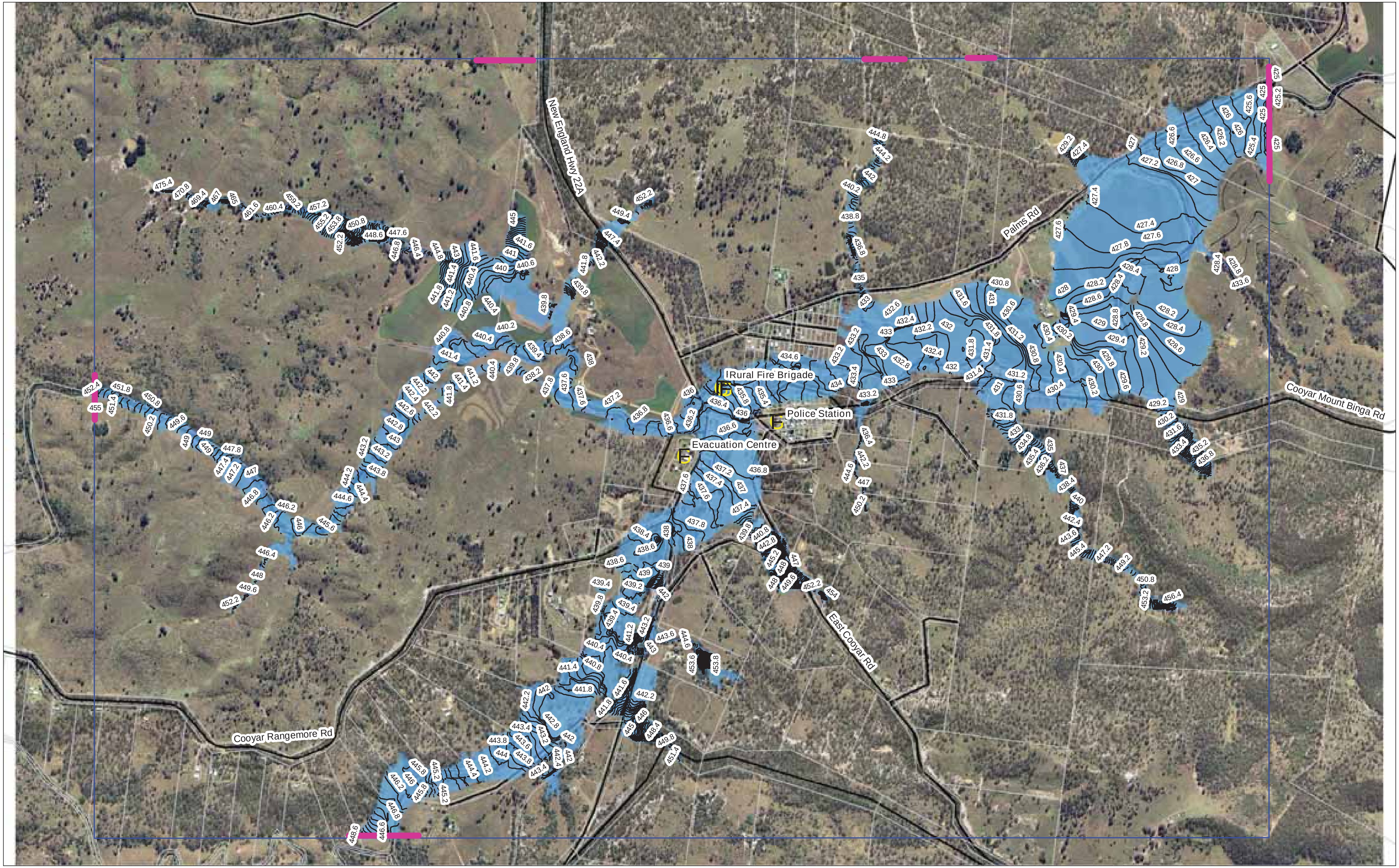

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 2 (+15%)
100 Year ARI Event Peak Water Level

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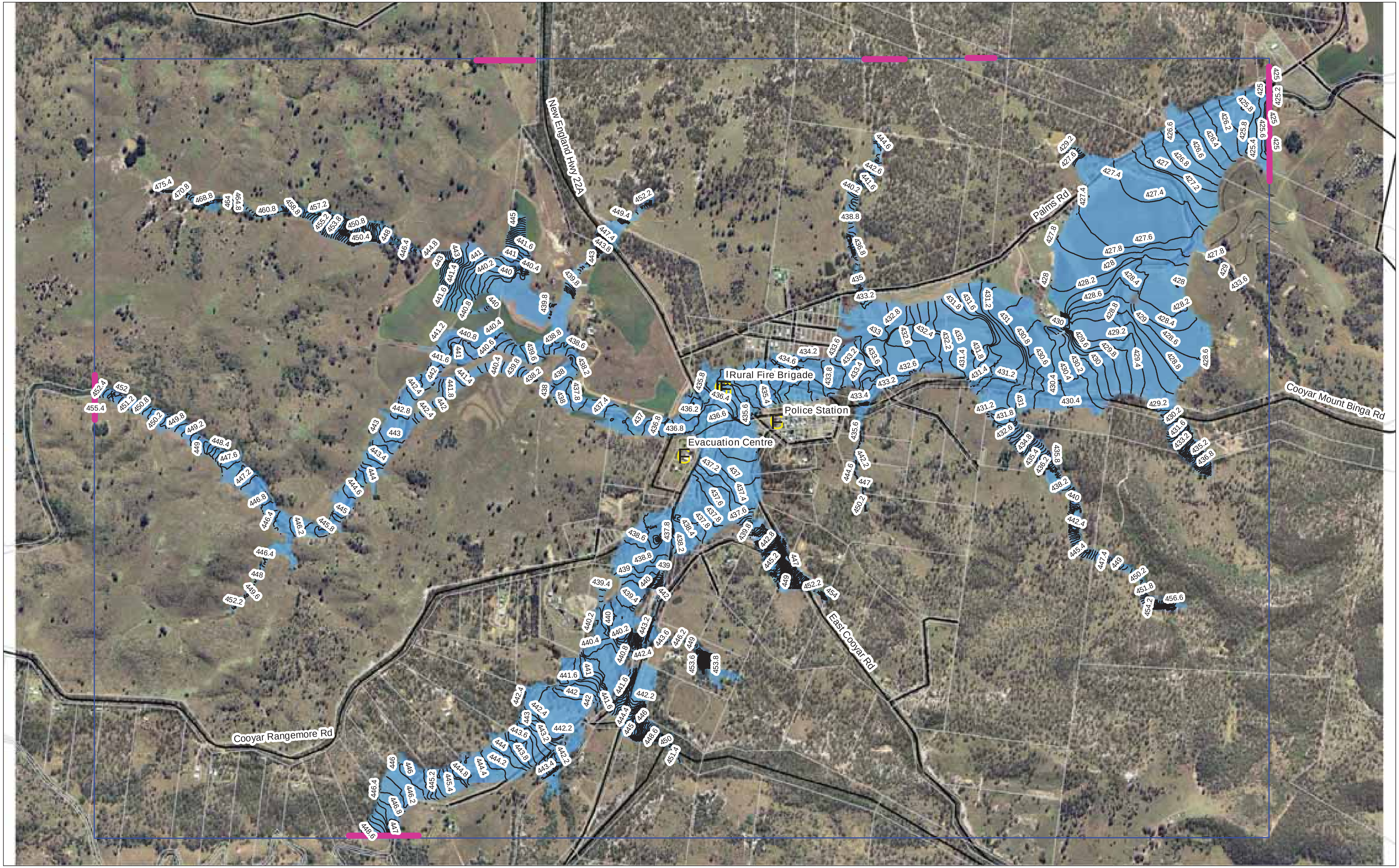

SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 3 (+20%)
100 Year ARI Event Peak Water Level

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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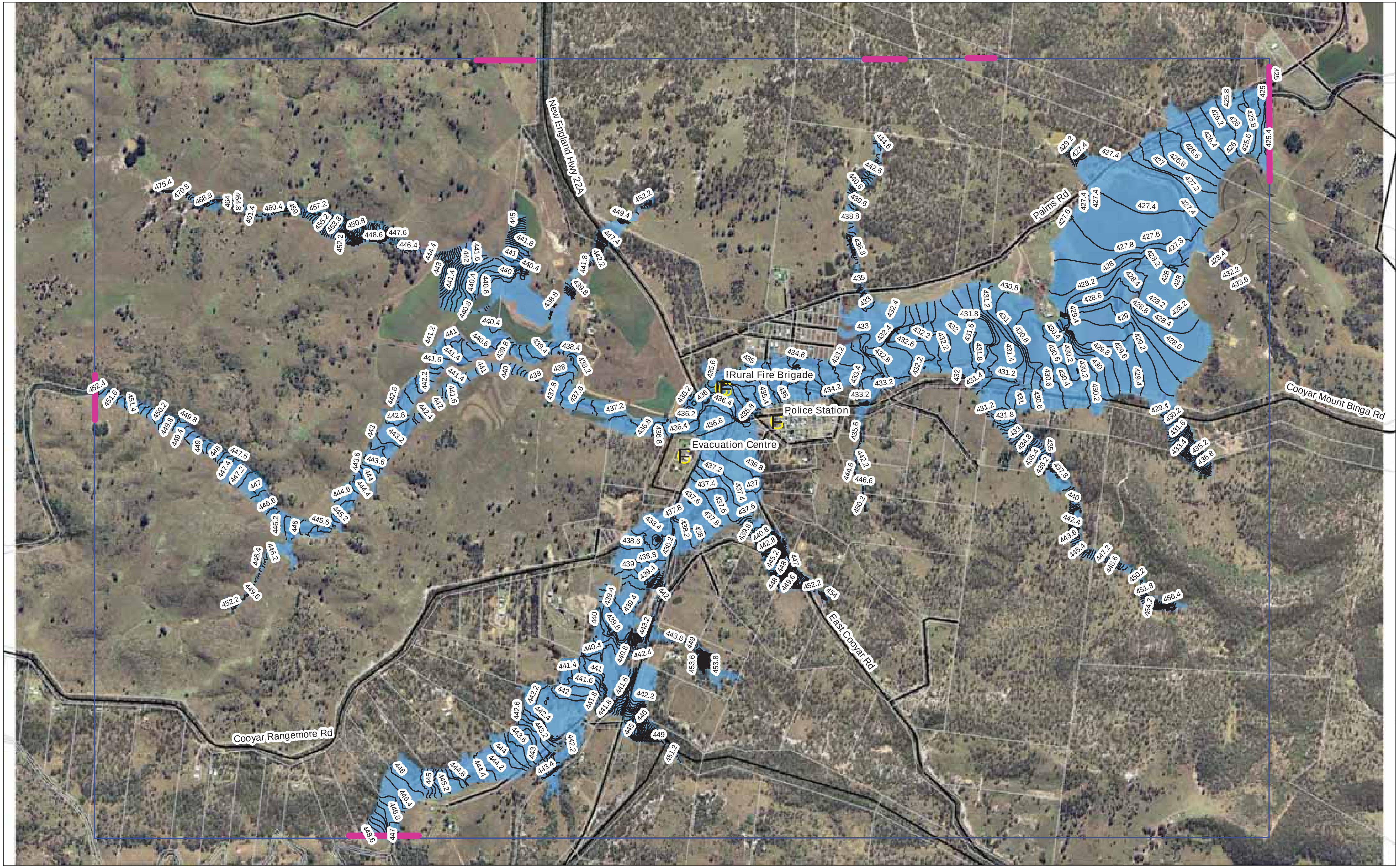

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0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 1 (+10%)
200 Year ARI Event Peak Water Level

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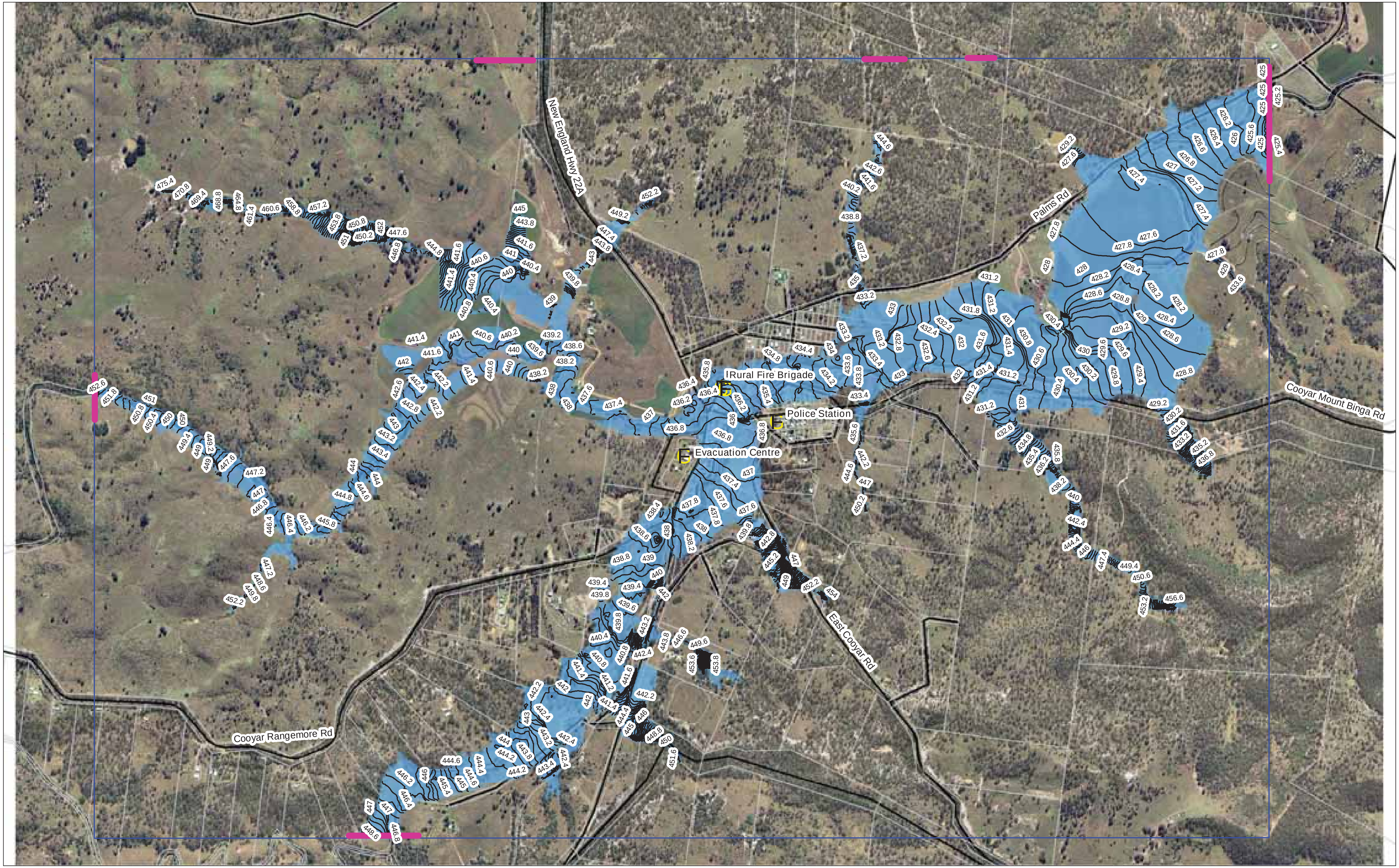

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 2 (+15%)
200 Year ARI Event Peak Water Level

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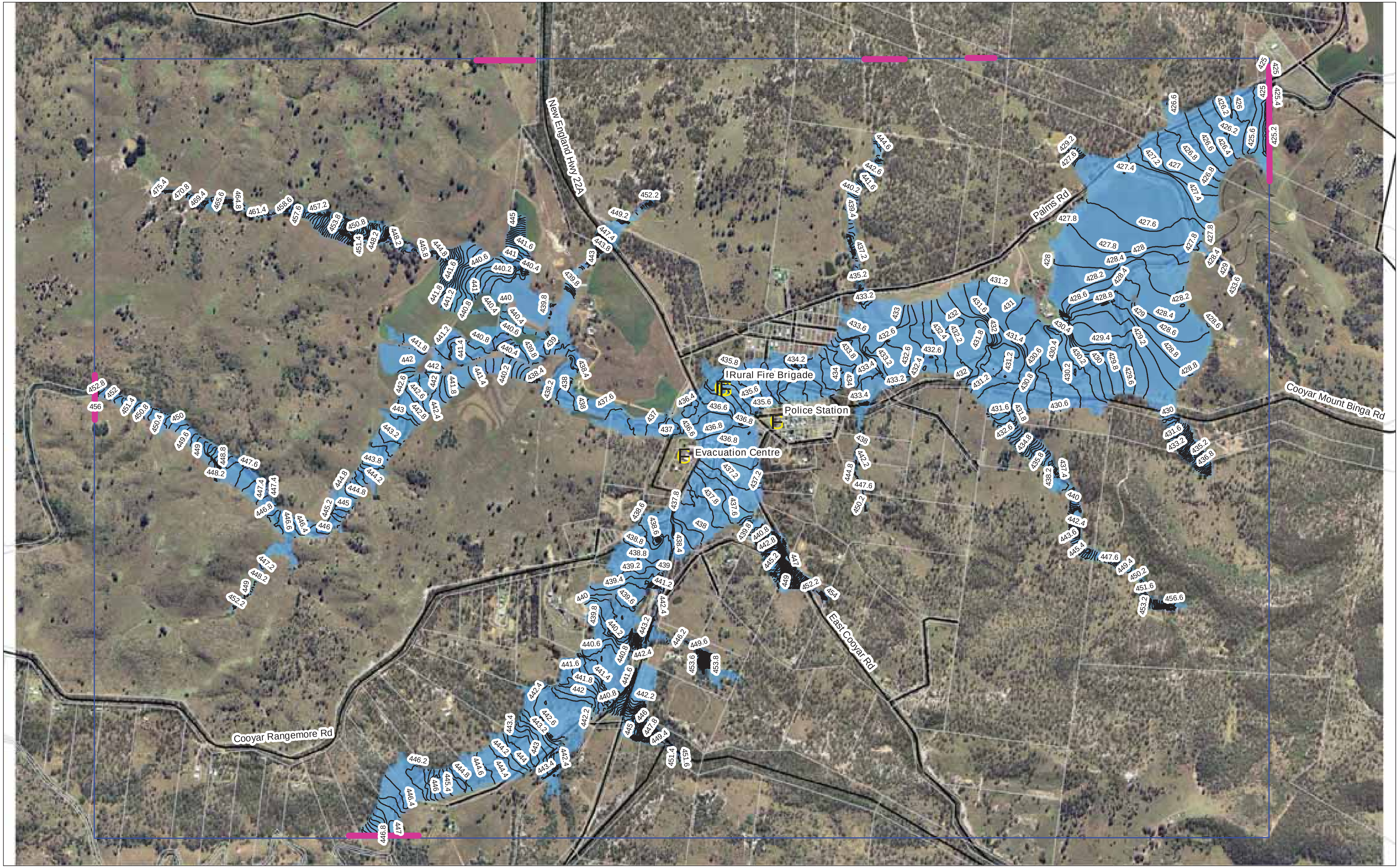

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 3 (+20%)
200 Year ARI Event Peak Water Level

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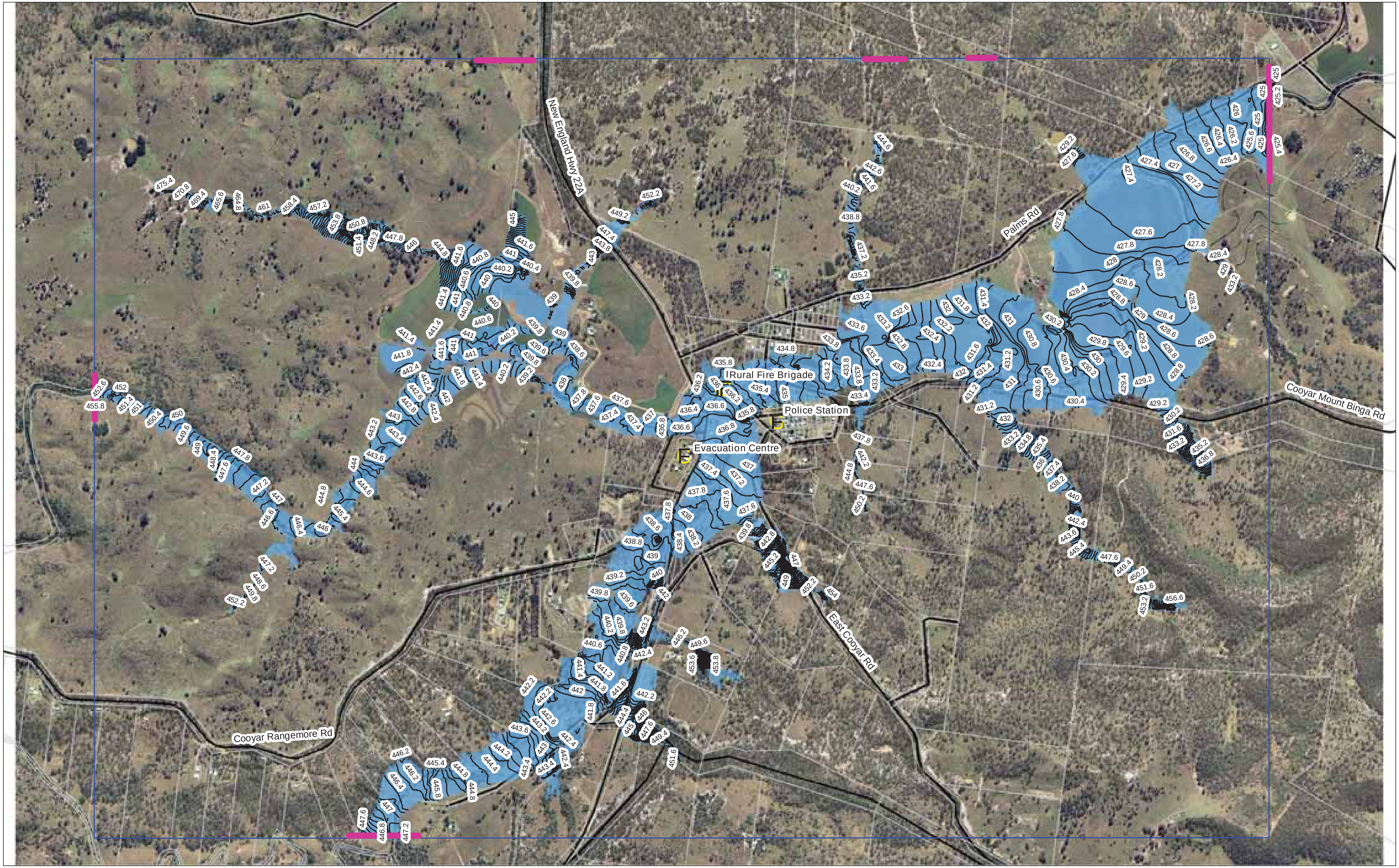

TOOWOOMBA REGIONAL COUNCIL

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 1 (+10%)
500 Year ARI Event Peak Water Level

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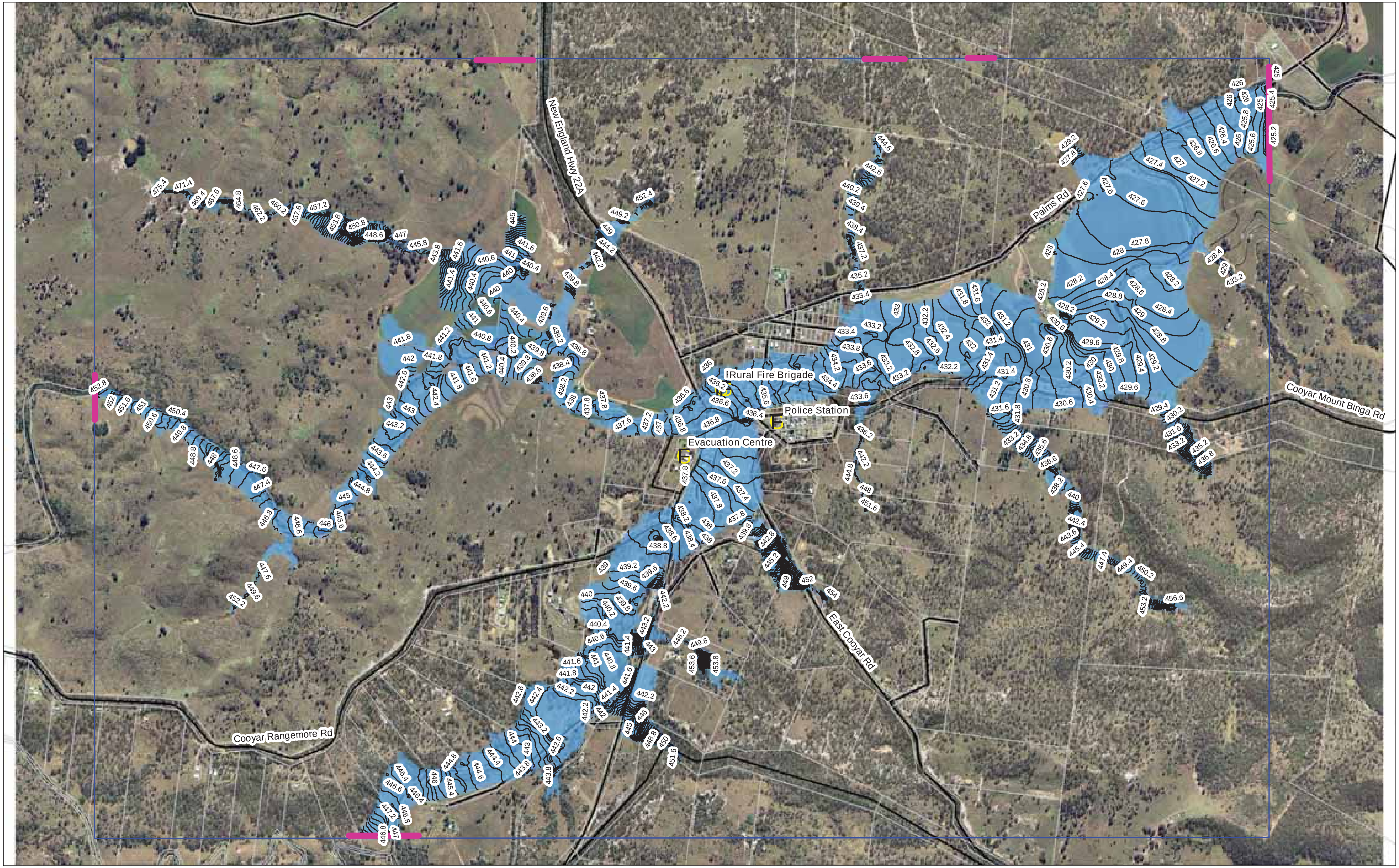

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 2 (+15%)
500 Year ARI Event Peak Water Level

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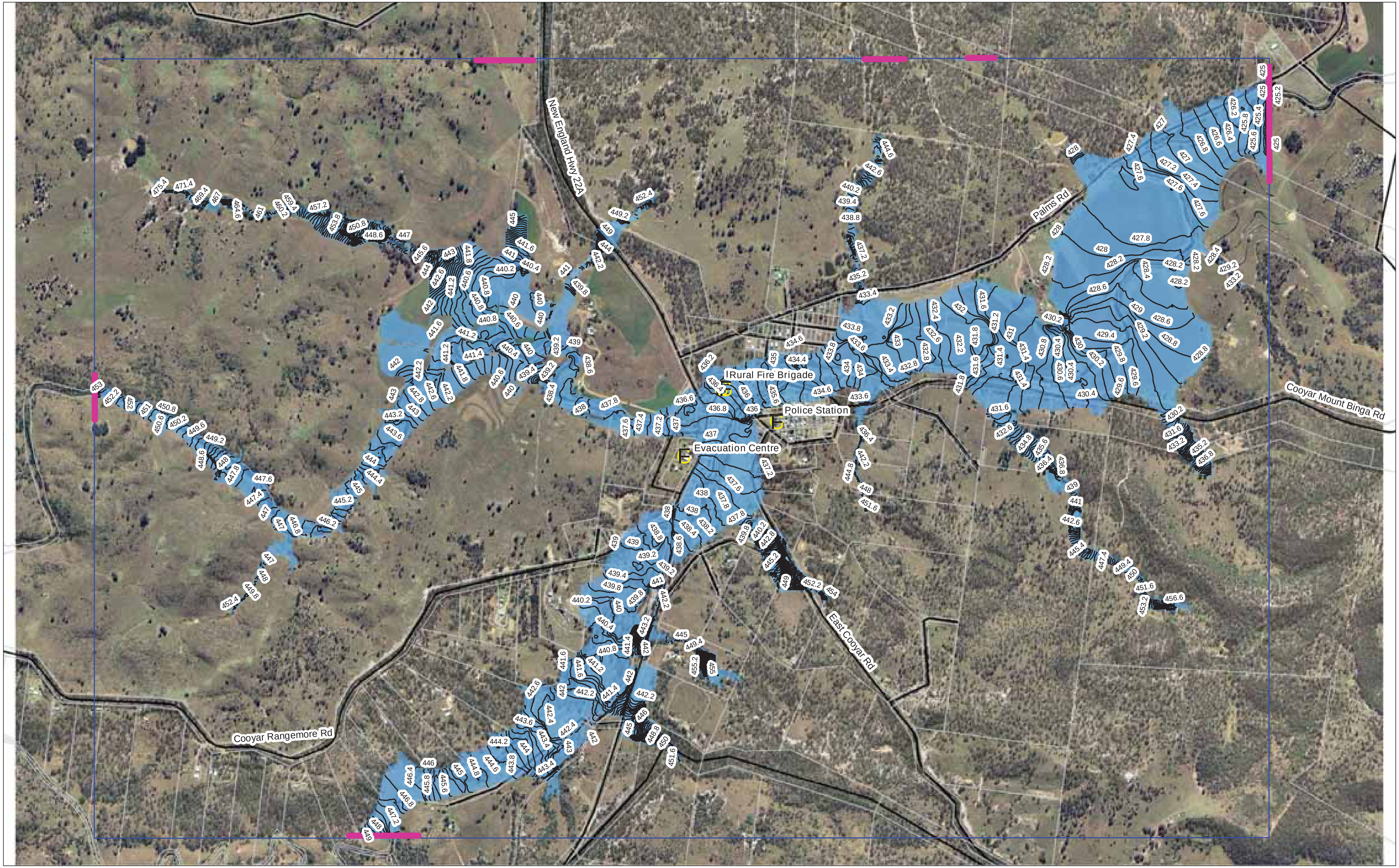

1:15,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Cooyar
Climate Change Scenario 3 (+20%)
500 Year ARI Event Peak Water Level

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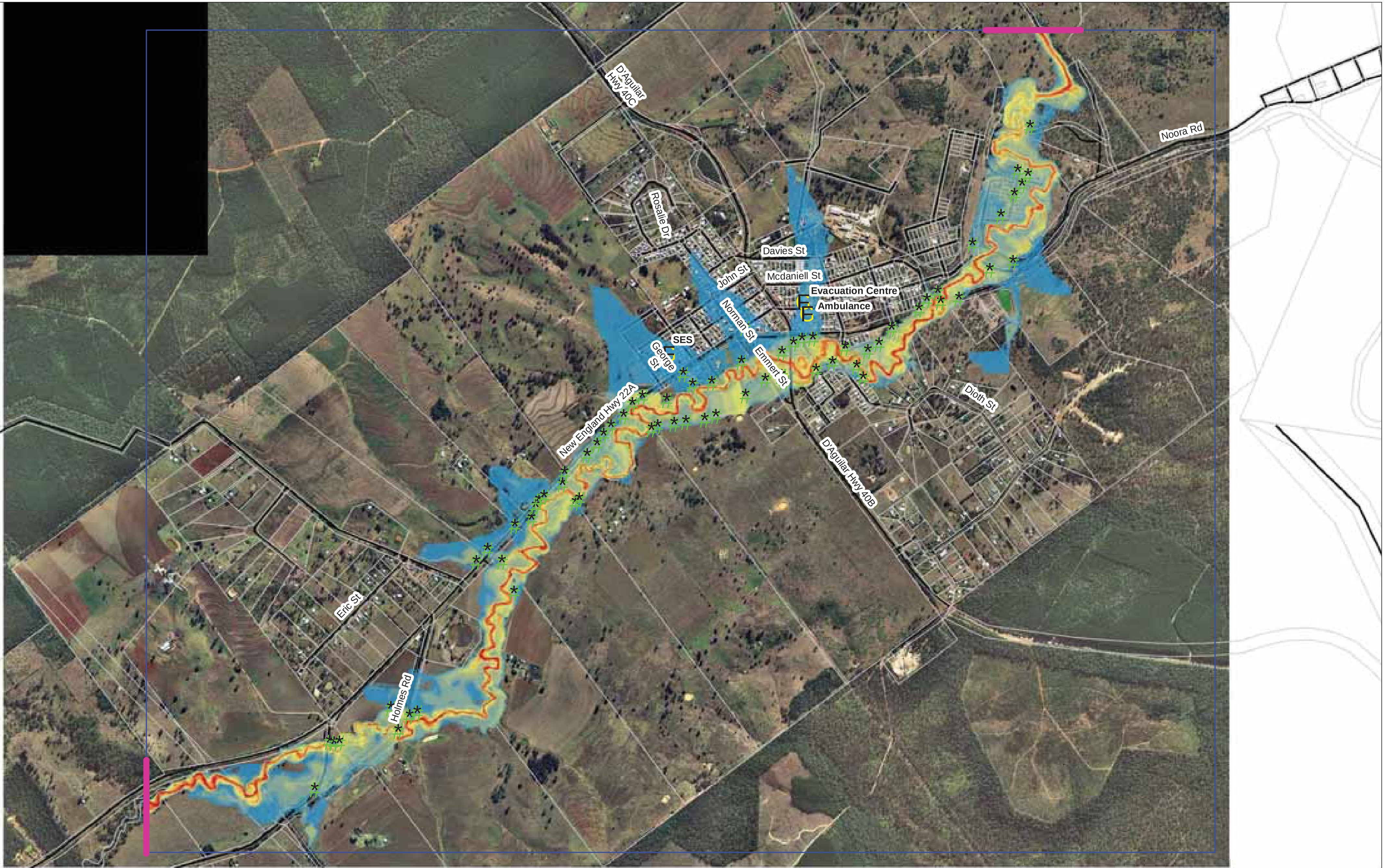
Appendix G. Design Flood Event Mapping – Yarraman



1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Validation Points
- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

< 0.1	1.0 - 1.5	3.0 - 3.5
0.1- 0.25	1.5 - 2.0	3.5 - 4.0
0.25 - 0.5	2.0 - 2.5	4.0 - 4.5
0.5 - 1.0	2.5 - 3.0	4.5 - 5.0
		> 5.0

Creek Flooding Model

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SP 051 Flood Studies
Work Package 10 - Yarraman
2011 Validation Event Peak Depth

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Date Saved: 13/02/2015

1:17,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Validation Points
- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

Creek Flooding Model

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SP 051 Flood Studies
Work Package 10 - Yarraman
2011 Validation Event Peak Water Level

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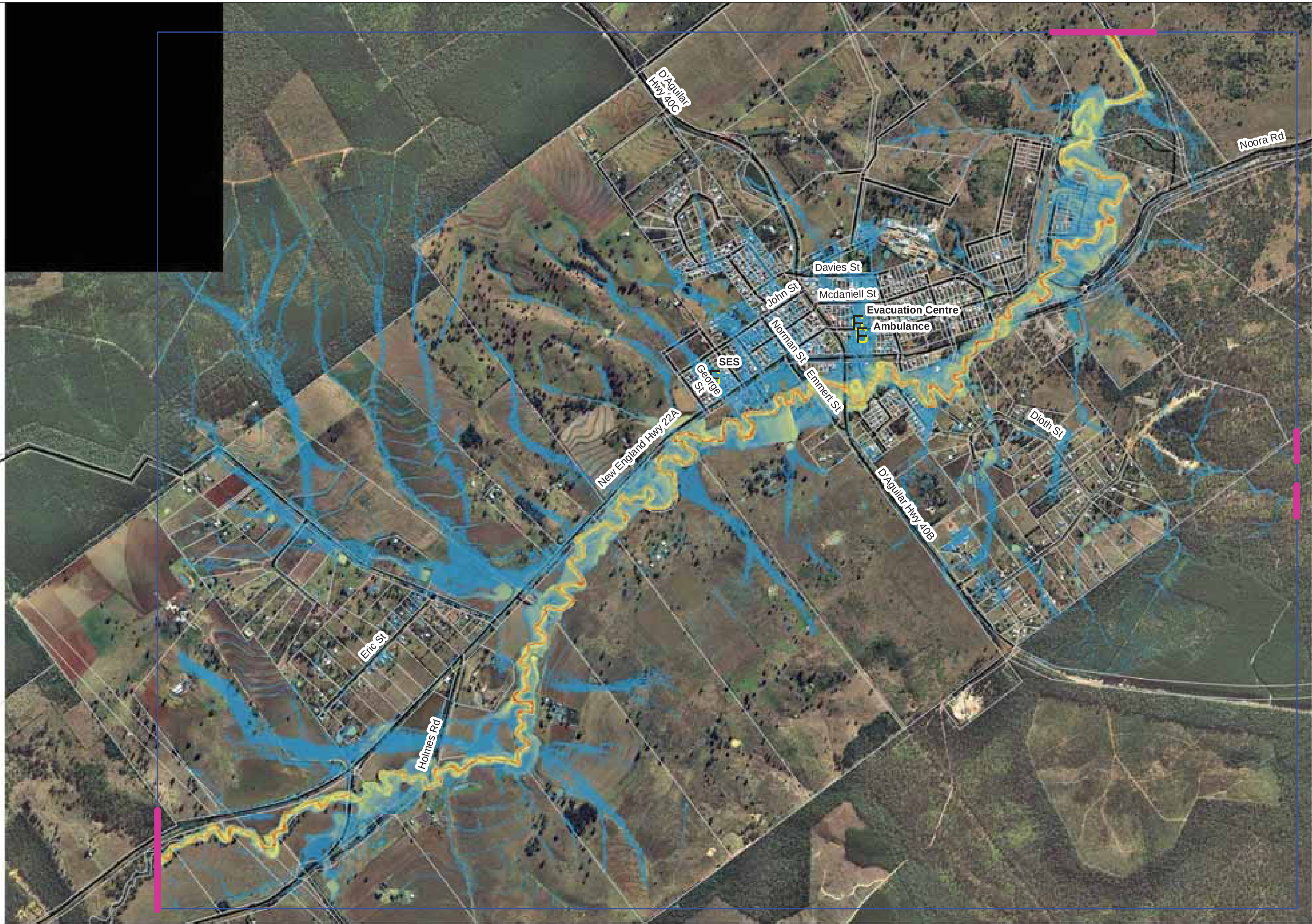

SP 051 Flood Studies
Work Package 10 - Yarraman
10 Year ARI Event Peak Depth

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

- < 0.1
- 0.1- 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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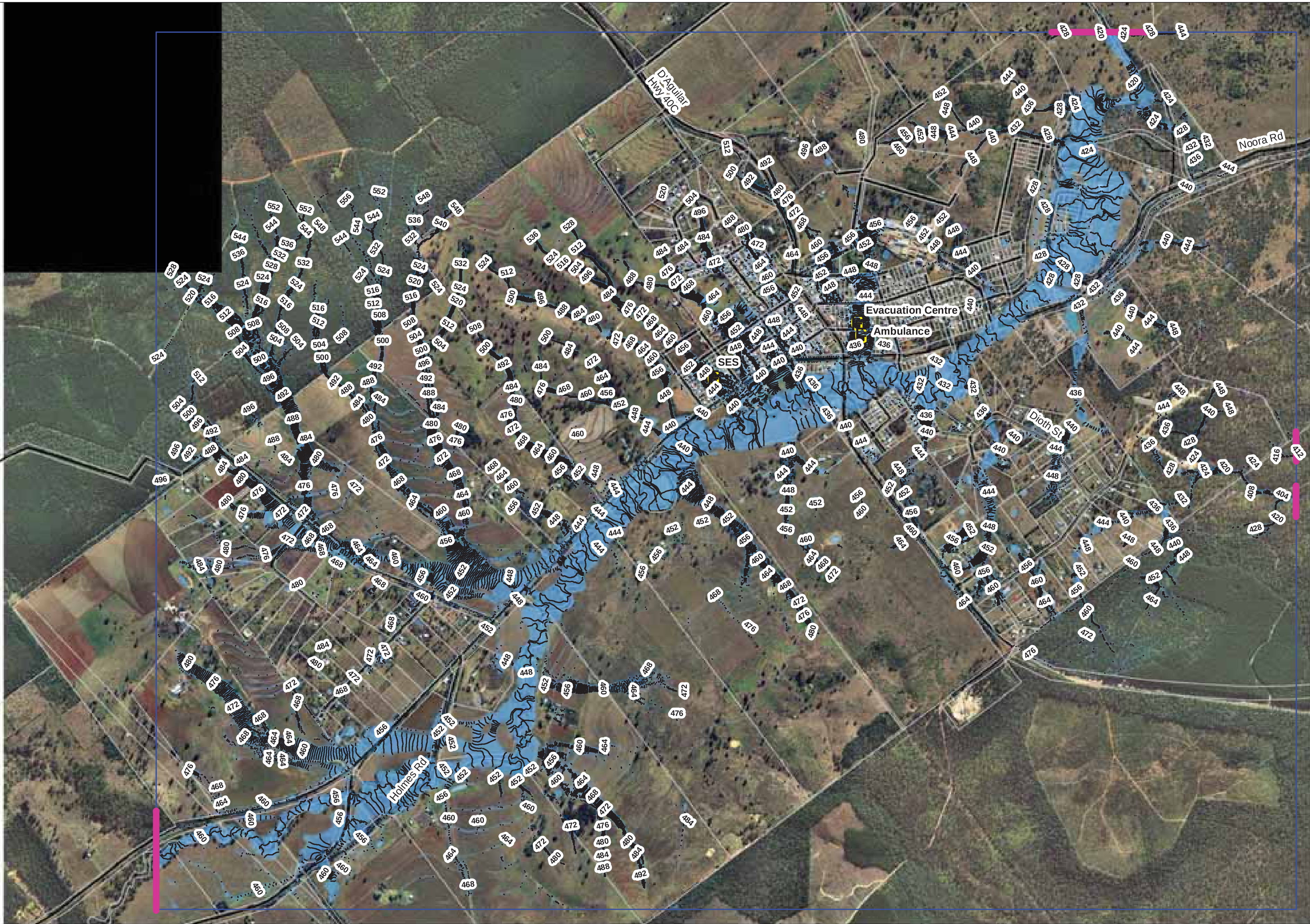

1:17,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Yarraman
10 Year ARI Event Peak Water Level

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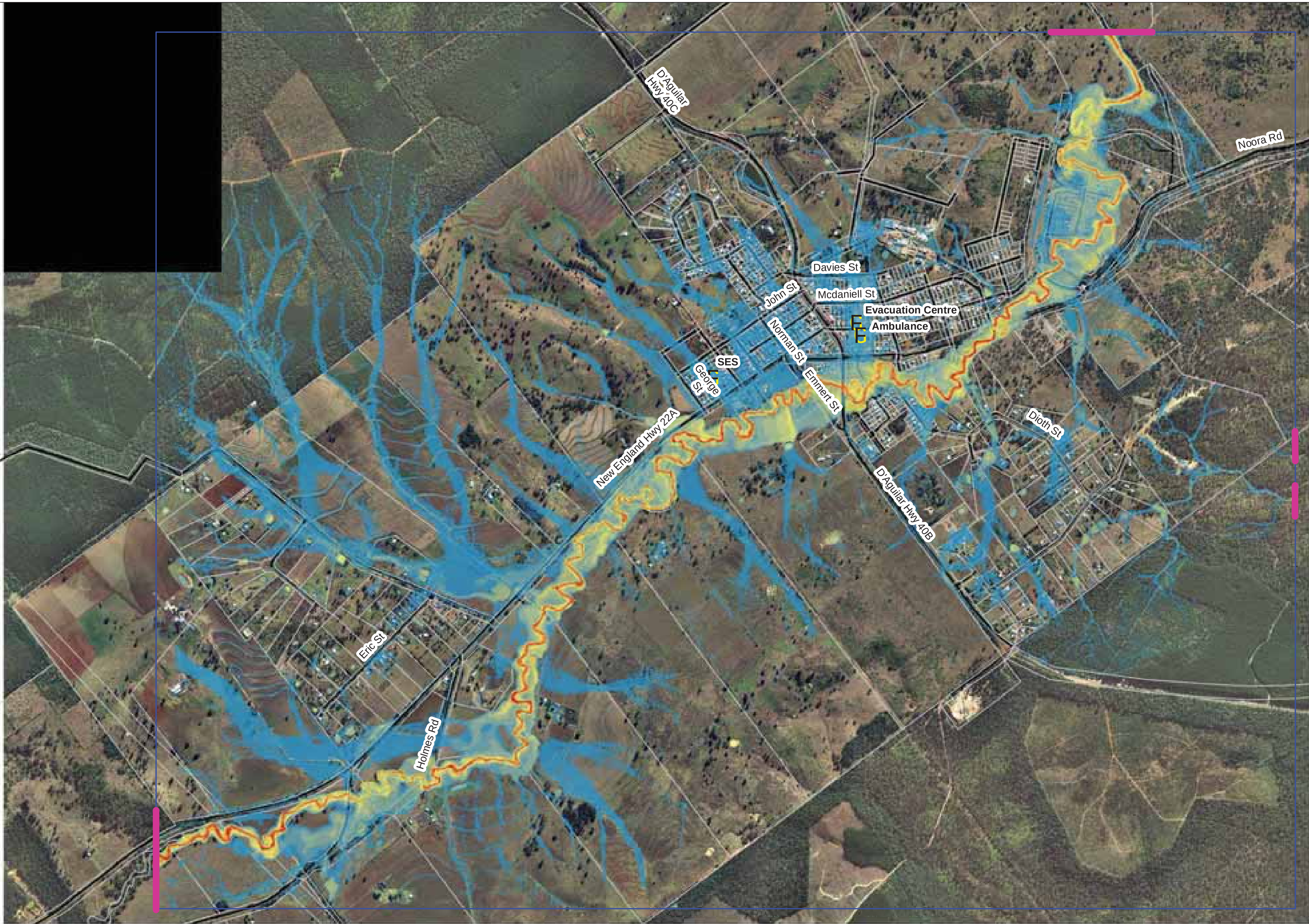

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

- < 0.1
- 0.1- 0.25
- 0.25 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

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SP 051 Flood Studies
Work Package 10 - Yarraman
50 Year ARI Event Peak Depth

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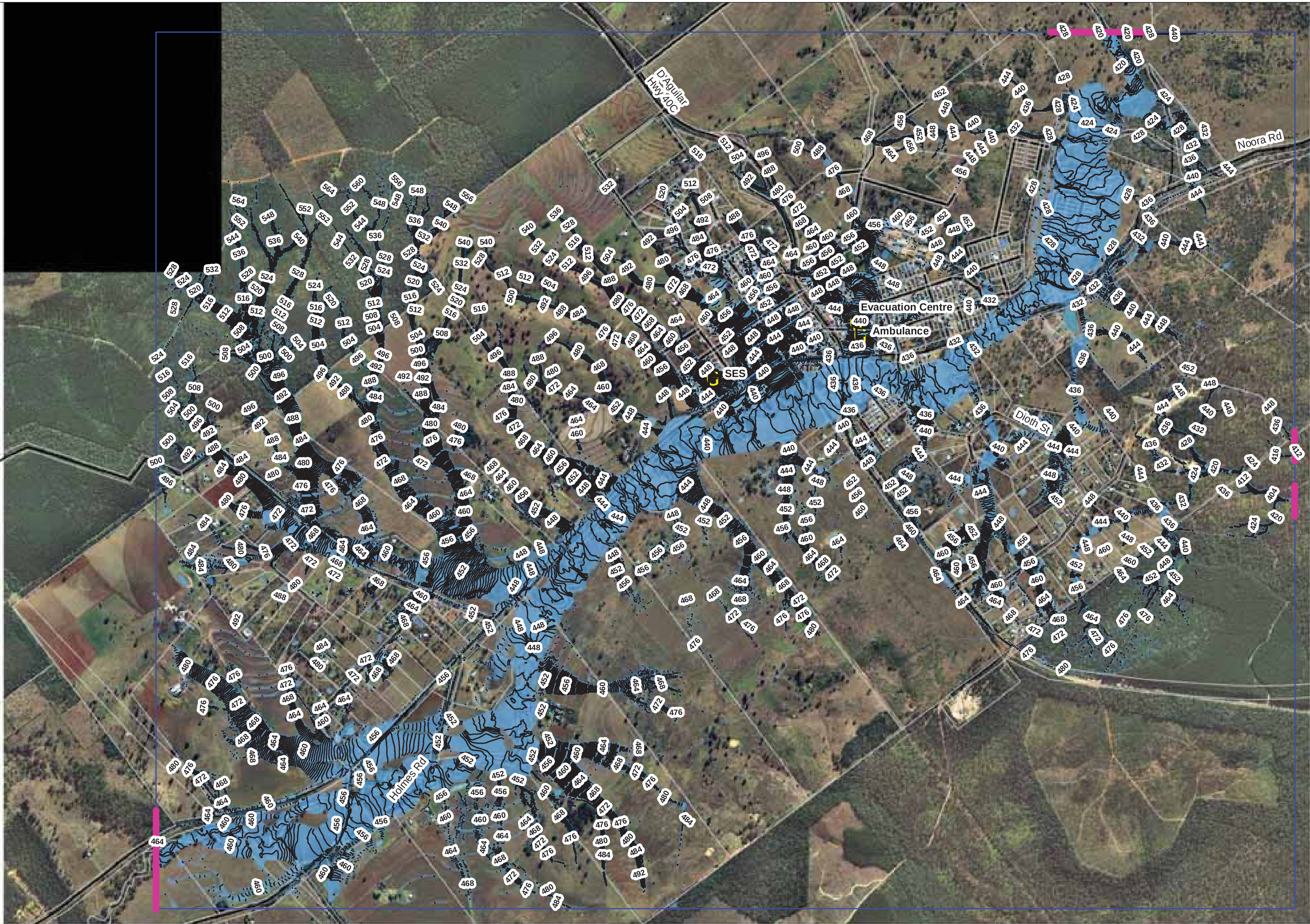

1:17,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Yarraman
50 Year ARI Event Peak Water Level

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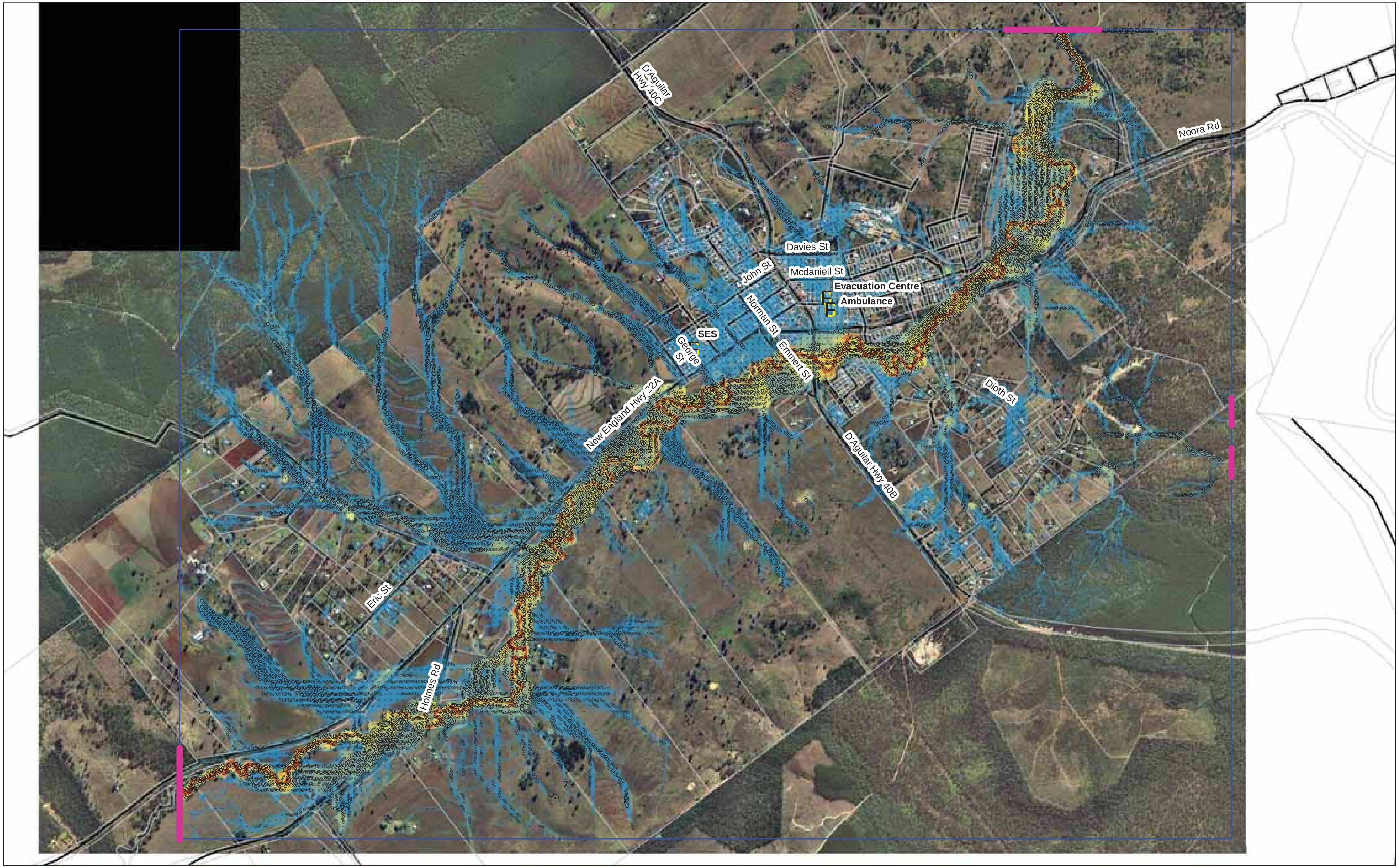

SP 051 Flood Studies
Work Package 10 - Yarraman
100 Year ARI Event Peak Depth

TOOWOOMBA REGIONAL COUNCIL

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Velocity Vectors

Peak Depth (m)

< 0.1	2.0 - 2.5
0.1- 0.25	2.5 - 3.0
0.25 - 0.5	3.0 - 3.5
0.5 - 1.0	3.5 - 4.0
1.0 - 1.5	4.0 - 4.5
1.5 - 2.0	4.5 - 5.0
	> 5.0

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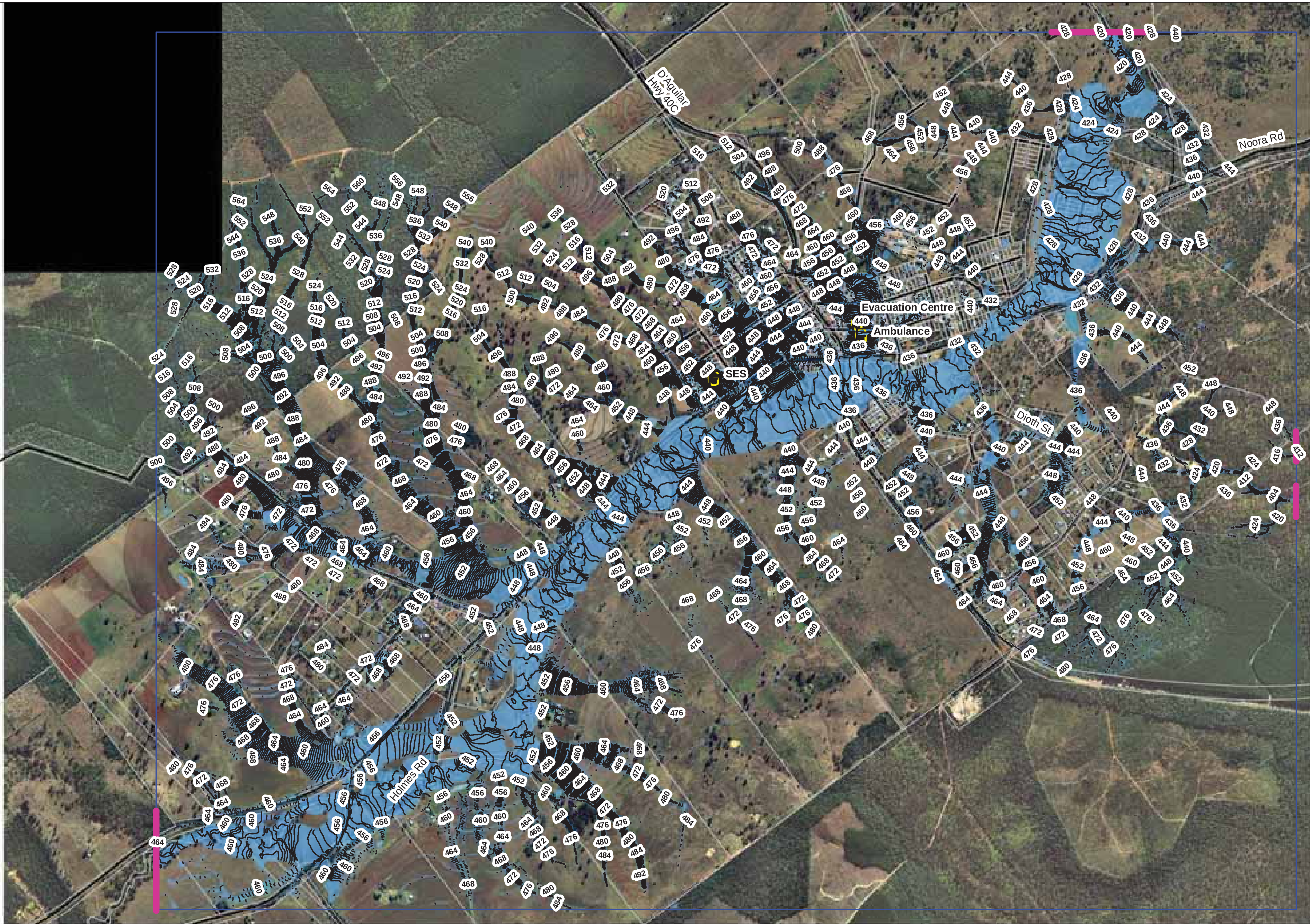

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0 125 250 500

Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

Disclaimer: The flood information contained in the maps is based on debris lines and marks that were visible and accessible at the time of recording after the January 2011 flood extent and may not be accurate or complete and reliance should not be placed on it. Toowoomba Regional Council makes no representations or warranties about the accuracy, reliability, completeness or suitability for any particular purpose and disclaim all responsibility and all liability (including without limitation, liability in negligence) for all expenses, losses, damages (including indirect or consequential damage) and costs which may be incurred in any way and for any reason as a result of the flood information contained in the maps being inaccurate or incomplete.

SP 051 Flood Studies
Work Package 10 - Yarraman
100 Year ARI Event Peak Water Level

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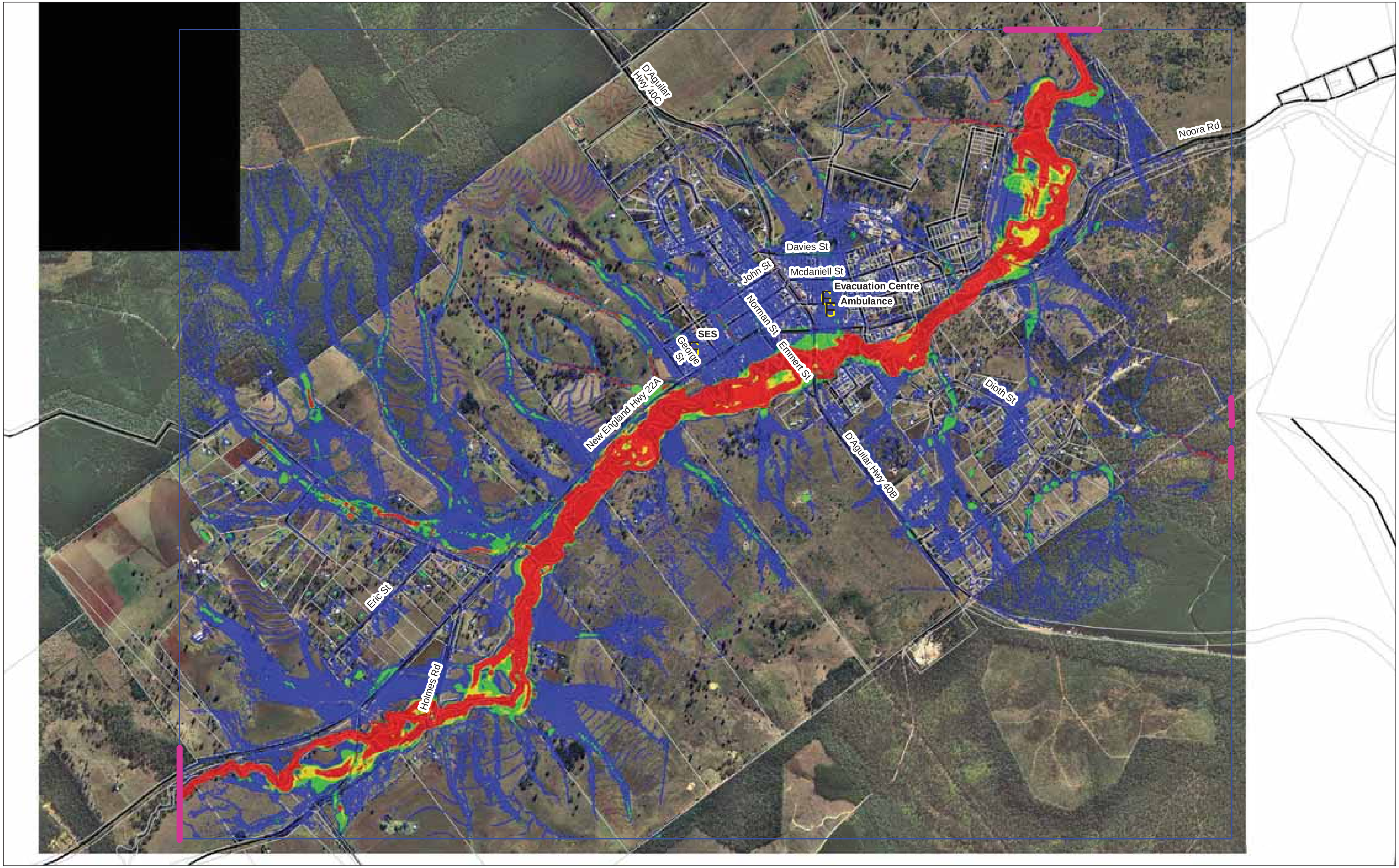

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Hazard Categories
  - Low
  - Significant
  - High
  - Extreme

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SP 051 Flood Studies
Work Package 10 - Yarraman
100 Year ARI Event Peak Hazard

TOOWOOMBA REGIONAL COUNCIL

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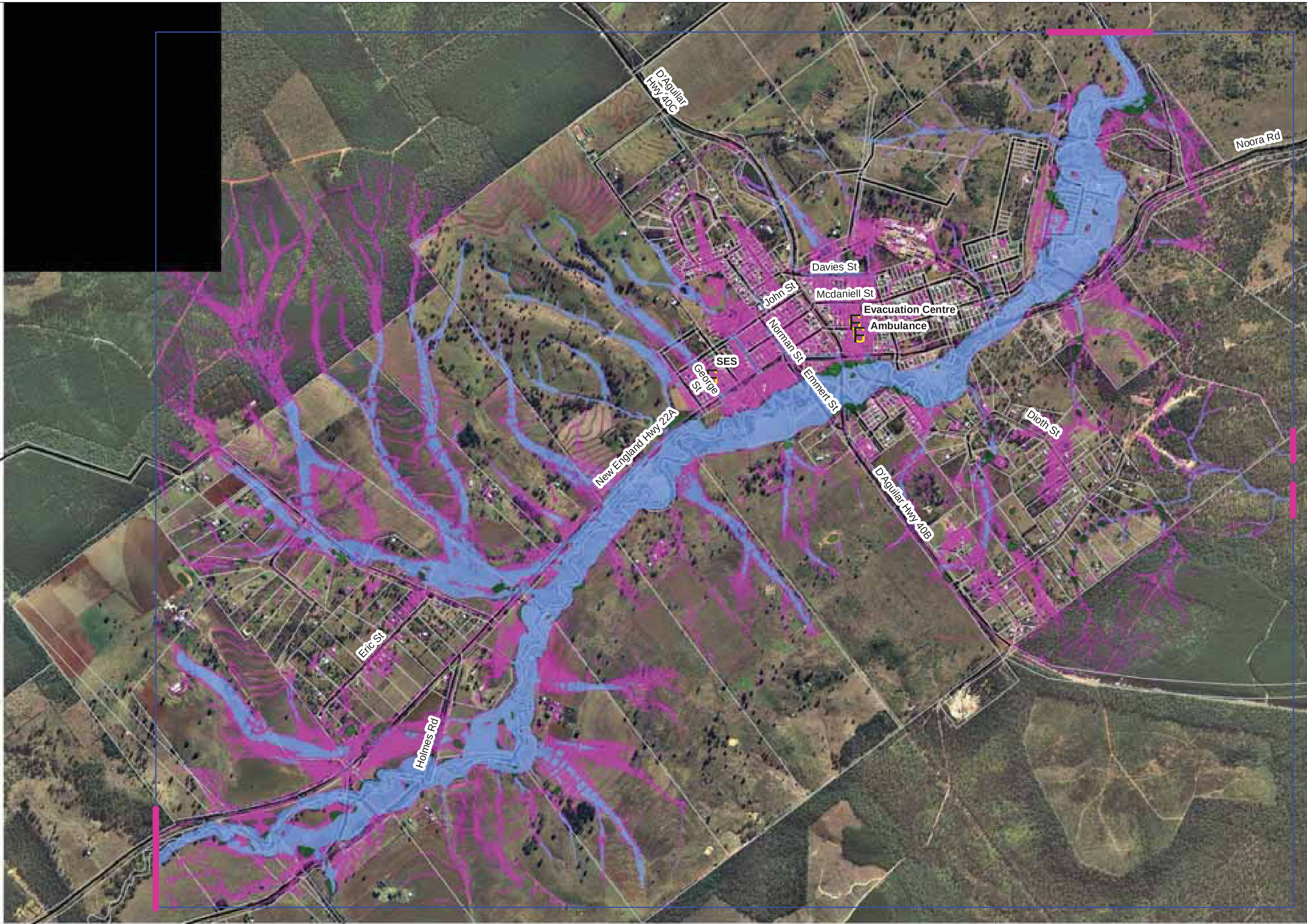

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1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Flood Category

- Flood Fringe
- Flood Storage
- Floodway

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SP 051 Flood Studies
Work Package 10 - Yarraman
100 Year ARI Event Flood Category

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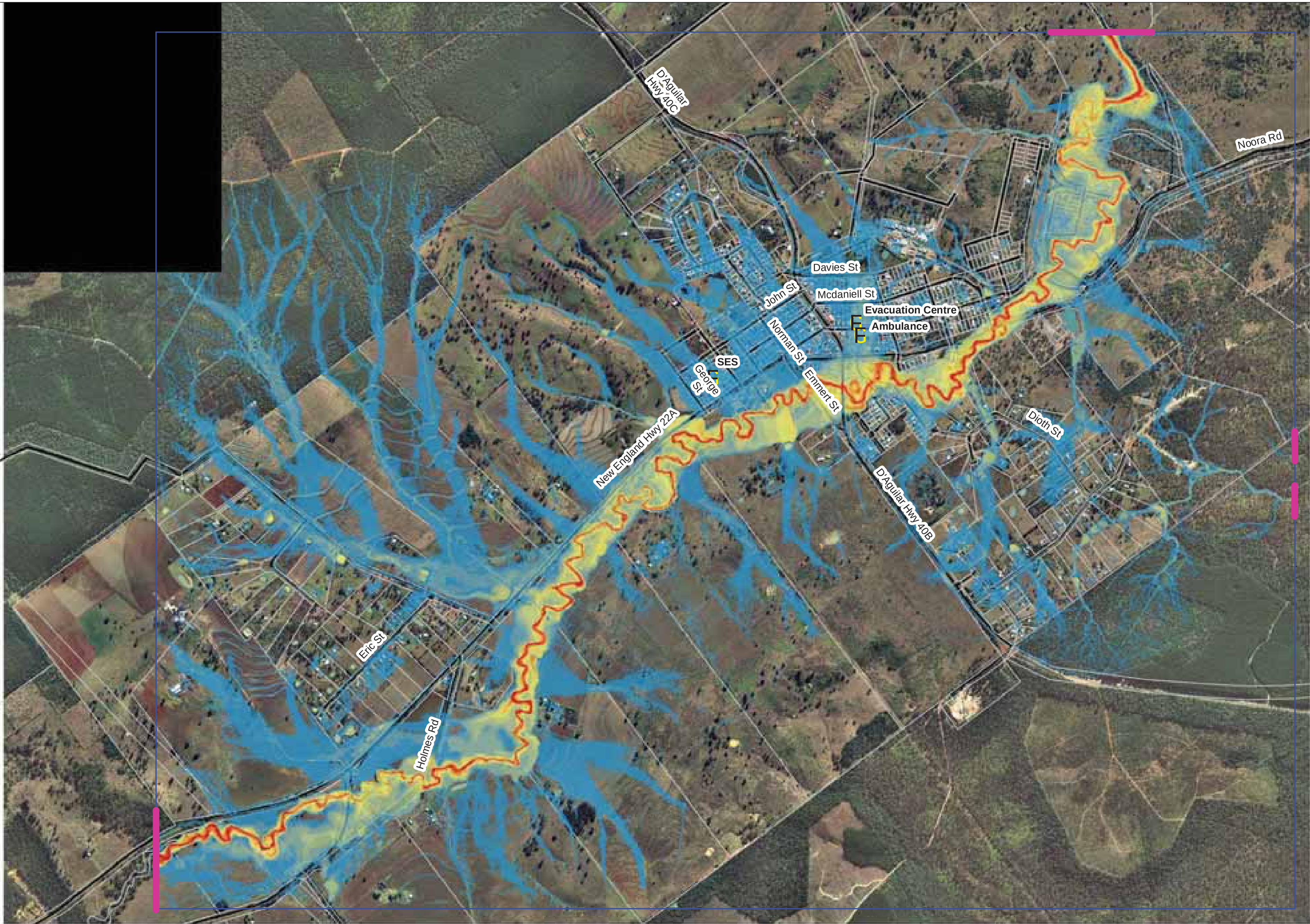

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

< 0.1	0.25 - 0.5
0.1- 0.25	0.5 - 1.0
	1.0 - 1.5
	1.5 - 2.0
	2.0 - 2.5
	2.5 - 3.0
	3.0 - 3.5
	3.5 - 4.0
	4.0 - 4.5
	4.5 - 5.0
	> 5.0

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SP 051 Flood Studies
Work Package 10 - Yarraman
500 Year ARI Event Peak Depth

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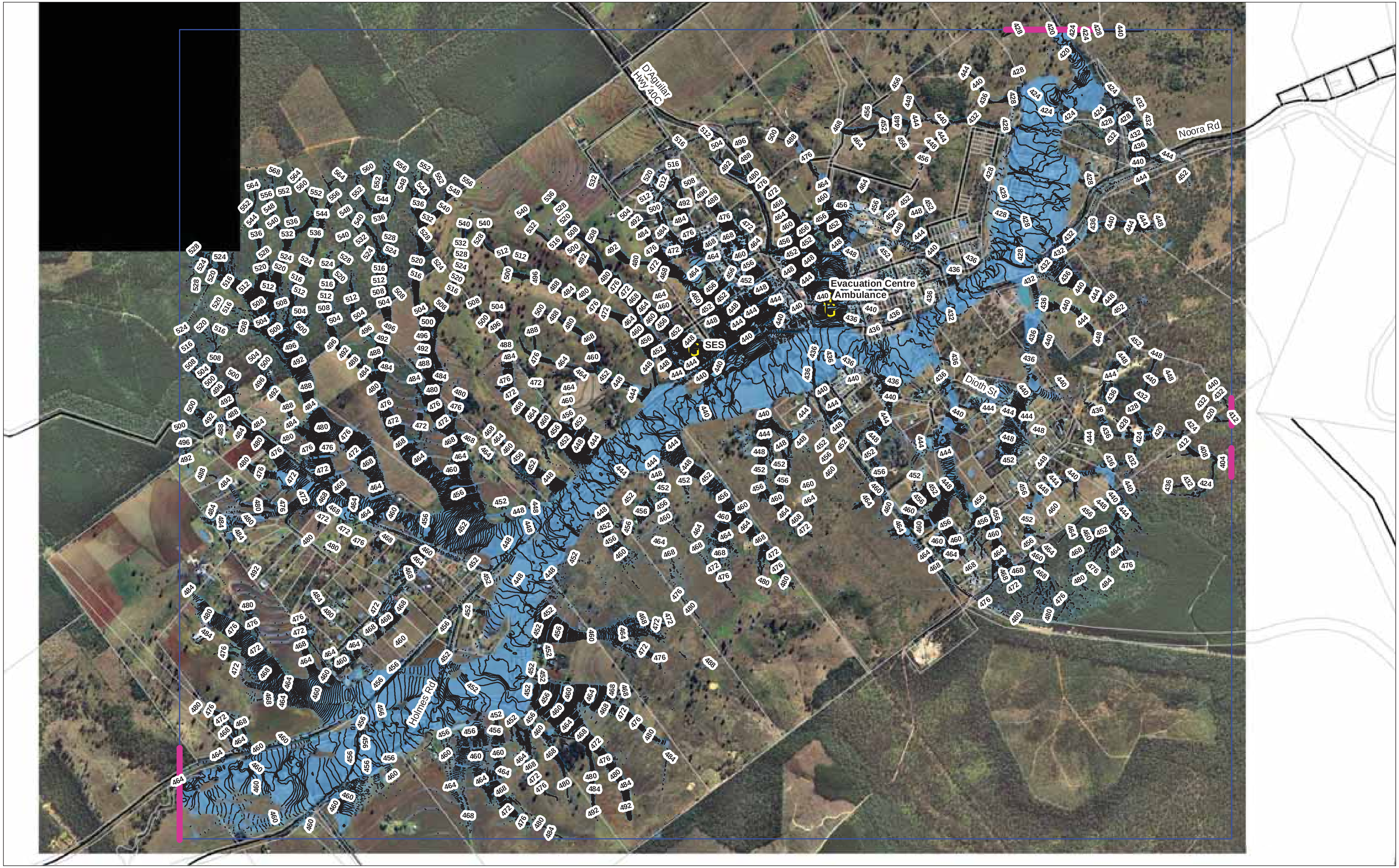

1:17,000 (at A3)

0 125 250 500

Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Yarraman
500 Year ARI Event Peak Water Level

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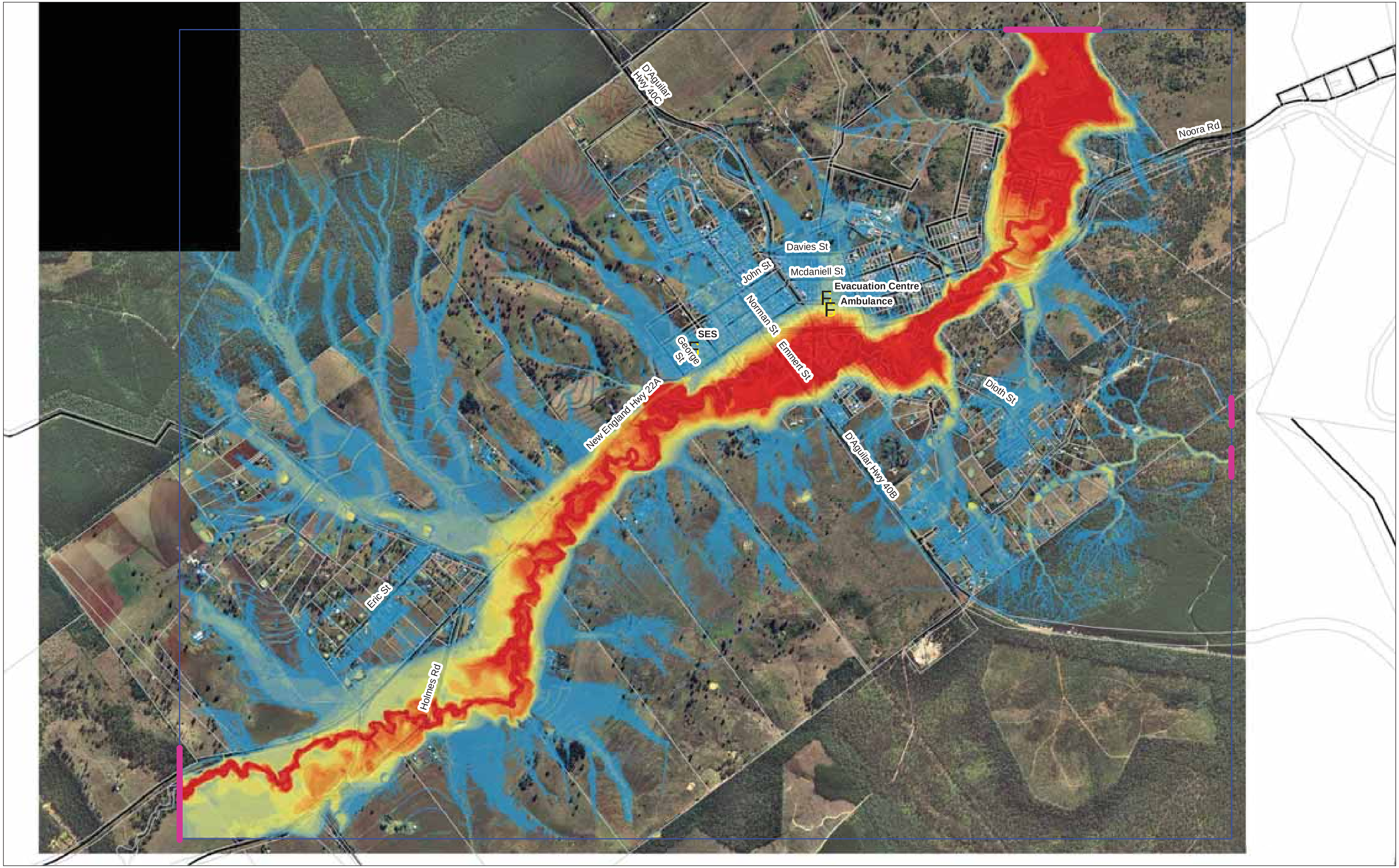

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Peak Depth (m)

< 0.1	0.25 - 0.5	2.5 - 3.0
0.1- 0.25	0.5 - 1.0	3.0 - 3.5
	1.0 - 1.5	3.5 - 4.0
	1.5 - 2.0	4.0 - 4.5
	2.0 - 2.5	4.5 - 5.0
		> 5.0

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SP 051 Flood Studies
Work Package 10 - Yarraman
PMP Event Peak Depth

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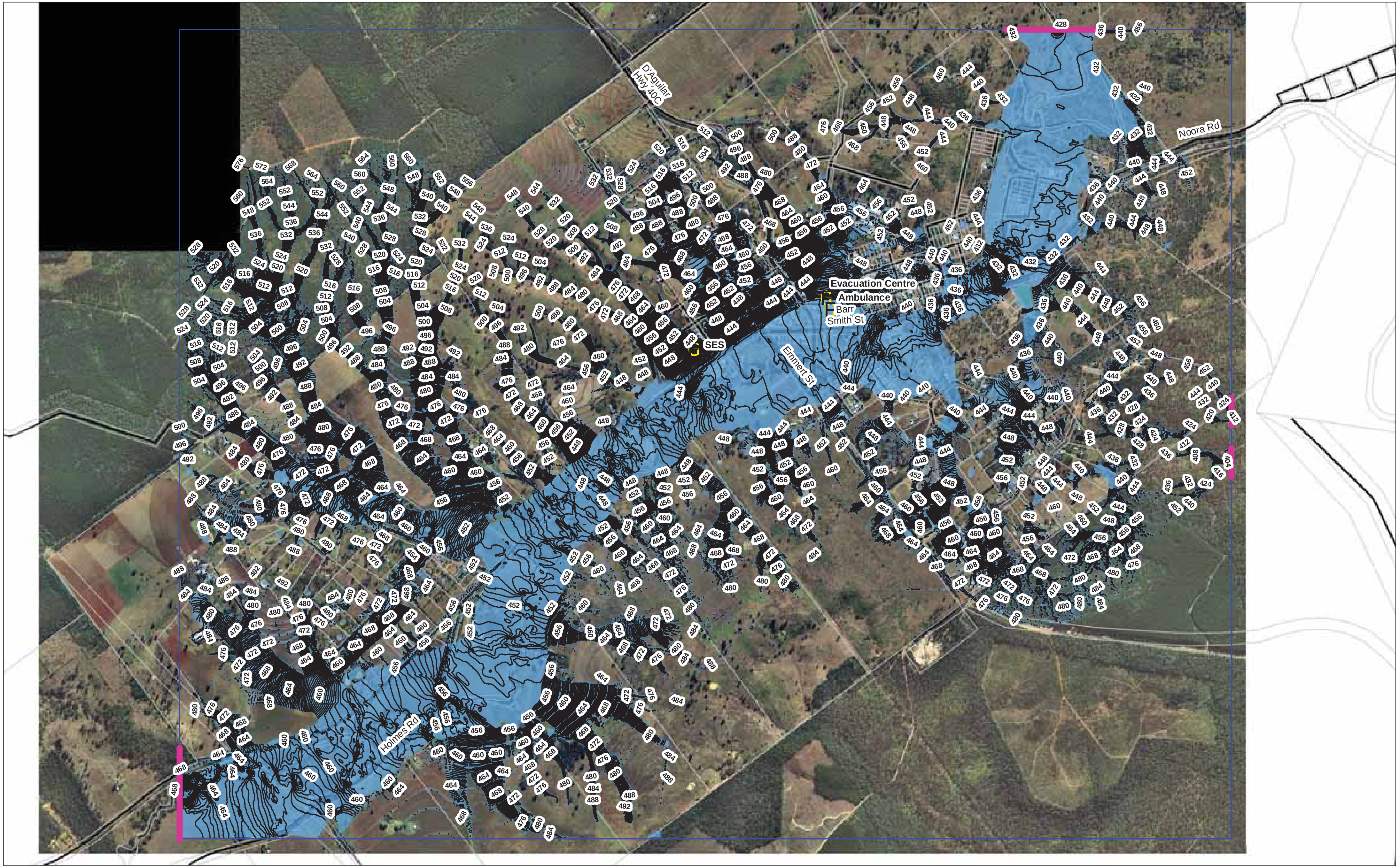

1:17,000 (at A3)	
0 125 250 500	
Metres	
GDA 1994 MGA Zone 56	

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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SP 051 Flood Studies
Work Package 10 - Yarraman
PMP Event Peak Water Level

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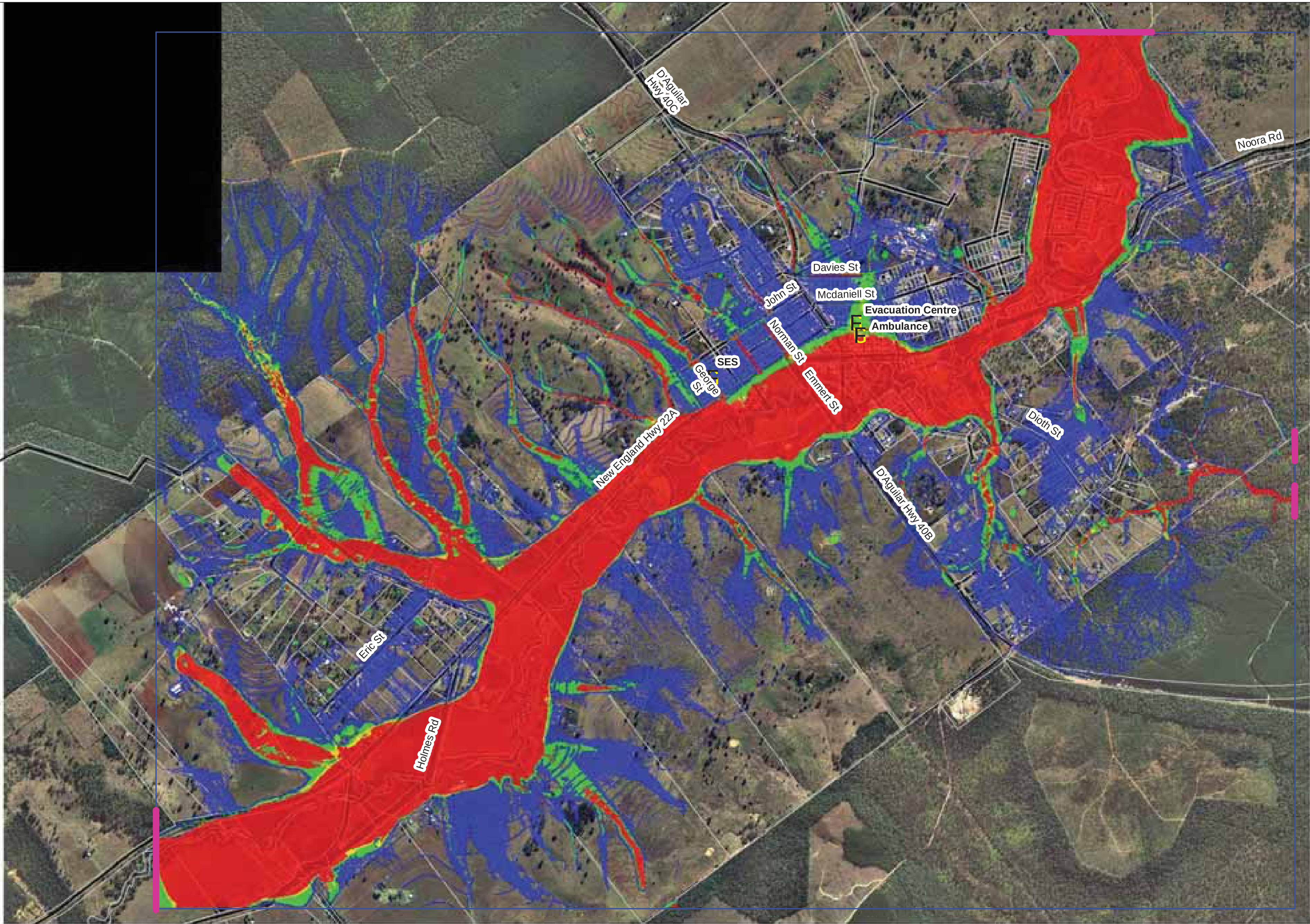

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Hazard Categories
  - Low
  - Significant
  - High
  - Extreme

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SP 051 Flood Studies
Work Package 10 - Yarraman
PMP Event Peak Hazard

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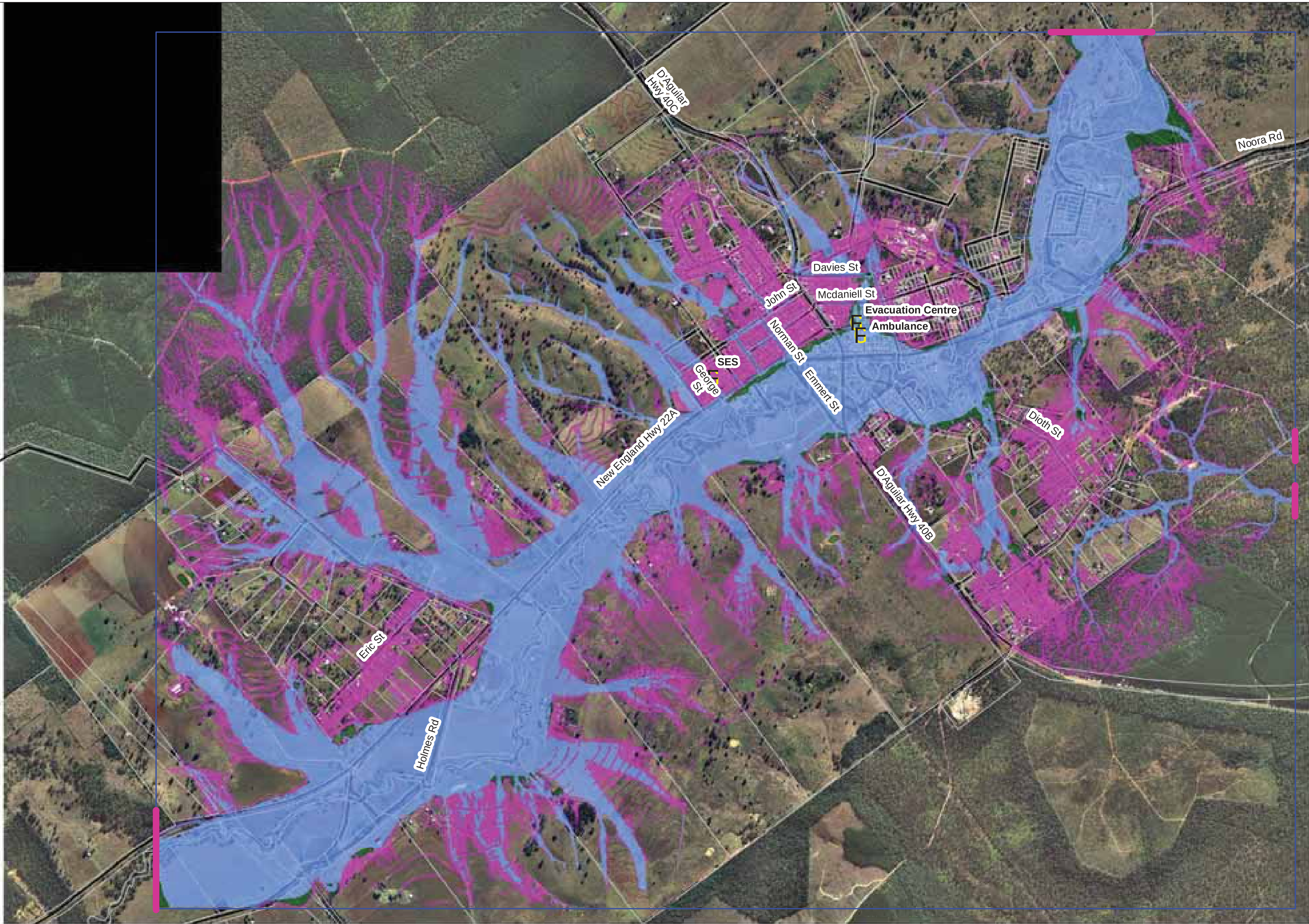

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

TOOWOOMBA REGIONAL COUNCIL

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent

Flood Category

- Flood Fringe
- Flood Storage
- Floodway

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SP 051 Flood Studies
Work Package 10 - Yarraman
PMP Event Flood Category

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Date Saved: 29/09/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Flood Extent (Base Case)
- Flood Extent (50% Blockage)

Creek Flooding Model

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SP 051 Flood Studies
Work Package 10 - Yarraman
Model Sensitivity to Structure Blockage
100 Year ARI Event Peak Flood Level

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I:\QENV2\Projects\QE06787\Spatial\ArcGIS\Figures\Pk10\YAR_RoC_Mapping\MXD\YAR_E_100Y_180M_SEN_Block_RevB.mxd
Date Saved: 13/10/2014

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Flood Extent (Base Case)
- Flood Extent (+30% Flow)
- Flood Extent (-30% Flow)
- Flood Extent (+30% Roughness)
- Flood Extent (-30% Roughness)

Creek Flooding Model

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SP 051 Flood Studies
Work Package 10 - Yarraman
Model Sensitivity to Roughness and Flow
100 Year ARI Event Peak Flood Extent

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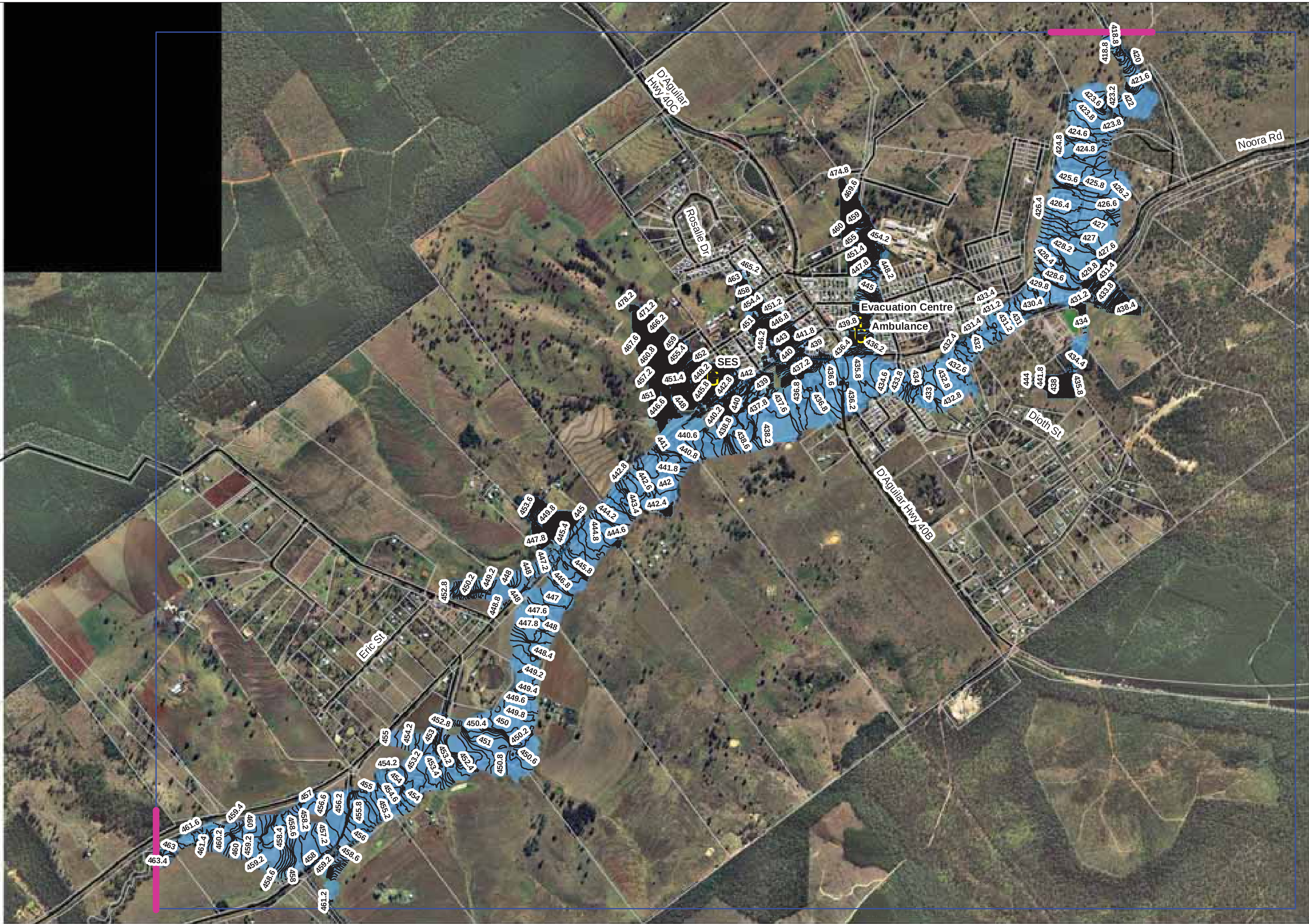

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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Creek Flooding Model

SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 1 (+10%)
100 Year ARI Event Peak Water Level

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Date Saved: 13/10/2014

SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 2 (+15%)
100 Year ARI Event Peak Water Level

Creek Flooding Model

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

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TOOWOOMBA REGIONAL COUNCIL

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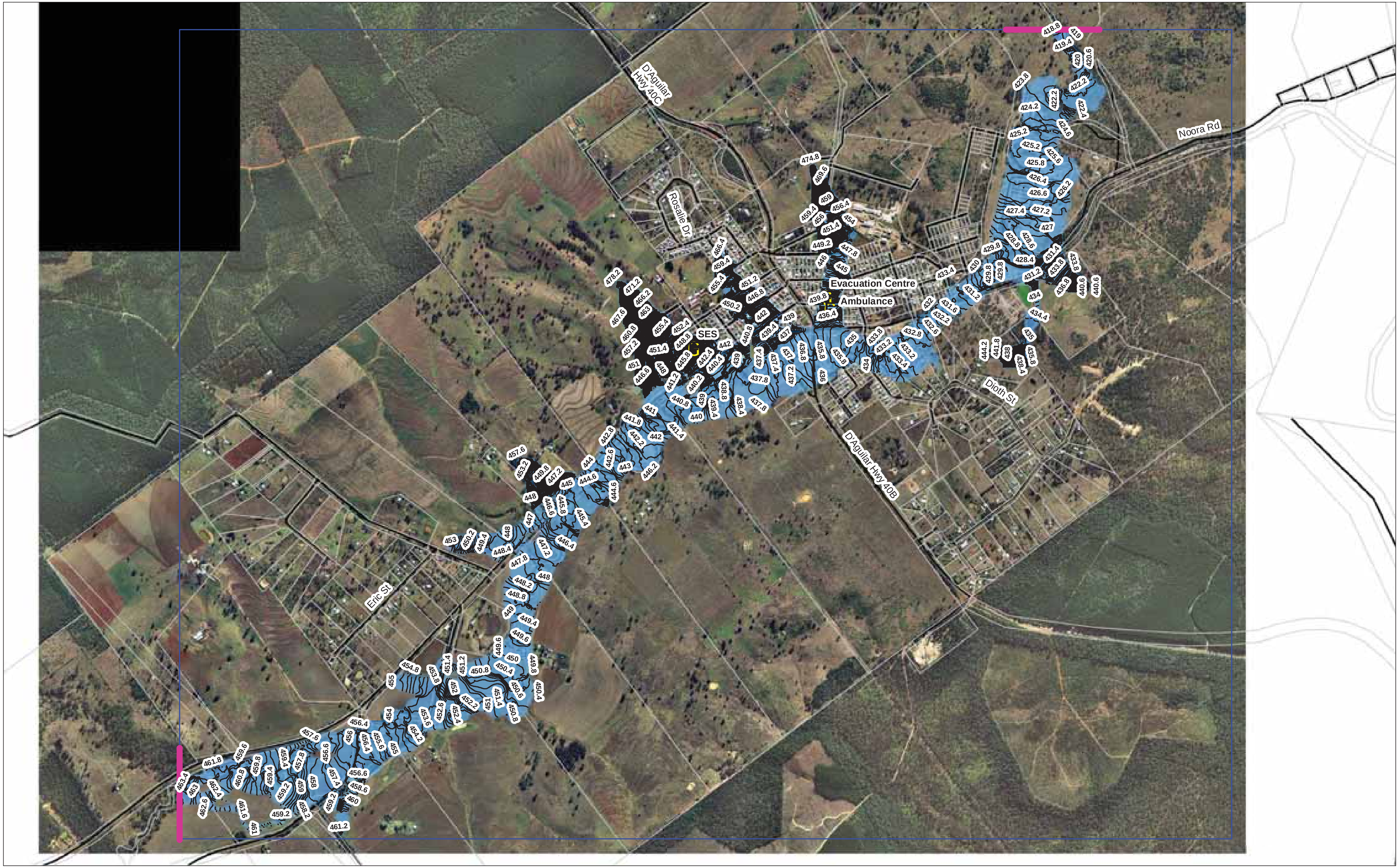

1:17,000 (at A3)

0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

Creek Flooding Model

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SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 3 (+20%)
100 Year ARI Event Peak Water Level

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0 125 250 500
Metres

GDA 1994 MGA Zone 56

Legend

- Emergency Locations
- Cadastre
- Road Centreline
- Model Boundaries
- Model Extent
- Water Level Contours (mAHD)
- Inundation Extent

Creek Flooding Model

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SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 1 (+10%)
200 Year ARI Event Peak Water Level

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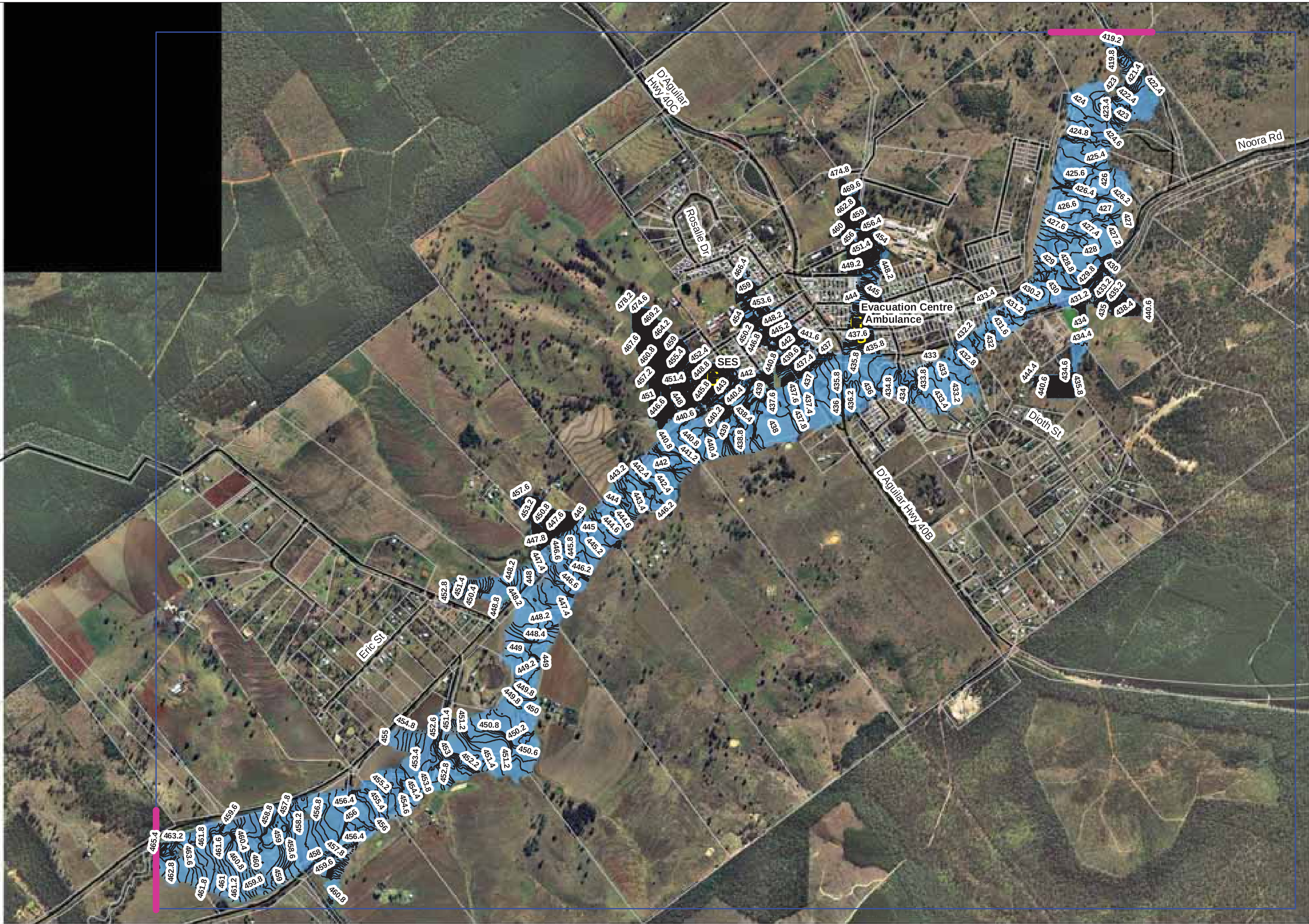

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Metres

GDA 1994 MGA Zone 56

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SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 2 (+15%)
200 Year ARI Event Peak Water Level

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SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 3 (+20%)
200 Year ARI Event Peak Water Level

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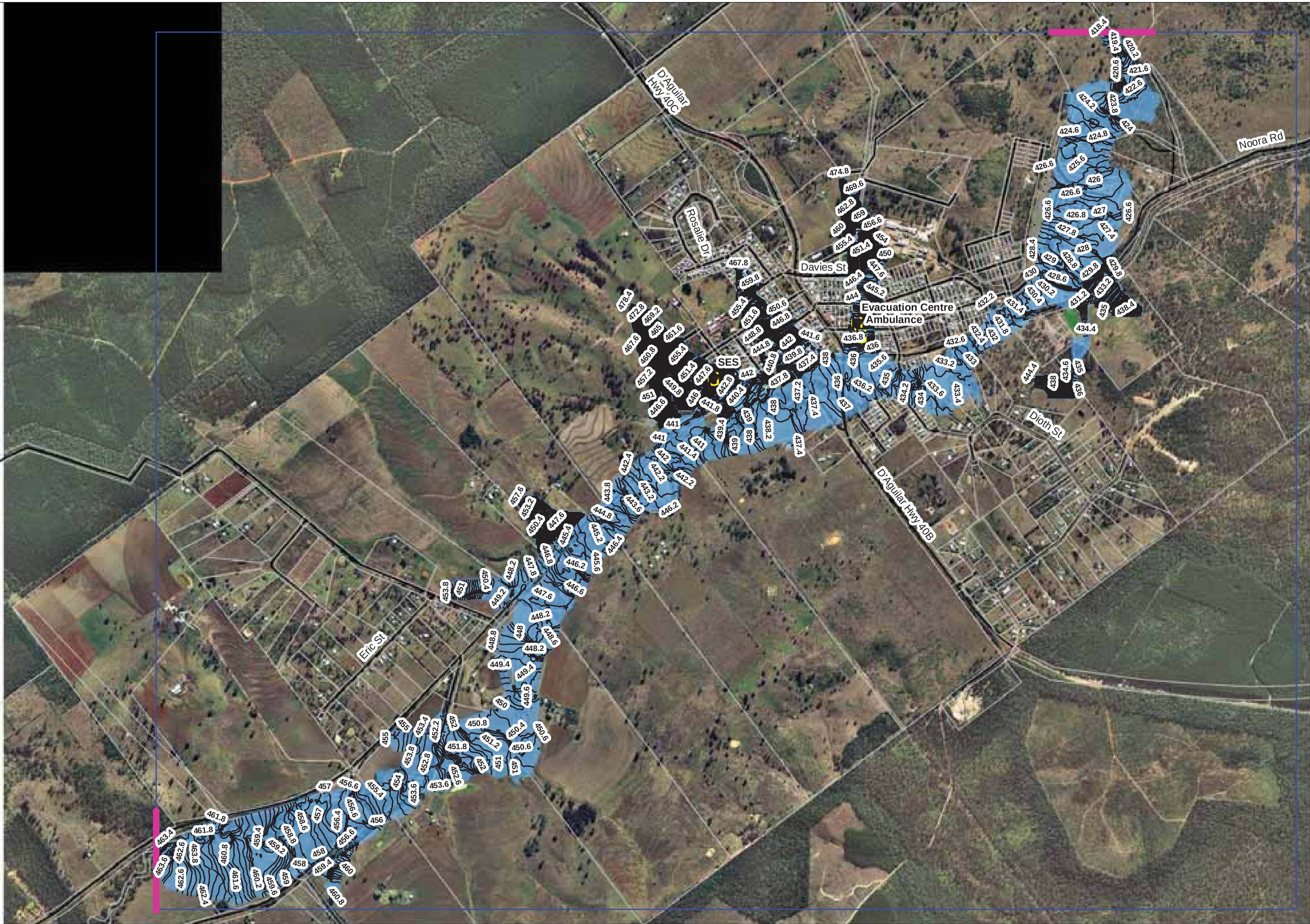

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SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 1 (+10%)
500 Year ARI Event Peak Water Level

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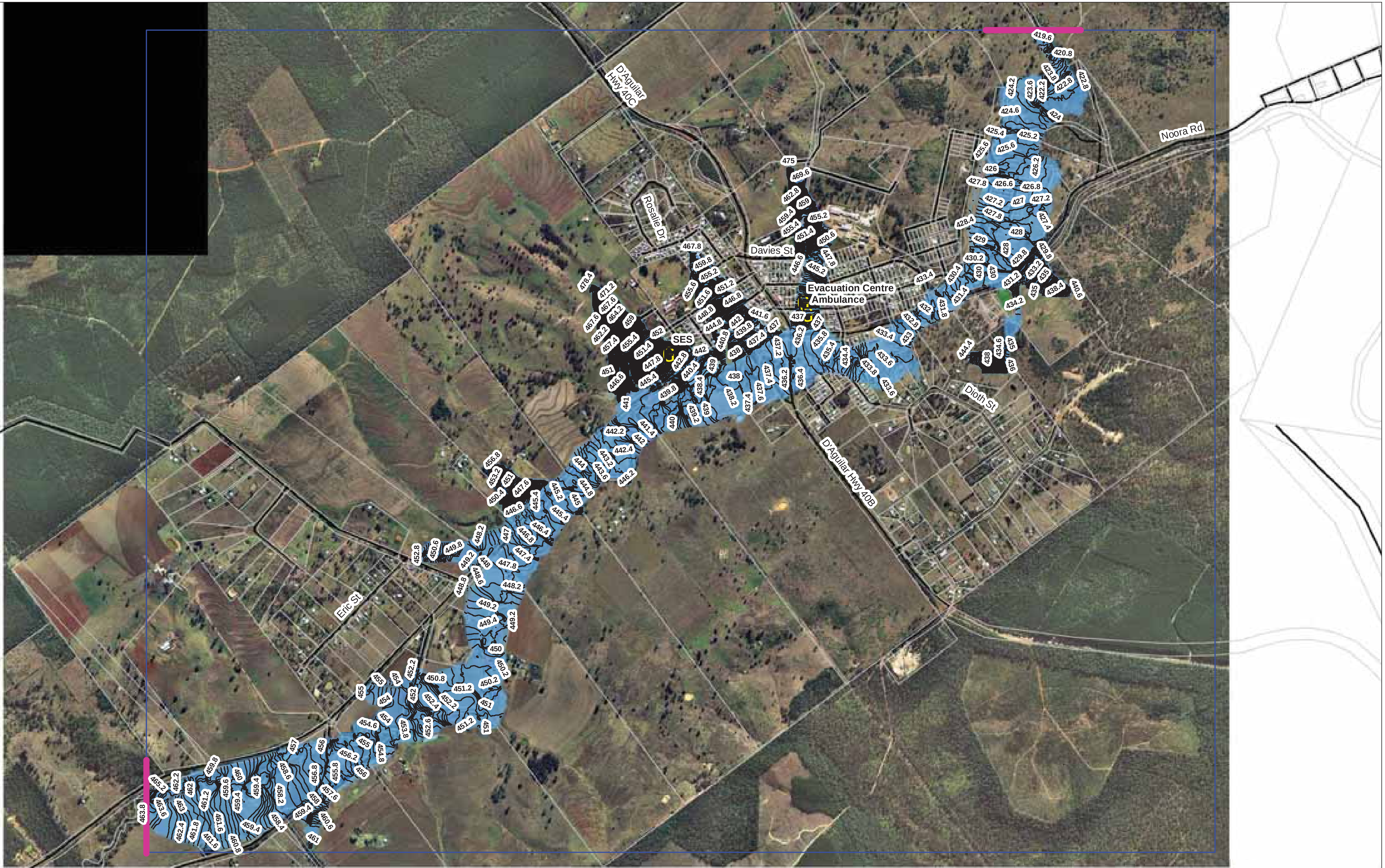

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SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 2 (+15%)
500 Year ARI Event Peak Water Level

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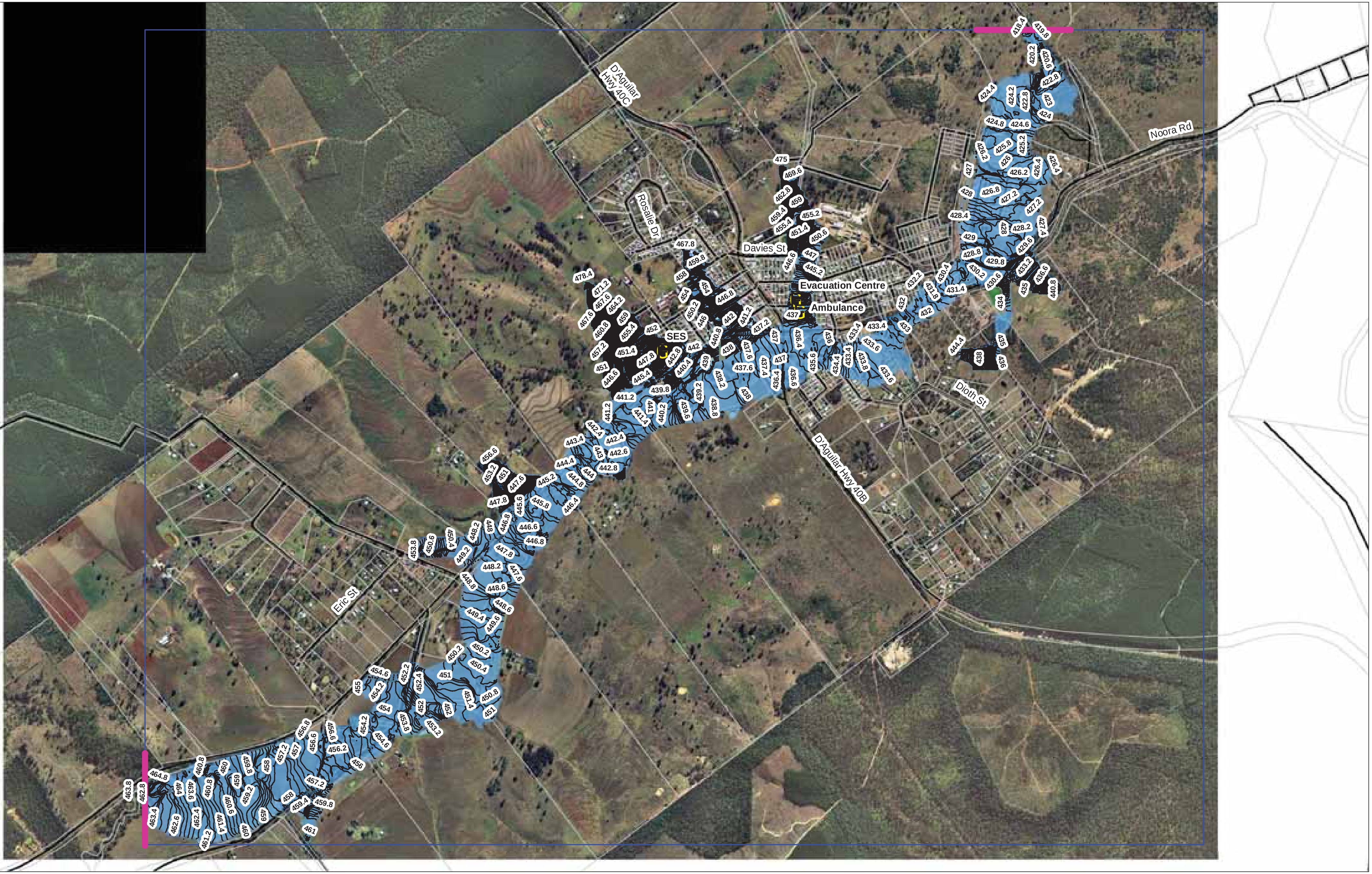

SP 051 Flood Studies
Work Package 10 - Yarraman
Climate Change Scenario 3 (+20%)
500 Year ARI Event Peak Water Level

Creek Flooding Model

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TOOWOOMBA REGIONAL COUNCIL

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yoursay.toowoombaRC.qld.gov.au/flood-resilience

TOOWOOMBA REGIONAL COUNCIL

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TOOWOOMBA REGION
Rich traditions. Bold ambitions.

Nobby Flood Studies Information Sheet

WHY UNDERTAKE FLOOD STUDIES?

Following extensive flooding across the Toowoomba region, we commissioned a number of flood studies to better understand how flooding can impact our communities. These studies are now complete and available on our website.

The flood studies found that flood behaviour can be complex and vary between locations, depending on landscape, infrastructure and rainfall pattern.

SOME BASIC FLOOD TERMS

1. **Overland flow** – short duration flooding of backyards, drainage paths, streets and rural properties caused by stormwater as it makes its way into the creek/river system;
2. **Creek flooding** – short to medium duration flooding caused by creeks rising and breaking their banks, which can then flood nearby homes, businesses and rural properties;
3. **River flooding** – longer duration flooding caused by significant rises in a river which can break its banks in the same way as smaller creeks.

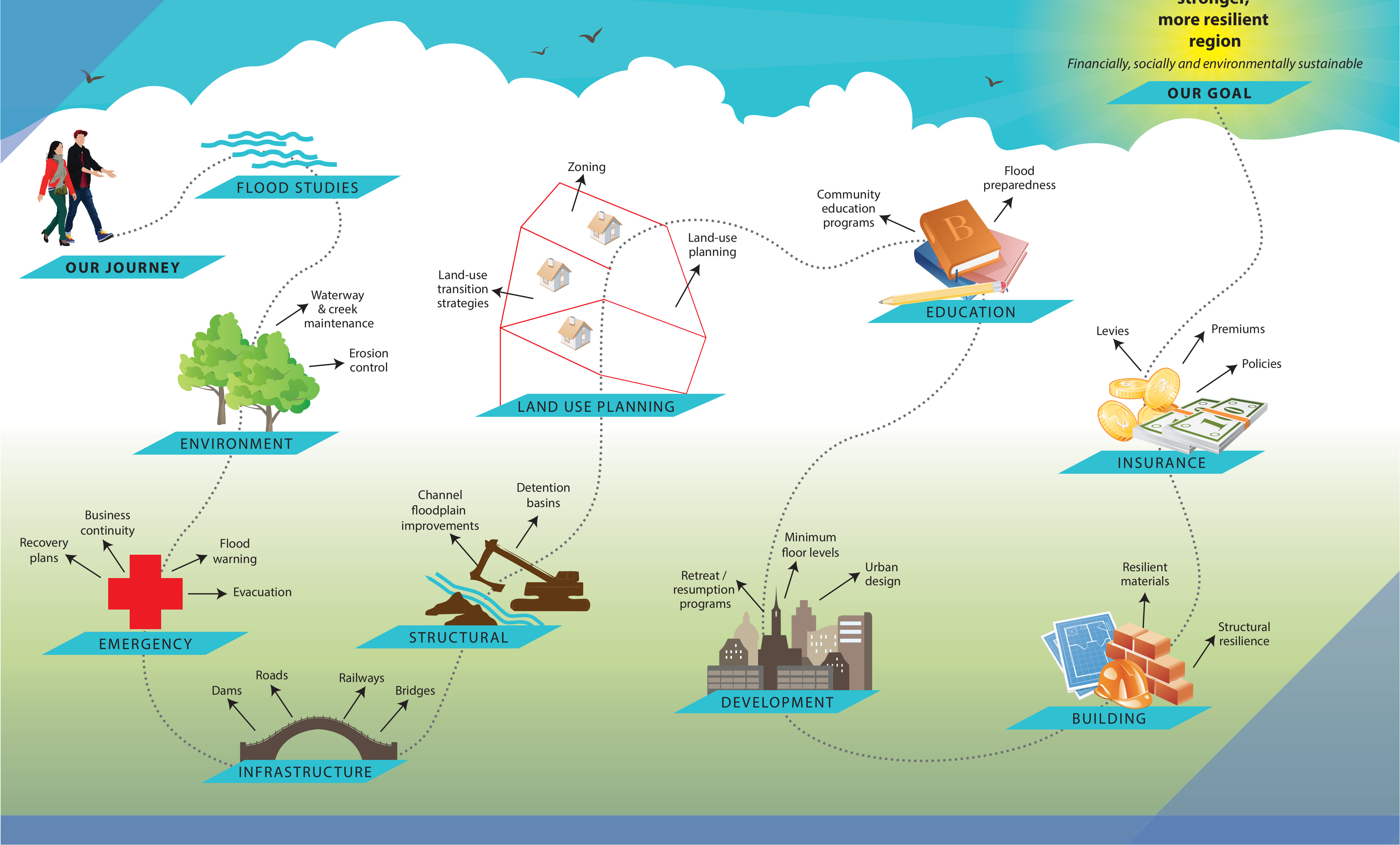
Most of the studies undertaken or commissioned by Council relate to the first two types of flooding – overland flow and creek flooding. It's important to note that these types of flooding can occur separately or together.

KEY MESSAGES

1. Council has a legislative requirement to undertake flood management and the whole community needs to be involved.
2. Flood studies are a foundation and an essential step towards our goal of a safer, stronger, more resilient region.
3. Flood studies have been undertaken by specialist engineers and incorporate the latest data, modelling techniques and community input.
4. Community consultation enables two-way information sharing about the project to increase community awareness, enhance decision making and help achieve our goal of a safer, stronger, more resilient region.

Flood + us - our journey

Steps on the path to achieving our goal



Nobby Flood Studies Information Sheet

WHAT'S NOBBY'S FLOOD STORY?

A flood study and flood maps are now available for Nobby residents. The township of Nobby is elevated and is therefore not at risk from river or creek flooding. The town is affected by overland flow, which can cause significant localised flooding as was seen during January 2011.

Mid-to-long term residents of Nobby informed the flood study by providing valuable insight into the January 2011 event. In particular, residents provided an indication of flood levels and flood behaviour, including four flood levels, anecdotal evidence and depth / speed of flood waters. Given the lack of flood gauges information available, information from residents, particularly about the flood behaviour surrounding the railway line, was key in validating the study. The study has concluded that the January 2011 event correlated well with a more rare or extreme event and is estimated to be approximately a 0.2% Annual Exceedance Probability event - meaning there is a 0.2% chance in any year to see this size event or larger occurring.

Two main flow paths exist, both on the western side of town, intersecting Commerford Street/ Mt Kent Boundary Road. These flow paths exhibit significant to extreme flood hazard. Properties at the western end of Commerford, Brodie and Murton streets are affected worst with depths of up to 2 metres, even in quite frequent events. Limited dwellings are constructed in this area, despite the historical subdivision.

An additional three flow paths intersect the township south of Commerford Street, with flow traversing westward near Free Street and between Norfolk Street and McGeever Street. These flow paths are considered low hazard in a 1% flood event but could cause flooding to residential properties. Much of the township includes raised, traditional Queenslander construction however some newer slab-on-ground dwellings are exposed to flooding.

The flood study has modelled a range of possible flood scenarios from moderate through to rare and extreme events and provides maps on depth, velocity and hazard.

Annual Exceedance Probability (AEP) means the chance of a flood of a given size or larger size occurring in any one year, usually expressed as a percentage.

COMMUNITY INVOLVEMENT

Improving the way we prepare for and respond to flooding as a community is very important to us. Many residents in our region contributed information to build and validate our flood knowledge during the region-wide consultation sessions and other flood studies engagement opportunities.

Community involvement with this project continues to help our region become safer, stronger and more resilient. We encourage you to access the flood study information online and stay up to date with the project by visiting the web address below.

GET INFORMED

You can access our region's current flood studies and maps by heading to
http://yoursay.toowoombarc.qld.gov.au/flood-resilience
For more information, please contact the project team by phone, email or post.

Phone: 131 872

Email: info@tr.qld.gov.au

Post: Strategic Planning & Economic Development,
Toowoomba Regional Council, PO Box 3021, Toowoomba Q 4350.

TOOWOOMBA REGION