Final Report

Bendemeer Flood Study

25 April 2012

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Bendemeer Flood Study

Draft Report

For: Tamworth Regional Council

APRIL 25, 2012

EXECUTIVE SUMMARY

Study Objective

The primary objective of the Flood Study for the town of Bendemeer was to develop hydrologic and hydraulic models for mainstream flooding and flooding from the main tributaries within the modelling area, and to provide information on flood extents, water levels, flows and velocities for a range of flood events, including 5 year ARI, 10%, 2%, 1%, 0.5% AEP and Probable Maximum Flood (PMF) events.

Further objectives were to identify hydraulic and preliminary hazard categories for the 1% AEP and PMF events, including the flood emergency response classification of communities, and to determine Flood Planning Levels based on the 1% AEP event plus 0.5m freeboard. Flood damages were also required to be assessed under existing catchment and floodplain conditions.

Catchment and Study Area

The subject area is located along the MacDonald River within the town of Bendemeer, situated approximately 40km north-east of Tamworth. The catchment leading to the town of Bendemeer has an area of about 1140km^2. The shape of the catchment is unusually narrow, with the MacDonald River dominating from the upper reaches through Woolbrook, Bendemeer, and further downstream towards Retreat.

The MacDonald River crosses the New England Highway to the south of Bendemeer and runs in a southerly to northerly direction, with additional flows arriving from the three tributaries. There are a number of hydraulic structures within the study area that may influence the performance and capacity of the river/creeks, including 5 bridges and a culvert crossing.

Data Sets

As part of the data submission for the project, Council provided various GIS data for the town of Bendemeer, including an aerial photo, cadastre, road area, 10m topographic contours, road centrelines, rivers/creeks, water supply lines, and hydraulic structures.

The data sets also included the report highlighting the “Assessment of Flood Risk in Various Towns and Villages” (Bewsher Consulting, 2007), with historic flood information for towns in the Tamworth Council LGA that included Bendemeer. In addition, a flood map for Bendemeer from the Tamworth Regional Development Control Plan 2010 was also obtained.

Additional data sets obtained for the study included gauged flow data from the NSW Office of Water (NOW), daily rainfall and pluviograph records from the Bureau of Meteorology, and topographic survey of the floodplain and hydraulic structures obtained through a local survey firm, Baxter Geo Consulting.

A community consultation program was undertaken as part of the project, providing flood information such as dates of floods, estimates of flood depths/floodmarks, durations and velocities.

History of Flooding

Bendemeer has experienced flooding in areas of the town in the past. The largest of these in recent memory occurred in January 1962, when significant flooding occurred through a number of sites throughout the town. The 1962 flood event has been previously assessed as being larger than the 100 year ARI event.

The community survey also highlighted a large degree of flooding in the November 2008 event, although not as large as the January 1962 event.

Community Consultation

The responses to the community survey were thoroughly reviewed for major flooding effects that could be beneficial in the calibration. Out of the many questionnaires sent out, 13 were considered to be positive, with relative relevance for calibration. To be beneficial for calibration, flood information needed to relate specifically to dates, since the rainfall data needs to correspond to the flood data. Many of the responses failed to indicate the date on which the flood affectation occurred. Responses that had photographs or videos were contacted for copies. Most of the data (19 properties) was associated with the Nov 2008 event. Four respondents referred to the Jan 1962 event, including references from past reports. Surveyors were employed to measure floodmarks on the ground. The data from the community consultation process was primarily used for modelling calibration to compare observed and modelled flood extents, levels and depths.

Study Methodology

The flood study involved an assessment of the rainfall runoff processes using a hydrologic model to compute flows and a hydraulic model to compute flood characteristics such as flood levels and extents, flow distributions, and water velocities. The hydrologic model used was the WBNM (Watershed Bounded Network Model), while the hydraulic model used was XPSWMM-2D. The modelling simulated mainstream flooding from the MacDonald River and the three incoming tributaries, and associated overland flooding.

Events assessed for calibration of the hydrologic model had a continuous record of data (both rainfall and flow) and had relatively large peak flows. These included the November 2008, January 1996, January 2004, and November 1984 events. Although the largest on record, the January 1962 event did not have the pluviograph records necessary to describe the temporal distribution of rainfall, therefore, it could not be included in the process. Calibration of the hydrologic model could not provide uniformity of modelling parameters across the range of the assessed events due to very pure pluviographic data coverage.

As most of the flood records related to the recent November 2008 flood, this event was used for a further calibration of the hydrologic model, in conjunction with the hydraulic model using observed floodmarks obtained from the community consultation process. The event did show a good calibration for adopted modelling parameters such as rainfall losses and the catchment storage/lag factor, with the hydraulic model accurately replicating the 2008 event and providing a close match to the observed flood levels. This provided a high level of confidence in the model and its capability to accurately represent the design flood events.

As, apart from the November 2008 event, the January 1962 event provided a number of observed floodmarks in the town, an attempt was made to use the event in a validation run of the hydraulic model. In absence of pluviograph records required to describe the temporal distribution of rainfall and modelling of flows, an estimate of the event peak flow was used for the XPSWMM-2D modelling, based on flows recorded at Woolbrook. The event flood levels could not be replicated to the same level of accuracy as for the 2008 event, indicating that the event peak was significantly larger than at Woolbrook.

Based on the results of calibration, the modelling parameters were adopted in communication with Council and OEH to enable modelling of design flood events.

Design Flood Modelling

Design flood events were run for the full range of different sized floods, as per the project requirements.

The design flood events were used to develop flood depth maps (including water levels), velocity maps, provisional hazard categories, hydraulic categorisation, and emergency response planning (ERP) maps.

The results indicate that the flood affectation for the 5 year ARI event and 10% AEP is relatively minor, affecting only low properties adjacent to the river, while the less frequent events will cause a significant affectation impacting a large number of properties and causing extremely hazardous conditions. The Low Level Bridge overtops in all design events while the High Level Bridge and both New England Highway bridges overtop in 2% and PMF events respectively.

A sensitivity analysis was conducted by varying model parameters and assessing the impact that varying the parameters would have on model results. A number of factors were varied, with the 1% AEP design event as the base figure. Varied factors included blockage at hydraulic structures, roughness coefficients, climate change scenarios affecting rainfall intensity, and the loss model used by the hydrologic model. The model was most sensitive to losses and climate change effects due to increased flowrates. Roughnesses also had a significant effect on water levels and velocities.

Flood Damage Assessment

Estimates of flood damages were computed using direct and indirect damage assessments. An OEH basic model was used for computation of the flood damage curves. The model included direct damages with structural damage, contents damage, and additional damages associated with the flood. The basic model was expanded to include indirect damages associated with factors such as loss of production, revenue and wages, and the post flood recuperative phase. These indirect damages were incorporated by applying a factor of 20% to the direct damages.

The assessment categorised the properties as Single Storey High Set House, Single Storey Low Set House, Two Storey House, Commercial, High Cost Commercial and Hydraulic Structures, with the hydraulic structures modelled using two different scenarios. WaterRIDE(TM) software was used in applying damage curves for computation of total damage for each design flood event, average annual damage (AAD) and total damage over fifty years at various discount rates. The total event damages were estimated to be within the range of $59K to $47M for the 5 year ARI and PMF events respectively, while the 1% AEP event damage estimate reached $8.8M. The average annual damage was estimated at $0.57M, while the total damage over the period of 50 years with discount rate of 7% reached $8.5M.

The flood damage estimates indicate that potential damage costs are relatively high considering the number of residencies affected. This is a result of a comparatively high number of bridges/ culverts in the area that may be damaged and require a full replacement in less frequent events.

Recommendations

The results of the study satisfy the objectives of the project, providing a solid basis for preparation of the Floodplain Risk Management Study, which is the next stage in the flood management process.

Based on the assessment of the quality of data available for calibration and verification for this project, the following is recommended to enable future comprehensive data collection and monitoring of flood behaviour within the catchment:

- Further collection of flood affectation information and regular update of the database with similar layout as in the flood questionnaire, including date of event for mainstream flooding with recorded depths and locations.
- Further validation of the model, if appropriate flood event data becomes available.
- Survey of floodmarks after major events and logging the surveyed levels into the Council's database.
- Installation of additional pluviographs within the catchment boundaries to form an accurate rainfall database representative of the catchment.
- Setup of a river flow gauge within the Bendemeer township area and reviewing and logging of flow information for the main flood events into Council's database.

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1 FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

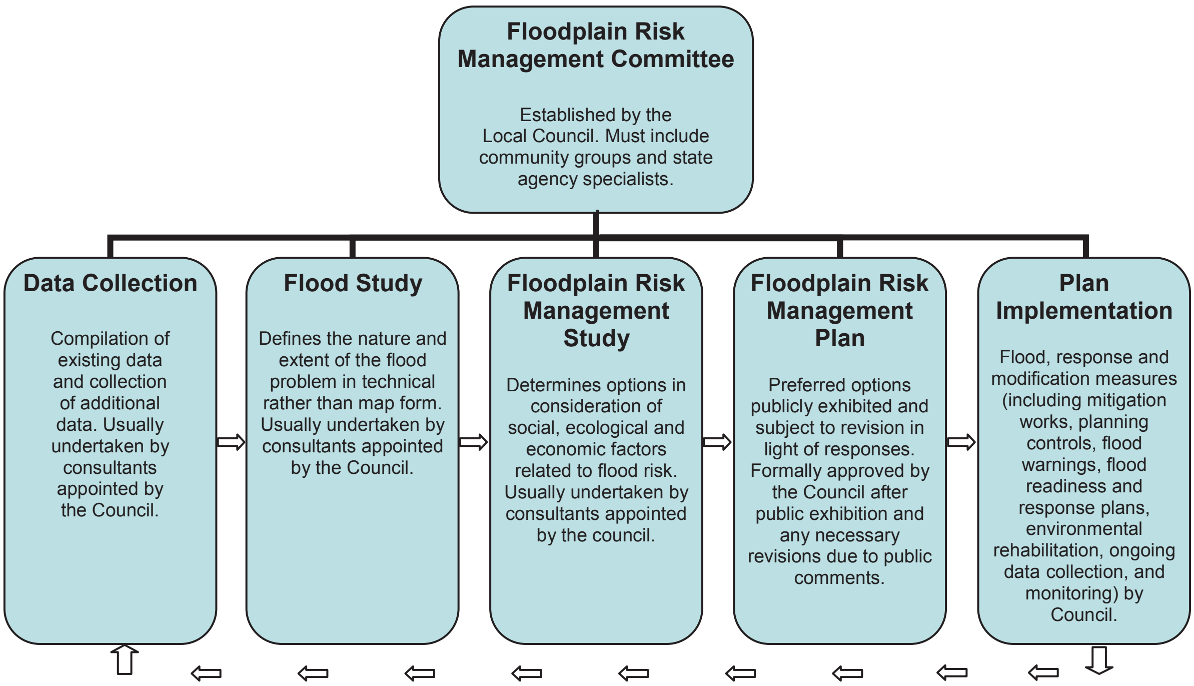
Under the Policy, the management of flood liable land remains the responsibility of Local Government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist councils with their floodplain management responsibilities.

The Policy provides for technical and financial support by the government through five sequential stages.

1. ***Data Collection*** (as part of asset management and preparation for the following stages of the process)
2. ***Flood Study*** (determining the nature and extent of the flood problem)
3. ***Floodplain Risk Management Study*** (evaluation of management options for the floodplain, with respect to both existing and proposed development)
4. ***Floodplain Risk Management Plan*** (involving formal adoption by Council of a plan of management for the floodplain)
5. ***Implementation of the Plan*** (construction of flood mitigation works to protect existing developments and use of Local Environmental Plans to ensure new developments are compatible with the flood hazard)

The floodplain risk management process is illustrated in Figure 1 below.

Figure 1: The Floodplain Risk Management Process



Tamworth Regional Council is responsible for local planning and land management within the MacDonald River floodplain at the town of Bendemeer, including the management of river flood events. Through its Floodplain Risk Management Committee the Council had allocated funds and proposed to prepare a comprehensive Bendemeer Flood Risk Study and Management Plan for the study area, in accordance with the NSW Government's "Floodplain Development Manual: the management of flood liable land", April 2005 (The Manual). The Bendemeer Flood Study constitutes the first stage of the floodplain risk management process for the MacDonald River and its tributaries within the town of Bendemeer, in which flooding may have impact upon residents, properties and infrastructure.

SMEC was commissioned by Tamworth Regional Council to prepare this flood study on behalf of the Tamworth Regional Council Floodplain Management Committee. The following report documents the work undertaken and presents outcomes that define flood behaviour for existing catchment conditions.

2 ACKNOWLEDGEMENT

This study was undertaken by SMEC Australia Pty Ltd, with funding provided from the Commonwealth and State Government's Flood Risk Management Program through the NSW Office of Environment and Heritage (OEH, formerly Department of Environment, Climate Change and Water - DECCW) and Tamworth Regional Council.

Numerous organisations and individuals have contributed both time and valuable information to the Bendemeer Flood Study. The study team acknowledges the contributions made by these groups and individuals, in particular:

- Mr William Ash (Senior Project Engineer and Project Leader, Tamworth Regional Council)
- Mr Neil Albert (NSW OEH representative)
- Members of the Tamworth Regional Council Catchment Floodplain Management Committee
- The landowners and residents of Bendemeer who contributed by providing flooding information during public consultation and discussed their experiences with the study team during the field visits
- Members of the NSW Office of Water and Bureau of Meteorology who assisted in obtaining the rainfall and hydrometric data
- Mr Peter Baxter (surveyor), Baxter Geo Consulting Pty Ltd
- XPSWMM Solutions, software technical support team.

3 INTRODUCTION

As a part of the Tamworth Regional Council Floodplain Risk Management Plan development, SMEC was engaged by the Council to undertake a flood study of the MacDonald River floodplain within the township of Bendemeer in August 2011. The purpose of the flood study was to identify the flooding issues that affect the town and establish hydrologic and hydraulic models required to determine flood behaviour under existing conditions. Findings from the flood study will be used in the subsequent Floodplain Risk Management Study and Plan to address the existing, future and continuing flood risks.

Tamworth is the major business centre of the North West and New England Region of NSW, situated about 310km north of Sydney and 180km due west from the coastline. Tamworth Regional Council (TRC) LGA covers an area of about 9,650km^2 and is bounded by:

- Walcha Council to the south-east
- Uralla Council to the north-east
- Gwydir Council in the north
- Narrabri Council to the north-west
- Gunnedah in the west
- Liverpool Plains to the south-west
- Upper Hunter Shire in the south.

The Tamworth region has a population in excess of 58,000, while Tamworth alone is home to over 50,000 people.

The township of Bendemeer is situated between Tamworth and Armidale, two relatively large regional centres, about 42km north-east of Tamworth along the New England Highway at the junction of the Oxley Highway. While Bendemeer lies in the Tamworth Regional Council LGA, the mid to upper parts of the catchment draining into the town lie in the Walcha LGA.

The Bendemeer area is primarily rural, famed for its wool, lamb and prime beef. The town is home to 487 residents with 122 family and 61 non-family households (as per Census 2006 data).

Figure 2: Tamworth Regional Council Local Government Area

4 OBJECTIVES

The town of Bendemeer has a history of mainstream river flooding and a need has been identified to define the extent of flood affectation and to determine appropriate development controls and risk management plans.

Council has estimated that currently twenty-six properties are at risk of flooding in Bendemeer. This risk has not been fully assessed and quantified. In recent years both residential and commercial properties in the township have experienced flooding due to MacDonald River flows from catchment areas outside the village boundary. The areas affected are to be determined as part of this flood study.

The primary objective of the study was to define the flood behaviour in the study area and to quantify the flood risk and damages that would occur under current flood conditions. The events of interest include the 0.5%, 1%, 2% and 10% AEP events and 5 year ARI event, together with the Probable Maximum Flood (PMF) event. Only mainstream flooding from the river and main tributaries and associated overland flow are proposed to be investigated.

The study is required to produce information on:

- flood levels and extents, velocities and flows for a range of flood events
- hydraulic categories for the 1% AEP and Probable Maximum Flood event as a minimum
- preliminary true hazard categorisation, considering both the provisional hazard categories for the 1% AEP and Probable Maximum Flood event as a minimum, and the flood emergency response classification of communities and the associated impacts on flood hazard. This breakdown is to identify the key drivers of hazard in different areas of the floodplain, for example, velocity, depth and emergency response classification
- flood emergency response classification of communities
- preliminary residential flood planning level and flood planning area (based upon 1% AEP plus a 0.5m freeboard)
- the sensitivity of flood behaviour to changes in flood, producing rainfall events due to climate change
- flood damages under existing conditions for a full range of design flood events under existing catchment and floodplain conditions.

It is expected that hydrologic and hydraulic modelling will satisfy the study objectives. This study may also form the basis for a subsequent flood risk management study, where detailed assessment of flood mitigation options and flood risk management measures will be undertaken. Therefore, the models established in the flood study are required to be suitable for use to assess a range of management options in the Flood Risk Study and Management Plan.

5 SITE DESCRIPTION

5.1 Study Area

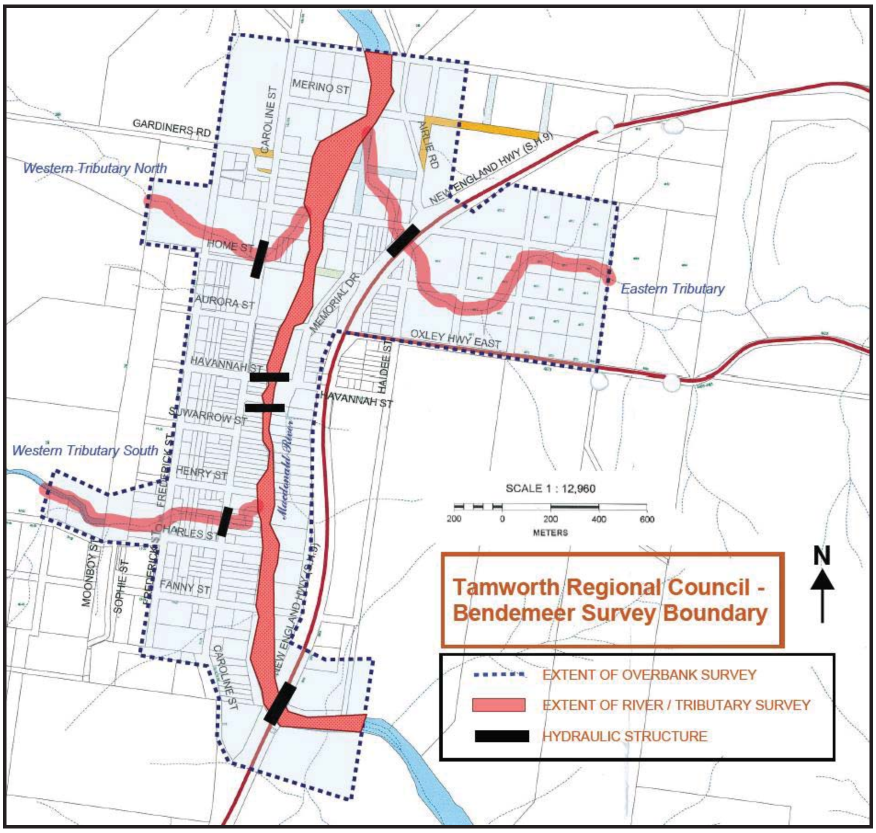
Bendemeer is a typical rural community with a traditional farming basis, with local flood knowledge guiding sensible development patterns and restricting development on the flood liable parts of the village. The village has experienced several flood events, with the MacDonald River causing flooding of the lower lying areas around Bendemeer. The flood behaviour has, in the past, noted high velocity events with limited warning times.

The MacDonald River runs in a northerly direction, first crossing the New England Highway at the upstream end of the township area. Most of the village is west of the river, with Caroline Street and Frederick Street running in a southerly to northerly direction, and a number of streets perpendicular to the direction of flow. Some of these streets include Fanny St, Charles St, Henry St, Suwarrow St, Havannah St, Aurora St, Home St, Gardiners Rd, and Merino St. Further downstream from the New England Highway bridge is the site of the Old England Highway bridge, which is out of use, followed by a low bridge crossing at Havannah St. The New England Highway continues in a northerly direction along the east side of the MacDonald River, crossing Havannah Street and passing Oxley Highway to the east, before heading in a north-easterly direction. Development lies east and west of the river near the Oxley Highway.

The study area includes the main river (MacDonald River), the south-western tributary between Charles and Henry Streets, the north-western tributary north of Home Street, and the north-eastern tributary crossing New England Highway north of the Oxley Highway.

A detailed hydraulic model is proposed to be used to assess flooding in the town of Bendemeer within the bounds that define the Study Area. These bounds are approximated by New England Highway in the South, Merino Street in the north, Frederick Street in the west, New England Highway immediately east of the MacDonald River, and the north-eastern tributary crossing the New England Highway to an extent of approximately 1.1km upstream of the New England Highway crossing.

Figure 3: Bendemeer Locality and Extent of Project Area



5.2 Hydraulic Structures

The study area of the township of Bendemeer includes a number of structures that are expected to have an impact on behaviour of flooding and, as such, require to be allowed for in modelling. These hydraulic structures include:

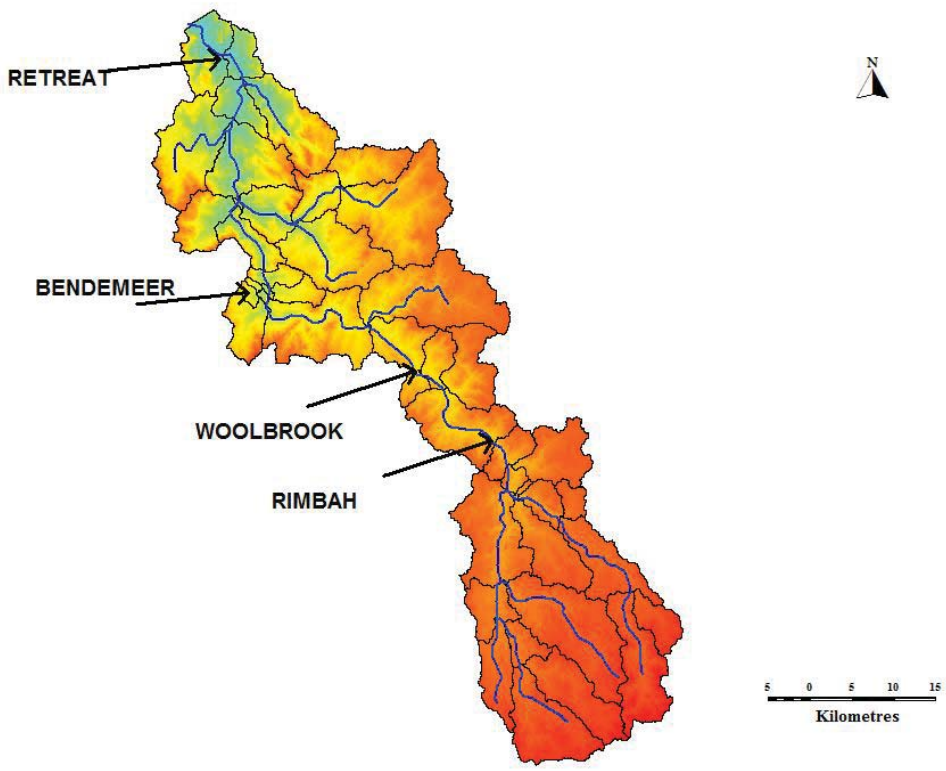
- The New England Highway bridge (the river)
- The Old England Highway bridge (the river)
- The low level crossing bridge at Havannah Street (the river)
- The culvert crossing at Caroline Street (western tributary/south)
- The underpass bridge crossing at Caroline St (western tributary/north)
- The New England Highway bridge (eastern tributary)

5.3 Catchment Description

The MacDonald River catchment is dominated by rural landscapes including farmland and forested areas. The river flows through the town of Bendemeer then to the north and west, where it joins the Namoi River before flowing into Keepit Dam, situated about 65km due west of Bendemeer.

The catchment leading to Bendemeer has an area of approximately 1140km^2. Further upstream at Woolbrook the catchment size is approximately 829km^2 and 699km^2 at Rimbah. Further downstream along the MacDonald River at Retreat the catchment area increases to 1760km^2. The overall catchment shape is unusually narrow for the most part, where the width of the catchment goes from about 25km in the upper reaches to 7km near Rimbah and 9km near Woolbrook. Downstream of Bendemeer the catchment widens again with the inclusion of additional tributaries, and again narrows near Retreat. The relatively complex shape may indicate unusual catchment hydrology.

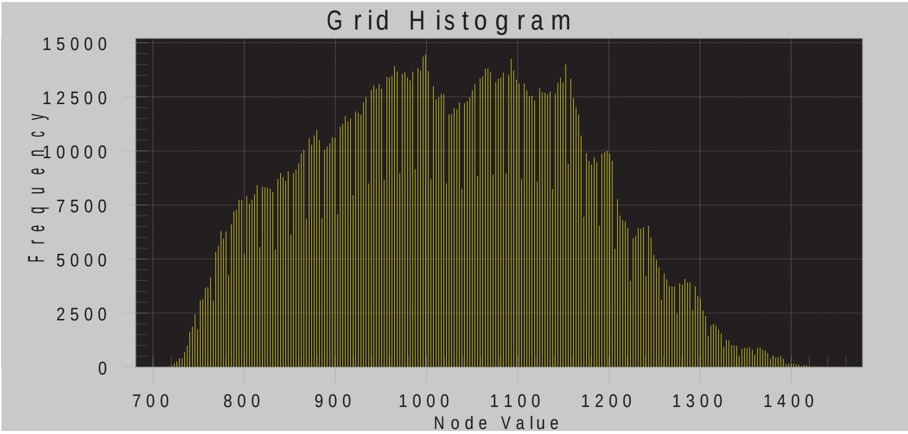
Figure 4: Catchment Diagram



Elevations within the catchment range from about 1440m AHD in the most upper reaches to 745m AHD downstream at Retreat. Elevations at Woolbrook and Bendemeer are about 910m AHD and 820m AHD respectively. The slopes are relatively steep in the upper reaches, followed by a fairly constant slope of approximately 1% grade to the outlet at Bendemeer.

The variation in elevation is shown graphically in a histogram in Figure 5 below. This graph uses the digital terrain model, using NASA Aster data, throughout the catchment, and analyses the number of points (up to about 15000) at a given elevation. This shows the variation in elevation from within the catchment, with most of the points between about 870m AHD and 1170m AHD. Above 1170m AHD the elevations decline to maximum of about 1440m AHD at the top of the catchment. Levels also decline to about 720m AHD at the downstream end. The x-axis shows the elevation and the y-axis shows the frequency/number of points for the corresponding level.

Figure 5: Histogram of Elevations within Catchment



10% of the points have an elevation greater than 1210m AHD, 50% of the points were above 1020m AHD, and 90% of the points were above 830m AHD.

6 DATA COLLECTION AND REVIEW

6.1 Drainage, Topographic, GIS Data Sets

As part of the data submission for the project, Tamworth Regional Council provided the following GIS data layers for use in the flood study:

- aerial photograph of the township
- cadastre showing property boundaries, lot number, property street name and number and LEP classification
- road area and name of road
- 10m topographic contour
- road centreline with surface type, such as gravel or bitumen
- rivers and creeks
- potable water supply lines and nodes, such as hydrants
- local bridges/culverts.

The projection of the submitted GIS data is MGA 1994, Zone 56. The data was imported into MapInfo and comprehensively assessed for consistency, forming the basis for further investigation, modelling and mapping. The GIS data provided was limited to the area covering the township of Bendemeer, however, not extending to the limits of the entire catchment.

6.2 Previous Reporting

The following documents relating to flooding in Bendemeer were provided by Council and assessed by SMEC in order to extract the information relevant for modelling and calibration.

Assessment of Flood Risk in Various Towns and Villages, Bewsher Consulting, Feb 2007

In February 2007 Bewsher Consulting released a report documenting an assessment of flood risk in various town and villages in the Tamworth LGA. This included a data compilation and review, site visits and interviews with residents, identification of potentially flood-affected properties, preliminary flood frequency analyses, a strategic plan for the preparation of detailed flood studies and floodplain management studies, and plans for towns/villages.

Towns included Manilla, Barraba, Bendemeer, Moore, Nemingha, Dungowan, Woolbrook, Moonbi, Kootingal, Somerton and Attunga. The strategic plan provided the recommendation to fulfil requirements under the NSW Government's Floodplain Development by data collection, and the preparation of flood studies and floodplain management studies, and a cost estimate to prepare such studies, including survey.

This report included a copy of a letter about the 1962 flood that is displayed in the Bendemeer Hotel, describing the severity of the event: "*The pub shook and trembled every time a surge of water or a tree hit it*". The letter mentioned that the upper level of the hotel was used for evacuation, including a horse that was taken upstairs, and that "*everyone and the horse survived".*

The report makes reference to floodwaters being at 8.2m floodmark in the January 1962 event, while the deck height of the bridge was 8.0m. An outcome of this report was a figure showing the approximate extent of the 1962 flood on both sides of the MacDonald River.

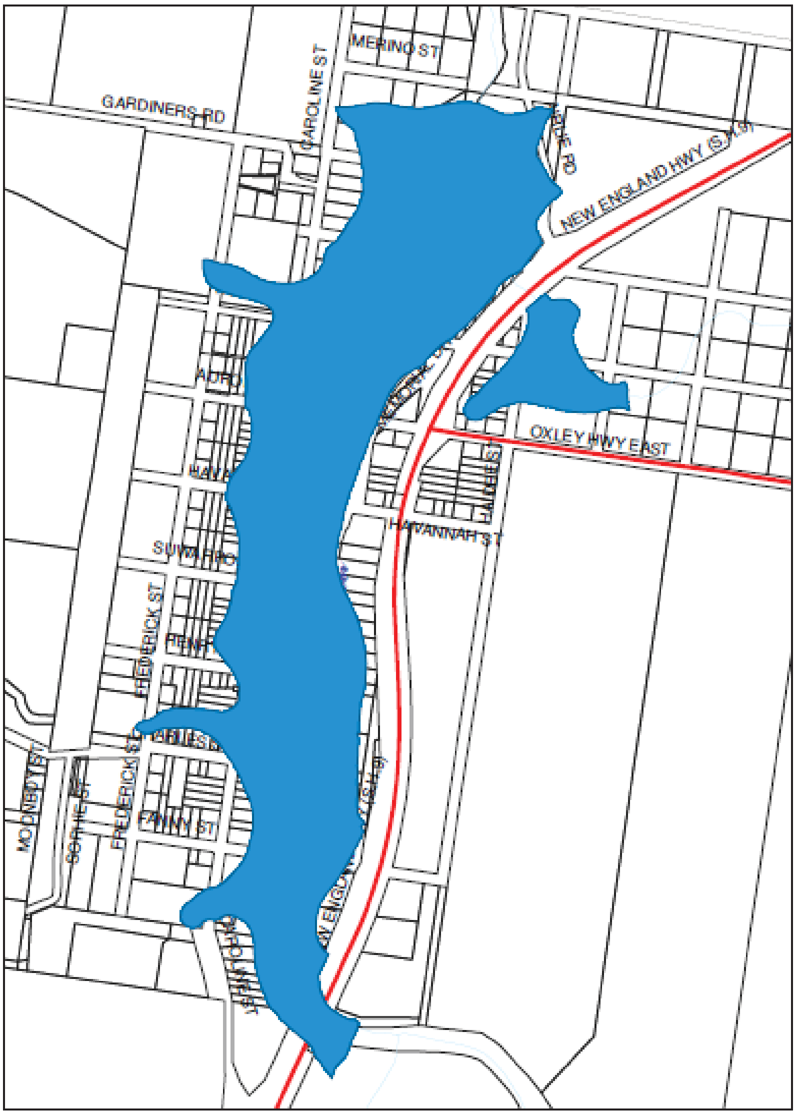
The Northern Daily Leader newspaper, sourced by the Bewsher report, highlighted that the 1962 flood caused 5 feet (1.5m) of water in the Police Station at 7pm on Friday 11th January. Locals indicated that while the BP service station on the east side of Caroline Street was flooded, the Caltex service station on the west side of the road remained free from floodwaters. The flood extent map of Bendemeer produced by Bewsher Consulting for the 1962 flood covers an extent beyond the Caltex service station to the west and is reproduced in Figure 6 below.

Figure 6: Flood Extent Map from Anecdotal Evidence – 1962 Flood Event (Bewsher Consulting, 2007)

Tamworth Regional Development Control Plan 2010, Oct 2010

The current Tamworth Regional Development Control Plan 2010 shows flood maps that are currently used to help assess development requirements in the Tamworth Regional LGA. Sheet 5 of 25 shows the map of flood affected land as applicable to Bendemeer. This flood extent map is reproduced in Figure 7 below and differs in some areas from the 1962 flood map in Figure 6 above.

Figure 7: Flood Extent Map from Council's DCP



6.3 Rainfall and Pluviograph Stations

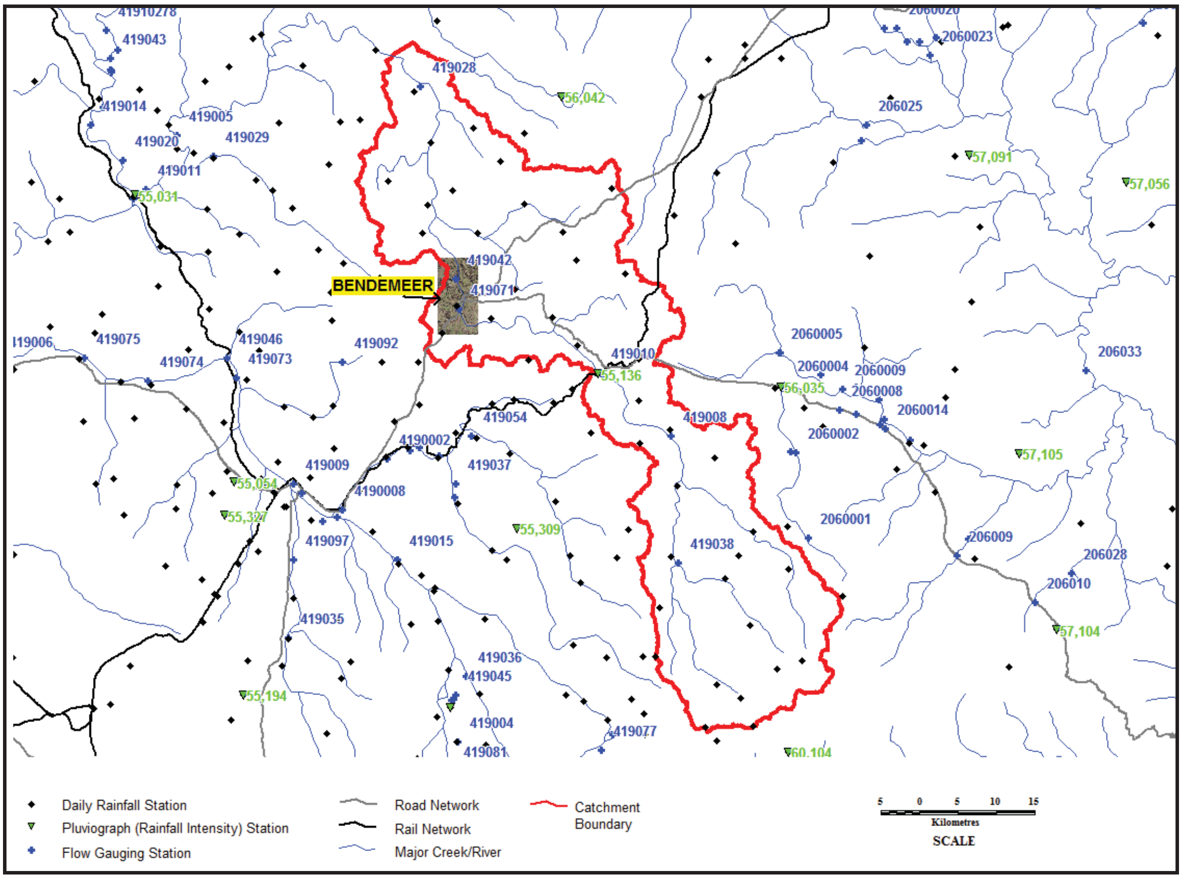
Locations of daily rainfall and pluviograph records were obtained from the Bureau of Meteorology and are shown in Figure 8. There are numerous daily rainfall stations situated throughout the catchment, however, many of these stations were not operational for all of the events used during the calibration. The pluviograph stations were very sparse with only one pluviograph station situated within the study area. The NSW Office of Water (NOW) was subsequently contacted for additional pluviograph data. However, the NOW database was also limited and did not add to the data from the Bureau of Meteorology.

Section 12 includes more detailed information on rainfall patterns and pluviograph data for specific events used to help calibrate the hydrologic and hydraulic models.

6.4 Streamflow Gauging Stations

The locations of the streamflow gauging stations were obtained from the NSW Office of Water based on records held in their database (Pinneena DVD). The locations of gauging sites are shown in Figure 8.

Figure 8: Rainfall and Streamflow Gauging Sites



The above Figure is also printed in Appendices for clarity. Six streamflow gauging stations were located within the study area, with two currently still in operation. Four of the sites have had more detailed continuous stream flow measurements, with ongoing water level measurements and rating curves. Table 1 shows the years of operation, including daily measurements that have been recorded at 9am, while Table 2 shows the periods of continuous records.

Table 1: Years of Operation

Station No	Station Name	Operational Record		Comments
		From	To	
419038	Cobrabald	1965	1987	ceased
419008	Rimbah	1924	1928	ceased
419010	Woolbrook	1927	-	current
419071	Bendemeer	1949	1949	ceased
419042	Bonnie Doon	1968	1987	ceased
419028	Retreat	1965	-	current

Table 2: Years of Continuous Flow Records

Station No	Station Name	Continuous Streamflow Records
419038	Cobrabald	1978-1981; 1984-1987
419008	Rimbah	N/A
419010	Woolbrook	1979-2009
419071	Bendemeer	N/A
419042	Bonnie Doon	1983-1987
419028	Retreat	1982-1987; 2000-2009

6.5 Site Inspection

Following thorough review of the available data submitted for the project by Council and familiarisation with the main project area characteristics, a site inspection was undertaken by the SMEC team members in August 2011. The inspection was carried out to:

- gain an appreciation of the study area and floodplain characteristics
- confirm the mainstream flooding area and tributaries
- confirm the relevant hydraulic structures
- confirm the Manning's roughness coefficients of the floodways
- obtain a photographic record of the study area and relevant structures within it
- establish the survey extents.

6.6 Survey

Based on the findings of the site inspection and established project boundaries the survey was arranged through a local survey firm, Baxter Geo Consulting, to provide the following information:

- Bathymetry of the MacDonald River and tributaries within the established project area
- Geometry of the relevant bridges and culverts along the river and tributaries
- Topographic survey of the riverbanks/floodplain area.

As a significant portion of the riverbanks and floodplain survey had to be extended over the majority of the town, the topographic information for this area was provided by Aerometrex, based on a photogrammetric survey with the following specifications:

- 5 cm pixel (GSD) high resolution
- Flying Height: 1920 ft (585m)
- Horizontal Accuracy (Ortho): +/- 0.10m RMSE
- Horizontal Accuracy (Feature): +/- 0.05m RMSE
- Vertical Accuracy of 0.04m (to 68% or 1 Sigma confidence)
- Vertical Accuracy of 0.08m (to 95% or 2 Sigma confidence)
- Suitable for 0.20m contours.

This approach assured the high quality survey coverage and terrain definition required for 2D hydraulic modelling. The bathymetric survey, which provided details of the riverbed and tributaries was additionally incorporated into the photogrammetric survey in order to form a digital terrain model (DTM) of the project area.

Survey of bridges and culverts included:

- the shape and size of the structure
- the number of segments, spacing between the piers and pier sizes
- the invert levels at the upstream and downstream ends of the structure
- the length (parallel with the water stream)
- the deck soffit level and top of the deck or road level above the structure
- photos of the structure.

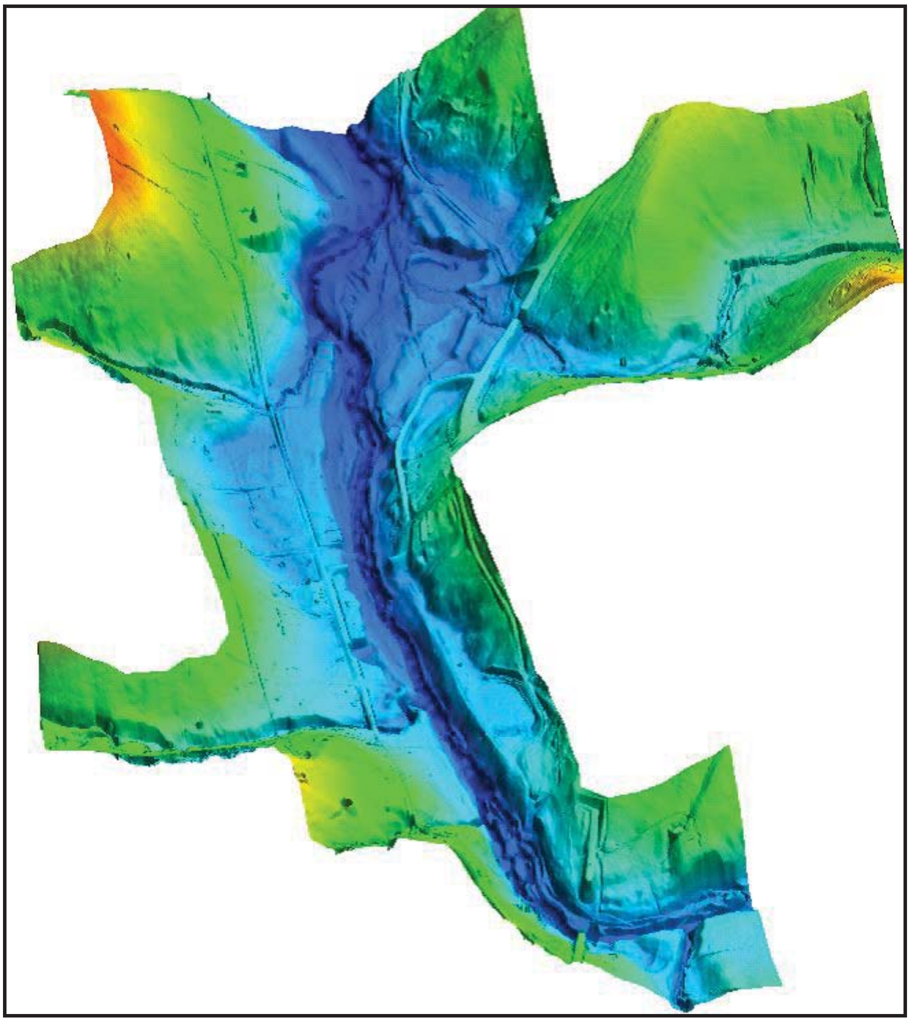
Generally, the survey provided a high level of detail to adequately define the topography of the study area and hydraulic structures. Information on the quality assurance of the topographic survey undertaken is presented in Appendix F.

Additional details on quality control of both the photogrammetric and ground survey are presented in Appendix F.

In addition to the topographic survey, the survey of floodmarks was carried out, upon obtaining the flood information through the flood questionnaire, as well as the finished floor level (FFL) survey of the habitable and commercial buildings required for flood damage assessment.

The additional contour data required for hydrological assessment of the wider catchment area was obtained from NASA ASTER (30m grid) database.

Figure 9: DTM Representation of the Modelling Area Based on the Topographic Survey



7 HISTORY OF FLOODING

Bendemeer has experienced several flood events with the MacDonald River causing flooding of the lower lying areas around the town through the 1950's, and in 1962 experienced a record flood that inundated numerous properties, including Bendemeer Hotel and cutting off the New England Highway. The largest flood since then seems to have occurred in November 2008. This event lead to flooding, with sandbagging of a number houses required to prevent ingress of water that reached about 7m in depth at the flood gauge. The November 2008 event seemed to inundate properties with floodwaters, with significant flooding occurring at the bowling green. A list of some of the significant historic flood events as recorded at Woolbrook flow gauging station include:

- Jan 1962
- Nov 2008
- Feb 1955
- Jan 1996
- Aug 1934
- Jan 2004
- Nov 1984
- Feb 1956
- Sep 1929
- July 1998
- Jun 2011
- Nov 2000
- Jan 1976

A report by Bewsher Consulting in February 2007 assessed flood risk in various towns and villages for Tamworth Regional Council, including Bendemeer. The report indicated that the flow gauging station at Woolbrook, upstream of Bendemeer, recorded a stage of 8.1m in depth in January 1962. By comparison, in Nov 2008 the stage reached 6.9m. These correspond to flowrates at Woolbrook of 137,000 ML/day and 82,700 ML/day for the 1962 and 2008 events respectively. There was no continuous streamflow gauge in operation in 1962 or 2008 at Bendemeer. The Bewsher report also highlighted anecdotal evidence stating that the 1962 flood was larger than that of the 1864 event, 98 years earlier.

Photographs in the report indicate the following affectation by the 1962 flood:

- Caroline Street was inundated with floodwaters
- Old New England Highway at the MacDonald River was overtopped
- Significant damage to the Bendemeer Bridge shown after the flood
- A floodmark is shown on a photo at Bendemeer Hotel at the windowsill.

While there was a stage of 8.1m at Woolbrook noted in the Bewsher Report, notes provided with photos indicate that there was a stage of 8.2m recorded at Bendemeer at the bridge.

Photos also indicate that the 1962 flood also caused significant damage to Woolbrook with large overland flow, and substantial damage to the rail bridge.

From the Bewsher report, an estimate of the 1962 flood extent was developed based on historical information and a site visit. This indicated that the flood overtopped riverbanks, affecting properties both east and west of the river. The flood extent map also notes that the police station was flooded, as well as the bridge and hotel, and that the Caltex service station was not inundated, however, floodwaters did surround it. West of the river flooding extended to properties between Frederick and Caroline Streets, while east of the river it extended to properties between the river and the New England and Oxley Highways.

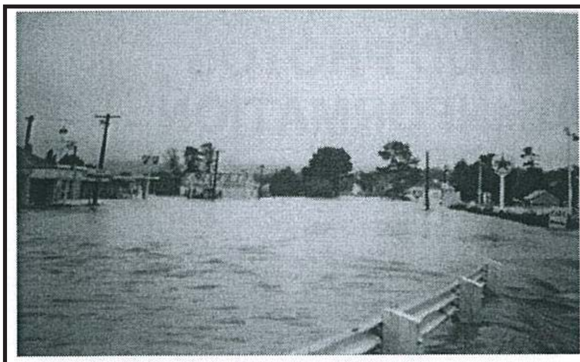
The Bewsher report also indicated that the 1962 flood was larger than the 100 year ARI flood event.

The flood frequency analysis carried out as part of this Flood Study and described later, based on the flow records at Woolbrook, indicates that the January 1962 flood was larger than the 100 year ARI flood event (96,700 ML/day), while the November 2008 event is considered to be smaller than the 100 year ARI flood event.

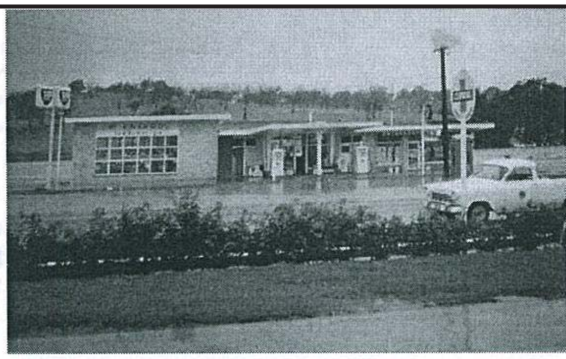
Figure 10: January 1962 Flood Photos Bendemeer (Source Bewsher, 2007)

a. House

b. House



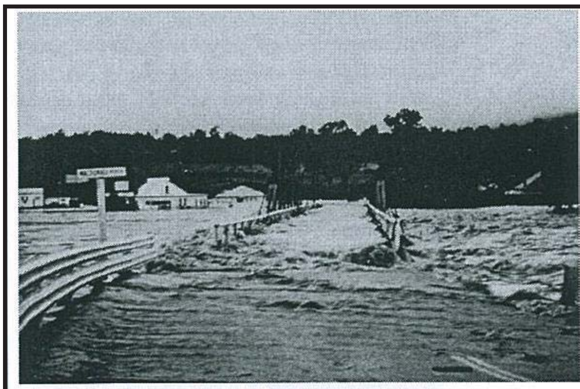
c. View south along Caroline Street



d. BP service station, Caroline Street

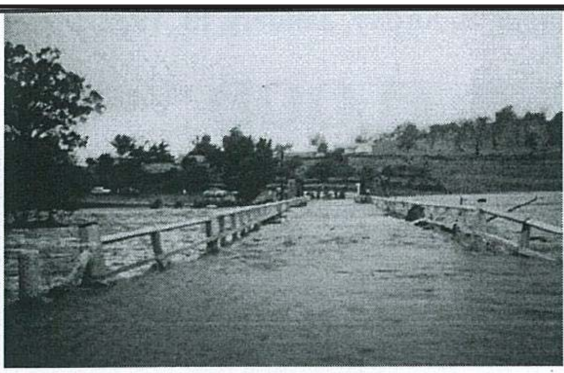
e. View south from Bendemeer Hotel

f. Flood debris in Bendemeer Hotel

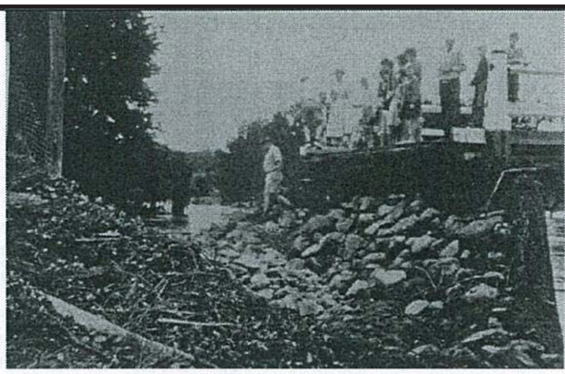


g. Old New England Highway bridge

h. Old New England Highway bridge

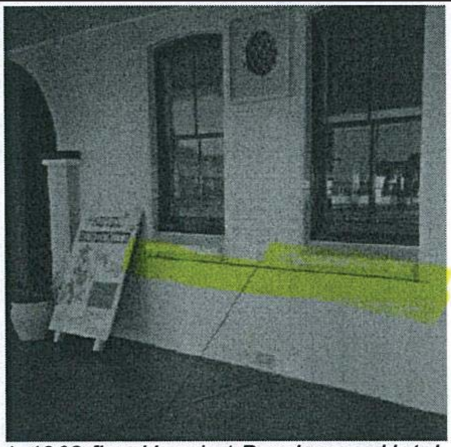


i. Old New England Highway bridge



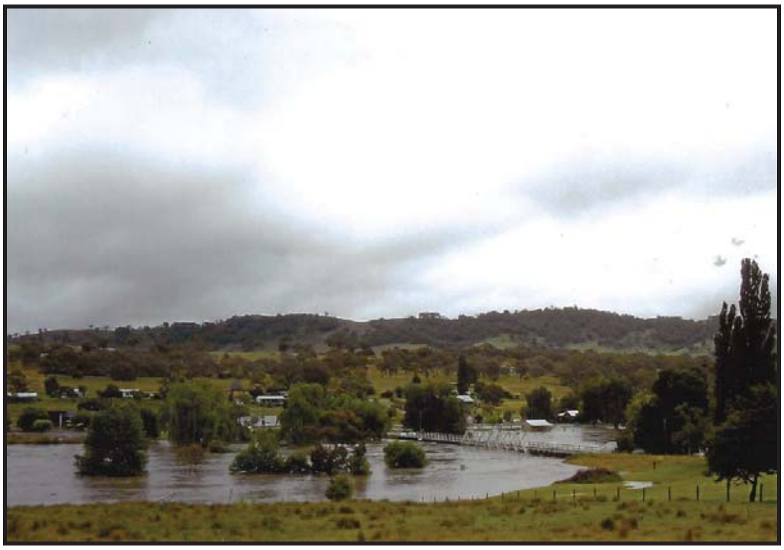
j. Damaged approaches to Bendemeer bridge

c. Flood runner west of Caroline Street



d. 1962 flood level at Bendemeer Hotel
(Source: Mr Gerard Ryan, TRC)

Figure 11: November 2008 Flood Photos Bendemeer



Old Bridge – Old Highway

Old Bridge – Old Highway

Bendemeer Bowling Green taken from Bendemeer Hotel

Taken from Caravan Park, Bendemeer

8 COMMUNITY CONSULTATION

8.1 Flood Questionnaire

A community consultation process was initiated to obtain flood information for past events. This involved issuing a newspaper article and sending a newsletter and flood questionnaire to residents and landowners within Bendemeer. The newsletter introduced the floodplain management program to the residents of the area, described the purpose of the questionnaire and provided the residents with contacts for their responses. The questionnaire was prepared in consultation with Council to help identify flood and drainage issues in the catchment and provide reliable flood information to assist in the calibration and verification phase of the hydrologic and hydraulic computer models. A total of 254 questionnaires were sent to landowners for flood information.

The flood information that was requested included:

- General information such as:
  - type of property
  - resident status at the property
  - how long the residents have lived at the property.

- Specific flood Information such as:
  - Whether the property has been flood affected in the past
  - which date(s) the property has been affected by floods
  - which parts of the property have been affected by floods and to what depth
  - how long the flooding lasted
  - where the water was flowing from and to
  - whether there were any floodmarks that highlight levels for a given date and, if so, could surveyors take measurements
  - the velocity and depth when the peak of the flood was experienced. (Three qualitative options were given for the velocity including stationary, walking pace and running pace)
  - whether there are any photographs or other records of the floods
  - any suggestions for resolving flood and drainage issues in the area, or other comments.

The responses to the community survey were thoroughly reviewed, with information of flooding effects that could be beneficial to calibration identified and extracted from the database.

8.2 Summary of Responses to Flood Questionnaire

Although a number of responses were provided (33), many were irrelevant for intended calibration, as a number of the properties were not directly affected by flooding. Also, to be beneficial for calibration, flood information needed to relate specifically to dates of the event, since rainfall data needs to correspond to the flood data. Many of the responses failed to indicate the date on which the flood affectation occurred.

Most of the data obtained from the questionnaire was associated with the November 2008 event, with a total of 19 sites indicating flood affectation during that event, while any remaining information related to the 1962 flood.

Only thirteen questionnaires contained comprehensive information that had relevance for calibration and were further considered to check the suitability of information in local conditions. These questionnaires indicated that floodmarks were on or near the property and provided estimates for depth of flooding either on ground, garage/shed, building or other structure. None were found to be minor conditions on the ground, such as less than 10cm in depth. Therefore, out of all the community survey forms released, only these thirteen questionnaires provided data that was considered to assist in the calibration of the hydraulic model. Respondents who indicated that they had photographs were contacted and copies requested. Most of the data obtained from the questionnaire was associated with the Nov 2008 event, with a total of 19 sites indicating flood affectation during that event.

Table 3: Community Survey Summary of Responses

Category	Number
Total questionnaires sent	254
Negative (i.e. no flood affectation at the property) with no comments regarding flooding/drainage issues	4
Negative (i.e. no flood affectation at the property) with comments regarding flooding/drainage issues	7
Positive (i.e. flood affectation registered at the property) but with incomplete information, thus irrelevant for calibration	8
Positive (i.e. flood affectation registered at the property) with complete data relevant for calibration	13

Table 4: Community Questionnaires – Summary of Positive Responses (i.e. Flood Affectation Registered at the Property) with Complete Data and Relevance for Calibration

	Address	Date of Flooding	Depth of Flooding	Parts of Property Damaged	Duration of Flooding	Velocity	Where was the Water Flowing	Flood-mark	Floodmark Available for Survey	Photos Available	Comments	Survey Point
1	14 Fanny St, Bendemeer	Nov 2009	0.20m	Ground/ Under House	-	Walking	Flowing through property	-	-	Yes	Dam needs overland flow path, not through properties.	Ground
2	74 Caroline St, Bendemeer	Jun 2011 Nov 2008	2011 event – about 1/3 from creek to Caroline St 2008 event – about 2/3 from creek to Caroline St 2008 event – Corner of Henry St and Caroline St	Ground Ground	> 24 hours > 48 hours	Walking Running	Rising in river	Yes	Yes	-	Debris blockage, low level bridge blockage.	Ground Ground Ground
3	2/16 Caroline St, Bendemeer	-	-	-	-	-	Rising in river, flowing through properties.	Yes	Yes	-	Regularly inundated, ~100yrARI design level.	Power pole base
4	125 - 131 Caroline St, Bendemeer	2008	- 0.5m 0.2m	- Ground Garage/Shed	2 days	- Stationary	Down roads, through properties, overflow from neighbours.	-	-	-	Runoff from Frederick St. Flooding not from river.	- Ground Garage/Shed floor
5	12 Havannah St, Bendemeer	29 Nov 2008	7.2m*	None						Yes	Photo Anzac Park. Debris under old bridge & under low level bridge, which has been there since flood of Nov 2008.	Gauged staff
6	153 Caroline St, Bendemeer	2008 2008	2m backyard both sides of house 4" Garage (~0.10m)	Ground Garage	1 day	Walking	Rising in river, tributary, ponding in properties, overflow from properties.	-	-	Yes (video)	Clean rubbish from river. Clean out creek under road. Stop dam at Frederick St from running over and into street, then into first property, then into other properties.	Ground – sides of house Ground – garage floor
7	104 Caroline St,							Yes	Yes	-		Floodmark –

	Address	Date of Flooding	Depth of Flooding	Parts of Property Damaged	Duration of Flooding	Velocity	Where was the Water Flowing	Flood-mark	Floodmark Available for Survey	Photos Available	Comments	Survey Point
	Bendemeer	1960's Nov 2010	- -	Building Ground								and date of floodmark
8	"Brooklyn" Bendemeer	Bendy RFS - Order of Houses to be sandbagged	Approx.								Have sandbags available in Bendemeer, not waiting for SES. Need organised flood warning system with flood levels, time to peaks. Contact numbers to relay info to Bendy FRS. Key to public hall e.g. Post Office or Pub for evacuation. Levels relative to mark in river.	Gauged staff
	Donny Farmer (Elbras Gully)	2008	6.2m*									N/A required address
	Lil & John (next door to Donny)	2008	6.2m*									
	Paul Cannon (Airlie Rd)	2008	6.2m*									
	Police Station (Caroline St)	2008	6.6m*									
	House opposite Donny's (Caroline St)	2008	6.6m*									
	John Murray (Old School - Caroline St)	2008	6.8m*									
	Bowling Club	2008	6.8m*									
	Old NRMA shop	2008	6.8m*									
	Elain Gillett (Caroline St)	2008	6.8m*									
	Shed/Shack (cnr Havannah & Caroline Sts)	2008	6.8m*									
	Gary & Liz Bailey	2008	7.0m*									
	Rest of lower Caroline St (front & back of houses)	2008	7.2m*									
	Bendemeer Pub	2008	6.8m*									
9	101 Caroline St, Bendemeer	Jan 1962	0.5-1.0m		2 hours house 12 hours block	Stationary	Rising in creek/tributary			-	Floodmark at the then BP, floodmark at top of workbench. Floodmarks were still visible in 2004 when premises was sold.	Ground
10	-	Jan 1962	8.2m								Location unknown. Deck Height @ 8.0m.	Deck Level of high level bridge
11	112 Caroline St, Bendemeer Hotel	Jan 1962	-	Just under windowsill			Rising in river, water flowing down roads	Yes	Yes	Yes	Photos of 1962 flood. But N/A to be sent. Bolted to wall. Floodmark and	Floodmark

	Address	Date of Flooding	Depth of Flooding	Parts of Property Damaged	Duration of Flooding	Velocity	Where was the Water Flowing	Flood-mark	Floodmark Available for Survey	Photos Available	Comments	Survey Point
											photos found in Bewsher Report	Floodmark
		Jan 1962	-	2 bricks under sill				Yes	Yes			Floodmark at base of ramp
		2008	-	Floodmark at base of ramp				Yes	Yes			
		2008	0.15m	Bowling Club building								Ground
		2008	0.15m	Bowling Green								Ground
		Noted for Jan 2009/2008	0.15m	Ground, garage/shed	1 hour	Walking		No	-			
12	Lots 8, 9, 10 Caroline St & 106-110 Caroline St	Jan 1962	300mm at Caroline St Boundary	All parts of property	4-6 hours, 1hr across Caroline St	1.5m/s at Caroline St Boundary		Yes	Yes	No	Council has flood investigation report.	Ground at Caroline St boundary
13	Caltex Petrol Station	1962		Above floor, noted by surveyors				Yes	Yes			Surveyor noted above floor floodmark

NOTE: * Relative to flood gauge at river near Bendemeer Hotel

** Owner name and street number not shown for privacy reasons

9 FREQUENCY ANALYSIS

A flood frequency analysis was performed on the gauged flow data recorded at the MacDonald River at Woolbrook (St 409010), approximately 25km upstream of Bendemeer. Woolbrook was chosen for the flood frequency analysis as it had a significantly longer period of record than the other sites and would therefore provide better estimates of the Annual Exceedance Probabilities (AEP) using peak flowrates. The analysis was performed for 81 years of data. The analysis was improved by extracting the maximum peak from the continuous flow records. However, for years where there were only daily measurements, the peak flow may not have been recorded, reducing the reliability of the analysis.

The flood frequency analysis was performed using annual series data, where the peak flow in any given year was used. The estimates used a LP3 distribution and a GEV-Shift 3 distribution, shown in Figures 12a and 12b respectively.

Figure 12a: Flood Frequency Analysis – Station 419010 using LP3

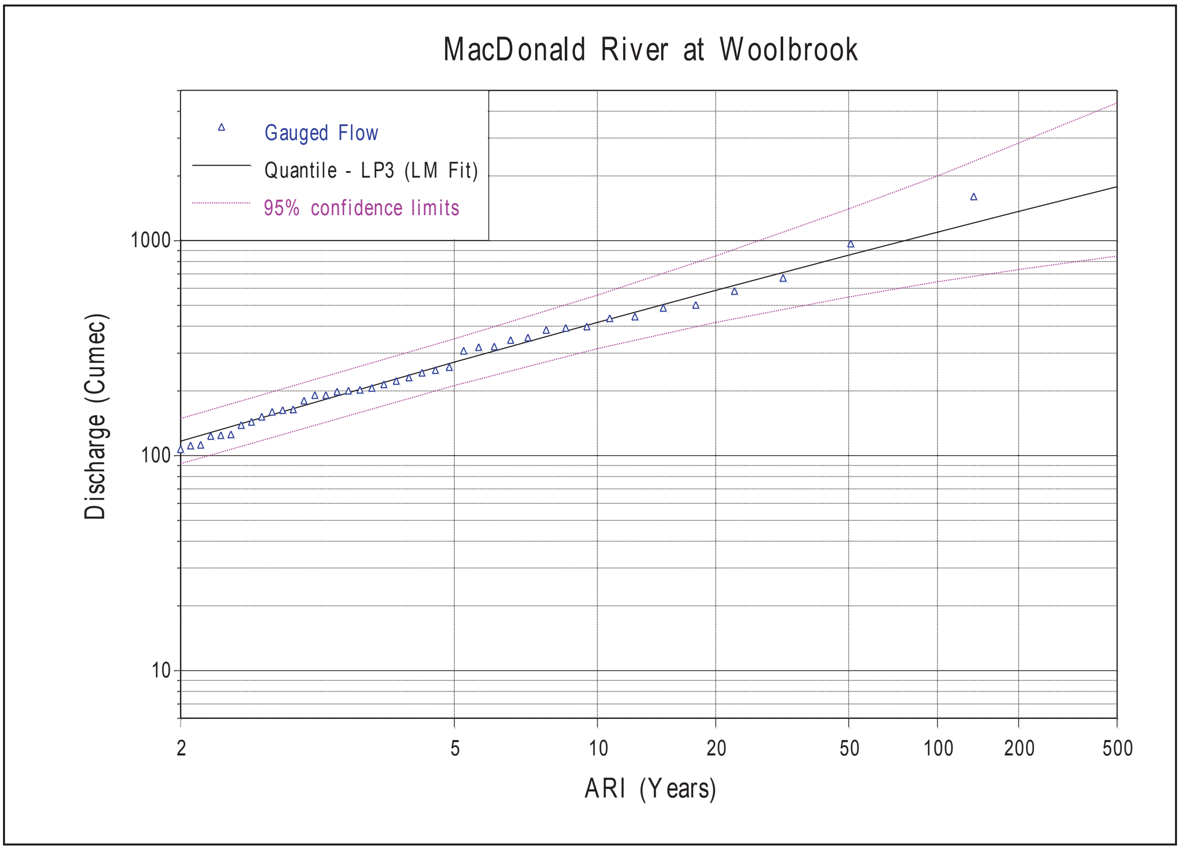
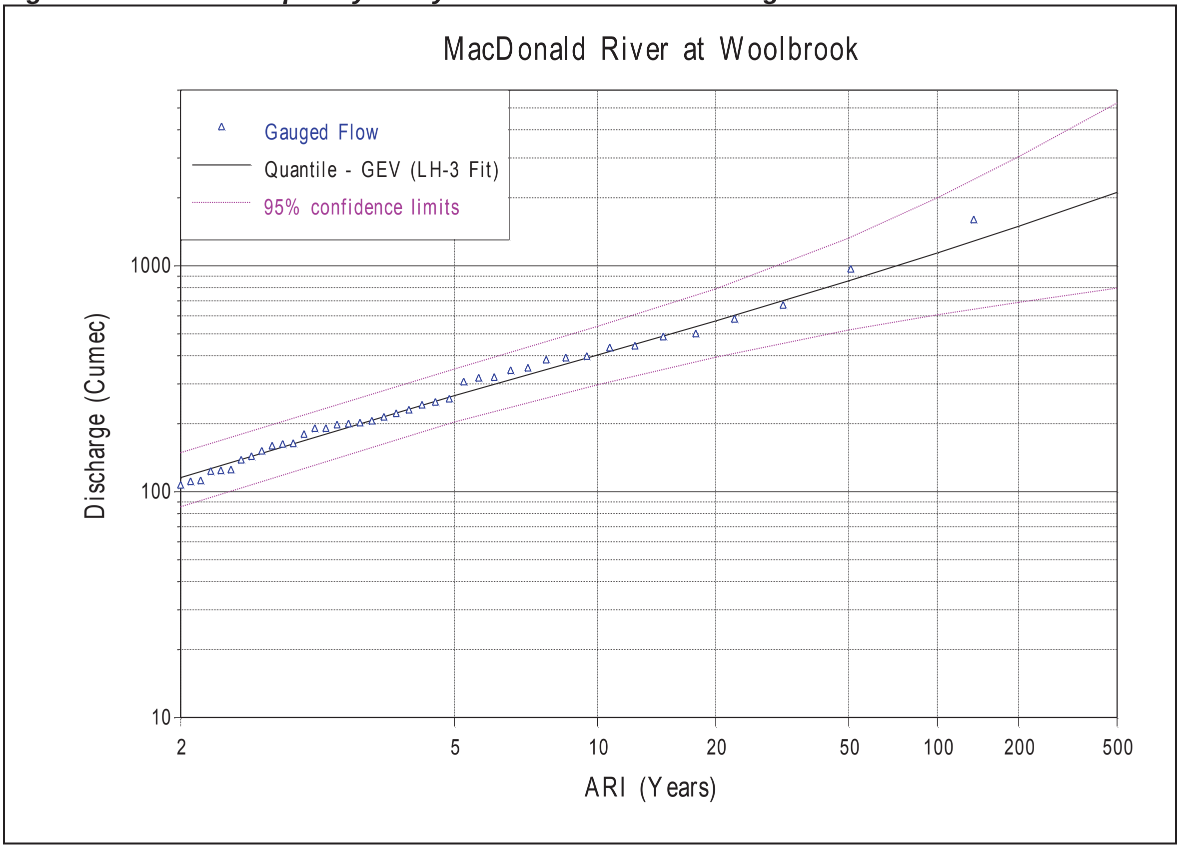


Figure 12b: Flood Frequency Analysis – Station 419010 using GEV Shift3



The ranking of the top 13 historic events from the annual series analysis at Woolbrook is shown in Table 5 in order of decreasing peak discharge.

Table 5: Top 13 Ranked Historic Events recorded at Woolbrook Gauging Station

Event	Peak Discharge (m^3/s)	Approximate ARI (by plotting position)	Approximate ARI (by fitted curve)
Jan 1962	1586	135	243
Nov 2008	958	51	68
Feb 1955	663	31	30
Jan 1996	576	23	21
Aug 1934	496	18	16
Jan 2004	481	15	15
Nov 1984	438	12	12
Feb 1956	430	11	12
Sep 1929	394	9	10
Jul 1998	388	8	9
Jun 2011	380	8	9
Nov 2000	350	7	8
Jan 1976	341	6	8

Using the GEV Shift3 distribution, the flood frequency analysis indicated that the 1% AEP event has a peak flow of 1140 m^3/s at Woolbrook. The analysis also indicates that the 95% confidence limit for this flow is within a range of 600 and 2020m^3/s. The 5% AEP event has a peak flow estimate of 570m^3/s, within a range of 392 and 785m^3/s.

Based on these results, the January 1962 flood event was larger than the 100 year ARI flood (approx 240 year ARI using fitted distribution), while the November 2008 event was smaller than the 100 year ARI flood event (approximately 70 year ARI using fitted distribution).

10 HYDROLOGY

10.1 Hydrologic Modelling Software

The Watershed Bounded Network Model (WBNM) was used in the rainfall-runoff modelling for the Bendemeer Flood Study. This type of model produces a time series of flows (a hydrograph) from rainfall information. The resulting hydrographs are input into the hydraulic model (described later) for modelling of flow distribution, flood levels, depths and velocities, and subsequent hydraulic and provisional hydraulic hazard categories.

WBNM separates overland flow routing from channel routing, thus allowing changes to either or both of these processes. The code for WBNM contains many useful features for flood studies, including built in design storms, runoff from impervious and pervious catchment surfaces, flood routing through storage reservoirs, built in culvert and weir hydraulics, and diversion of surcharging flows. The program is menu driven and designed to satisfy quality assurance requirements.

Some of WBNM's features are:

- Design storms, durations 5 minutes to 72 hours, ARI 1 to 500 years.
- Probable Maximum Precipitation using GSDM, Bulletin 53.
- Capability of incorporating long term PMP storms such as GSAM and GTSMR methods.
- Embedded design storms, with critical burst embedded within longer storms.
- Historic storms.
- Built in culvert and weir hydraulics.
- Fully Windows based.
- GUI template for building data file.
- GIS map overlays.
- Input/output files documented and saved for QA purposes.
- Extensive graphics for viewing results.
- Sub-catchments that can be easily added/deleted.
- Onsite detention is easily added/deleted.
- Storage reservoirs/detention basins are easily added/deleted.
- Multiple diversions of surcharging flow.
- Erodible fuseplug spillway.
- Excel interface allowing easy build of runfiles and easy viewing of results.

WBNM was developed in Australia and is used extensively throughout NSW and other states. WBNM has been shown to work well on catchments ranging in size from a few square metres to over 10,000km^2 of both urban and rural nature.

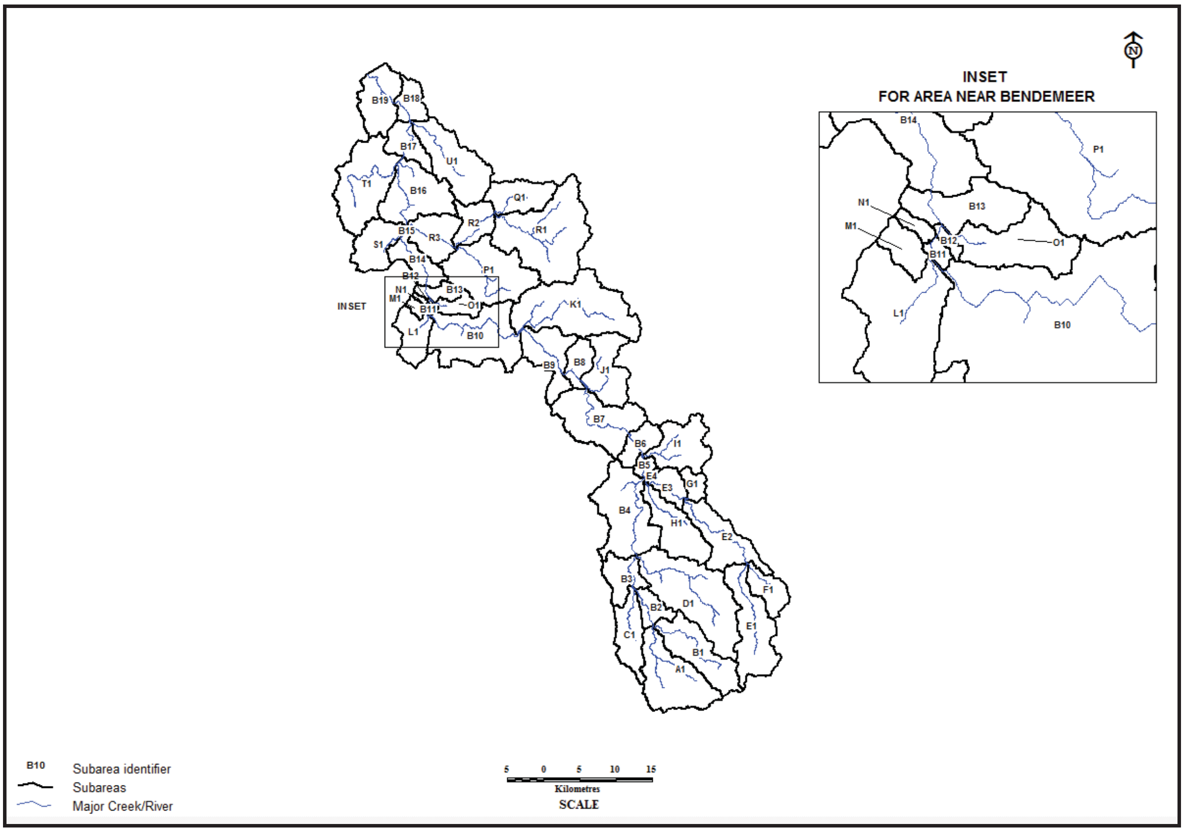
10.2 Catchment Delineation

The modelling area was divided into sub-catchments based on the available topographic information sourced from NASA Aster data. The location of boundary conditions for the hydraulic model was also considered when establishing the locations of sub-catchments. That is, sub-catchments were located where hydrographs were required as input data for the hydraulic model and at locations where streamflow gauging stations were situated. The total catchment area to the site at Bendemeer is approximately 1140km^2.

The delineation of the entire catchment was carried out by utilising the specialised terrain analysis and hydrologic algorithms in the Manifold software. This software provides sub-catchment delineation by accurate identification of overland flowpaths. A total of 44 sub-areas were used throughout the study area, 30 leading to the site at Bendemeer.

The catchment delineation is shown in Figure 13.

Figure 13: Catchment Delineation



10.3 WBNM Model Setup

10.3.1 Rainfall Losses

The loss model employed for the modelling area used was an initial loss-continuing loss (IL-CL) approach. This is considered the most commonly accepted methodology, due to the nature of the process, that losses such as infiltration and depression storages occur in the field. The initial loss-continuing loss method is useful since more complex loss models of soil stores often don't produce better reliability. Also, the vast majority of flood studies using the IL-CL method in practice have been proven to be successful in providing a representative rainfall-runoff model.

For impervious surfaces, such as concrete, water is not considered to infiltrate into the ground surface. In this case there is no continuing loss and the initial loss for depression storages is very small. For pervious surfaces such as grass, water infiltrates initially at a higher level with less infiltration over time. The initial loss simulates the high, early infiltration, while the continuing loss models an average infiltration over time.

AR&R (Institutions of Engineers Australia 1997, Book 2, Table 3.2) recommended median design loss rates for NSW (for regions with mean annual rainfall >300mm) of 10–35mm for initial losses and 2.5mm/hr for continuing loss rates for pervious surfaces. For the PMF event the AR&R publication suggests that an IL of 0mm and CL of 1mm/hr be employed.

10.3.2 Percentage Imperviousness

The MacDonald River catchment was considered to be primarily in an undeveloped condition, with zero percentage imperviousness, as small impervious areas within the villages were negligible compared to the overall catchment area and would not alter the hydrology of the catchment.

10.3.3 Lag Factor

The natural lag factor is used as a modelling parameter in the storage routing for pervious surfaces. An initial pervious lag factor of 1.7 was trialled based on research of NSW catchments with 129 floods on 10 catchments (WBNM Theory Manual). The lag factor of 1.7 is a mean value and results vary within the region and within the floods for a particular site.

For the Bendemeer Flood Study, observed flows were available to be used to calibrate the hydrologic model and, therefore, provided a means to optimise storage by varying the lag factor. A lag factor of 1.1 was derived, based on the calibrations, using flowrates at Woolbrook. The lag factor of 1.1 is considered to be within a reasonable range of recommended values.

11 HYDRAULICS

11.1 Hydraulic Modelling Software

The two-dimensional hydrodynamic modelling software XPSWMM-2D is internally coupled with TUFLOW for a fully dynamic modelling of stormwater systems and rivers/creeks in 1d, 2d or combined 1d/2d models. The modelled stormwater systems can also include floodplains, ponds, basins, culverts, bridges and underground drainage such as pit and pipe networks. The models may be used for the analysis or design of existing or proposed drainage networks. The model has the capability to communicate directly with other geographic information system (GIS) mapping software and offers a significant reduction of total time in model computation running times, compared with other 2D programs.

Two-dimensional analysis programs such as XPSWMM-2D use the topography in conjunction with continuity and momentum equations to assess the true direction of floodwater as it travels through the catchment. The XPSWMM/TUFLOW combination is a particularly powerful tool for the hydraulic modelling, as it provides a fully dynamic link between the modelled 1D elements and the free surface.

Two-dimensional modelling offers significant advantages over the 1D model technique for the reasons outlined below:

- Real time modelling from the beginning to the end of the storm.
- Accurate representation of overland flowpaths based on the topography (DTM), avoiding conceptualisation specific to 1D models.
- Accurate representation of the complex distribution of flows in the network of flowpaths, which can vary with storm magnitude and, therefore, cannot be predetermined with any certainty ahead of the modelling.
- More accurate determination of the active part of the floodplain and the delineation of the extent of the floodway zones, because in 2D modelling the velocity is allowed to vary laterally across the floodplain.
- More accurate determination of the floodplain storage zones.
- Easy assessment of impact of major developments, buildings or vegetation along active flowpaths on flooding behaviour.
- Easy assessment of impact of existing and proposed levees on flooding behaviour in terms of flood levels, flow and velocity distribution.
- Demonstrates the role of flow structures, bridges, culverts, embankments and levees in the distribution of flows across the floodplain.
- Demonstrates the impact of opening of presently closed historic flowpaths on flood behaviour.
- Velocity calculation along channels and assessment of the stability of channel banks, erosion potential and super elevation.
- Enhanced graphical presentation of the spatial distribution of the flooding, flood depth, flood hazard and velocity distribution. This is particularly useful in presentation of results to the Flood Plain Management Committee or in public meetings.

11.2 XPSWMM-2D Model Setup

11.2.1 Model Configuration

2D Domain

The geometry of the 2D model was established by constructing a uniform grid of square elements based on the Digital Terrain Model (DTM) created from the obtained topographic survey data. The key considerations in establishing a 2D hydraulic model related to the selection of an appropriate grid element size, as this affects the resolution, or degree of accuracy, of the representation of the physical properties of the study area. Selection of the grid element size depends on the size of the computer model and its resulting run times, as selecting a very fine grid element size will result in both a higher resolution and longer model run times.

In determining the element size for the 2D model, the above issues were considered, in conjunction with the final objectives of the study. Given the relatively large size of the study area, run times of the model were still of an acceptable length for a grid element size of 10m. This element size over the study area provided a good definition of the available topography of the floodplain required for modelling.

1D Domain
Although considered to provide a good resolution for the general floodplain within the project site, the 10m element size could not provide a good definition of the river and tributaries within the 2D model. Consequently, a dynamically nested one-dimensional (1D) network including the river, tributaries, bridges and culverts was embedded into the 2D model to improve the definition of the associated water flows.

11.2.2 Boundary Conditions

The hydraulic model is governed by boundary conditions that occur at both the upstream and downstream extent of the model. The upstream condition for the model was the flow data for the modelled storm, including both the historic and design events.

The upstream boundary conditions were represented by the hydrographs obtained from the hydrologic model. These hydrographs were inserted into the 2D model at the upstream end of the river and all three tributaries.

The dynamic nesting of the 1D network allowed for a dynamic interaction between the 1D and 2D elements. Provided there was capacity in a specific 1D element, such as a river or tributary channel, floodwaters would flow into it from the overland flowpaths. Wherever the capacity of the 1D network was exceeded, overflow would reverse back onto the flowpath (the 2D domain), providing a full interchange of flows between the 1D and 2D domains.

The downstream boundary condition was established at the most downstream section of the river as the normal flow. There were no flow obstructions or hydraulic structures further downstream of modelling that would have an impact on the established boundary.

11.2.3 Surface Roughness

Based on the aerial photographs submitted by Council, the environment within the modelling area was categorised into the following major land uses:

- sealed roads
- unsealed roads
- creek
- trees
- pasture
- fenced properties

These categories provided a basis for the establishment of the roughness required for modelling. Different surface material types were identified for the setting of roughness ‘n’ values for the initial modelling runs, based on the sourced technical literature.

Some of the roughness values were established as a composite roughness value to allow for variations in roughness within the specific land use category. For example, the roughness used for a typical residential (urban block) category represents a composite roughness value that covers a combination of grassed and paved surface treatment, buildings within the block and, in particular, fences.

The adoption of specific roughness values will be discussed in the following sections of the report.

11.2.4 Modelling of Buildings In Floodways

Consideration was also given to modelling of buildings in floodways to assure that significant obstructions to overland flooding were represented in the model. To represent buildings as 3D structures, the inactive area option was used by excluding the obstruction area from the 2D modelling domain. The polygons representing the building footprints were established from the aerial photographs.

11.2.5 Model Behaviour

Preliminary runs were carried out to test the model and review inconsistencies, in order to provide a stable and reliable modelling environment for the calibration and design runs. Some instabilities and inconsistencies were solved by adjusting the initial and/or incorrect modelling parameters of the associated structures.

The initial results obtained after model debugging indicated that the model was generally behaving as expected, with the main overland flow forming through the areas coinciding with the floodplain along the river and tributaries.

Further refinement of the model was required around the bridges and culverts to allow for the complex geometry of the existing structures and appropriate hydraulics of the overflow.

12 CALIBRATION

12.1 Introduction

The calibration process involved two stages, initially involving the hydrologic model and comparison of recorded and simulated hydrographs, followed by a comparison of recorded flood levels and flood levels simulated in the hydraulic model. Once the hydrologic model was calibrated, the modelling outputs provided flows that were to be used in the calibration of the hydraulic model. Satisfactory results from both models confirmed the adequacy of the modelling parameters for application in modelling design flood events.

12.2 Selection of Events for Calibration

Data from the NSW Office of Water, published in the latest version of their Pinneena DVD, included daily read and continuous read flow data, depending on the site and date of measurement. The streamflow data measured daily does not provide a fully reliable data source, as the peak flowrate may not have necessarily occurred at 9am when daily measurements are taken. In addition, measuring the hydrograph once a day does not provide sufficient points to adequately record the shape of the hydrographs. Therefore, continuous measurements recorded at Woolbrook (25km upstream of Bendemeer) and Bonnie Doon (3km downstream of Bendemeer) were used in favour of daily read records. The events with larger flowrates were also used in favour of smaller events to provide more reliable results when modelling.

Woolbrook and Bonnie Doon were also selected because they were the two sites situated closest to Bendemeer and would, therefore, provide the most reliable comparison for flows arriving at the town. The selected historic events used for calibration of the hydrologic model included November 2008, January 1996, January 2004, Nov 1984, and January 1976. Although the January 1976 event had no continuous record at either Woolbrook or Bonnie Doon, the event was still modelled for comparative reasons.

The January 1962 flood had no pluviograph records to describe the temporal distribution of rainfall and no streamflow data to setup and calibrate the hydrologic model with, and, therefore, was not used in the calibration of the hydrology. However since the January 1962 was the largest flood on record and had a number of recorded floodmark data, this event was considered to be an important factor in Bendemeer’s flooding history and was selected for verification of the hydraulic model.

12.3 Hydrologic Model Calibration

12.3.1 Spatial Distribution of Rainfall

Rainfall data has shown to vary across the catchment, not only for different events but also in different areas of the catchment. To develop the maps of total rainfall (i.e. isohyetal maps), varying across the catchment, daily rainfall data was obtained from the Bureau of Meteorology website and compiled for each event. Three-dimensional (3D) surfaces of rainfall were modelled using the MapInfo GIS software, with the results applied to each sub-area in the hydrologic model.

The spatial distribution (or isohyetal maps) for each historic event are shown in Figures 14a-14e. The daily read stations used in developing the maps have also been included, together with the total rainfall for the entire event. In some cases, rainfall stations did not have data, either due to malfunctioning of the equipment or because the station was not in operation at that time.

Figure 14a: Isohyetal Map November 2008 Event

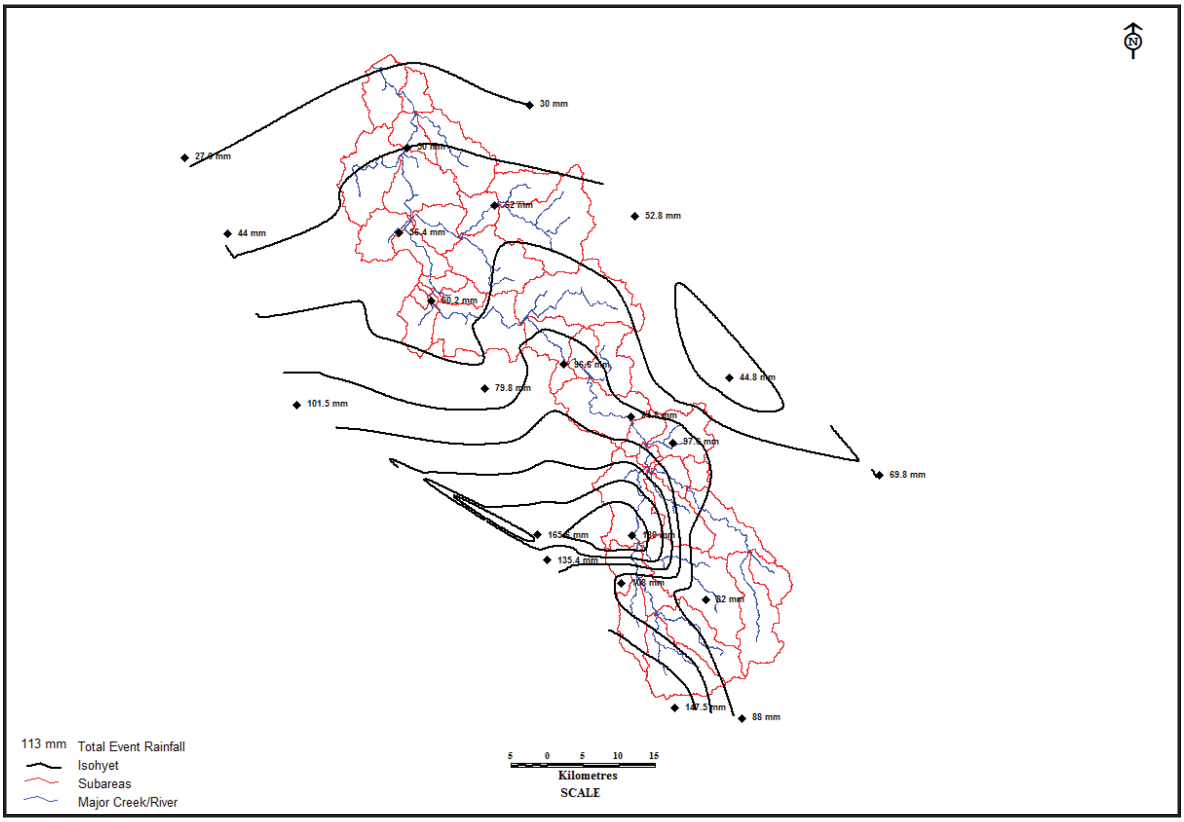


Figure 14b: Isohyetal Map January 2004 Event

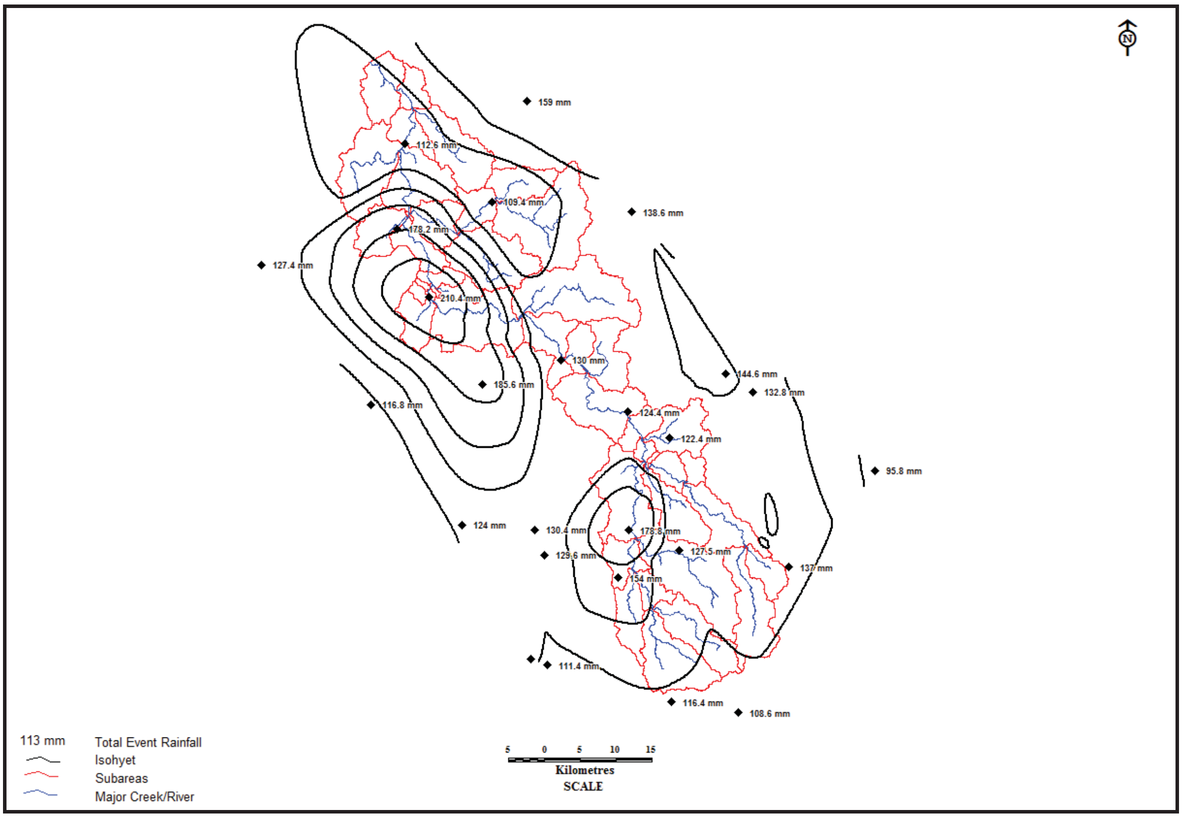


Figure 14c: Isohyetal Map January 1996 Event

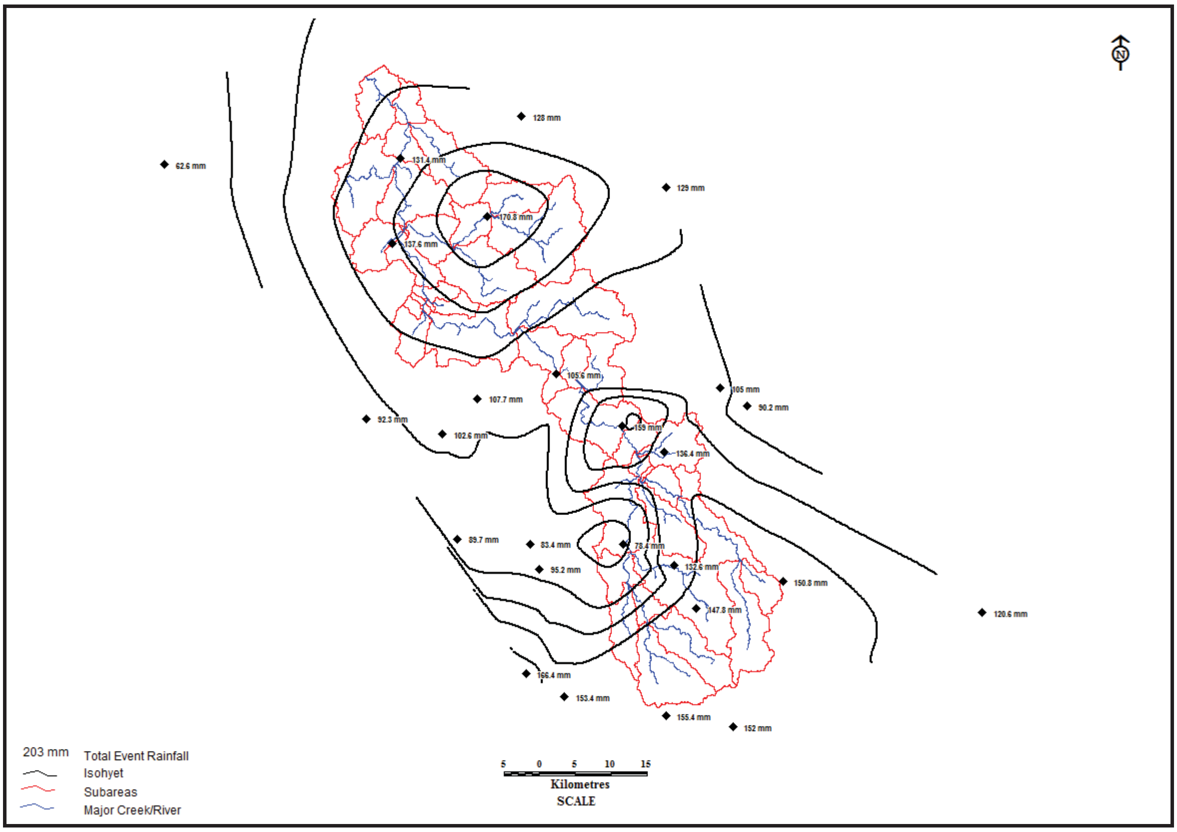


Figure 14d: Isohyetal Map November 1984 Event

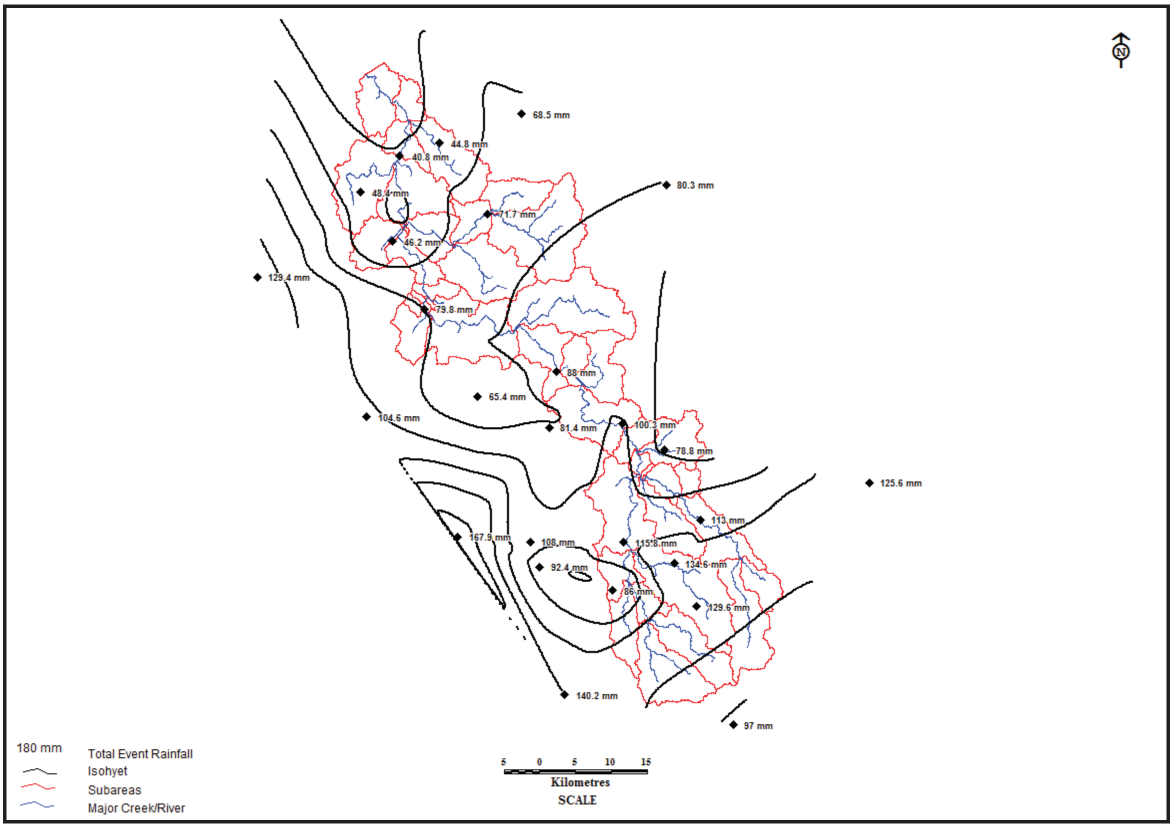
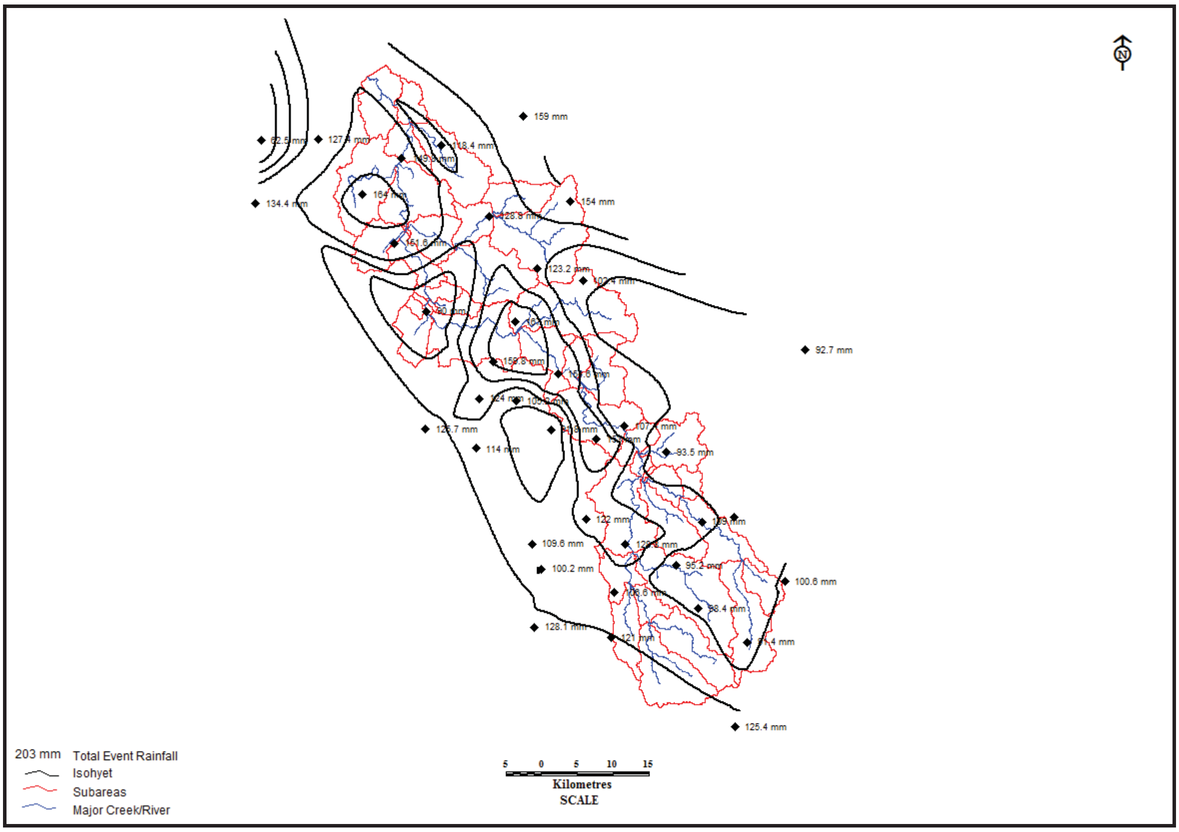


Figure 14e: Isohyetal Map January 1976 Event



12.3.2 Temporal Distribution of Rainfall

The temporal distribution of rainfall is derived from pluviograph records that describe the rainfall intensity or instantaneous rainfall over time. Locations of pluviograph stations from the Bureau of Meteorology were plotted in the Mapinfo GIS (Geographic Information System), and superimposed with the catchment layout and daily rainfall and streamflow stations previously shown in Figure 8. The plot indicated that only one pluviograph station is situated within the study area.

12.3.3 Calibration Against Streamflow Records

The initial calibration/verification attempted to match recorded and simulated hydrographs, describing the time series of flowrates over time (i.e. the hydrographs).

An attempt was made to use common losses and storage factors uniformly for all events. Losses affect the depression storages, infiltration rates and potential evapotranspiration, while storage affects the catchment response and lag times of rainfall to runoff, including both overland flow routing and channel routing. It was found that a consistent set of parameters could not produce a good match of flows for all observed storm events. In some cases the peak discharge, and volumes, were underestimated, while in other cases they were overestimated. Therefore, a uniform set of parameters could not achieve a consistently good match in the results.

The hydrographs were plotted using both an attempted best fit of losses common to all events and design losses from AR&R common to all events. A relatively low lag factor was used in both cases to describe the catchment and channel storage routing effects. The storage effects attenuate and retard the hydrograph while reducing the peak discharge. The results of these calibrations are shown in Appendix B.

Following this assessment, more focus was given to match the flows for a single large event, namely the November 2008 event, considering that there are a number of recorded flood marks relating to this event. The modelled 2008 peak flow (980m^3/s) approximately simulated the observed flows at Woolbrook (960m^3/s) for the following set of parameters:

- Initial loss (25mm)
- Continuous loss (2.5mm/hr)
- Lag (1.1)

The peak flow at Bendemeer modelled using these parameters was 980m^3/s, which was identical to modelled peak flow at Woolbrook. This was attributed to the small additional contributing area between these two locations that would drain a long time before the arrival of the peak flow from the upstream catchment. This calibration result is shown along with the full simulated and observed hydrographs in Appendix B.

12.3.4 Hydrologic Model Calibration Summary

The calibration of the hydrologic model could not provide a close match of hydrographs for all storm events selected for assessment, primarily due to an absence of sufficient pluviographic data required to accurately describe rainfall temporal distribution throughout the catchment, in conjunction with catchment size and its unusually elongated shape. The actual temporal distribution of rainfall within the study area may vary more than indicated by applying a single pluviograph station record. In addition, the pluviograph station at Woolbrook (the only pluviographic station within the catchment) did not register data for the Nov 2008 event. The nearest gauge that could be applied was Nowendoc (Green Hills), situated outside of the catchment boundary.

Orographic impacts may also affect the results. These occur where mountain ranges are located near the upper reaches of the catchment, causing clouds and water vapour to suddenly rise due to the topography of the mountain ranges. The rise in water vapour causes an increased potential of rainfall in the vicinity of the ranges and may significantly vary the temporal distribution of rainfall in that localised area, which is difficult to confirm without the pluviographic data.

In an attempt to increase the accuracy of the hydrologic model calibration, the NSW Office of Water was contacted for potential additional pluviograph stations that they may hold that could improve results. It was found that the only pluviograph station held by the NSW Office of Water was at the same site as the BoM gauge at Woolbrook and did not record rainfall during the January 1962 or November 2008 event, although it had records for other selected events, including pluviograph data from the Woolbrook site provided by the BoM.

The sensitivity to changes in the lag parameter, simulating the storage effects, was assessed for the overall range of calibrated storm events, although the manuals recommended that this parameter should not be altered for individual storm events, as the catchment response is believed to be independent of events over time for similar catchment conditions. The adjustment of the lag parameter proved to have an impact on individual events, however, it could not improve the results for the overall range.

Variable rainfall losses for each historic event may also contribute to inconsistencies in the results, as the antecedent moisture condition and loss rates may vary between events. Varying the losses did not provide a significant improvement of calibration, even if the extreme loss values recommended by AR&R were used.

In order to avoid large errors while modelling design floods and to increase the reliability of the overall calibration, it was necessary to confirm the hydrological model parameters in line with the results of the calibration of the hydraulic model, by comparing gauged floodmarks obtained from the community survey with the modelled flood levels. This approach is often used where no gauged hydrographs are available and is an assessment of the joint performance of both the hydrologic and hydraulic model (WBNM and XPSWMM-2D). The 2008 and 1962 flood events were seen as most suitable for this, as most of the flood information obtained from the responses to the flood questionnaire related to these two events.

12.4 Hydraulic Model Calibration and Validation

12.4.1 Model Calibration/Validation Approach and Results

In order to calibrate/validate the model performance, an iterative process was undertaken, during which the hydraulic model was modified to represent floodplain conditions at the time of the event and provide a reasonable correlation between modelled and observed flood behaviour. Calibration of the hydraulic model used the November 2008 event, with floodmarks identified during the community consultation process. The 1962 event was used for validation. Values for Manning's roughness coefficients used for the calibration were obtained from literature sourced from the HEC-RAS manual. Blockage was represented using an increased roughness coefficient at bridge and culvert sites.

The surveyed flood levels were assessed, with due consideration of the nature/source of the level, and then assigned a level of confidence rating based on their potential accuracy or reliability (see Table 6). The process focused on the township area, where the surveyed floodmarks had a higher level of confidence. These observed levels were mostly found on inundated buildings and generally showed a clear water line or were recorded on photos (such as Fig 10 and 11). The low confidence marks were the ones generally associated with a broad description of the location and/ or water depth. A small number of flood levels were rejected because they were considered to not provide a fair or proper representation of the flood level based on a comparison with the floodmarks of the high level of confidence.

In conjunction with the hydrologic model and gauged flow data from the station at Woolbrook, a flowrate of 980m^3/s was targeted as the peak flow at Bendemeer. The initial calibration runs, using average values of Manning's coefficients sourced from literature, indicated that a peak discharge of approximately 900-1,100m^3/s was required to provide a good agreement between the modelled and observed water levels.

Using the targeted 980m^3/s for the November 2008 event, surface roughnesses had to be only slightly adjusted from the initial values to obtain a good match between the observed and modelled water levels through the town and provide the calibrated model that could be used to simulate design events with a high level of confidence.

The modeled flood extent matched closely the observed extent at numerous locations, including the access ramp at the Hotel (no difference), flood gauge (+0.07mm difference), bowling club building (+0.02mm difference) and downstream of Merino Street (0-0.11mm difference). The difference between observed and simulated water levels for all high confidence floodmarks ranged from -0.13m to +0.11m. At the corner of Henry and Caroline St the observed flood extent was matched accurately, although there was a discrepancy in levels, believed to be due to uncertainty of locations for survey.

Figure 15 and Table 6 summarise the results of calibration for the 2008 event.

Figure 15: November 2008 Event - Flood Map

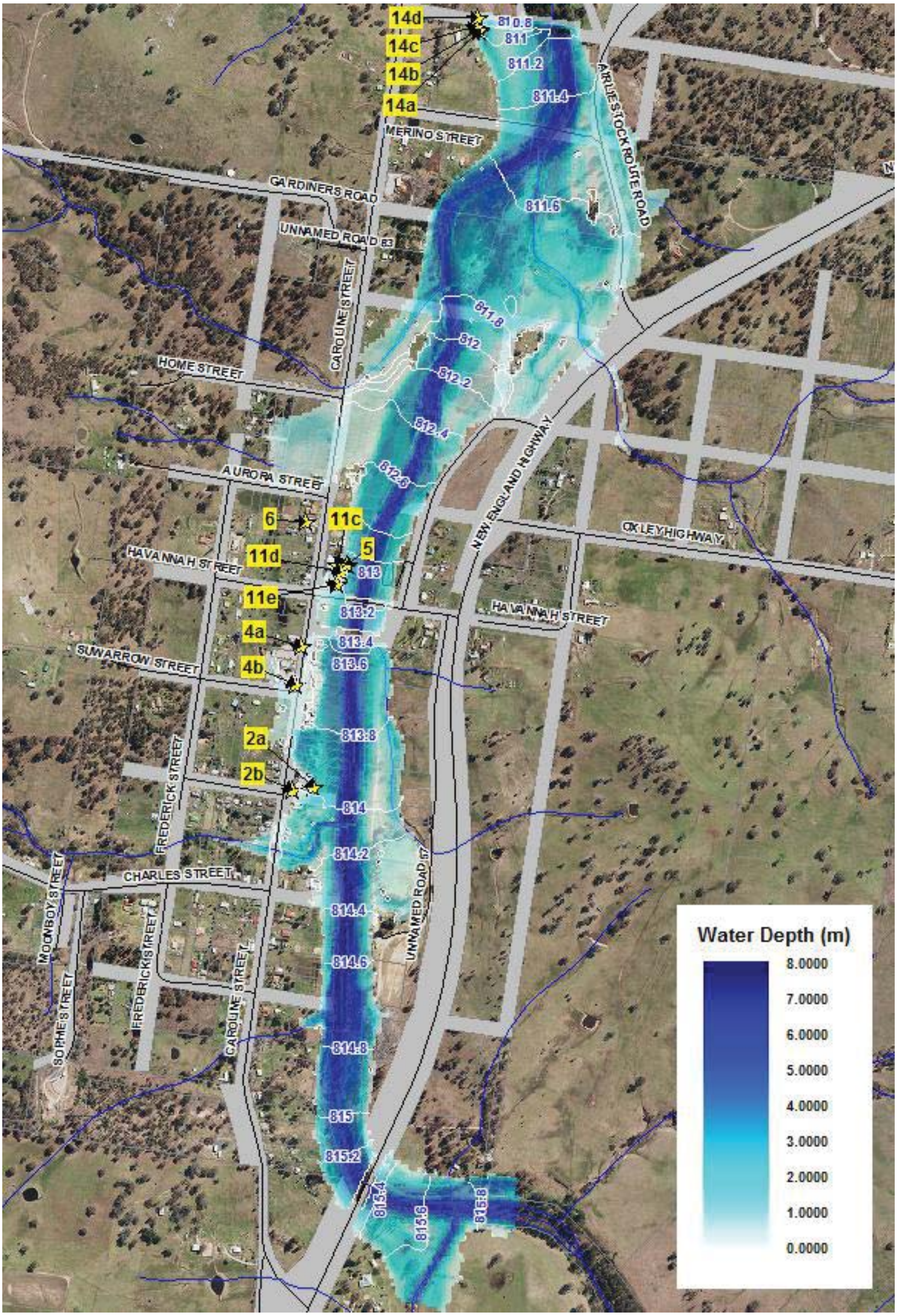


Table 6: Calibration Results – November 2008 Event

Flood Mark ID	Floodmark Description	Confidence Rating	Observed Level (mAHD)	Modelled Level (mAHD)	Difference (m)
2a (1)	HENRY STREET ADJACENT TO CREEK (Disregarded, as comparison with surrounding flood levels showed inconsistency)	Low / Disregarded	812.90	813.93	+1.03
2b (2)	CORNER OF HENRY AND CAROLINE ST (Flood extent matched, while terrain steep and survey sensitive to selection of locations)	Medium	814.26	814.02	-0.24
4a	CAROLINE ST UPSREAM OF HIGH LEVEL BRIDGE (Outside the modeled flood extent - possibly local flooding)	Low	814.73	n/a (5)	n/a (5)
4b	CORNER OF CAROLINE ST AND SUWARROW ST	High	814.00	813.87	-0.13
5a (3)	BENDEMEER HOTEL - 7.0m at flood gauge (Resident statement obtained during the site visit)	High	813.18	813.05	-0.13
5b (3)	BENDEMEER HOTEL - 6.8m at flood gauge (From emergency planning with sandbags)	High	812.98	813.05	+0.07
6	CAROLINE ST NEAR AURORA ST (Outside flood extent - possibly local flooding)	Low	812.92	n/a (5)	n/a (5)
11c	BENDEMEER HOTEL (Base of the access ramp at the hotel)	High	813.15	813.15	+0.00
11d	BOWLING CLUB BUILDING (Resident report)	Low	813.13	813.15	+0.02
11e (4)	BOWLING GREEN (Photo and resident report)	Low	812.94	813.22	+0.28
11f	BOWLING GREEN - 6.8m at flood gauge (From emergency planning with sandbags)	Medium	812.98	813.22	+0.24
15	POLICE STATION - 6.6m at flood gauge (From emergency planning with sandbags)	Medium	812.78	812.44	-0.34
14a	~250M DOWNSTREAM OF MERINO ST (Based on video footage viewed by the surveyor)	High	810.69	810.76	+0.07
14b	~250M DOWNSTREAM OF MERINO ST (Based on video footage viewed by the surveyor)	High	810.65	810.76	+0.11
14c	~250M DOWNSTREAM OF MERINO ST (Based on video footage viewed by the surveyor)	High	810.76	810.76	+0.00
14d	~250M DOWNSTREAM OF MERINO ST (Based on video footage but surveyed level inconsistent in comparison with adjacent levels)	Low	810.54	810.76	+0.22

(1) 2a disregarded based on comparison of more reliable levels at the hotel
(2) 2b reasonable calibration using flood extent
(3) 5a/5b similar site at the hotel 7.0m, 6.8m (6.8m closer match with model)
(4) 11e observed level lower than surrounding floodmarks. Refer 11c & 11d
(5) n/a not within the modelled flood extent — potentially local flooding

Since the January 1962 event had no pluviograph data near the catchment, this event could not be applied to the WBNM hydrologic model to generate flows. However, as the 1962 event was the largest in recorded history and as there were a number of sites where floodmarks were available to help to validate the model, the 1962 event peak flow was estimated as 1580m^3/s, based on the recorded water levels at Woolbrook (8.2m. Source: Bewsher, 2007). This assumed that increase in flow between Woolbrook and Bendemeer was offset by a significant difference in size of the contributing catchment compared to the catchment upstream of Woolbrook, the behavior that was noted for the 2008 event. Following this approach, the estimated peak flow of 1580m^3/s was used as an input into the XPSWMM-2D model.

The hydraulic model for the 1962 event was modified to represent floodplain conditions at the time of the event by removing the Low Level Bridge and New England Highway Bridge.

Due to the limited reliability of the adopted approach for estimation of the event peak flow, the outcomes from the 1962 event modelling produced a greater difference in observed flood levels compared with the 2008 event. The difference in observed and simulated levels ranged between -0.73m and +0.31m, with an average absolute difference of 0.37m. Although the validation indicated overestimated levels at Caltex Service Station (0.31m) and a relatively close match of the levels at the High Bridge (-0.11m), the modelled levels at Bendemeer Hotel were up to 0.73m lower than observed. Similarly, all other modelled water levels were lower than observed. Considering the uncertainty in estimating the peak flow for this event, these inconsistencies were, to a certain degree, expected. As the majority of the floodmarks show underestimation of modelled water levels, it is likely that the event peak flow at Bendemeer was greater than the estimated 1580m^3/s.

Figure 16 and Table 7 summarise the results of validation for the 1962 event.

Figure 16: January 1962 Event – Flood Map

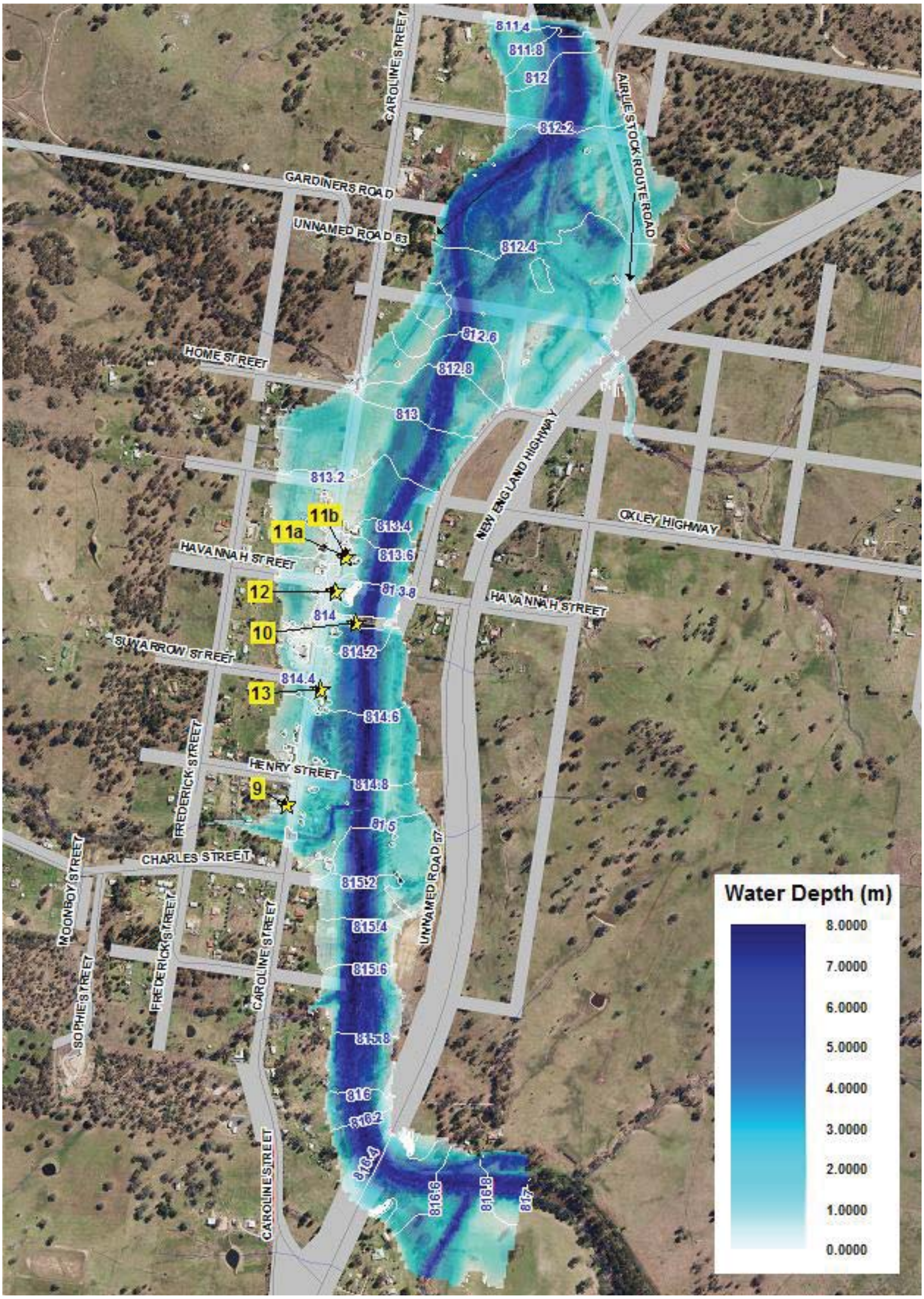


Table 7: Validation Results – January 1962 Event

Flood Mark ID	Floodmark Description	Confidence Rating	Observed Level (1) (2) (mAHD)	Modelled Level (mAHD)	Difference (m)
9	CAROLINE ST UPSTREAM OF HENRY ST (Very rough estimate of water depth: 0.5-1m)	Low	815.07	814.90	-0.17
10	HIGH LEVEL BRIDGE (Overtopped by 200mm)	High	814.40	814.29	-0.11
11a	BENDEMEER HOTEL (Floodmark just below the windowsill as per the photo)	High	814.38	813.65	-0.73
11b	BENDEMEER HOTEL (Floodmark two bricks below the window as per resident's statement obtained during the site visit)	High	814.20	813.65	-0.55
12	CNR CAROLINE ST AND HAVANNAH ST (Disregarded due to inconsistency – much lower than downstream levels)	Low / Disregarded	813.40	813.57	+0.16 (3)
13	CNR CAROLINE ST AND SUWARROW ST – Caltex Service Station (Surveyed floodmark above the floor)	High	814.24	814.55	+0.31

(1) Low Level bridge did not exist

(2) New England Highway bridge did not exist

(3) Disregarded based on comparison with levels of surrounding, more reliable floodmarks

It was noted however that the simulated 1962 flood extent modelled in the current study closely resembles the flood extent developed by Bewsher Consulting from anecdotal evidence (refer Figure 6).

Considering the results of the calibration, the prepared models are considered to replicate the floodplain conditions with a sufficient level of confidence to be used for estimation of design flood conditions.

12.4.2 Hydraulic Model Calibration Summary

Despite an initial uncertainty caused by inability to calibrate the hydrological model against a number of significant storm events using the same modelling parameters, the results of the hydraulic calibration provided the required confidence in both models. The calibration results for the 2008 event show that, generally, the modelled flood levels correlate well with the observed data. Some differences were to be expected due to localised variations in water levels (wave effects), the accuracy or nature of some floodmarks and uncertainty regarding changing floodplain conditions (scouring under the existing bridges and along the river bed) during the actual flood event. The modelled flood levels in the township area are approximately -0.13m below to 0.11m above the observed flood levels for floodmarks that have a high confidence rating. This is well within the normal limits of accuracy expected for such situations and provides a good degree of confidence in the ability of the models to replicate actual flood behaviour in this area.

Modelled flood levels for the 1962 validation event are showing a larger error, with the majority of the levels lower than observed and a difference in levels of up to 0.73m. Although the peak flow might have been underestimated due to the absence of the pluviographic data for this event and estimation assumptions used, it is also possible that the state of the floodplain was different than in current conditions. The higher level of vegetative overgrowth along the riverbanks, as well as higher riverbeds (as in the case of more intensive sedimentation), could result in higher water levels that could not be replicated by modelling. For these reasons, the results of the validation using the 1962 event should be taken with some reserve, in particular because modelling of the 2008 event provided a good match with the observed conditions.

Modelling of overtopping conditions at the bridges along the MacDonald River corresponds to records, i.e. the High Level Bridge did not overtop in the 2008 event but did overtop in 1962, while the Low Level Bridge, which did not exist in 1962, did overtop in 2008.

Table 8: Bridge Overtopping Results

Bridge	Overtopping Level	Simulated Water Levels at Bridge Sites	
		November 2008	January 1962
New England Highway	819.24	815.35	Bridge did not exist
High Level Bridge	814.20	813.55 (1)	814.29 (2)
Low Level Bridge	810.01	813.24 (3)	Bridge did not exist

(1) Did not overtop High Level bridge as indicated in photos

(2) Did overtop High Level bridge as indicated in photos

(3) Overtopped Low Level bridge as indicated in photos

12.5 Adopted Modelling Parameters

The calibration of the hydrologic/hydraulic models against the historic flood event confirmed the appropriateness of the final modelling parameters. The results of the assessment were presented to Council and OEH and the parameters were adopted as representative of the catchment for further modelling of design flood events.

Table 9: Summary – Adopted Hydrologic Modelling Parameters

Parameter	Value	
	Average	Calibrated
Initial Loss (mm)	10-35*	25
Continuous Loss (mm/hr)	2.5*	2.5
Lag	1.74	1.1

* Average Values from AR&R for NSW

Table 10: Summary – Adopted Hydraulic Modelling Parameters

Roughness Category	Manning's Roughness Coefficient		
	Average	Upper	Calibrated
Sealed Road	0.016	0.020	0.017
Unsealed Road	0.025	0.030	0.027
Creek	0.050	0.060	0.050
Trees	0.060	0.080	0.065
Pasture	0.035	0.050	0.040
Fenced Properties	0.060	0.080	0.070
Local roughness in the river at its downstream end	0.050	0.060	0.100
Local roughness in the river from Henry St to High Level Bridge	0.050	0.060	0.040 channel 0.050 bank
Local roughness under bridges/culverts where blockage expected to occur	0.080	0.100	0.080-0.100

13 DESIGN STORM EVENTS

13.1 Modelling Parameters for Design Events

13.1.1 Design Rainfall Parameters

The temporal patterns and design rainfall intensities for the design flood events were derived from Australian Rainfall and Runoff IFD curves and maps. The key parameters used for derivation were established for the location of the catchment and are presented below:

Table 11a: Geographic Rainfall Factors for Bendemeer Catchment

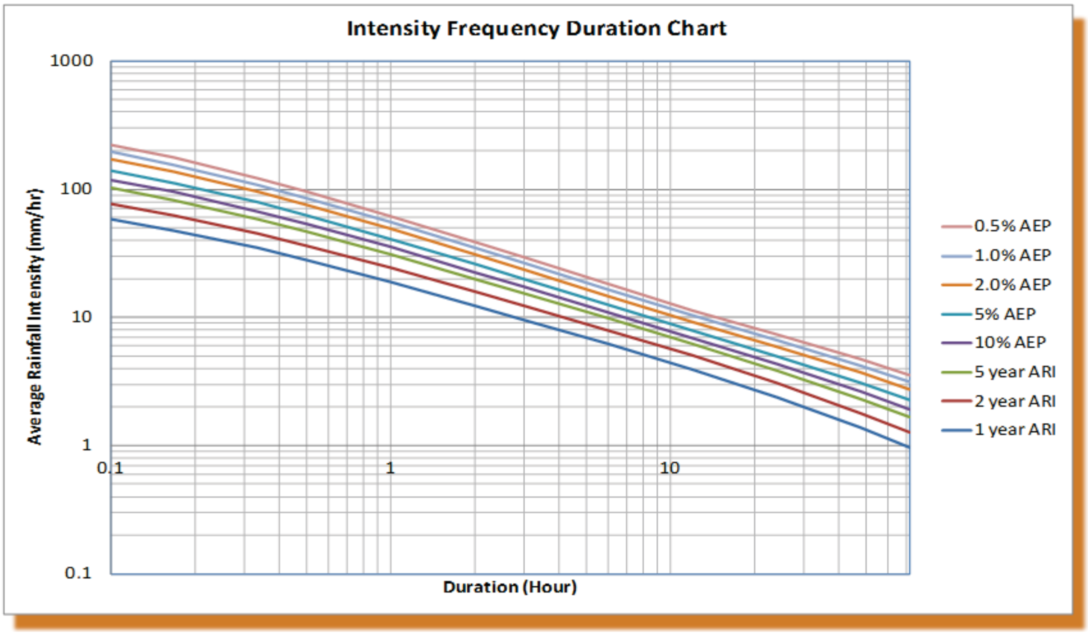
Factor	Value
Skewness G	0.30
F2	4.34
F50	16.11

Table 11b: Log Normal Intensities for Bendemeer Catchment

Duration	2 Year ARI	50 Year ARI
1 hr	24.91	46.16
12 hr	5.16	8.80
72 hr	1.29	2.58

The basic IFD data was applied in the WBNM model for design events between 5 year ARI and 0.5% AEP. Figure 17 shows the relationship between average intensity, duration of rainfall, and frequency of event (i.e. IFD data) for the modelling area.

Figure 17: IFD Curves for Bendemeer Catchment



As found in practice in general, shorter duration rainfall events have higher rainfall intensities for a given frequency, with longer duration storms having lower average intensities but larger volumes. The critical duration flood event, with respect to flows, may not necessarily be of the largest average intensity or largest total volume. Therefore, a number of durations were run as part of WBNM modelling for design storms to find the critical duration of the storms that produce the flow peaks at Bendemeer. The established critical durations for various design storms are presented in Table 12.

Table 12: Critical Durations for Various Design Flood Events

Description	CRITICAL DURATION (hours)					
	5 year ARI	10% AEP	2% AEP	1% AEP	0.5% AEP	PMF
MacDonald River	30	30	72	72	72	6
South-west Tributary	36	48	48	48	48	1
North-west Tributary	36	48	48	18	18	1
Eastern Tributary	36	48	48	48	48	2

13.1.2 Rainfall For Probable Maximum Flood (PMF)

Rainfall for the PMF (known as Probable Maximum Precipitation — PMP) was derived for short and long duration storm events, as outlined in AR&R and published in the Bureau of Meteorology's Generalised Short Duration Method (GSDM), Revised Generalised Tropical Storm Method (GTSMR) and Generalised South-East Method (GSAM). The GSDM method outlines PMP estimates for storm durations up to 6 hours in duration, and the GTSMR method is for durations up to 120 hours. The GSAM method was not applicable for the location of the Bendemeer catchment.

Both the GSDM and GTSMR methods were modelled with varying temporal and spatial patterns. The critical storm durations that produced the maximum PMP inflows at Bendemeer included:

- the 6 hour storm event along the MacDonald River
- the 1 hour event along the south-west tributary
- the 1 hour event along the north-west tributary
- the 2 hour event along the north-east tributary.

13.1.3 Joint Probability

In order to establish the appropriate downstream conditions for the tributaries, an estimate was made for the joint probability of coincidence of occurrence of the peak flows in tributaries and the conditions in the MacDonald River. The peak flow from each tributary was adjusted to coincide with the peak flow in the main river, corresponding to a more frequent design event in line with the current floodplain management practice. For example, flooding in the tributaries under the 1% AEP flood event corresponded with flows in the river at a timing where flows produced the 5% AEP flood event.

This approach is considered to be more appropriate than if coincident flooding is used by applying the same timing for peak flows from the river and tributaries, which is less likely to occur and was considered to be too conservative. At the same time, if flows from the tributaries arrive before the flows from the main catchment, the downstream levels in the tributaries may be much lower than those that could potentially occur. Hence, the joint probability approach provides an estimate of corresponding levels in the river that are between potential low flows and peak flood levels.

Table 13: Joint Probability for the River and Tributaries

DESCRIPTION	JOINT PROBABILITY PARAMETERS						
Design Flood Event of Tributary	ARI/ AEP	5 year ARI	10%	2%	1%	0.5%	PMF
Design Flood Event of River for Joint Probability	ARI/ AEP	5 year ARI	5 year ARI	5%	5%	2%	1%
Peak Flow in River	m^3/s	578	795	1471	1888	2350	15418
Peak Flow for Joint Probability	m^3/s	578	578	1141	1141	1471	1888
Timing of Peak Flow in River	hours	12.9	9.0	10.7	9.1	9.0	3.8
Peak Flow of Tributary SW	m^3/s	11	14	22	26	31	374
Peak Flow of Tributary NW	m^3/s	5	7	9	11	13	169
Peak Flow of Tributary NE	m^3/s	26	34	55	66	79	976

13.2 Design Runs

Events up to the 0.5% AEP were run using IFD and temporal patterns from ARR87 in the WBNM model, producing flowrates for incorporation into the XP-SWMM2D model. The resulting peak inflows for all events are shown in Table 14. These indicate that majority of the flow at Bendemeer is associated with the MacDonald River catchment upstream of the town while the tributaries contribute to a significantly lesser extent.

Table 14: Peak Flowrates at Bendemeer – 5 year ARI to PMF

Location	Peak Flowrates at Bendemeer (m^3/s)						
	WBNM NODE	5 year ARI	10% AEP	2% AEP	1% AEP	0.5% AEP	PMF
MacDonald River	ADD	578	795	1471	1888	2 350	15 418
South-west Tributary	M1	11	15	22	26	31	374
North-west Tributary	N1	5	7	9	11	13	169
North-east Tributary	O1	26	34	55	66	79	976

Maps showing flood extents, water levels, depths and velocities are shown in Appendix C. The overtopping of bridge and culvert sites for a range of different sized flood events, together with corresponding flood levels, are shown in Table 15.

The Low Level Bridge overtops in all design events, while the High Level Bridge and both New England Highway bridges overtop in 2% and PMF events respectively. The north-west tributary bridge overtops in the 1% AEP event, while the south-west tributary culvert overtops in the 2% AEP event.

Table 15: Design Flood Levels at Hydraulic Structures

CROSSING	DESIGN FLOOD LEVEL (mAHD)						
	Road Level	5 year ARI	10% AEP	2% AEP	1% AEP	0.5% AEP	PMF
New England Highway upstream	819.66	814.09	814.84	816.47	817.17	817.87	828.10
High Level Bridge	814.20	812.50	813.11	814.43	814.93	815.40	823.45
Low Level Bridge	810.01	812.29	812.85	814.01	814.53	815.05	823.27
New England Highway Eastern Tributary	815.98	812.13	812.40	812.87	813.28	813.87	822.49
North-west Tributary	813.32	812.59	812.69	813.16	813.63	814.17	822.79
South-west Tributary	814.56	813.04	813.58	814.99	815.56	816.11	824.09

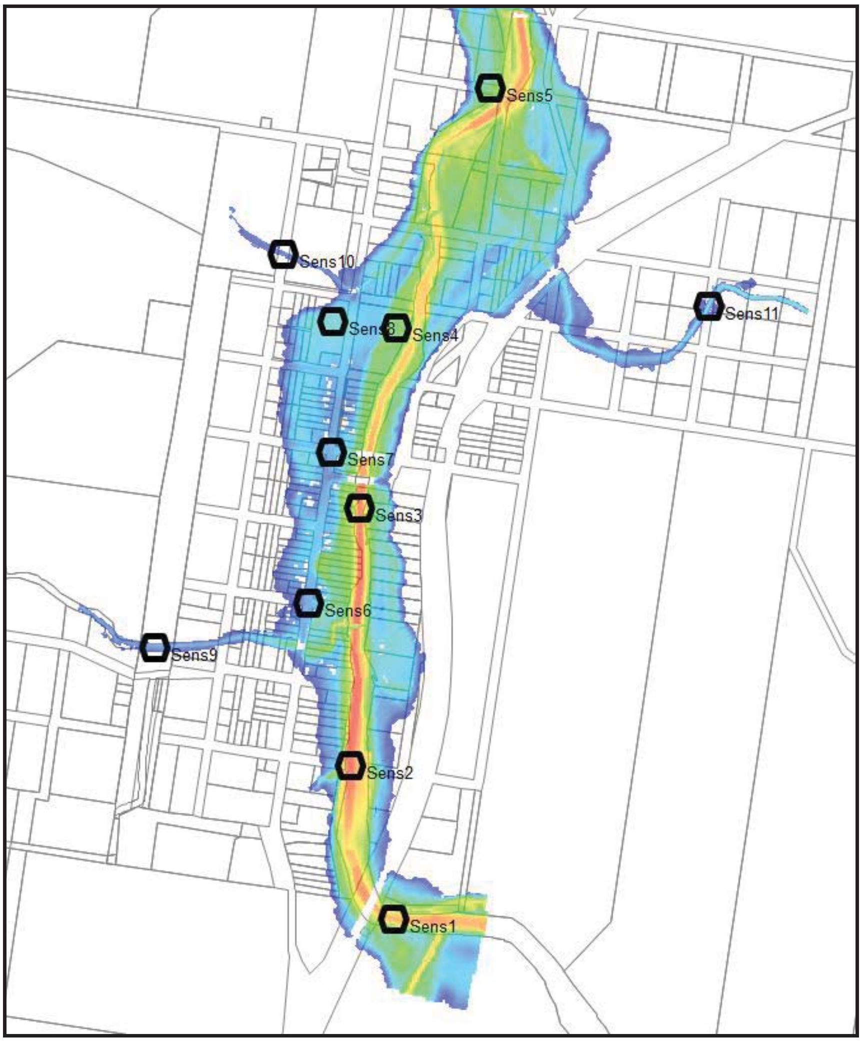
* *highlighted values indicate overtopping of the structure*

14 SENSITIVITY ANALYSIS

14.1 Varying Model Parameters

A sensitivity analysis of model results was conducted by varying model parameters and assessing the impact on water levels and velocities within the Bendemeer floodplain. The results of simulations are compared to the 1% AEP design event as the base case. The analysis was carried out for a number of locations along the river and tributaries, presented in Figure 18 below.

Figure 18: Check Locations Used in the Sensitivity Analysis



A total of 7 sensitivity runs (Runs 1-6) were undertaken initially for assessment of change at check locations, while two additional runs (Runs 7 and 8) used analogy of comparison of AEP flood events:

- Sensitivity Run 1: Fully blocked at crossings
- Sensitivity Run 2a: No blockage at crossings
- Sensitivity Run 2b: Increased blockage as roughness (n=0.200) at crossings
- Sensitivity Run 3: Increased floodplain roughness to upper recommended range
- Sensitivity Run 4: Decreased floodplain roughness to lower recommended range
- Sensitivity Run 5: Increased flow/climate change scenario 1 — Increased rainfall intensity of 10%
- Sensitivity Run 6: Increased flow/climate change scenario 2 — Increased rainfall intensity of 30%
- Sensitivity Run 7: Reduced rainfall losses (to 10mm initial and 1.5 mm/hr continuing loss)
- Sensitivity Run 8: Reduced rainfall losses (to 0mm initial and 1.5 mm/hr continuing loss)

14.2 Variations in Results from Sensitivity Analysis

The comments regarding the model sensitivity for the specific parameter groups are presented in the following sections. The resulting water levels, changes to water levels and velocities for the 11 check locations used in the analysis are shown in Tables 17a-15c.

14.2.1 Blockage

Although it is relatively unlikely that the larger crossings become totally blocked, particularly the New England Highway (upstream of Bendemeer) and High Level Bridge, both of which have relatively large openings, Scenario 1 gives an indication of potential consequences to water levels and velocities if such a scenario were to occur.

Immediately upstream of the High Level Bridge, water levels rise by about 1.1m, while further upstream levels increase by about 0.6m (at site 2) in the case of full blockage. At the New England Highway, full blockage increases water levels by over 4m and reduces velocities by 2m/s, however, full blockage at this site is relatively unlikely.

Sites 6, 7, and 8 change by about 0.9m, 0.4m and 0.1m respectively, potentially as a result of the redistribution in flows from the Low level and High Level bridge crossings. Velocities also change, with the most notable being at Site 7 at the corner of Havannah and Caroline St. Changes to water levels and velocities at Sites 4 and 5 downstream of the Low Level Bridge are relatively insignificant. Sites 9, 10, and 11 are located further up the tributaries and have no change to the calculated water levels and velocities in this scenario.

Two other scenarios were run by varying the amount of blockage at waterway crossings. Scenario 2a was run with zero blockage at the bridge and culvert sites by applying roughness associated with the nearby channel at the crossing site, the condition that simulates the debris (initially applied in a base case modelling scenario) is washed away by high flows. Scenario 2b was run with an increased roughness coefficient at the crossing sites to simulate an increase in blockage due to the additional vegetative overgrowth and floating debris.

Scenario 2a created relatively minor changes to water velocities, with water levels being marginally reduced, while Scenario 2b allowed for increased blockage, so some flow could still pass through the waterway opening before overtopping the bridges. Scenario 2a resulted in relatively minor water level reductions at Sites 1, 2, 3, 6, and 7, situated along the MacDonald River upstream of the low level bridge, and no changes in levels at Sites 4, 5, and 8 downstream of the low level bridge. Changes to velocities were also minor in this case. The effects of increased blockage in Scenario 2b created inverted effects from those experienced with reduced blockage in Scenario 2a.

The results of the analysis are presented in Tables 16a-16d. No changes occurred along the tributaries for either Scenario 2a or 2b.

14.2.2 Roughness

The next two cases modelled the increase and decrease of the roughness coefficients along the river- and creek beds and their overbanks. Scenario 3 used an increased roughness, which may represent a development of a more dense vegetative cover compared to the base case. Scenario 4 applied lower roughness coefficients that may represent clearing or thinning of vegetative cover during prolonged periods of drought. These coefficients were varied within the upper and lower range of expected values found in engineering literature for a given category. For example, values for sealed roads were varied from 0.016 to 0.020, as referenced from the HEC-RAS user manual. Values for unsealed roads, as identified in the aerial photo supplied by Council, were varied from 0.022 to 0.030, not converted to a different land use type such as a sealed road that would minimise their roughness. Similar conditions were applied for pasture, trees and the other roughness categories.

The scenarios for variations in roughness had a significant impact on the variability of model results. Increased roughnesses increased levels at all control locations, even the tributaries. Decreased roughness in Scenario 4 reduced water levels at all control locations, with the largest reduction occurring at Location 5 near the downstream end of the model. Levels along the river overbank (Locations 6, 7 and 8 along Caroline Street) were reduced by about 0.1m, 0.5m and 0.6m respectively for Scenario 4, and increased by about 0.5m, 0.4m and 0.4m under increased roughness in Scenario 3.

Increases in velocities are, for the same flow, normally associated with reductions in roughness and water levels, while decreases in velocities are associated with increased roughness. This behaviour was noted in the three tributaries in modelled Scenarios 3 and 4. However, in the river area and associated overbanks, this behaviour was not consistent, potentially as a result of redistribution of flows. Refer Table 17d for Sites 5-8 of Scenario 3 and Sites 6-7 of Scenario 4.

14.2.3 Increased Flow/Climate Change Scenario

Climate change could potentially impact a flood by sea level rise or by increased rainfall intensities. Due to the high elevation of the project area, sea level rise would not have any impact on flood results. Changes in rainfall intensities are less certain than sea level rise, though evidence so far suggests that there could be an increase in rainfall intensity due to the impacts of climate change. The NSW Office of Environment and Heritage (formerly Department of Environment, Climate Change and Water - DECCW) have issued a Floodplain Risk Management Guideline, relating to the “Practical Consideration of Climate Change”. Apart from an upper range sea level rise of 0.91m, this Guideline suggests 10-30% increases in rainfall intensities and storm volumes for various locations in NSW and ARI events.

The effects of increased rainfall intensities have been simulated as part of the sensitivity analysis by increasing the rainfall intensities (and volumes) by 10% and 30% respectively in the WBNM hydrologic model, and assessing the impact to water levels and velocities by running the new hydrographs through the XPSWMM-2D model. These two scenarios (Sensitivity Run 5 and Sensitivity Run 6) had a significant impact on potential flood levels and flow velocities. Upstream of the High Level Bridge, for example, water levels increased by about 0.4m and 1.1m in the case of 10% and 30% increase in rainfall intensities respectively. At the same site, water velocities increased by about 0.2m/s and 0.6m/s for the 10% and 30% increase in rainfall intensities respectively. At the New England Highway bridge (MacDonald River), water levels increased by 0.5-1.8m and velocities by 0.0-0.4m/s. For climate change conditions where rainfall intensities potentially increase by 20% results may be directly interpolated from the 10% and 30% sensitivity runs.

The changes to water levels and velocities are primarily driven by changes to flowrates, with peak flows in the MacDonald River increasing from 1888m^3/s in the base case to 2272m^3/s in Scenario 5 and 2999m^3/s in Scenario 6. A peak flowrate of 2272m3/s lies between the 1% AEP and 0.5% AEP flood events under current conditions, while 2999m^3/s lies between the 0.5% AEP and PMF flood events under current conditions (refer to Table 14).

Table 16 below shows the flowrates for the scenarios considered in the sensitivity analysis.

Table 16: Peak Flowrates in Sensitivity Analysis

Description	100yr ARI PEAK FLOWRATE (m^3/s)		
	Sensitivity Runs 1-4 (Base case flow)	Sensitivity Run 5 (10% intensity increase)	Sensitivity Run 6 (30% intensity increase)
MacDonald River upstream of New England Highway	1888	2272	2999
South-west Tributary	26	30	37
North-west Tributary	11	13	17
North-east Tributary	66	77	96

Table 17a: Water Levels at Control Locations Used in Sensitivity Analysis

Location	Description	100yr ARI WATER LEVELS (mAHD)							
		Base Case	Sensitivity Run 1	Sensitivity Run 2a	Sensitivity Run 2b	Sensitivity Run 3	Sensitivity Run 4	Sensitivity Run 5	Sensitivity Run 6
1	MacDonald River upstream of New England Hwy	817.29	821.84	817.24	817.46	817.86	817.20	817.83	819.08
2	MacDonald River between NEH and Charles St	816.40	816.97	816.38	816.49	816.92	816.01	816.90	817.67
3	Upstream of High Level Bridge	815.15	816.27	815.08	815.36	815.52	814.84	815.56	816.23
4	Overbank near Home St	813.69	813.72	813.69	813.70	814.04	813.03	814.15	814.86
5	Overbank near Merino St	812.99	812.99	812.99	812.99	813.17	811.95	813.48	814.23
6	Corner of Henry St and Caroline St	815.48	816.42	815.43	815.65	815.95	815.36	815.92	816.61
7	Corner of Havannah St and Caroline St	814.52	814.90	814.50	814.58	814.90	814.00	814.99	815.68
8	Between Aurora St and Home St	813.89	813.96	813.89	813.90	814.25	813.33	814.35	815.06
9	SW tributary at Moonboy St upstream of Frederick St	819.30	819.30	819.30	819.30	819.38	819.26	819.36	819.46
10	NW tributary at Frederick St	817.68	817.68	817.68	817.68	817.74	817.66	817.73	817.82
11	NE tributary at Aurora St	818.33	818.33	818.33	818.33	818.57	818.14	818.61	818.72

Table 17b: Change in Water Levels at Control Locations Used in Sensitivity Analysis

Location	Description	100yr ARI CHANGE IN WATER LEVELS (m)							
		Base Case	Sensitivity Run 1	Sensitivity Run 2a	Sensitivity Run 2b	Sensitivity Run 3	Sensitivity Run 4	Sensitivity Run 5	Sensitivity Run 6
1	MacDonald River upstream of New England Hwy	-	4.55	-0.05	0.17	0.57	-0.09	0.54	1.79
2	MacDonald River between NEH and Charles St	-	0.57	-0.02	0.09	0.52	-0.39	0.50	1.27
3	Upstream of High Level Bridge	-	1.12	-0.07	0.21	0.37	-0.31	0.41	1.08
4	Overbank near Home St	-	0.03	0.00	0.01	0.35	-0.66	0.46	1.17
5	Overbank near Merino St	-	0.00	0.00	0.00	0.18	-1.04	0.49	1.24
6	Corner of Henry St and Caroline St	-	0.94	-0.05	0.17	0.47	-0.12	0.44	1.13
7	Corner of Havannah St and Caroline St	-	0.38	-0.02	0.06	0.38	-0.52	0.47	1.16
8	Between Aurora St and Home St	-	0.07	0.00	0.01	0.36	-0.56	0.46	1.17
9	SW tributary at Moonboy St upstream of Frederick St	-	0.00	0.00	0.00	0.08	-0.04	0.06	0.16
10	NW tributary at Frederick St	-	0.00	0.00	0.00	0.06	-0.02	0.05	0.14
11	NE tributary at Aurora St	-	0.00	0.00	0.00	0.24	-0.19	0.28	0.39

Table 17c: Water Velocities at Control Locations Used in Sensitivity Analysis

Location	Description	100yr ARI Velocities (m/s)							
		Base Case	Sensitivity Run 1	Sensitivity Run 2a	Sensitivity Run 2b	Sensitivity Run 3	Sensitivity Run 4	Sensitivity Run 5	Sensitivity Run 6
1	MacDonald River upstream of New England Hwy	2.34	0.34	2.38	2.20	2.03	2.83	2.35	2.70
2	MacDonald River between NEH and Charles St	2.52	2.26	2.53	2.47	2.28	2.69	2.75	3.10
3	Upstream of High Level Bridge	3.02	2.19	3.08	2.83	2.46	3.09	3.24	3.66
4	Overbank near Home St	2.91	2.86	2.90	2.92	2.43	3.98	3.12	3.46
5	Overbank near Merino St	1.92	1.93	1.92	1.93	1.96	2.35	2.09	2.34
6	Corner of Henry St and Caroline St	1.04	0.87	1.03	1.03	1.25	0.96	1.20	1.32
7	Corner of Havannah St and Caroline St	1.67	3.61	1.56	2.03	1.80	1.41	2.15	2.37
8	Between Aurora St and Home St	0.60	0.88	0.59	0.63	0.66	0.62	0.74	0.90
9	SW tributary at Moonboy St upstream of Frederick St	1.72	1.72	1.72	1.72	1.49	1.85	1.78	1.89
10	NW tributary at Frederick St	1.69	1.69	1.69	1.69	1.52	1.82	1.79	1.99
11	NE tributary at Aurora St	2.96	2.96	2.96	2.96	2.63	3.53	2.97	2.97

Table 17d: Change in Water Velocities at Control Locations Used in Sensitivity Analysis

Location	Description	100yr ARI Velocities (m/s)							
		Base Case	Sensitivity Run 1	Sensitivity Run 2a	Sensitivity Run 2b	Sensitivity Run 3	Sensitivity Run 4	Sensitivity Run 5	Sensitivity Run 6
1	MacDonald River upstream of New England Hwy	-	-2.00	0.04	-0.14	-0.31	0.49	0.01	0.36
2	MacDonald River between NEH and Charles St	-	-0.26	0.01	-0.05	-0.24	0.17	0.23	0.58
3	Upstream of High Level Bridge	-	-0.83	0.06	-0.19	-0.56	0.07	0.22	0.64
4	Overbank near Home St	-	-0.05	-0.01	0.01	-0.48	1.07	0.21	0.55
5	Overbank near Merino St	-	0.01	0.00	0.01	0.04	0.43	0.17	0.42
6	Corner of Henry St and Caroline St	-	-0.17	-0.01	-0.01	0.21	-0.08	0.16	0.28
7	Corner of Havannah St and Caroline St	-	1.94	-0.11	0.36	0.13	-0.26	0.48	0.70
8	Between Aurora St and Home St	-	0.28	-0.01	0.03	0.06	0.02	0.14	0.30
9	SW tributary at Moonboy St upstream of Frederick St	-	0.00	0.00	0.00	-0.23	0.13	0.06	0.17
10	NW tributary at Frederick St	-	0.00	0.00	0.00	-0.17	0.13	0.10	0.30
11	NE tributary at Aurora St	-	0.00	0.00	0.00	-0.33	0.57	0.01	0.01

14.2.4 Rainfall Loss

Two further sensitivity runs were undertaken where the hydrologic model was run with reduced rainfall losses, producing larger peak flows and volumes. Reduced rainfall losses can be associated with increased antecedent moisture conditions and increased saturation of the soil after prolonged wet periods. Sensitivity Run 7 used an initial loss of 10mm and continuing loss of 1.5 mm/hr. Sensitivity Run 8 applied an initial loss of 0mm and continuing loss of 1.5mm/hr and can be associated with a highly saturated soil condition.

Table 18 shows the peak flows obtained after running the WBNM hydrologic model for the two sensitivity runs associated with reduced losses.

Table 18: Peak Flows in MacDonald River with Reduced Losses

Description	100yr ARI PEAK FLOWRATE (m^3/s)		
	Base	Sensitivity Run 7	Sensitivity Run 8
MacDonald River upstream of New England Highway	1888	2279	2599
South-west Tributary	26	32	40
North-west Tributary	11	16	20
Eastern Tributary	66	75	88

In terms of peak flowrates along the MacDonald River, Sensitivity Run 7 is approximately equivalent to a 1% AEP to 0.5% AEP flood event and Sensitivity Run 8 is associated with a flood event along the MacDonald River larger than the 0.5% AEP flood event.

15 MAPPING

15.1 Mapping of Modelling Results

The MapInfo GIS system was used as the platform for map production. A digital surface was created for each model parameter to present the model results.

The results have been mapped under the following categories:

- flood depths and flood extents, including flood level contours
- water velocities
- hydraulic categories
- flow hazards
- preliminary true hazard categorisation
- flood emergency response classification
- flood planning levels.

The basic hydraulic parameters, such as flood extents and depths, flood level contours and water velocities, were mapped by gridding the results directly obtained from the XPSWMM-2D result data sets. The flood planning level map was generated from 1% AEP flood level information by increasing the levels by 0.5m and establishing the appropriate extent of the new grid.

15.2 Hydraulic Categories

The NSW Floodplain Development Manual defines hydraulic categories for further definition of flooding. Generally three categories should be delineated:

- floodway
- flood storage
- flood fringe.

Floodway areas are those areas of the floodplain where a significant discharge of water occurs during floods; they are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

Flood storage areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation.

Flood fringe areas are the remaining area of flood prone land after floodway and flood storage areas have been defined.

However, the Floodplain Development Manual does not provide specific criteria for defining hydraulic categories, as the significance of such categories is site specific.

The issue has been tested by overlying series of maps with affected areas, including flood extents for various design events, water depths, velocities and the velocity/depth product (VxD).

The final hydraulic category delineation, following these generalised guidelines and with best results achieved, adopted as floodways the areas that were within:

- the VxD => 0.6m^2/s and velocity => 1m/s threshold with local adjustments to provide for continuation of floodway.

The hydraulic category delineation adopted as flood storage:

- the VxD => 0.6m^2/s and velocity < 1m/s AEP threshold.

The hydraulic category delineation adopted as flood fringe:

- the VxD < 0.6m^2/s or any other area within the design flood extent not previously defined as either floodway or flood storage.

The results of Hydraulic Category delineation are presented in Appendix D.

15.3 Flow Hazard

The flow hazard ratings have been mapped using velocity depth criteria sourced from the Stage 1 report of AR&R (IEAust, 2010), providing flow hazard categorisation criteria for application in flood studies. This categorisation supersedes the previous Provisional Hydraulic Categorisation described by Figure L2 of the NSW Floodplain Development Manual. The Stage 1 Report, named Project 10 - Appropriate Safety Criteria for People, relates flood hazard categories for:

- infants, small children and frail/older persons
- children
- adults.

AR&R has also produced further safety criteria relating to velocities and depths for vehicles in the Stage 2 Report, named Project 10 - Appropriate Safety Criteria for Vehicles.

The application of these categories may be applied for the various categories under different conditions, however, for the purposes of mapping undertaken in this flood study, hazard maps have been produced for conditions related to adults (i.e. height/mass products greater than 50). Hence, six hazard maps have been produced for adults for the full range of flood sizes.

Note that higher hazard ratings apply for infants, small children and frail/older persons, and children. These categories are, however, more applicable to the flood prone areas exposed to flash flooding with a very short time to peak (typical for small urban catchment), while the MacDonald River peaks at 8-16 hrs from the beginning of the storm.

For adults the Stage 1 report categories are:

- safe
- low hazard
- moderate hazard/dangerous to some
- significant hazard/dangerous to most
- extreme hazard/dangerous to all.

The limits of velocity/depth products, maximum velocity and maximum depths are shown in Table 17. For adults, depths above 1.2m would produce an extreme hazard rating regardless of velocity, while velocities above 3m/s produce an extreme hazard rating regardless of depth. For children the threshold depth is 0.5m for extreme hazards and the threshold velocity is 3m/s. The Stage 2 report relating to vehicle stability is shown in Table 20.

Table 19: Provisional Hazard Categories for People

<table>
<tr><th>DV (m^2s^{-1})</th><th>Infants, small children (H.M ≤ 25) and frail/older persons</th><th>Children (H.M = 25 to 50)</th><th>Adults (H.M > 50)</th></tr>
<tr><td>0</td><td>Safe</td><td>Safe</td><td>Safe</td></tr>
<tr><td>0 – 0.4</td><td rowspan="5">Extreme Hazard; Dangerous to all</td><td>Low Hazard[1]</td><td rowspan="2">Low Hazard[1]</td></tr>
<tr><td>0.4 – 0.6</td><td>Significant Hazard; Dangerous to most</td></tr>
<tr><td>0.6 – 0.8</td><td rowspan="3">Extreme Hazard; Dangerous to all</td><td>Moderate Hazard; Dangerous to some[2]</td></tr>
<tr><td>0.8 – 1.2</td><td>Significant Hazard; Dangerous to most[3]</td></tr>
<tr><td>> 1.2</td><td>Extreme Hazard; Dangerous to all</td></tr>
</table>

[1] Stability uncompromised for persons within laboratory testing 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).
[2] Working limit for trained safety workers or experienced and well equipped persons (D.V < 0.8 m^2s^{-1})
[3] Upper limit of stability observed during most investigations (D.V > 1.2 m^2s^{-1})

Table 20: Provisional Hazard Categories for Vehicles

Proposed *DRAFT INTERIM* criteria for stationary vehicle stability

Class of vehicle	Length (m)	Kerb Weight (kg)	Ground clearance (m)	Limiting still water depth[1]	Limiting high velocity flow depth[2]	Limiting velocity[3]	Equation of stability
Small passenger	< 4.3	< 1250	< 0.12	0.3	0.1	3.0	$DV \leq 0.3$
Large passenger	> 4.3	> 1250	> 0.12	0.4	0.15	3.0	$DV \leq 0.45$
Large 4WD	> 4.5	> 2000	> 0.22	0.5	0.2	3.0	$DV \leq 0.6$

[1] At velocity = 0 ms^{-1}; [2] at velocity = 3ms^{-1}; [3] at low depth

15.4 Flood Emergency Response Classification

Flooding in the town of Bendemeer was also classified for flood emergency response planning (ERP) that could potentially assist the SES in their emergency responses. Different areas of flood prone land up to the PMF event were classified according to categories in the DECCW Floodplain Risk Management Guideline - Flood Emergency Response Planning - Classification of Communities. These are presented in Appendix D.

The ERP classifications include:

- High Flood Island (HFI)
- Low Flood Island (LFI)
- High Trapped Perimeter (HTP) Area
- Low Trapped Perimeter (LTP) Area
- Areas with Overland Escape Route (OER)
- Areas with Rising Road Access (RRA)
- Indirectly Affected Areas (IAA)
- Overland Refuge Areas.

The above descriptive criteria was used to delineate areas of the floodplain for different scale events, also taking into consideration main drivers for classification being possible access, isolation, water depths and velocities.

16 FLOOD DAMAGES

This study estimates the flood damage likely to occur in Bendemeer for the following two major damage categories:

- the **direct financial costs** of damage to property
- the **indirect financial costs** associated with the disruption of social, community, industrial and commercial relationships during the post-flood period.

For residential properties, direct damage estimates represent the sum of structural, contents and additional factors such as external damage, cleanup costs and costs for additional accommodation as a direct result of flooding.

Indirect costs may be associated with the disruption of social, community and business relationships during the aftermath of a flood. Indirect flood damages to the community include the costs of removal and storage, loss of business confidence, production, revenue and wages in the post-flood recuperative phase. Further, indirect costs may be also related to loss of amenity, including possible loss of schooling, loss of personal mementoes, cancellation of social events and the like, many of which are intangible losses that are very difficult to quantify. These may also arise as a result of the disruption and diversion of traffic, both during and immediately after a flood (SMEC, 2001).

Indirect residential damages may also include cleanup costs (although normally included in direct damages).

The damage costs were calculated as total present day value damages (including residential and commercial damages) and average annual damages (AAD) for all modelled flood events, using damage curves, in line with recommendation by the NSW Office of Environment and Heritage (OEH, formerly DECCW). The modelling was performed using WaterRIDE™ software, utilising the flood water levels modelled in XPSWMM-2D and surveyed finished floor level (FFL) data.

16.1 Direct Damages

16.1.1 Flood Damage Curves

The damages curves required for modelling in WaterRIDE™ were established by adjusting the applicable parameters in a basic model that used flood damage spreadsheet published by OEH. The spreadsheet computes the curves for structural damages for three categories of residential properties:

- single storey – low (floor) set
- single storey – high (floor) set
- double storey

The spreadsheet was reviewed and adjusted for this project to include the following applicable parameters for structural damages:

- post 2001 cost adjustments (up to 2012) applied to structural damage
- adjustments for specific locations using a regional cost variation factor from Rawlinson's Australian Construction Handbook
- post-flood inflation factor dependent on number of houses affected and regional city/ town
- typical duration of immersion

- a Building Damage Repair Limitation Factor with no insurance
- typical house size of 240m^2.

The contents were computed based on the following parameters:

- post 2001 cost adjustments (up to 2012) applied to contents
- an average contents value for the area of $60,000
- a Contents Damage Repair Limitation Factor with no insurance
- a level of flood awareness, either high or low (low adopted)
- effective warning time (negligible).

The additional factors for direct damages allowed for:

- post 2001 cost adjustments (up to 2012) applied to additional factors
- external damage (estimated to $6700)
- cleanup costs (estimated to $4000)
- time in alternate accommodation with loss of rent (3 weeks @ $200 per week).

The basic model for residential calculations produced a damage cost that varied with depth. The established curves are presented in the tables in Appendix E.

16.1.2 Alterations to Flood Damage Curves

Additional factors added to the basic model for estimation of flood damage curves included the following factors:

- Commercial properties, based on the size of the property and using a basic damage value per square meter of the low set single storey property increased by 25%, to allow for additional equipment, appliances, furniture and tools. This approach was adopted as information provided by WaterRIDE™ indicated that damages to commercial properties are better estimated using the area as an additional parameter.
- High cost commercial properties as per above but allowing for an increase of 100%.
- An additional allowance for roads and services such as water, sewerage systems, gas, electricity and telephone/internet lines. In this case both residential and commercial properties were factored up by a set percentage (25%).
- Hydraulic structures (bridges/culverts) were additionally assessed considering the potentially high ratio of replacement cost in total flood damages. Two types of runs were included to account for damages to these structures. The first type incorporated an elevated factor to the additional allowances for roads and services (50%), and the second used estimates for replacement applied separately from the residential and commercial computations. These estimates are shown below.

Table 21: Flood Damage to Hydraulic Structures (Replacement Cost)

Location	DAMAGE ($)
New England Highway (upstream) Bridge	$ 9 000 000
High Level (old) Bridge	$ 4 500 000
Low Level Bridge	$ 1 575 000
New England Highway Eastern Tributary Bridge	$ 1 350 000
North-west Tributary Bridge	$ 225 000
South-west Tributary Culverts	$ 337 500
South-west Tributary Footbridge	$ 135 000

A depth of overtopping of the structure of 3.5m (without justification) was used as a trigger for calculation of the full structure damage, assuming that at that depth the damage would be of such a magnitude that the full replacement of the structure would be required.

16.2 Indirect Damages

Indirect damages were estimated by factoring up direct damages by 20% and applied to both residential and commercial properties. This mark-up does not include clean-up costs that have been incorporated into the basic model as additional costs.

16.3 Modelling in WaterRIDE™ Software

The WaterRIDE™ software package was used to compute damages, using the six categories developed from basic categories in spreadsheets. These are:

- Single Storey High Set House
- Single Storey Low Set House
- Two Storey House
- Commercial
- High Cost Commercial
- Hydraulic Structures (such as bridges and culverts).

To enable the assessment, the results from XP-SWMM (flood levels) were imported into WaterRIDE™. A range of different sized flood events were imported, including the 5 year ARI, 10% AEP, 2% AEP, 1% AEP, 0.5% AEP and PMF flood events. For each flood event, WaterRIDE™ establishes the depth at each property/structure and uses the damage curves previously developed to calculate a cost estimate of damage for the particular depth. The damages from all properties/structures are then added together for a total damage estimate for the given flood event. Also computed is the breakdown of damages for each category.

The six design flood events are then used to calculate the Average Annual Damage (AAD) by integrating the damages versus probability of each flood event. The AAD came to $572,735 and $525,056 per year, depending on methodology used. Finally, an estimate for the long-term cost of flooding was calculated over a period of 50 years and 100 years respectively, using a discount factor of 7% (+/-3%).

Table 22a: Flood Damages – Scenario 1

Flood Event	Residential		Commercial		Hydraulic Structures		TOTAL DAMAGE ($)
	Residential Damage ($)	Number of Houses Affected	Commercial Damage ($)	Number of Properties Affected	Hydraulic Structures Damage ($)	Number of Structures Affected	Residential + Commercial + Hydraulic Structures
5 year ARI	58,940	2	0	0	0	0	58,940
10% AEP	224,681	5	0	0	0	0	224,681
2% AEP	2,722,324	28	2,383,044	7	1,575,000	1	6,680,368
1% AEP	3,923,176	30	3,252,601	8	1,575,000	1	8,750,777
0.5% AEP	4,785,656	31	5,075,955	9	1,575,000	1	11,436,611
PMF	19,037,118	76	10,771,540	10	17,122,500	7	46,931,158

Note: Damage to bridges/culverts in Scenario 1 computed separately

Table 22b: Flood Damages – Scenario 2

Flood Event	Residential		Commercial		Hydraulic Structures		TOTAL DAMAGE ($)
	Residential Damage ($)	Number of Houses Affected	Commercial Damage ($)	Number of Properties Affected	Hydraulic Structures Damage ($)	Number of Structures Affected	Residential + Commercial + Hydraulic Structures
5 year ARI	70,728	2	0	0	N/A	N/A	70,728
10% AEP	269,616	5	0	0	N/A	N/A	269,616
2% AEP	3,266,787	28	2,860,325	7	N/A	N/A	6,127,112
1% AEP	4,707,806	30	3,903,107	8	N/A	N/A	8,610,913
0.5% AEP	5,742,784	31	5,890,975	9	N/A	N/A	11,633,759
PMF	22,844,534	76	12,435,657	10	N/A	N/A	35,280,191

Note: Damage to bridges/culverts in Scenario 2 incorporated into residential and commercial damage calculations

Table 23a – Average Annual Damages and Damage After 50 years

DAMAGE CATEGORY	DAMAGE VALUE($)	
	SCENARIO 1 (1)	SCENARIO 2 (2)
Average Annual Damage (AAD)	572,735	525,056
Total Damage after 50 years @ discount rate = 7%	8.477 M	7.771 M
Total Damage after 50 years @ discount rate = 4%	12.876 M	11.804 M
Total Damage after 50 years @ discount rate = 10%	6.251 M	5.731 M

(1) Scenario 1 – Damage to Hydraulic Structures computed separately
(2) Scenario 2 – Damage to Hydraulic Structures incorporated into residential and commercial calculations

Table 23b – Average Annual Damages and Damage After 100 years

DAMAGE CATEGORY	DAMAGE VALUE($)	
	SCENARIO 1 (1)	SCENARIO 2 (2)
Average Annual Damage (AAD)	572,735	525,056
Total Damage after 100 years @ discount rate = 7%	8.745 M	8.017 M
Total Damage after 100 years @ discount rate = 4%	14.608 M	13.392 M
Total Damage after 100 years @ discount rate = 10%	6.300 M	5.775 M

(1) Scenario 1 – Damage to Hydraulic Structures computed separately
(2) Scenario 2 – Damage to Hydraulic Structures incorporated into residential and commercial calculations

It was noted that a significant difference in the results between Scenario 1 (where bridges/culverts were computed separately) and Scenario 2 (where bridges/culverts were incorporated into residential and commercial calculations) was due to the potential failure of the New England Highway Bridge upstream of Bendemeer, where damage costs in the PMF were estimated to be $9M. This made an impact by increasing the AAD cost in Scenario 1.

17 CONCLUSION AND RECOMMENDATIONS

In defining the flood behaviour of the MacDonald River and its major tributaries within the modelling area in Bendemeer, this study has followed accepted Australian practice and used applicable hydrologic and hydraulic software.

The model was set up using the Council's GIS data, as well as various information obtained during field visits and surveys. Although the comprehensive rainfall data was not available, the calibration of the models provided a high level of confidence in the capability of the models to produce good quality outputs for the design storm events required to be modelled.

As most of the flood records obtained through community consultation related to the November 2008 flood, this event was used for the calibration of both hydrologic and hydraulic models. The models replicated the event very well, with modelled water levels matching the floodmarks very closely. Although the January 1962 event flood levels could not be replicated to the same level of accuracy as the 2008 event, the confidence in the model remains high, as the estimate of the 1962 peak flows at Bendemeer was, due to the absence of the pluviograh records, very rough (based on the observed flows at Woolbrook).

Design flood events were run for the full range of different sized floods, as per the project requirements. The results of the design flood events modelling were used to develop flood extent and depth maps (including water levels), velocity maps, hydraulic categorisation, flow hazard categories, preliminary true hazard categorisation, emergency response planning (ERP) and flood planning maps.

The results indicate that the flood affectation for the 5 year ARI event and 10% AEP is relatively minor, affecting only low properties adjacent to the river, while the less frequent evens will cause a significant affectation, impacting a large number of properties and causing extremely hazardous conditions. The Low Level Bridge overtops in all design events, while the High Level Bridge and both New England Highway bridges overtop in 2% and PMF events respectively.

The sensitivity analysis, which was conducted by varying model parameters and assessing the impact on modelling results, focussed on blockage at hydraulic structures, floodplain roughness coefficients, climate change scenarios affecting rainfall intensity, and rainfall loss. The model was most sensitive to change in rainfall losses and climate change effects due to increased flowrates. The change of floodplain roughness also had a significant effect on water levels and velocities.

The flood damage estimates indicate that potential damage costs are relatively high considering the number of residencies affected. This is a result of a comparatively high number of bridges/culverts in the area that may be damaged and require a full replacement in less frequent events.

The results of the study satisfy the objectives of the project, providing sufficient information on flooding within the township required for the next stage of the process (being the Floodplain Risk Management Study).

Based on the assessment of the quality of data available for calibration and verification, the following is recommended to enable future comprehensive data collection and monitoring of flood behaviour within the catchment:

- Further collection of flood affectation information and regular update of the database with similar layout as in the flood questionnaire, including date of event for mainstream flooding with recorded depths and locations.
- Further validation of the model if appropriate flood event data becomes available.
- Survey of floodmarks after major events and logging the surveyed levels into the Council's database.
- Installation of additional pluviographs within the catchment boundaries to form an accurate rainfall database representative of the catchment.
- Setup of a river flow gauge within the Bendemeer township area and reviewing and logging the flow information for main flood events into the Council's database.

18 GLOSSARY

Annual Exceedance Probability (AEP) - the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is 1-in-20 chance) of a peak flood discharge of 500 m^3/s or larger occurring in any one year (see average recurrence interval).

Australian Height Datum (AHD) - a common national surface level datum approximately corresponding to mean sea level.

Average Recurrence Interval (ARI) - the long-term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.

Catchment - the land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.

Development - is defined in clause 4 of the Environmental Planning and Assessment Act (EP&A Act).

Discharge - the rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

Extreme event - an extreme flood is one which has a very low probability of occurrence and can be used to consider flood damages and emergency management within a floodplain.

Flash flooding - flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

Flood - relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

Flood fringe areas - the remaining area of flood prone land after floodway and flood storage areas have been defined.

Flood liable land - is synonymous with flood prone land i.e. land susceptible to flooding by the Probable Maximum Flood (PMF) event. The term flood liable land now covers the whole of the floodplain, not just that part below the flood planning level, as indicated in the 1986 Floodplain Development Manual.

Flood mitigation standard - the average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.

Floodplain - area of land which is subject to inundation by floods up to and including the Probable Maximum Flood event, that is, flood prone land.

Floodplain risk management options - the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.

Floodplain Risk Management Plan - a management plan developed in accordance with the principles and guidelines in the Floodplain Management Manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.

Flood Plan (local) - A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.

Flood planning area - the area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Floodplain Development Manual.

Flood planning levels (FPL) - are the combinations of flood levels and freeboards selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans. The concept of flood planning levels supersedes the "standard flood event" of the first edition of the Floodplain Development Manual.

Flood prone land - is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.

Flood risk - potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in the Floodplain Management Manual is divided into 3 types, existing, future and continuing risks; these are described below.

- **Existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain.
- **Future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain.
- **Continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

Flood storage areas - those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

Floodway areas - those areas of the floodplain where a significant discharge of water occurs during floods; they are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.

Freeboard - a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. It is usually expressed as the difference in height between the adopted flood planning level and the flood used to determine the flood planning level. Freeboard provides a factor of safety to compensate for uncertainties in the estimation of flood levels across the floodplain, such as wave action, localised hydraulic behaviour and impacts that are specific event related, such as levee and embankment settlement, and other effects such as "greenhouse" and climate change. Freeboard is included in the flood planning level.

Hazard - a source of potential harm or a situation with a potential to cause loss. In relation to this report the hazard is flooding which has the potential to cause damage to the community.

Local overland flooding - inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

Local drainage - are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

Mainstream flooding - inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

Minor, moderate and major flooding - both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:

- **Minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.
- **Moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.
- **Major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

Modification measures - measures that modify either of the flood, the property or the response to flooding.

Peak discharge - the maximum discharge occurring during a flood event.

Pluviograph - a self-registering rain gauge typically measuring and recording hourly rainfall depths

Probable Maximum Flood (PMF) - the largest flood that could conceivably occur at a particular location, usually estimated from Probable Maximum Precipitation. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with the PMF event should be addressed in a floodplain risk management study.

Probable Maximum Precipitation (PMP) - the theoretical greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to the estimation of the Probable Maximum Flood.

Probability - a statistical measure of the expected chance of flooding (see Annual Exceedance Probability).

Risk - chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of this report it is the likelihood of consequences arising from the interaction of floods, communities and the environment. The risk of such an event occurring over a longer period is much higher.

Risk management - the systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring flood risk. Flood risk management is undertaken as part of a Floodplain Risk Management Study. The Floodplain Risk Management Plan reflects the adopted means of managing flood risk.

Runoff - the amount of rainfall that actually ends up as streamflow, also known as rainfall excess.

Stage - equivalent to “water level”. Both are measured with reference to a specified datum.

Stage hydrograph - a graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.

Temporal pattern – refers to the overall pattern of the rainfall event over time and is specific to spatial location and storm duration.

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APPENDICES

APPENDIX A – GENERAL CATCHMENT AND MODELLING INFORMATION

Figure A1 – Modelling Area
Figure A2 - Catchment Topography
Figure A3 - Hydraulic Structures

EXTENT OF MODELLING

RIVER

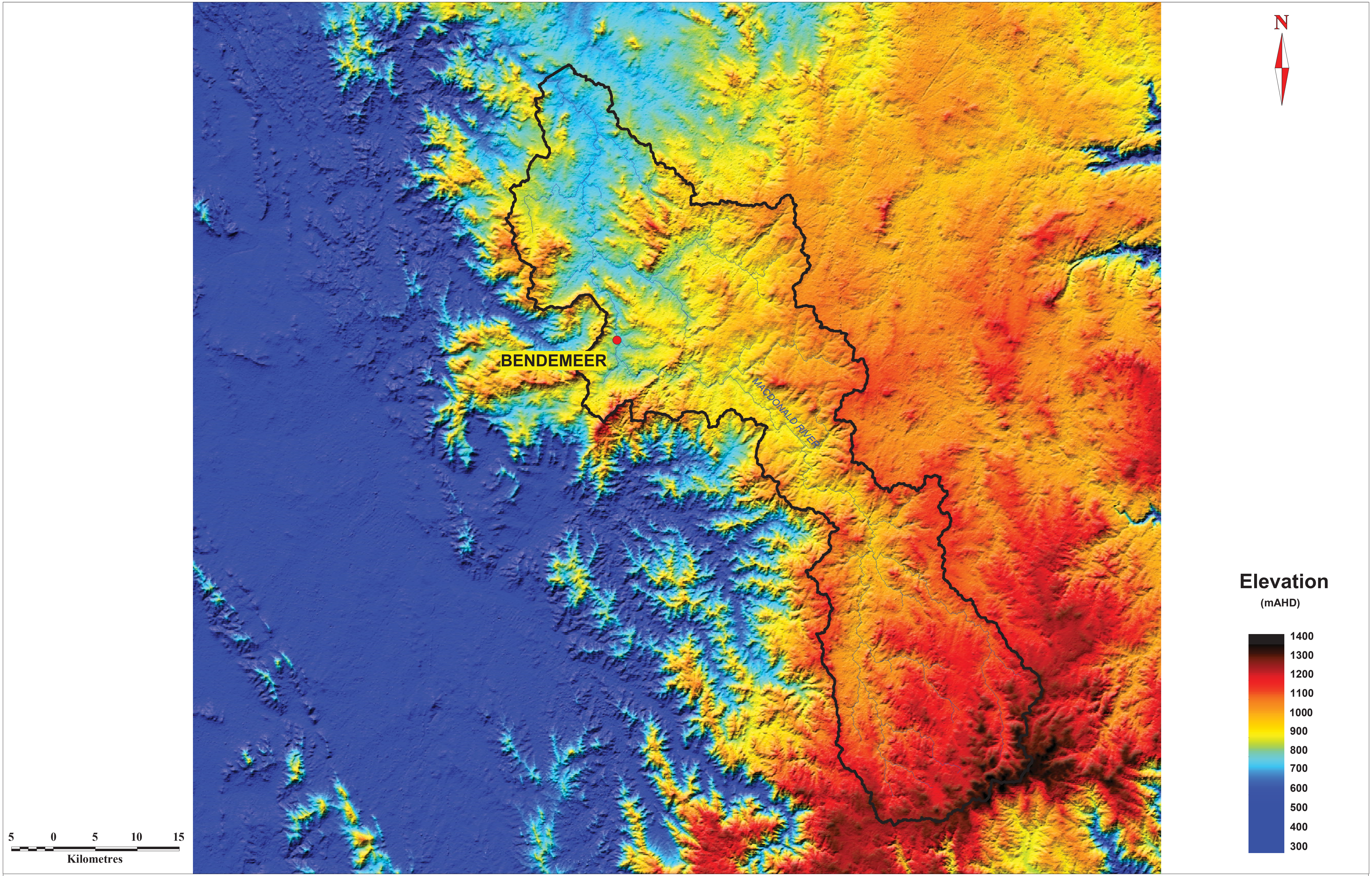
TOPOGRAPHIC CONTOUR

Hydraulic Structure

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

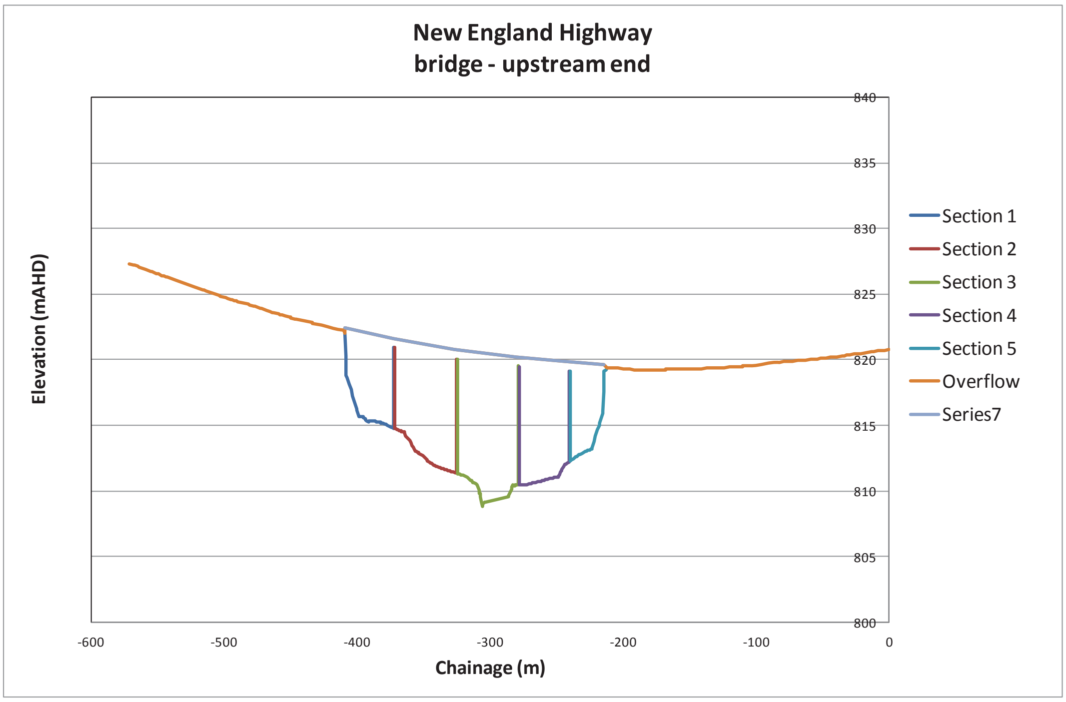
Figure A1
Modelling Area

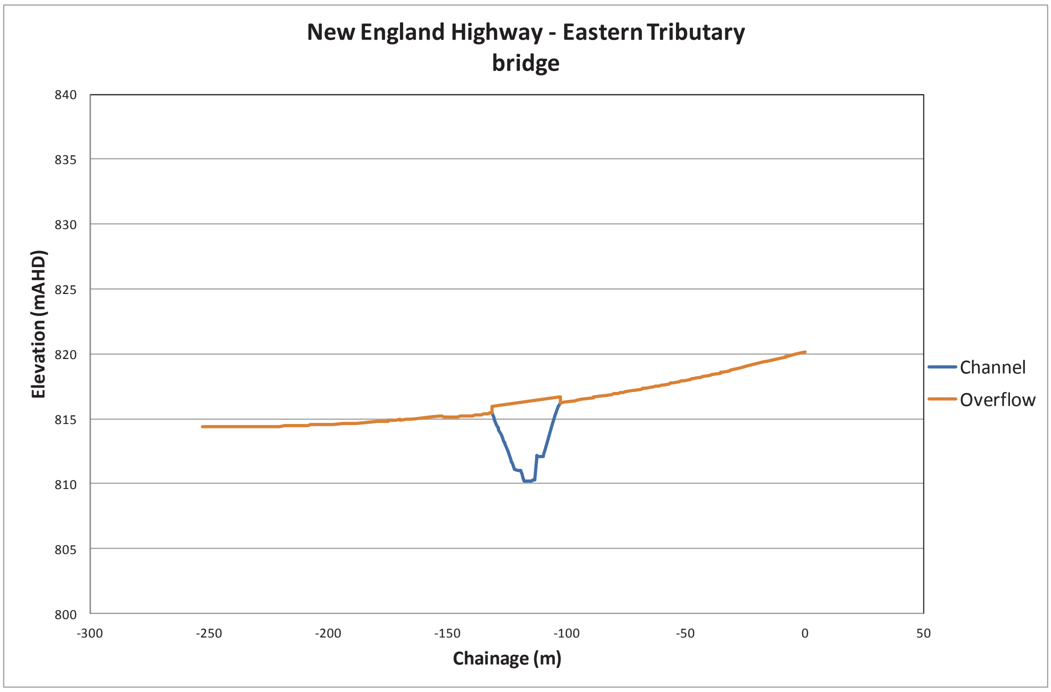


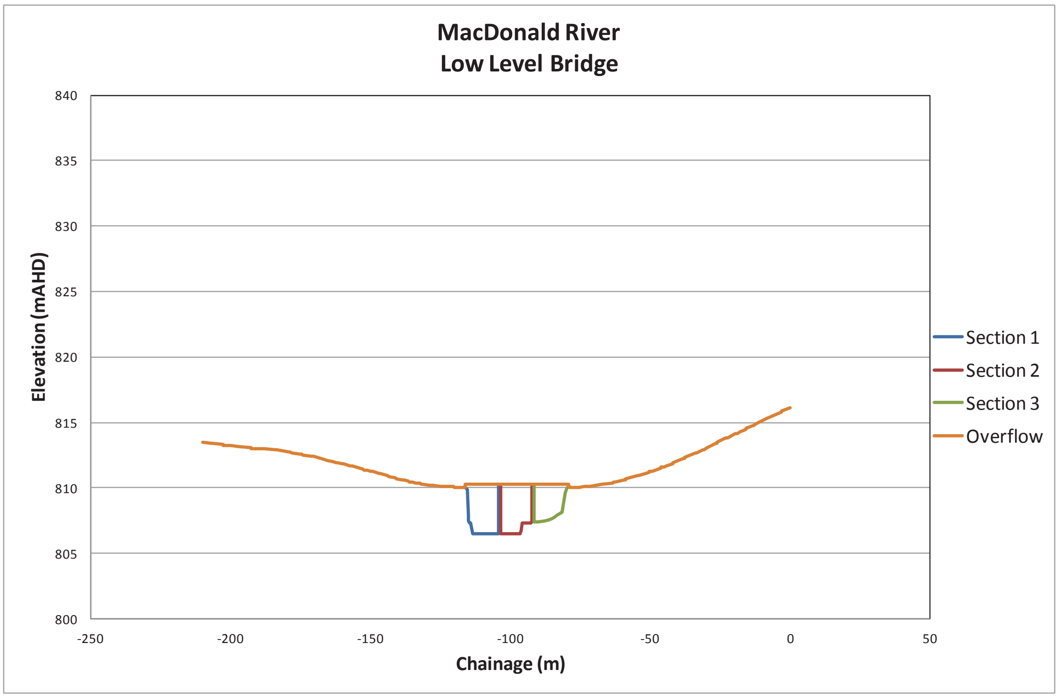
TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

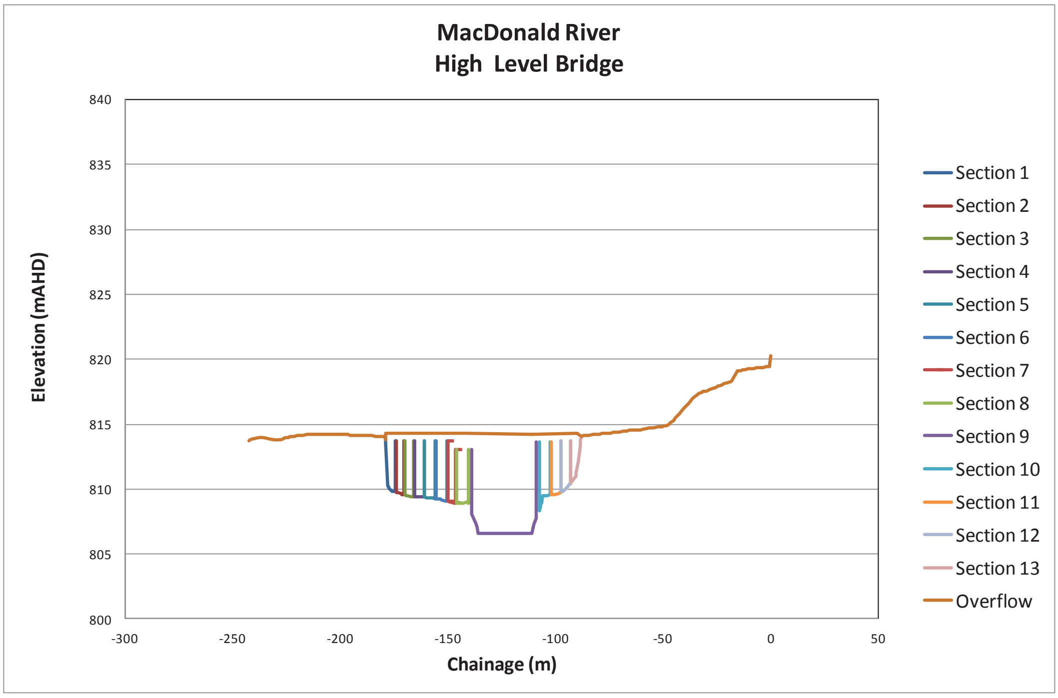
Figure A2
Catchment Topography

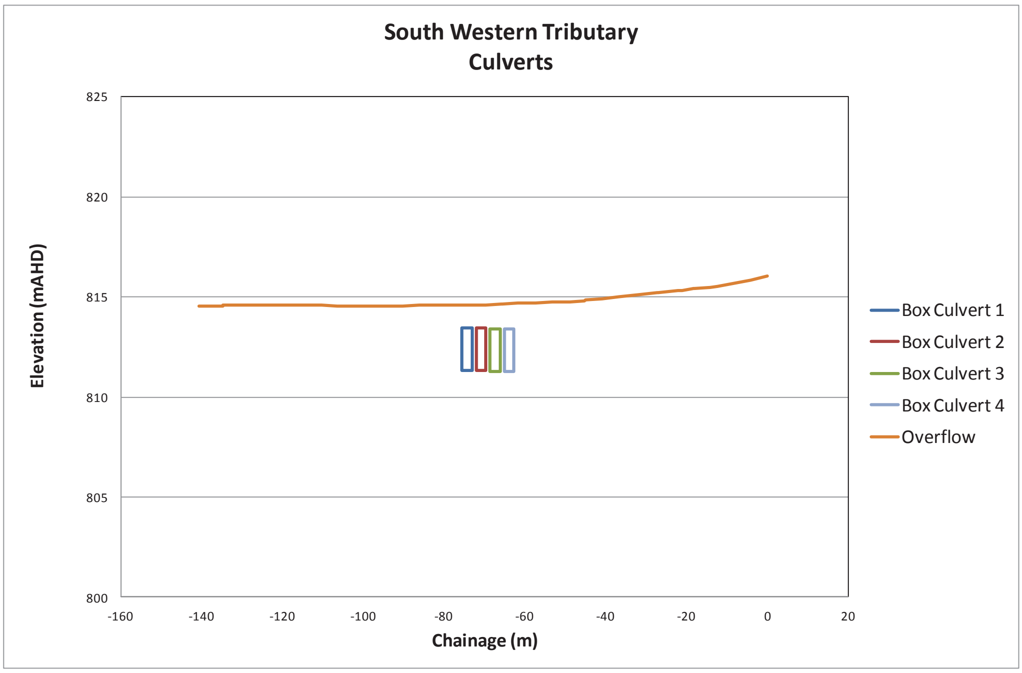
Figure A3 - Hydraulic Structures

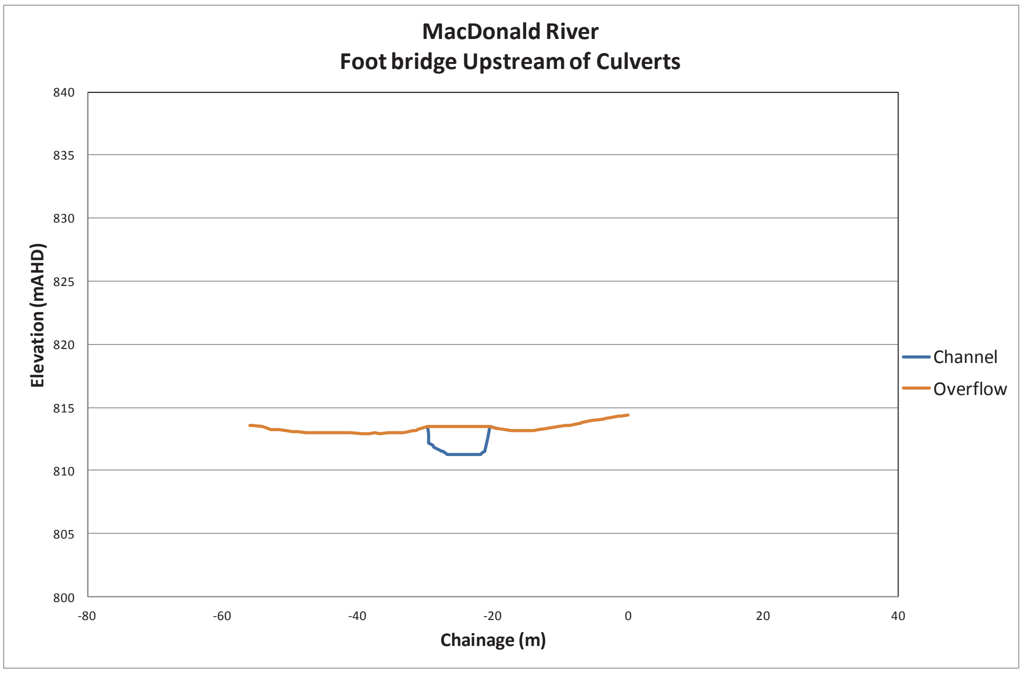


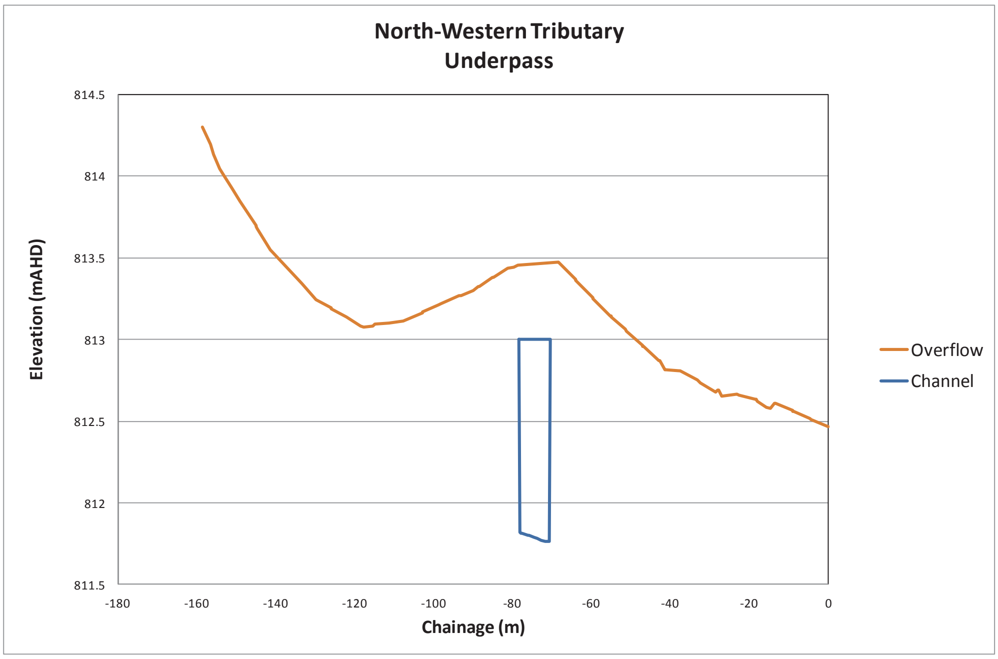

New England Highway - Eastern Tributary bridge
Elevation (mAHD)
840
835
830
825
820
815
810
805
800
-300
-250
-200
-150
-100
-50
0
50
Chainage (m)
Channel
Overflow


MacDonald River
Low Level Bridge
Elevation (mAHD)
840
835
830
825
820
815
810
805
800
-250
-200
-150
-100
-50
0
50
Chainage (m)
Section 1
Section 2
Section 3
Overflow


MacDonald River
High Level Bridge
Elevation (mAHD)
840
835
830
825
820
815
810
805
800
-300
-250
-200
-150
-100
-50
0
50
Chainage (m)
Section 1
Section 2
Section 3
Section 4
Section 5
Section 6
Section 7
Section 8
Section 9
Section 10
Section 11
Section 12
Section 13
Overflow


South Western Tributary
Culverts
Elevation (mAHD)
825
820
815
810
805
800
-160
-140
-120
-100
-80
-60
-40
-20
0
20
Chainage (m)
Box Culvert 1
Box Culvert 2
Box Culvert 3
Box Culvert 4
Overflow

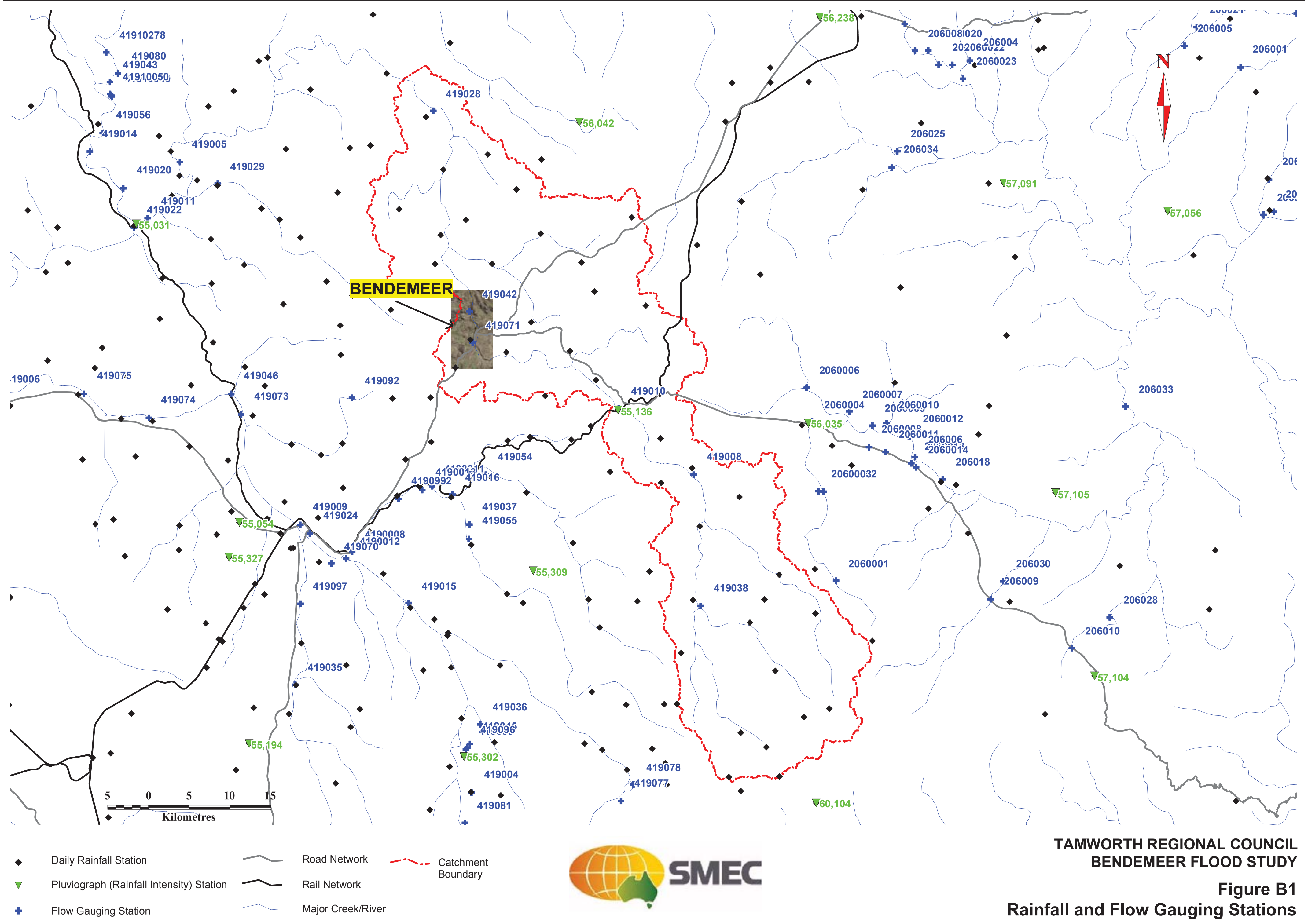

MacDonald River
Foot bridge Upstream of Culverts
Elevation (mAHD)
840
835
830
825
820
815
810
805
800
-80
-60
-40
-20
0
20
40
Chainage (m)
Channel
Overflow



North-Western Tributary
Underpass
Elevation (mAHD)
814.5
814
813.5
813
812.5
812
811.5
-180
-160
-140
-120
-100
-80
-60
-40
-20
0
Chainage (m)
Overflow
Channel

APPENDIX B – CALIBRATION AND VALIDATION

Figure B1 - Rainfall and Flow Gauging Stations
Figure B2A - Results of Hydrologic Model Calibration - Run 3
Figure B2B - Results of Hydrologic Model Calibration - Run 4 (Final Parameters)
Figure B3 - Modelling Surface Roughness Coefficients



TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

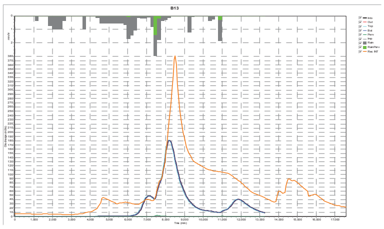
Figure B1
Rainfall and Flow Gauging Stations

RUN3

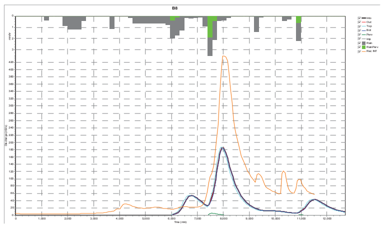
BENDEMEER | WOOLBROOK

event Nov-84
IL 5.0
CL 1.6
LAG 1.0

B13



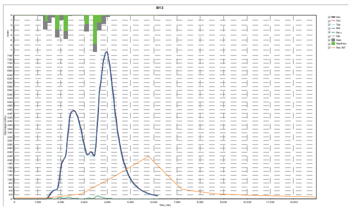
B8



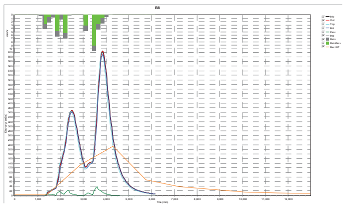
	B13			B8	
Peak Recorded	381 m3/s	65148 ML	Peak Recorded	438 m3/s	41737 ML
Peak Simulated	181 m3/s	18448 ML	Peak Simulated	186 m3/s	16068 ML

event Jan-76
IL 5.0
CL 1.6
LAG 1.0

B13



B8



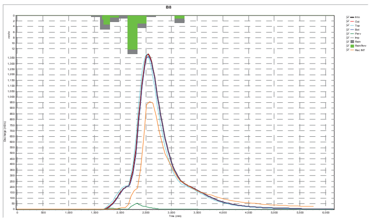
	B13			B8	
Peak Recorded	219 m3/s	41260 ML	Peak Recorded	214 m3/s	45312 ML
Peak Simulated	760 m3/s	72296 ML	Peak Simulated	625 m3/s	50002 ML

event Nov-08
IL 5.0
CL 1.6
LAG 1.0

B13

n/a at Bendemeer

B8



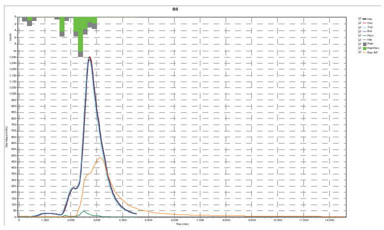
	B13			B8	
Peak Recorded	n/s m3/s		Peak Recorded	958 m3/s	43885 ML
Peak Simulated	m3/s		Peak Simulated	1381 m3/s	58570 ML

event Jan-04
IL 5.0
CL 1.6
LAG 1.0

B13

n/a at Bendemeer

B8



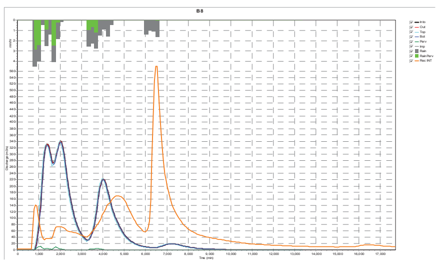
	B13			B8	
Peak Recorded	n/s m3/s		Peak Recorded	481 m3/s	42809 ML
Peak Simulated	m3/s		Peak Simulated	1301 m3/s	68988 ML

event Jan-96
IL 5.0
CL 1.6
LAG 1.0

B13

n/a at Bendemeer

B8



	B13			B8	
Peak Recorded	n/s m3/s		Peak Recorded	576 m3/s	64915 ML
Peak Simulated	m3/s		Peak Simulated	340 m3/s	44134 ML

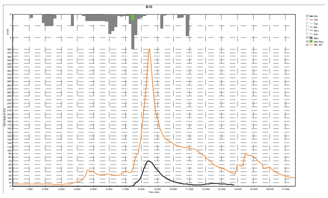
RUN4

BENDEMEER

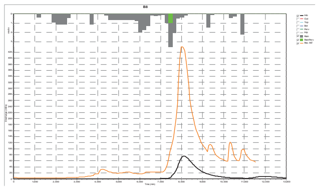
WOOLBROOK

event **Nov-84**
IL 25
CL 2.5
LAG 1.1

B13



B8



	B13			B8	
Peak Recorded	381 m3/s	65148 ML	Peak Recorded	438 m3/s	41737 ML
Peak Simulated	70 m3/s	6575 ML	Peak Simulated	76 m3/s	5912 ML

event **Jan-76**
IL
CL
LAG

B13

NOT USED - Daily Records

B8

NOT USED - Daily Records

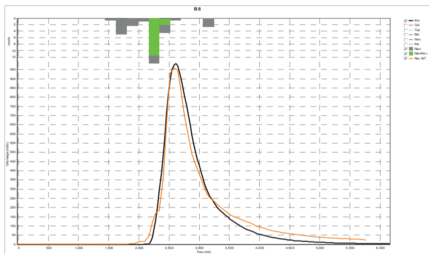
	B13			B8	
Peak Recorded	m3/s	ML	Peak Recorded	m3/s	ML
Peak Simulated	m3/s	ML	Peak Simulated	m3/s	ML

event **Nov-08**
IL 25
CL 2.5
LAG 1.1

B13

n/a at Bendemeer

B8



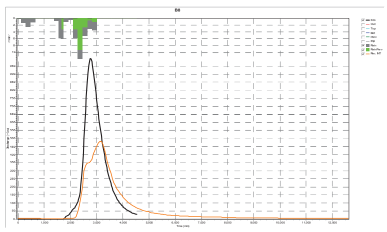
	B13				B8	
Peak Recorded	n/s	m3/s		Peak Recorded	958 m3/s	43885 ML
Peak Simulated		m3/s		Peak Simulated	983 m3/s	41651 ML

event **Jan-04**
IL 25
CL 2.5
LAG 1.1

B13

n/a at Bendemeer

B8



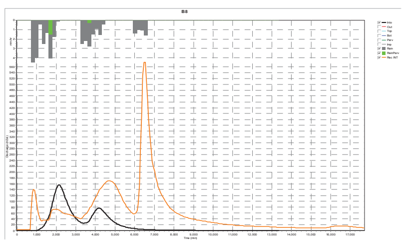
	B13				B8	
Peak Recorded	n/s	m3/s		Peak Recorded	481 m3/s	42809 ML
Peak Simulated		m3/s		Peak Simulated	998 m3/s	49219 ML

event **Jan-96**
IL 25
CL 2.5
LAG 1.1

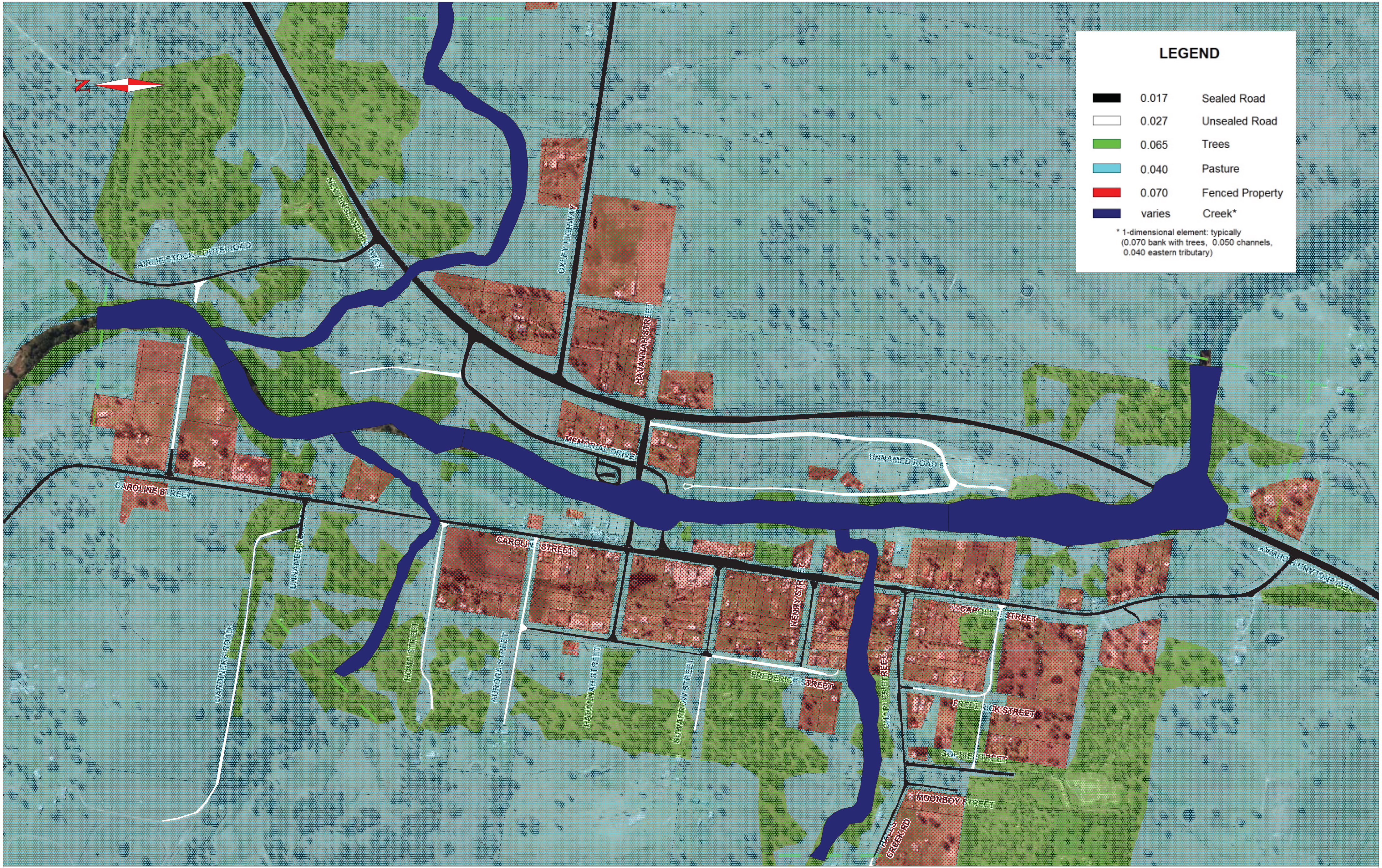
B13

n/a at Bendemeer

B8



	B13				B8	
Peak Recorded	n/s	m3/s		Peak Recorded	576 m3/s	64915 ML
Peak Simulated		m3/s		Peak Simulated	157 m3/s	15889 ML



TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

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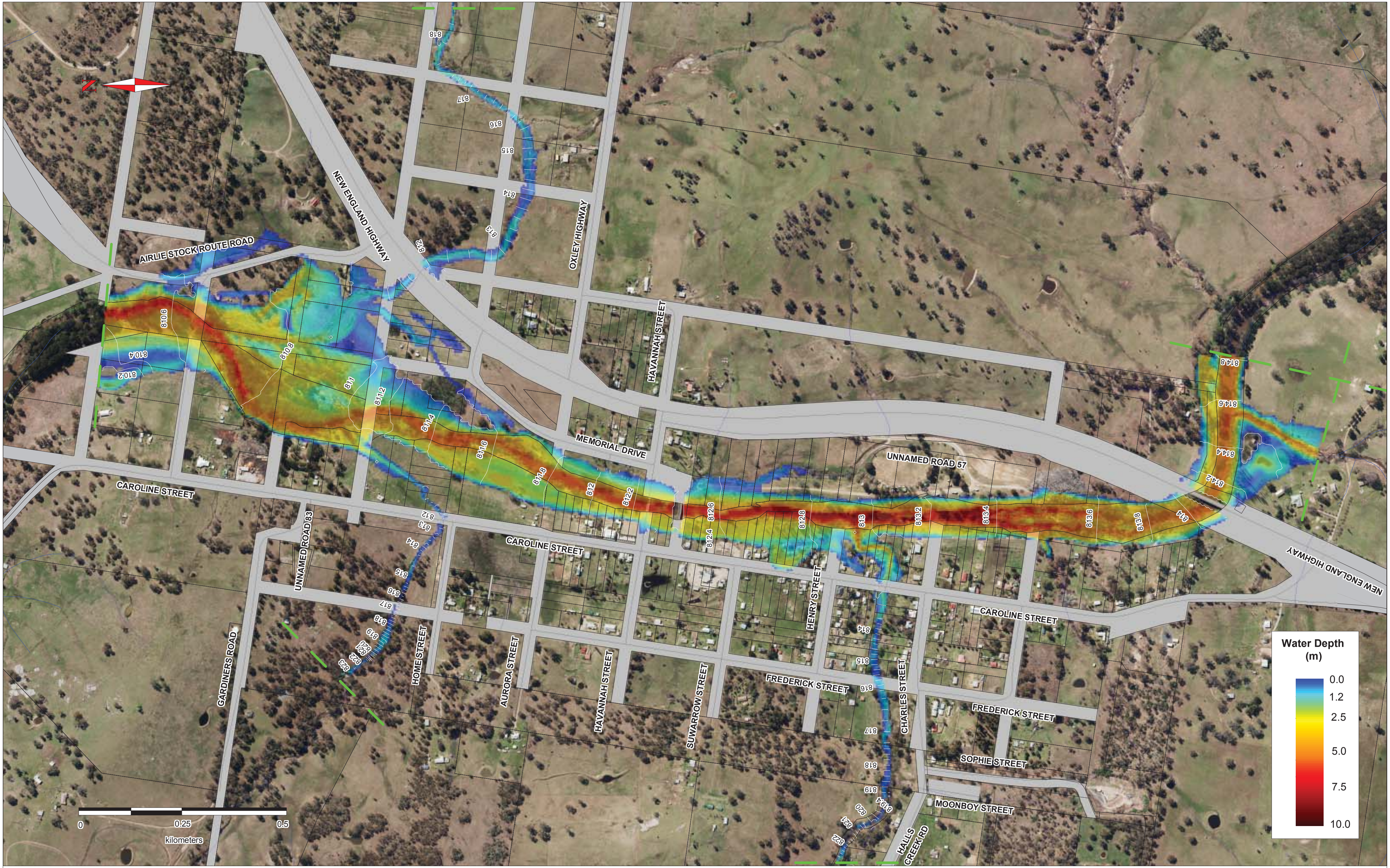
Figure B3
Modelling Surface Roughness Coefficients

APPENDIX C – DESIGN FLOOD MAPPING

Figure C1A - 5 year ARI Flood Depths and Levels
Figure C1B - 10% AEP Flood Depths and Levels
Figure C1C - 2% AEP Flood Depths and Levels
Figure C1D - 1% AEP Flood Depths and Levels
Figure C1E - 0.5% AEP Flood Depths and Levels
Figure C1F - Probable Maximum Flood (PMF) Flood Depths and Levels

Figure C2A - 5 year ARI Water Velocities
Figure C2B - 10% AEP Water Velocities
Figure C2C - 2% AEP Water Velocities
Figure C2D - 1% AEP Water Velocities
Figure C2E - 0.5% AEP Water Velocities
Figure C2F - Probable Maximum Flood (PMF) Water Velocities



DISCLAIMER

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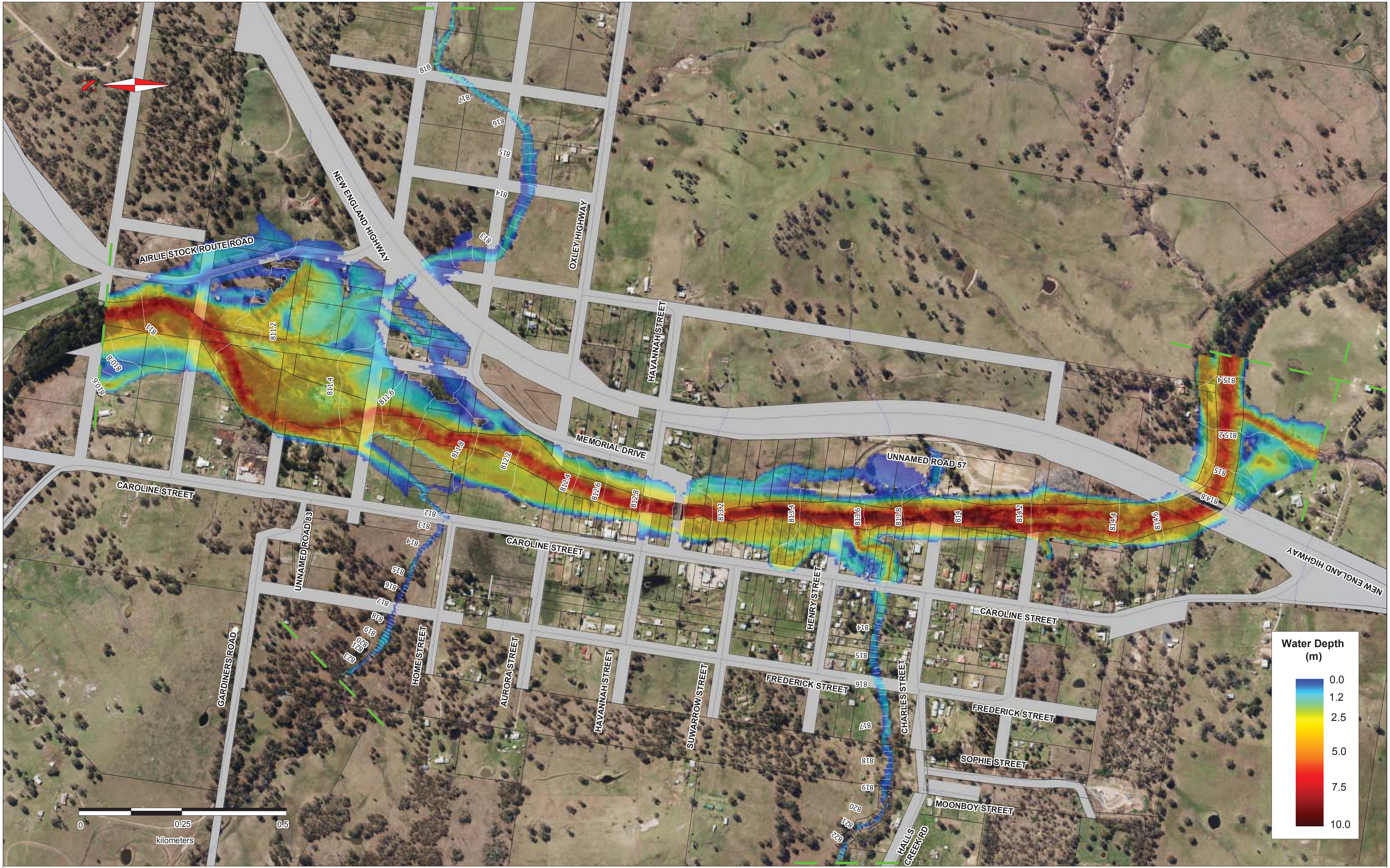
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C1A
5 year ARI Flood Depths and Levels



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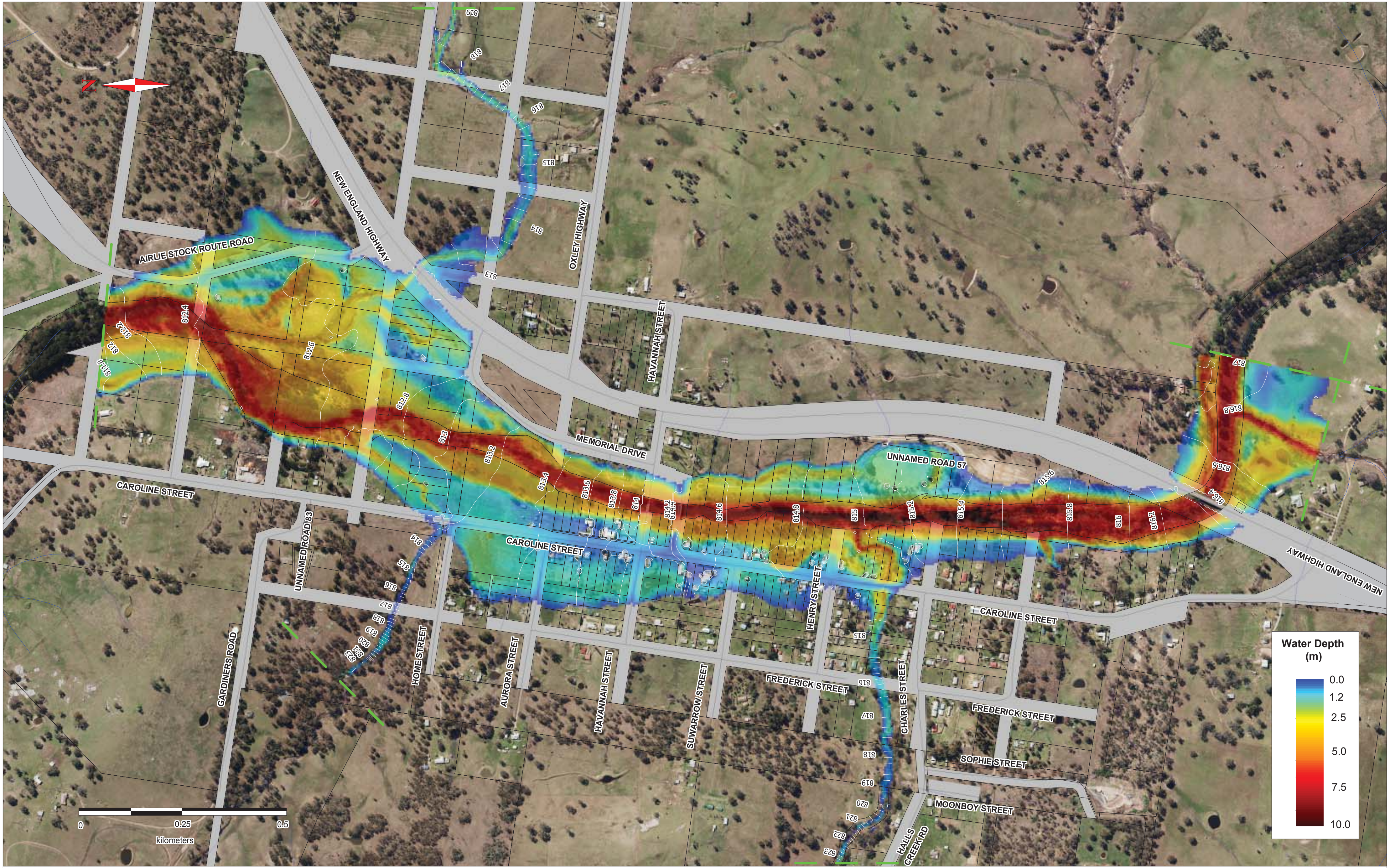
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C1B
10% AEP Flood Depths and Levels



DISCLAIMER

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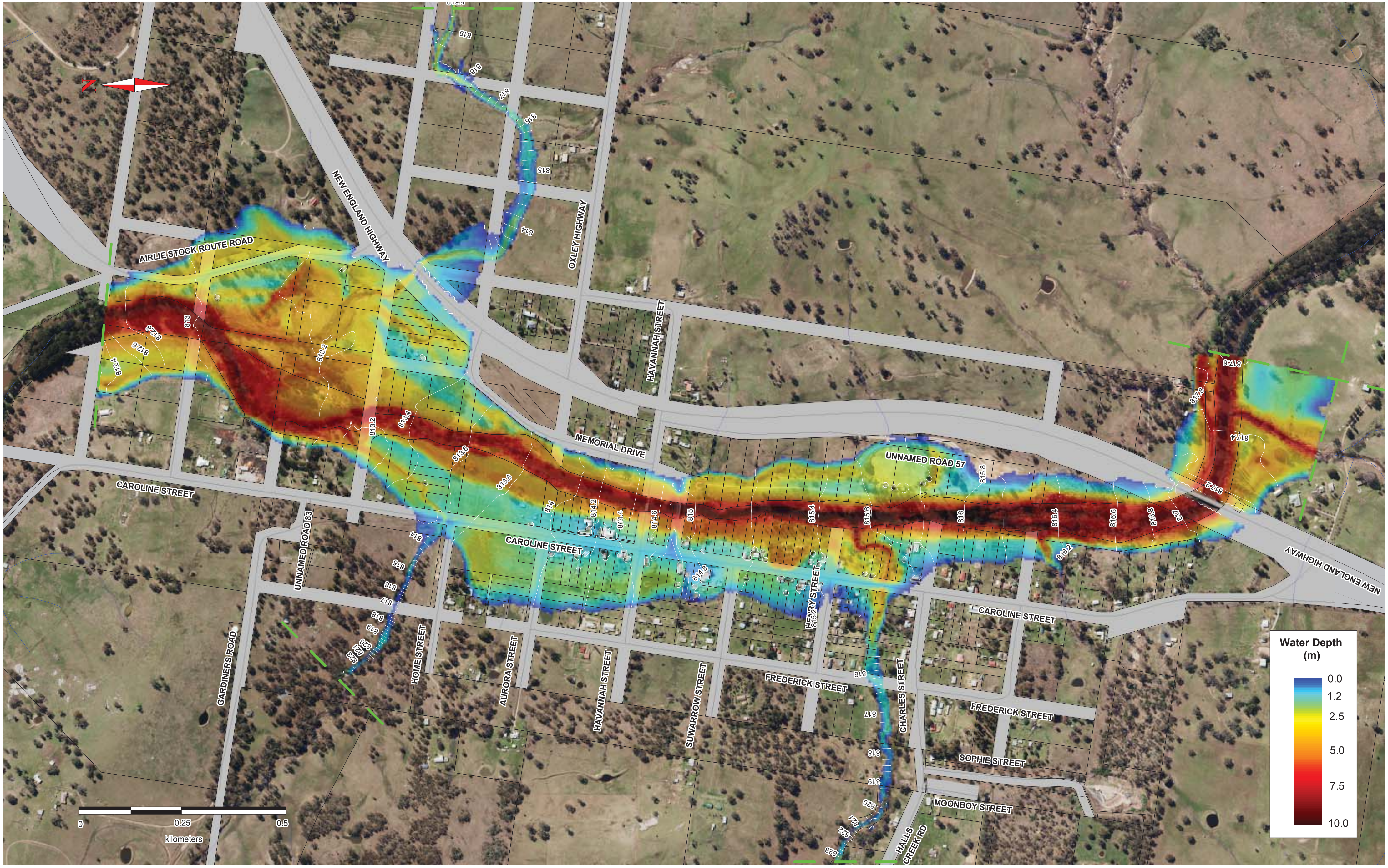
BENDEMEER FLOOD STUDY

Figure C1C
2% AEP Flood Depths and Levels



EXTENT OF MODELLING

DISCLAIMER

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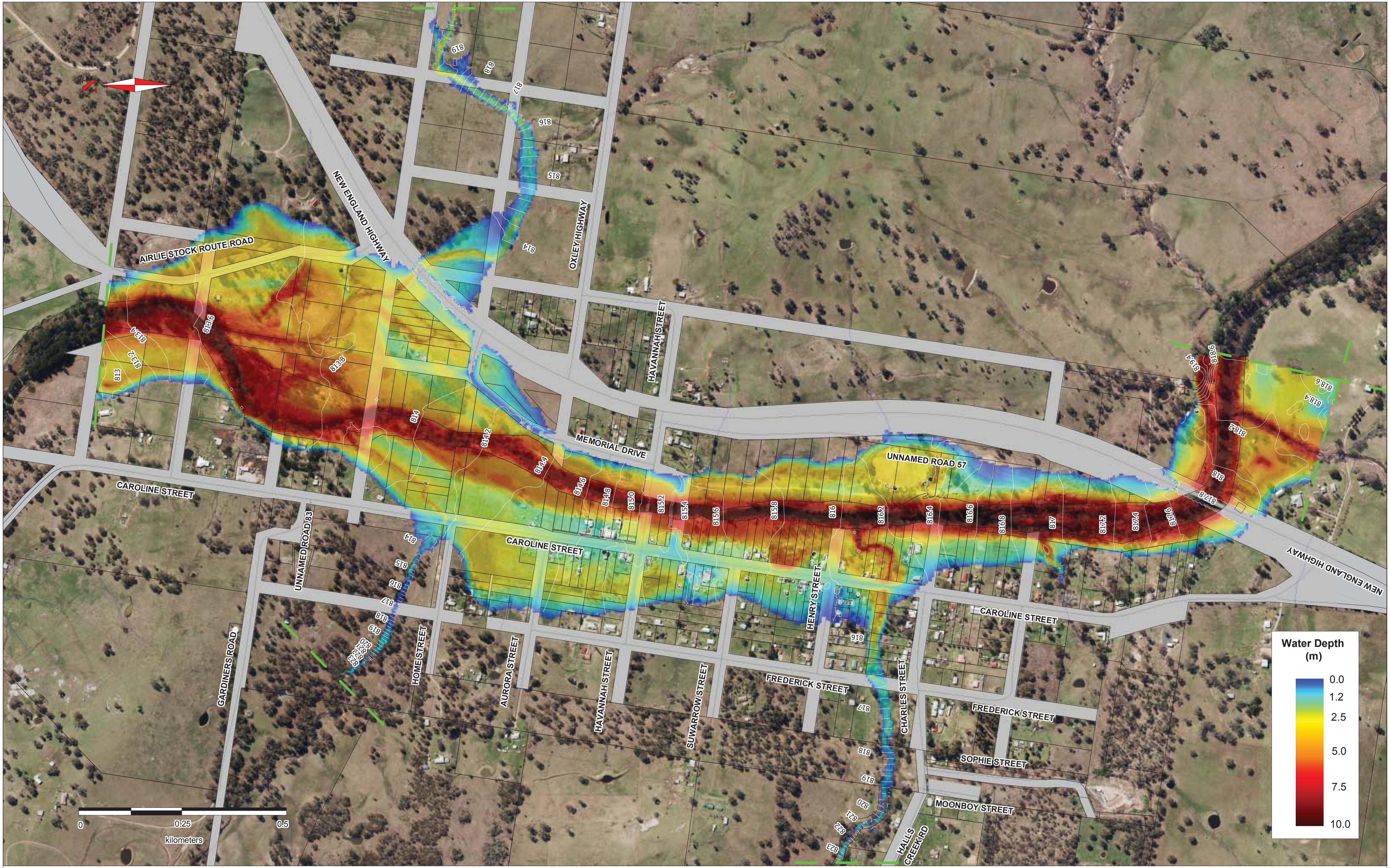
BENDEMEER FLOOD STUDY

Figure C1D
1% AEP Flood Depths and Levels



DISCLAIMER

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EXTENT OF MODELLING

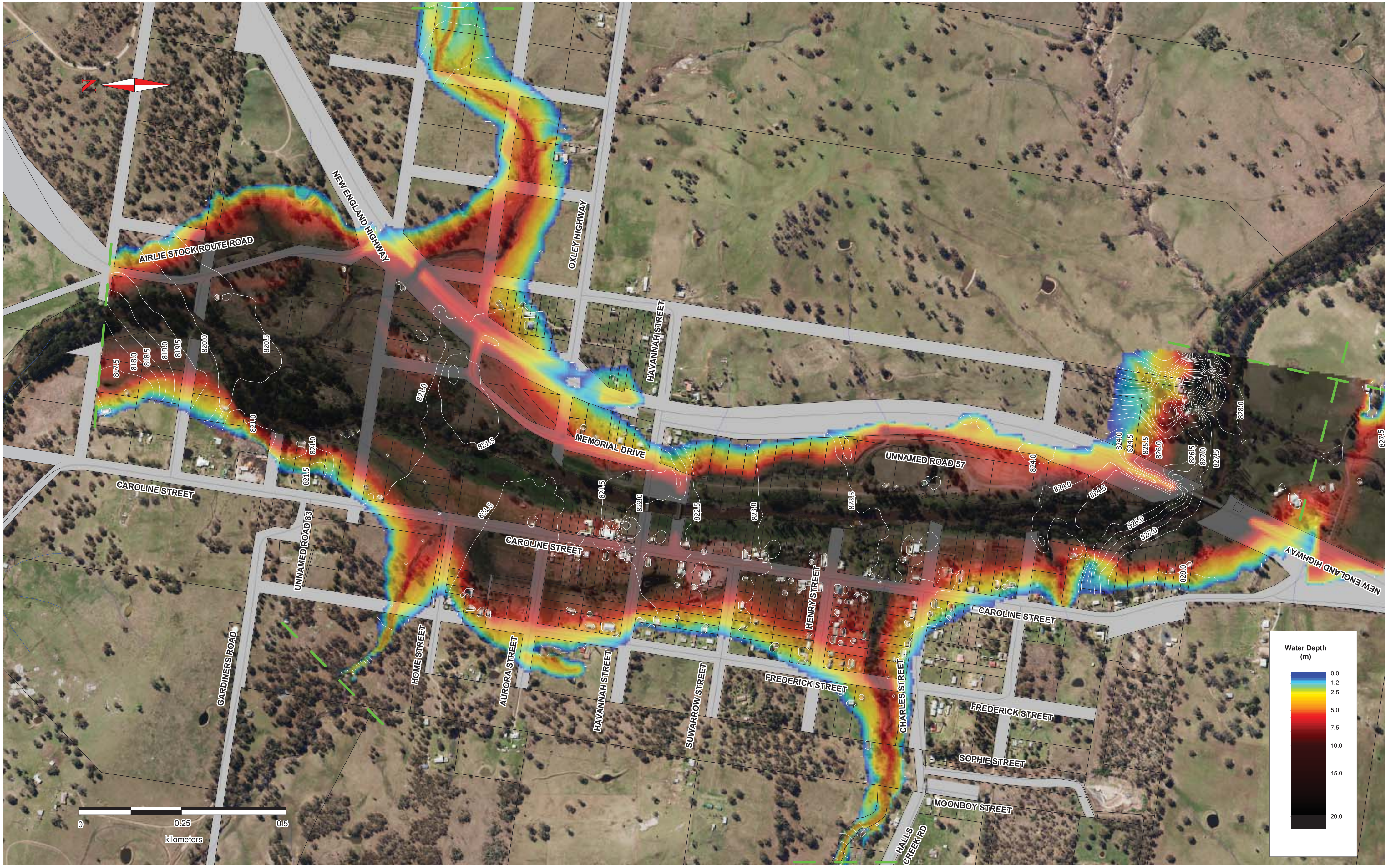
SMEC

TAMWORTH REGIONAL COUNCIL

BENDEMEER FLOOD STUDY

Figure C1E

0.5% AEP Flood Depths and Levels



EXTENT OF MODELLING

DISCLAIMER

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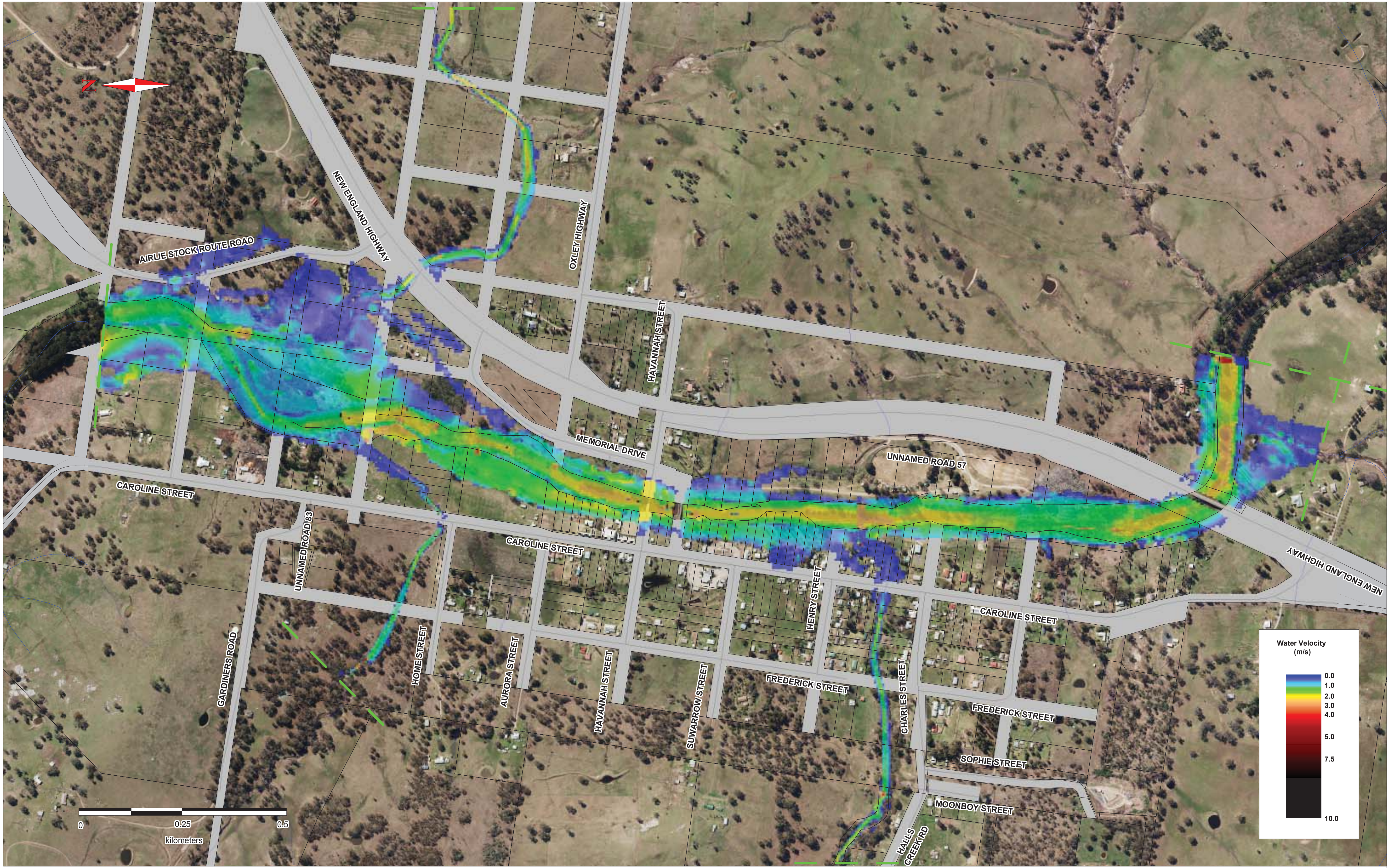
TAMWORTH REGIONAL COUNCIL

BENDEMEER FLOOD STUDY

Figure C1F

Probable Maximum Flood (PMF) Flood Depths and Levels



DISCLAIMER

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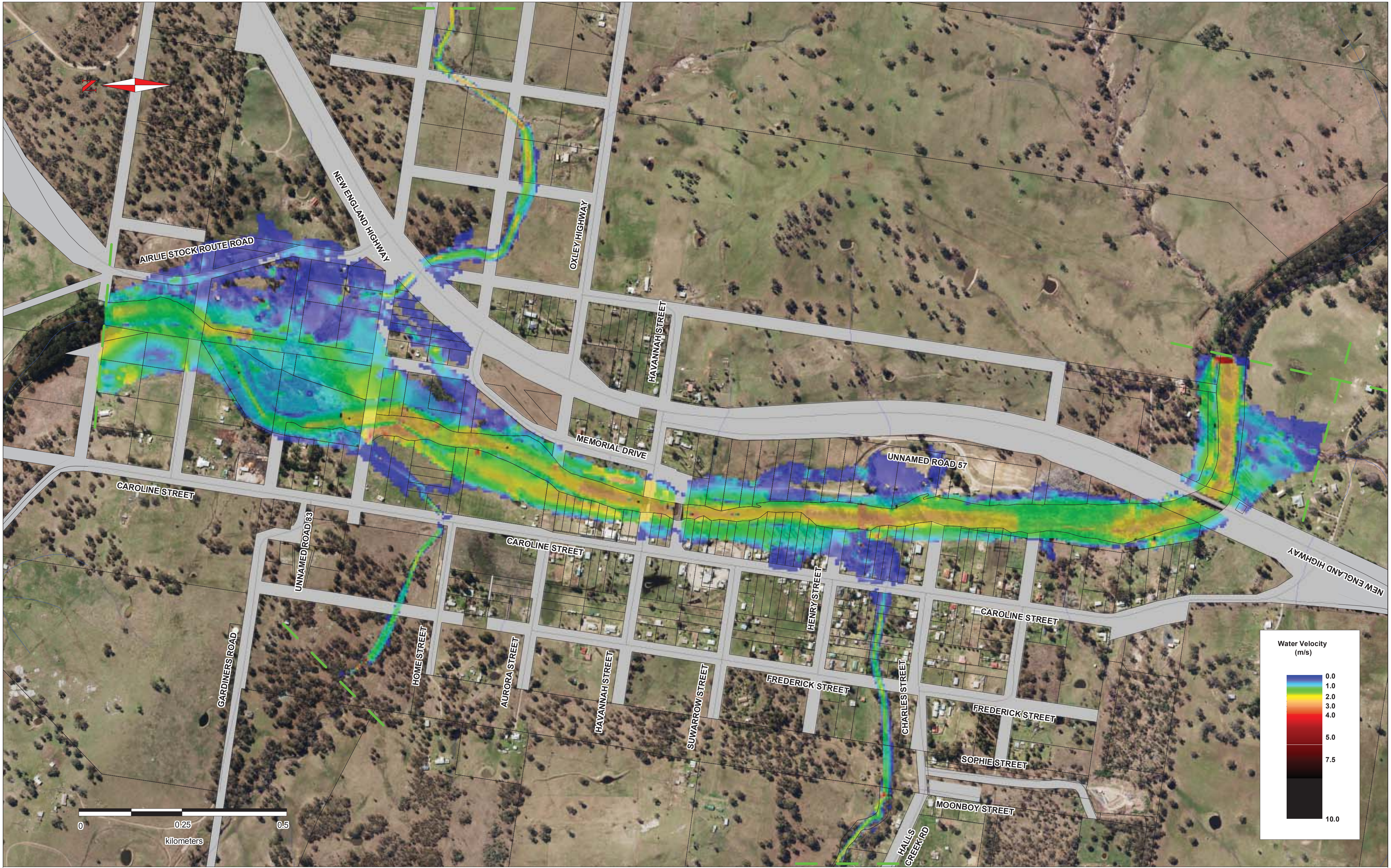
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C2A
5 year ARI Water Velocities



DISCLAIMER

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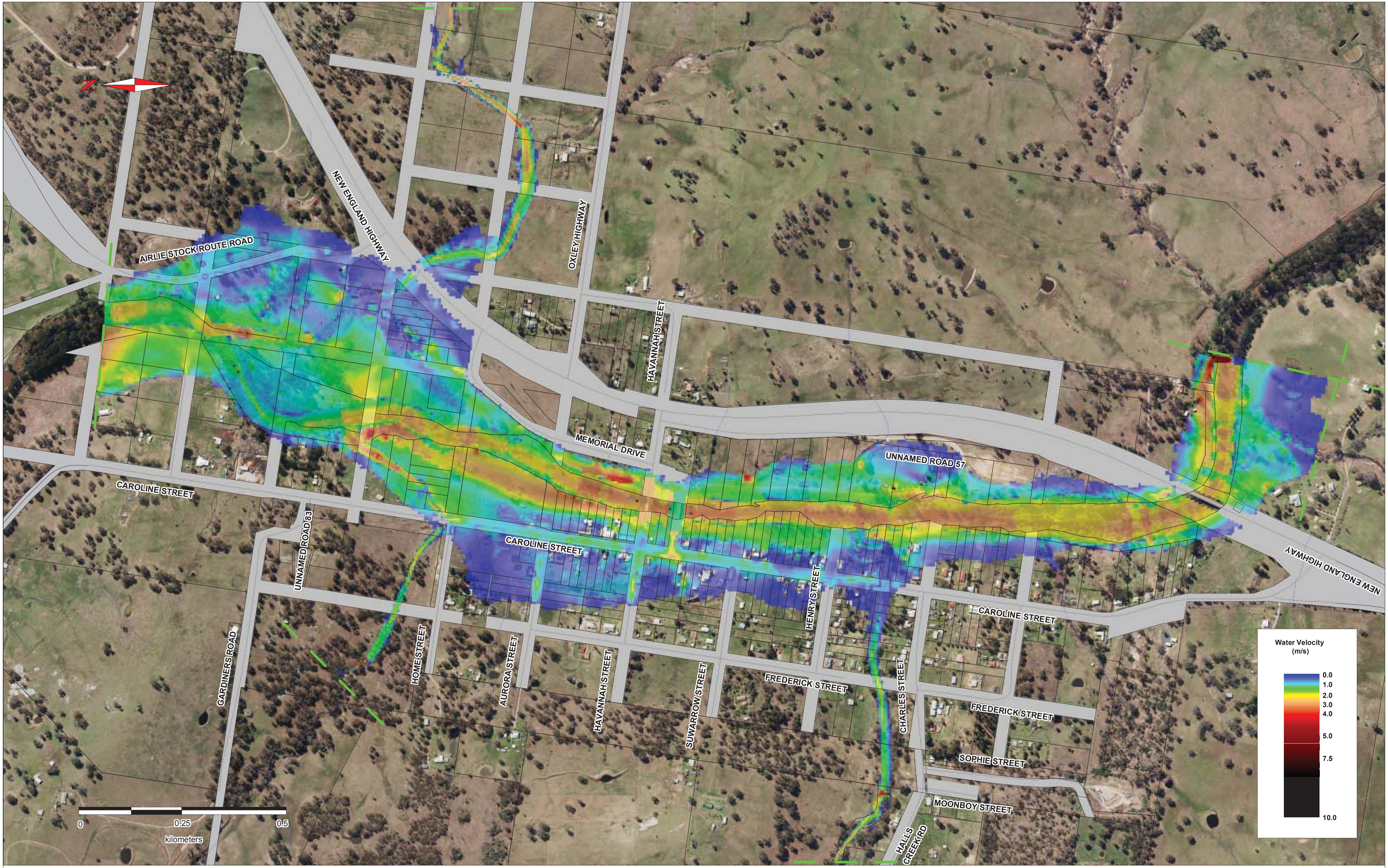
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C2B
10% AEP Water Velocities



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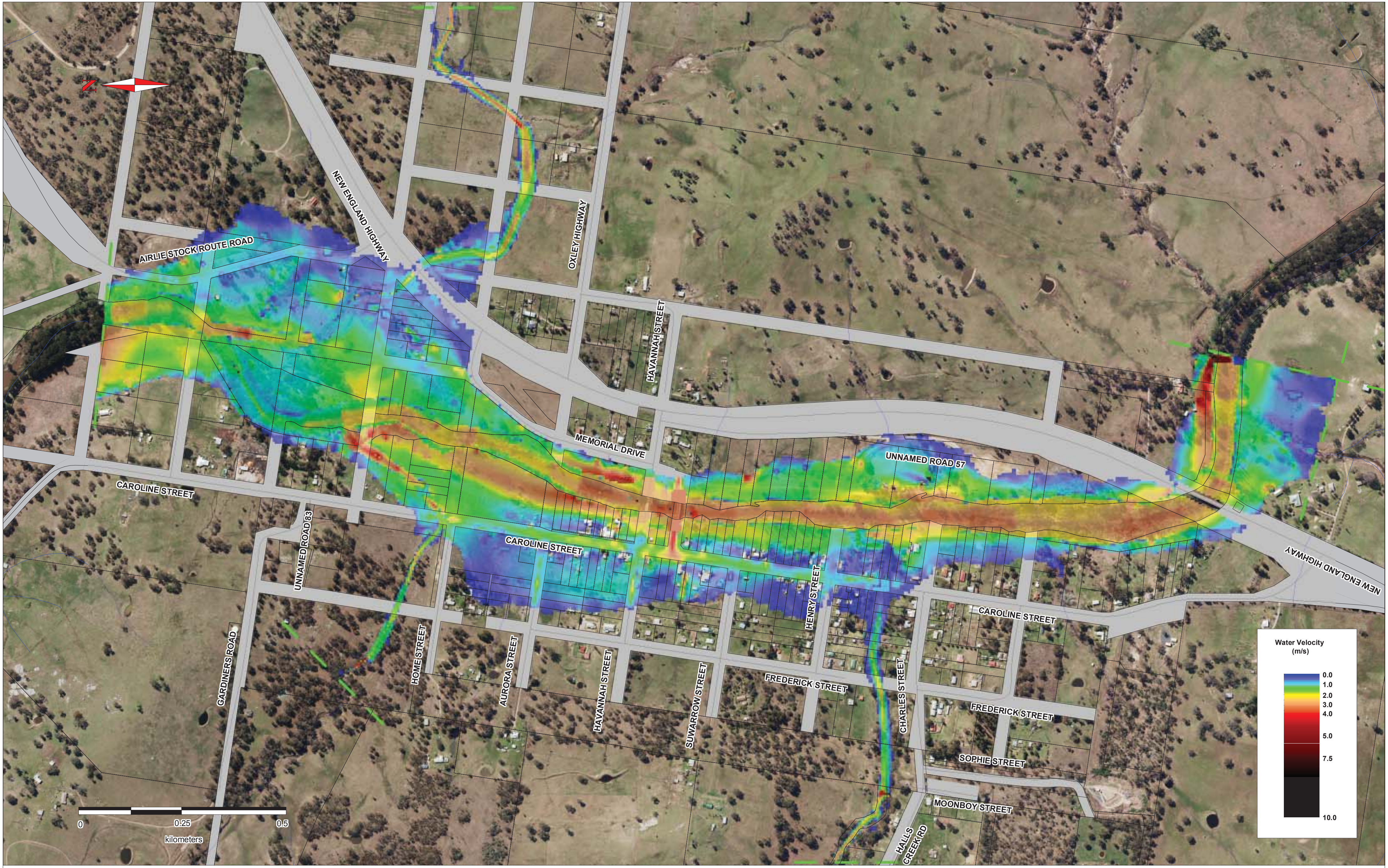
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C2C
2% AEP Water Velocities



DISCLAIMER

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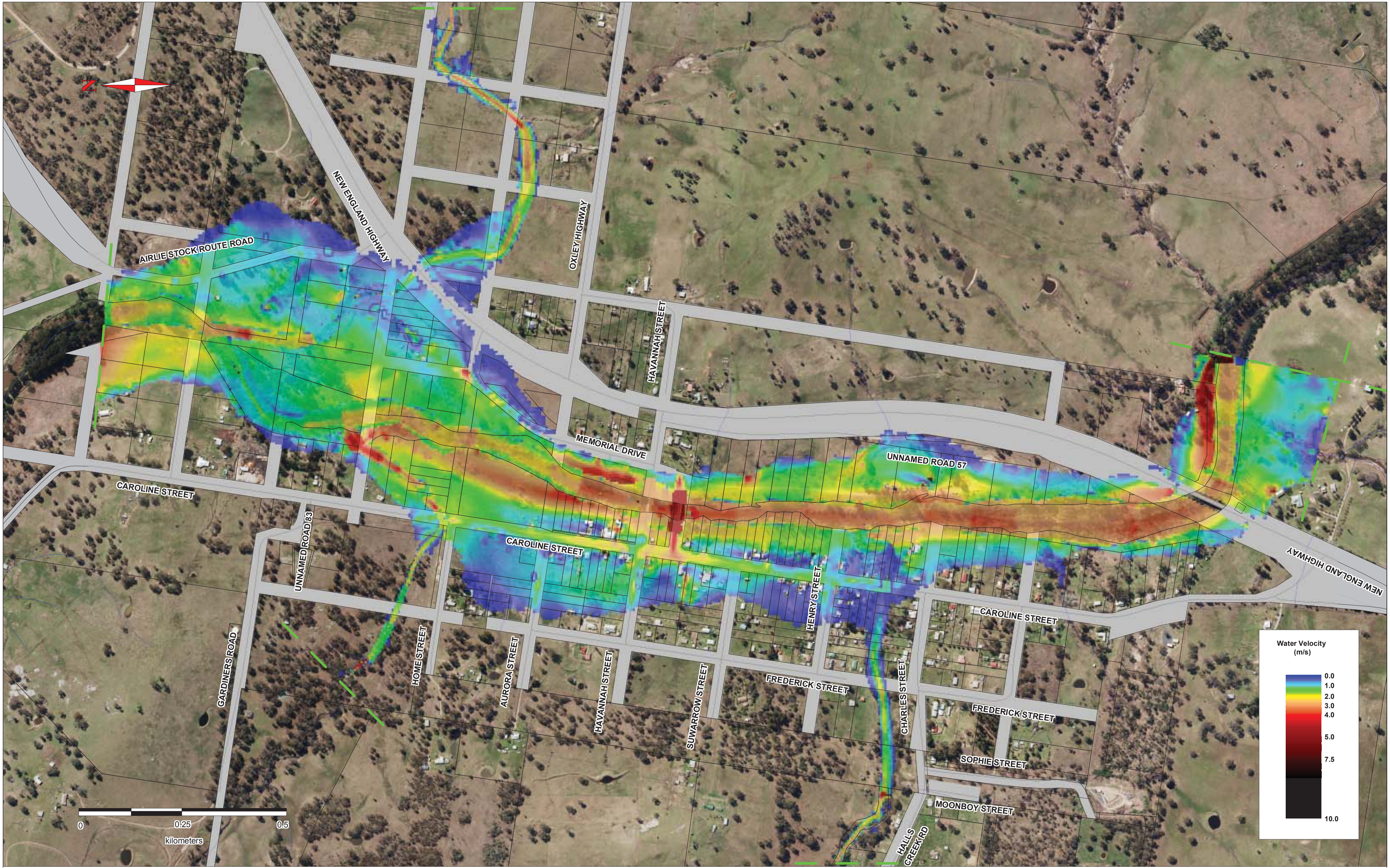
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C2D
1% AEP Water Velocities



DISCLAIMER

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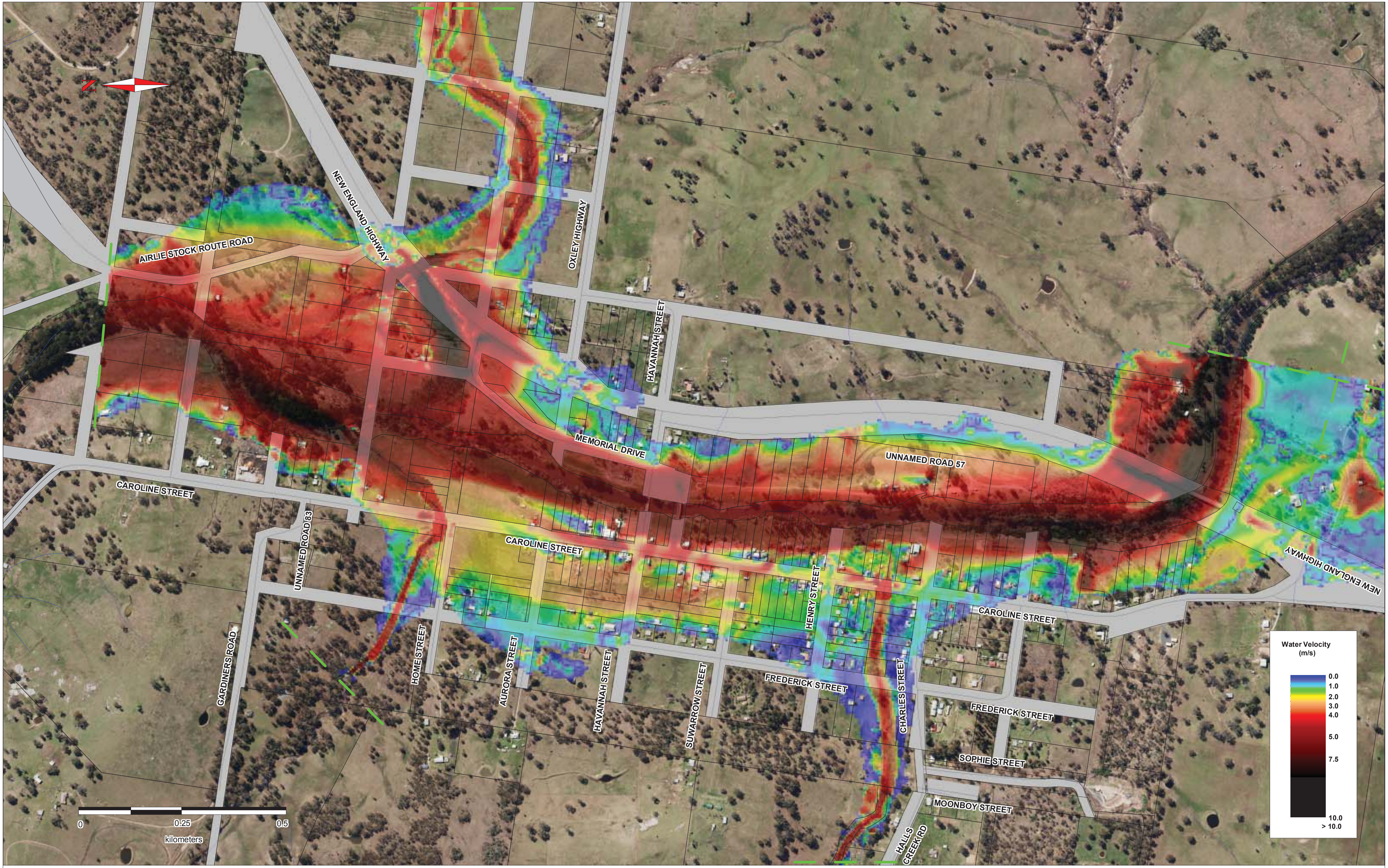
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C2E
0.5% AEP Water Velocities



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EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure C2F
Probable Maximum Flood (PMF) Water Velocities

APPENDIX D – HYDRAULIC AND HAZARD CATEGORISATION AND FLOOD PLANNING

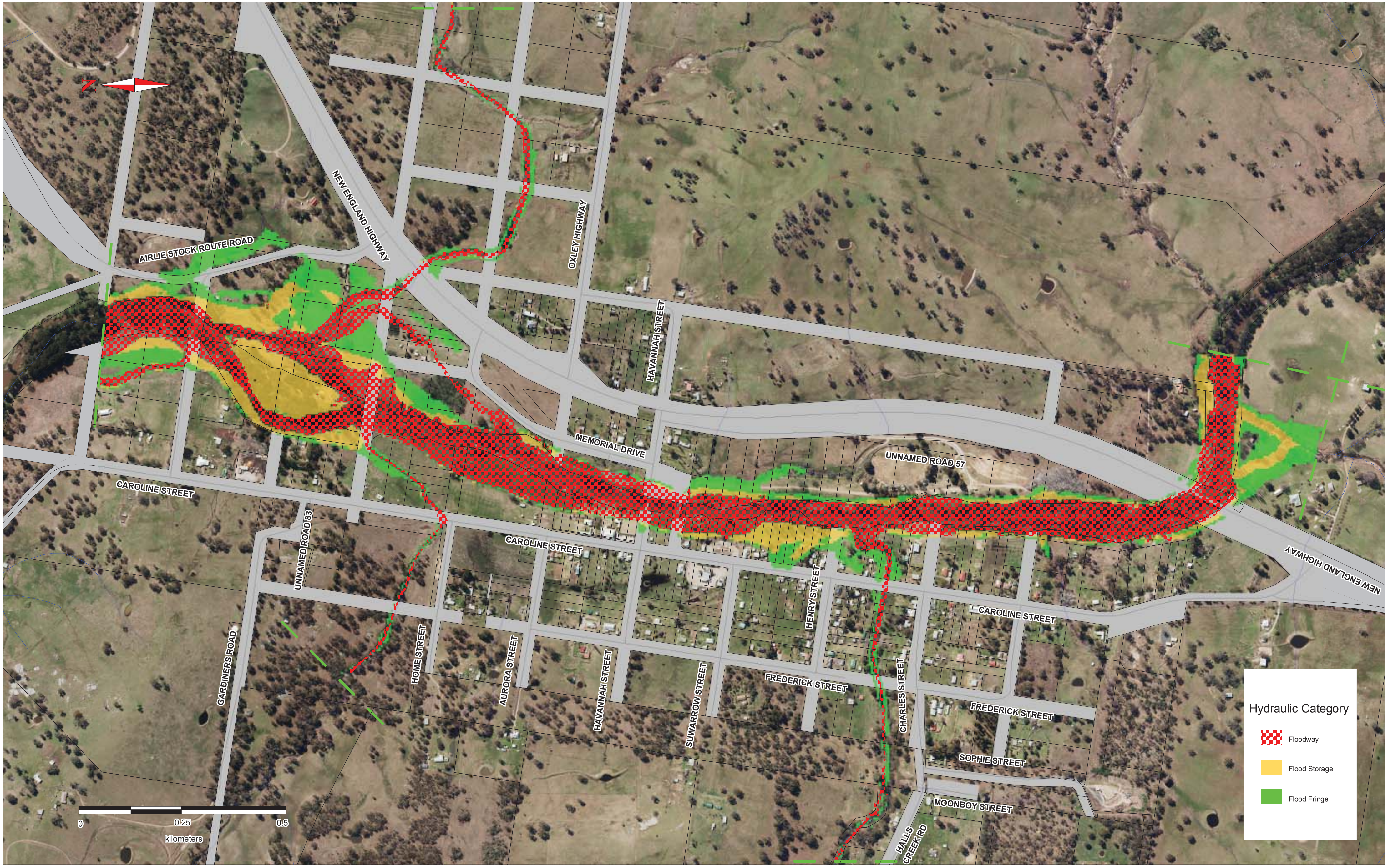
Figure D1A - 5 year ARI Hydraulic Categories
Figure D1B - 10% AEP Hydraulic Categories
Figure D1C - 2% AEP Hydraulic Categories
Figure D1D - 1% AEP Hydraulic Categories
Figure D1E - 0.5% AEP Hydraulic Categories
Figure D1F - Probable Maximum Flood (PMF) Hydraulic Categories

Figure D2A - 5 year ARI Flow Hazard
Figure D2B - 10% AEP Flow Hazard
Figure D2C - 2% AEP Flow Hazard
Figure D2D - 1% AEP Flow Hazard
Figure D2E - 0.5% AEP Flow Hazard
Figure D2F - Probable Maximum Flood (PMF) Flow Hazard

Figure D3A - 5 year ARI Preliminary True Hazard Categories
Figure D3B - 10% AEP Preliminary True Hazard Categories
Figure D3C - 2% AEP Preliminary True Hazard Categories
Figure D3D - 1% AEP Preliminary True Hazard Categories
Figure D3E - 0.5% AEP Preliminary True Hazard Categories
Figure D3F - Probable Maximum Flood (PMF) Preliminary True Hazard Categories

Figure D4A - 5 year ARI Flood Emergency Response Classification
Figure D4B - 10% AEP Flood Emergency Response Classification
Figure D4C - 2% AEP Flood Emergency Response Classification
Figure D4D - 1% AEP Flood Emergency Response Classification
Figure D4E - 0.5% AEP Flood Emergency Response Classification
Figure D4F - PMP Flood Emergency Response Classification

Figure D5 - Flood Planning Levels (1% AEP + 0.5m)



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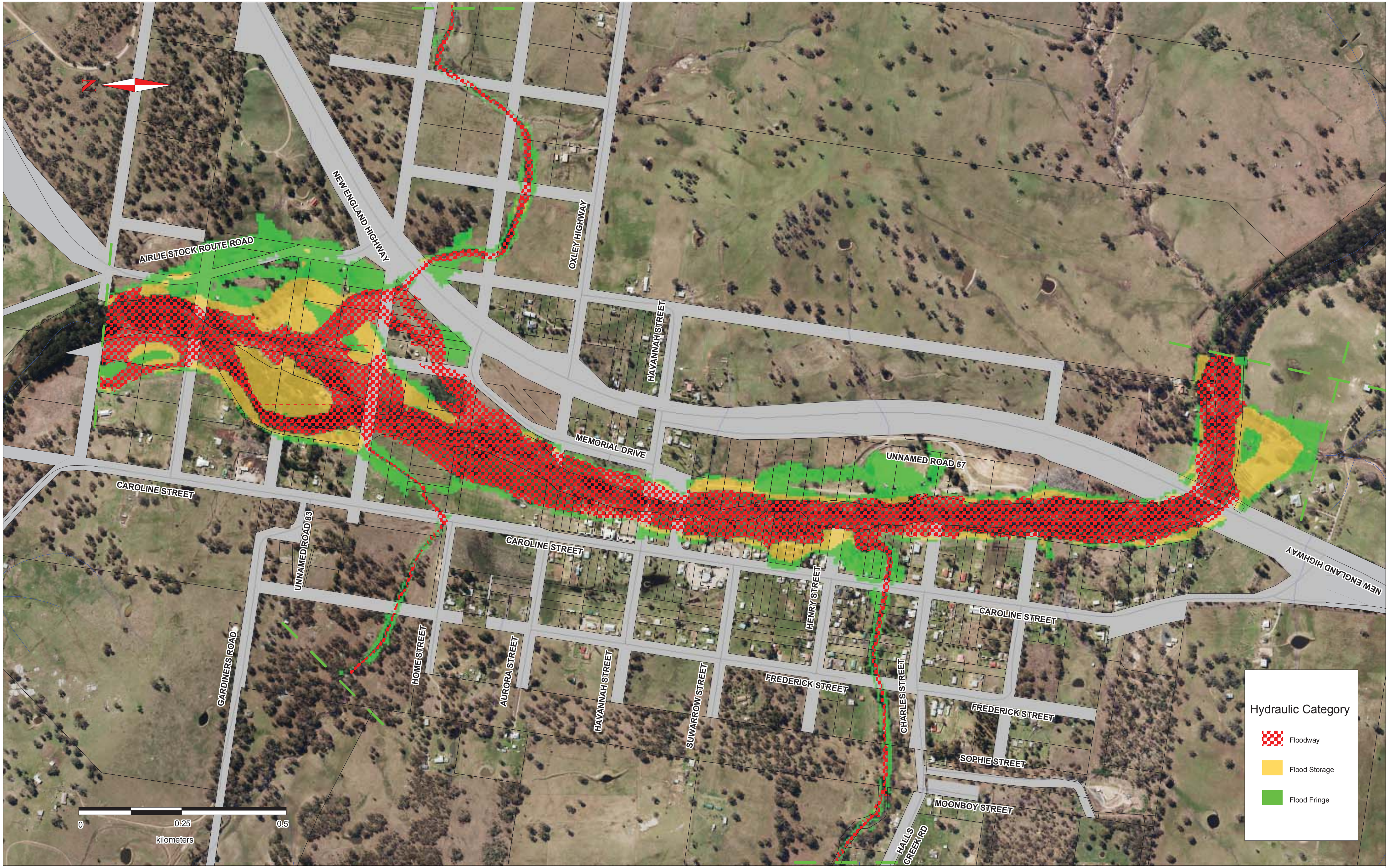
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D1A
5 year ARI Hydraulic Categorisation



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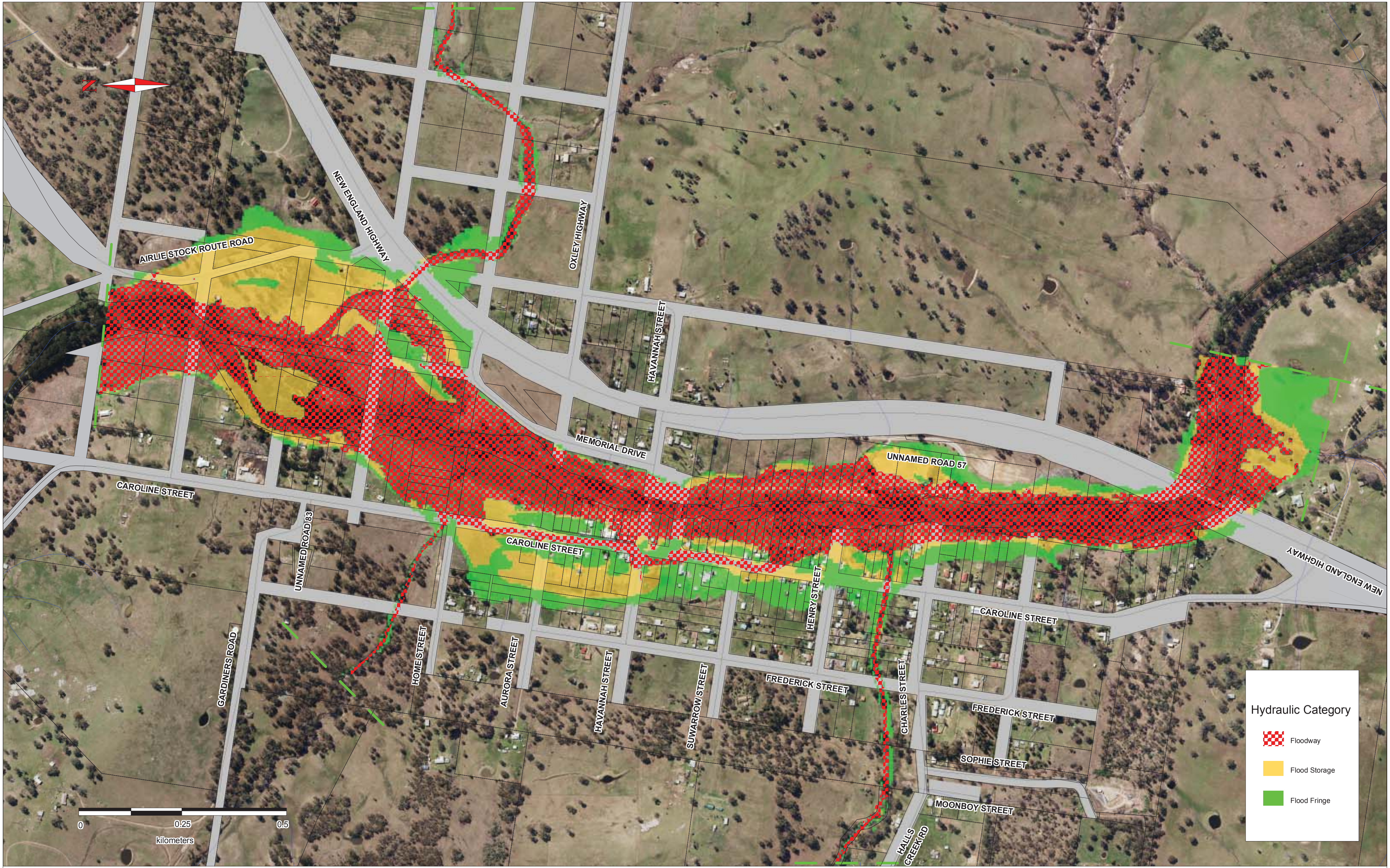
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D1B
10% AEP Hydraulic Categorisation



DISCLAIMER

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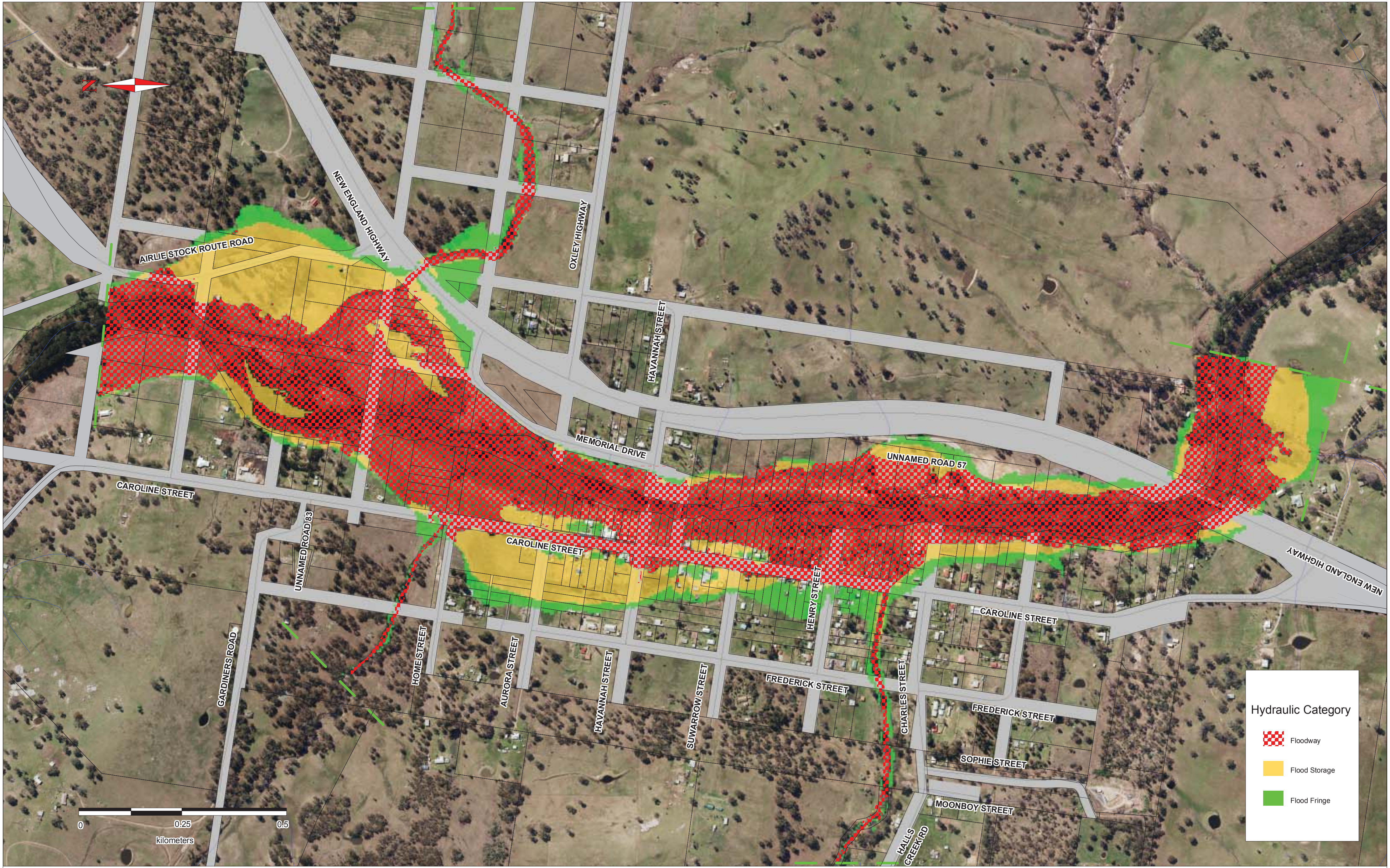
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D1C
2% AEP Hydraulic Categorisation



DISCLAIMER

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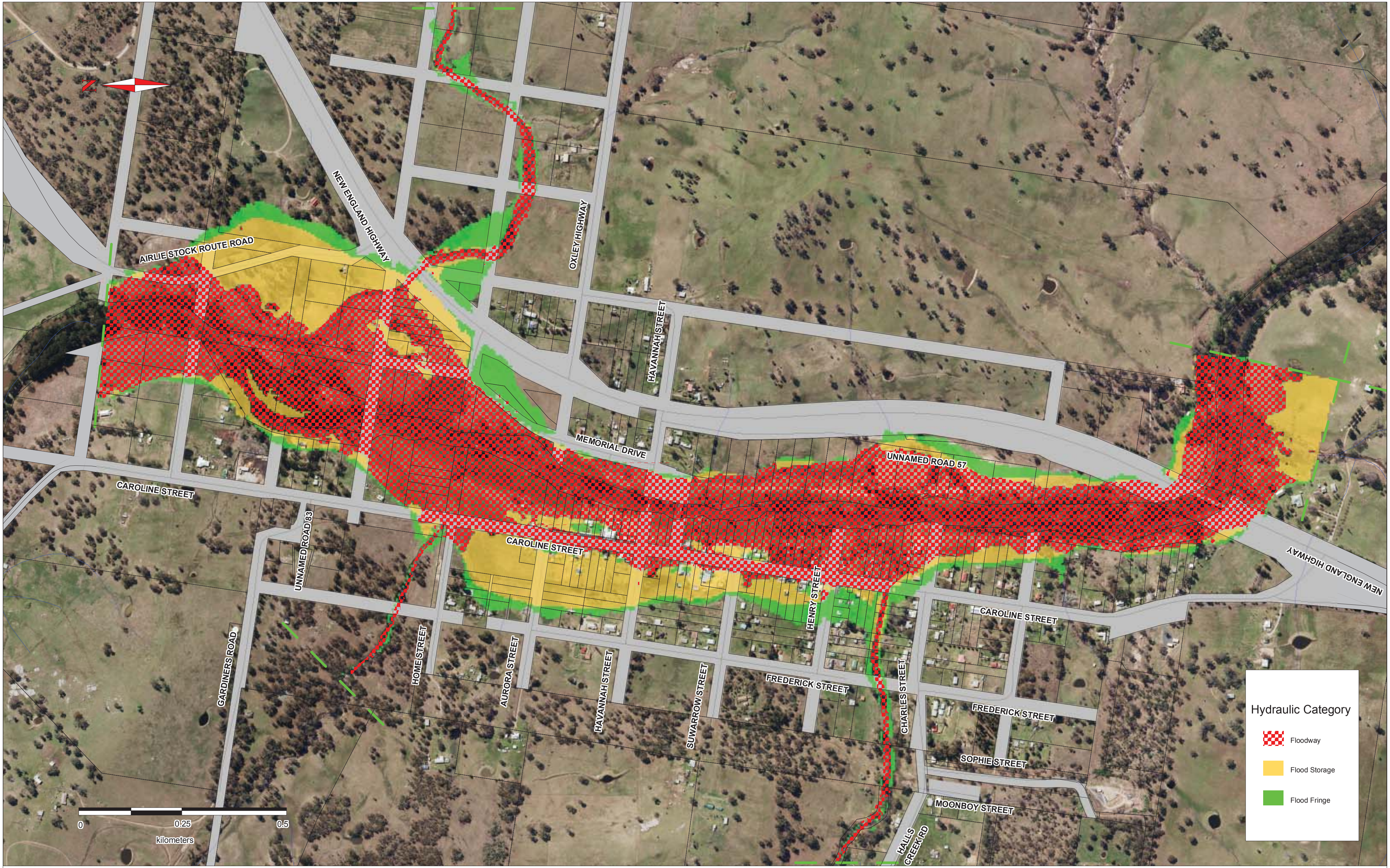
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D1D
1% AEP Hydraulic Categorisation



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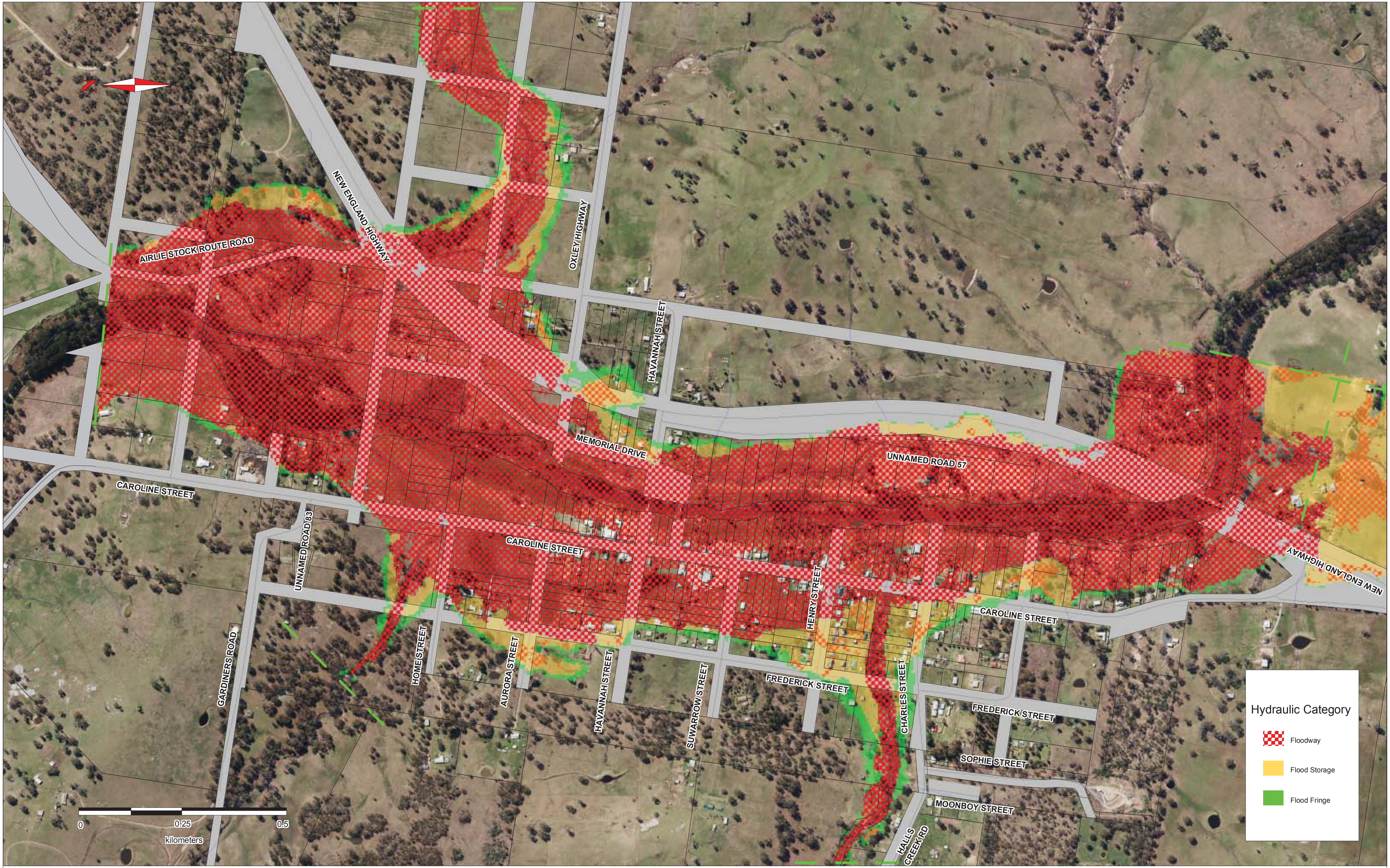
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D1E
0.5% AEP Hydraulic Categorisation



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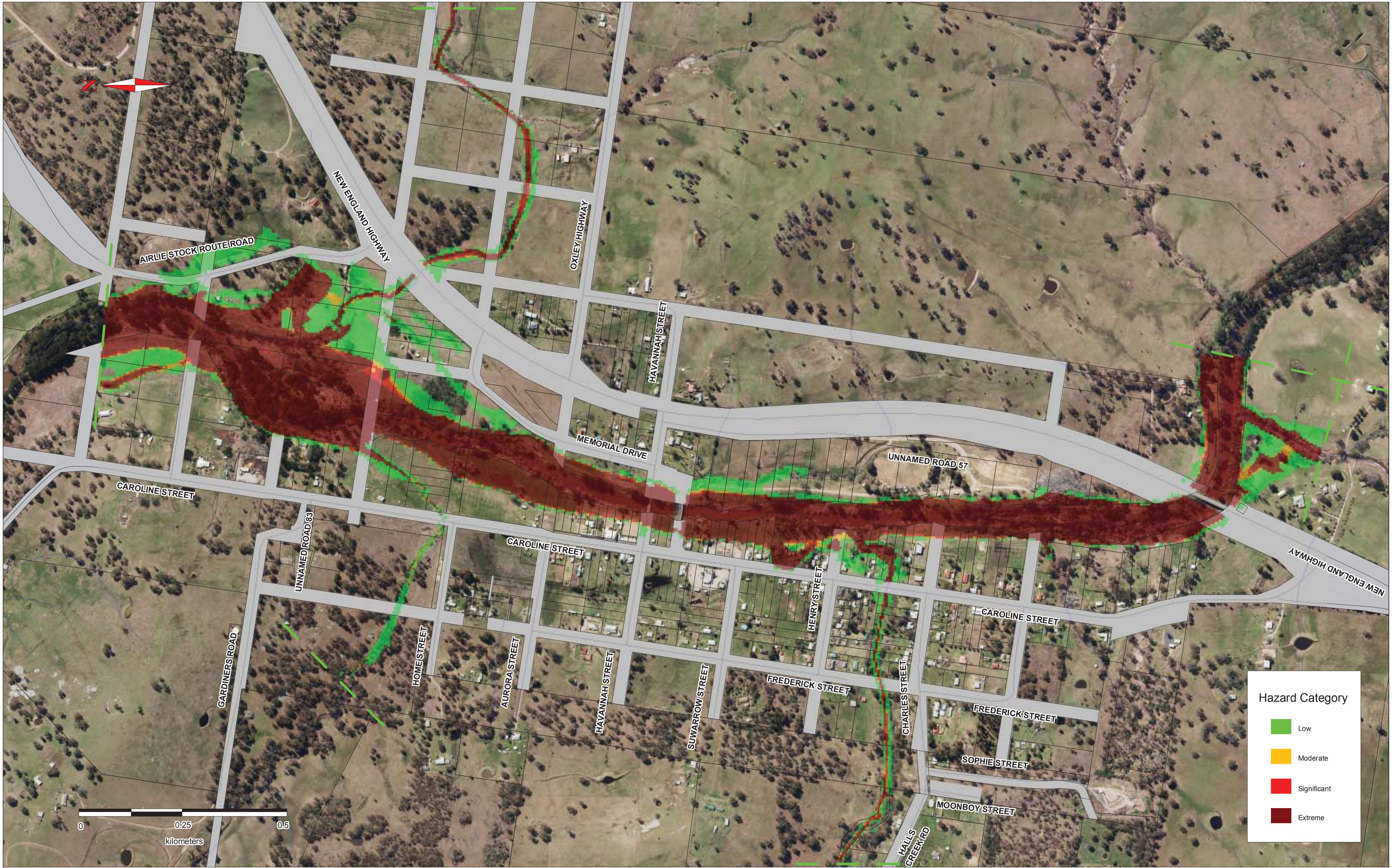
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D1F
Probable Maximum Flood (PMF) Hydraulic Categorisation



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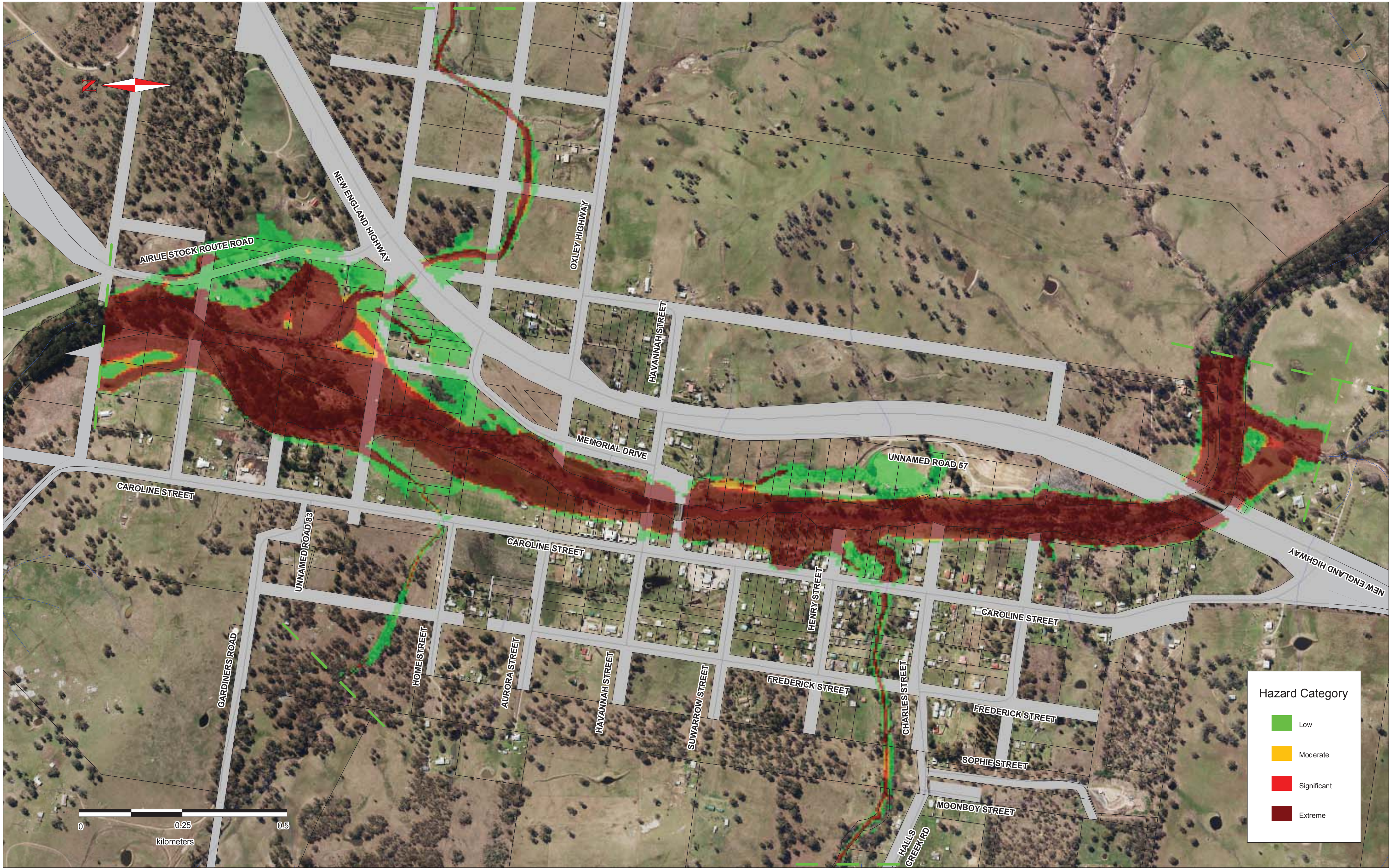
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D2A
5 year ARI Flow Hazard



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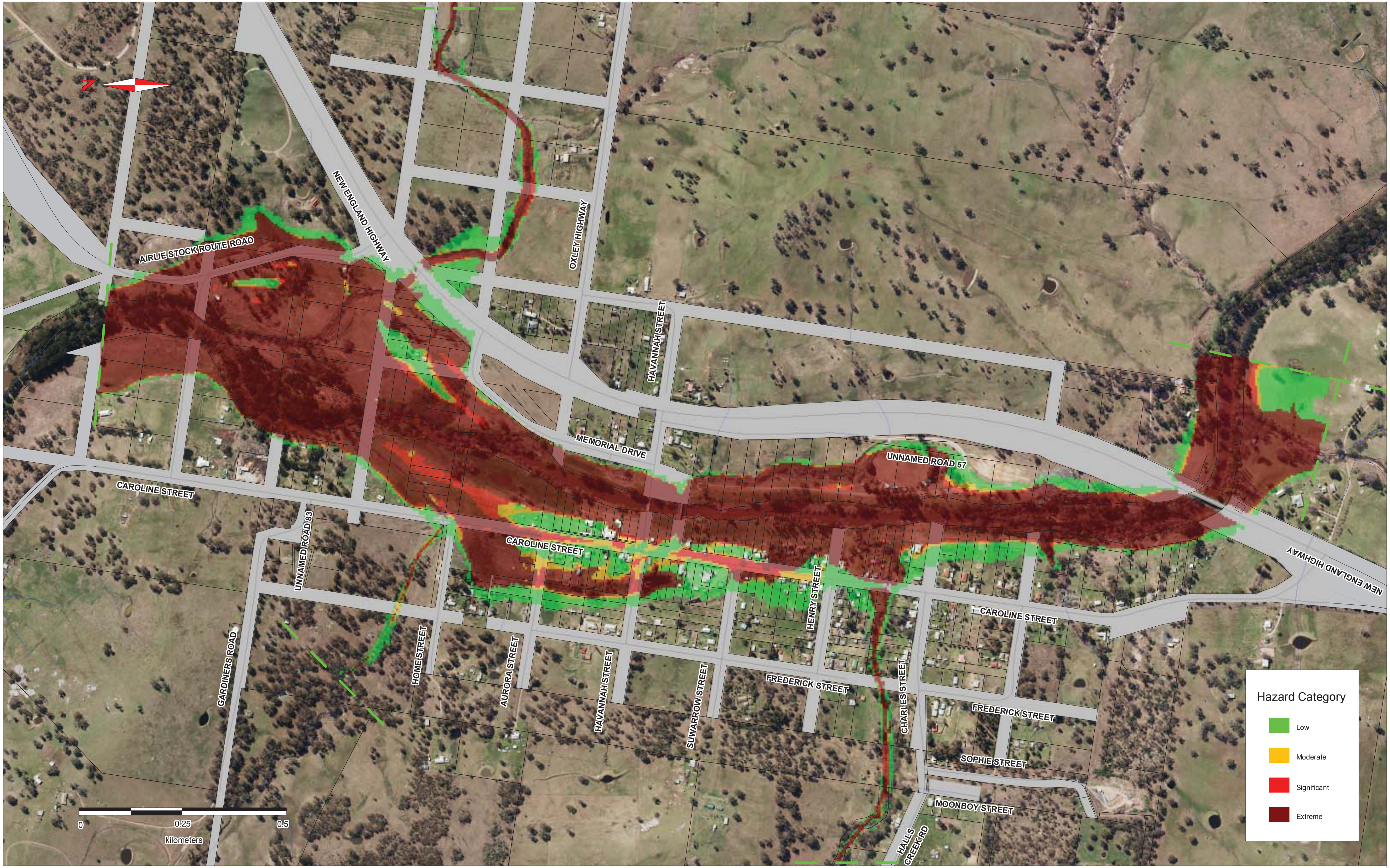
EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D2B
10% AEP Flow Hazard



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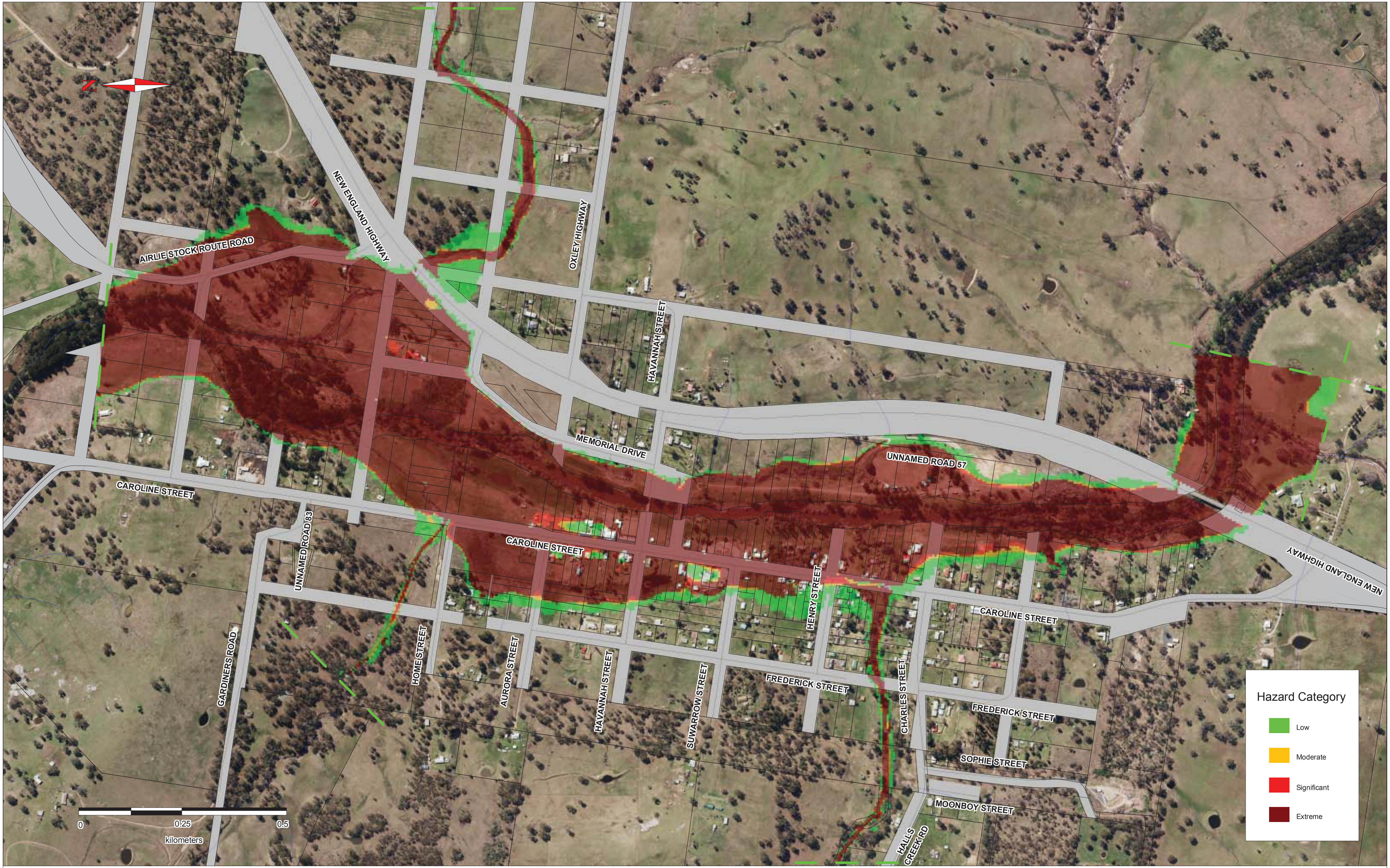
BENDEMEER FLOOD STUDY

Figure D2C
2% AEP Flow Hazard



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EXTENT OF MODELLING

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D2D
1% AEP Flow Hazard

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EXTENT OF MODELLING

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Figure D2E
0.5% AEP Flow Hazard

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EXTENT OF MODELLING

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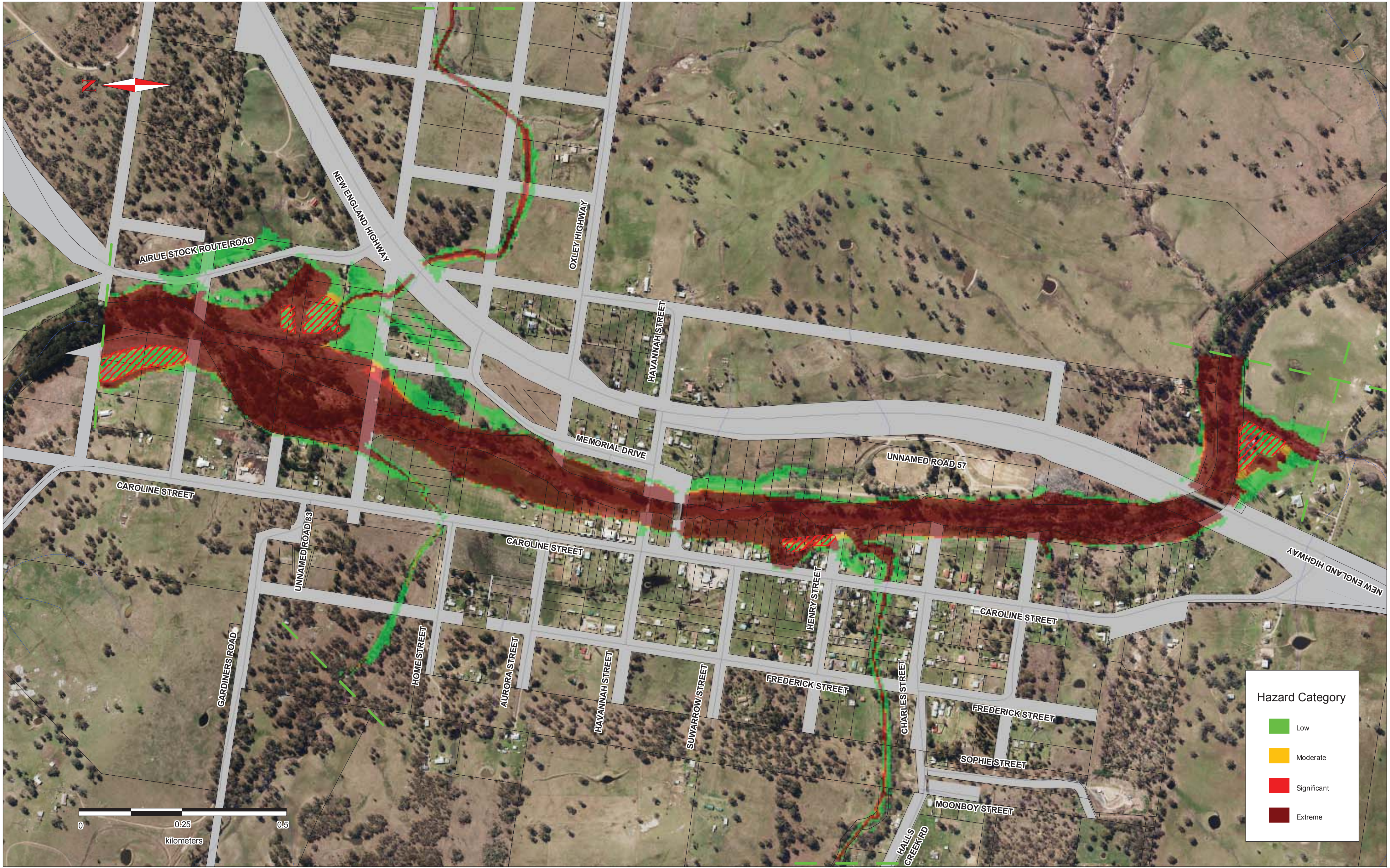
BENDEMEER FLOOD STUDY

Figure D2F
Probable Maximum Flood (PMF) Flow Hazard



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EXTENT OF MODELLING

Flow Hazard Category Upgraded to Significant Preliminary True Hazard Category

SMEC

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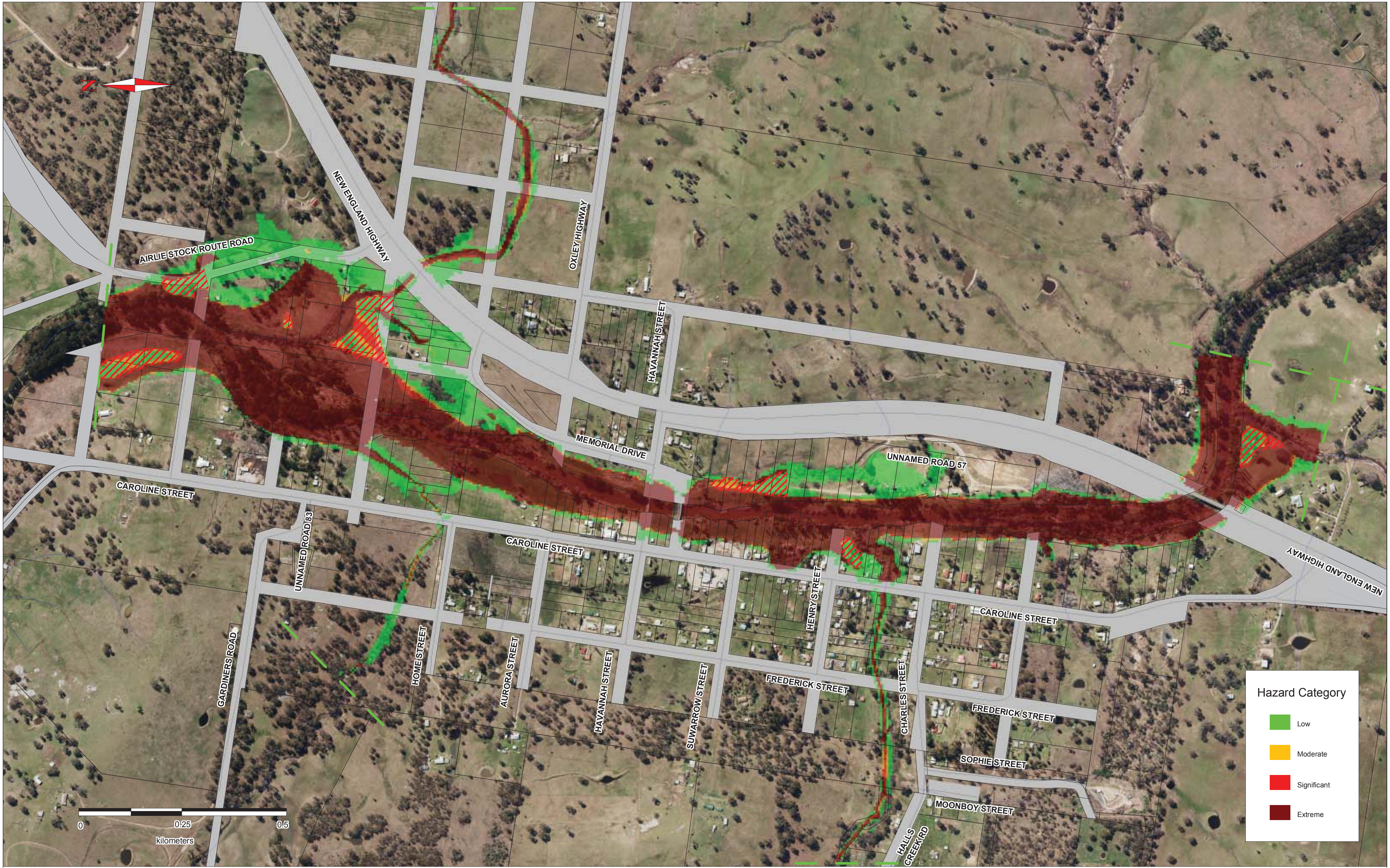
BENDEMEER FLOOD STUDY

Figure D3A
5 year ARI Preliminary True Hazard Categories



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EXTENT OF MODELLING

Flow Hazard Category Upgraded to Significant Preliminary True Hazard Category

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TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D3B
10% AEP Preliminary True Hazard Categories

DISCLAIMER

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EXTENT OF MODELLING

Flow Hazard Category Upgraded to Significant Preliminary True Hazard Category

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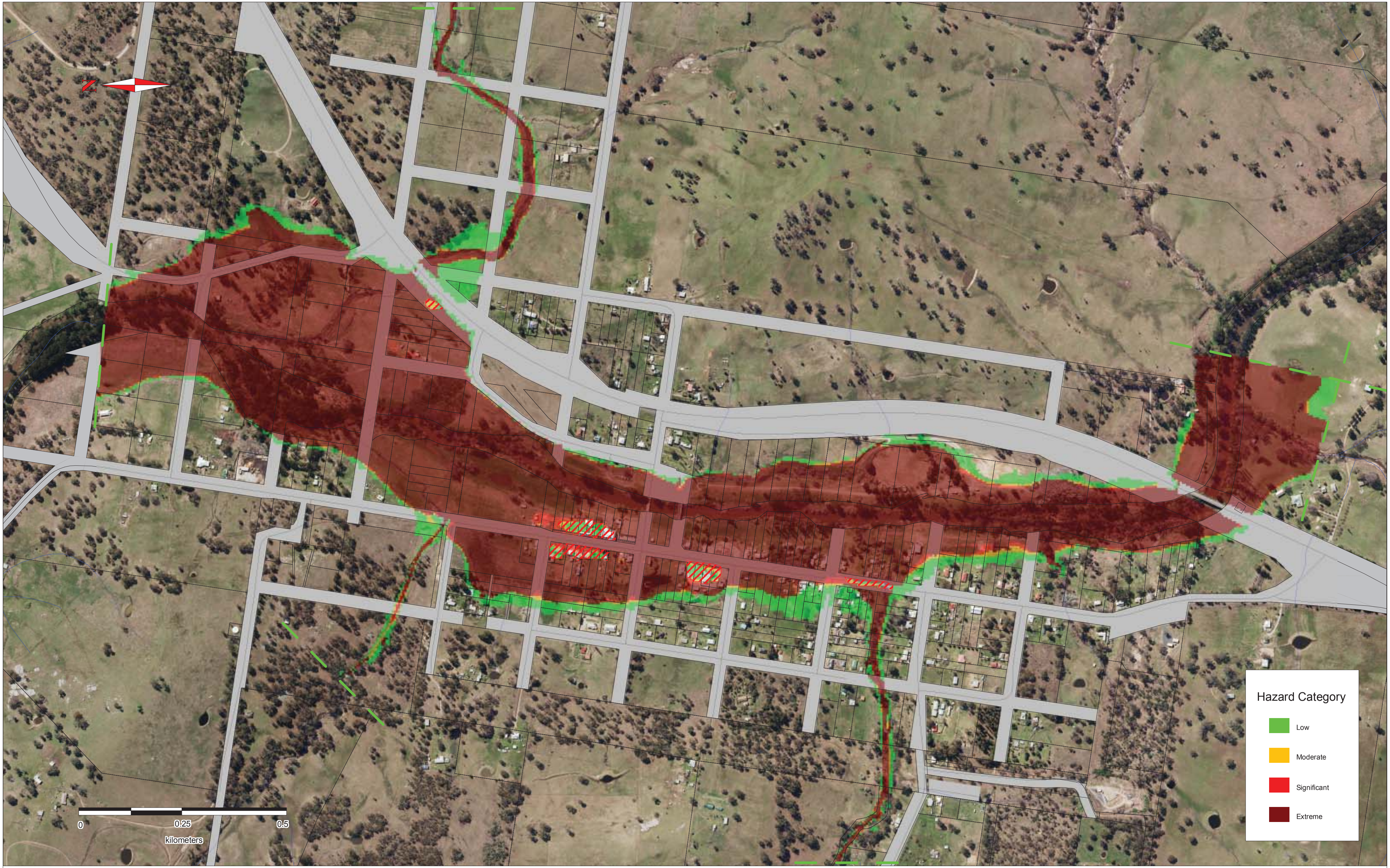
BENDEMEER FLOOD STUDY

Figure D3C
2% AEP Preliminary True Hazard Categories



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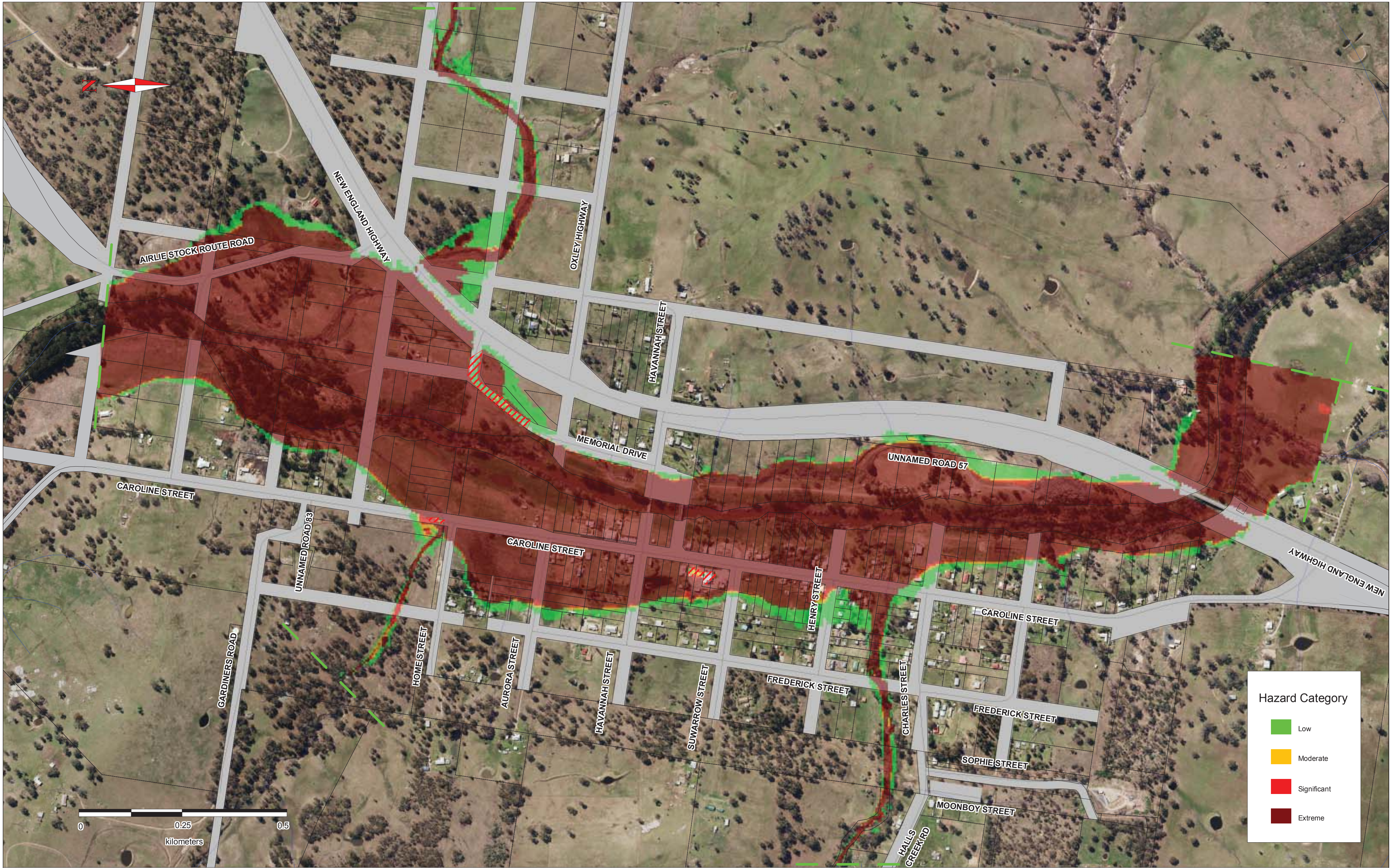
EXTENT OF MODELLING

Flow Hazard Category Upgraded to Significant Preliminary True Hazard Category

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D3D
1% AEP Preliminary True Hazard Categories



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EXTENT OF MODELLING

Flow Hazard Category Upgraded to Significant Preliminary True Hazard Category

SMEC

TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D3E
0.5% AEP Preliminary True Hazard Categories

DISCLAIMER

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EXTENT OF MODELLING

Flow Hazard Category Upgraded to Significant Preliminary True Hazard Category

SMEC

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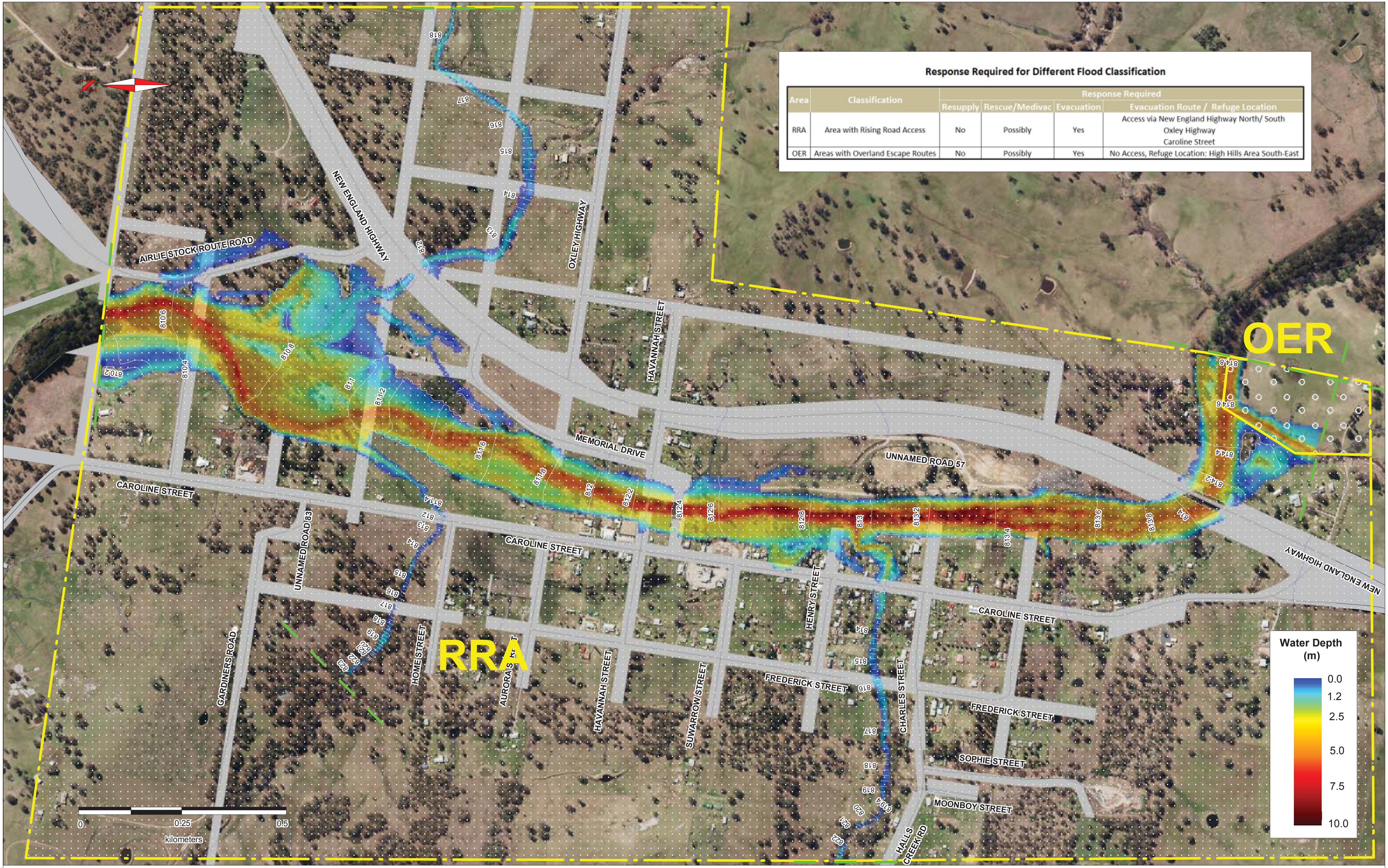
BENDEMEER FLOOD STUDY

Figure D3F
PMF Preliminary True Hazard Categories



Response Required for Different Flood Classification

Area	Classification	Response Required			
		Resupply	Rescue/Medivac	Evacuation	Evacuation Route / Refuge Location
RRA	Area with Rising Road Access	No	Possibly	Yes	Access via New England Highway North/ South Oxley Highway Caroline Street
OER	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: High Hills Area South-East

EXTENT OF MODELLING

DISCLAIMER

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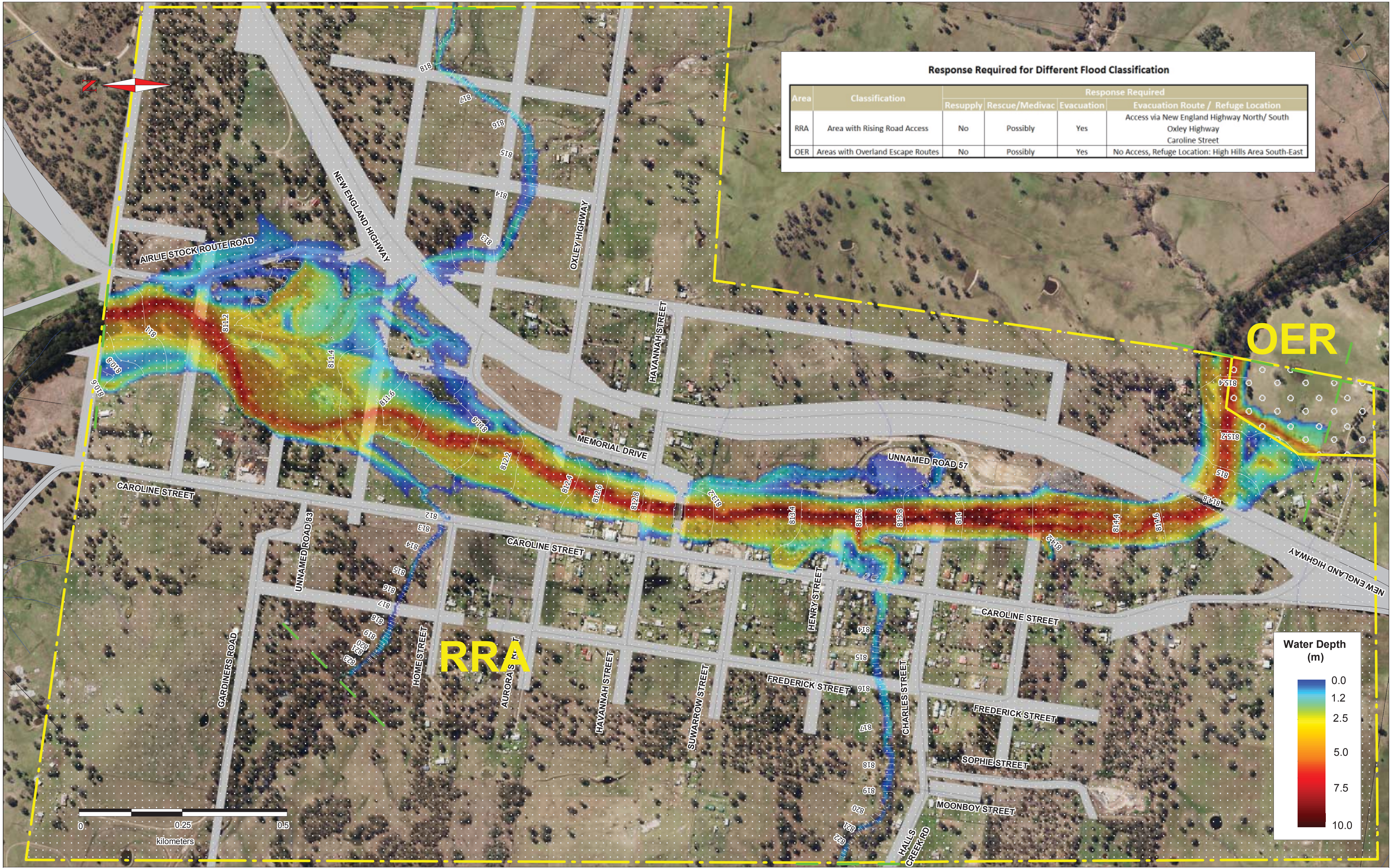
BENDEMEER FLOOD STUDY

Figure D4A
5 year ARI Flood Emergency Response Classification



Response Required for Different Flood Classification

Area	Classification	Response Required			
		Resupply	Rescue/Medivac	Evacuation	Evacuation Route / Refuge Location
RRA	Area with Rising Road Access	No	Possibly	Yes	Access via New England Highway North/ South Oxley Highway Caroline Street
OER	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: High Hills Area South-East

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EXTENT OF MODELLING

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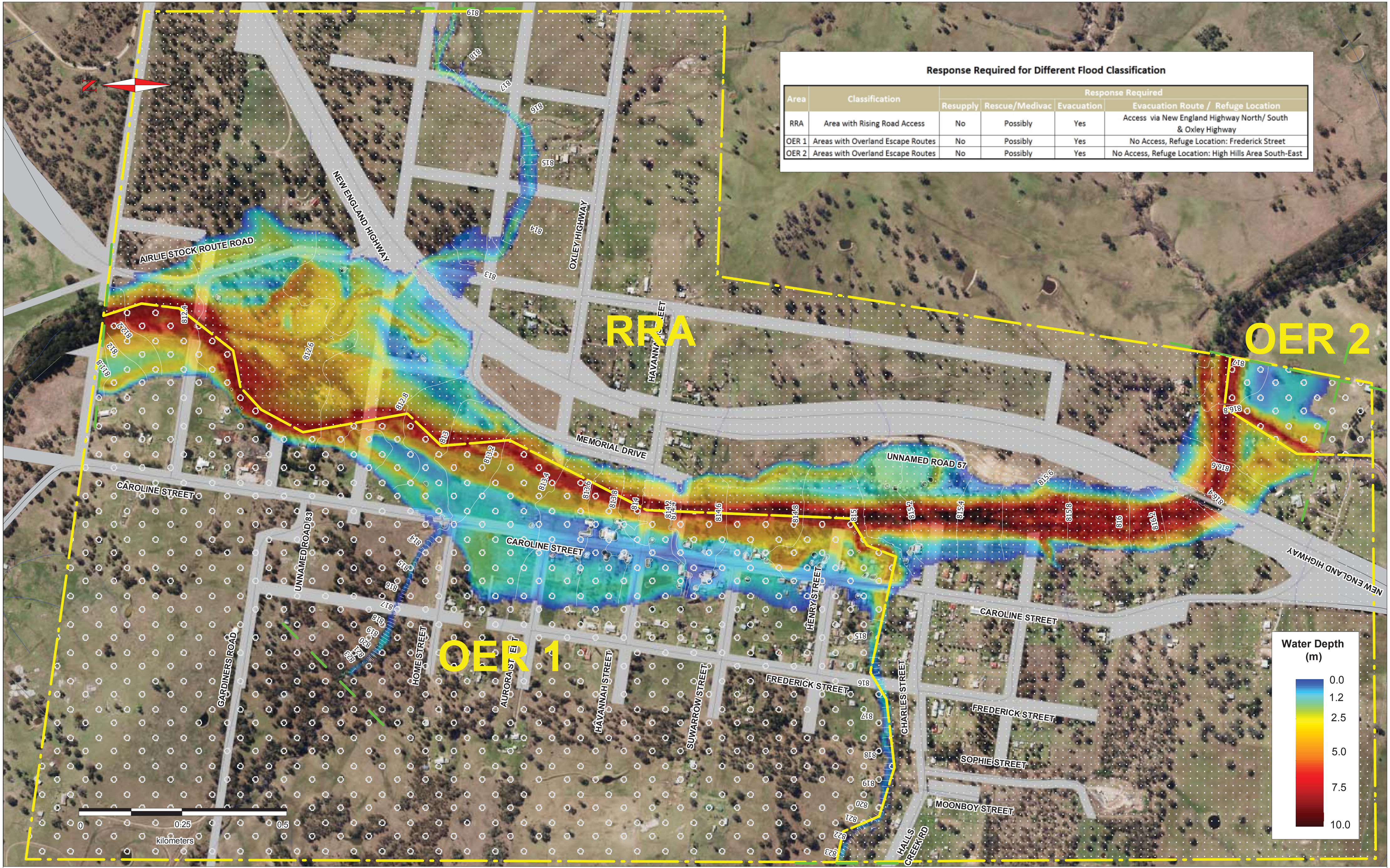
TAMWORTH REGIONAL COUNCIL
BENDEMEER FLOOD STUDY

Figure D4B
10% AEP Flood Emergency Response Classification



Response Required for Different Flood Classification

Area	Classification	Response Required			
		Resupply	Rescue/Medivac	Evacuation	Evacuation Route / Refuge Location
RRA	Area with Rising Road Access	No	Possibly	Yes	Access via New England Highway North/ South & Oxley Highway
OER 1	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: Frederick Street
OER 2	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: High Hills Area South-East

DISCLAIMER

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EXTENT OF MODELLING

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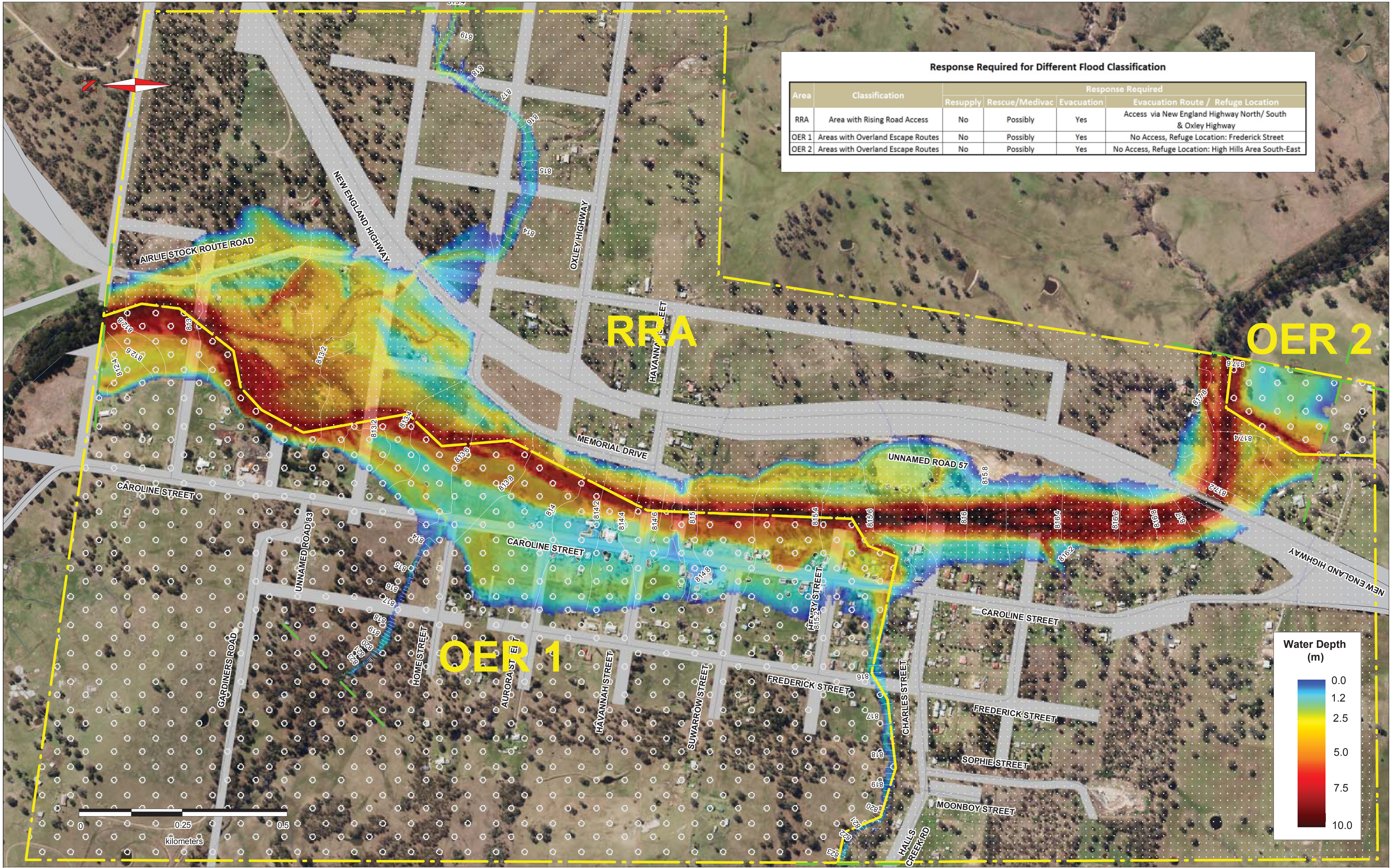
BENDEMEER FLOOD STUDY

Figure D4C
2% AEP Flood Emergency Response Classification



Response Required for Different Flood Classification

Area	Classification	Response Required			
		Resupply	Rescue/Medivac	Evacuation	Evacuation Route / Refuge Location
RRA	Area with Rising Road Access	No	Possibly	Yes	Access via New England Highway North/ South & Oxley Highway
OER 1	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: Frederick Street
OER 2	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: High Hills Area South-East

DISCLAIMER

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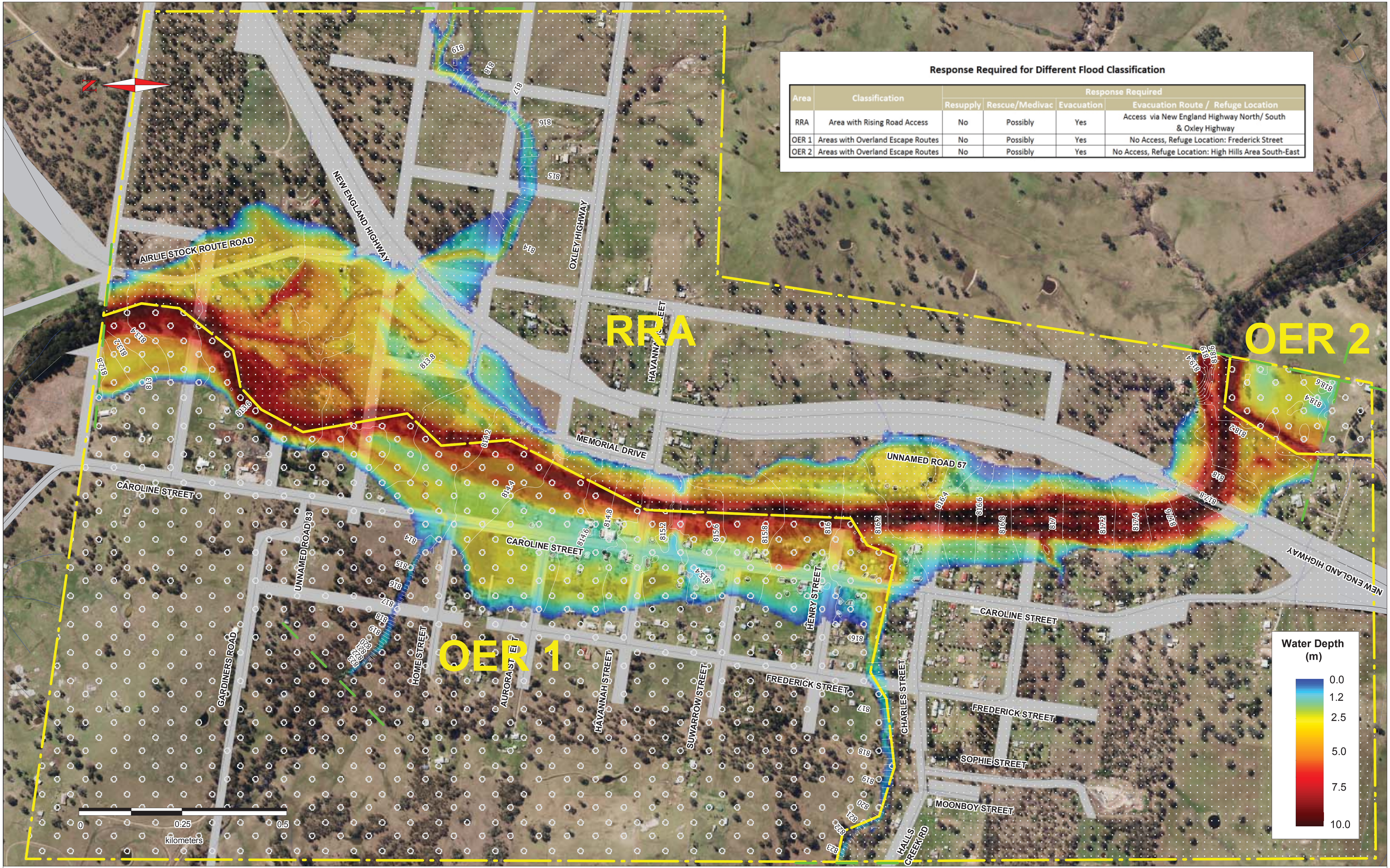
BENDEMEER FLOOD STUDY

Figure D4D
1% AEP Flood Emergency Response Classification



Response Required for Different Flood Classification

Area	Classification	Response Required			
		Resupply	Rescue/Medivac	Evacuation	Evacuation Route / Refuge Location
RRA	Area with Rising Road Access	No	Possibly	Yes	Access via New England Highway North/ South & Oxley Highway
OER 1	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: Frederick Street
OER 2	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: High Hills Area South-East

EXTENT OF MODELLING

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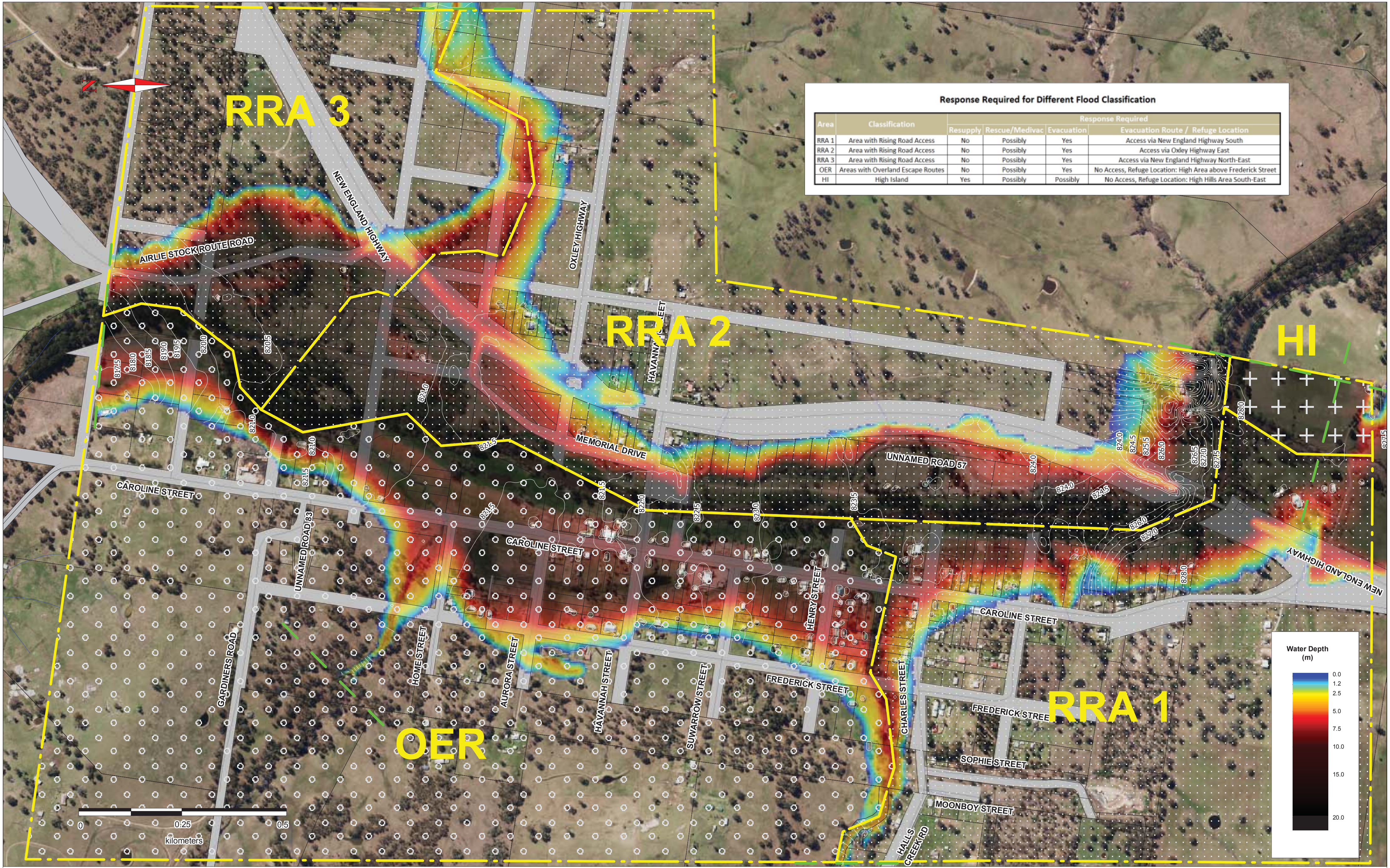
SMEC

TAMWORTH REGIONAL COUNCIL

BENDEMEER FLOOD STUDY

Figure D4E

0.5% AEP Flood Emergency Response Classification



Response Required for Different Flood Classification

Area	Classification	Response Required			
		Resupply	Rescue/Medivac	Evacuation	Evacuation Route / Refuge Location
RRA 1	Area with Rising Road Access	No	Possibly	Yes	Access via New England Highway South
RRA 2	Area with Rising Road Access	No	Possibly	Yes	Access via Oxley Highway East
RRA 3	Area with Rising Road Access	No	Possibly	Yes	Access via New England Highway North-East
OER	Areas with Overland Escape Routes	No	Possibly	Yes	No Access, Refuge Location: High Area above Frederick Street
HI	High Island	Yes	Possibly	Possibly	No Access, Refuge Location: High Hills Area South-East

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EXTENT OF MODELLING

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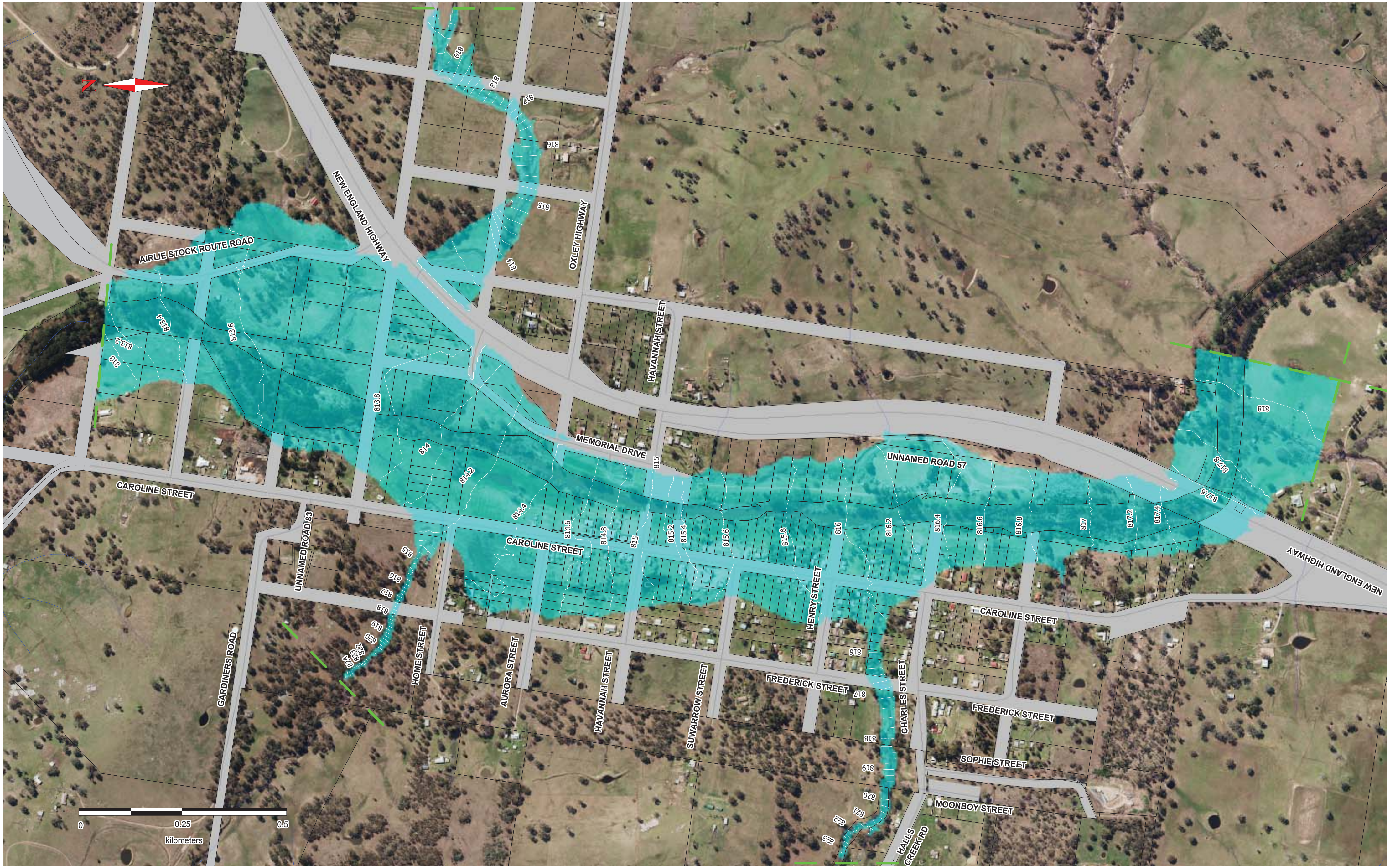
BENDEMEER FLOOD STUDY

Figure D4F

PMF Flood Emergency Response Classification



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EXTENT OF MODELLING

Flood Planning Area based on 1% AEP Water Levels + 0.5m

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BENDEMEER FLOOD STUDY

Figure D5
Flood Planning Levels (1% AEP + 0.5m)

APPENDIX E – FLOOD DAMAGE BASE MODELLING DATA CURVES

SITE SPECIFIC INFORMATION FOR RESIDENTIAL DAMAGE CURVE DEVELOPMENT

Version 3.00 October 2007 | Queries to duncan.mcluckie@dnr.nsw.gov.au

PROJECT	DETAILS	DATE	JOB No.
Bendemeer Flood Study	by SMEC	14-Feb-12	30011083

BUILDINGS

Regional Cost Variation Factor	1.07	*From Rawlinsons*				
Post late 2001 adjustments	1.53	*Changes in AWE see AWE Stats Worksheet*				
Post Flood Inflation Factor	1.00	*1.0*	*to*	*1.5*		
Multiply overall structural costs by this factor		*Judgement to be used. Some suggestions below*				
	Regional City			*Regional Town*		
	Houses Affected		*Factor*	*Houses Affected*		*Factor*
Small scale impact	*<*	*50*	*1.00*	*<*	*10*	*1.00*
Medium scale impacts in Regional City		*100*	*1.20*		*30*	*1.30*
Large scale impacts in Regional City	*>*	*150*	*1.40*	*>*	*50*	*1.50*
Typical Duration of Immersion	1	hours				
Building Damage Repair Limitation Factor	1.00	*due to no insurance*	*short duration*			*long duration*
		Suggested range	*0.85*	*to*		*1.00*
Typical House Size	240	m^2	*240 m^2 is Base*			
Building Size Adjustment	1.0					
Total Building Adjustment Factor	**1.64**					

CONTENTS

Average Contents Relevant to Site	$ 60,000	*Base for 240 m^2 house*	*$ 60,000*		
Post late 2001 adjustments	1.53	*From above*			
Contents Damage Repair Limitation Factor	0.90	*due to no insurance*	*short duration*		*long duration*
Sub-Total Adjustment Facto	1.38	*Suggested range*	*0.75*	*to*	*0.90*
Level of Flood Awareness	low	*low or high only. Low default unless otherwise justifiable.*			
Effective Warning Time	0	hour			
Interpolated DRF adjustment (Awareness/Time)	1.00	IDRF = Interpolated Damage Reduction Factor			
Typical Table/Bench Height (TTBH)	0.90	*0.9m is typical height. If typical is 2 storey house use 2.6m.*			
Total Contents Adjustment Factor AFD <= TTBH	**1.38**	AFD = Above Floor Depth			
Total Contents Adjustment Factor AFD > TTBH	**1.38**				

Most recent advice from Victorian Rapid Assessment Method

Low level of awareness is expected norm (long term average) any deviation needs to be justified.

Basic contents damages are based upon a DRF of	*0.9*				
Effective Warning time (hours)	***0***	***3***	***6***	***12***	***24***
RAM Average IDRF Inexperienced (Low awareness)	*0.90*	*0.80*	*0.80*	*0.80*	*0.70*
DRF (ARF/0.9)	*1.00*	*0.89*	*0.89*	*0.89*	*0.78*
RAM AIDF Experienced (High awareness)	*0.80*	*0.80*	*0.60*	*0.40*	*0.40*
DRF (ARF/0.9)	*0.89*	*0.89*	*0.67*	*0.44*	*0.44*
Site Specific DRF (DRF/0.9) for Awareness level for iteration	*1.00*	*0.89*	*0.89*	*0.89*	*0.78*
Effective Warning time (hours)	*0*	*3*	*0*		
Site Specific iterations	*1.00*	*0.89*	*1.00*		

ADDITIONAL FACTORS

Post late 2001 adjustments	1.53	*From above*
External Damage	$ 6,700	*$6,700 recommended without justification*
Clean Up Costs	$ 4,000	*$4,000 recommended without justification*
Likely Time in Alternate Accommodation	3	weeks
Additional accommodation costs /Loss of Rent	$ 220	*$220 per week recommended without justification*

TWO STOREY HOUSE BUILDING & CONTENTS FACTORS

Up to Second Floor Level, less than	2.6	m	70%	Single Storey Slab on Ground
From Second Storey up, greater than	2.6	m	110%	Single Storey Slab on Ground

Base Curves

AFD = Above Floor Depth

Single Storey Slab/Low Set	13164	+	4871		x	AFD in metres
Structure with GST	AFD	greater than	0.0	m		
Validity Limits	AFD	less than or equal to			6	m
Single Storey High Set	16586	+	7454		x	AFD
Structure with GST	AFD	greater than	-1.50	m		
Validity Limits	AFD	less than or equal to			6	m
Contents	20000	+	20000		x	AFD
Contents with GST	AFD	greater than			0	
Validity Limits	AFD	less than or equal to			2	

Floodplain Specific Damage Curves - Scenario 1

		1S_HighSet	1S_LowSet	2S_House	Commercial	HighCostCommercial	HydrStructure
Steps in Curve	0.25						
Type		Single Storey High Set	Single Storey Slab/Low Set	2 Storey Houses	Commercial	HighCostCommercial	Bridge/ Culvert
Criteria		(depth)	(depth)	(depth)	(area)	(area)	($)
AFD from Modelling	AFD adjusted datum	Damage	Damage	Damage	Damage	Damage	Damage
-2.00	0.00	$0	$0	$0	$0	$0	0
-1.50	0.50	$15,377	$0	$0	$80	$128	0
-1.25	0.75	$33,226	$0	$0	$173	$277	0
-1.00	1.00	$37,802	$0	$0	$197	$315	0
-0.75	1.25	$42,378	$0	$0	$221	$353	0
-0.50	1.50	$46,954	$15,377	$15,377	$245	$391	0
-0.25	1.75	$51,530	$15,377	$15,377	$268	$429	0
0.00	2.00	$108,110	$47,702	$38,004	$563	$901	0
0.25	2.25	$123,013	$113,024	$83,730	$641	$1,025	0
0.50	2.50	$137,917	$126,342	$93,052	$718	$1,149	0
0.75	2.75	$152,820	$139,660	$102,375	$796	$1,274	0
1.00	3.00	$167,724	$152,978	$111,697	$874	$1,398	0
1.25	3.25	$182,627	$166,295	$121,020	$951	$1,522	0
1.50	3.50	$197,530	$179,613	$130,342	$1,029	$1,646	0
1.75	3.75	$212,434	$192,931	$139,665	$1,106	$1,770	0
2.00	4.00	$227,337	$206,249	$148,987	$1,184	$1,894	0
2.25	4.25	$231,913	$209,239	$151,080	$1,208	$1,933	0
2.50	4.50	$236,489	$212,229	$153,173	$1,232	$1,971	0
2.75	4.75	$241,065	$215,219	$235,204	$1,256	$2,009	0
3.00	5.00	$245,640	$218,210	$238,493	$1,279	$2,047	0
3.25	5.25	$250,216	$221,200	$241,782	$1,303	$2,085	0
3.50	5.50	$254,792	$224,190	$245,071	$1,327	$2,123	1
3.75	5.75	$259,368	$227,180	$248,361	$1,351	$2,161	1
4.00	6.00	$263,944	$230,171	$251,650	$1,375	$2,200	1
4.25	6.25	$268,520	$233,161	$254,939	$1,399	$2,238	1
4.50	6.50	$273,096	$236,151	$258,229	$1,422	$2,276	1
4.75	6.75	$277,671	$239,141	$261,518	$1,446	$2,314	1
5.00	7.00	$282,247	$242,132	$264,807	$1,470	$2,352	1
5.25	7.25	$286,823	$245,122	$268,096	$1,494	$2,390	1
5.50	7.50	$291,399	$248,112	$271,386	$1,518	$2,428	1
5.75	7.75	$295,975	$251,102	$274,675	$1,542	$2,466	1
6.00	8.00	$300,551	$254,093	$277,964	$1,565	$2,505	1
6.25	8.25	$305,127	$257,083	$281,253	$1,589	$2,543	1
6.50	8.50	$309,702	$260,073	$284,543	$1,613	$2,581	1
6.75	8.75	$314,278	$263,063	$287,832	$1,637	$2,619	1
7.00	9.00	$318,854	$266,054	$291,121	$1,661	$2,657	1
7.25	9.25	$323,430	$269,044	$294,410	$1,685	$2,695	1
7.50	9.50	$328,006	$272,034	$297,700	$1,708	$2,733	1
7.75	9.75	$332,582	$275,024	$300,989	$1,732	$2,772	1
8.00	10.00	$337,158	$278,014	$304,278	$1,756	$2,810	1
8.25	10.25	$341,733	$281,005	$307,568	$1,780	$2,848	1
8.50	10.50	$346,309	$283,995	$310,857	$1,804	$2,886	1
8.75	10.75	$350,885	$286,985	$314,146	$1,828	$2,924	1
9.00	11.00	$355,461	$289,975	$317,435	$1,851	$2,962	1
9.25	11.25	$360,037	$292,966	$320,725	$1,875	$3,000	1
9.50	11.50	$364,613	$295,956	$324,014	$1,899	$3,038	1
9.75	11.75	$369,189	$298,946	$327,303	$1,923	$3,077	1
10.00	12.00	$373,764	$301,936	$330,592	$1,947	$3,115	1
10.25	12.25	$378,340	$304,927	$333,882	$1,971	$3,153	1
10.50	12.50	$382,916	$307,917	$337,171	$1,994	$3,191	1
10.75	12.75	$387,492	$310,907	$340,460	$2,018	$3,229	1

	240	area_m2
Contribution	Factor	
25%	**1.25**	Additonal allowance roads/services (such as water, STP, gas, elec
25%	**1.25**	Additional damage allowance Commercial (percentage) without jus
100%	**2.00**	Additional damage allowance HighCostCommercial (percentage) w
20%	**1.20**	Indirect Damage Factor excl additonal

Floodplain Specific Damage Curves- Scenario 2

Steps in Curve 0.25

		1S_HighSet	1S_LowSet	2S_House	Commercial	HighCostCommercial	HydrStructure
Type		Single Storey High Set	Single Storey Slab/Low Set	2 Storey Houses	Commercial	HighCostCommercial	Bridge/ Culvert
Criteria		(depth)	(depth)	(depth)	(area)	(area)	($)
AFD from Modelling	AFD adjusted datum	Damage	Damage	Damage	Damage	Damage	Damage
-2.00	0.00	$0	$0	$0	$0	$0	0
-1.50	0.50	$18,452	$0	$0	$96	$154	0
-1.25	0.75	$39,871	$0	$0	$208	$332	0
-1.00	1.00	$45,362	$0	$0	$236	$378	0
-0.75	1.25	$50,853	$0	$0	$265	$424	0
-0.50	1.50	$56,344	$18,452	$18,452	$293	$470	0
-0.25	1.75	$61,835	$18,452	$18,452	$322	$515	0
0.00	2.00	$129,732	$57,242	$45,605	$676	$1,081	0
0.25	2.25	$147,616	$135,629	$100,476	$769	$1,230	0
0.50	2.50	$165,500	$151,611	$111,663	$862	$1,379	0
0.75	2.75	$183,384	$167,592	$122,850	$955	$1,528	0
1.00	3.00	$201,268	$183,573	$134,037	$1,048	$1,677	0
1.25	3.25	$219,152	$199,554	$145,224	$1,141	$1,826	0
1.50	3.50	$237,036	$215,536	$156,411	$1,235	$1,975	0
1.75	3.75	$254,920	$231,517	$167,597	$1,328	$2,124	0
2.00	4.00	$272,804	$247,498	$178,784	$1,421	$2,273	0
2.25	4.25	$278,295	$251,087	$181,296	$1,449	$2,319	0
2.50	4.50	$283,786	$254,675	$183,808	$1,478	$2,365	0
2.75	4.75	$289,277	$258,263	$282,244	$1,507	$2,411	0
3.00	5.00	$294,769	$261,851	$286,191	$1,535	$2,456	0
3.25	5.25	$300,260	$265,440	$290,139	$1,564	$2,502	0
3.50	5.50	$305,751	$269,028	$294,086	$1,592	$2,548	0
3.75	5.75	$311,242	$272,616	$298,033	$1,621	$2,594	0
4.00	6.00	$316,733	$276,205	$301,980	$1,650	$2,639	0
4.25	6.25	$322,224	$279,793	$305,927	$1,678	$2,685	0
4.50	6.50	$327,715	$283,381	$309,874	$1,707	$2,731	0
4.75	6.75	$333,206	$286,970	$313,821	$1,735	$2,777	0
5.00	7.00	$338,697	$290,558	$317,768	$1,764	$2,822	0
5.25	7.25	$344,188	$294,146	$321,716	$1,793	$2,868	0
5.50	7.50	$349,679	$297,734	$325,663	$1,821	$2,914	0
5.75	7.75	$355,170	$301,323	$329,610	$1,850	$2,960	0
6.00	8.00	$360,661	$304,911	$333,557	$1,878	$3,006	0
6.25	8.25	$366,152	$308,499	$337,504	$1,907	$3,051	0
6.50	8.50	$371,643	$312,088	$341,451	$1,936	$3,097	0
6.75	8.75	$377,134	$315,676	$345,398	$1,964	$3,143	0
7.00	9.00	$382,625	$319,264	$349,345	$1,993	$3,189	0
7.25	9.25	$388,116	$322,852	$353,293	$2,021	$3,234	0
7.50	9.50	$393,607	$326,441	$357,240	$2,050	$3,280	0
7.75	9.75	$399,098	$330,029	$361,187	$2,079	$3,326	0
8.00	10.00	$404,589	$333,617	$365,134	$2,107	$3,372	0
8.25	10.25	$410,080	$337,206	$369,081	$2,136	$3,417	0
8.50	10.50	$415,571	$340,794	$373,028	$2,164	$3,463	0
8.75	10.75	$421,062	$344,382	$376,975	$2,193	$3,509	0
9.00	11.00	$426,553	$347,971	$380,922	$2,222	$3,555	0
9.25	11.25	$432,044	$351,559	$384,870	$2,250	$3,600	0
9.50	11.50	$437,535	$355,147	$388,817	$2,279	$3,646	0
9.75	11.75	$443,026	$358,735	$392,764	$2,307	$3,692	0
10.00	12.00	$448,517	$362,324	$396,711	$2,336	$3,738	0
10.25	12.25	$454,008	$365,912	$400,658	$2,365	$3,783	0
10.50	12.50	$459,499	$369,500	$404,605	$2,393	$3,829	0
10.75	12.75	$464,990	$373,089	$408,552	$2,422	$3,875	0

240 area_m2

Contribution	Factor	
50%	**1.50**	Additonal allowance bridges/roads/services (such as
25%	**1.25**	Additional damage allowance Commercial (percenta
100%	**2.00**	Additional damage allowance HighCostCommercial (
20%	**1.20**	Indirect Damage Factor excl additonal

SUMMARY OF FINISSHED FLOOR LEVEL SURVEY AND ADJUSTMENT OF DATA REQUIRED FOR FLOOD DAMAGE CALCULATIONS IN WATERRID

Survey Point Number	Survey Set	Easting (m)	Northing (m)	Point Elevation (mAHD)	DEM Ground (mAHD)	Surveyed or Estimated Floor Level	Property Address	Floor to Ground Height Survey Observation	Structure Material / Survey Observation	Surveyor Comment	Established Damage Category for Modelling	Estimated Floor Area (m2)	FFL Datum Adjustment for Under Floor Damage (mAHD)	Modelling Depth Treshold - PMF Depth (m)
126	100yr	323615.77	6581580.61	816.364	815.095	SFL	60 CAROLINE	RAISED	CC-BOARD		1S_HighSet	0	814.36	0
128	100yr	323659.66	6581599.01	814.754	814.627	SFL	62 CAROLINE	LOW	CC-BOARD		1S_LowSet	0	812.75	9.58
142	100yr	323623.24	6581677.53	813.543	813.242	SFL	64-68 CAROLINE	MEDIUM	BK - WBOARD		1S_HighSet	0	811.54	0
144	100yr	323624.34	6581700.9	813.741	813.302	SFL	70 CAROLINE	LOW	WBOARD		1S_LowSet	0	811.74	0
146	100yr	323641.13	6581754.17	814.253	813.846	SFL	72 CAROLINE	LOW	BK WBOARD		1S_LowSet	0	812.25	10.4
150	100yr	323595	6581762.05	815.639	815.245	SFL	103 CAROLINE	LOW	CR BRICK	OLD POST OFFICE	Commercial	333	813.64	0
152	100yr	323582.73	6581715.72	815.151	814.711	SFL	101 CAROLINE	MEDIUM	WBOARD	2 STOREY	2S_House	0	813.15	9.41
154	100yr	323593.09	6581730.09	815.465	814.592	SFL	101A CAROLINE	RAISED	TELSTRA	EXCHANGE	HighCostCommercial	143	813.47	9.68
156	100yr	323570.63	6581705.78	815.002	814.346	SFL	99 CAROLINE	MEDIUM	WBOARD & PRESSED METAL		1S_LowSet	0	813	9.93
184	100yr	323652.68	6581825.77	814.979	813.894	SFL	76-78 CAROLINE	RAISED	CC-SHEET	BK FNDN	1S_HighSet	0	812.98	0
186	100yr	323643.33	6581798.2	814.321	814.072	SFL	74 CAROLINE	LOW	CLAD		1S_LowSet	0	812.32	10.02
188	100yr	323599.52	6581804.41	815.458	814.935	SFL	105 CAROLINE	LOW	CLAD		1S_LowSet	0	813.46	0
190	100yr	323605.3	6581829.58	815.033	814.396	SFL	107 CAROLINE	LOW	WBOAD & CC SHEET		1S_LowSet	0	813.03	0
192	100yr	323610.66	6581843.3	814.54	814.259	SFL	109-111 CAROLINE	LOW	BRICK	2 STOREY SHOP	2S_House	0	812.54	0
194	100yr	323618.74	6581897.77	814.088	813.812	SFL	113-115 CAROLINE	LOW	BRICK		1S_LowSet	0	812.09	0
196	100yr	323673.44	6581941.28	814.179	813.519	SFL	88 CAROLINE	MEDIUM	CC-BOARD		1S_HighSet	0	812.18	0
198	100yr	323670.77	6581957.01	814.849	813.576	SFL	90 CAROLINE	RAISED	CC-BOARD		1S_HighSet	0	812.85	10.06
200	100yr	323664.85	6581977.81	813.92	813.638	SFL	92 CAROLINE	LOW	WBOARD		1S_LowSet	0	811.92	0
202	100yr	323630.33	6582074.91	814.704	814.352	SFL	127 CAROLINE	LOW	BRICK	CONVERTED GARAGE	Commercial	704	812.7	0
204	100yr	323680.95	6582087.03	814.052	813.811	SFL	100 CAROLINE	LOW	BRICK MIXED	SHOP RESIDENCE	Commercial	190	812.05	0
206	100yr	323692.61	6582125.71	813.833	813.598	SFL	104 CAROLINE	LOW	WBOARD		1S_LowSet	0	811.83	9.72
208	100yr	323647.58	6582139.78	813.907	813.367	SFL	133 CAROLINE	LOW	WBOARD		1S_LowSet	0	811.91	0
210	100yr	323706.81	6582214.27	813.166	813.044	SFL	106-110 CAROLINE	LOW	CLAD PLASTIC		1S_LowSet	0	811.17	0
212	100yr	323668.55	6582265.46	813.769	813.218	SFL	141 CAROLINE	LOW	BRICK		1S_LowSet	0	811.77	0
214	100yr	323683.59	6582322.7	813.654	813.304	SFL	145 CAROLINE	LOW	CLAD		1S_LowSet	0	811.65	9.62
216	100yr	323714.72	6582316.27	813.654	813.235	SFL	PUB 112 CAROLINE	LOW	BK		Commercial	2447	811.65	0
218	100yr	323680.32	6582367.58	813.624	813.149	SFL	147-149 CAROLINE	MEDIUM	CLAD		1S_HighSet	0	811.62	0
220	100yr	323678.56	6582390.13	813.645	812.993	SFL	151 CAROLINE	MEDIUM	CC-BOARD		1S_HighSet	0	811.65	0
222	100yr	323681	6582404.92	813.98	812.875	SFL	153 CAROLINE	RAISED	BRICK		1S_HighSet	0	811.98	0
224	100yr	323687.81	6582436.95	813.285	813.027	SFL	155 CAROLINE	LOW	BRICK		1S_LowSet	0	811.29	0
226	100yr	323707.9	6582486.95	813.009	812.533	SFL	POLICE CAROLINE	MEDIUM	BRICK	POLICE	Commercial	287	811.01	10.39
228	100yr	323744.67	6582361.48	814.147	813.258	SFL	112-130 CAROLINE	MEDIUM	BRICK	PUB RES	Commercial	578	812.15	0
265	100yr	323946.09	6583061.5	812.407	811.344	SFL	156-158 CAROLINE	RAISED	CC-BOARD		1S_HighSet	0	810.41	0
287	100yr	324365.49	6582952.52	811.588	811.086	SFL	11 AIRLIE	MEDIUM	WBOARD		1S_HighSet	0	809.59	0
289	100yr	324152.13	6582784.52	813.026	812.074	SFL	11SELINA	RAISED	METAL		1S_HighSet	0	811.03	10.42
291	100yr	323961.51	6582388.63	816.479	815.61	SFL	MEMORIAL	RAISED to LOW	CC-SHEET		1S_HighSet	0	814.48	0
293	100yr	323951.57	6582350.22	816.78	816.429	SFL	10-12 MEMORIAL	LOW	WBOARD & CC-SHEET		1S_LowSet	0	814.78	0
295	100yr	323942.7	6582287.14	818.342	817.332	SFL	6-8 MEMORIAL	MEDIUM to LOW	WBOARD & CC-BOARD		1S_HighSet	0	816.34	0
297	100yr	323935.02	6582241.86	819.5	818.446	SFL	14 HAVANNAH	MEDIUM to LOW	CC-BOARD		1S_HighSet	0	817.5	4.36
104	PMF	323644.07	6580918.35	822.239	821.288	SFL	18 CAROLINE	LOW	CC-BOARD	2STOREY	2S_House	0	820.24	6.94
106	PMF	323582.33	6580947.6	829.97	829.476	SFL	20 CAROLINE	RAISED	TIMBER	2 STOREY	2S_House	0	827.97	0
108	PMF	323669.2	6581187.57	818.951	818.604	SFL	40 CAROLINE	RAISED	TIMBER	2STOREY	2S_House	0	816.95	6.37
110	PMF	323568.05	6581288.39	824.746	824.439	SFL	42 CAROLINE	LOW	TIMBER & CC-SHEET		1S_LowSet	0	822.75	0
112	PMF	323596.87	6581383.45	821.921	821.102	SFL	46 CAROLINE	LOW	BRICK		1S_LowSet	0	819.92	0
114	PMF	323585.61	6581443.65	821.376	821.11	SFL	50 CAROLINE	LOW	BRICK		1S_LowSet	0	819.38	0
116	PMF	323556.44	6581492.72	821.633	820.904	SFL	91-93 CAROLINE	MEDIUM	WBOARD		1S_HighSet	0	819.63	3.54
118	PMF	323613.21	6581470.56	819.652	818.764	SFL	54-56 CAROLINE	RAISED	BRICK		1S_HighSet	0	817.65	0
120	PMF	323560.14	6581532.39	819.533	818.971	SFL	95 CAROLINE	RAISED	WBOARD		1S_HighSet	0	817.53	0
122	PMF	323625.7	6581508.95	817.77	817.003	SFL	54-58 CAROLINE	RAISED	BRICK		1S_HighSet	0	815.77	0
124	PMF	323562.6	6581576.16	818.166	817.14	SFL	6 CHARLES	RAISED	CC-BOARD		1S_HighSet	0	816.17	7.18
130	PMF	323532.66	6581581.25	819.307	818.825	SFL	8 CHARLES	MEDIUM	CC-BOARD		1S_HighSet	0	817.31	0
132	PMF	323502.38	6581588.36	820.698	820.151	SFL	10 CHARLES	LOW	BRICK		1S_LowSet	0	818.7	4.11
134	PMF	323464.71	6581582.86	821.682	821.512	SFL	12 CHARLES		CC-BOARD		1S_LowSet	0	819.68	2.76
136	PMF	323444.43	6581599.71	822.351	821.226	SFL	16 CHARLES	RAISED	CC-BOARD		1S_HighSet	0	820.35	0
138	PMF	323418.62	6581553.05	826.086	825.197	SFL	13 CHARLES	RAISED	IMMITATION BRICK		1S_HighSet	0	824.09	0
140	PMF	323476.8	6581533.01	825.455	824.353	SFL	9 CHARLES	RAISED	CC-SHEET		1S_HighSet	0	823.46	0
158	PMF	323559.62	6581765.76	816.219	815.622	SFL	5 HENRY	LOW	CC-BOARD		1S_LowSet	0	814.22	8.51
160	PMF	323537.46	6581767.58	816.335	815.769	SFL	7 HENRY	LOW	WBOARD	CWA HALL	Commercial	124	814.34	0
162	PMF	323510.77	6581768.65	816.217	816.007	SFL	9 HENRY	LOW	CC-BOARD		1S_LowSet	0	814.22	0
164	PMF	323491.5	6581775.02	816.892	816.265	SFL	11 HENRY	MEDIUM	BRICK		1S_HighSet	0	814.89	7.9
166	PMF	323464.61	6581773.17	817.14	816.827	SFL	13 HENRY	LOW	BRICK		1S_LowSet	0	815.14	0
168	PMF	323436.98	6581783.71	819.089	818.407	SFL	15 HENRY	MEDIUM	CLAD & BK		1S_HighSet	0	817.09	0
170	PMF	323406.85	6581787.01	820.846	820.018	SFL	48 FREDERICK	RAISED	CC-BOARD		1S_HighSet	0	818.85	0
172	PMF	323404.12	6581726.15	818.644	818.187	SFL	46 FREDERICK	RAISED	CC-BOARD		1S_HighSet	0	816.64	5.97
174	PMF	323331.55	6581703.4	820.09	819.815	SFL	34-47 FREDERICK	LOW	CORR IRON	SHED HOUSE	1S_LowSet	0	818.09	0
176	PMF	323358.66	6581751.58	822.653	821.791	SFL	49 FREDERICK	RAISED	WBOARD		1S_HighSet	0	820.65	2.37
178	PMF	323434.49	6581831.77	820.822	820.432	SFL	16 HENRY	LOW	BRICK		1S_LowSet	0	818.82	3.77
180	PMF	323456.36	6581831	819.497	818.643	SFL	12 HENRY	L OW to RAISED	CC-BOARD ON BK		1S_HighSet	0	817.5	0
182	PMF	323479.52	6581833.45	817.6	817.308	SFL	10HENRY	LOW	BRICK		1S_LowSet	0	815.6	0
230	PMF	323499.25	6582357.08	817.153	816.853	SFL	76 FREDERICK	LOW	BRICK		1S_LowSet	0	815.15	0
232	PMF	323500.3	6582325.18	818.14	817.763	SFL	24-28 HAVANNAH	LOW	BRICK		1S_LowSet	0	816.14	0
234	PMF	323483.68	6582220.47	823.579	823.233	SFL	72FREDERICK	LOW	CC-SHEET		1S_LowSet	0	821.58	0
236	PMF	323466.47	6582139.18	823.877	823.368	SFL	66FREDERICK	MEDIUM	CC-SHEET		1S_HighSet	0	821.88	0
238	PMF	323442.58	6581914.4	822.612	821.537	SFL	52-54 FREDERICK	MEDIUM	CC-BOARD		1S_HighSet	0	820.61	2.74
240	PMF	323440.91	6581946.49	823.856	823.185	SFL	56-58 FREDERICK	MEDIUM	BRICK		1S_HighSet	0	821.86	0
242	PMF	323463.09	6582066.3	823.912	823.753	SFL	64 FREDERICK	MEDIUM	WBOARD		1S_HighSet	0	821.91	0
244	PMF	323493.2	6582075.12	821.656	821.268	SFL	14 SUWARROW	LOW	CC-SHEET		1S_LowSet	0	819.66	2.4
246	PMF	323506.24	6581998.84	820.976	819.871	SFL	9-11 SUWARROW	RAISED	CC-BOARD		1S_HighSet	0	818.98	3.89
248	PMF	323555.34	6581997.77	818.055	817.038	SFL	5-7 SUWARROW	RAISED	CC-BOARD		1S_HighSet	0	816.06	0
250	PMF	323504.69	6582194.69	820.372	820.798	SFL	29-33HAVANNAH	L OW to RAISED	CONC BLK		1S_HighSet	0	818.37	0
252	PMF	323546.65	6582647.01	818.201	816.567	SFL	92 FREDERICK	LOW	CC-SHEET	HT 0.3	1S_LowSet	0	816.2	0
254	PMF	323555.64	6582695.96	822.078	821.374	SFL	94 FREDERICK	MEDIUM	CC-BOARD		1S_HighSet	0	820.08	1.44
259	PMF	323594.16	6581362.64	822.066	821.731	SFL	44 CAROLINE	LOW	BRICK		1S_LowSet	0	820.07	0
261	PMF	323813.31	6582873.02	816.974	816.618	SFL	134-148 CAROLINE	L OW to RAISED	WBOARD		1S_HighSet	0	814.97	5.94
263	PMF	323843.48	6583018.04	823.886	823.422	SFL	150-154 CAROLINE	MEDIUM to RAISED	CC-SHEET		1S_HighSet	0	821.89	0
275	PMF	324018.26	6583539.72	816.546	816.172	SFL	7-17 MERINO	LOW	MUD BRICK		1S_LowSet	0	814.55	2.53
277	PMF	324031.3	6583241.86	817.212	816.453	SFL	8-12 MERINO	RAISED to LOW	CLAD		1S_HighSet	0	815.21	0
279	PMF	324232.23	6582489.92	819.763	819.594	SFL	AURORA	L OW to RAISED	WBOARD		1S_HighSet	0	817.76	2.93
281	PMF	324648.18	6582394.57	822.722	822.46	SFL	OXLEY Hwy	L OW to RAISED	WBOARD		1S_HighSet	0	820.72	0
283	PMF	324077.61	6582300.3	825.847	819.043	SFL	4957 NEHwy	RAISED	WBOARD ON BK		1S_HighSet	0	823.85	3.55
285	PMF	324075.94	6580943.97	824.348	823.83	SFL	3834 NEHwy	LOW	CONC BLK		1S_LowSet	0	822.35	0
299	PMF	323974.48	6582220.33	823.826	822.899	SFL	12 HAVANNAH	MEDIUM to LOW	CLAD ON BK		1S_HighSet	0	821.83	0
301	PMF	323941.4	6582155.8	823.931	822.552	SFL	19 HAVANNAH	RAISED	CC-BOARD	RESIDENCE CARAVAN PARK	Commercial	661	821.93	0
304	PMF	323789.07	6580655.64	822.1	821.846	EFL	NEHwy	LOW	WBOARD		1S_LowSet	0	820.1	0
305	PMF	323825.39	6580596.2	820.25	819.949	EFL	NEHwy	LOW	WBOARD		1S_LowSet	0	818.25	8.05
0		0	0	819.66	0						HydrStructure	90000000	817.66	18.59
0		0	0	815.98	0						HydrStructure	1350000	813.98	11.63
0		0	0	810.25	0						HydrStructure	1575000	808.25	16.78
0		0	0	814.2	0						HydrStructure	4500000	812.2	16.84
0		0	0	814.56	0						HydrStructure	337500	812.56	9.73
0		0	0	813.48	0						HydrStructure	135000	811.48	12.56
0		0	0	813.48	0						HydrStructure	225000	811.48	10.58

APPENDIX F – SURVEY QA INFORMATION

aerometrex.
ABN 94 153 103 925
Digital Mapping Specialists
www.aerometrex.com.au

Adelaide Office: 413 Magill Road, St. Morris SA 5068
Contact: Todd Dunow – Senior Account Manager
T: (08) 8361 3111 Mobile: 0419 712 897
E: todd.dunow@aerometrex.com.au

Project Reference: A3203 Bendemeer 2011

8 February 2012

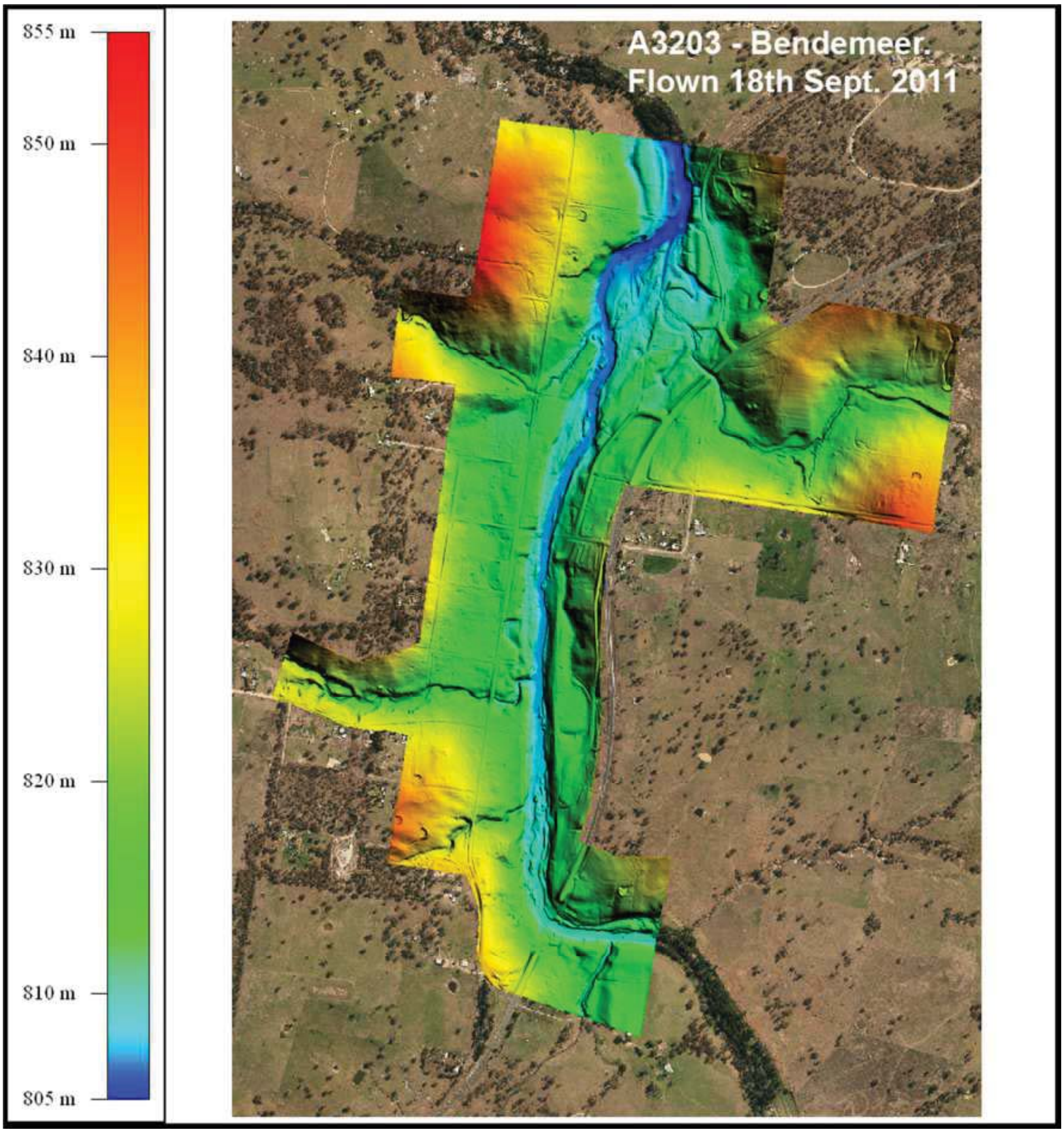
The General Manager
Tamworth Regional Council
P.O. Box 555
TAMWORTH NSW 2340

Dear Sir,

Please find below survey specifications and accuracy statements for the aerial survey Aerometrex conducted over the township of Bendemeer in September 2011.

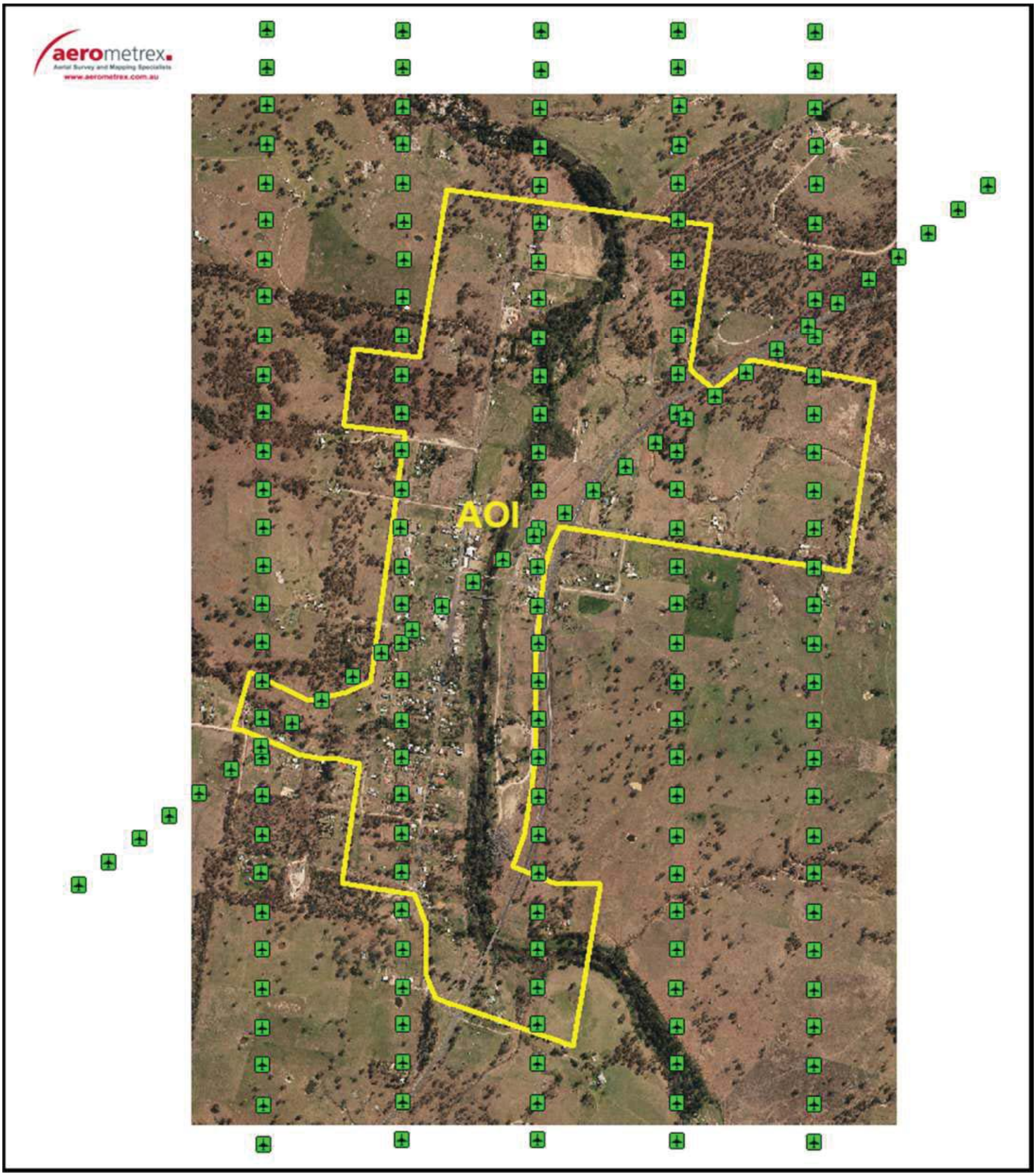
Survey Reference: A3203 Bendemeer / Baxter.

Overview:



Survey Details:

Flown – 18th September 2011
Plane – Shrike VH-UJN
Capture Height – Approx. 1900 Feet
Number of Runs – 5 (+ 1 Cross Strip)
Number of Frames - 181
Direction of Runs – North / South (Diagonal Cross strip)
Ground Sample Distance – 5cm
Forward frame overlap: 70%
Side frame overlap: 30%



Sensor Details:

The sensor used in this survey was fully calibrated in mid 2011.

Sensor – Vexcel Ultracam X, Large Format Mapping Camera - UCX-20316203
Focal Length: 100.500mm
Image Extent: (-33.91, -51.95)mm (33.91, 51.95)mm
Image Format: 9420 pixels (width) x 14430 pixels (height)
Pixel Size: 7.200 micron x 7.200 micron
PPA: X_ppa = -0.216 mm , Y_ppa = 0.000 mm
Please refer to included document “Calib-Report_20316203_V70_short.pdf”

Flight Report:

aerometrex
Aerial Survey and Mapping Specialists
www.aerometrex.com.au

AIR PHOTOGRAPHY REPORT

All Times in UTC (DTG)

System Times	172210 to 180226
GPS Session No	GDH_A11.260
Antenna Height	1.332m (uncorrected)
Possible Images	4244
Navigator	Nicholas Rusk
Aircraft Time	172245 to 180048

Camera - Vexcel Camera UCX	Calibrated FL - 100.5mm	Date	20110918A
Capture Time Interval 2-12 sec	GPS Base Station Gunnedah Airport - AMX 024	Pilot	Will Dyer
Max Aircraft Speed 125 -- 170kts	Data Download Time 172155 to 180241	Aircraft Registration	VH-UJN

JOB NO.	PROJECT	GSD	AMSL(ft)	RUN No.	DIRECTION	START SU	START Wpt	END SU	END Wpt	Comments	Sun Angle
A3203	Bendemeer	5cm	5240	+001	001	95014	001	95043	030	ok (camera setting: f8 -- 1/500)	39
			5240	-002	181	95044	030	95073	001	ok (camera setting: f8 -- 1/500)	40
			5240	+003	001	95074	001	95103	030	ok (camera setting: f8 -- 1/500)	41
			5240	-004	181	95104	030	95133	001	ok (camera setting: f8 -- 1/500)	42
			5240	+005	001	95134	001	95163	030	ok (camera setting: f8 -- 1/500)	43
			5240	-006	233	95164	031	95194	001	ok (camera setting: f8 -- 1/500)	44

Survey Accuracy:

The table below defines the accuracy Aerometrex is able to quote and obtain from this survey. The highest quality equipment combined with hundreds of surveys of experience allows Aerometrex to confidently quote these accuracies. Numerous cross checking techniques are employed, previous surveys over the Bendemeer township were used in one checking procedure.

Aerometrex has considerable resources and time over the past 10 years in research and development proving its ability to conform to specified accuracies.

Accuracy	5cm pixel resolution
Horizontal (Point) Horizontal (Ortho)	+/- 0.05m RMSE +/- 0.10m RMSE
Vertical (With BGC ground survey inputs)	+/- 0.04m (68% c.i., 1σ) +/- 0.08m (95% c.i., 2σ)

The above vertical accuracies were obtained by incorporating ground control supplied by Baxter Geo Consulting.

Supplied data details:

5cm GSD Orthophoto – Supplied in TIFF, ECW & JPEG2000 Format.
2m spacing gridded DTM with breaklines.
2m spacing gridded DTM with breaklines converted to breakpoints every 50cm
4 DTM Points around the base of all buildings.

Please do not hesitate to contact me if any more information is required.

Yours sincerely,

Todd Dunow
Senior Account Manager
Aerometrex Pty Ltd.

aerometrex
Aerial Survey and Mapping Specialists
www.aerometrex.com.au

Ph. (08) 8361 3111
Mobile: 0419 712 897

Calibration Report

Short version

Camera:	**UltraCam X, S/N UCX-SX-1-20316203**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Aug-12-2011**
Date of Report:	**Sep-02-2011**
Camera Revision:	**7.0**
Revision of Report:	**7.0**

Calibration Report

Geometric Calibration

Camera:	**UltraCam X, S/N UCX-SX-1-20316203**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Panchromatic Camera:	**ck = 100.500mm**
Multispectral Camera:	**ck = 100.500mm**
Date of Calibration:	**Aug-12-2011**
Date of Report:	**Sep-02-2011**
Camera Revision:	**7.0**
Revision of Report:	**7.0**

Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track	67.824mm	9420pixel
	cross track	103.896mm	14430pixel
Image Extent		(-33.91, -51.95)mm	(33.91, 51.95)mm
Pixel Size		7.200µm*7.200µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point	X_ppa	0.000 mm	± 0.002mm
(Level 2)	Y_ppa	0.216 mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Multispectral Camera

Medium Format Multispectral Output Image (Upscaled to panchromatic image format)

Image Format	long track	67.824mm	3140pixel
	cross track	103.896mm	4810pixel
Image Extent		(-33.91, -51.95)mm	(33.91, 51.95)mm
Pixel Size		21.600µm*21.600µm	
Focal Length	ck	100.500mm	
Principal Point	X_ppa	0.000 mm	± 0.002mm
(Level 2)	Y_ppa	0.216 mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

Individual Panchromatic Cone Data

Cone 0, Parametric Description, Not Effective in Output Image

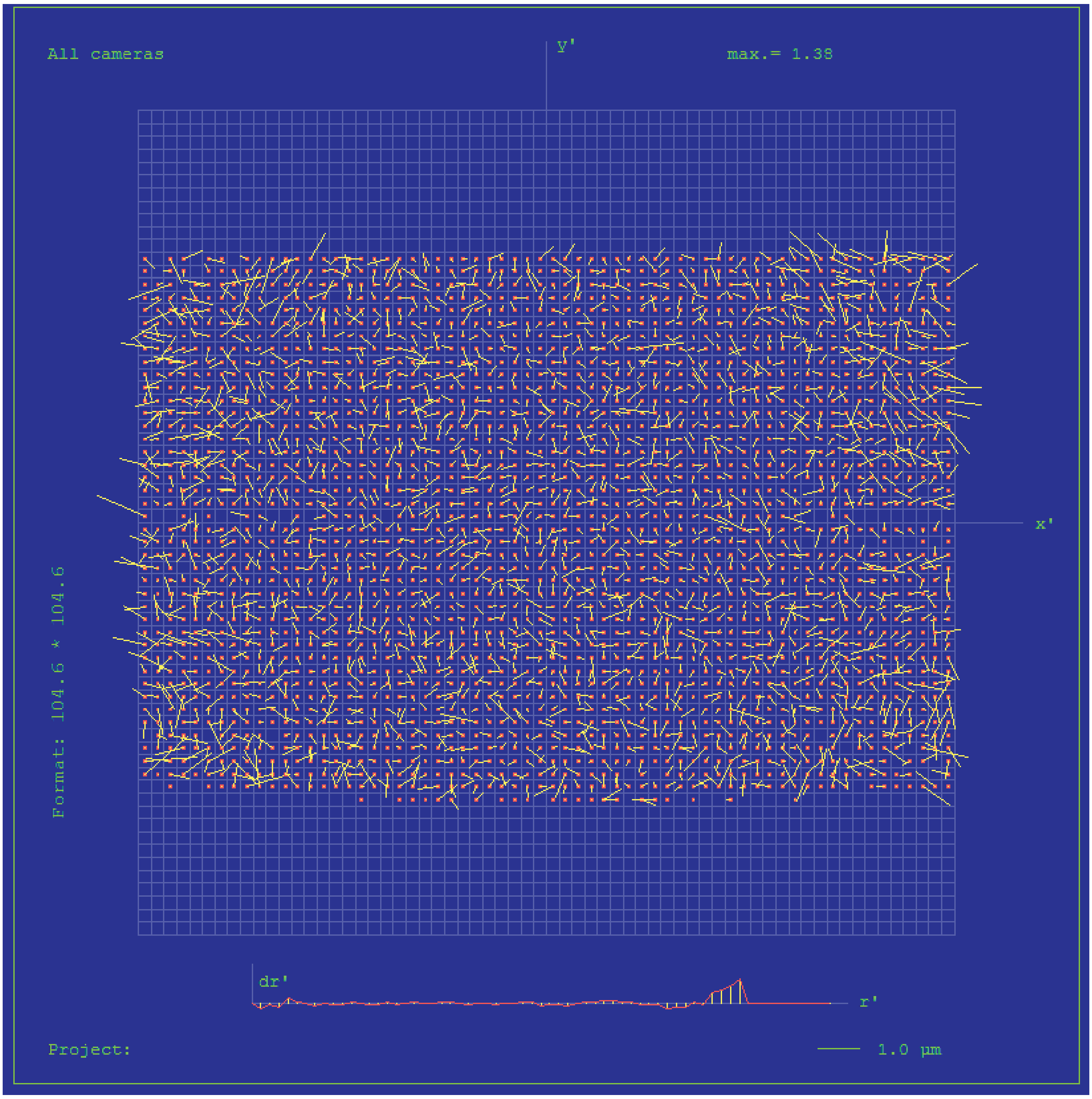
Cone # C0		
Lens	Linos Vexcel Apo-Sironar Digital 100mm Linos GmbH, Germany	
Shutter	Prontor Magnetic Prontor-Werk Alfred Gauthier GmbH	
Image Extent (nominally)	(-34.28, -52.22)mm	(34.28, 52.22)mm
Extent CCD 0	(-34.28, -52.22)mm	(-10.32, -16.28)mm
Extent CCD 1	(-34.28, 16.28)mm	(-10.32, 52.22)mm
Extent CCD 2	(10.32, -52.22)mm	(34.28, -16.28)mm
Extent CCD 3	(10.32, 16.28)mm	(34.28, 52.22)mm

Parameters	Shift X	ShiftY	Rotation	Scale
CCD0	6,1953950E-02 mm ± 0.0008 mm	-1,5081679E-01 mm ± 0.0013 mm	7,6835951E-02 gon ± 0.0001 gon	1,0047296 ± 0.00005
CCD1	1,0110854E-02 mm ± 0.0008 mm	-2,2754050E-01 mm ± 0.0013 mm	0,0000000 gon	1,0051176 ± 0.00005
CCD2	1,5357737E-02 mm ± 0.0008 mm	-1,7020517E-01 mm ± 0.0013 mm	3,2588178E-02 gon ± 0.0001 gon	1,0050753 ± 0.00005
CCD3	-1,2777774E-02 mm ± 0.0008 mm	-1,9020107E-01 mm ± 0.0013 mm	5,1578638E-02 gon ± 0.0001 gon	1,0054643 ± 0.00005

Radial Distortion

R [mm]	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0
dr [µm]	-3.2	-5.3	-6.6	-7.4	-7.7	-7.3	-6.0	-3.3	1.4	9.2	20.8	37.6	61.0

Full Pan Image, Residual Error Diagram



Residual Error (RMS): 0.73 µm

Explanations:

1) Calibration Method:

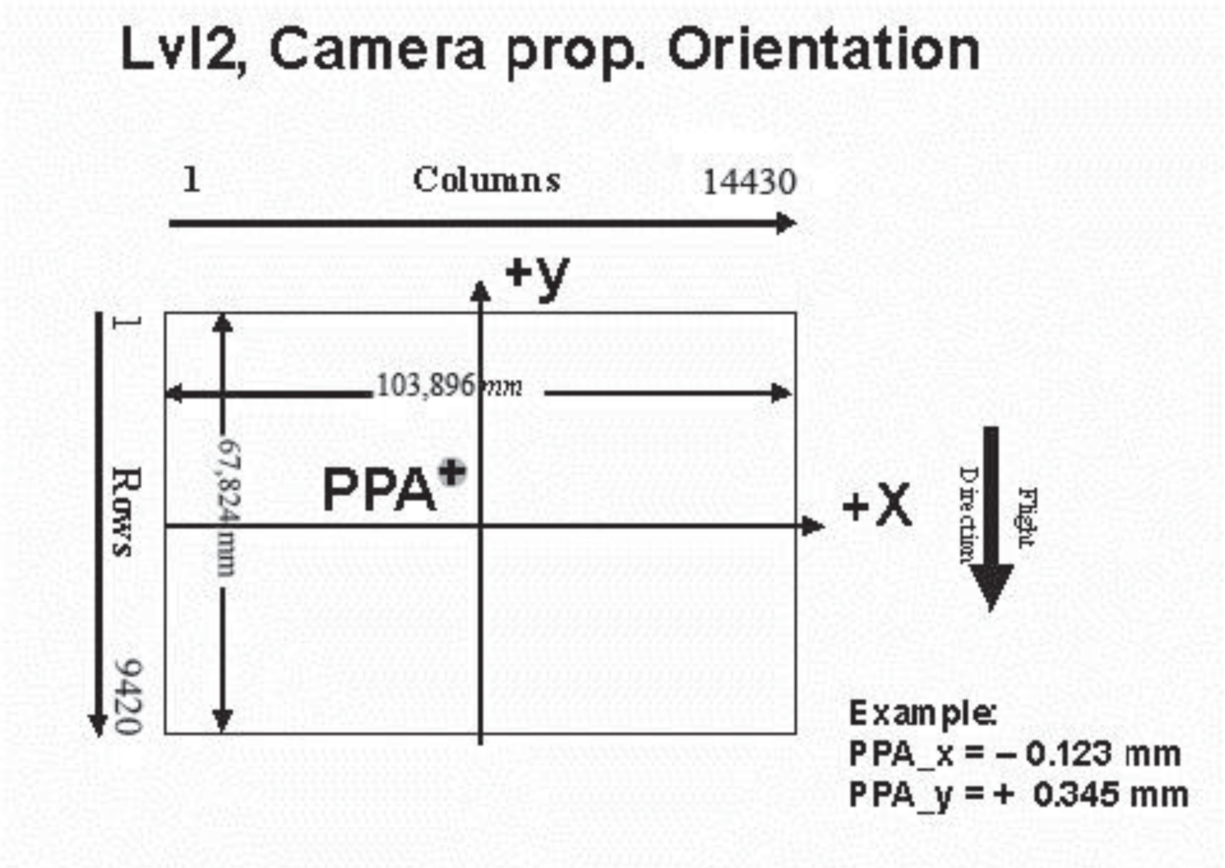
The geometric calibration is based on a set of 84 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera : 19134
Number of point measurements for the multispectral camera : 72582

Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

2) Level 2 Image Coordinate System:

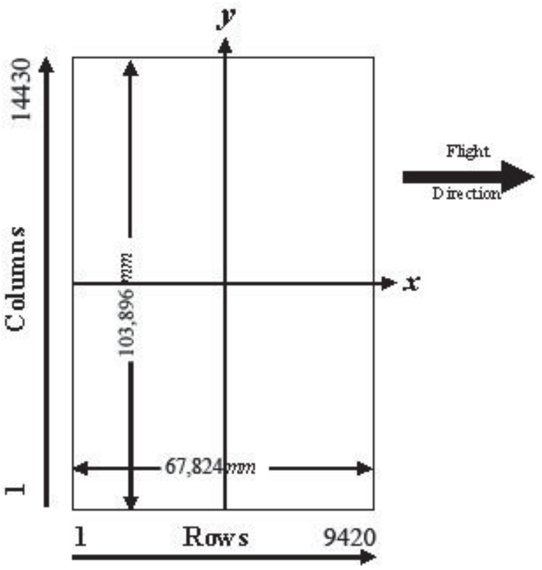
PAN 14430 pixel by 9420 pixel
MS 4810 pixel by 3140 pixel



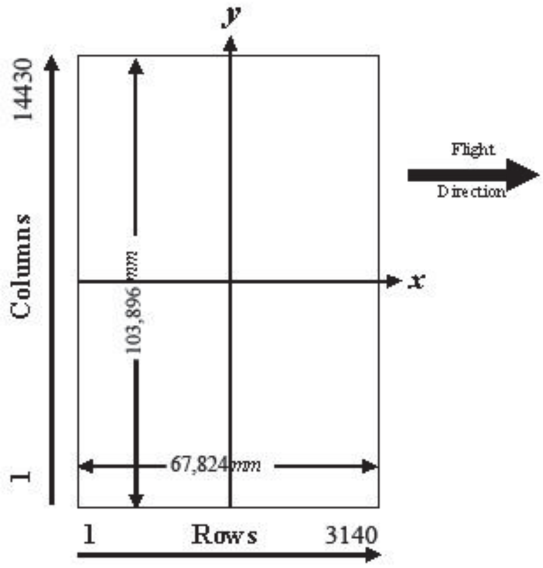
The image coordinate system of the Level 2 images is shown in the above figure. The level 2 image consists of 14430 columns and 9420 rows, which leads to a total image format of 103.896 x 67.824 mm. The coordinate of the principal point in the level 2 image is given on page 3 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).

3) Level 3 Image Coordinate System: (after rotation of 270° CW)

PAN 14430 pixel by 9420 pixel
MS 4810 pixel by 3140 pixel



Panchromatic Image Format



Multispectral Image Format

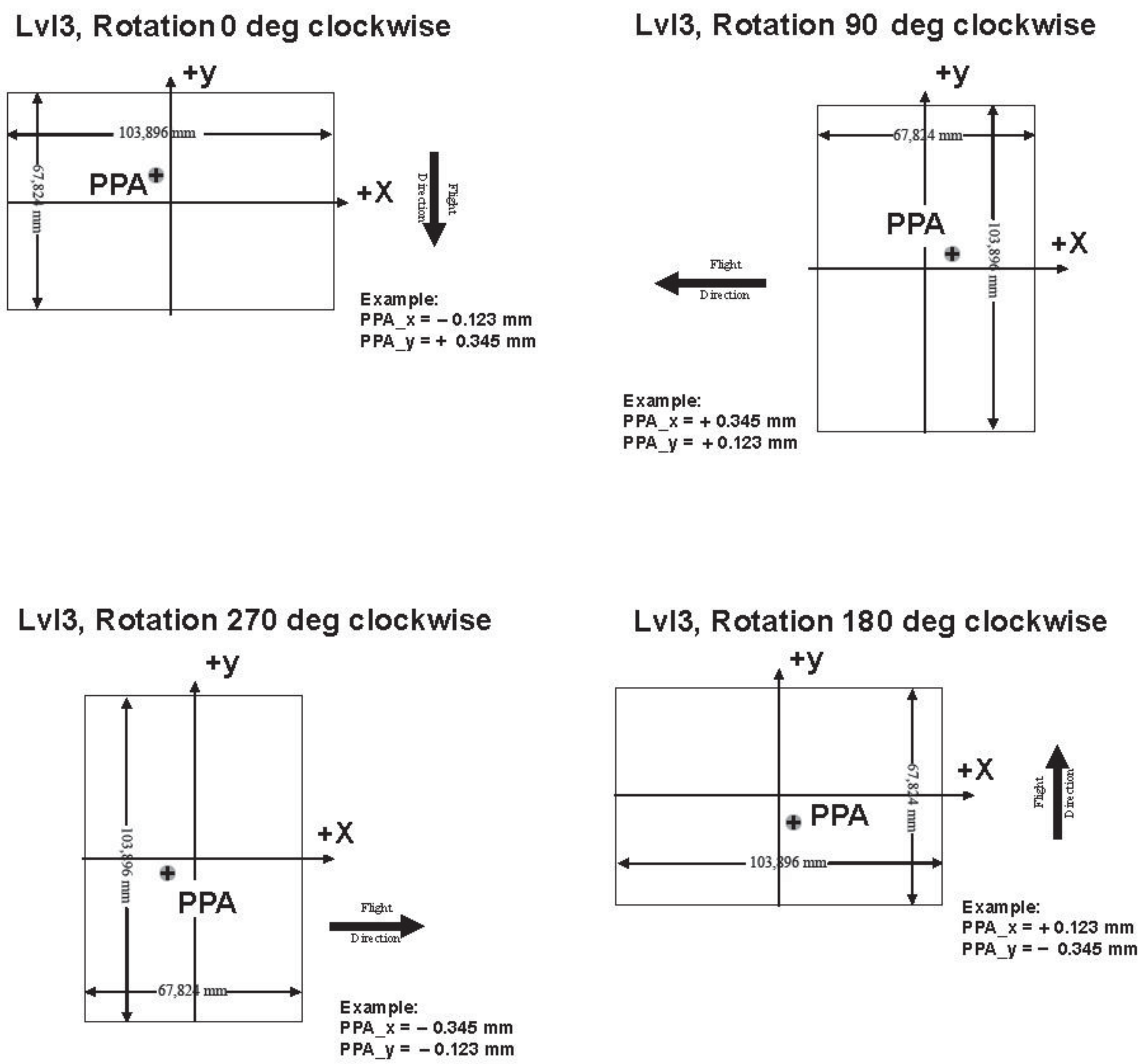
==

4) Position of Principal Point in Level 3 Image

The position of the principal point in the level 3 image depends on the “rotation” setting used in the OPC during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in the OPC. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 3 for high- and low resolution images.

Image Format	Clockwise Rotation (Degree)	PPA	
		X	Y
Level 2	-	0.000	0.216
Level 3	0	0.000	0.216
Level 3	90	0.216	0.000
Level 3	180	0.000	-0.216
Level 3	270	-0.216	0.000

The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

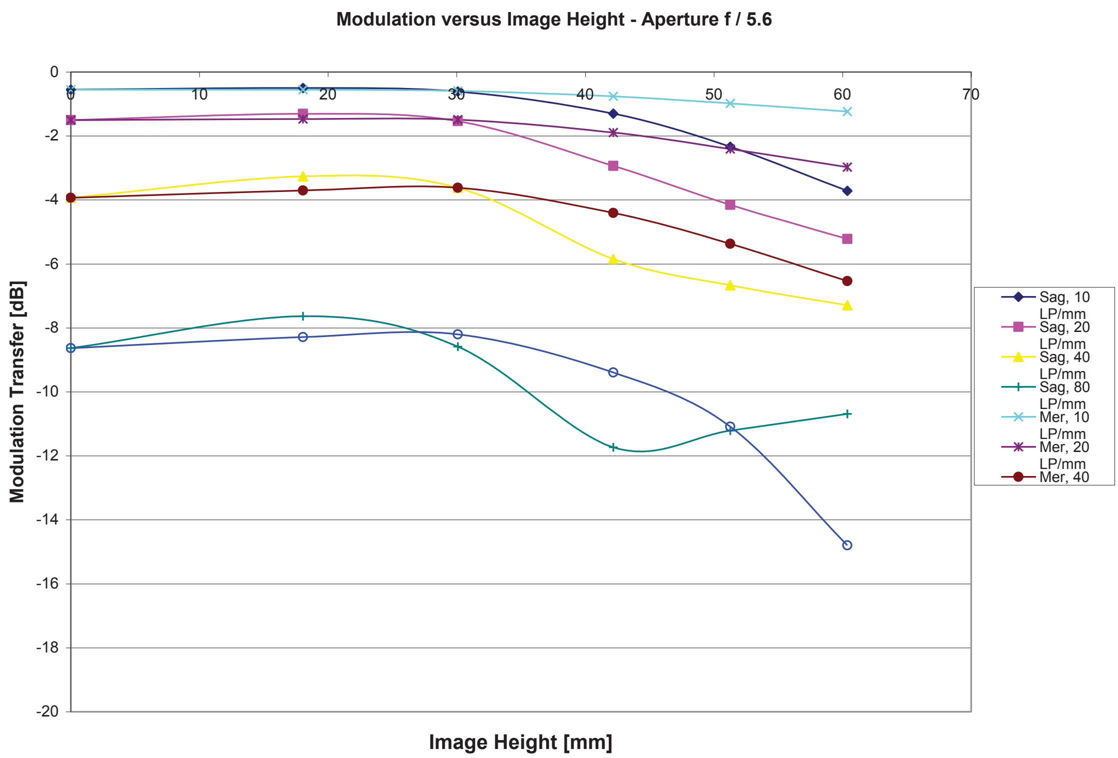


Lens Resolving Power

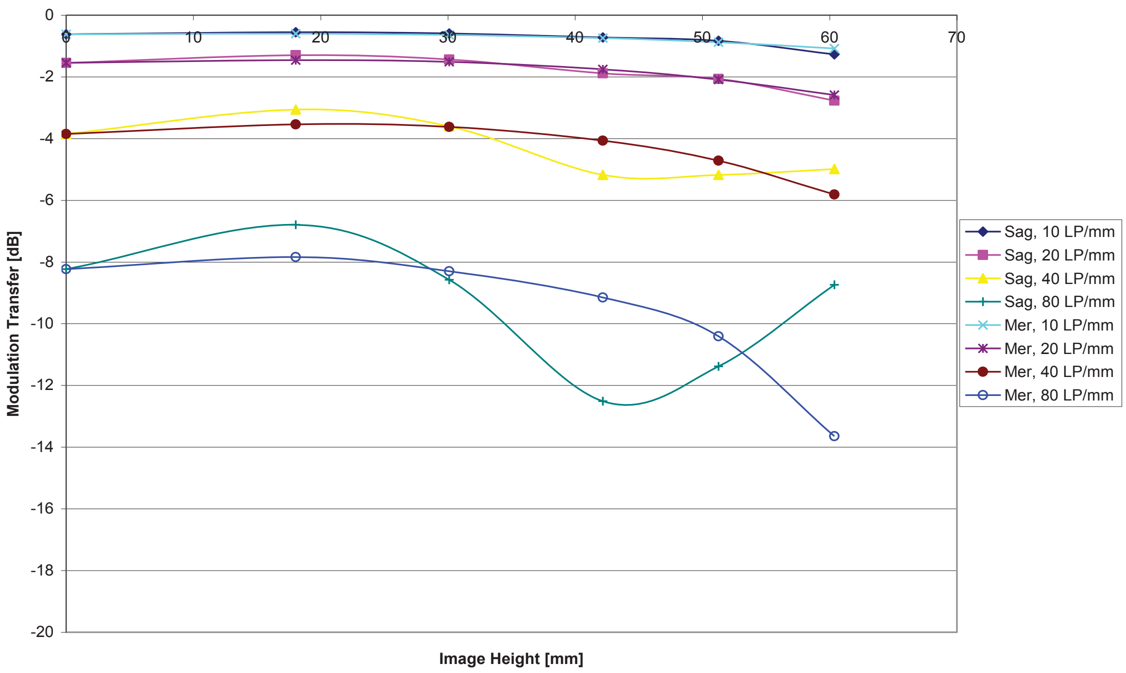
The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones.

The curves are given for the meridonial (tangential) and sagital (radial) component of signals at frequencies of 10, 20, 40 and 80 line pairs per millimeter.

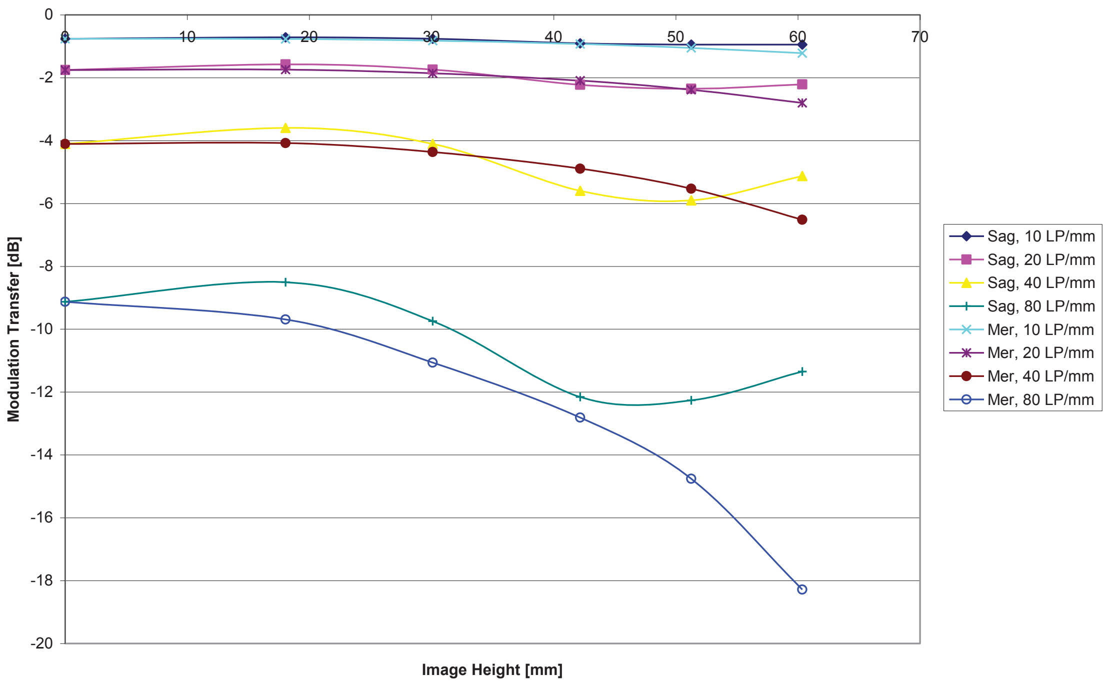
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

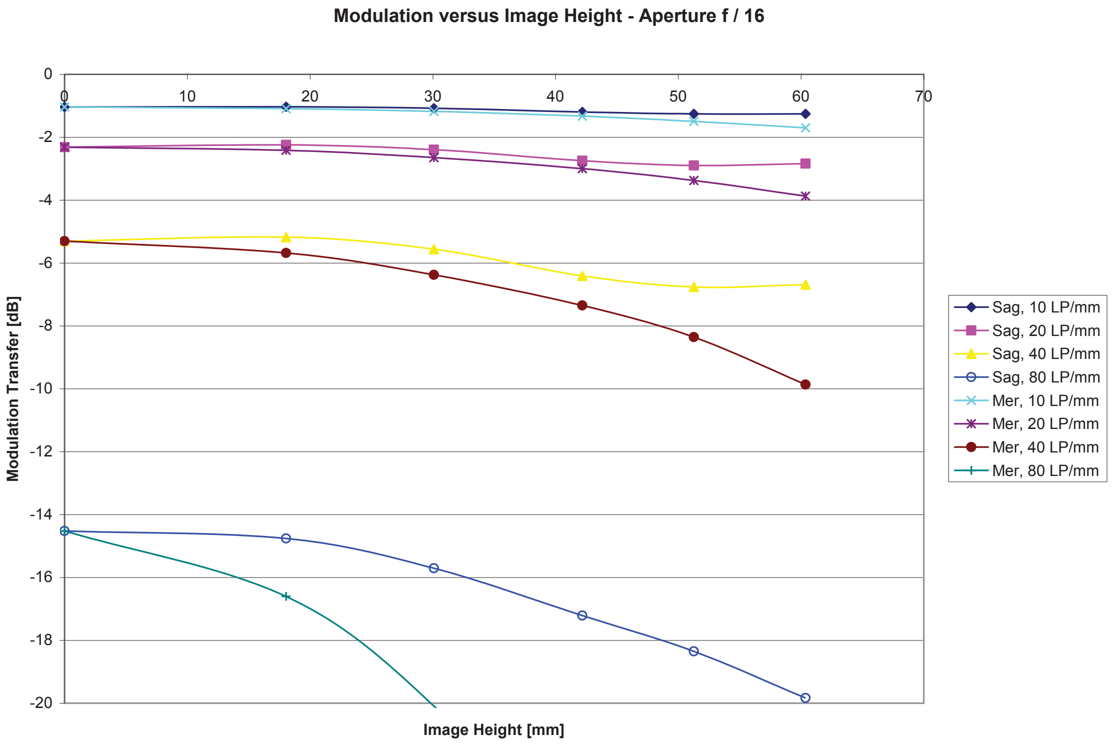


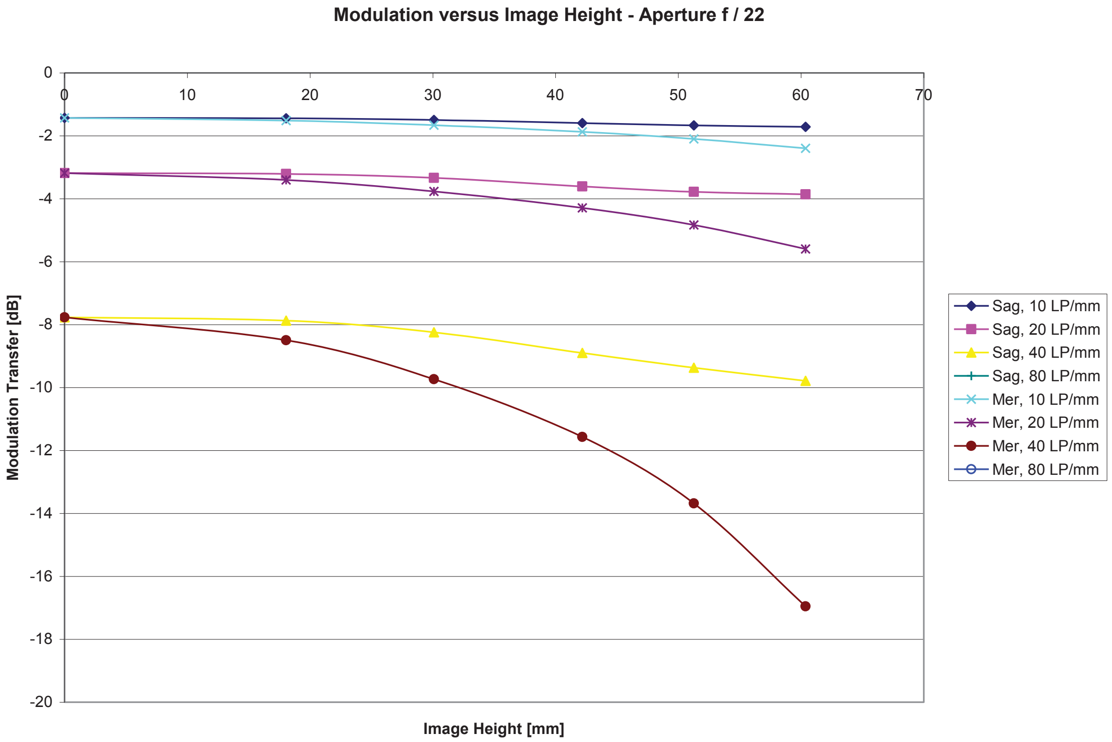
Modulation versus Image Height - Aperture f / 8



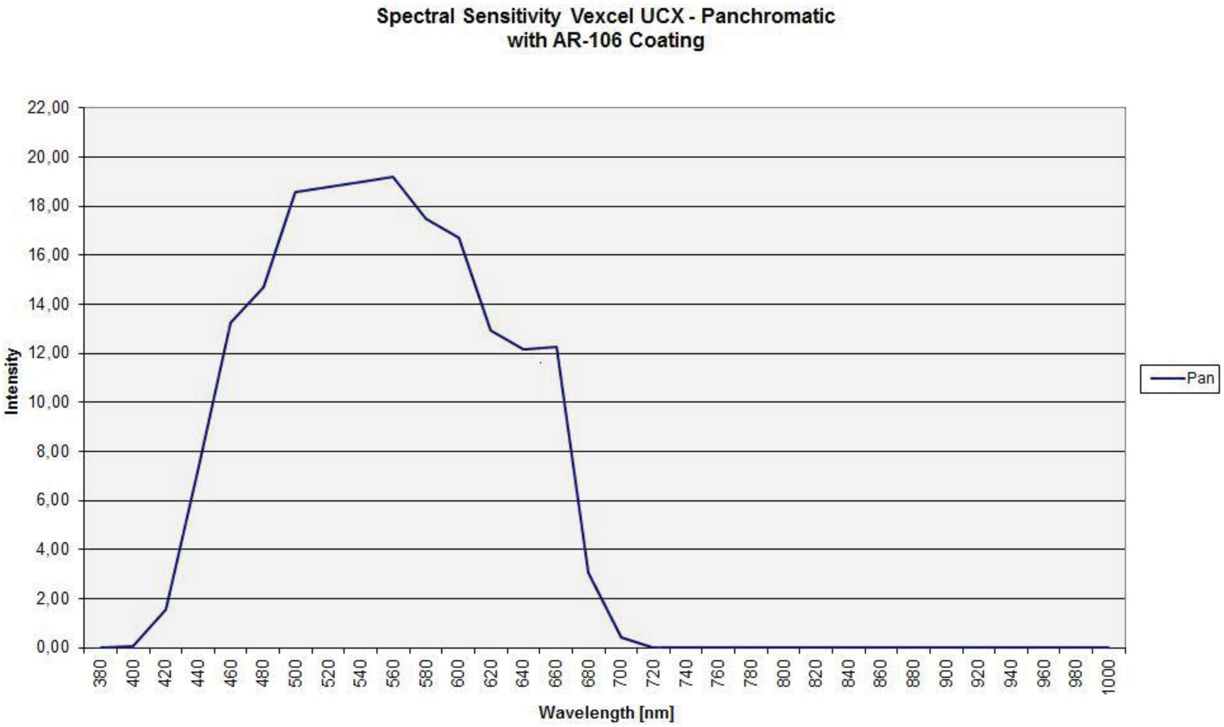
Modulation versus Image Height - Aperture f / 11

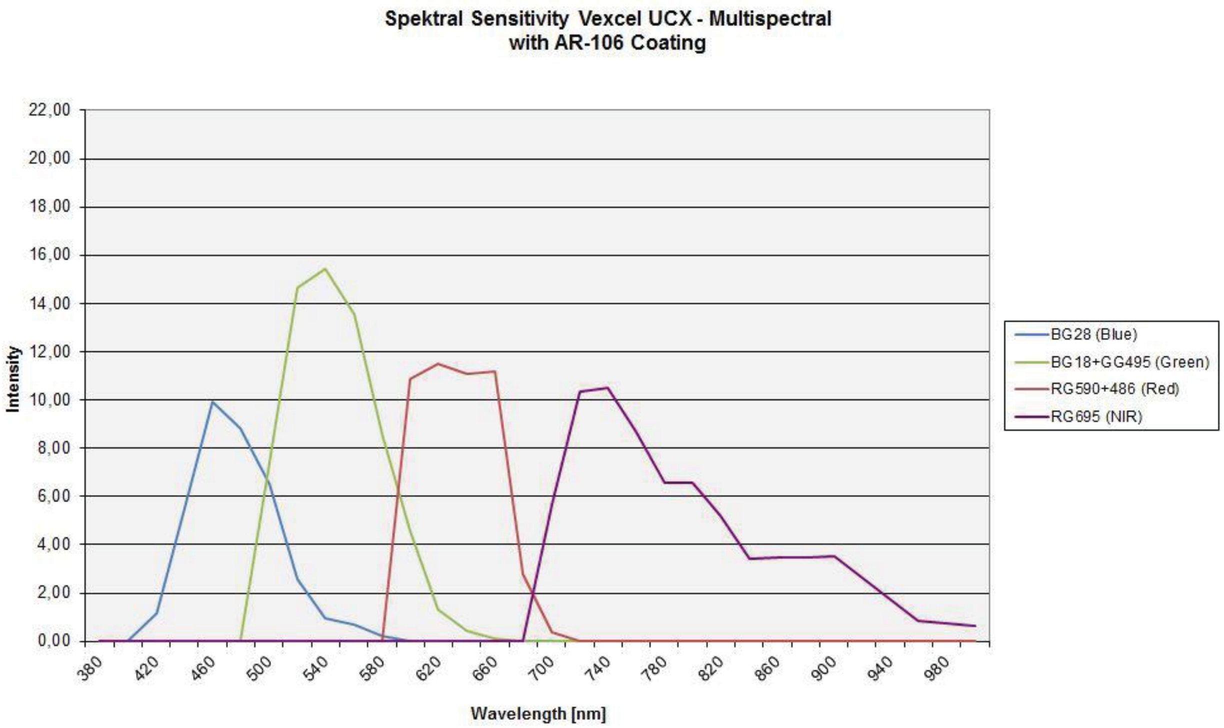



Modulation versus Image Height - Aperture f / 16
Modulation Transfer [dB]
Image Height [mm]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Sag, 10 LP/mm
Sag, 20 LP/mm
Sag, 40 LP/mm
Sag, 80 LP/mm
Mer, 10 LP/mm
Mer, 20 LP/mm
Mer, 40 LP/mm
Mer, 80 LP/mm


Modulation versus Image Height - Aperture f / 22
Modulation Transfer [dB]
Image Height [mm]
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
10
20
30
40
50
60
70
Sag, 10 LP/mm
Sag, 20 LP/mm
Sag, 40 LP/mm
Sag, 80 LP/mm
Mer, 10 LP/mm
Mer, 20 LP/mm
Mer, 40 LP/mm
Mer, 80 LP/mm

Spectral Sensitivity





VEXCEL IMAGING GmbH
a Microsoft company

Calibration Report

Radiometric Calibration

Camera:	**UltraCam X, S/N UCX-SX-1-20316203**	
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**	
Panchromatic Camera:	**Apertures:**	**f/5.6, f/8, f/11, f/16, f/22** (All Pan)
Multispectral Camera:	**Apertures:**	**f/4, f/5.6, f/8, f/11, f/16** (Red, Green, NIR)
		f/2.8, f/4, f/5.6, f/8, f/11 (Blue)

Date of Calibration:	**Aug-12-2011**
Date of Report:	**Sep-02-2011**
Camera Revision:	**7.0**
Revision of Report:	**7.0**

Explanations:

Calibration Method:

The radiometric calibration is based on a series of 60 flat field images for each aperture size and sensor. The flat field is illuminated by eight normal light lamps with known spectral illumination curves.

These images are used to calculate the specific sensitivity of each pixel to compensate local as well as global variations in sensitivity. Sensitivity tables are calculated for each sensor and aperture setting, and applied during post processing from level 0 to level 1.

Outlier Pixels that do not have a linear behavior as described in the CCD specifications are marked as defective during the calibration procedure. These pixels are not used or only partially used during post processing and the information is restored by interpolation between the neighborhood pixels surrounding the defective pixels.

Certain pixels that are named Qmax pixels due to the fact that they can only store and transfer charge up to a certain maximum amount are detected in an additional calibration step. These pixels are treated differently during post processing, since their behavior can affect not only single pixel values but whole columns.

Calibration Report

Summary

Camera: UltraCam X, S/N UCX-SX-1-20316203

Manufacturer: Vexcel Imaging GmbH, A-8010 Graz, Austria

Date of Calibration: Aug-12-2011
Date of Report: Sep-02-2011
Camera Revision: 7.0
Revision of Report: 7.0

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Verification of Lens Quality and Sensor Adjustment
- Radiometric Calibration
- Calibration of Defective Pixel Elements
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber
Chief Scientist, Photogrammetry
Vexcel Imaging GmbH

Ing. Peter Prassl
Senior Calibration Engineer
Vexcel Imaging GmbH

Baxter Geo Consulting Pty Ltd
Surveying - Development Planning & Co-ordination
ACN: 103 579 335 ABN : 63 323 316 716

2/13 Hill Street
TAMWORTH NSW 2340

please address all correspondence to
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general: okbaxter@baxtergeo.com
writers email: peter@baxtergeo.com

Our Ref: 0492
File Location: Z:\0492 Bendemeer Flood Study\Doc\0492-120208 SMEC Bendemeer Quality Doc.docx

Your Ref: Bendemeer Flood Study

8th February 2012.

The General Manager
Tamworth Regional Council
P.O. Box 555
TAMWORTH NSW 2340

Dear Sir,

Re: Quality Control Bendemeer Flood Study – Joint Venture Aerometrex, Baxter Geo & SMEC

Survey Control

Establish Survey Control
A SCIMS search was undertaken on 9th Oct 2011 to locate reliable Survey Control in the Village of Bendemeer. PM 1299, PM39722 & PM142565 each being Class A Order 1 were chosen as control stations.

A GNSS base station and eccentric check station were established on assumed co-ordinates and the primary control measured using two rovers, one on a tripod and the other on a range pole with bi-pod. This methodology provides an independent check on heights. It was my opinion PM39722 & PM142565 were unsuitable as a base station because of the proximity of tree canopies. PM 1299 was deemed unsuitable as it was located on the main street and in close proximity to a small tree. The new base station was remote form pedestrian traffic and had a clear skyview.

Following the initial survey the base station co-ordinates were calculated from the established control. A new job was created and the control marks remeasured. The co-ordinates were compared with SCIMS and agreement was good.

Eccentric Control Station
The co-ordinates of the eccentric control station were documented and on each subsequent survey a check measurement was taken to the eccentric station at the beginning and end of each day. The check co-ordinates were compared to establish no errors were made in setting up the base station each day and that the base station had not been disturbed or tampered with during the days observations.

Establish Photo Control
Aerometrex required photo control points to be established in eight areas. An RTK survey was undertaken with two rovers set at different heights. A minimum of two control points (each determined by observations using two rovers) were taken in each of the eight areas. This gave a redundancy of 100% for Aerometrex.

Establish Quality Control
During the control survey a rover was fixed to the top of the car and random measurements at an approximate interval of 50m spacing.

Control Data was forwarded to Aerometrex for processing.

Processed Photogrammetric Data

Aerometrex supplied digital data which was read into AutoCAD Civil 3D. The data was processed and a Digital Terrain Model created.

Checking and Quality Control
The heights of the check points were compared to the heights generated in the TIN. Agreement was very good with a high number of points being within 0.025m and 0.05m. A small number of points showed up to 0.15m variation, but due the location of the point and nature of the ground surface the difference was seen as being acceptable.

The heights were also checked against a large topographic survey undertaken by Baxter Geo Consulting for Tamworth Regional Council's emergency water supply. Once again agreement was typically within 0.025m and 0.05m.

It is our opinion the data supplied by Aerometrex and the subsequent DTM is superior to what could be achieved by conventional ground survey or LiDAR.

Additional Information

Additional survey data was required to be collected by ground survey. This data included existing flood heights, the invert of the river bed, bridges and culverts. This data was collected by GNSS and total station measurements. The Leica TPS 1200 instrument used to collect the data allows all total station measurements to be collected in MGA 56 in the same file as the GNSS data. Each total station setup was compared to control points in the GNSS data base at the beginning of each observation epoch.

A separate file containing the 3D models of the culverts and bridges was created and checked against other work previously undertaken in Bendemeer.

Supply of data to SMEC

The electronic data was supplied on CD and by FTP to SMEC.

Floor Level Survey

A data set containing the 1:100 and PMF flood lines was provided to Baxter Geo by SMEC. This data was loaded into the model and a series of four field sheets produced to identify the floor levels required to be measured.

Floor levels were determined using GNSS and a laser level. The system was checked prior to field survey to ensure accuracy. The initial check showed what we believe to be a collimation error in the laser level. A new laser level was obtained and a further field check undertaken to confirm accuracy. This check proved satisfactory and the filed survey was then undertaken using the previous GNSS control station and the eccentric control station. During the course of the floor level survey measurements were taken to known points and the values of the laser level survey compared. All results showed good agreement. We are of the opinion our levels determine by this method are good to 0.05m or better.

The greatest source of uncertainty in determining the floor levels is picking a point on the outside of the building that is representative of the floor level inside. Our instruction was to determine the floor levels within +/- 0.1m. We are of the opinion that this criteria has been met.

Each measurement with the laser level was measured in metres and inches. Each value was entered into the data recorder. The observed inches were converted to metres on a handheld calculator and compared to the noted reading in metres before the data was stored. This methodology provided quality control in the field.

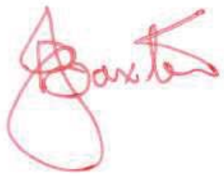
The GNSS and level observations were downloaded and converted to an Excel spreadsheet. The data was checked and appropriate corrections made where required. The processed data was then read into the Civil 3D model and a visual check made against the aerial photography. This was then checked against a data file of Bendemeer showing the cadastral layout and street numbers supplied by Tamworth Regional Council. A number of amendments to the addressing collected in the field were required to be made to be consistent with Council's data set.

The processed floor levels were exported to an Excel spreadsheet and this was supplied to SMEC as a Excel spreadsheet and a pdf print of the file.

Personnel

All surveys were undertaken by the undersigned with the assistance of Dan Whale who is a competent field assistant and a qualified town planner.

Yours faithfully



Peter J Baxter *B.Surv M.I.S(NSW) S.S.S.I.*
Registered Surveyor / Licensed Strata Managing Agent
for Baxter Geo Consulting Pty. Ltd.