LOCKHART FLOOD STUDY

LOCKHART SHIRE COUNCIL

FINAL REPORT

JULY 2014

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FINAL REPORT

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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 in the discharge of their floodplain management responsibilities. The Federal Government may also provide subsidies in some circumstances.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. Flood Study
- Determine the nature and extent of the flood problem.

2. Floodplain Risk Management
- Evaluates management options for the floodplain in respect of both existing and proposed development.

3. Floodplain Risk Management Plan
- Involves formal adoption by Council of a plan of management for the floodplain.

4. Implementation of the Plan
- Construction of flood mitigation works to protect existing development, use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

The Lockhart Flood Study presented herein constitutes the first stage in the NSW Floodplain Risk Management Program for the township of Lockhart (see Figure 1 for town location). WMAwater was been engaged by Lockhart Shire Council to prepare this Study under the guidance of Council's Floodplain Risk Management Committee (FRMC).

EXECUTIVE SUMMARY

Following the flood events of October 2010 and March 2012 which directly impacted Lockhart, causing dozens of homes and businesses to suffer over floor inundation, Lockhart Shire Council (Council) has engaged WMAwater Pty Ltd under the NSW Floodplain Risk Management Program, to carry out flood and floodplain risk management studies and to produce a draft plan.

Together this work aims to define and manage flood risk for now and into the future, assisting Council with their planning duties and also helping to refine NSW State Emergency Service (SES) flood response.

The following report documents work undertaken during the course of the flood study. This involves data collection, model build and calibration/validation work as well as design flood results including mapping.

A wide variety of data have been found and utilised to build the model, all of which have been found fit for purpose. Model calibration/validation work demonstrates an excellent fit to a comprehensive observed data set for both events and this gives confidence that model design flood predictions are the best estimates available.

Design flood results indicate that the 1% AEP flood is near identical to the March 2012 event. As such flood liability in Lockhart during the 1% AEP event is well represented by the March 2012 event which saw approximately 98 buildings flooded (approximately 70 of which were residential and suffered over floor inundation). The fact that the March 2012 event is an excellent match to the 1% AEP event, plus little sensitivity in design flood results to variations in parameters combine to give good confidence in design flood estimates.

Key issues coming out of the flood study are as follows:

- Urana Street residences lie in a floodway and high hazard area and as such must be an ongoing priority for both the SES and Council in regard to managing flood risk at Lockhart;
- Mitigation of flood liability may be achieved for some residents on the floodplain under specific conditions and further work needs to be done on this as part of the subsequent management study;
- Defining the flood planning area (FPA) will likely require a variation on the standard approach whereby the 1% AEP plus freeboard extent is utilised, as use of such a method in Lockhart, given the relatively flat overbank, will tend to exaggerate the FPA extent. Recommendation is to ignore all flood depths less than 200 mm, classifying these as drainage/stormwater issues. Then utilise the mainstream 1% AEP flood levels plus a freeboard of 300 mm to create the first cut of the FPA extent. Then add any other homes impacted by overland flow (where some minimum percentage of the lot is impacted by flooding, say 20% for example); and
- Carry out damages work using surveyed floor levels (to be done once design floods confirmed via review.

1. INTRODUCTION

This flood study has been prepared by WMAwater on behalf of the Lockhart Shire Council (Council). The main objective of this study is to define the flood behaviour in the townships of Lockhart under existing conditions. The study has examined past flood events in addition to undertaking a flood assessment for a range of design storms. The findings in this report provide information to inform Council with regards to managing existing and future flood risk within the catchment. Additionally information is provided to the SES to aid in their emergency response planning.

All levels provided in this report are to Australian Height Datum (AHD). A glossary of terms is provided as Appendix A.

1.1. Objectives

The information and results obtained from these studies define existing flood behaviour and provide a firm basis for the development of a subsequent Floodplain Risk Management Study and Plan (FRMS&P).

Primarily, the study was developed in order to meet the objective of defining the flood behaviour (5 year ARI, 10%, 5%, 1%, 0.5% AEP events and the Probable Maximum Flood (PMF)) in the township of Lockhart and to:

- Define flood behaviour in terms of flood levels, depths, velocities, flows and flood extents within the study area (provided electronically to Council);
- Prepare flood extent mapping (for all design events modelled);
- Prepare provisional flood hazard category mapping for the 5% and 1% AEP events as well as the PMF;
- Provide hydraulic category mapping as well as a discussion of the method used relative to other guidelines and methods;
- Provide Interim Flood Planning Area maps (FPAs);
- Identify flooding “hotspots” – existing and future – for further consideration as part of the FRM Study; and to
- Create a modelling system that might be used in the subsequent FRMS&P to test whatever flood mitigation works might be proposed by either the community, OEH, Council or the consultant.

1.2. Study Area

The township of Lockhart (population 837 at the 2006 Census) is located 60 km southwest of Wagga Wagga, 56 km south of Narrandera and 97 km north of Albury in Lockhart Shire Council Local Government Area.

The township of Lockhart experiences regular flooding from the Brookong Creek and also from major overland flow. This Study considers flooding from both sources.

Brookong Creek flows from north to south through the township of Lockhart (Figure 1) and discharges into Urangeline Creek, which drains to the Murray River via Billabong Creek and the Edward River. Brookong Creek is fed by numerous small ephemeral streams. At Lockhart the Creek has a catchment area of approximately 150 km^2. Upstream of Wattles Road, the Brookong Creek channel is incised within a confined floodplain. However, downstream of the Wattles Road crossing, the channel slope flattens and the floodplain opens up. The Creek itself consists mainly of shallow gullies that remain dry for the majority of the year.

Overland flow flooding in the region is generally caused by overland flow paths and runners meeting manmade structures such as roads and railways. This situation causes flood waters to backup and be diverted into urban areas. This is the mechanism for flows that travel in a westerly direction through town causing flooding in areas along and to the south of Brookong Street. Flooding in this area is due to flows from a number of unnamed tributaries in the Milbrulong area (situated east of the town) interacting with The Rock/Oaklands railway.

1.3. Lockhart Flood History

Brookong Creek at Lockhart has been subjected to numerous flood events since white settlement of the town. Significant flood events causing property inundation are known to have occurred in 1934 (see Image 1), 1931, 1974 and 1939 (presented in order of magnitude). However, the March 2012 and October 2010 floods surpassed all previous flood events in term of both magnitude and damage. Accordingly, these two events have been used for calibration/validation purposes with further details contained in the following sections.

Table 1 presents estimated flood levels for significant events at the Green Street Causeway gauge in Lockhart (Reference 3) displayed in chronological order.

Table 1: Flood History at Lockhart (Table 24.1, Reference 3)

Date	Rainfall at Lockhart Bowling Club	Estimated level near Green Street causeway**	Comment	source
1931 June	87mm (24th)	153.9m AHD (based on photo from corner Green/Urana)[1] 1.75m depth	Houses inundated; two week duration; flowed over railway bridge washing away approaches; Walter Day Park submerged; photo shows flood reached top of plinth at Dalgety building at corner Green/Urana Streets.	Bayley (1979); Lockhart Flood Study (PB, 2001)
1934 January	157mm (8th) 27mm (9th)	154.0m AHD 1.85m depth	Floodwaters higher than in 1931 but did not enter Greens Gunyah Hotel; two feet [0.6m] through open air picture theatre (which became site of the Rio theatre); dams burst along Brookong Creek; many dwellings and other business houses inundated; Green Street awash; campers displaced; fencing at showground damaged; market gardens destroyed; railway damaged.	The Argus, Mon 8th Jan 1934 pp.7-8 & Tues 9th Jan 1934 pp.7-8; Bayley (1979); Greens Gunyah Museum
1939 March	31mm (17th) 28mm (18th)	153.75m AHD[2]	Heavy rain on Galore Hill; Brookong Creek overflowed; four houses inundated to depth of two feet [0.6m]; a number of houses flooded in eastern section of town; floor of Rio Theatre under a foot [0.3m] of water at height of storm; depth of water in streets brought traffic to standstill; Walter Day Park submerged.	The Argus, Sat 18th Mar 1939 p.2; Bayley (1979); Lockhart Flood Study (PB, 2001)
1968 May	21mm (10th) 54mm (11th)	153.5m AHD?[3]	Flows entered town from the east, flooding eastern end of Brookong and Drummond Streets, across Walter Day Park to creek; this caused no property damage but was a significant nuisance; most problems attributed to slow discharge of stormwater due to elevated water levels in Brookong Creek.	Lockhart Flood Study (PB, 2001)
1974 January 4	51mm (4th) 23mm (5th)	?	Less severe flood.	Lockhart Flood Study (PB, 2001)
1974 January 10	11mm (10th) 57mm (11th)*	153.6m AHD	Heavy rainfall over 6 hour period on wet catchment; water entered five houses with many others surrounded. Highest since 1939.	Lockhart Flood Study (PB, 2001)
1974 October 17	67mm (17th) 30mm (18th)	?	Less severe flood.	Lockhart Flood Study (PB, 2001)
1978 May	46mm (30th) 10mm (31st)	153.0m AHD	Less severe flood.	Lockhart Flood Study (PB, 2001)
2010 October	19mm (13th) 70mm (14th) 101mm (15th-16th)	154.1m AHD (surveyed) 1.95m depth	Note floodwaters entered former Greens Gunyah Hotel and ~0.75m in former Rio theatre. About 45 houses and 20 businesses or public sector buildings inundated over floor.	Bewsher Consulting (2012).
2012 March	69mm (29th Feb) 123mm (4th)	154.25m AHD (surveyed) 2.1m depth	Record flood. Note floodwaters ~0.37m in former Greens Gunyah Hotel and ~0.79m in former Rio theatre. About 67 houses and 31 businesses or public sector buildings inundated over floor.	Rapid Impact Assessment

* Rainfall date adjusted based on surrounding stations.

** Gauge zero is 152.17 mAHD.

[1] It appears to have been assumed that the photo represents the peak level.

[2] The floor level of the old Rio Theatre was surveyed as 153.46 mAHD for the Reference 3 investigation. This suggests that the March 1939 flood, which was reportedly one foot [0.3m] above floor level, and assuming floor levels have not changed, would have reached about 153.7-153.8 mAHD. However, the Flood Study (Reference 1) estimated the floor level to be 153.3 mAHD, seemingly based on photographic evidence. This appears to be too low for what was regarded as a severe flood. Afflux across the Green Street causeway might mean slightly higher levels upstream of the causeway.

[3] Contradictory information is provided for the 1968 event. Pritchard (cited in Reference 1) indicates that floodwaters reached a depth of 1.6 m across the Green Street causeway, which – assuming the causeway has not changed – corresponds to 153.7 mAHD. However, this would rank the flood as higher than the well-established January 1974 level, which does not ring true with the description of 'no property damage' in the 1968 and the description of the 1974 as the highest since 1939. There is a suggestion the causeway was reconfigured between the 1958 and 1974 floods. Accordingly, the 1968 flood is estimated to be slightly lower than the 1974 flood.

It should be noted that the levels and depths described in Table 1 relate to the two gauge boards (one on the eastern side and one on the western side) at the Green Street causeway (see Image 8). These gauges are designed primarily for traffic control purposes and as such levels may vary over time due to the boards being moved, replaced or upgraded. As such the above referenced common gauge zero may not be accurate for older flood events.

Image 1: 1934 Flood Event, Corner of Green and Urana Street, Looking North-West
(source:Lockhart Museum)

1.3.1. March 2012 Flood Event

The March 2012 Flood Event is the largest flood event in the town of Lockhart's history (see Image 2), exceeding the next largest event by approximately 0.1 – 0.3 m (difference dependent on location). During this event at least 67 houses and 31 commercial/public sector buildings were flooded above floor level in Lockhart. This is approximately 33 buildings more than what were inundated during the October 2010 event.

Image 2: View east across Green Street, post peak
(source: Reference 3)

Image 3: Destroyed footbridge at Green Street
(source: Reference 3)

Brookong Creek reached a peak level of 2.1 m at the Green Street causeway gauge at approximately 5:30 am 4 March 2012. This is 0.15 m higher than the next largest flood event which occurred in October 2010. Areas bordering the Creek were directly inundated and a number of homes along Galore and Ferrier Streets were flooded by Brookong Creek floodwaters spilling over the crest of the Old Government Dam near the eastern end of Galore Street. This caused flood waters to flow from east to west along these streets. It was noted that significant blockage of structures occurred along Brookong Creek, in particular the Green Street Causeway. In addition to this the Green Street footbridge was also reportedly impacted by blockage with this possibly contributing to its failure during the event (see Image 3) (Reference 3).

Overland flows were predominately generated from sheet flows in the Milbrulong region (see Section 4.7.3) meeting The Rock/Oaklands Railway and then being diverted in a westerly direction towards Lockhart. These flows then crossed East Street before flowing along Brookong Street and other roads to the south. Regions in South Lockhart were predominately inundated by this overland flow mechanism and in some instances a combination of both overland flow and creek flood waters.

An examination of the rainfall that created the March 2012 flood event is contained in Section 2.4.4.1.

1.3.2. October 2010 Flood Event

The second highest flood on record occurred in Lockhart on the 15th of October 2010 with some 65 buildings (including 45 houses) inundated above floor level. During this event properties were inundated by both local overland flows and by Brookong Creek flooding (see Image 4 - Image 7). It is understood that local overland flow flooding occurred prior to creek peak flood levels however timing for the two mechanisms was not dissimilar.

Brookong Creek reach a peak level of 1.9 m at the Green Street causeway gauge between 4:00 – 5:00 pm. This is approximately 0.1 m higher than the next largest flood event which occurred in January 1934. Flood mechanisms for both overland flow and creek flooding during this event were similar to that which occurred in the March 2012 event (Reference 3).

Image 4: View from corner of Galore/Hayes Street
(source: Reference 2)

Image 5: View north along Urana Street
(source: Reference 2)

Image 6: Former New Gunyah Hotel, Urana Street (source: Reference 2)

Image 7: Billabong Motors, Urana Street
(source: Reference 2)

An examination of the rainfall that created the October 2010 flood event is contained in Section 2.4.4.2.

1.4. Overview of Existing Catchment

1.4.1. Land Use and Demographic Overview

Understanding the social characteristics of the area can help in ensuring that the right risk management practices are adopted. The Census data can provide useful information on categories including dwelling and tenure type, languages spoken, age of population and movement of people into and from the area. Information has been extracted for the 2011 Census. The urban centre of the suburb of Lockhart has a population of 800 living in 391 private dwellings.

Of interest is the data on population movement in recent years. Generally residents who have lived in an area for a longer time will have a better understanding of flooding issues in their area than those who have recently moved to the area. Within the last five years 23% of the population has moved to the Lockhart area and in the year prior to the 2011 census 10% of the population moved into the area. This means that the majority of the current population would have experienced one or both of the recent flood events and therefore likely has good awareness of flood risk in the region.

It is useful to consider the tenure of housing. Those living in properties which they own are more likely to be aware of the flood risks and have measures in place to reduce them. Rental properties are likely to have a higher turnover of people living in them compared to privately owned properties and therefore those people in rental properties may be less aware of the flood risks unless they have been there for enough time to have experienced flooding or have been sufficiently informed by their landlords. In Lockhart 19% of houses are rented with 77% of dwellings being privately owned.

The languages spoken by the population are also useful to consider as this can have implications in regard to the provision of flood information to the public. In Lockhart 94% of the population speak English at home.

Land use from the LEP 2012 is shown in Figure 2. The majority of Lockhart is comprised of lots zoned RU5 rural 'village' areas while Brookong Creek is designated as W1 natural waterway. Land use outside of the township of Lockhart in the Brookong Creek catchment is generally zoned 'primary production' with usage primarily devoted to grazing and cropping endeavours. Sheep and cattle are the main livestock farmed in the area and cereals (wheat, oats and barley) are the main crops. Outside the town boundaries, the only structures on the floodplain are roads and rail, individual farmhouses and other farm related infrastructure. Most roads are unsealed and creek and stream crossings are generally formed by low level causeways.

1.4.2. Key Infrastructure on the Floodplain

A summary of key infrastructure on the Brookong Creek floodplain in the vicinity of Lockhart is contained in the ensuing sections. Structures of interest are those that impact on flood levels, for example upstream backwatering (and retention of floodwater) and lower levels in the downstream (relative to the case if the major structure was not there).

A summary of the performance of these key structures for each of the design runs is contained in Section 4.5.3.7. The associated point ID is mentioned in each of the following sections.

1.4.2.1. Lockhart Government Dam

The Lockhart Government Dam (point #1, Figure 3) is located upstream of the township to the north of Galore Street (see Figure 10). The Dams were constructed in the 1800's to provide water for the railway. Results from the community consultation (see Section 3) indicate that the alignment and crest height of these dams likely impacted on the severity of flooding along Galore Street during the 2010 and 2012 flood events (see Section 4.7.2).

Hotspot 7 (see Section 4.7.7) provides further details of the Lockhart Government Dam.

1.4.2.2. East and Galore Streets Channel and Embankment

The East and Galore Streets drainage channel transfers flows from the Milbrulong region situated to the east of Lockhart (see Section 4.7.2 and 4.7.3). The channel runs parallel to East Street and conveys flow in a northerly direction before turning west at Galore Street and discharging into Brookong Creek (see Figure 28). An embankment to the north of the section of the channel parallel to Galore Street restricts flow in the region (see Section 4.7.2) and is reported to exacerbate flooding along Galore Street.

1.4.2.3. Green Street Causeway

The Green Street Causeway (point #2, Figure 3 and see Section 4.7.1 for further details) is the main traffic crossing over Brookong Creek from east to west Lockhart (see Image 8 and Figure 10). The causeway is constructed of nine 2.1 x 0.9 m box culverts and was built prior to the 1974 event. Details of the previous road crossing structures at this location are unknown. The causeway is first inundated at a level of 152.16 mAHD (-0.01 m on the Green Street gauge).

Image 8: The Green Street Causeway (source: Reference 2)

1.4.2.4. Green Street Footbridge

Due to the relatively low crest level of the Green Street causeway a footbridge (point #3, Figure 3) has been in-situ since at least 1931 (note footbridge in Image 9). At this time the footbridge was located upstream of the road crossing. It is not known when this historical bridge was replaced with the more modern bridge (displayed in Image 10) which was destroyed in the March 2012 Flood. However, it is known that the bridge displayed in Image 11 was in place during the October 2010 flood. Since the March 2012 flood, the destroyed footbridge has been replaced by a new concrete structure. The chronology of these bridges in relation to the calibration/validation and design events has been taken into account for modelling purposes. This includes a model run that simulates the destruction of the footbridge during the March 2012 calibration run (see Section F1.5 Appendix F).

Image 9: 1931 Flood Brookong Creek Crossing, Green Street (source: Lockhart Museum)

Image 10: Green Street Footbridge pre March 2012 Flood (source: Google Earth)

Image 11: Green Street Footbridge post March 2012 Flood (source: WMAwater)

1.4.2.5. Oaklands Railway Bridge

The Oaklands Railway Bridge (point #4, Figure 3) was constructed in 2007 to its current condition (see Image 12). The previous structure has been reported by local residents to have had larger conveyance capacity than the current structure (for an equivalent stage). Details of the railway bridge for modelling purposes were obtained from design drawings.

Image 12: Oaklands Railway Bridge (source: Reference 3)

1.4.2.6. Urana Road Bridge

The Urana Road Bridge (point #5, Figure 3) was constructed to its current state in 1989. Reports from the community consultation indicate that reshaping and resurfacing of the bridge approaches (particularly on the eastern side) have led to higher peak flood levels upstream of the bridge. It is unclear exactly when road works impacting on the stage-discharge relationship at the bridge were implemented.

Image 13: Urana Road Bridge (source: Reference 3)

2. AVAILABLE DATA

2.1. Background

Various items of data as well as reports salient to the study have been collected and reviewed. Most reports and datasets were sourced from Council and supplemented by additional survey where required. Reports were reviewed particularly for topographic/hydrologic parameters as well as observations of historical flood events. The key focus of the exercise was to collect data suitable for the model calibration and validation process as well as to develop an understanding of the flood history and mechanisms for the three towns.

This section provides a summary of the reports as well as a description of the various forms of data utilised in the study.

2.2. Previous Reports

2.2.1. Lockhart Flood Study (Reference 1)

This study examined Brookong Creek flooding in the township of Lockhart. As part of the study, a RAFTS hydrologic model was developed and this was used in combination with a UNET model for hydraulic modelling. Due to a lack of rainfall and stream flow data, the models could not be properly calibrated. Instead, a pseudo-calibration was undertaken in the hydraulic model using surveyed peak flood levels marks from the 1974 flood.

Results indicate that the 1974 flood event had a recurrence interval between the 2 and 5% AEP and that the 1931 flood level could be approximated by the 1% AEP flood levels and extent.

2.2.2. Flood Intelligence Collection and Review for Towns and Villages in the Murray and Murrumbidgee Regions following the October 2010 Flood (Reference 2)

The aim of this study was to compile and then review flood intelligence pertinent to the October 2010 Flood events for towns and villages in the Murray and Murrumbidgee regions for the NSW State Emergency Service (SES). Flood intelligence describes flood behaviour and the consequences that flooding has on the community. Flood intelligence also enables the SES to determine the actions that should be undertaken by response agencies. Such information is inserted into SES Flood Plans and Flood Intelligence Cards (FIC) in order to guide the SES response during future events.

The focus regions for this study were:

- Tumbarumba
- Mannus Creek catchment
- Jingellic
- Holbrook
- Culcairn
- Walbundrie
- Walla Walla
- Henty
- Tumut
- Adelong
- Tarcutta
- Ladysmith
- Uranquinty
- Lockhart
- The Rock

Particularly of use from the Reference 2 study were surveyed peak flood levels of which there were 45 in total. The peak flood levels obtained from this report were used for model validation in the current study (see Section 2.6 for further details on calibration data). Other useful information included details on private rainfall records and a stage hydrograph (see Chart 6) and descriptions of flood mechanism and levels of affectation (i.e. consequences).

2.2.3. Flood Intelligence Collection and Review for Towns and Villages in the Murray and Murrumbidgee Regions following the March 2012 Flood (Reference 3)

This study was performed using the same techniques and for the same regions as that described above in Reference 2 but for the rainfall event that occurred in early March 2012. Flooding in Lockhart Shire was generally larger for the March 2012 event than what was experienced in October 2010. Numerous peak flood levels (43 in total), rainfall data (daily read and hourly accumulated) and two stage hydrographs (see Chart 5 and Chart 6) were available and were used in model calibration work.

2.3. Model Build Data

Topographical and survey data provide a basis for both the hydrologic and hydraulic models in terms of catchment delineation and properties. Furthermore in a hydraulic model this data is vital for model configuration. Structures such as bridges, levees, culverts and pipes need to be realistically represented to reproduce accurate hydraulic properties. A surveyor (Hinchcliffe T J & Associates Pty Ltd) was commissioned to survey these structures. The Survey Brief is contained in Appendix B. Digital survey data will be provided with final reports.

All topographical and survey data used in The Lockhart Flood Study is outlined in Section 2.3.1 - 2.3.6.

2.3.1. ALS Data

Airborne Laser Scanning (ALS) data of the Study Area was obtained from Council in conjunction with LPI to define ground surface elevations with the provided ALS data being flown in February 2012. The ALS provides ground level spot heights from which a Digital Elevation Model (DEM) can be constructed. This data has a vertical accuracy of +/- 0.15 m and a horizontal accuracy of +/- 0.5 m at the first confidence interval (68% of all data). When interpreting the above, it should be noted that the accuracy of the ground definition can be adversely affected by the nature and density of vegetation and/or the presence of steeply varying terrain. For the purpose of this study a one metre DEM grid was constructed and this data fundamentally informed the foundation of the 2D hydraulic model build process. The ALS data for the study area is displayed in Figure 4.

2.3.2. 30 m SRTM Data

For the wider catchment, Council, through OEH, have also provided SRTM DEM-S data, which is a 30 m resolution CEM from the Shuttle Radar Topographic Mission. This data has been used in catchment delineation for Brookong Creek (See Section 4.3.1.1) and is displayed in greyscale on Figure 4. Whist not of a comparable accuracy or resolution relative to the ALS the SRTM data is perfectly adequate for catchment delineation work.

2.3.3. Bridge and Culvert Data

Numerous bridges and culverts in Lockhart and surrounds were surveyed (by Hinchcliffe T J & Associates Pty Ltd) so that the conveyance capacity and other details of these structures could be accurately modelled. The following features were surveyed for each bridge:

- Creek cross section survey at upstream face;
- Creek cross section survey at downstream side offset a few meters from structure;
- Pier locations and width;
- Level of deck underside at each creek side (and middle if curved bridge deck);
- Level of deck top at each creek side (and middle if curved bridge deck); and
- Level of fence/railing top at each creek side (and middle if curved bridge deck).

For each culvert the following data was requested:

- Provide internal dimensions of circular culverts (diameter) and rectangular box culverts (width, height);
- Provide upstream and downstream levels of culvert inverts; and
- Provide cross section survey of culvert topping flow path (e.g. road height).

Further details and locations of the surveyed features are displayed in the Survey Brief contained in Appendix B.

In addition to the structures surveyed as part of the current study, design plans of the railway bridge at Lockhart and the new footbridge beside the Green Street causeway have been used to implement these structures into the hydraulic model (Appendix C).

2.3.4. Government Dam Survey Data

As a variation to the works assigned to the surveyor, Hinchcliffe T J & Associates Pty Ltd were also engaged to survey the crest of the Lockhart Government Dam. This crest height was input into the hydraulic model so that proper representation of the flooding mechanism responsible for flooding along Galore and Ferrier Streets could be undertaken. The variation to the survey Brief is contained in Appendix B with the survey results contained in Appendix C.

2.3.5. Floor Level Survey

Floor level survey was performed by Rivland Surveyors Pty Ltd for flood affected properties which experienced significant flooding during the March 2012 event (Reference 3). In total 112 properties (47 non-residential, 65 residential) were surveyed with the location of these properties being displayed in Figure 24.3, Reference 3.

The floor levels of other properties within the PMF extent were estimated by use of ALS data (see Section 2.3.1) in combination with visual inspection of properties by WMAwater engineers. Survey data is presented in Appendix C.

2.3.6. Channel Data

Specific channel data was not surveyed as part of the current study. However, creek cross sections were surveyed both upstream and downstream of surveyed bridges (See Section 2.3.3 above for further details). These cross sections were able to be used to investigate channel conveyance so that comparisons to ALS derived conveyance could be examined. Model conveyance was found to be comparable to calculated (based on survey section) conveyance for all test cases.

Given adequate in-bank resolution for the ALS data it was considered unnecessary to obtain additional cross section survey.

2.3.7. Pit and Pipe Data

The pit and pipe network in Lockhart provides only limited drainage and would have negligible impact on peak flood levels during a flood event. The limited impact expected to be exhibited by incorporating the system into the hydraulic model, modelling of the pit and pipe network has not been undertaken as part of this study. It should be noted that pit and pipe networks tend to deal with events up to the 5-10Y ARI at most, whereas this Flood Study is focussed on larger events such as the 1% AEP planning event.

2.4. Historic Rainfall Data

The rainfall data described in the following sections pertains to information that was used in calibration/validation of the hydrologic model. The model was calibrated to the March 2012 event and validated against the October 2010 event. Due to a lack of suitable rainfall data from any one source, a combination of data described in Sections 2.4.1 and 2.4.2 has been used to create rainfall inputs for the hydrologic model. Dataset details are contained in Section 2.4.3.

2.4.1. Pluviometer Data

Pluviometer rainfall data (high temporal resolution rainfall data) is advantageous as it contains information on both a storms temporal pattern and total rainfall depth. No official pluviometers are located within the Brookong Creek catchment near Lockhart. Bureau of Meteorology (BoM) and NSW Office of Water (NoW) gauges do exist in the region however the closest is situated 67 km away at the Wagga Wagga AMO gauge (072150). Examples of proximate rainfall gauge data are contained in Chart 3 and Chart 4 for the 2010 and 2012 rainfall events.

Fortunately, a local resident of Lockhart (Reid Street) provided readings from a privately owned automated weather station that records rainfall accumulations at hourly intervals[1]. This gauge is reported to slightly underestimate rainfall volumes (Reference 2) and as such only rainfall temporal patterns have been utilised from this gauge. Rainfall depths have been applied from the more reliable daily read rainfall data described in Section 2.4.2.

Data from the Reid Street rainfall gauge was only available for the peak bursts of the 2012 and 2010 events (see Chart 3 and Chart 4 for duration of available data) with no antecedent rainfall data available for modelling purposes. As such the baseflow in Brookong Creek created from rainfall prior to the available data was not able to be calculated via hydrologic modelling directly and an estimate of baseflow has been made for input into the hydraulic model (see Section 4.3.4). Plots of accumulated rainfall for the two events as per the Reid Street gauge are presented in Chart 1 and Chart 2.

2.4.2. Daily Read Rainfall Data

Daily read rainfall gauges do not adequately define the shorter duration intensities that are responsible for flooding in the Catchment and (in isolation) are therefore not suitable for calibration/validation of the hydrologic model. However due to the inaccuracies of the sub-daily rainfall data mentioned in Section 2.4.1, daily read rainfall data has been used to determine total rainfall depths.

Regional official and private daily read gauges (see Table 2) were investigated to determine catchment rainfall depths. Investigation into BoM gauges within a 30 km radius of Lockhart displayed only minor variance in recorded daily depths between gauges (standard deviation approximately 10% of average depth) and distances from these gauges to the catchment are generally large. Therefore it is considered that no benefit would be achieved by incorporating gauges situated large distances from the Catchment.

Instead the Lockhart Bowling Club gauge (74064) has been used in this study as this is the most central official gauge in the region and, as established above, is a reasonable indicator of catchment average rainfall. A number of private gauges also exist in the township of Lockhart, however the difference in rainfall between these gauges and the official Lockhart gauge is

[1] Ideally the temporal pattern would be at a higher resolution than hourly. However, given that Brookong Creek at Lockhart has a critical duration in the order of approximately 6 hours, the hourly resolution still facilitates reasonable emulation of the event as evinced by the calibration and validation results presented in Section 4.

relatively minor due to a lack of spatial distribution and the uniformity of the rainfall event over the area gauged.

Chart 3: October 2010 Rainfall (15th October 2010)

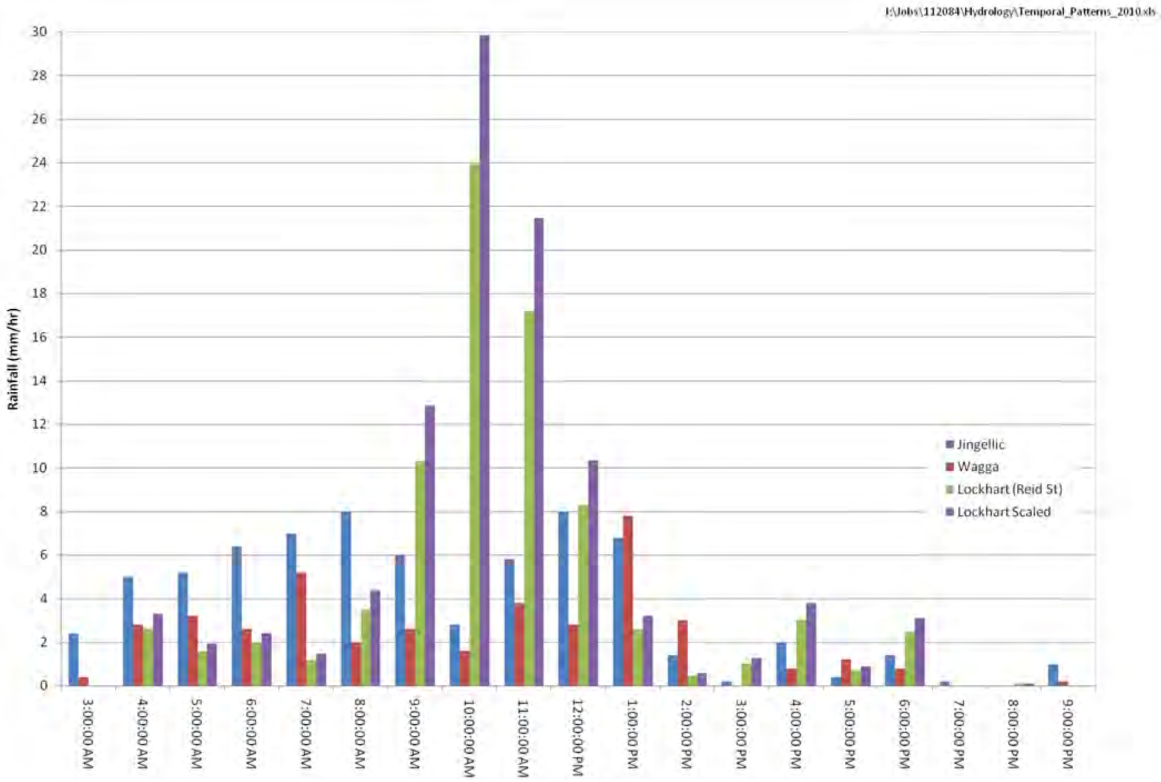


Chart 4: March 2012 Rainfall (from 9am 3rd March 2012)

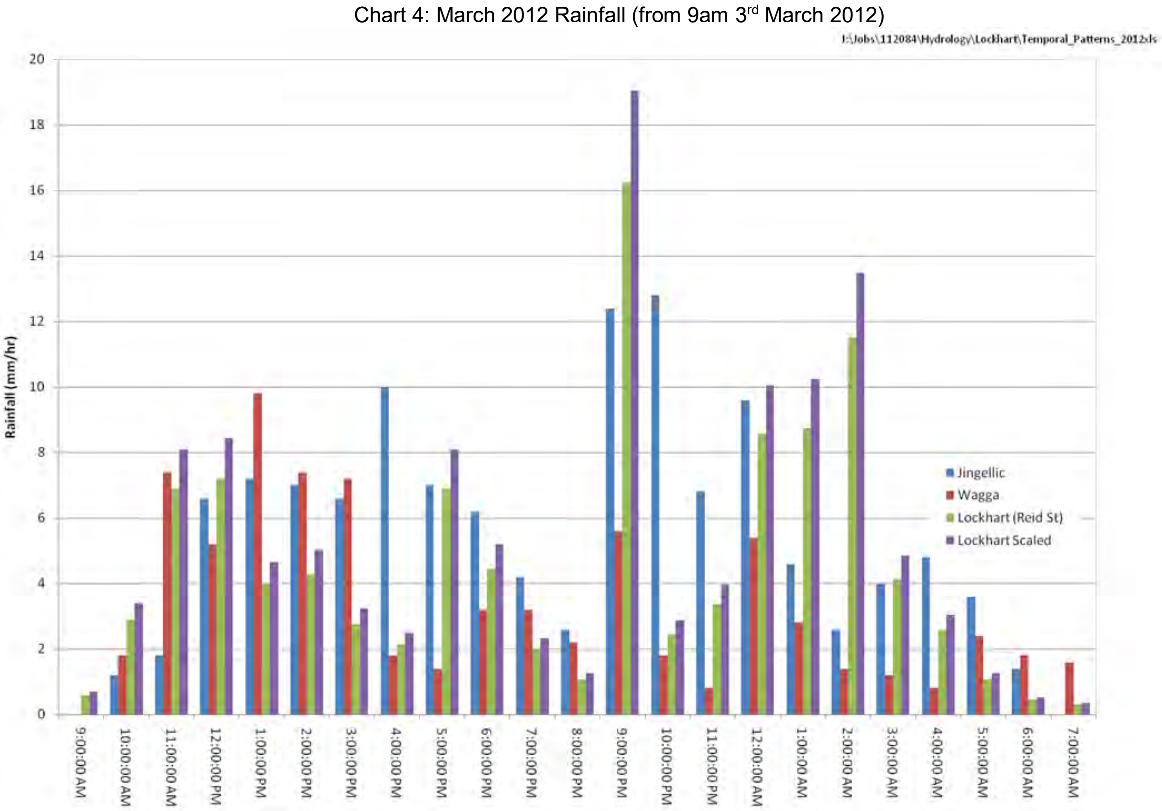


Table 2: Daily Rainfall Gauges with 30 km of Catchment

ID	Name	Owner	2010 Data	2012 Data
74014	Boree Creek	BoM	Yes	No
74064	Lockhart Bowling Club	BoM	Yes	Yes
74021	The Rock	BoM	No	Yes
74179	Tootool (Toronto)	BoM	Yes	Yes
74017	Tootool (Bryntirion)	BoM	Yes	Yes
74257	Pleasant Hills	BoM	Yes	No
-	Hebden Street	Private	Yes	No
-	9 Galore Street	Private	No	Yes
-	23 Galore Street	Private	No	Yes
-	35 Galore Street	Private	No	Yes
-	98 Reid Street	Private	No	Yes
	100 Reid Street	Private	No	Yes

2.4.3. Rainfall Data Merge

Rainfall data mentioned in Sections 2.4.1 and 2.4.2 was used to create rainfall data sets with one hour temporal resolution for input into the hydrologic model. It has been assumed that the Lockhart Bowling Club gauge is representative of the catchment average rainfall and rainfall depths recoded at this gauge have been applied to the temporal patterns obtained from the Reid Street gauge. This gauge is central to the modelled area and variance in recorded rainfall depths between gauges is minor and thus the assumption is considered reasonable. The results of the merged rainfall data for the October 2010 and March 2012 events are contained in Chart 3 and Chart 4 along with other regional pluviometer data sets for these events.

2.4.4. Historical Event Rainfall Analysis

Due to the magnitude of the October 2010 and March 2012 floods and abundance of associated data in regards to calibration, focus has been on these two events. The rainfall burst intensity and frequency of these events was examined with results contained in the following sections.

Figure 5 and Figure 6 display the rainfall burst intensity and frequency for the March 2012 and October 2010 events respectively. This has been done for the Lockhart gauge (see Section 2.4.1) as well as for a number of other proximate gauges.

These figures display the Brookong Creek catchment critical duration (ARR derived, 6 hours) and the catchment estimated time of concentration 5 hours[2] at the Green Street Bridge to give an indication of rainfall exceedance probability for these events.

2.4.4.1. March 2012 Event Rainfall Analysis

The rainfall burst intensity and frequency of the March 2012 event was examined (refer to Figure 5). It can be seen that the rainfall intensity at the Lockhart gauge exceeded 1% AEP intensities for durations exceeding 15 hours. An approximate AEP of 5% was calculated for durations between 6 and 9 hours. Rainfall generally exceeded other gauges in the region with the exception of the Albury pluviometer.

It should be noted that the exceedance probability of the associated flood event was found to differ significantly to the rainfall exceedance probability (see Section 4.5.4).

2.4.4.2. October 2010 Event Rainfall Analysis

The rainfall burst intensity and frequency of the October 2010 event was examined (refer to Figure 6). It can be seen that rainfall intensity at the Lockhart gauge greatly exceeded that of other regional gauges and also slightly exceeded the 1% AEP for durations between 4.5 and 12 hours. This includes the catchments critical duration of six hours (ARR derived) and the catchments estimated time of concentration of 5 hours[2].

As per the 2012 event, it should be noted that the exceedance probability of the associated flood event was found to differ from the rainfall exceedance probability (see Section 4.5.4).

2.5. Design Rainfall Data

2.5.1. Design Rainfall Data (Non PMP)

Design rainfalls were obtained from the Bureau of Meteorology (BoM) at the centroid of the Brookong Creek catchment displayed in Figure 4. Temporal patterns are for Zone II and were obtained from Australian Rainfall and Runoff (Reference 4).

The raw data for establishing Intensity-Frequency-Duration (IFD) data for the study area is provided below in Table 3.

Table 3: IFD Data for the Lockhart Region (Temporal Pattern Zone II)

Location	$^{2}I_{1}$	$^{2}I_{12}$	$^{2}I_{72}$	$^{50}I_{1}$	$^{50}I_{12}$	$^{50}I_{72}$	FF2	FF50	G
Brookong Creek	19.70	3.53	0.91	43.28	6.82	1.62	4.32	15.28	0.17

Design rainfall was determined using the Table 3 information and methods described in ARR87 for the 5Y ARI, 10%, 5%, 2%, 1% and 0.5% AEP events.

2.5.2. Probable Maximum Precipitation

Lockhart has a catchment area of less than 1,000 km^2 and is located in the Inland Zone of the Generalised South-East Australian Method (GSAM). PMP depth calculation for Lockhart is therefore calculated by the Generalised Short Duration Method (GSDM) (Reference 5).

XP-Rafts the hydrological model (see Section 4.3.1) used in PMF hydrologic modelling has inbuilt functionality to determine PMP depths and intensities for modelled catchments. The catchment average PMP rainfall used in determining PMF flows is displayed in Table 4. Figure

[2] As per the Anderson equation from ARR87.

7 displays the PMP spatial rainfall distribution and the rainfall depths allocated to each ellipsoid.

Table 4: XP-Rafts Calculated Catchment Average PMP Depths and Intensitiy

Duration (HRS)	Rainfall Depth (mm)	Rainfall Intensity (mm/hr)
1.0	207	207
2.0	315	158
3.0	381	127

2.6. Model Calibration/Validation Data

Generally calibration/validation is a process whereby historical events are used to test a model's ability to accurately replicate observed behaviour (i.e. match historical flood levels). This process requires rainfall data (pluviometer and daily read) and then observations such as:

- Creek discharge and velocities;
- Gauged water levels;
- Peak flood level at specific locations; and
- Peak flood level extent at a specific location at a specific time.

The following data sets were collected to calibrate/validate the hydrologic model and hydraulic model.

2.6.1. Stream Gauge Data

2.6.1.1. Manual Read Gauged Data

There are no flow gauges in the Brookong Creek catchment. However, at the Green Street causeway a manual gauge exists for which stage hydrographs have been generated for both the 2010 and 2012 events. During the October 2010 and March 2012 events, local residents, SES personnel and Councillors and council staff took photographs and recorded time specific flood levels that were able to be used to create the stage hydrographs (Reference 2 and 3). It should be noted that the March 2012 flood occurred at night and as such the amount of data available to inform an observed stage hydrograph was limited in comparison to the October 2010 event which occurred during the day. This affected the resolution and likely the accuracy of the March 2012 stage hydrograph.

These stage hydrographs have been used in hydraulic model calibration/validation and can be seen in Chart 5 and Chart 6. It is noteworthy that the Green Street causeway gauge is likely suitable/desirable for use in SES flood intelligence cards.

In addition to the Green Street gauge a local resident (100 Reid Street) provided timed photographic evidence of flood levels that was used to construct a stage hydrograph at this location (displayed in green on Chart 5). The Reid Street hydrograph displays the peak flood levels for inundation caused by local stormwater backing up from the Creek. Reference 3 explains that the water was entirely clear whereas the Brookong Creek water was muddy. This stage hydrograph is only available for the March 2012 event.

Chart 5: March 2012 Event Stage Hydrographs and Cumulative Rainfall (Reference 3)

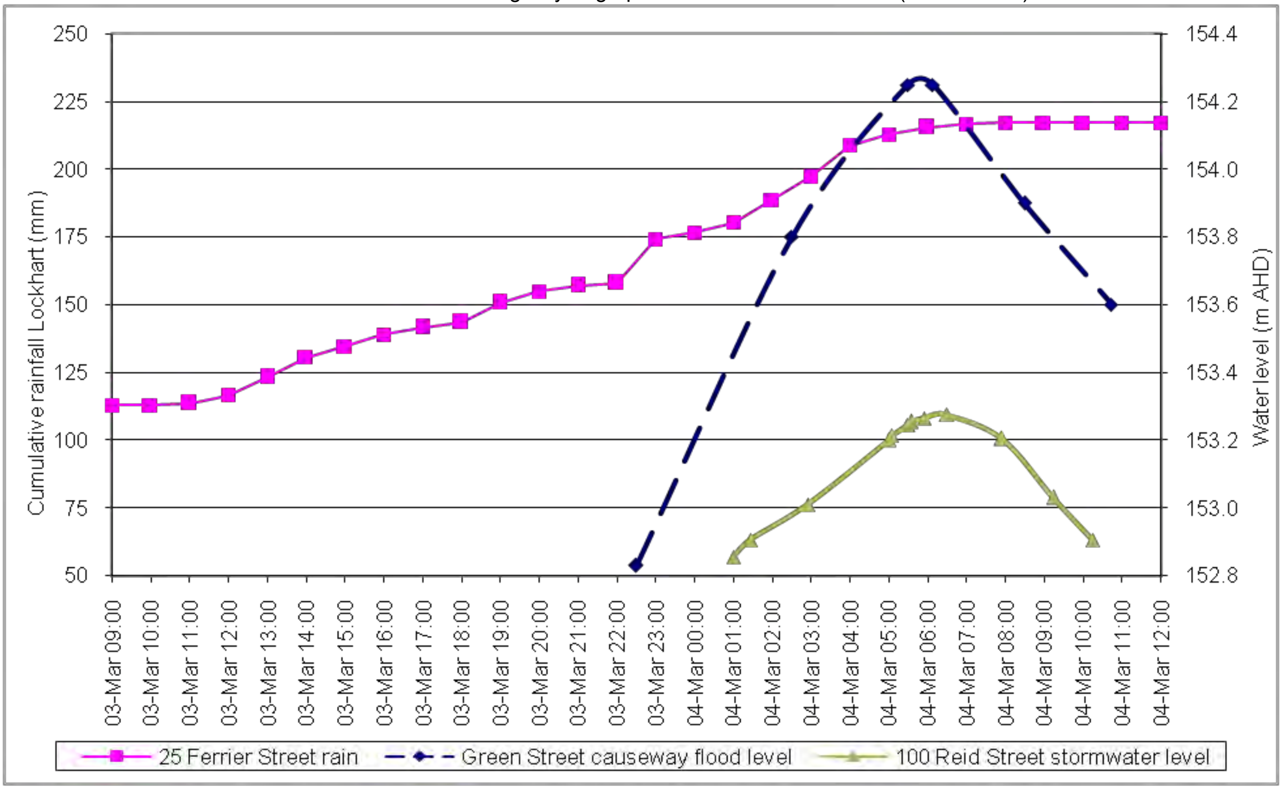
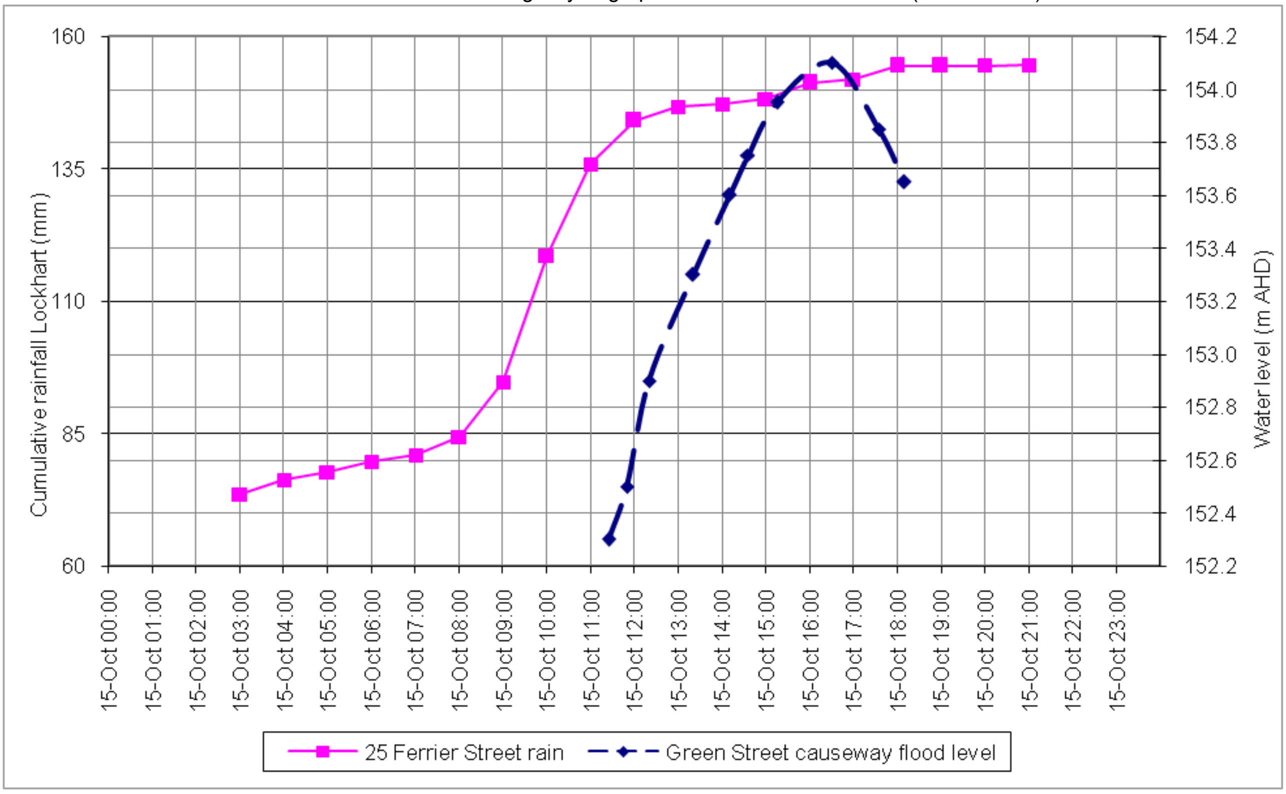


Chart 6: October 2010 Event Stage Hydrographs and Cumulative Rainfall (Reference 2)



2.6.2. Peak Flood Levels

Peak flood levels used in model calibration for the March 2012 and October 2010 events were obtained from Reference 2 and 3 respectively. Both events had a large number of surveyed peak flood levels (43 for 2012, 45 for the 2010). Details of these surveyed levels are contained in Appendix D.

3. COMMUNITY CONSULTATION

Community consultation is an important element of the floodplain risk management process ultimately facilitating community engagement and acceptance of the overall project. During the Flood Study, community consultation was undertaken to assess the flood experience of the community and gather additional data. The final community consultation will be in the form of public exhibition of the final draft of the report. Further community consultation will also be undertaken as part of the FRMS&P component of the study.

It should also be noted that as part of the Reference 2 & 3 studies considerable consultation was performed including questionnaire distribution and interviews.

3.1. Community Open Day

A WMAwater engineer attended the township of Lockhart on 8th and 9th February 2013 with the purpose of interviewing residents to gain relevant information on flooding in the Study Area. Overall the meetings were attended by approximately 25 people. Valuable information on flood behaviour as well as calibration/verification data was obtained, including:

- Identification of the mechanism responsible for flooding on Galore and Ferrier Street. This is caused by overtopping of the southern crest of the Lockhart Government Dam;
- Unanimous information that indicates that the 2012 event was larger than the 2010 event;
- Various flood water depths for both events;
- Identification of the location of inundated residences;
- Explanation of overland flow paths along The Rock/Oaklands railway; and
- Indication of direction of flow in the Lockhart urban areas due to overland flows.

A newsletter was distributed by Council to inform people of these meeting times. A copy of this newsletter is contained in Appendix E.

3.2. Questionnaire Distribution

A community questionnaire survey was undertaken during February 2013. 400 surveys were distributed to residents in the Study Area and a total of 41 responses were received. This equates to a return rate of 10% and as such the views expressed by this sample may not accurately reflect that of the total population. However it is normal that responses predominately come from residents that have been affected by flooding. In contextualising the return rate it is noteworthy that residents have been canvassed already in regards to the October 2010 and March 2012 events as part of SES flood intelligence review work.

The locations of the community consultation respondents are shown in Figure 8 with colour coding to indicate the level of flood affectation. All community consultation respondents agreed that the March 2012 event was the largest they had experienced followed by the October 2010 event. Other notable events include the August 1974, March 1989 and the 1990 event.

It should also be noted that over 39% of respondents (out of the 41 who replied) had been flooded over floor during at least one of the recent events. The full set of results from the community consultation questionnaire are summarised in Figure 9.

In addition to the questionnaire distribution associated with the current study, a large number of questionnaires were distributed as part of the work undertaken in Reference 2 and 3. The results of these questionnaires are summarised in these reports.

A copy of the distributed Community Consultation Newsletter and Questionnaire is contained in Appendix E.

3.3. Lockhart Floodplain Risk Management Committee

The FRMC comprises a number of representatives from the local community, including residents, members of Council, OEH representatives and the SES.

To date the committee has taken an active role in regard to providing feedback on model build work, flood mechanisms impacting on the town and model calibration results. It is anticipated that the FRMC will provide feedback in regard to this draft flood study, such that the work may be amended for subsequent reports and built on in regard to damages, calculations, etc.

4. FLOOD STUDY

4.1. Aims and Objectives

The primary objective of the Flood Study is to define the flood behaviour under historical and existing conditions in the study area. The Flood Study will define:

- Flood levels and extents of inundation;
- Flood velocities and flows;
- Hydraulic categorisation of the floodplain;
- Provisional hazard categorisation of the floodplain;
- Flood damages under a full range of design flood events under existing catchment and floodplain conditions; and
- Flood Intelligence at SES points of interest (hotspots).

The Flood Study considered the 5Y ARI, 10%, 5%, 2%, 1% and 0.5% AEP events as well as the PMF.

4.2. Modelling Approach

In order to achieve the aims above the development of hydrologic and hydraulic models was required. The overall modelling approach was to establish a hydrologic model in conjunction with a 1D/2D hydraulic model. The hydrologic model is used to generate flow hydrographs for input to the hydraulic model. The 1D/2D hydraulic model then utilises flows from the hydrologic model to calculate flood levels and velocities in the region. The hydrologic model used was the Watershed Bounded Network Model (WBNM) and the hydraulic model used was TUFLOW, a 1D/2D fully dynamic fixed grid based model. Both models are discussed in greater detail in Section 4.3 and Section 4.4.

The approach adopted in flood studies to determine design flood levels largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). Due to the limited flood record in the Study Areas a preferable purely flood frequency approach cannot be undertaken for this study and modelling must therefore rely on the use of design rainfalls and establishment of a hydrologic/hydraulic modelling system. A diagrammatic representation of the flood study process is shown over the page (Diagram 1).

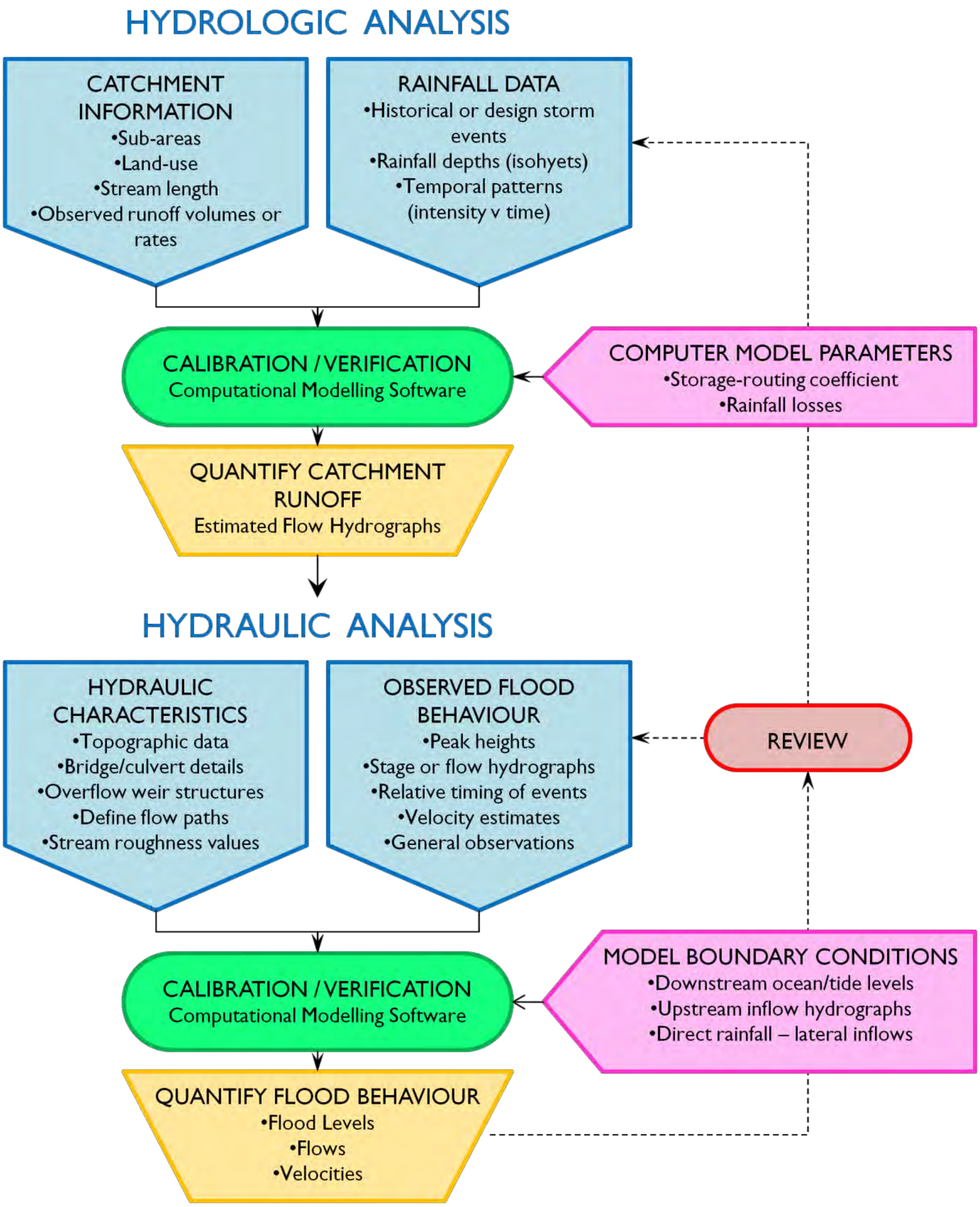


Diagram 1: Flood Study Process

4.3. Hydrology

4.3.1. Hydrology Introduction

No long term stream gauging data is available for the Lockhart catchment so Flood Frequency Analysis is not possible. Therefore, hydrologic modelling was undertaken using WBNM. WBNM is a widely used hydrologic model which has been substantially tested on Australian catchments. The default runoff routing and linearity parameters are based on data from 54 catchments in Queensland, NSW, Victoria and South Australia.

For this study hydrologic modelling was separated into two separate models; a global model which modelled major catchments in the region to determine creek and major overland flows (see Section 4.3.1.1) and a local model which modelled the urban hydrology in the township of Lockhart (see Section 4.3.1.3).

Calibration and validation of the hydrologic model was undertaken simultaneously with the hydraulic model. The hydrologic parameters that are usually adjusted in calibrating/validating a hydrologic model are rainfall losses and lag parameters.

4.3.1.1. Major Hydrologic Model

Creeks and major overland flow paths in the region were modelled in a global model which covers the entire Brookong Creek catchment to the downstream Study Area boundary. The hydrologic model layout is presented in Figure 4 and a summary of the global hydrology catchment properties is displayed in Table 5.

Table 5: Global Hydrology Catchment Properties

Study Area	Number of Catchments	Total Area (km²)	Average Area (km²)	Minimum Area (km²)	Maximum Area (km²)
Lockhart	93	269	2.9	0.1	12.7

The global model delineation was determined from the 30m-SRTM grid (see Section 2.3.2). A WBNM Lag Parameter (also referred to as the C value) of 1.6 was used to calculate the catchment response time for intra-catchment runoff and channel flow. The Lag Parameter is important in determining the timing of runoff from a catchment which influences the shape of the hydrograph as well as the catchments channel routing properties that affect routing speed and attenuation. In catchments for which reliable gauge data is available, the WBNM model should be calibrated against recorded flood data in order to ensure that the adopted lag parameter is representative of the catchment being modelled. For ungauged catchments, such as the Brookong Creek catchment, Reference 9 recommends a Lag Parameter value of 1.6 and this has been used for the current study.

The catchments percentage imperviousness was designated as zero for all catchments within the global model. The impact on total flow associated with imperviousness of towns and roads within the larger catchment are considered negligible.

Hydrologic model results are contained in Section 4.5.2.

4.3.1.2. PMF Hydrologic Model

XP-Rafts (Reference 10) was used to perform hydrologic modelling for the PMF so that the spatially variable PMP rainfall function could be utilised. The XP-Rafts model uses the same delineation as the WBNM design hydrologic model (see Section 4.3.1.1). XP-Rafts requires a number of additional model parameters (slope and lag time) that are not required by WBNM and these parameters have been determined by examination of the DEM and local catchment conditions. As a pseudo calibration of the XP-Rafts model the Manning's 'n' and hydrograph Lag times were adjusted so that modelled 1% and 5% AEP flows were comparable to the WBNM model mentioned above. It was found that using a Mannings 'n' of 0.04 for roughness and a lag time calculated assuming a flow velocity of 1.5 m/s achieves a reasonable match between the WBNM and XP-Rafts models for the 1% and 5% AEP events. It has been assumed that the non-linearity of flow velocity with changes in event magnitude is insignificant in the context of uncertainties surrounding PMP calculation. The B Modification Factors (B and Bx) were not adjusted and XP-Rafts default parameter values were used.

The PMF was then determined using the XP-Rafts model which automates the GSDM (see Section 2.5.2). This includes the spatial distribution of PMP rainfall which utilises the ellipses displayed in Figure 7.

4.3.1.3. Local Models

Modelling of urban hydrology was carried out in the township of Lockhart to provide local flows in the urban and rural regions of the town. Sub-catchment delineation was undertaken using the 1 m DEM (derived from ALS) (see Section 2.3.1) and the delineation details are contained below in Table 6 and the hydrologic model layout is contained in Figure 4.

Table 6: Local Hydrology Catchment Properties

Study Area	Number of Upstream Catchments	Total Area (ha)	Average Area (ha)	Minimum Area (ha)	Maximum Area (ha)
Lockhart	77	131	1.7	0.5	4.2

The local sub-catchments percentage imperviousness was based on aerial inspection of a sample region within Lockhart. The average percentage imperviousness was calculated to be 37% however some variability does occur between sub-catchments. For example regions such as fields or rural lands generally were assigned a percentage imperviousness of zero.

4.3.2. Hydrologic Model Losses

4.3.2.1. Calibration/Validation Model Losses

An initial loss of 25 mm was applied to the March 2012 calibration event with a continuing loss of 2.0 mm/h. For the October 2010 validation event an initial loss of 50 mm was applied and continuing losses remain constant again at 2.0 mm/h. This variation in initial loss is likely due to the lack of spatiotemporal resolution of available rainfall data and also possibly due to differences in the dry periods before the main rainfall bursts for both events.

A discussion as to how these losses were determined is contained in Appendix F (Section F1.2).

4.3.2.2. Design Loss Parameters

Reference 4 suggests the following losses for ungauged NSW catchments (Table 7).

Table 7: Suggested losses for ungauged NSW catchments (Reference 4)

Location	Initial Loss (IL)	Continuing Loss (CL)
East of Western Slopes	10-35 mm	2.5 mm/h
Arid Zone, mean Annual rainfall <300mm	15 mm/h	4 mm/h

Neither of the categories is entirely appropriate for the region surrounding Lockhart. The Study Areas are inland of the Western Slopes (Great Dividing Range) but are not in the arid zone. As such further guidance was sought with Reference 11 suggesting a non-linear hydrologic model system for initial losses. The losses for various recurrence intervals are contained in Table 8.

Table 8: Suggested Initial Losses for a Non-Linear Hydrologic Model in Zone II

ARI (YRS)	2	5	10	20	50	100
IL (mm)	25	30	30	25	20	15
Accuracy (mm)	±15	±15	±15	±15	±15	±15

Taking into account the Zone II losses displayed in Table 8 the loss parameters displayed in Table 9 were adopted. It should be noted that a continuing loss of 2.5 mm/hr has been adopted for Lockhart.

Table 9: Adopted Rainfall Pervious Loss Parameters (Non PMP)

Loss Parameter	Pervious
Initial Loss, <=10Y ARI	15 mm
Initial Loss, >20Y ARI	10 mm
Continuing Loss	2.5 mm/h

For the impervious regions a 0 mm/h continuing loss has been applied and an initial loss of 1.5 mm has been assigned to account for ponding.

PMP rainfall losses are based on Reference 12 and are shown in Table 10. Note losses shown in Table 10 are valid for PMP burst hydrology.

Table 10: Adopted PMP Losses

Initial Loss (mm)	Continuous Loss (mm/h)
0	1

The above losses are comparable to those adopted in the nearby Wagga Wagga Major Overland Flow Flood Study (Reference 6), Culcairn, Henty and Holbrook Flood Studies (Reference 7) and the ongoing study at The Rock.

4.3.3. Aerial Reduction Factors

The aerial reduction factors (ARF) published in ARR87 (Reference 4) are based on American data and have now been superseded by application of the CRC-Forge method developed with Australian data (Reference 13 and 14). The following equations has been utilised in the current study along with applicable regional parameters from Table 11 to determine the ARF for Lockhart design hydrology.

Equation 1: Short duration aerial reduction factor equation (less than 18 hours)

$$ARF = min\{1, [1 + a(Area^{b} + c) + d(Area^{e})(f - log_{10}Duration)]\}$$

Where:

$Duration\ =\ storm\ duration\ (h)$

$Area = area\ of\ interest\ (sq.km)$

$AEP\ =\ Annual\ exceedance\ probablity\ as\ a\ fraction\ between\ 0.5\ and\ 0.0005$

Table 11: Parameters for ARF equations

Region	Duration	a	b	c	d	e	f	g
NSW (GSAM)	<18h	-0.0439	0.23	-0.923	-0.0255	0.309	1.17	NA

The aerial reduction factors determined for the critical durations of three and six hours at Lockhart are 0.82 and 0.85 respectively.

4.3.4. Baseflow

Official examination of the baseflow characteristics of Brookong Creek was unable to be undertaken as there is no official flow gauge in the region. However after examination of the rainfall data (see Section 2.4) it has been assumed that baseflow during both events may have had some impact on flood levels, particularly during the rising limb of the flood hydrograph. Unfortunately the true baseflow was unable to be calculated by hydrologic/hydraulic modelling due to the relatively short record of available sub-daily rainfall and stage hydrograph data (see Section 2.4.1 and 2.6.1.1). Instead a baseflow of 10 m^3/s (approximately 8% of the 5Y ARI event) has been applied to the hydraulic model for both the March 2012 and October 2010 events. This improved the fit between the observed and modelled levels for the stage hydrographs mentioned in Section 2.6.1. A further discussion on baseflow is contained in Section F1.3 Appendix F.

4.4. Hydraulic Modelling

The hydraulic model converts applied flow (discharge hydrographs generated by a hydrologic model) into flood levels and velocities. The hydrodynamic modelling program TUFLOW (Reference 8) has been used in this study. TUFLOW is a finite difference grid based 1D/2D hydrodynamic model which uses the St Venant equations in order to route flow according to gravity, momentum and roughness.

TUFLOW is ideally suited to this study because it facilitates the identification of the potential overland flow paths and flood problem areas as well as inherently representing the available floodplain storage within the 2D model geometry. In addition to this, TUFLOW allows for the utilisation of breaklines at differing resolution to the main grid. Breaklines are used to ensure the correct representation of features which may affect flooding (features such as roads, embankments, etc.) which is especially important in an urban environment.

The incorporation of 1D elements into the 2D domain is another beneficial factor of TUFLOW. This allows such elements as culverts represented in 1D to function dynamically within the 2D grid. This suits the study as it facilitates the inclusion of channel flow within the context of a medium resolution 2D approach as well as facilitating the inclusion of 1D culverts.

Importantly, TUFLOW models can clearly define spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped in detail across the model extent. This information can then be easily integrated into a GIS based environment enabling outcomes to be efficiently incorporated into Council's planning activities (in for example waterRIDE or Mapinfo).

4.4.1. Model Build Process

Model construction begins with the DEM (Digital Elevation Model) which defines at high resolution a catchment's topographical characteristics. Finer features (drainage channel and levees) that have significant impacts on flows may then be incorporated via additional spatial layers of information. Also, via the inclusion of dynamically linked 1D elements, drainage pits and pipes are also incorporated. Numerous spatial layers are applied to the model with the aim of closely replicating the catchment's true hydraulic conditions.

4.4.2. Model Domain and Grid Size

The selection of grid size for use in a hydraulic model is based on ensuring hydraulic features are adequately defined whilst not creating excessively long model run times. An important feature of a hydraulic model (depending on site characteristics and applicable flood mechanism) is the capacity to model channel in-bank conveyance accurately. Emulation of in-bank capacity is key to correctly modelling the study area and as such the conveyance characteristics of the in-bank, based on the model, have been compared to cross-sections achieved by survey (see Section 2.3.6).

As per the Brief, a 5 m finite difference grid was utilised for the Lockhart Study Area with the hydraulic model covering an area of 54 km² (displayed in hashed red in Figure 10). The model extends approximately 4 km upstream (north) and 7 km downstream (south) of Lockhart and approximately 2 km west and 7 km east along the railway line from town. The selected grid size allowed for reasonable run times without the need for modelling of creeks and channels in 1D. Ground elevations in the model were informed by the DEM (see Section 2.3.1).

4.4.3. Breaklines

Flow paths, open drains, levee banks, farm dams, railway lines and road embankments are hydraulic features that have a significant impact on flood behaviour, especially in a relatively flat area such as the areas surrounding Lockhart. Such features have been represented in the model by breaklines with crest and invert heights determined by analysis of the 1m DEM information (the 1 m DEM was derived from ALS data). An exception to this is the Government Dam (situated to the north of Lockhart) crest height which has been based on survey (see Section 2.3.4). The locations of these various hydraulic features are displayed in Figure 10.

The 1 m DEM was constructed from ALS survey and is essentially point data, as point separation is generally in the order of 1.2 m (horizontal).

Generally use of the 1 m DEM to inform breaklines is considered best practice in most modern 2D modelling work. For fine features or where initial modelling indicates that the breaklines taken from the 1 m DEM are not effective/realistic, the actual ALS strike points are referred to and the crest values from this set are utilised in defining the structure. Often the model schematisation work is also influenced by site visits to inspect such elements and to inform how they should be schematised in the model.

4.4.4. Roughness Values

As mentioned in the previous section various hydraulic characteristics are combined with the model grid in order to inform the final hydraulic model properties. This is equally true for cell roughness estimates. The Manning's 'n' values for each grid cell were estimated based on established references and previous studies and were then confirmed by calibration/validation of the hydraulic model. Values were applied to the 2D overland area based on land use information as shown in Table 12 below.

Sensitivity testing of the applied roughness values has been carried out. See Section 4.4.8 for further details and Section 4.5.6 for the results of this analysis.

Table 12: Mannings 'n' values

Land Use	Manning's 'n'
Open Areas (grazing, cropping etc.	0.045
Roads	0.02
Railway Tracks	0.03
Urban Residential Lots*	0.045
Creek in-bank (with low density vegetation)	0.05
Table Drains	0.035
Medium to Dense Bush	0.09

*Buildings were nulled out in the hydraulic model

For this study it is considered that properties adjacent to a flow path would not be part of the effective flow path due to the presence of fences and buildings which retard flow. In the model this was achieved by nulling grid cells based on digitised building outlines which effectively constricted the available flow area. The "loss" of temporary floodplain storage by nulling the building outlines is a slightly conservative assumption as in reality some floodwaters may enter these buildings under some flooding scenarios. However this approach was adopted as it was considered that the impact of such an assumption would be negligible relative to the overall flood runoff volume. Note that in adopting this strategy it was ensured that buildings do not form unrealistic water tight seals to downstream or laterally available inundation areas.

4.4.5. Bridges, Culverts and Pipes

Four key water crossings are present in the hydraulic model of Brookong Creek. These are the Green Street causeway, the Green Street Footbridge, the Railway Bridge and Urana Road Bridge. Bridge and culvert information was sourced from survey commissioned as part of this study (see Section 2.3.3). These details were input into the model as 1D and 2D elements where appropriate with the locations of these structures displayed in Figure 10. Further information on these structures is contained in Section 1.4.2.

4.4.5.1. Blockage

The effect of blockage in urban drainage systems (pipes and open channels) has become a significant factor in design flood estimation following the post flood observations from the North Wollongong August 1998 and Newcastle June 2007 events. Blockage of hydraulic structures can occur with the transportation of a number of materials by flood waters. This includes vegetation, garbage bins, building materials and cars, the latter of which has been seen post-flood in Newcastle. However, the disparity in materials that may be mobilised within a catchment can vary greatly.

Debris availability and mobility can be influenced by factors such as channel shear stress, height of floodwaters, severity of winds, storm duration and seasonal factors relating to vegetation. The channel shear stress and height of floodwaters that influence the initial dislodgment of blockage materials are also related to the average exceedance probability (AEP) of the event. Storm duration is another influencing factor, with the mobilisation of blockage materials generally increasing with increasing storm duration (Barthelmess and Rigby 2009, cited in Engineers Australia 2013).

The potential effects of blockage include:

- decreased conveyance of flood waters through the blocked hydraulic structure or drainage system;
- variation in peak flood levels;
- variation in flood extent due to flows diverting into adjoining flow paths; and
- overtopping of hydraulic structures.

Existing practices and guidance on the application of blockage can be found in:

- the Queensland Urban Drainage Manual (Department of Natural Resources and Water, 2008);
- AR&R Revision Project 11 Blockage of Hydraulic Structures (Engineers Australia, 2013); and
- the policies of various local authorities and infrastructure agencies.

The guidelines proposed by the AR&R Revision Project 11 utilise generic blockage factors presented in Table 13.

Details of the blockages for the various calibration/validation and design runs pertinent to the above mentioned structures are described in the following sections.

Sensitivity testing of the applied roughness values has been carried out. See Section 4.4.8 for further details and Section 4.5.6 for the results of this analysis.

Table 13: Suggested 'Design' and 'Severe' Blockage Conditions for Various Structures (Engineers Australia, 2013)

Type of structure		Blockage conditions	
		Design blockage	Severe blockage
Sag Kerb Inlet	Kerb slot inlet only	0/20%	100% (all cases)
	Grated inlet only	0/50%	
	Combined inlets	[1]	
On-grade kerb inlets	Kerb slot inlet only	0/20%	100% (all cases)
	Grated inlet only (longitudinal bars)	0/40%	
	Grated inlet only (transverse bars)	0/50%	
	Combined inlets	[2]	
Field (drop) inlets	Flush mounted	0/80%	100% (all cases)
	Elevated (pill box) horizontal grate	0/50%	
	Dome screen	0/50%	
Pipe inlets and waterway culverts	*Inlet height < 3m and width < 5m* Inlet Chamber	0/20% [3]	100% [4]
	Inlet height > 3m and width > 5m Inlet Chamber	0/10% [3]	25% [3]
	Culverts and pipe inlets with effective debris control features	As above	As above
	Screened pipe and culvert inlets	0/50%	100%
Bridges	Clear opening height < 3 m	[5]	100%
	Clear opening height > 3 m	0%	[6]
	Central piers	[7]	[7]
Solid handrails and traffic barriers associated with bridges and culverts		100%	100%
Fencing across overland flow paths		[8]	100%
Screened stormwater outlets		100%	100%

[1] At a sag, the capacity of a combination inlet (kerb inlet with grate) should be taken to be the theoretical capacity of the kerb opening with 100% blockage of the grate.
[2] On a continuous grade the capacity of a combination inlet should be taken to be 90% of the combined theoretical zero-blockage capacity of the grate plus kerb opening.
[3] Adopt 25% bottom-up sediment blockage unless such blockage is unlikely to occur.
[4] Degree of blockage depends on availability of suitable 'bridging' matter. If a wide range of bridging matter is available within the catchment, such as large branches and fallen trees, then 100% blockage is possible for such culverts.
[5] Typical event blockage depends on risk of debris rafts and large floating debris.
[6] Blockage considerations are normally managed by assuming 100% blockage of handrails and traffic barriers, plus expected debris matter wrapped around central piers.
[7] Typical event blockage depends on risk of debris wrapped around central piers. The larger the piers, the lower the risk normally associated with debris wrapped around piers.
[8] Typically 50 to 100% blockage depending on debris availability.

4.4.5.2. Calibration/Validation Blockage

All bridges on Brookong Creek were modelled as 50% blocked for the March 2012 calibration and October 2010 validation events. References 2 and 3 indicated that flood waters during these events were full with debris which blocked the Green Street causeway and footbridge (the footbridge was destroyed in the 2012 event, presumably due to debris loading, see Section 1.4.2.4). The community consultation process also indicated that the railway bridge was affected by blockage during both events.

However, References 2 and 3 also indicated that overland flow flood waters were significantly cleaner and were not affected by the same amount of debris. As such, culverts in the urban areas of Lockhart (not on Brookong Creek) were assigned 0% blockage for both events.

The sensitivity to assumed blockages for calibration/validation runs has been investigated further in Appendix F (Section F1.4).

4.4.5.3. Design Runs Blockage

In this study for design runs the approach adopted for all pipes and culverts has been to assume 25% blocked which is the same parameter that has been adopted in the nearby Wagga Wagga Major Overland Flow Flood Study (Reference 6), Culcairn, Henty and Holbrook Flood Studies (Reference 7) and the ongoing study at The Rock. This approach has been adopted to take into account blockage caused by larger debris (such as cars, fencing, vegetation etc.) being swept into drainage structures.

Sensitivity analysis has been performed to determine the impact on varying design blockages (see Section 4.5.6).

4.4.6. Lockhart Boundary Conditions

Inflows were applied at different locations within the model based on the hydrologic model layout (refer to Figure 10). All inflows were supplied by the hydrologic model.

One downstream boundary condition was utilised in the Lockhart hydraulic model with the outflow represented by a Stage vs. Flow relationship based on an average bed slope of 0.004. This boundary has been placed a significant distance from the Study Area so that it does not impact on flood levels within the area of interest. Sensitivity analysis confirmed that the downstream boundary does on not impact on study area results (see Section 4.5.6).

Local drainage inflows have been inserted into the model where applicable and flow hydrographs have been obtained from the local hydrologic model described in Section 4.3.1.3.

4.4.7. Hydraulic Model Calibration/Validation

Calibration/validation was performed on the March 2012 and October 2010 flood events with results contained in Section 4.5.3.1. Calibration/validation of the hydraulic model generally consisted of matching surveyed peak flood levels (obtained from Reference 2 and 3) and stage hydrographs (see Chart 5 and Chart 6) to the modelled levels. Flood behaviour identified via the community consultation process (see Section 3) and References 2 & 3 was also recreated. References 2 & 3 also provide estimates of flood extents for the 2010 and 2012 floods however confidence in these extents is low and the modelled flood extents are likely much closer to the true flood extent.

Due to a lack of flow data in Brookong Creek observed flood levels can be produced by multiple parameter combinations. As such, numerous iterations were attempted to obtain the best fit for the observed stage hydrographs (see Section 2.6.1) by adjusting parameters within reasonable ranges (as informed by catchment characteristics) such as the WBNM lag, losses, baseflow, bridge blockage and Manning's 'n'. In addition to this the removal of the Green Street footbridge was modelled to simulate destruction of this bridge as occurred during the 2012 event. An examination of these findings is contained in Appendix F.

4.4.8. Hydraulic Sensitivity Analysis

Sensitivity analysis was carried out in order to assess the effect that adjusting model parameters had on model results. Comparisons were carried out using peak flood levels and flows for the 1% AEP design event. The following scenarios were modelled in the hydraulic models:

- An increase in rainfall losses of 20% (both initial and continuing losses);
- A decrease in rainfall losses of 20% (both initial and continuing losses);
- An increase in lag parameter 'C' of 20%;
- A decrease in lag parameter 'C' of 20%;
- An increase in bed resistance (Manning's 'n') of 20%;
- A decrease in bed resistance (Manning's 'n') of 20%;
- Pipe/culvert blockage at 50%;
- Sensitivity of the downstream boundaries;
- Comparison of ARF (ARR87 relative to CRC-Forge method); and
- Increases in rainfall of 10%, 20% and 30% in order to assess potential impact of climate change.

All sensitivity analysis results are contained in Section 4.5.6 with the exception of increases to rainfall which is covered in the section on climate change (Section 4.5.7).

4.4.9. Design Event Critical Duration

Various duration design events were assessed in order to determine the design event durations that produce the greatest flows and flood levels for Lockhart. The assessment was undertaken using the 1% AEP event results from the hydrologic model and the calculated critical duration was then adopted for all other AEP (excluding the PMF). The same process was then used to determine the critical duration for the PMF. Design event critical duration results are contained in Section 4.5.1. The critical duration runs were then used to create peak flood level envelopes over the study area (see Section 4.5.3.4)

4.5. Modelling Results

A summary of hydrologic (see Section 4.5.2) and hydraulic (see Section 4.5.3) results are contained in the following sections. The hydrologic results detail peak flow and hydrograph findings at key locations throughout the region. Hydraulic results provide peak flood surface levels, depths and extents for the calibration (see Section 4.5.3.1) and validation (see Section 4.5.3.2) events as well as design floods (see Section 4.5.3.4). Calibration/validation peak flood levels have been compared to surveyed flood levels and gauged data where available (obtained from References 2 and 3). In addition to this, flood hazard and categorisation mapping has been performed for the 1% and 0.5% AEP design events (see Section 4.5.8). All design results are displayed for the critical durations determined in Section 4.5.1.

4.5.1. Critical Duration Assessment Results

Critical duration assessments were undertaken to determine which storm duration is responsible for generating the highest peak flood levels. For all events excluding the PMF the critical duration was found to vary spatially between 3 and 6 hours (see Figure 11) with flooding associated with Brookong Creek generally having a critical duration of 6 hours. Minor tributary flooding and flooding resulting from catchments to the east of town and along the railway generally tend to have a critical duration of 3 hours.

Local flows generated from the local catchment model (see Section 4.3.1.3) were determined to have a critical duration of 2 hours however peak flood levels only differed by approximately 10 – 20 mm between the 2, 3 and 6 hour durations. As peak flood levels in nearly all region of the town were dominated by Creek and overland flow flood waters, a local model critical duration matching that of the global model (see Section 4.3.1.1) was implemented for the various model runs (i.e. 6 hour global and 6 hour local etc.).

The critical duration of the PMF at Lockhart was found to be 3 hours.

4.5.2. Hydrologic Results

The following sections contain modelled peak flow results for the various calibration and design runs. Hydrologic model calibration results are summarised in Section 4.5.2.1 and design results have been presented for each of the Study Area inflows (see Section 4.5.2.2).

4.5.2.1. Hydrologic Calibration Results

Due to a lack of flow data for Brookong Creek rigorous calibration of the hydrologic model could not be undertaken. Instead hydrologic model flows were input into the hydraulic model to determine suitability of hydrologically determined flows (typically called 'joint calibration'). Therefore model calibration results are purely based on the performance of the hydraulic model and calibration results should be interpreted from these findings. The hydraulic calibration/validation results are contained in Sections 4.5.3.1 and 4.5.3.2 respectively.

As an indication of the magnitude of the October 2010 and March 2012 floods the flows determined from the hydrologic model are displayed in Table 14 and are further discussed in Section 4.5.4).

4.5.2.2. Design Hydrologic Results

Hydrologic modelling has been undertaken to produce flow hydrographs for the 5Y ARI, 10% 5%, 2%, 1%, 0.5% AEP events and the Probable Maximum Flood (PMF). The peak flows for Brookong Creek at the Green Street Causeway for the calibration/validation and design flood events are presented in Table 14.

Table 14: Green Street Bridge Flows Derived from WBNM Model (m³/s)

	5Y ARI	10% AEP	5% AEP	2010 Event	2% AEP	2012 Event	1% AEP	0.5% AEP	PMF
Lockhart	67	95	134	177	185	231	231	281	2876

A discussion of these results is contained in Section 4.5.4).

4.5.3. Hydraulic Results

Calibration of the hydraulic model generally consisted of matching observed peak flood levels to the modelled TUFLOW levels via joint calibration of the hydrologic and hydraulic models. The calibration results are presented and discussed in the following sections.

Details of each of the surveyed observed flood marks are presented in Appendix D.

Note that the flood maps (Figure 12 - Figure 19) that have been created for the calibration, validation and design events have been clipped so that shallow/superficial flooding is not displayed. For the design events depths less than 200 mm are classified as local drainage (see Section 4.5.3.4 for further details) and have been removed from these maps. For the calibration/validation maps depths greater than 100 mm only have been displayed in order to clarify the presentation of the material.

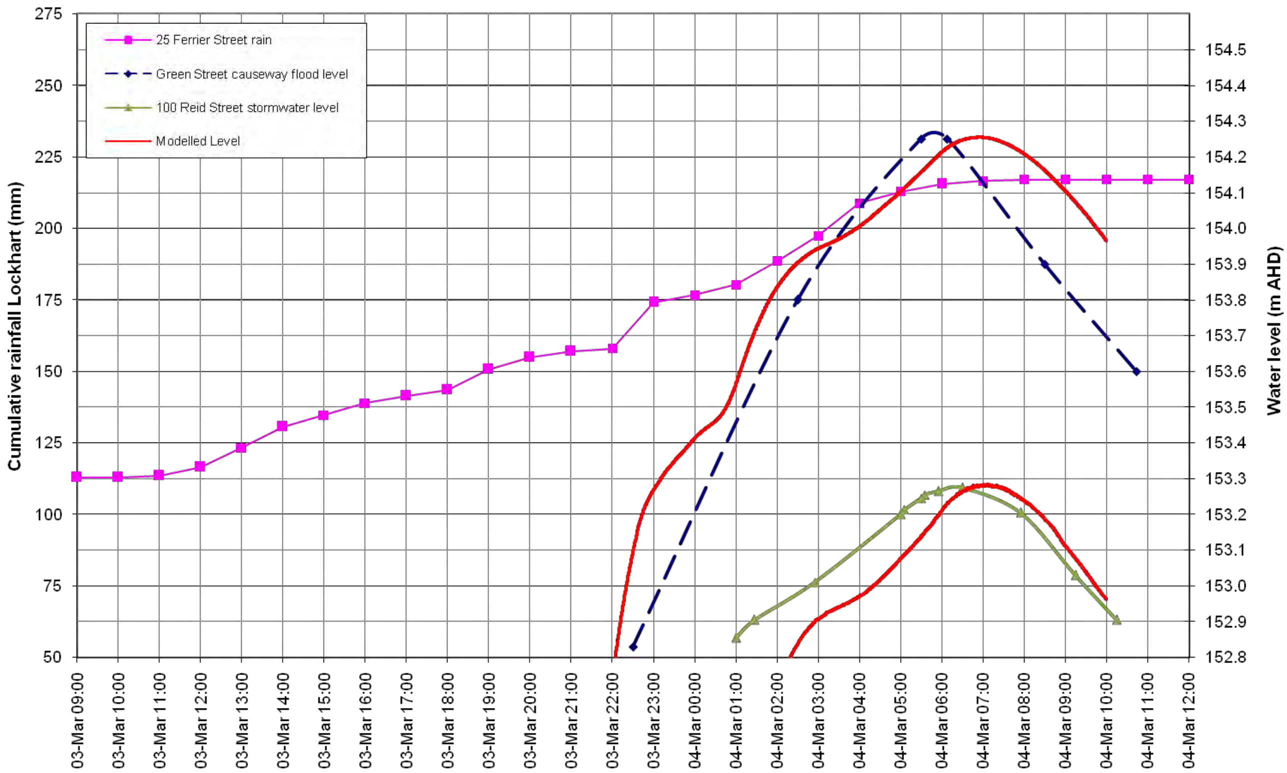
4.5.3.1. Hydraulic Calibration Results

Figure 12 shows the modelled March 2012 flood event depths and extent (raster) as well as a comparison of observed peak flood levels to modelled levels (displayed as red points) at Lockhart. The maximum difference in peak flood level is an under estimate of 0.3 m at one point and an over estimate of 0.3 m at another (i.e. the modelled level is 0.3 m lower and 0.3 m higher than that observed), however a mean absolute error of approximately 0.05 m was achieved. This calibration is based on comparison of modelled and surveyed peak flood levels at 43 locations (see Section 2.6.2). Variation between observed and modelled levels was not noticed to be positively or negatively biased, i.e. variance was due to minor localised effects, not overall model behaviour.

Furthermore, the observed stage hydrographs at the Green Street and Reid Street manual gauges (Reference 3) (see Section 2.6.1.1) were compared to modelled flood levels. The modelled flood level and timing was found to accurately represent observed conditions (zero difference in peak and timing approximately one hour late for both gauges, see Chart 7).

Performance of key hydraulic structures is contained in Section 4.5.3.7 for the March 2012 calibration event.

Chart 7: Lockhart 2012 – Model Calibration Stage Hydrograph Comparison



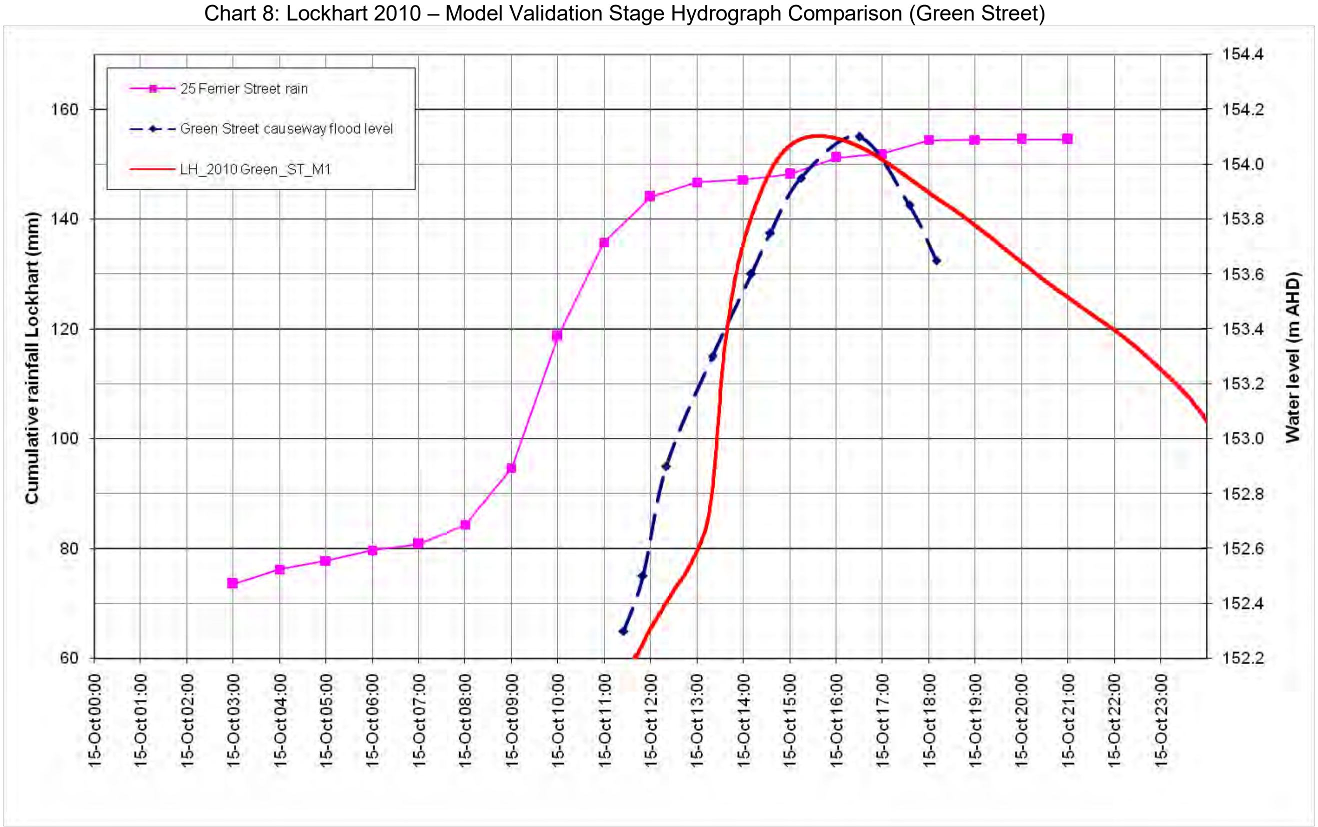
4.5.3.2. Hydraulic Validation Results

Figure 13 shows the modelled October 2010 flood event depths and extent (raster) as well as a comparison of observed peak flood levels to modelled levels (displayed as red points) at Lockhart. The maximum difference in peak flood level is an under estimate of 0.2 m (i.e. the modelled level is 0.2 m lower than that observed), however a mean absolute error of less than 0.1 m was achieved. This calibration is based on comparison of modelled and surveyed peak flood levels at 45 locations (see Section 2.6.2). Variation between observed and modelled levels was not noticed to be particularly positively or negatively biased, i.e. variance was due to minor localised effects, not overall model behaviour.

Furthermore, the observed stage hydrograph at the Green Street gauge (Reference 2) (see Section 2.6.1.1) was compared to the modelled flood levels. The modelled flood level and timing was found to accurately represent observed conditions (zero difference in peak and timing approximately one hour early, see Chart 7).

Performance of key hydraulic structures is contained in Section 4.5.3.7 for the October 2010 validation event.

Chart 8: Lockhart 2010 – Model Validation Stage Hydrograph Comparison (Green Street)



4.5.3.3. Discussion of Calibration/Validation Results

Given the absence of rated stream gauges (see Section 4.3) a joint calibration approach was utilised in which the hydrologic flow estimates are determined via the water levels they subsequently achieve in the hydraulic model. It was found at a range of model parameter combinations could achieve the same result (levels similar to those observed). As such an investigation was undertaken to determine the best combination of parameters for model calibration so that modelled levels not only matched surveyed peak flood levels but also observed stage hydrographs. A further discussion of this is contained in Appendix F.

The overall calibration/validation results are considered to be good with respect to both timing and modelled peak flood levels.

A unique feature of the Lockhart study is the match between the 2012 event and the estimated 1% AEP design flood. This fact, combined with the lack of general model sensitivity relative to freeboard, implies that a very high degree of confidence can be had in Lockhart design flood estimates.

4.5.3.4. Design Hydraulic Results

A number of maps have been produced to display the flood affected regions for the various design events. It should be noted that inundation patterns and/or peak flood levels shown for design events are based on best available estimates of flood behaviour within the catchment. Inundation from creek and particularly local overland flow may vary depending on the actual rainfall event, relative timing of flows and local influences (parked cars, change in topography, road works etc.). Please note however that results produced herein are relatively conservative in that local flow and creek systems are assumed to flood simultaneously.

A summary of the provided results are displayed below with further details in the following sections:

- Peak flood depths and levels for the design flood events (PMF, 5Y ARI, 10%, 5%, 2%, 1% and 0.5% AEP) (all depths < 200 mm clipped);
- Flood profiles along Brookong Creek for each design flood event modelled;
- Interim FPA and Provisional Hazard and Hydraulic Category maps; and
- A summary of the performance of key hydraulic structures.

4.5.3.5. Peak Flood Depths and Extents

Peak flood depths and extents for Lockhart are presented in Figure 14 - Figure 20 with the associated peak flood levels and flows displayed in Section 4.7.1 (Hotspot 1). Peak flood profiles for each modelled event at Brookong Creek are presented in Figure 21 along with the invert and obvert of Brookong Creek key hydraulic structures (see Figure 3 for structure locations). The performance of these hydraulic structures is detailed in Section 4.5.3.7.

Design results indicate that flooding along Galore Street (see Hotspot 2, Section 4.7.2) due to creek breakouts on the southern bank of Lockhart Government Dam can occur for events as small as the 5Y ARI event. For the 1% AEP flood as many as 18 homes are likely to become inundated and significant flooding of property lots (not necessarily over floor level inundation) in this region will also occur during this event.

During the 1% AEP event much of Lockhart will become inundated and overland flows from the Milbrulong region (see Section 4.7.3) are likely to cause flooding in the regions bordering East and Brookong Streets (see Sections 4.7.4 and 4.7.5 respectively). Access to the township of Lockhart will be restricted by flooding in these regions making Lockhart a high flood island (see Section 4.6). The timing of Creek and overland flows impacts on the access to the region (see Section 4.5.3.6). The PMF is found to inundate the entire town and is approximately 2 m higher than the 1% AEP event in which case central Lockhart will become a low flood island (see Section 4.6).

Flood depths and velocities along Urana Street are the highest in the region making the flood risk in this area significant. Sections 4.6 and 4.7.6 give further details on flooding characteristics along Urana Street.

4.5.3.6. Relative Timing of Major Overland Flow and Creek Flow

Significant overland flow that arrives from the Milbrulong region (see Section 4.7.3) causes flooding in the eastern and southern regions of Lockhart (primarily East and Brookong Streets, see Sections 4.7.4 and 4.7.5 respectively) away from Brookong Creek. As Brookong Creek causes flooding in the northern and western regions of town the combination of flood waters from the two mechanisms can cause Lockhart to become isolated (see Section 4.6).

In both the 2010 and 2012 events it was observed that Milbrulong peak flows arrived prior to Brookong Creek peak however it was noted that the timing was near coincidental. This was reproduced for both the calibration and validation models with peak flows arriving from the Milbrulong region approximately one hour prior to the Brookong Creek peak. Investigation of the design results indicates that the peak of the Milbrulong overland flows arrives in town (intersection of Brookong and East Streets) approximately 80 minutes prior to the peak at the Green Street gauge. However, during the 1% AEP event Brookong Creek is within 0.1 m of the peak flood level, and as such the two mechanisms effectively peak simultaneously.

The limiting factor from an access and emergency response aspect is the duration which flood levels remain elevated. Brookong Creek flows remain elevated much longer than Milbrulong overland flows. Flood levels on East Street remain elevated (greater than 0.1 m deep) for 1-2 hours and on Brookong Street they remain elevated for approximately 3.5 hours during the 1% AEP event which limits access to Lockhart. Timing and the duration of inundation is relatively insensitive to the design run (with the exception of the PMF) however is likely affected by storm duration. It is recommended that longer duration runs are undertaken as part of the FRMS&P in order to better inform SES flood planning.

4.5.3.7. Performance of Key Hydraulic Structures

A summary of the performance of key hydraulic structures within the hydraulic model extent is contained in the following tables. Table 15 presents the peak flood discharge and the structure details, Table 16 the peak flood level and structure overtopping level and Table 17 the peak flow velocity through each structure. The locations of these structures are contained in Figure 3.

It should be noted that the results displayed in the tables below apply purely to the hydraulic structures (bridge/culvert) displayed in Figure 3. The results for the 1D culverts pertain to the level at the upstream end of the pipe and the peak flow and velocity through the pipe. The 2D bridge results pertain to the peak flow and velocity under and over the bridge but not for flows that pass outside of the bridge extent (i.e. around the bridge).

Another important piece of infrastructure is the Lockhart Sewerage Works situated off the Urana-Lockhart Road south of the Brookong Creek Bridge. The sewerage works has a levee constructed to a level of 152.5 mAHD and is not inundated in the 0.5% AEP flood event. The PMF will overtop the levee by approximately 1.5 m.

Table 15: Peak Flood Discharge (m³/s)

Map ID	Name	Type	5Y ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	October 2010	March 2012
1	Lockhart Government Dam*	see Section 4.7.7	50	69	94	125	151	177	798	125	151
2	Green Street Pond Weir	Weir	37	44	53	61	69	76	228	61	69
3	Green Street Causeway**	9 x 2.1 x 0.9 m BC	36	43	52	61	69	76	160	46	52
4	Railway Bridge	Bridge	68	86	95	97	99	100	186	97	99
5	Urana Road Bridge	Bridge	66	85	95	104	110	116	203	104	110
6	East Street South Culverts	0.9 x 0.3 m & 0.6 x 0.3 m BC	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5
7	Railway Culverts	3 x 0.9 m Pipe	0.0	0.0	0.0	0.0	0.1	0.6	3.1	0.0	0.0
8	Milbrulong East Culverts***	8 x 1.06 m Pipe	2.2	3.3	5.0	6.9	8.3	9.8	13.5	8.3	8.3
9	Milbrulong Mid Culverts***	2 x 1.2 x 0.9 m BC	2.0	2.3	2.5	2.7	3.1	3.5	9.6	3.7	3.7
10	Lockhart-The Rock Rd Culverts	3 x 1.2 x 0.6 m BC	2.3	2.5	2.9	3.2	3.4	3.5	4.0	4.0	3.8
11	Milbrulong West Culverts***	7 x 0.6 m Pipe	0.1	0.3	1.1	2.0	2.7	3.1	3.8	2.4	2.6
12	East Street North Culverts	1.2 x 0.6 m & 1.2 x 0.45 m BC	0.7	0.7	0.8	0.8	0.8	0.8	1.2	1.0	1.0
13	Urana-Lockhart Rd Culverts	2 x 1.8 x 0.45 m Culverts	3.1	3.1	3.1	3.1	3.1	3.1	3.1	4.1	4.0

Table 16: Peak Flood Levels (mAHD)

Map ID	Name	Structure Overtopping Level	5Y ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	October 2010	March 2012
1	Lockhart Government Dam*	see Section 4.7.7	156.1	156.2	156.2	156.3	156.3	156.4	157.8	156.3	156.3
2	Green Street Pond Weir	151.7	153.6	153.8	154.0	154.3	154.4	154.6	156.6	154.3	154.4
3	Green Street Causeway**	see Section 4.7.1	153.5	153.7	153.9	154.1	154.3	154.4	156.4	154.1	154.3
4	Railway Bridge	154.5	152.5	152.8	153.2	153.4	153.6	153.7	155.3	153.4	153.6
5	Urana Road Bridge	154.0	152.1	152.4	152.6	152.9	153.1	153.2	155.0	152.9	153.1
6	East Street South Culverts	156.6	156.7	156.7	156.7	156.7	156.7	156.8	157.3	156.7	156.7
7	Railway Culverts	156.5	-	-	-	155.4	155.6	155.8	156.9	155.4	155.6
8	Milbrulong East Culverts***	162.4	161.6	161.7	161.8	162.0	162.2	162.3	162.3	162.0	162.2
9	Milbrulong Mid Culverts	159.8	158.8	158.8	158.9	158.9	159.0	159.0	159.7	158.9	159.0
10	Lockhart-The Rock Rd Culverts	162.1	161.8	161.9	161.9	162.0	162.0	162.1	162.1	162.0	162.0
11	Milbrulong West Culverts***	158.5	157.4	157.5	157.7	157.9	158.1	158.3	158.5	157.9	158.1
12	East Street North Culverts	157.2	156.6	156.6	156.6	156.7	156.7	156.8	157.6	156.7	156.7
13	Urana-Lockhart Rd Culverts	152.0	152.1	152.1	152.1	152.2	152.2	152.2	153.1	152.2	152.2

Table 17: Peak Flow Velocity (m/s)

Map ID	Name	Type	5Y ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF	October 2010	March 2012
1	Lockhart Government Dam*	see Section 4.7.7	0.5	0.8	1.0	1.2	1.4	1.5	1.6	1.2	1.4
2	Green Street Pond Weir	Weir	0.6	0.6	0.7	0.8	0.8	0.9	0.9	0.7	0.8
3	Green Street Causeway**	9 x 2.1 x 0.9 m BC	0.4	0.5	0.7	0.8	0.9	0.9	1	0.8	0.9
4	Railway Bridge	Bridge	1.0	1.4	1.7	1.7	1.7	1.7	1.8	1.6	1.7
5	Urana Road Bridge	Bridge	1.7	2.1	2.3	2.5	2.6	2.7	2.4	2.5	2.6
6	East Street South Culverts	0.9 x 0.3 m & 0.6 x 0.3 m BC	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8
7	Railway Culverts	3 x 0.9 m Pipe	0.0	0.0	0.0	0.2	0.7	1.0	2.2	0.0	0.2
8	Milbrulong East Culverts***	8 x 1.06 m Pipe	1.2	1.4	1.5	1.8	2.1	2.4	2.6	1.8	1.8
9	Milbrulong Mid Culverts***	2 x 1.2 x 0.9 m BC	2.1	2.1	2.1	2.2	2.2	2.2	5.2	2.2	2.2
10	Lockhart-The Rock Rd Culverts	3 x 1.2 x 0.6 m BC	2.1	2.1	2.1	2.1	2.1	2.1	4.0	2.2	2.2
11	Milbrulong West Culverts***	7 x 0.6 m Pipe	0.4	0.7	1.0	1.3	1.8	2.1	2.6	1.2	1.3
12	East Street North Culverts	1.2 x 0.6 m & 1.2 x 0.45 m BC	1.5	1.6	1.6	1.6	1.6	1.6	1.8	1.6	1.5
13	Urana-Lockhart Rd Culverts	2 x 1.8 x 0.45 m Culverts	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.1	4.0

* See Section 4.7.7 for further details

** see Section 4.7.1 for further details

*** see Section 4.7.3 for further details

Further investigation into the hydraulic performance of the Lockhart Government Dam (Location 1, see Figure 3) has been undertaken for the 1% AEP event. The main spillway and northern flow path convey 63% of the Brookong Creek flow (122 m³/s) whilst the centre breakout conveys 15% (30 m³/s). The western breakout that is responsible for diverting flow along Galore Street conveys the remaining flow to this region (22%, 43 m³/s). Remarkably similar flows and distribution were experienced during the March 2012 event.

4.5.4. Comparison of Design Results to Reference 1 Study

Results and model parameters were compared between the Reference 1 study and the current study. Both studies determined a critical duration of 6 hours for design events. It was noted that losses used in the Reference 1 study (15 mm and 3.5 mm/hr) were considerably higher than that used in the current study (10 mm and 2.5 mm/hr). This impacted on peak flows and flood levels indicating some sensitivity to changes in losses of this magnitude. Table 18 makes comparisons between the two studies at the Green Street causeway. It can been seen that the current study has higher flows and associated flood levels than the Reference 1 and this is mainly due to the lower losses than have been used.

It is considered that a continuing loss of 3.5 mm/hr is on the higher end of what is acceptable for the Brookong Creek catchment and that a continuing loss of 2.5 mm/hr (see Section 4.3.2.2) is more suitable for the region.

In the context of previous flood events (see Table 1) it also makes sense that the 1% AEP flood level at the Green Street causeway is higher than that determined in the Reference 1 study as otherwise there have been 5 events that approximately equal or exceed the 1% AEP event at Lockhart since 1931 (1931, 1934, 1936, 2010, 2012). It is therefore logical that lower losses be utilised and that design flood levels are revised upwards.

Table 18: Comparison of Flows and Levels to the Reference 1 Study

Event	Flow (m³/s)		Level (m AHD)	
	Reference 1 Study	Current Study	Reference 1 Study	Current Study
5Y ARI	46	67	152.7	153.5
1% AEP	198	231	153.8	154.3
PMF	2100	2876	155.7	156.6

4.5.5. Relative Magnitude of Historic Events

Examination of peak flood profiles (Figure 21) and hydrologic model flows (Table 14) reveals the approximate recurrence interval of the 2012/2010 flood events for Brookong Creek at Lockhart. Remarkably the March 2012 flood event had a flow equal to the 1% AEP flow (231 m³/s) and flood levels are generally the same with the exception of regions proximate to the footbridge (see Section 1.4.2.4). A summary of findings for the 2010 flood are displayed below in Table 19. It should be noted that the upper and lower limiting recurrence intervals are estimates only obtained from the peak flood profiles (Figure 21). The interpolated approximate recurrence interval was determined via the logarithmic interpolation of flows (Table 14).

Table 19: 2010 Upper and Lower Limiting Recurrence Intervals

Study Area	2010 Event		
	upper limiting	low limiting	Interpolated
Lockhart	50Y	20Y	~48Y

The exceedance probabilities of the October 2010 and the March 2012 flood events vary significantly to the exceedance probabilities of the associated rainfall (see Section 2.4.4). In the March 2012 event, 5% AEP rainfall became a 1% AEP flood whilst in the October 2010 event 1% AEP rainfall became an approximately 2% AEP event.

The discrepancy between rainfall and flood probability relates to differences in excess rainfall between historical and design events, aerial reduction factors (applied to design rainfalls) as well as the temporal distribution of rainfall.

4.5.6. Sensitivity Analysis Results

Sensitivity analysis was carried out in order to assess the effect that adjusting model parameters had on design model results. Comparisons were carried out using peak flood levels and flows for the 1% AEP design event. Results are presented in Table 20 and the locations of the points are displayed in Figure 3. Sensitivity to increases in rainfall intensities have also been investigated with results being displayed in the climate change section (Section 4.5.7).

Table 20: Model Parameter Sensitivity

ID	Location	Change in Peak Level (m)**							
		Loss +20%	Loss -20%	Lag +20%	Lag -20%	n' +20%	n' -20%	Blockage 50%	Old ARF*
A	Green St Causeway	-0.07	0.07	-0.11	0.13	0.06	-0.06	0.04	0.09
B	Railway Bridge	-0.06	0.05	-0.10	0.10	0.03	-0.03	0.05	0.07
C	Urana Road Bridge	-0.10	0.08	-0.16	0.16	0.11	-0.15	0.07	0.11
D	Government Dams	-0.04	0.03	-0.07	0.07	0.04	-0.04	0.00	0.05
E	Milbrulong Area	-0.01	0.01	-0.01	0.01	0.00	0.00	0.01	0.01
F	Green Street East	-0.01	0.01	-0.01	0.01	0.00	0.00	0.00	0.01
G	Reid Street	-0.09	0.08	-0.15	0.15	0.07	-0.08	0.06	0.11
H	Hospital	-0.01	0.01	-0.01	0.02	0.00	0.00	0.01	0.02
I	Post Office	-0.03	0.04	-0.04	0.09	0.06	-0.03	0.01	0.06
J	Conflux Creeks	-0.07	0.07	-0.12	0.14	0.08	-0.09	0.01	0.10
K	Galore/O'Connell St	-0.01	0.01	-0.01	0.02	0.01	0.00	0.00	0.01
L	D/S Channel	-0.06	0.06	-0.10	0.11	0.08	-0.09	0.00	0.08
	Average	**-0.05**	**0.04**	**-0.07**	**0.08**	**0.04**	**-0.05**	**0.02**	**0.06**

* Comparison of design flows derived using ARR87 ARF and the CRC-Forge method ARF.

** A positive value indicates that the flood level in the base case is lower than in the sensitive run.

The model is generally insensitive to tested parameter variability, with the average variation to peak flood levels associated with the tested parameters being less than 0.1 m for all tested scenarios. Variation to losses had little impact on peak flood levels with an absolute average difference of -0.09 m and 0.07 m for both positive and negative variations. Variation to the WBNM lag parameter had the largest impact on peak flood levels of all tested parameters however as a catchment average an absolute difference of 0.08 m was still achieved. Flood levels at the selected comparison points showed almost no sensitivity to differences in the blockage percentage of structures.

The ARR87 ARF created slightly higher flood levels than the new CRC-Forge method ARF, however changes to peak flood levels were generally not much greater than 0.1 m indicating only minor sensitivity for the 1% AEP event.

Sensitivity analysis showed that downstream boundary conditions at Lockhart had zero impact on peak flood levels and flows in the defined study area.

4.5.7. Climate Change

Climate change is predicted to have an effect on rainfall intensities, although estimates of how much and timescales of this phenomenon vary. To account for a possible increase in rainfall intensities associated with climate change, modelling was performed with increases of 10%, 20% and 30% increase to rainfall for the 1% AEP event. To put the climate change sensitivity runs into context a 30% rainfall increase for the 1% AEP event implies that a 0.2% AEP event is being run (i.e. 500Y ARI event).

Table 21 presents the corresponding increases in peak flood levels at key locations (displayed in Figure 3) within the study area. Generally peak flood levels are relatively insensitive to increases in rainfall. The Urana Road Bridge experiences the greatest increase to peak flood level (0.4 m increase for a 30% increase in rainfall). Flooding on Reid Street is also affected in a similar manner (0.3 m increase for a 30% increase in rainfall). Generally then, relative to freeboard, the results of the climate change runs are that 1% AEP levels plus freeboard will generally account for changes due to climate change as currently predicted.

Table 21: Climate Change Peak Flood Levels

ID	Location	1% AEP Flood Level (mAHD)	Change in Peak Level (m)		
			10% rainfall increase	20% rainfall increase	30% rainfall increase
A	Green St Causeway	154.29	0.11	0.21	0.31
B	Railway Bridge	153.58	0.09	0.15	0.24
C	Urana Road Bridge	153.05	0.14	0.28	0.39
D	Government Dams	156.99	0.06	0.11	0.16
E	Milbrulong Area	156.74	0.01	0.03	0.05
F	Green Street East	156.69	0.01	0.02	0.03
G	Reid Street	153.29	0.14	0.27	0.36
H	Hospital	154.90	0.02	0.03	0.05
I	Post Office	154.64	0.08	0.15	0.23
J	Conflux Creeks	154.59	0.12	0.23	0.32
K	Galore/O'Connell St	155.70	0.02	0.04	0.07
L	d/s Channel	151.46	0.10	0.19	0.26
-	**Average**	**-**	**0.08**	**0.14**	**0.21**

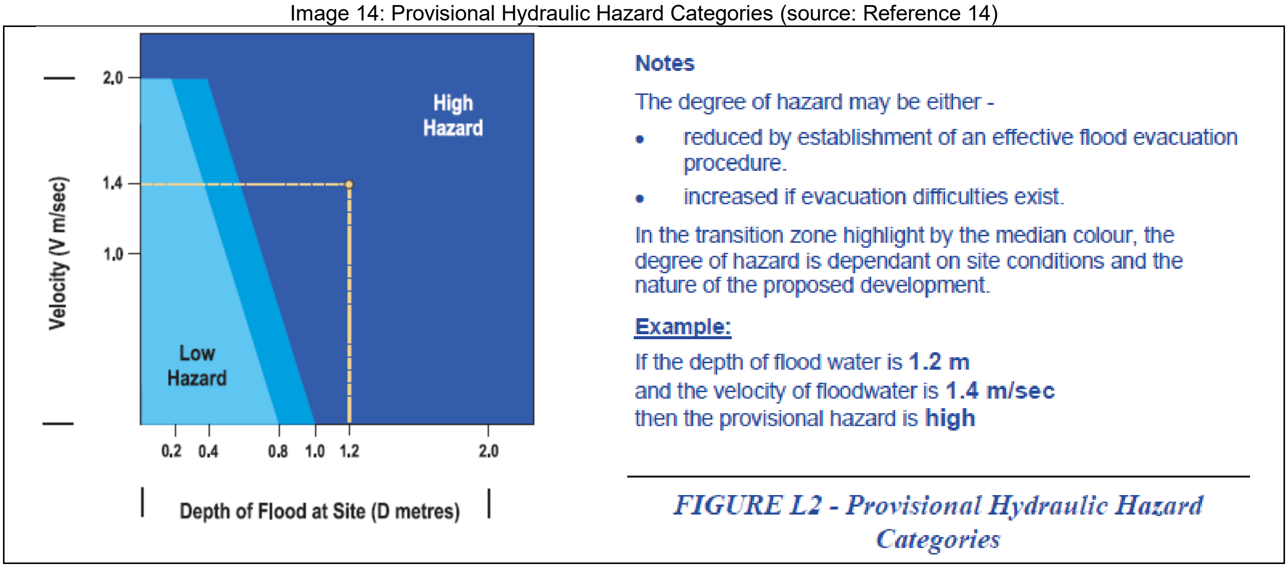
4.5.8. Preliminary Hazard Classification

The risk to life and potential damages to buildings during floods varies both in time and place across the floodplain. In order to provide an understanding of the effects of a proposed development on flood behaviour and the effects of flooding on development and people, the floodplain can be sub-divided into hydraulic and hazard categories. This categorisation should not be used for the assessment of development proposals on an isolated basis, rather they should be used for assessing the suitability of future types of land use and development in the formulation of a floodplain risk management plan.

Hazard is a measure of the overall harm caused by flooding and should consider a number of factors including the depth of flooding, velocity of flood waters, access to escape routes, duration etc. In the first instance provisional hazard categories can be defined based on the depth and velocity of floodwaters. Provisional flood hazard categories were defined in this study in accordance with the *Floodplain Development Manual - Figure L2* (Reference 15) as indicated below.

The hazards are provisional because they only consider the hydraulic aspects of flood hazard. High and low provisional hazard areas were defined for the 1% and 0.5% AEP events and are displayed in Figure 22 and Figure 23. The *Floodplain Development Manual* (Reference 15) requires that other factors be considered in determining the “true” hazard such as size of flood, effective warning time, flood readiness, rate of rise of floodwaters, depth and velocity of flood waters, duration of flooding, evacuation problems, effective flood access, type of development within the floodplain, complexity of the stream network and the inter-relationship between flows.

Image 14: Provisional Hydraulic Hazard Categories (source: Reference 14)



4.5.9. Hydraulic Categorisation

Hydraulic categorisation of the floodplain is used in the development of the Floodplain Risk Management Plan. The *Floodplain Development Manual* (Reference 15) defines flood prone land to fall into one of the following three hydraulic categories (refer definition in Appendix A):

- Floodway,
- Flood Storage, and
- Flood Fringe.

Floodways are areas of the floodplain where a significant discharge of water occurs during floods and by definition if blocked would have a significant effect on flood flows, velocities or depths. Flood storage are areas of importance for the temporary storage of floodwaters and if filled would significantly increase flood levels due to the loss of flood attenuation. The remainder of the floodplain is defined as flood fringe. There is no technical definition of hydraulic categorisation and different approaches are used by different consultants and authorities.

Appendix G details the methods used to determine the floodway at Lockhart. Once the floodway was defined the remainder of the floodplain outside the floodway becomes either flood storage or flood fringe. In this study Flood Storage was defined as the land outside the Floodway if the depth is greater than 0.5 m and Flood Fringe if the depth is less than 0.5 m.

Hydraulic categorization of the 1% and 0.5% AEP events is presented in Figure 24 and Figure 25. The investigation into appropriate criteria for defining floodways is provided in Appendix G.

Using the implemented classification system, the floodway extent is defined mainly to the Brookong Creek inbank not in the overbank areas away from defined watercourses which seems appropriate given the distributed nature of flows. Note it is likely levee failure scenarios to be investigated as part of the subsequent FRMS will lead to additional areas being defined as floodway.

In Lockhart it can be seen that multiple residential lots are defined within the Burkes Creek floodway particularly along Urana Street (see Hotspot 6, Section 4.7.6) and Galore Street (see Hotspot 2, Section 4.7.2). Overland flows from the Milbrulong region were determined to not have a significant floodway due to the relatively slow velocities and shallow depths in the region.

4.6. Provisional Flood Emergency Response Planning Classification

To assist in the planning and implementation of response strategies, the SES in conjunction with OEH has developed guidelines to classify communities according to flood affectation and risk. These Emergency Response Planning (ERP) classifications consider flood affected communities as those in which the normal functioning of services is altered, either directly or indirectly, because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue. Communities are classified as either; Flood Islands (high and low); Road Access Areas; Overland Access Areas; Trapped Perimeter Areas (high and low) or Indirectly Affected Areas.

Key considerations for flood emergency response planning in these areas include:

- cutting of external access isolating an area;
- key internal roads being cut;
- transport infrastructure being shut down or unable to operate at maximum efficiency;
- flooding of any key response infrastructure such as hospitals, evacuation centres, emergency services sites;
- risk of flooding to key public utilities such as gas, power, sewerage; and
- the extent of the area flooded.

The ERP classification can identify the type and scale of information needed by the SES to assist in emergency response planning (refer to Table 22).

Table 22: Emergency Response Planning Classification of Communities

	EMERGENCY RESPONSE		
Classification	**Resupply**	**Rescue/Medivac**	**Evacuation**
High flood island	Yes	Possibly	Possibly
Low flood island	No	Yes	Yes
Area with rising road access	No	Possibly	Yes
Area with overland escape routes	No	Possibly	Yes
Low trapped perimeter	No	Yes	Yes
High trapped perimeter	Yes	Possibly	Possibly
Indirectly affected areas	Possibly	Possibly	Possibly

Provisional ERP classification was undertaken for the 5Y ARI, 1% AEP and PMF events with the classified regions presented in Figure 26. It is worth noting at this point that the PMF event is a highly improbable event. Its probability can be estimated as somewhere between 100,000Y ARI and 1,000,000Y ARI.

Figure 26 displays that the township of Lockhart is situated on a high flood island during the 1% AEP event and is likely to become a low flood island during events greater than the 0.5% AEP up to the PMF. This creates a high risk situation as the region is first isolated and then later inundated during large flood events.

The flood island is created when flows from the Milbrulong region meet the Oakland/The Rock Railway and are forced west towards town (see Hotspot 3, Section 4.7.3). Flood waters continue west along Brookong Street (see Hotspot 5, Section 4.7.5) and north along East Street (see Hotspot 4, Section 4.7.4) restricting evacuation access to the south and east of town. Generally peak flood levels in this region peak 1.5 hours before Brookong Creek and remain elevated for 1 – 3.5 hours restricting access to Lockhart (see Section 4.5.3.6 for further details on flood timing).

South Lockhart experiences similar access problems due to Brookong Creek flows to the west and Milbrulong overland flows to the east. The two flow paths meet to the south of town restricting access in all directions.

Other regions in the Study Area are generally classed as either 'Rising Road Access Areas' or 'Areas with Overland Escape Routes'.

Examination of the design results maps (Figure 14 - Figure 20) and flood hazard maps (Figure 22 and Figure 23) display the regions which are likely to be affected from various sized events and the associated flood hazard. The high risk regions are primarily situated bordering Brookong Creek, with Urana, Galore, Ferrier and lower Green Streets all significantly affected (during the 1% AEP event). Milbrulong overland flows predominantly affect Brookong Street however can also affect East, Drummond and Hebden Streets.

Urana Street (see Hotspot 6, Section 4.7.6) experiences the most dangerous flood characteristics in the region with deep high velocity flows. It is likely that during a major flood event emergency rescues may be required to avoid risk to life.

It is recommended longer duration design runs are undertaken for the subsequent FRMS&P in order to better inform the SES regarding evacuation and access to town for SES personnel.

4.7. Hotspots/SES Locations of Interest

It is standard practice to identify flooding hotspots as part of the Flood Study and provide some detailed information for flood mechanisms impacting on these locations. A hotspot is identified as an area of interest from a flooding perspective. For example, locations where many residences are liable to flooding might be defined as hotspots as might other locations where key drainage assets are not meeting design standards or where key infrastructure, such as a highway, is flood affected.

Further as part of the Brief information for up to 10 hotspots, or SES locations of interest, were specified. This section provides information on hotspots/locations of interest. Further locations will likely be examine as part of the FRMS&P.

4.7.1. Hotspot 1 - Green Street Causeway

The Green Street causeway is overtopped at a level of 152.2 mAHD and is the main road crossing that separates east and west Lockhart (see Figure 27). The gauge at the causeway is recommended as the gauging station for the Lockhart FIC in References 2 & 3. The hydraulic performance of the causeway can be seen in Section 4.5.3.7 and a summary of design flows (see Table 14) and peak flood levels (see Table 16) is reiterated in
Table 23.

Table 23: Hotspot 1 – Green Street Causeway Flow Characteristics

Event	Level (mAHD)	Stage (m)	Flow (m³/s)
5Y ARI	153.5	1.3	67
10% AEP	153.7	1.6	95
5% AEP	153.9	1.8	134
October 2010	154.1	2.0	177
2% AEP	154.1	2.0	185
March 2012	154.3	2.1	231
1% AEP	154.3	2.1	231
0.5% AEP	154.4	2.2	281
PMF	156.4	4.2	2876

* Flows taken at Cross Section A, Figure 27. Stage and levels recorded at Green Street causeway gauge.

As discussed previously a result of interest is that the March 2012 flood had the same flow and peak flood level as the 1% AEP event and the October 2010 event very closely approximated the 2% AEP event. The difference in peak flood level between these two events is 0.2 m.

4.7.2. Hotspot 2 - Galore Street

Galore Street was significantly affected by flooding during both the October 2010 and March 2012 flood events. Flooding in Galore St is predominantly caused by Government Dam being overtopped on the southern bank which diverts flows towards Galore Street (see Figure 28). A small drainage canal with a raised embankment runs behind the houses on the northern side of Galore Street (see Section 1.4.2.2). Flood waters were reported to have entered Galore Street near its intersection with East Street but were then unable to flow back towards the creek further downstream due to the raised embankment.

Table 24 displays design flows entering Galore Street due to overtopping of Government Dam on the southern bank.

Table 24: Hotspot 2 – Galore Street Flows

Event	5Y ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Flow (m³/s)	8.6	14.3	22.6	33.4	43	53.7

* Flows taken at Cross Section B, Figure 28.

Flood depths at Galore St range from approximately 0.1 m in the 5Y ARI event to 0.4 m in the 1% AEP event (at the road centreline) and velocities are in the order of 1 m/s (~ walking speed) for the 1% AEP event.

18 homes in the region were flooded over floor level during the March 2012 event (Reference 3) which is the same number of homes that are likely to be overtopped during the 1% AEP event. For all of the larger flood events modelled (5% AEP and greater), significant flows are also predicted to travel down Ferrier Street.

Examination of the hydraulic categorisation maps (Figure 24 and Figure 25) show that the majority of homes on the northern side of Galore Street are situated in the Brookong Creek floodway.

4.7.3. Hotspot 3 - The Rock/Oaklands Railway East of Lockhart

A number of overland flow paths originate in the Milbrulong region (situated to the east of Lockhart) and flow in a southerly direction until they meet The Rock/Oaklands Railway (see Figure 29). These flow paths have a combined catchment area of 22.6 km². The Railway has a number of culverts to transfer flow to the southern side however the capacity (combined culvert flow during 1% AEP event is ~30 m³/s) is not sufficient to fully transfer all flows. As such 15.1 m³/s flows into the township of Lockhart during the 1% AEP event (see Table 25 for other design events) which causes flooding along East Street (see Section 4.7.4) and Brookong Street (see Section 4.7.5).

Table 25: Hotspot 3 – The Rock/Oaklands Railway East of Lockhart

Event	5Y ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	PMF
Flow (m³/s)	3.4	5.3	7.4	11.0	15.1	17.3	69.9

* Flows taken at Cross Section C, Figure 29.

4.7.4. Hotspot 4 - East Street

Flooding in East Street (see Figure 30) is due to flood waters from the Milbrulong region that flow along The Rock/Oaklands Railway (see Section 4.7.3) from the east. In smaller events (less than 5Y ARI) flows do not overtop East Street and thus travel in a northerly direction in the channel that flows past Galore Street (see Section 4.7.2), however when the capacity of this channel is exceed ponding occurs on the eastern side of East Street. For all tested design events flood levels exceed the level of East Street causing flood waters to overtop the road and flow into Lockhart.

Flood depths and velocities in the region are relatively low (generally less than 0.2 m, ~ 1 m³/s respectively in the 1% AEP event) however it is not recommended to drive through flood waters and as such vehicle access along this road is likely to be restricted, particularly during larger events.

Due to the damming affect that East Street has on flows from the east, flood waters in the region can remain elevated for in excess of two hours. An examination of the timing and flow characteristics that affect this area are contained in Section 4.5.3.6.

4.7.5. Hotspot 5 - Brookong Street

Flooding along Brookong Street (see Figure 31) is due to flood waters that arrive from the east of town that flow along The Rock/Oaklands Railway (see Section 4.7.3). The majority of flow which comes from the Hotspot 3 region (see Section 4.7.3) travels down Brookong Street and discharges into Brookong Creek after passing Urana Street. Table 26 displays the flow travelling down Brookong Street for the design events. Depths for the 1% AEP flood along Brookong Street generally range from 0.1 - 0.3 m (at the road crest) up to 0.5 m in the gutters. Velocities generally do not exceed 1 m/s.

Table 26: Hotspot 5 – Brookong Street Flows

Event	5Y ARI	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP
Flow (m^3/s)	1.1	2.4	4.1	5.7	9.4	13.6

* Flows taken at Cross Section D, Figure 31.

4.7.6. Hotspot 6 – Urana Street

Significant yard/shed flooding for events as small as the 5Y ARI event is likely for properties along Urana Street (see Figure 32) between Green Street and Brookong Street. For the 10% AEP event and larger, flood waters begin to exit Brookong Creek and flow down Urana Street at both the Urana Street and Green Street causeways.

The Reference 3 study indicated that all properties and business (24) on the western side of Urana Street became inundated during the March 2012 flood and accordingly the same number will become inundated during the 1% AEP flood. Figure 22 displays that the entire Urana Street region is subject to high hazard flow during the 1% AEP event and flood depths and velocities along the road centreline exceed 1.5 m and 2 m/s in some locations.

Due to the high velocities and flood depths along Urana Street the flood risk and hazard is the highest in the region.

Examination of the hydraulic categorisation maps (Figure 24 and Figure 25) show that the majority of homes on the western side of Urana Street are situated in the Brookong Creek floodway.

Urana Streets flood affectation will be a major focus of the subsequent FRMS&P, as it is here that the highest levels of flood risk exist within Lockhart.

4.7.7. Hotspot 7 – Government Dam

The Lockhart Government Dam (see Section 1.4.2.1) is located upstream of the township to the north-east of Galore Street (see Figure 33). The dam is actually a combination of two dams which have a combined capacity (at the spillway level, approximately 155.1 m AHD) of 12,000 m^3. Once the dam exceeds 73,000 m^3 floodwaters begin to flow over the southern bank (at a level of approximately 156.1 mAHD) and cause flooding in Galore Street (see Hotspot 2, Section

4.7.2).

During the 1% AEP event 194 m³/s of flow enters the Dam at the flood peak. Of this 60 m³/s is discharges over the spillway, 43 m³/s flows over the southern bank and into Galore Street, 30 m³/s flows over the mid-bank and 60 m³/s flows around the embankment to the north of the Dam. The breakdown of flow distribution of all events up to the 0.5% AEP flood is presented in Table 27 with the locations of the flow distribution displayed in Figure 33.

Table 27: Hotspot 7, Government Dam Flow Distribution (m³/s)

Event	Peak Inflow	Spillway	Southern Bank	Mid Bank	North of Dam
5Y ARI	58	33	9	1	15
10% AEP	82	39	13	5	25
5% AEP	115	47	22	11	36
2% AEP	156	54	32	21	50
1% AEP	194	60	43	30	60
0.5% AEP	235	67	54	39	75

As can be seen in Table 27 the Dam provides no mitigation of peak flows for events from the 5Y ARI event or larger.

5. MOVING FORWARD

This report is a draft flood study. Feedback received in reference to this report will be incorporated in the next stages, namely the draft flood study, floodplain management study and draft plan report. At this stage damages will be calculated and various measures to ameliorate flooding or reduce overall flood risk will be presented. Key to this will be looking at the flood liability of Urana Street in particular, but also other heavily impacted areas such as Green Street and Galore Street.

In particular there is a need to examine both ways the Government Dam might be altered to achieve better outcomes in regards to flood liability, and how failure of Government Dam might impact flood risk relative to design flood events presented herein.

6. ACKNOWLEDGEMENTS

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Figures

FIGURE 1
LOCKHART STUDY AREA

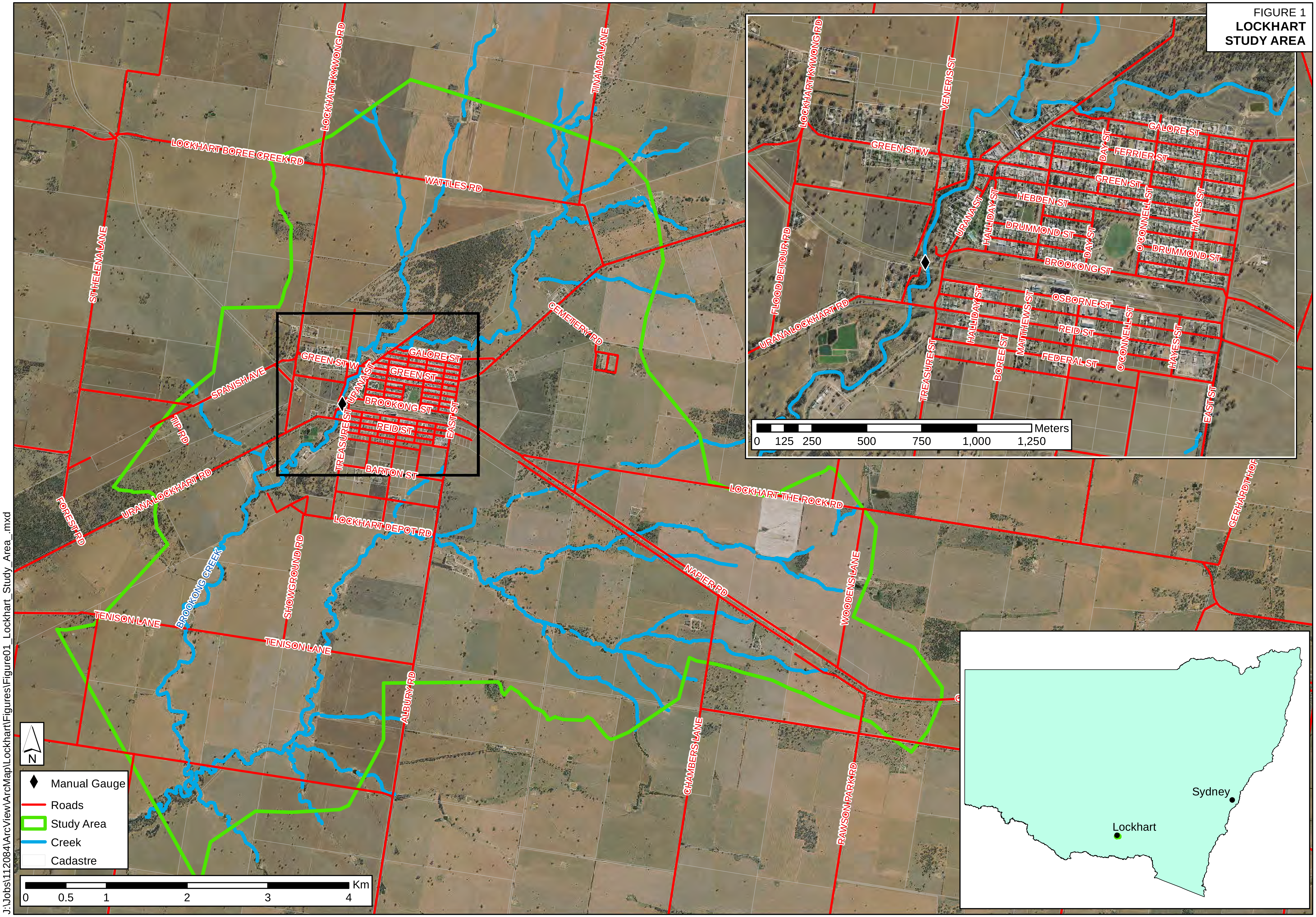
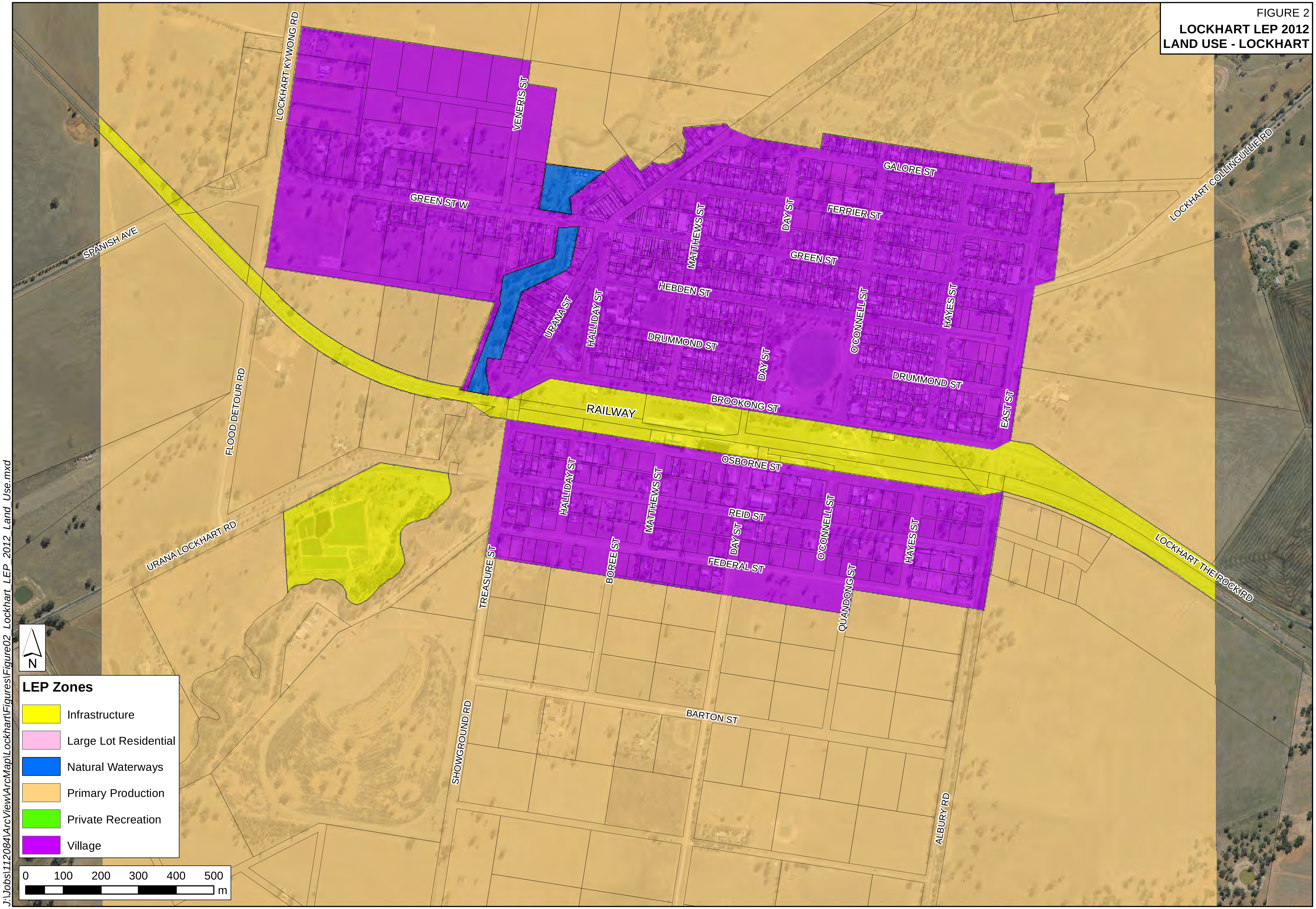
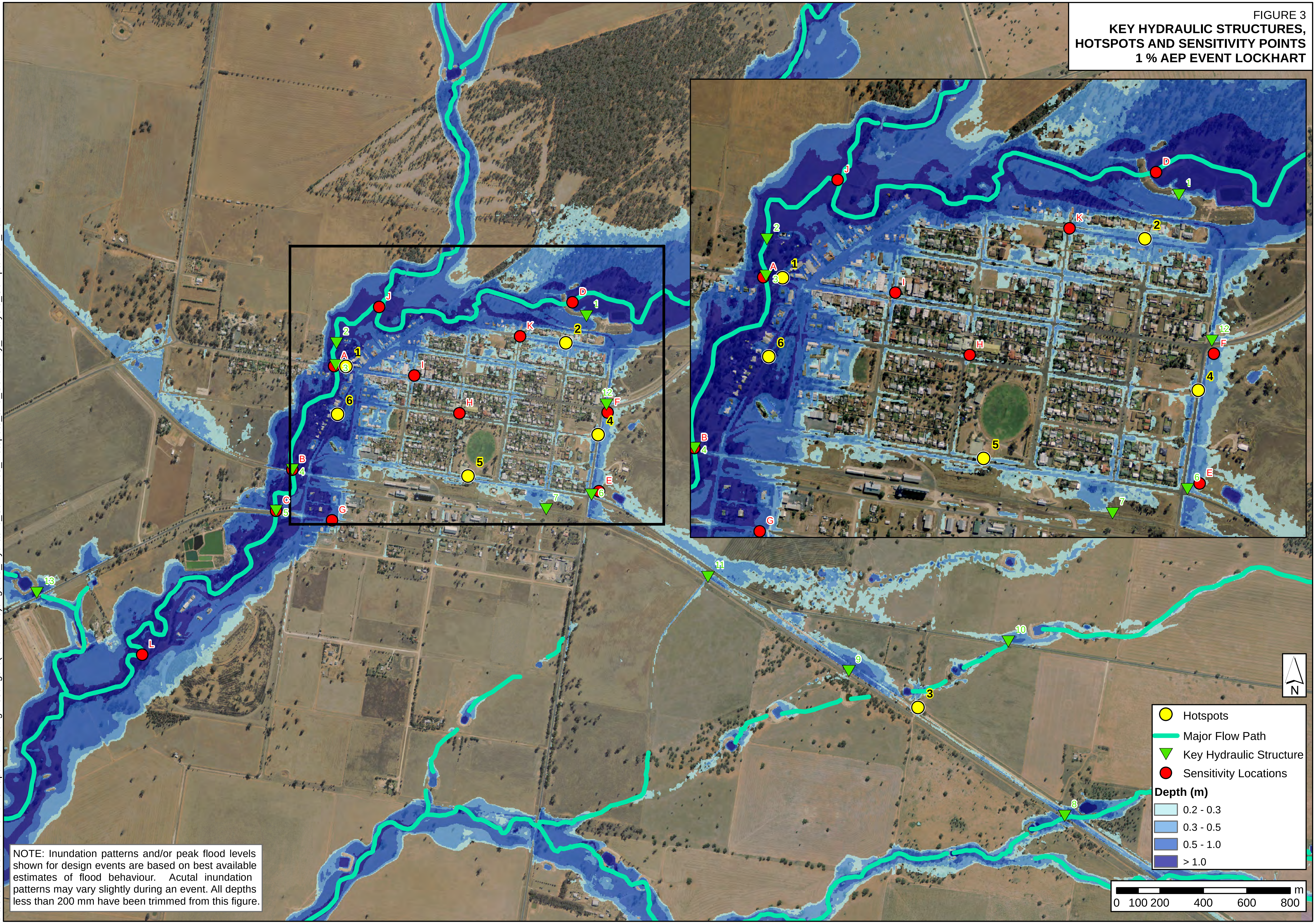


FIGURE 2
LOCKHART LEP 2012
LAND USE - LOCKHART

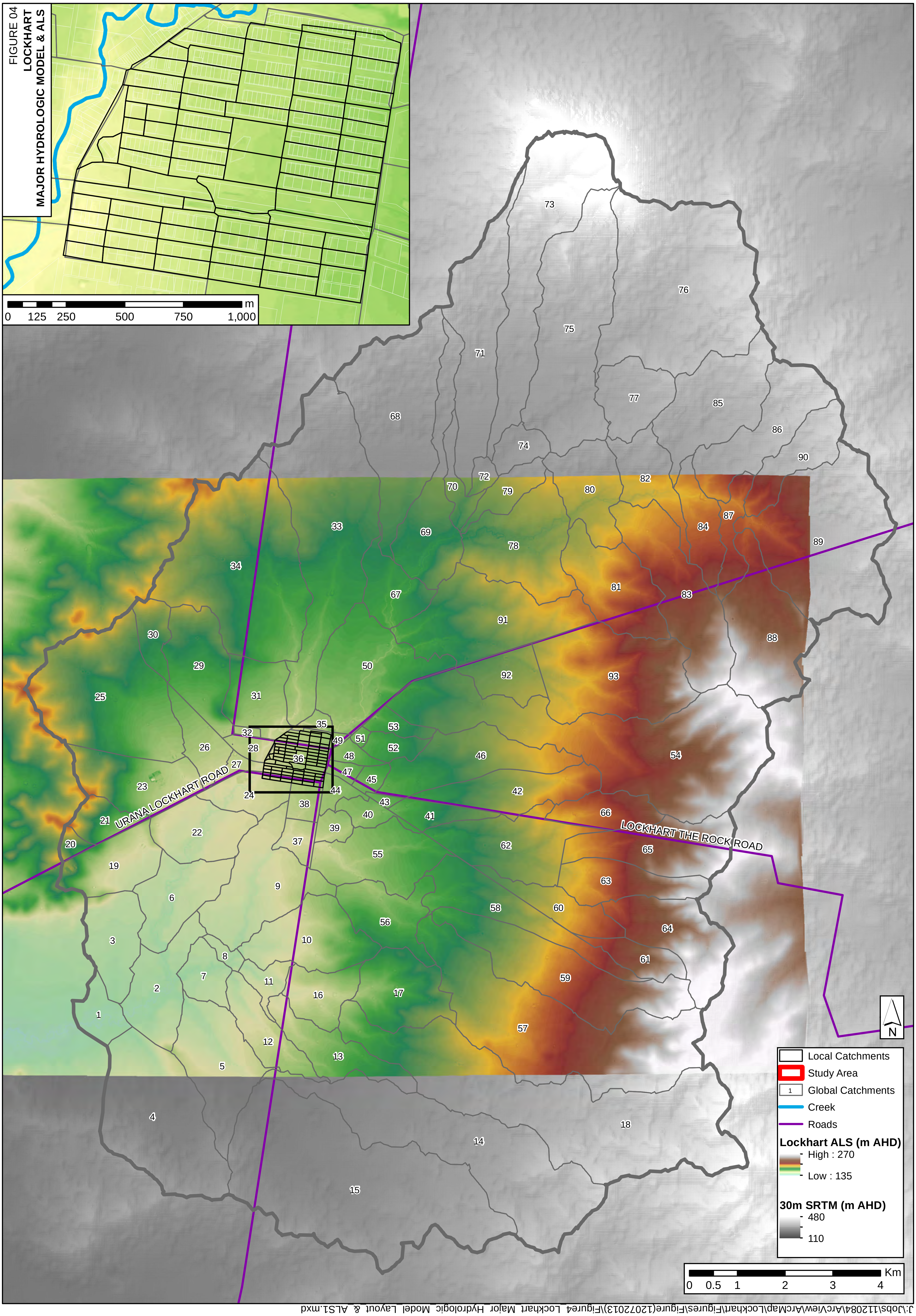


J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure02_Lockhart_LEP_2012_Land_Use.mxd

FIGURE 3
KEY HYDRAULIC STRUCTURES, HOTSPOTS AND SENSITIVITY POINTS 1 % AEP EVENT LOCKHART



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure3_Hydraulic_Structures_Hotspots_and_Sensitivity_Analysis_Comparison_Points.mxd



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure4_Lockhart_Major_Hydrologic_Model_Layout_&_ALS1.mxd

J:\Jobs\112084\Hydrology\Lockhart\Figure5_Lockhart_IFD_Bursts_MACRO_2012.xlsm

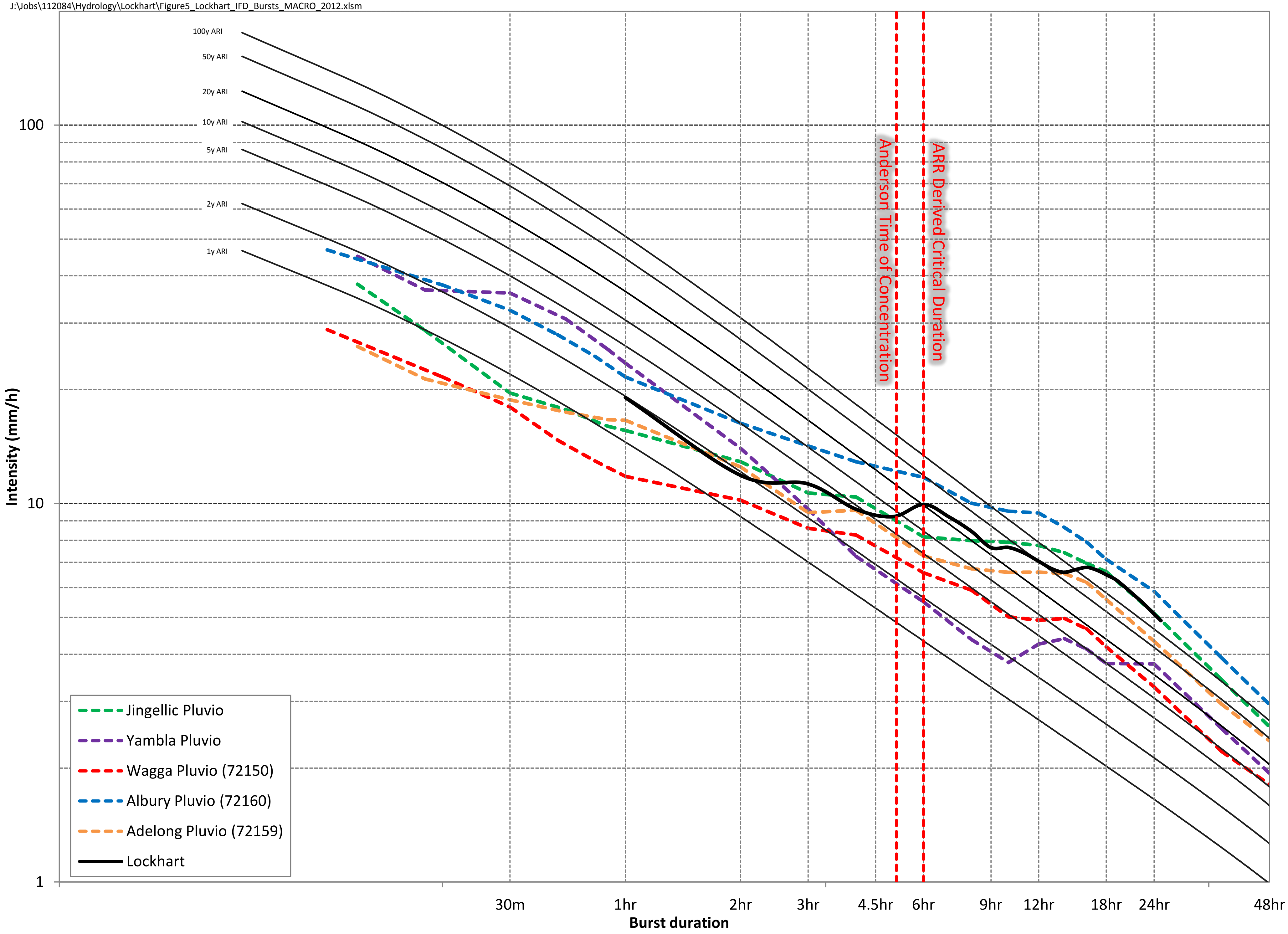


FIGURE 5
MARCH 2012
BURST INTENSITIES AND FREQUENCIES

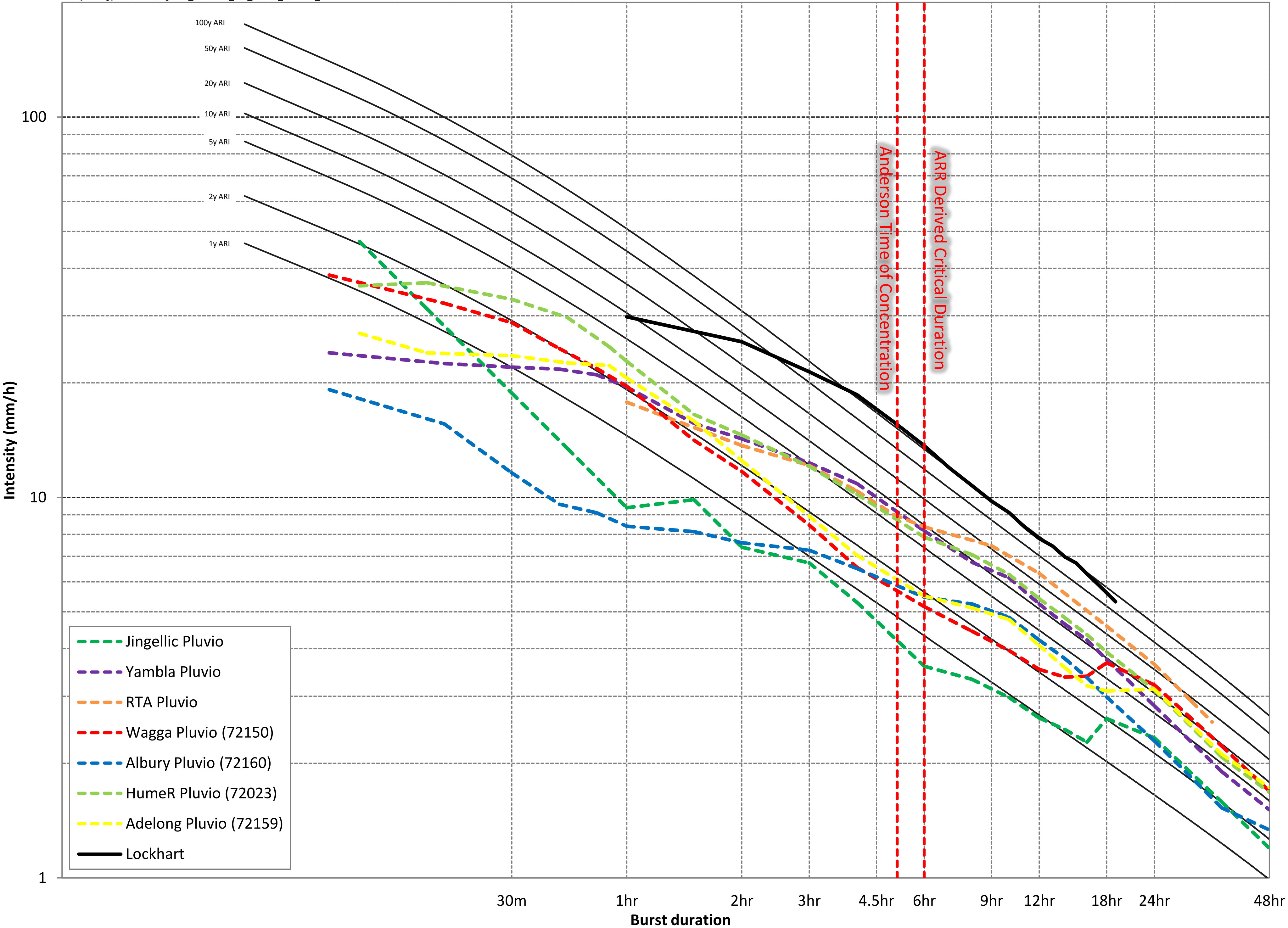
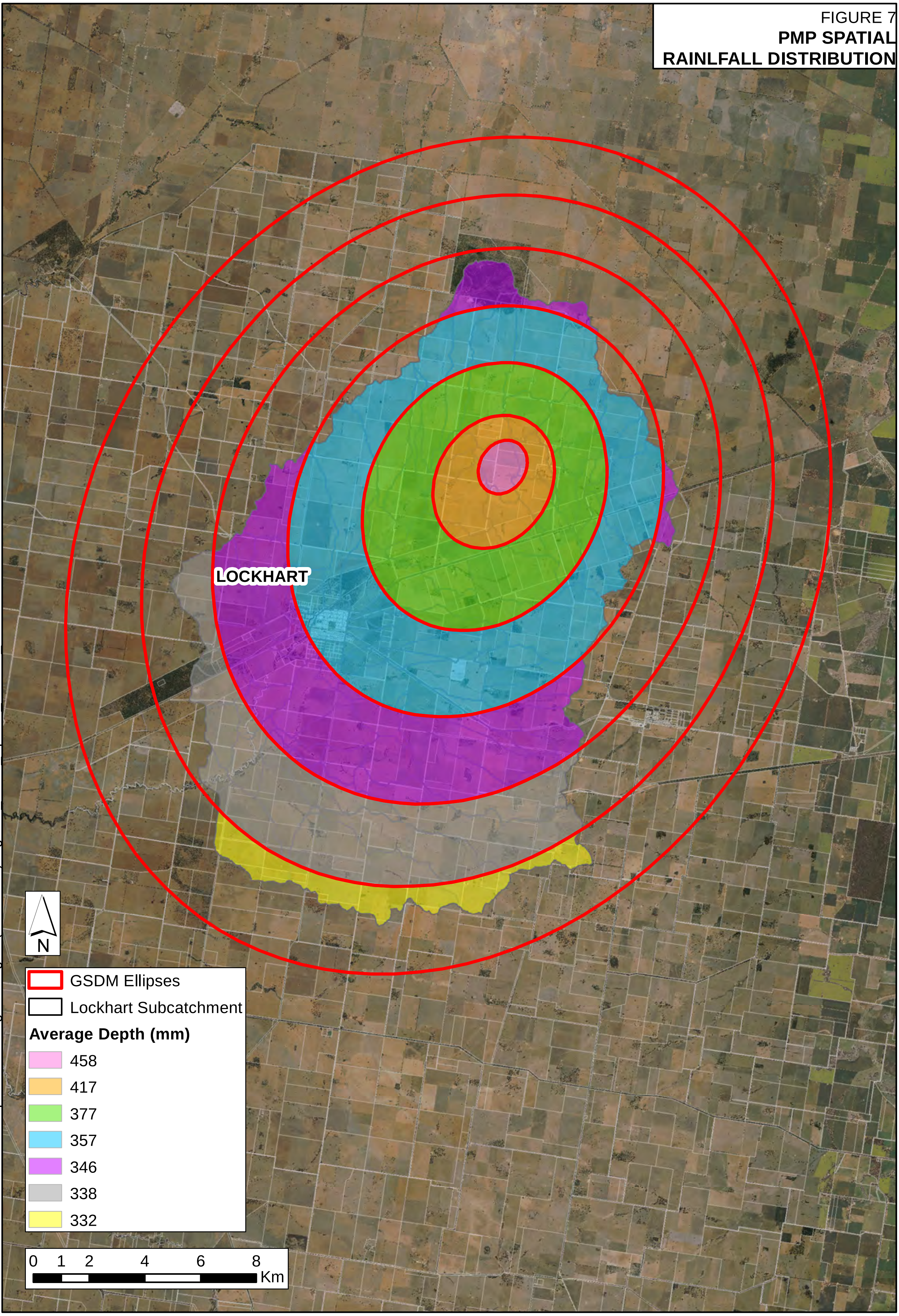


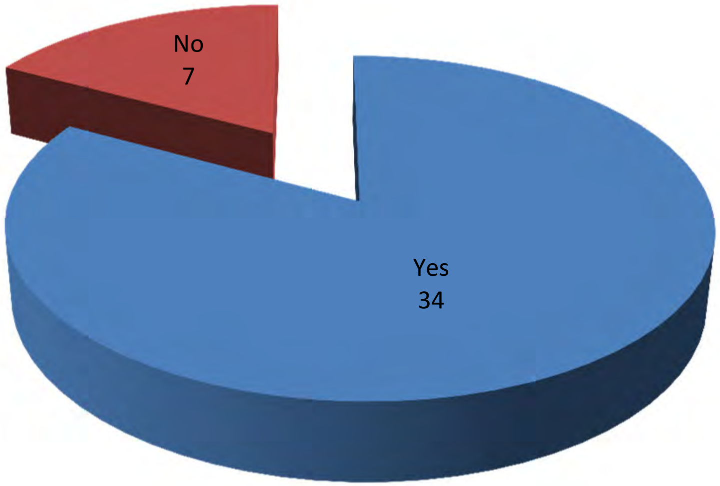
FIGURE 6
OCTOBER 2010
BURST INTENSITIES AND FREQUENCIES



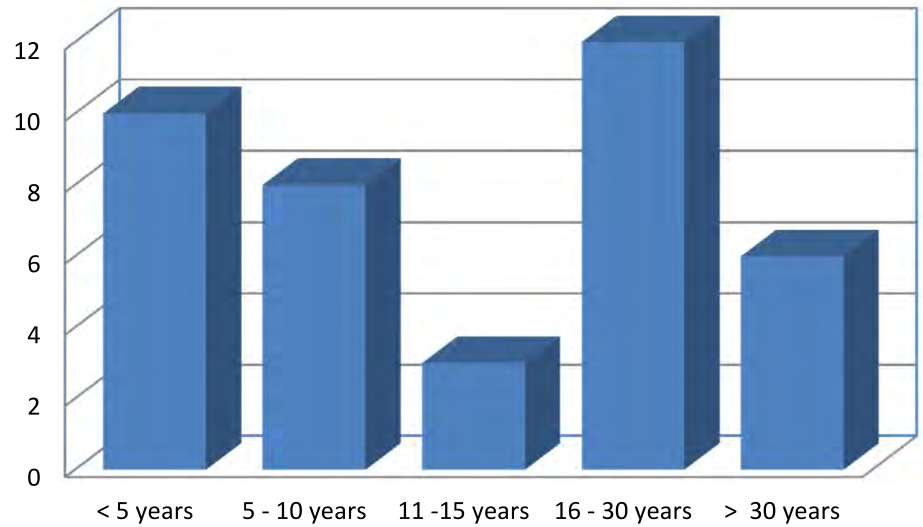
J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure7 PMP Spatial Rainfall Distribution.mxd

FIGURE 8
LOCKHART
COMMUNITY CONSULTATION RESPONSES

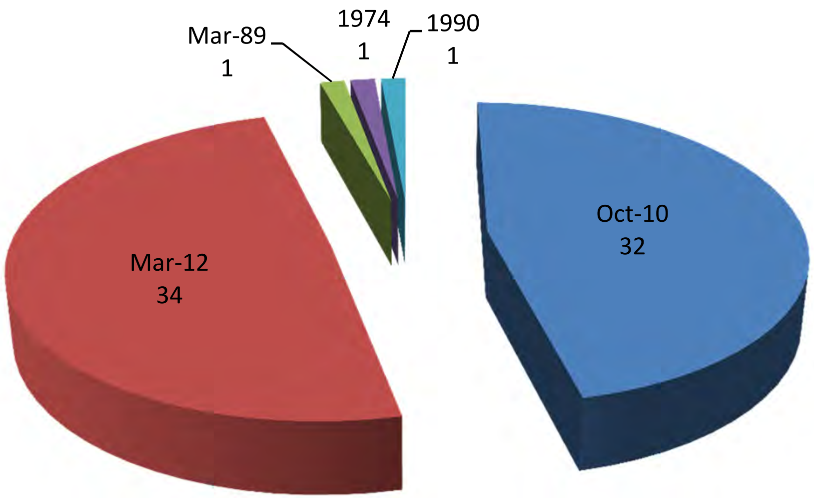
Any Flood Exprience on Property?



Period of Residency



Flooding Experienced by Event



Was Water Above Floor Levels?

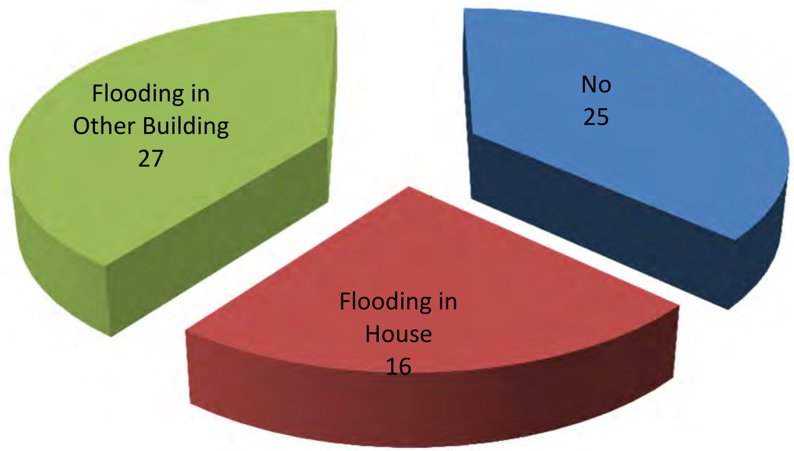


FIGURE 9
LOCKHART
COMMUNITY CONSULTATION RESULTS

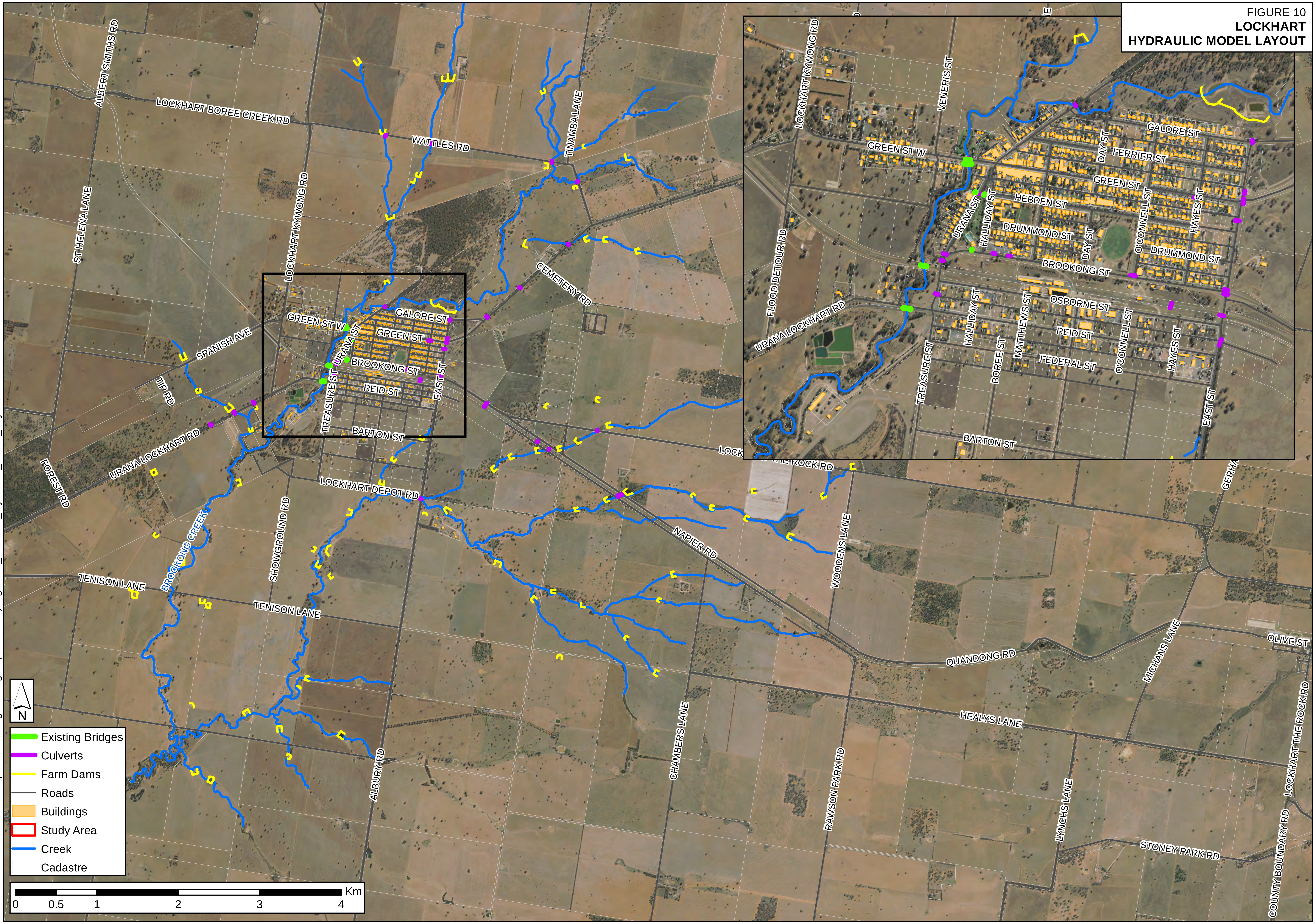


FIGURE 10
LOCKHART
HYDRAULIC MODEL LAYOUT
Existing Bridges
Culverts
Farm Dams
Roads
Buildings
Study Area
Creek
Cadastre
0 0.5 1 2 3 4 Km
N
LOCKHART BOREE CREEK RD
WATTLES RD
TINAMBA LANE
ALBERT SMITHS RD
ST HELENA LANE
LOCKHART KYWONG RD
SPANISH AVE
TIP RD
URANA LOCKHART RD
FOREST RD
BROOKONG CREEK
TENISON LANE
SHOWGROUND RD
LOCKHART DEPOT RD
CEMETERY RD
NAPIER RD
WOODENS LANE
LOCKHART THE ROCK RD
QUANDONG RD
HEALYS LANE
CHAMBERS LANE
RAWSON PARK RD
ALBURY RD
LYNCHS LANE
MICHANS LANE
OLIVE ST
STONEY PARK RD
COUNTY BOUNDARY RD
GALORE ST
GREEN ST W
GREEN ST
BROOKONG ST
REID ST
BARTON ST
EAST ST
TREASURE ST
URANA ST
FERRIER ST
HEBDEN ST
DRUMMOND ST
DAY ST
O'CONNELL ST
HAYES ST
OSBORNE ST
FEDERAL ST
HALLIDAY ST
BOREE ST
MATTHEWS ST
VENERIS ST
FLOOD DETOUR RD
J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure10_Lockhart_Hydraulic_Model_Layout.mxd

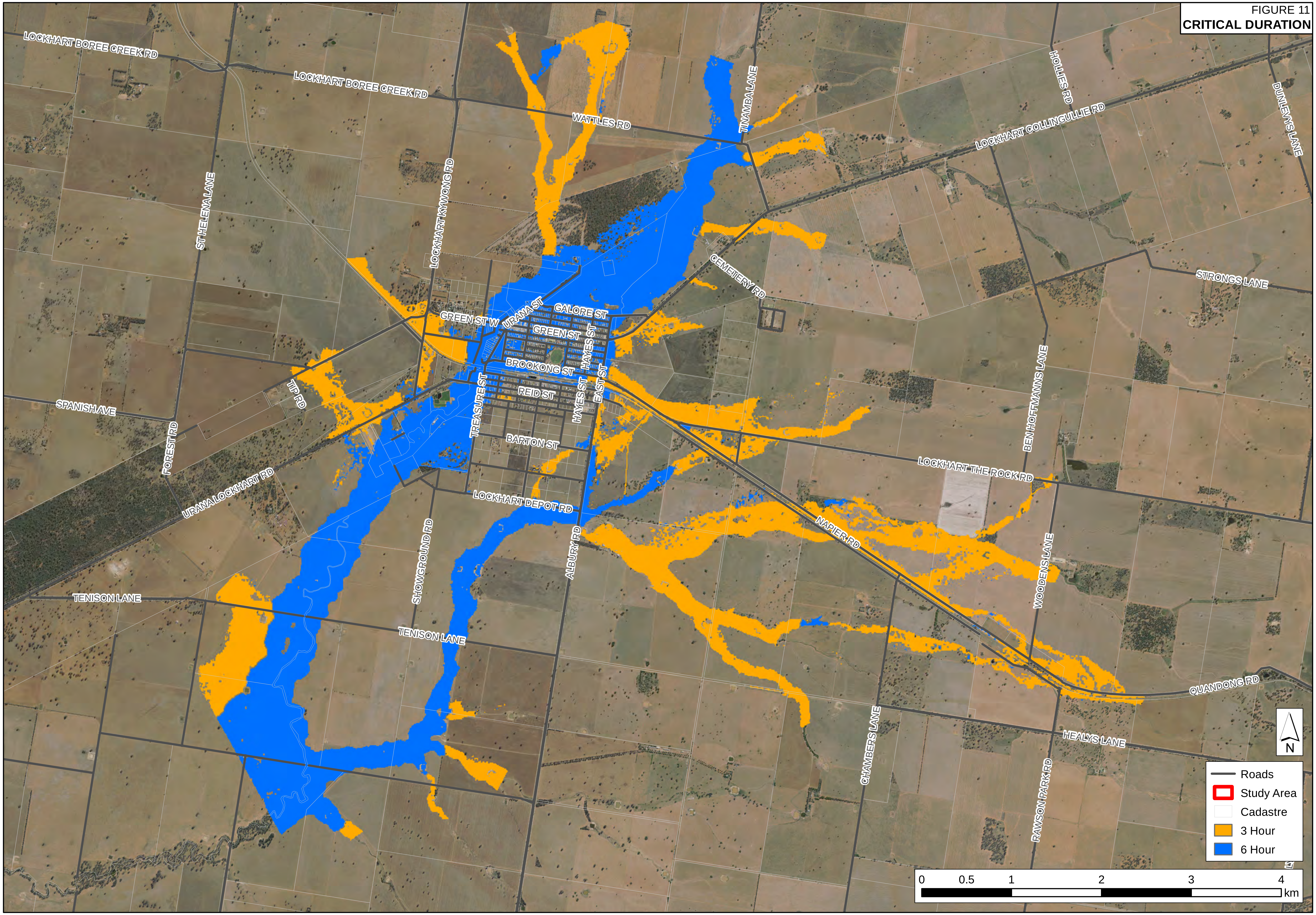


FIGURE 11
CRITICAL DURATION
LOCKHART BOREE CREEK RD
LOCKHART BOREE CREEK RD
WATTLES RD
TINAMBA LANE
HOLLIES RD
DUNLEYS LANE
LOCKHART COLLINGULLIE RD
ST HELENA LANE
LOCKHART KYWONG RD
CEMETERY RD
STRONGS LANE
GREEN ST W
URANA ST
GALORE ST
GREEN ST
HAYES ST
BROOKONG ST
EAST ST
TIP RD
REID ST
HAYES ST
TREASURE ST
SPANISH AVE
BARTON ST
BEN HOFFMANNS LANE
FOREST RD
URANA LOCKHART RD
LOCKHART THE ROCK RD
LOCKHART DEPOT RD
NAPIER RD
SHOWGROUND RD
ALBURY RD
WOODENS LANE
TENISON LANE
TENISON LANE
QUANDONG RD
CHAMBERS LANE
HEALYS LANE
RAWSON PARK RD
N
Roads
Study Area
Cadastre
3 Hour
6 Hour
0
0.5
1
2
3
4
km
J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure11_CriticalDuration.mxd

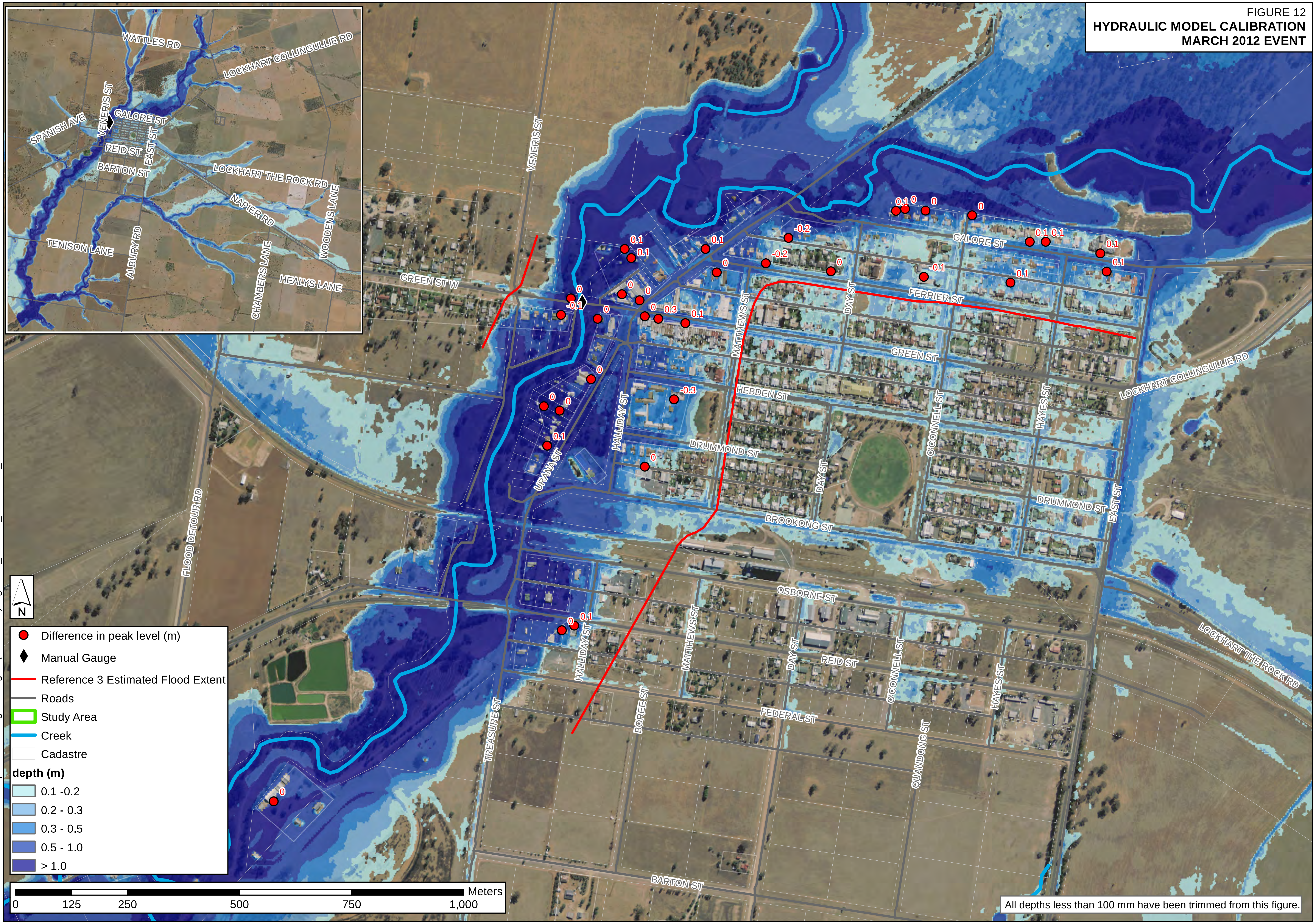


FIGURE 12
HYDRAULIC MODEL CALIBRATION
MARCH 2012 EVENT

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure12_lockhart_calibration_2012.mxd

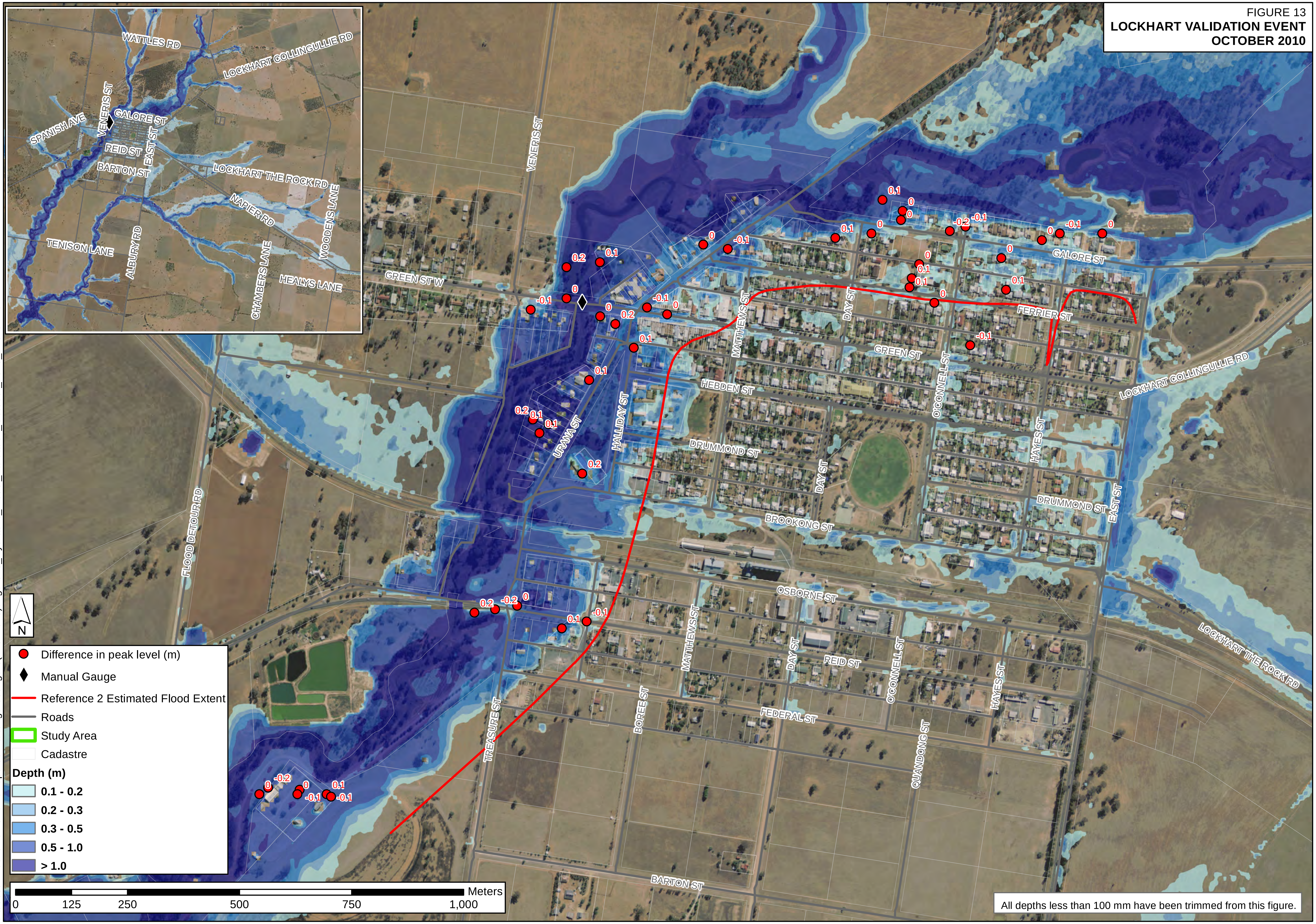


FIGURE 13
LOCKHART VALIDATION EVENT
OCTOBER 2010
WATTLES RD
LOCKHART COLLINGULLIE RD
VENERIS ST
GALORE ST
SPANISH AVE
REID ST
EAST ST
BARTON ST
LOCKHART THE ROCK RD
NAPIER RD
WOODENS LANE
TENISON LANE
ALBURY RD
CHAMBERS LANE
HEALYS LANE
GREEN ST W
FERRIER ST
GREEN ST
HEBDEN ST
DRUMMOND ST
BROOKONG ST
OSBORNE ST
FEDERAL ST
URANA ST
HALLIDAY ST
MATTHEWS ST
DAY ST
O'CONNELL ST
HAYES ST
QUANDONG ST
BOREE ST
TREASURE ST
FLOOD DETOUR RD
N
Difference in peak level (m)
Manual Gauge
Reference 2 Estimated Flood Extent
Roads
Study Area
Cadastre
Depth (m)
0.1 - 0.2
0.2 - 0.3
0.3 - 0.5
0.5 - 1.0
> 1.0
0
125
250
500
750
1,000
Meters
All depths less than 100 mm have been trimmed from this figure.
J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure13_Hydraulic_Model_Validation_October_2010_Event.mxd

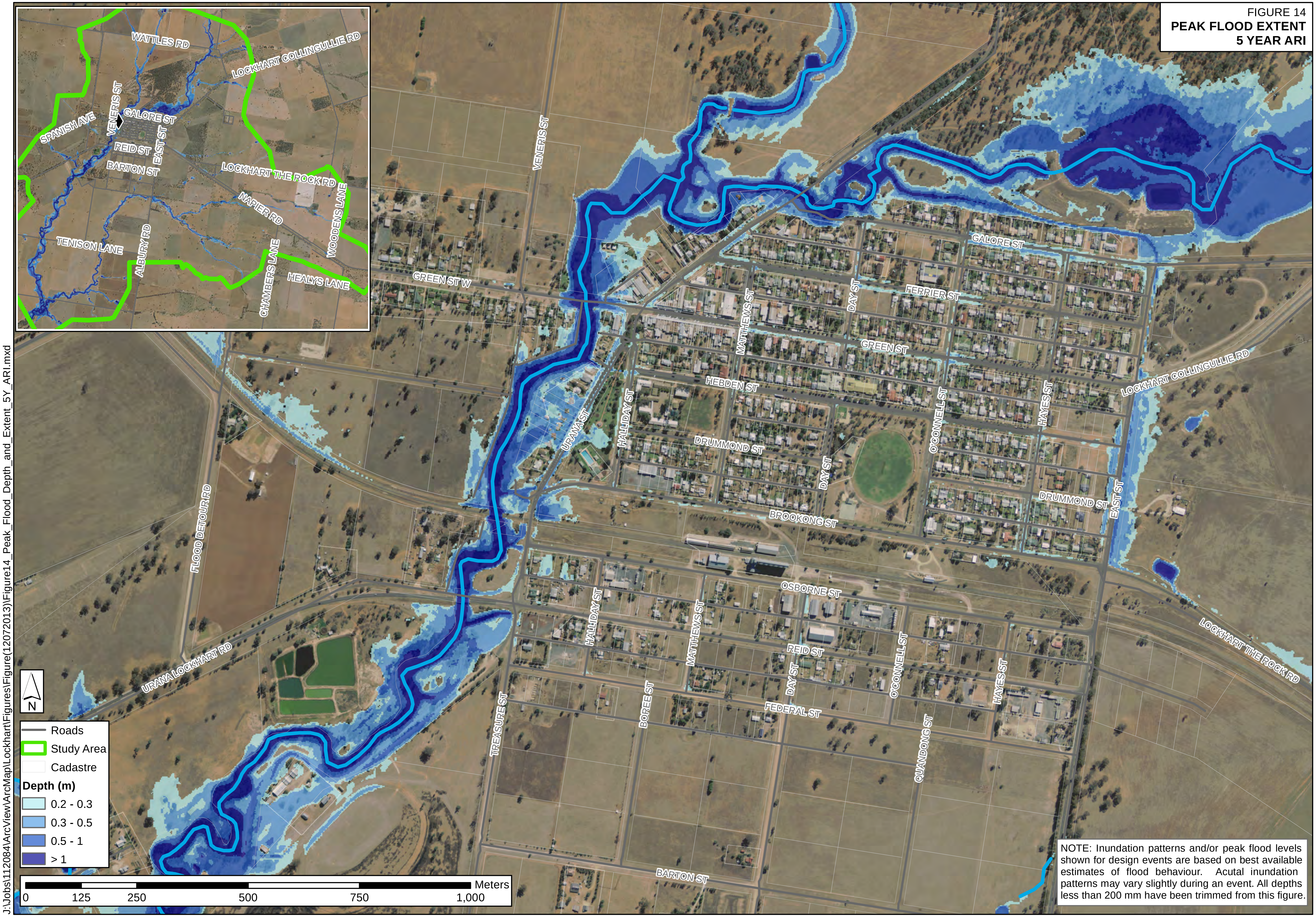


FIGURE 14
PEAK FLOOD EXTENT
5 YEAR ARI

NOTE: Inundation patterns and/or peak flood levels shown for design events are based on best available estimates of flood behaviour. Acutal inundation patterns may vary slightly during an event. All depths less than 200 mm have been trimmed from this figure.

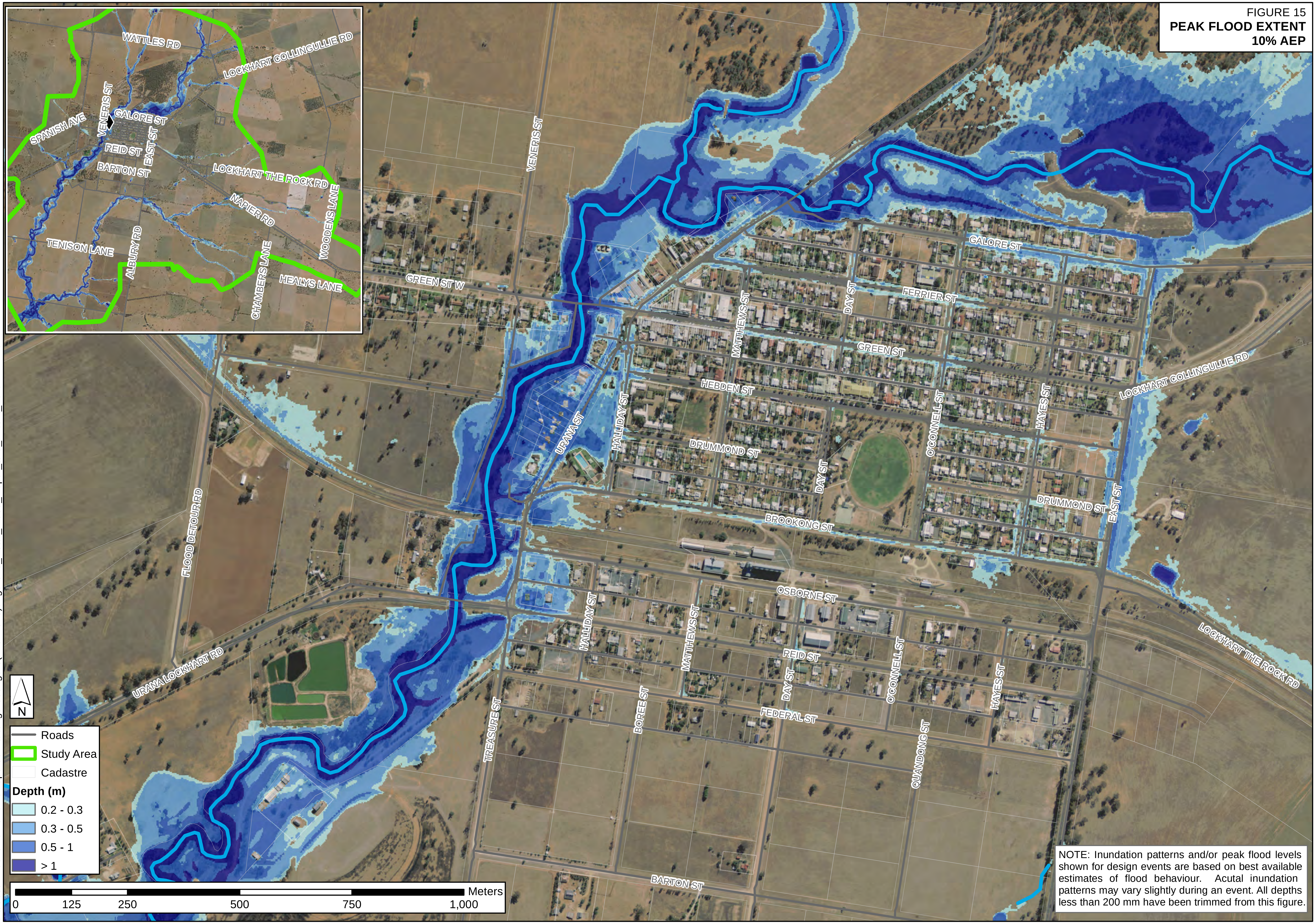


FIGURE 15
PEAK FLOOD EXTENT
10% AEP

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure15_Peak_Flood_Depth_and_Extent_10%AEP.mxd

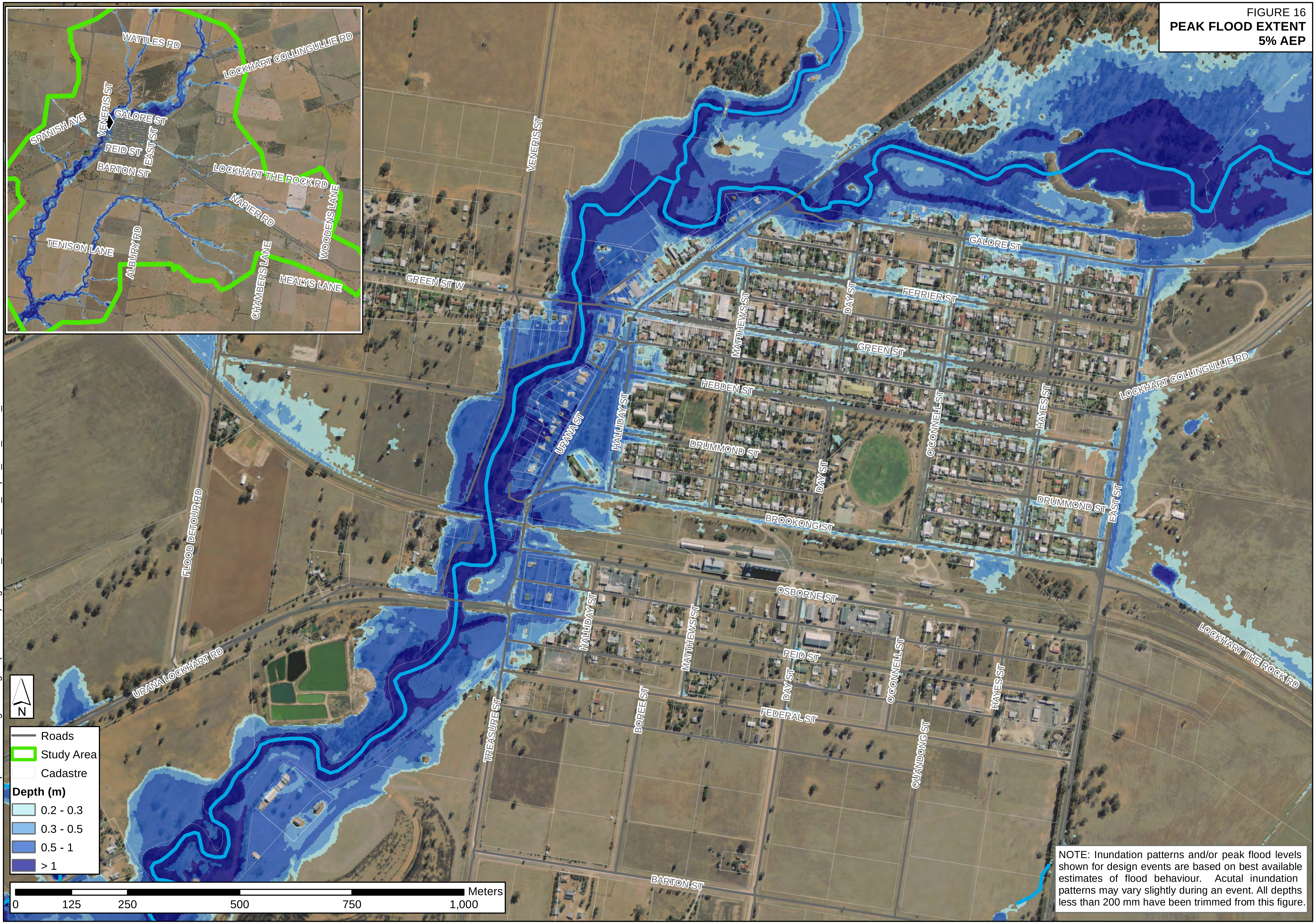


FIGURE 16
PEAK FLOOD EXTENT
5% AEP

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure16_Peak_Flood_Depth_and_Extent_5%AEP.mxd

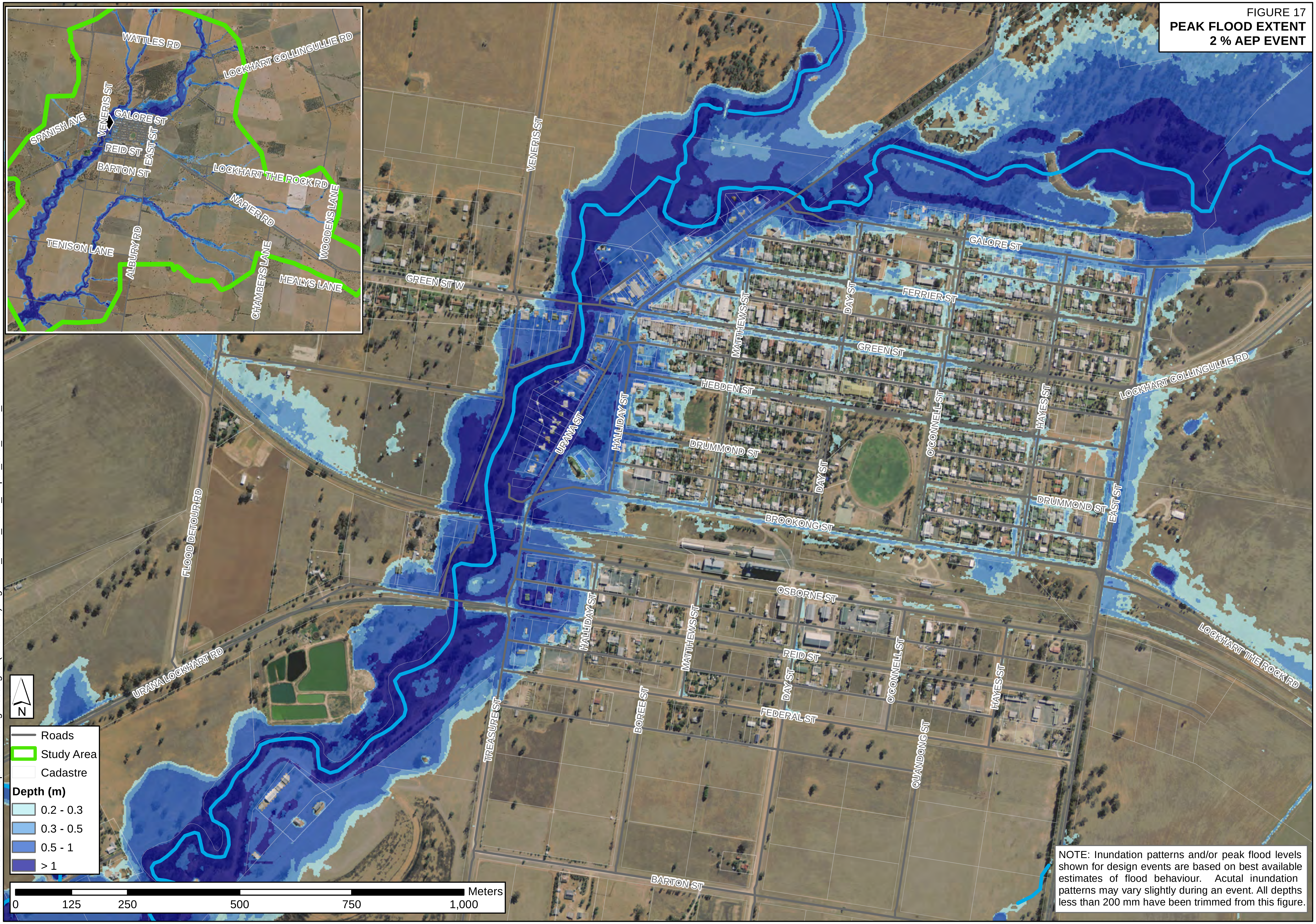


FIGURE 17
PEAK FLOOD EXTENT
2 % AEP EVENT

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure17_Peak_Flood_Depth_and_Extent_2%AEP.mxd

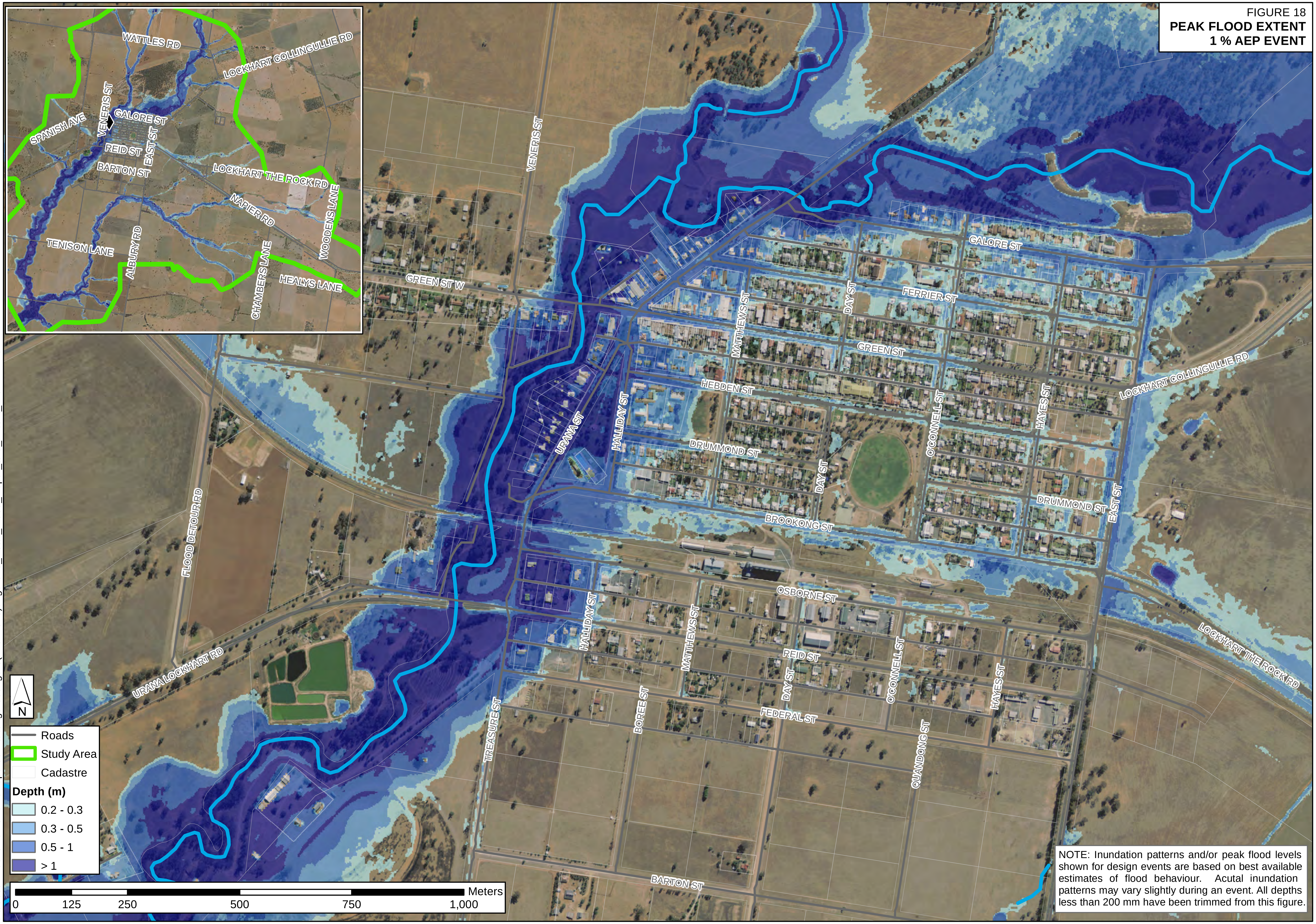
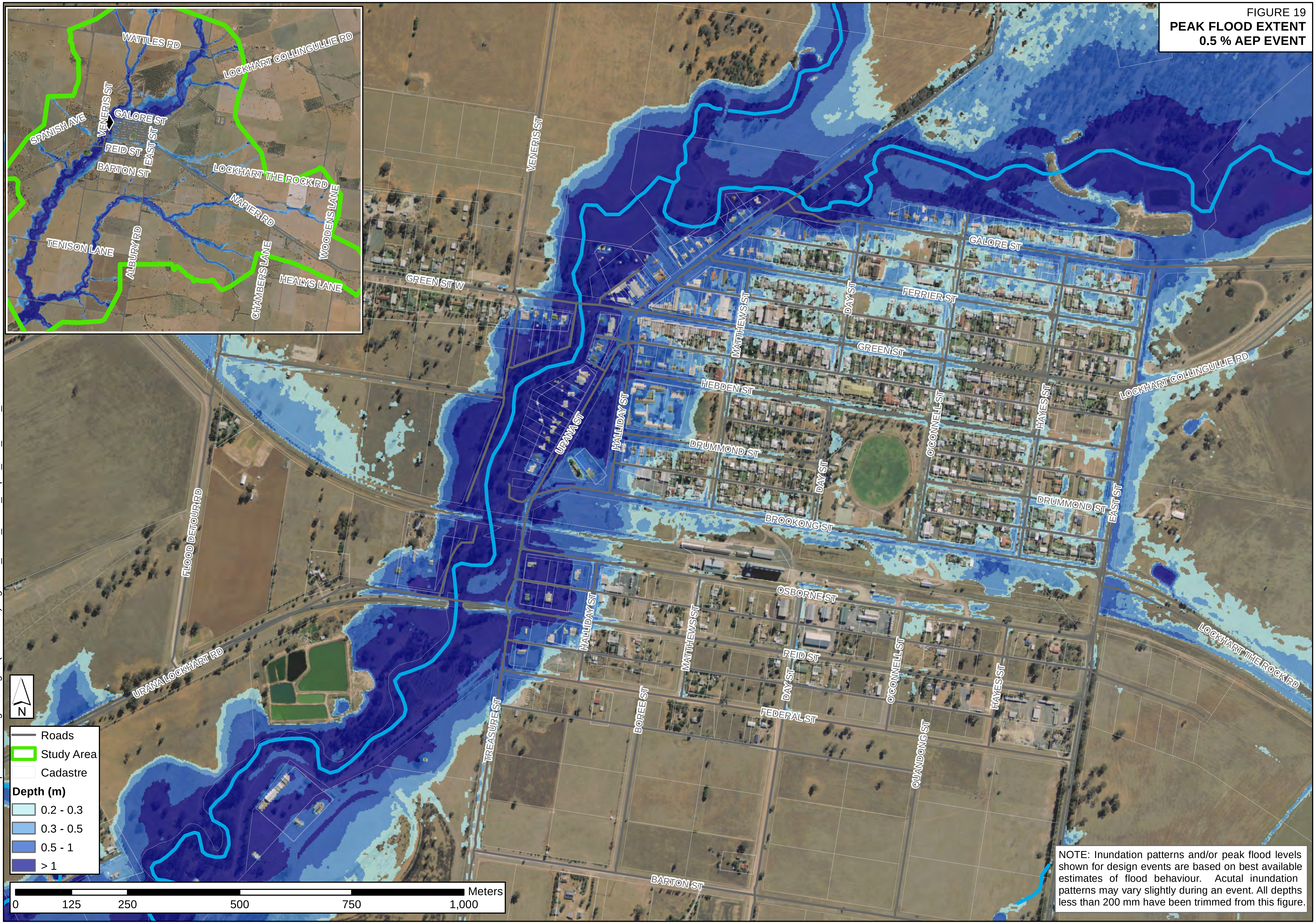
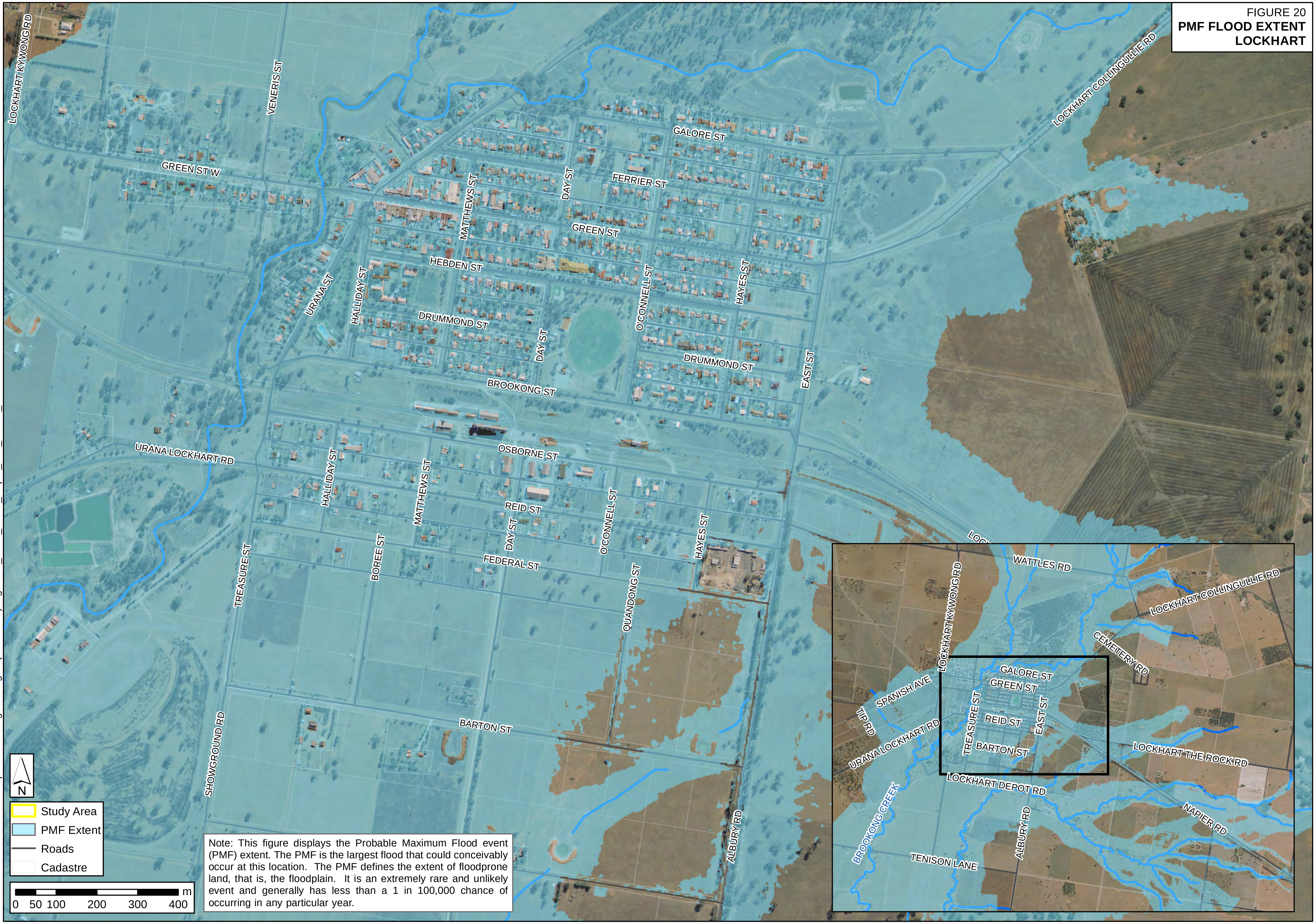


FIGURE 18
PEAK FLOOD EXTENT
1 % AEP EVENT

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure18_Peak_Flood_Depth_and_Extent_1%AEP.mxd



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure19_Peak_Flood_Depth_and_Extent_0.5%AEP.mxd



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure20_Peak_Flood_Depth_and_Extent_PMF.mxd

J:\Jobs\112084\TUFLOW\Lockhart\Calibration\LH_TUFLOW_Profile.xlsm

FIGURE 21

PEAK FLOOD PROFILES DESIGN EVENTS

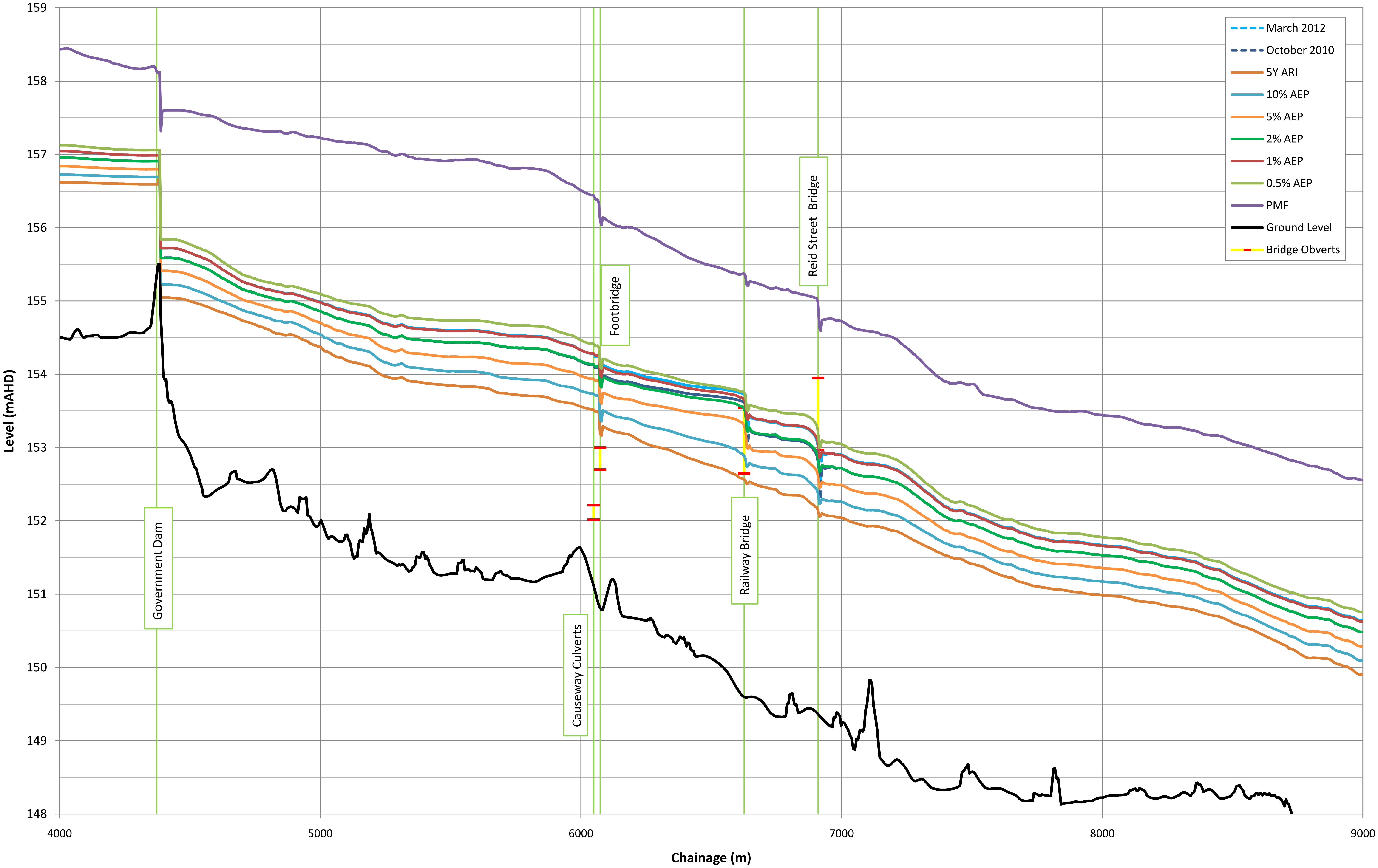
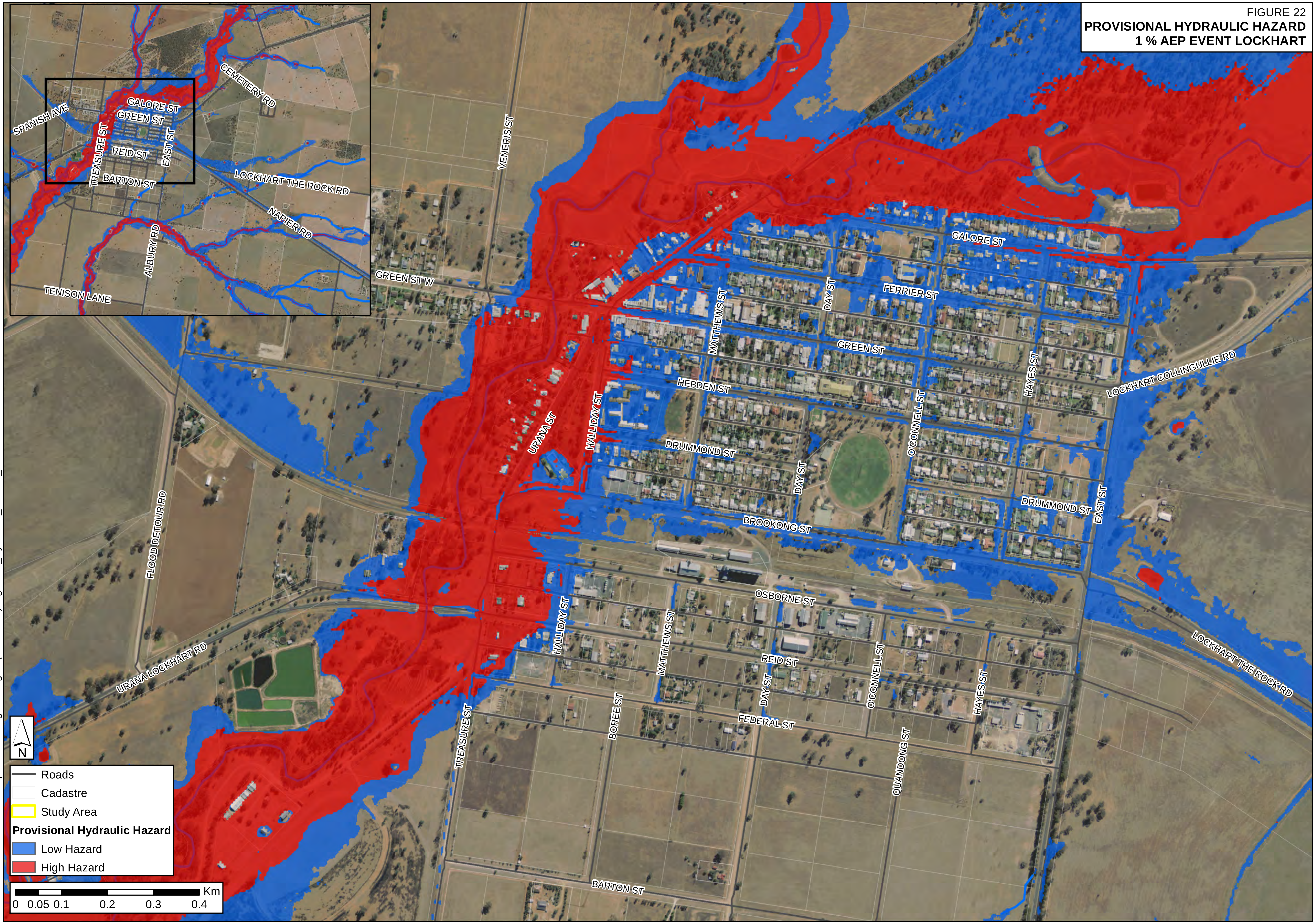
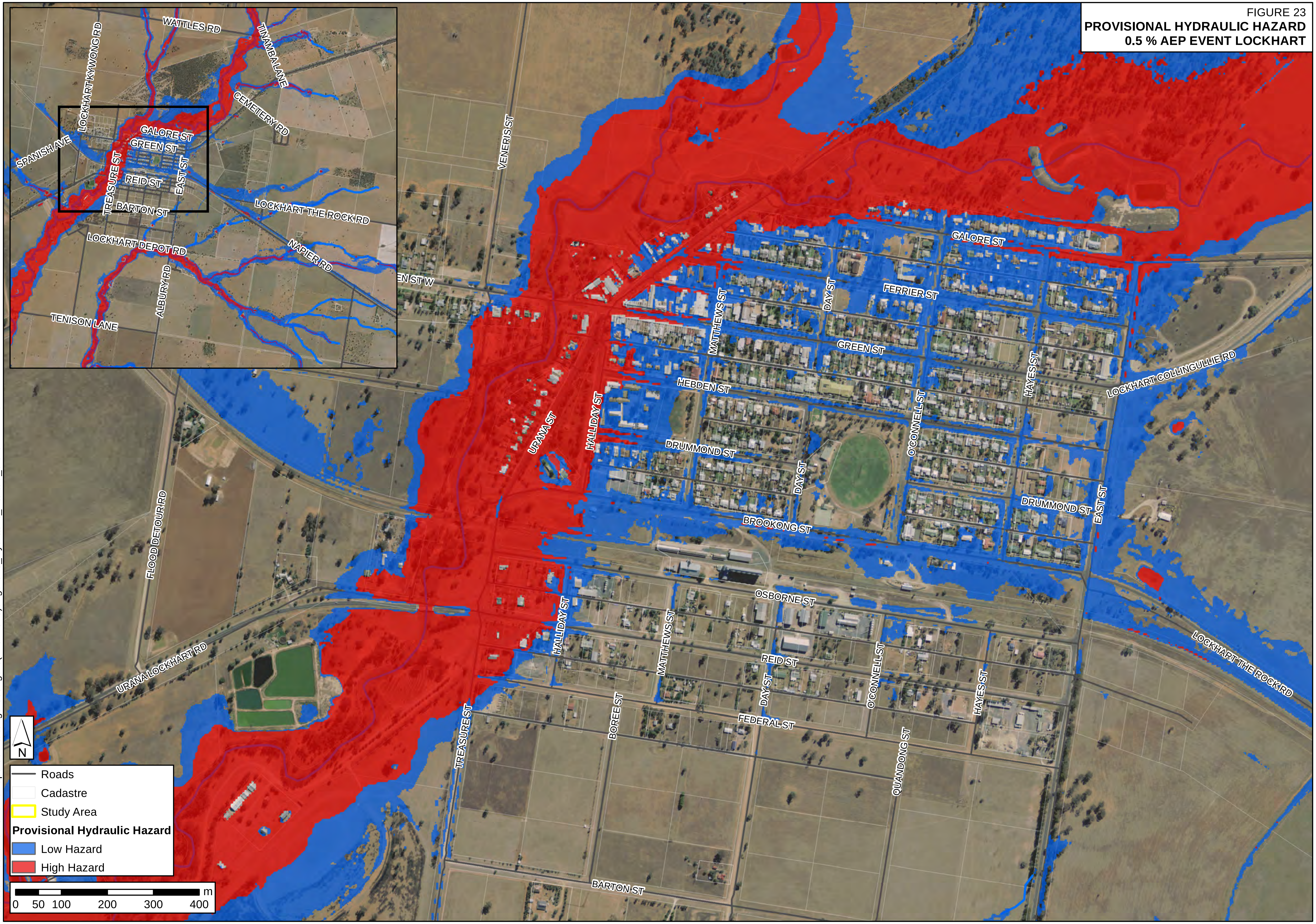


FIGURE 22
PROVISIONAL HYDRAULIC HAZARD
1 % AEP EVENT LOCKHART



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure22_Hydraulic_Hazard_1%AEP.mxd

FIGURE 23
PROVISIONAL HYDRAULIC HAZARD
0.5 % AEP EVENT LOCKHART



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure23_Hydraulic_Hazard_0.5%AEP.mxd

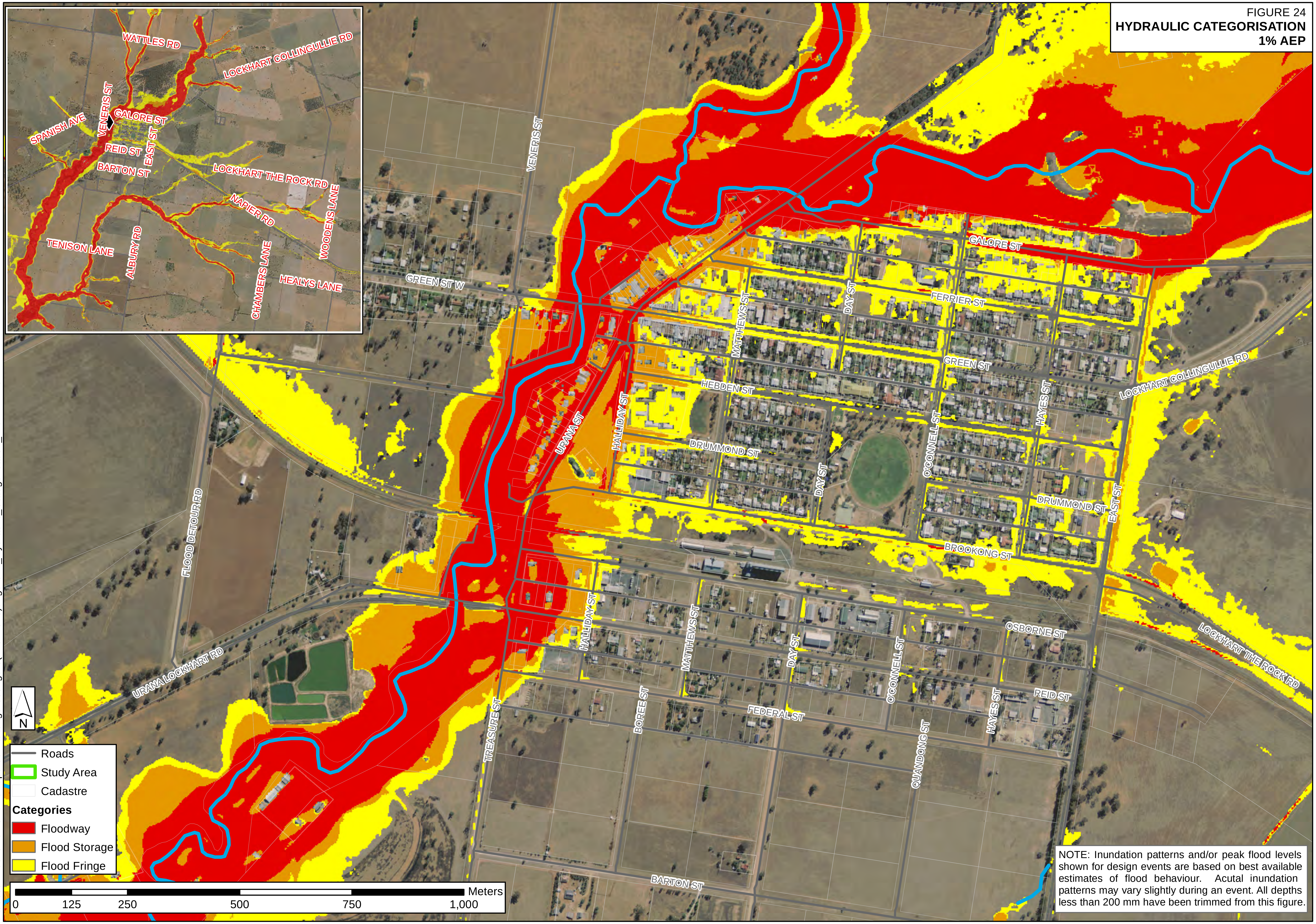
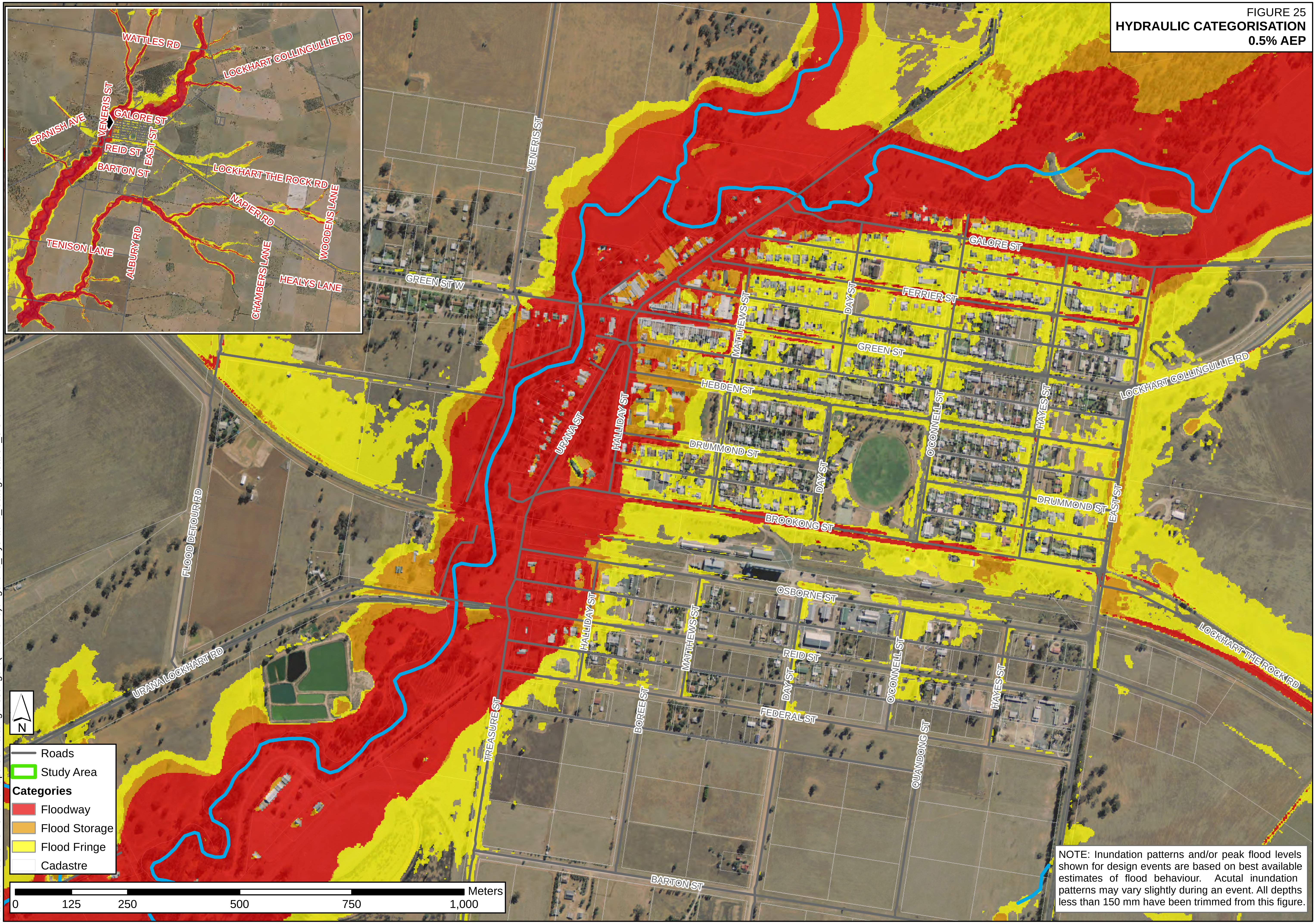


FIGURE 24
HYDRAULIC CATEGORISATION
1% AEP
WATTLES RD
LOCKHART COLLINGULLIE RD
VENERIS ST
GALORE ST
SPANISH AVE
REID ST
EAST ST
BARTON ST
LOCKHART THE ROCK RD
NAPIER RD
WOODENS LANE
TENISON LANE
ALBURY RD
CHAMBERS LANE
HEALYS LANE
GREEN ST W
FERRIER ST
MATTHEWS ST
DAY ST
GREEN ST
HEBDEN ST
HALLIDAY ST
URANA ST
DRUMMOND ST
O'CONNELL ST
HAYES ST
BROOKONG ST
FLOOD DETOUR RD
URANA LOCKHART RD
OSBORNE ST
TREASURE ST
BOREE ST
FEDERAL ST
QUANDONG ST
BARTON ST
N
Roads
Study Area
Cadastre
Categories
Floodway
Flood Storage
Flood Fringe
0 125 250 500 750 1,000 Meters
NOTE: Inundation patterns and/or peak flood levels shown for design events are based on best available estimates of flood behaviour. Acutal inundation patterns may vary slightly during an event. All depths less than 200 mm have been trimmed from this figure.
J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure24_Hydraulic_Categorisation_1%AEP.mxd



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure25_Hydraulic_Categorisation_0.5%AEP.mxd

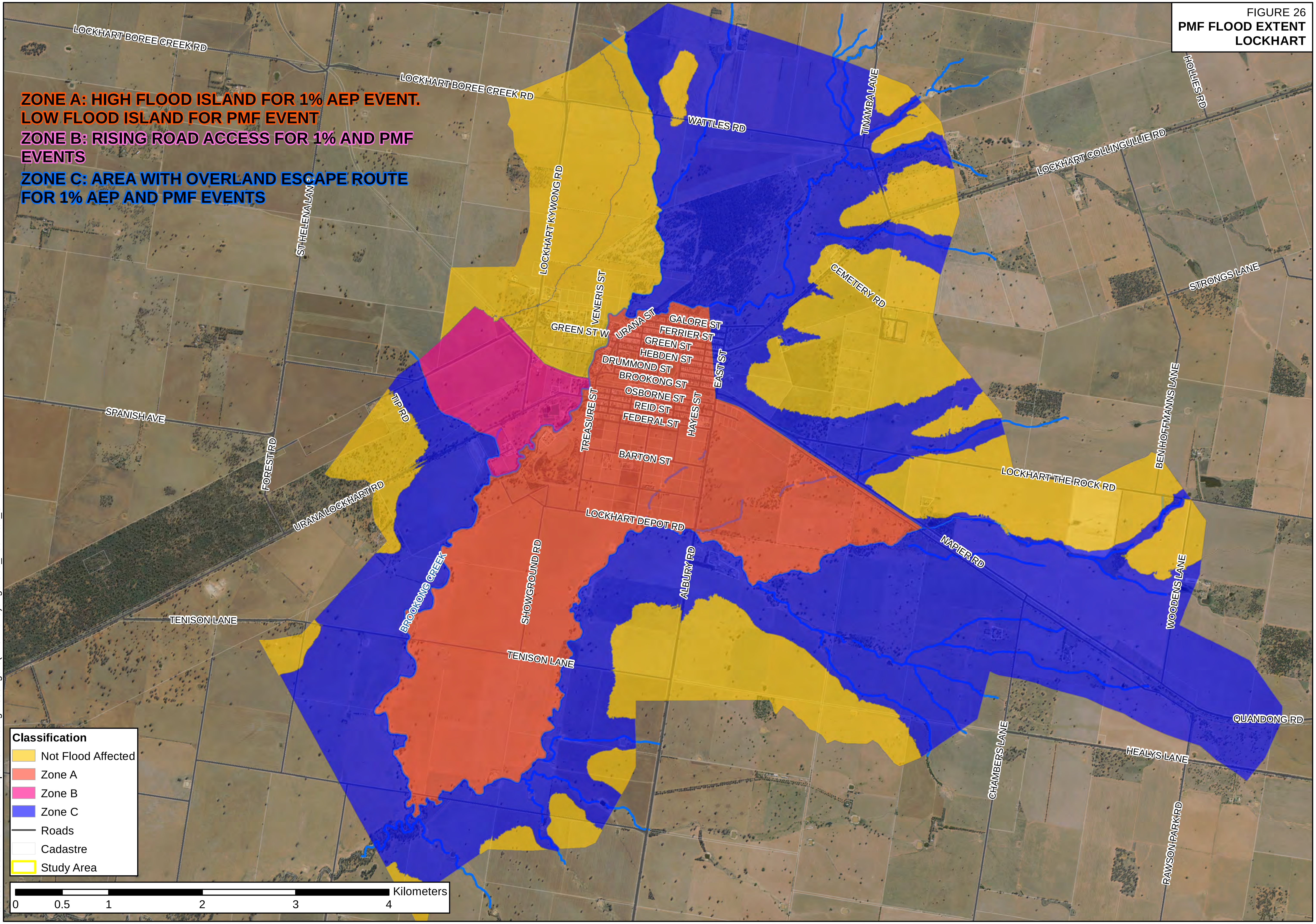


FIGURE 26
PMF FLOOD EXTENT LOCKHART

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure26_Lockhart_SESERP.mxd

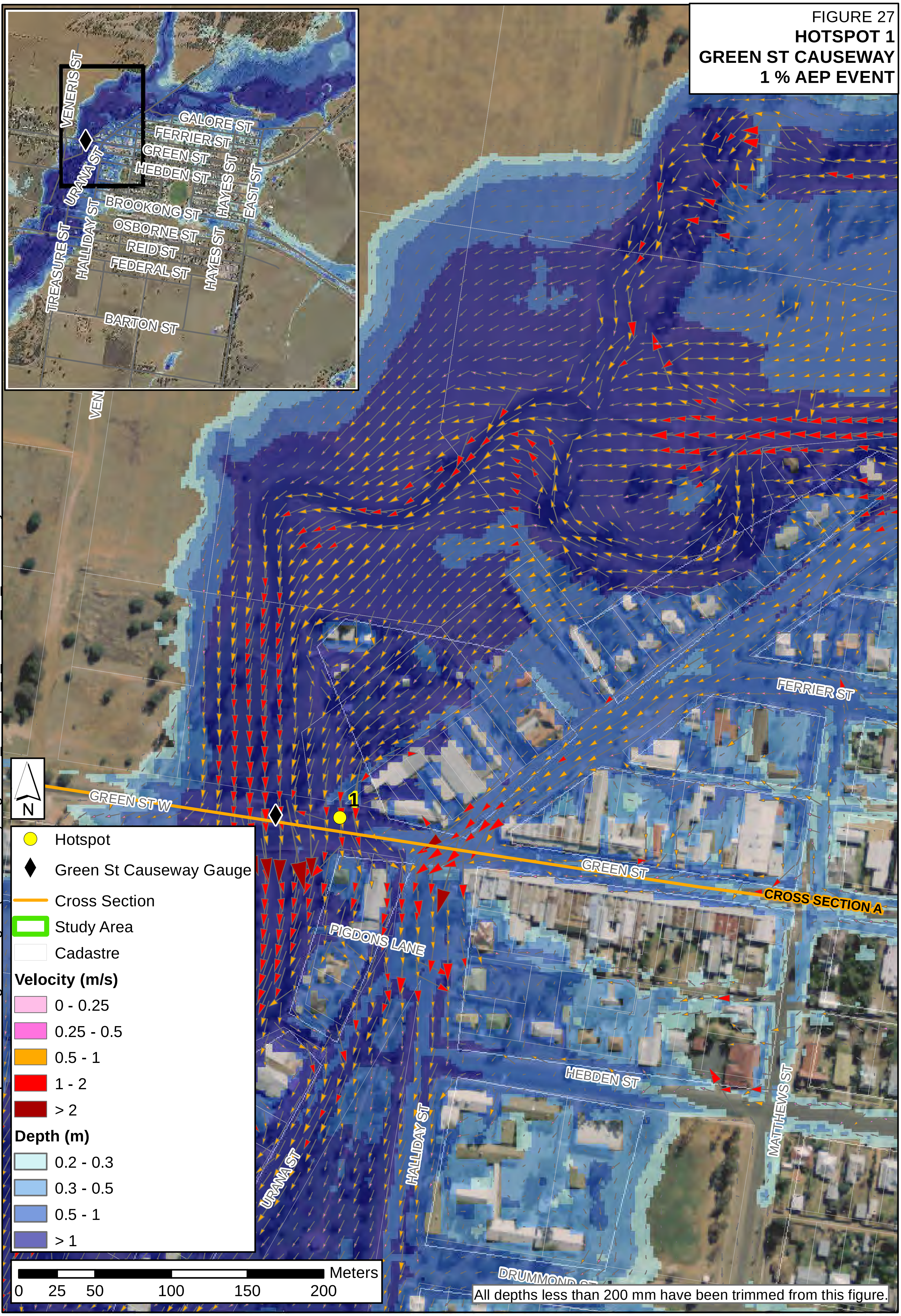
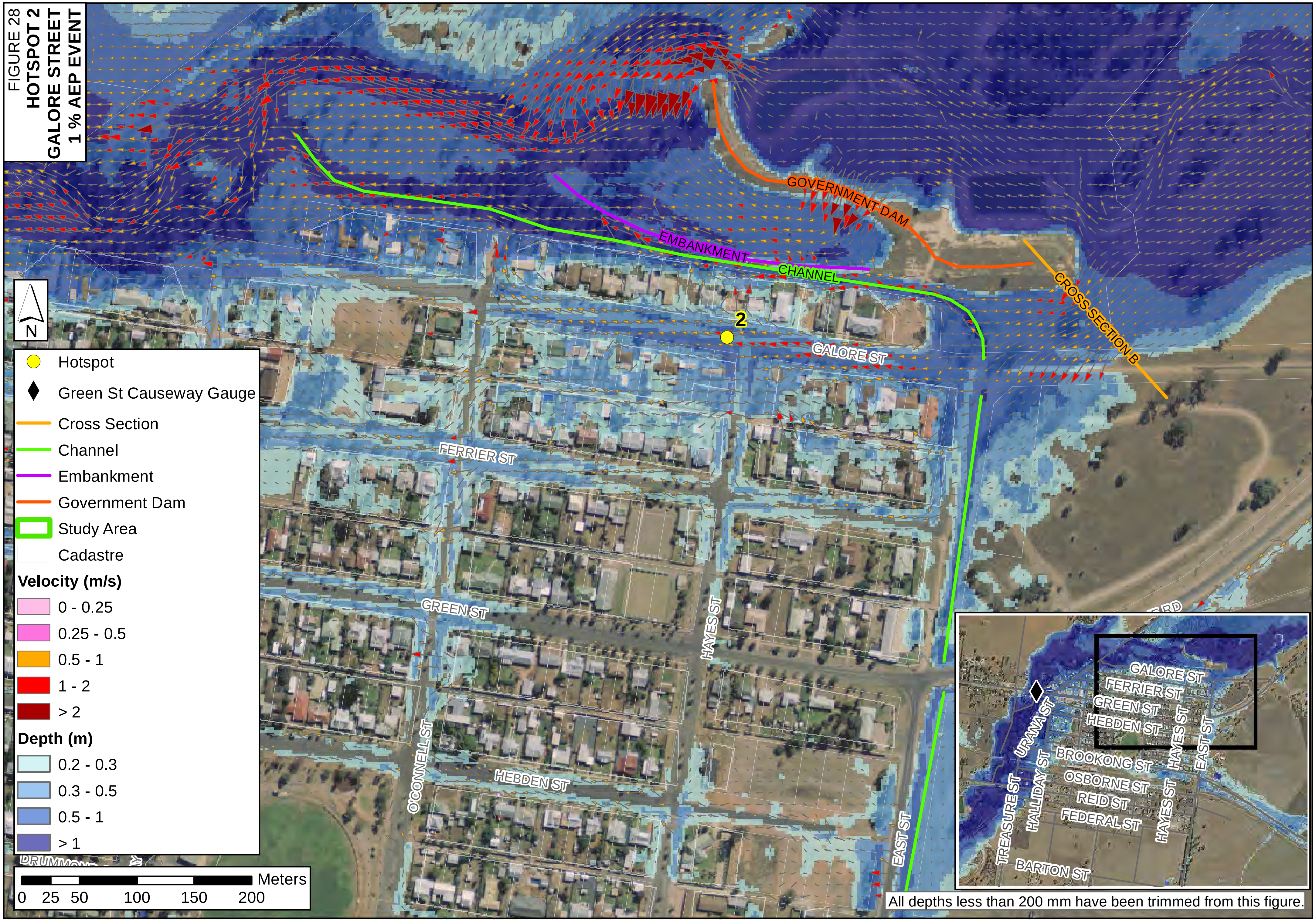


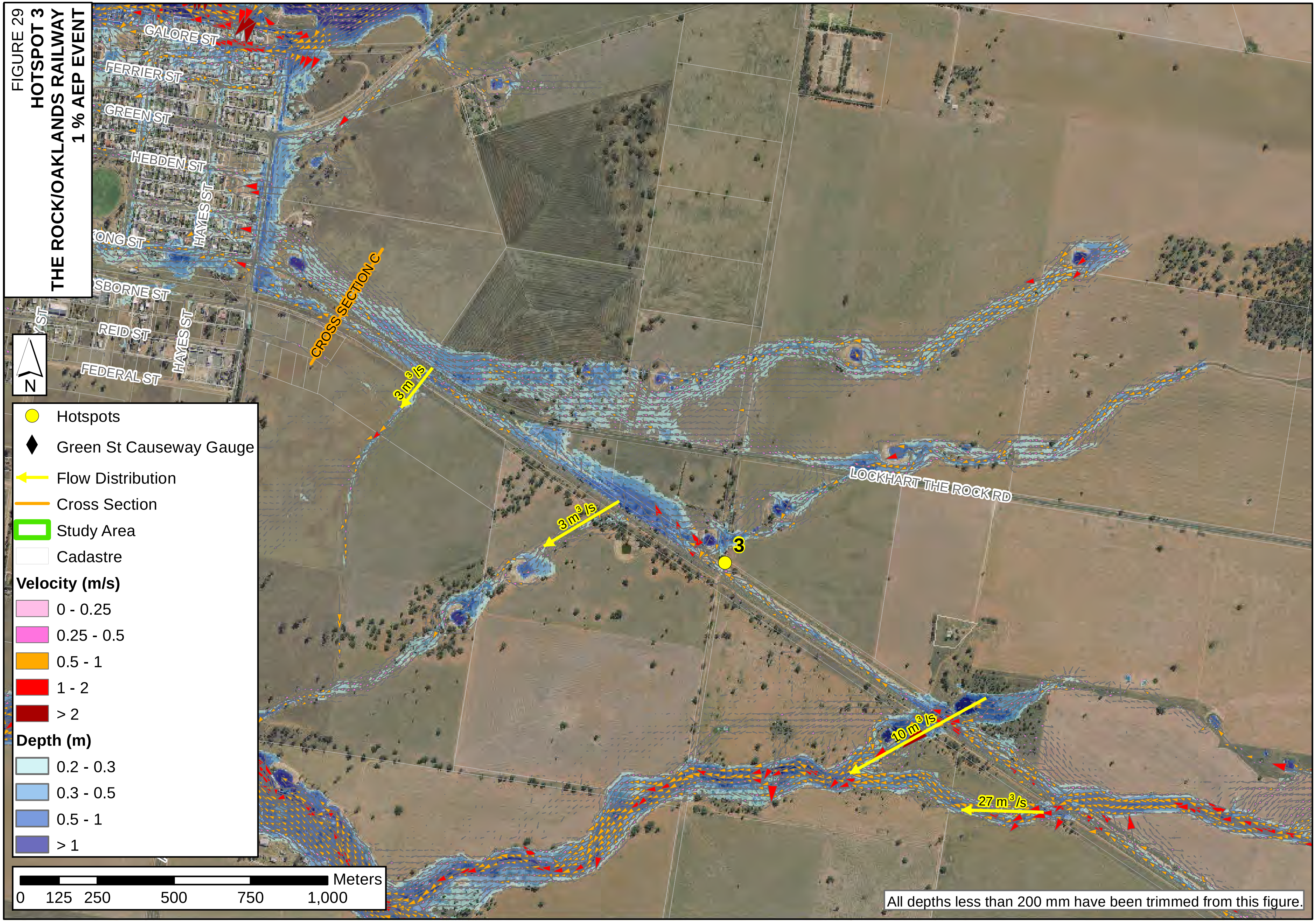
FIGURE 27
HOTSPOT 1
GREEN ST CAUSEWAY
1 % AEP EVENT

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure27_Hotspot_1_Green_St_Causeway.mxd

FIGURE 28
HOTSPOT 2
GALORE STREET
1 % AEP EVENT



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure28_Hotspot_2_Galore_St.mxd



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure29_Hotspot_3_TheRock_Oaklands_Rail.mxd

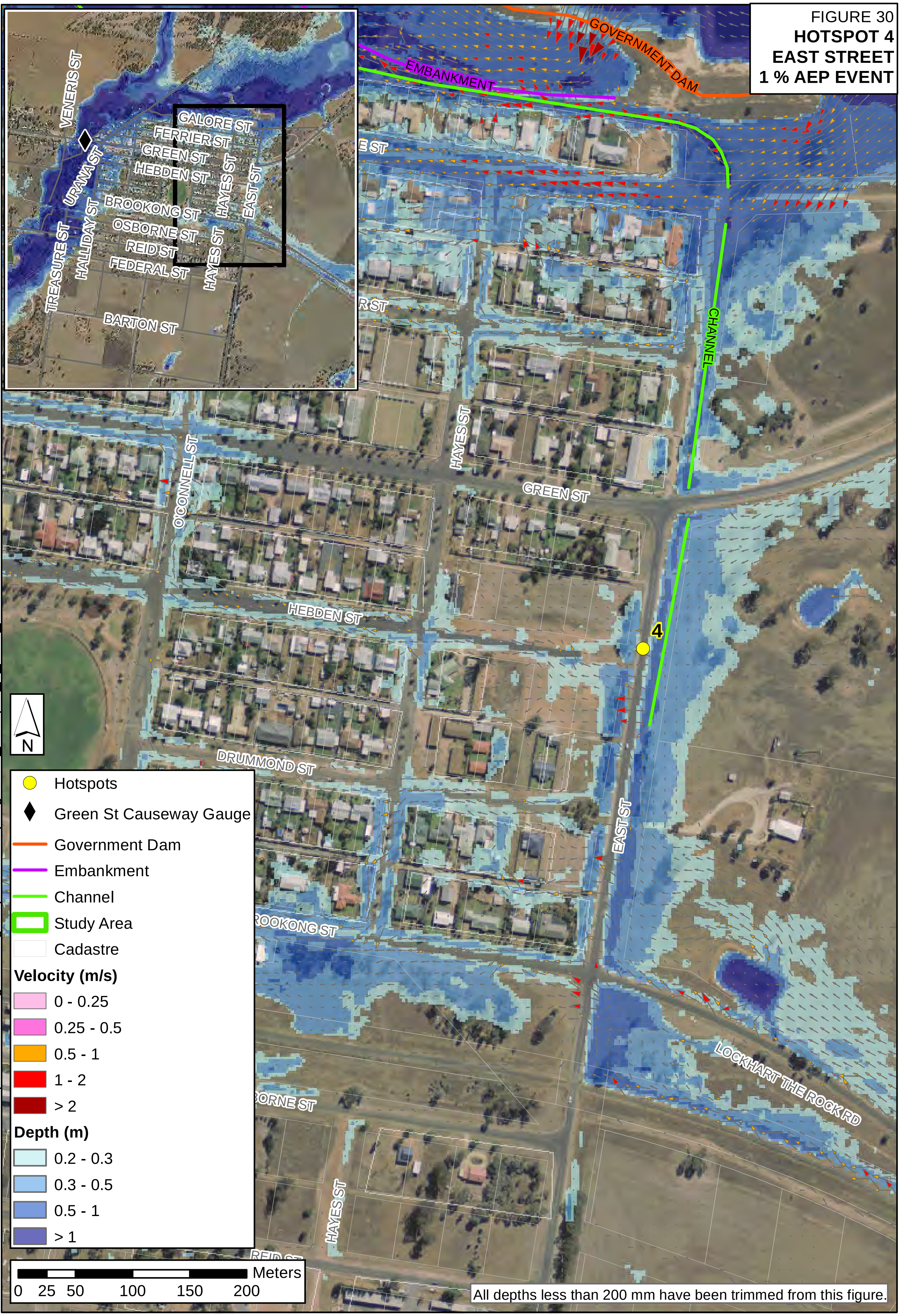


FIGURE 30
HOTSPOT 4
EAST STREET
1 % AEP EVENT

J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure30_Hotspot_4_East_Street.mxd

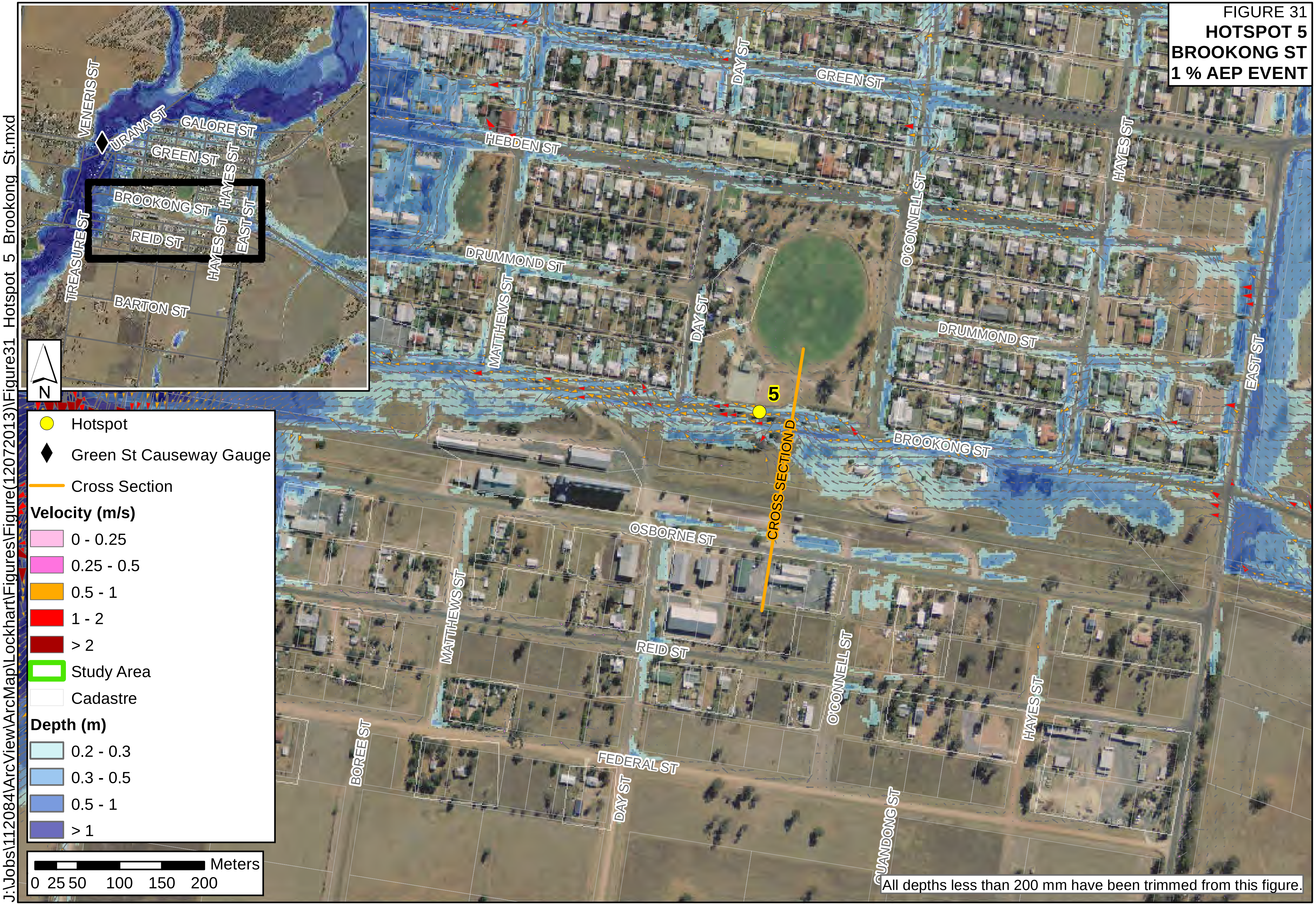


FIGURE 31
HOTSPOT 5
BROOKONG ST
1 % AEP EVENT
Hotspot
Green St Causeway Gauge
Cross Section
Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
> 2
Study Area
Cadastre
Depth (m)
0.2 - 0.3
0.3 - 0.5
0.5 - 1
> 1
Meters
0 25 50 100 150 200
N
5
CROSS SECTION D
GREEN ST
HEBDEN ST
DRUMMOND ST
BROOKONG ST
OSBORNE ST
REID ST
FEDERAL ST
DAY ST
O'CONNELL ST
HAYES ST
EAST ST
MATTHEWS ST
BOREE ST
QUANDONG ST
VENERIS ST
URANA ST
GALORE ST
TREASURE ST
BARTON ST
All depths less than 200 mm have been trimmed from this figure.
J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure31_Hotspot_5_Brookong_St.mxd

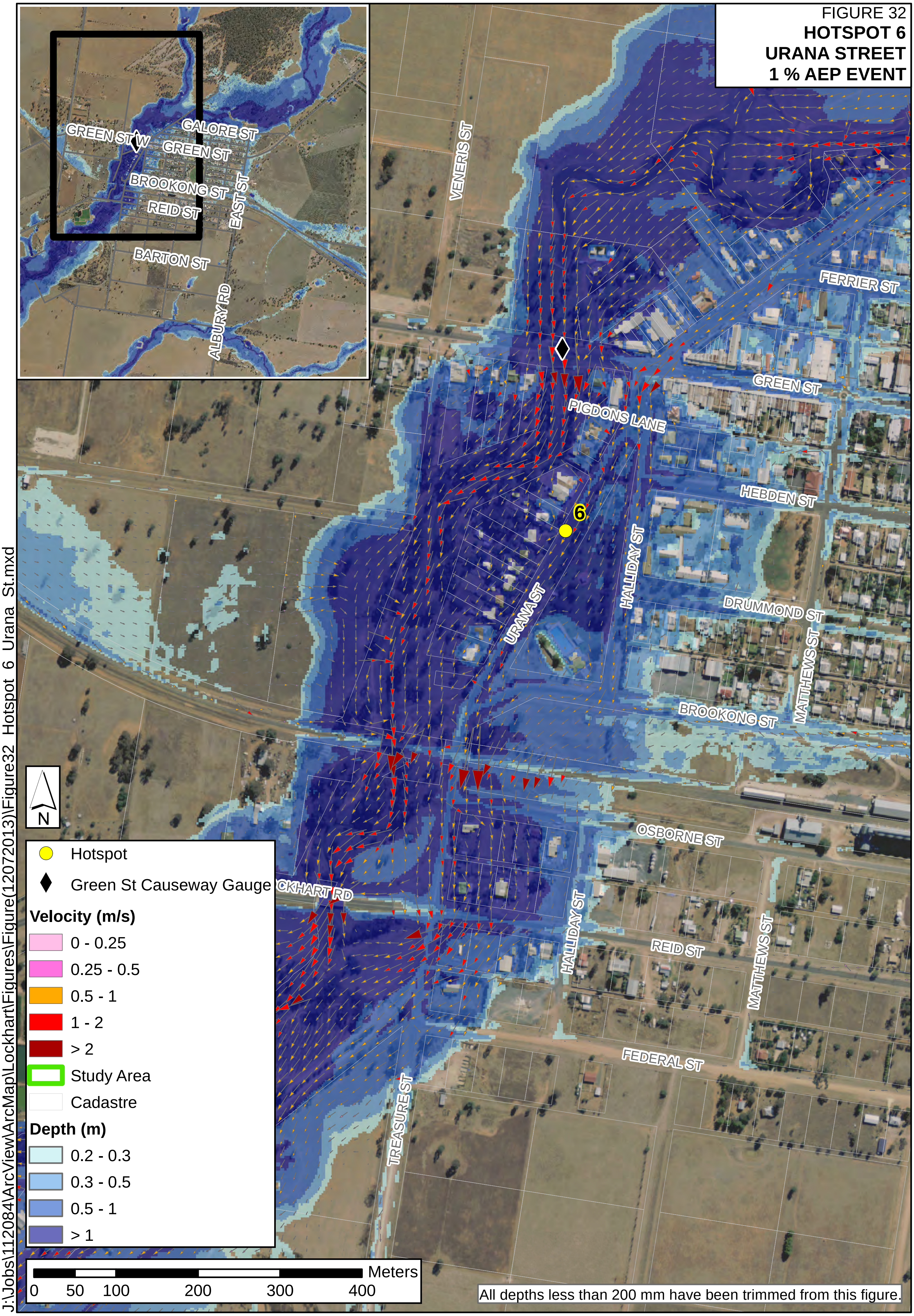
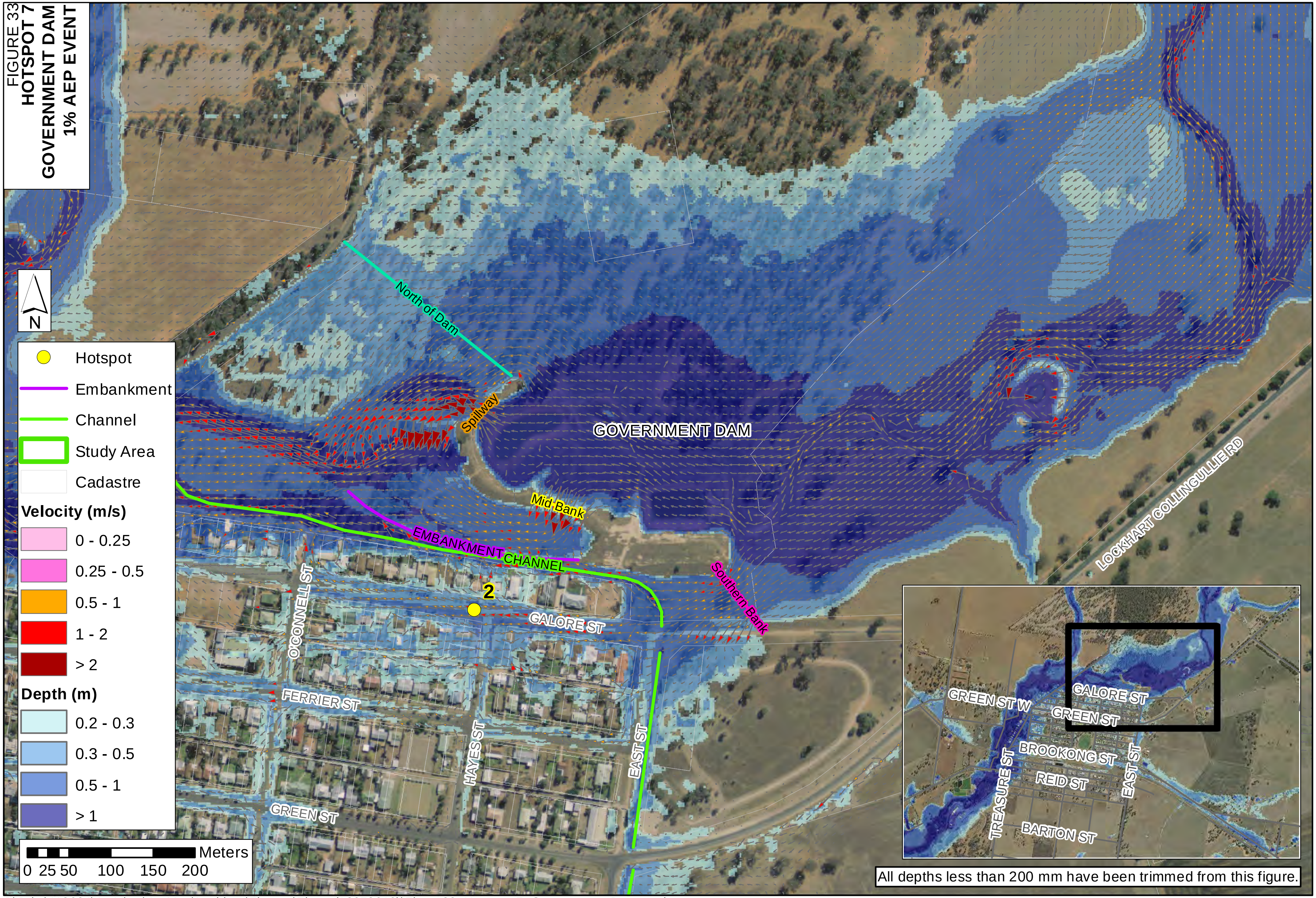


FIGURE 32
HOTSPOT 6
URANA STREET
1 % AEP EVENT
GALORE ST
GREEN ST
BROOKONG ST
REID ST
EAST ST
BARTON ST
ALBURY RD
VENERIS ST
FERRIER ST
GREEN ST
PIGDONS LANE
HEBDEN ST
6
HALLIDAY ST
URANA ST
DRUMMOND ST
MATTHEWS ST
BROOKONG ST
OSBORNE ST
CKHART RD
HALLIDAY ST
REID ST
MATTHEWS ST
FEDERAL ST
TREASURE ST
N
Hotspot
Green St Causeway Gauge
Velocity (m/s)
0 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
> 2
Study Area
Cadastre
Depth (m)
0.2 - 0.3
0.3 - 0.5
0.5 - 1
> 1
Meters
0 50 100 200 300 400
All depths less than 200 mm have been trimmed from this figure.
J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure32_Hotspot_6_Urana_St.mxd

FIGURE 33
HOTSPOT 7
GOVERNMENT DAM
1% AEP EVENT



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Figure33_Hotspot_7_Government_Dam.mxd

Appendix A

APPENDIX A: GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acidsulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
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 one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the 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.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
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.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.

development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.
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).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
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 awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
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). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
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 this manual. Usually includes both written and diagrammetic 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 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
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 readiness	Flood readiness is an ability to react within the effective warning time.

flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during 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 flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
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.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: ▪ the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or ▪ water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or ▪ major overland flow paths through developed areas outside of defined drainage reserves; and/or ▪ the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State♣s rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
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 the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.

Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which 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.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

Hinchcliffe tj & Associates Pty Ltd
Po Box 5497
Wagga Wagga, NSW 2650

Lockhart_Survey.docx

20 December 2012

Attention: Mr Hinchcliffe

Dear Terry,

Re: Survey Brief for Hydraulic Structures in towns of Lockhart and The Rock

WMAwater have been commissioned by Lockhart Shire Council to perform Flood Studies for the towns of Lockhart and The Rock. To conduct these studies we require survey of key hydraulic structures such as culverts, pipes and bridges.

This document is a brief for required survey and will form the basis of subsequent quotations.

Survey is required for each of the 48 structures listed below in Tables 1 and 2. Table 1, Appendix 1 and Figure 1 relate to 28 structures that require survey in the regions surrounding Lockhart. Table 2, Appendix 2 and Figure 2 relate to the 20 structures that require survey in the regions surrounding The Rock. The ID numbers are labelled in these Tables, Appendices and Figures to provide details for each structure which requires survey.

Please note the survey requirements for each structure type below.

BRIDGE:
Please provide scaled diagrammatic representation of available flow area under and over bridge including:

- Creek cross section survey at upstream face;
- Creek cross section survey at downstream side offset a few meters from structure;
- Pier locations and width;
- Level of deck underside at each creek side (and middle if curved bridge deck);
- Level of deck top at each creek side (and middle if curved bridge deck); and
- Level of fence/railing top at each creek side (and middle if curved bridge deck).

Additional to diagrammatic representation please provide ASCII (X, Y, Z) electronic format of all survey points. Examples of these requirements are contained in Figures 3 and 4.

CULVERT:
Please provide scaled diagrammatic representation of available flow area through structure and via over flow path (i.e. road topping) including:

- Provide internal dimensions of circular culverts (diameter) and rectangular box culverts (width, height);
- Provide upstream and downstream levels of culvert inverts; and
- Provide cross section survey of culvert topping flow path (eg road height).

Additional to diagrammatic representation please provide ASCII (X, Y, Z) electronic format of all survey points.

ADDITIONAL REQUIREMENTS:

For all structure types please addition note:

- All coordinates should be reported as Map Grid of Australia (MGA) Zone 55.
- All levels should be reduced to Australian Height Datum (AHD).
- Sections should show the distance relative to a zero point on the left bank looking downstream.
- Provide labelled photographs of all structures surveyed.
- Permission is necessary if any access to private property is required. If there are property access issues please contact David Webb at Lockhart Shire Council on 6920 5305.
- The surveyor is to follow all OEH/Council protocols for entering private property and the relevant Occupational Health and Safety requirements for working in traffic.
- Vertical accuracy should be ± 25 mm and Horizontal accuracy ± 1 m.

Table 1: Lockhart Structures (X,Y coordinates in MGA55)

ID	X	Y	Description
1	473,871	6,102,308	Footbridge over channel, west side of Urana St
2	473,888	6,102,303	Culvert under Urana St
3	473,910	6,102,297	Footbridge over channel, east side of Urana St
4	473,721	6,101,999	Culvert under Treasure St south of Brookong St
5	473,742	6,102,030	Culvert under Urana St north of Brookong St
6	473,855	6,102,049	Walkway bridge over channel, north side of Brookong St
7	473,956	6,102,034	Culvert under drive, north side of Brookong St
8	474,024	6,102,024	Culvert under drive, north side of Brookong St
9	474,581	6,101,935	Culvert under O'Connell St at Brookong St
10	475,003	6,101,869	Culvert under East St at Brookong St (north)
11	475,000	6,101,845	Culvert under East St at Brookong St (south)
12	475,580	6,101,517	Culvert under Napier Road (east of Lockhart-The Rock Rd)
13	475,553	6,101,481	Culvert under Railway (west of Lockhart-The Rock Rd)
14	476,208	6,101,044	Culvert under Railway (east of Lockhart-The Rock Rd)
15	476,369	6,100,934	Culvert under Railway (east of Lockhart-The Rock Rd)
16	477,235	6,100,384	Culvert under Napier Road (west of Chambers Ln)
17	477,184	6,100,372	Culvert under Railway (west of Chambers Ln)
18	479,510	6,103,828	Culvert under Lockhart The Rock Road (west of Ben Hoffmanns Ln)
19	482,628	6,104,705	Culvert under Ben Hoffmans Ln south of Lockhart Collingullie Rd
20	476,580	6,103,472	Culvert under Lockhart Collingullie Road
21	475,962	6,102,930	Culvert under Lockhart Collingullie Road
22	475,581	6,102,581	Culvert under Lockhart Collingullie Road
23	474,318	6,102,698	Wier/Culvert under Urana St, over creek
24	473,561	6,101,783	Bridge over Urana Lockhart Rd, over creek
25	473,694	6,101,840	Culvert under Treasure St
27	473,836	6,102,467	Footbridge over creek near Green St
28	473,837	6,102,456	Bridge over creek near Green St
29	473,834	6,102,467	Weir over creek near north of Green St

Table 2: The Rock Structures (X,Y coordinates in MGA55)

ID	X	Y	Description
0	508,936.41	6,097,314	Culvert under The Rock Oaklands railway track
1	509,001.89	6,097,364	Culvert under Lockhart The Rock Rd
2	509,160.21	6,097,171	Culvert under The Rock Oaklands railway track
3	509,511.31	6,097,282	2x Box culverts Bretton St
4	509,713.97	6,096,769	Culverts under The Rock Oaklands railway track
5	509,442.95	6,096,453	2x Box culverts under Main Southern railway track
6	509,448.25	6,096,427	Culvert(s) under Olympic Hwy
7	509,694.84	6,096,523	3x box culverts under Main Southern track
8	509,698.01	6,096,492	Culvert(s) under Olympic Hwy
9	510,119.03	6,096,579	Culvert(s) under Olympic Hwy near Hill St
10	510,235.65	6,096,615	Culvert(s) under Olympic Hwy near Park St
11	510,617.14	6,096,717	Culvert(s) under Olympic Hwy - west corner of Emily St
12	510,645.92	6,096,725	Culvert(s) under Olympic Hwy - east corner of Emily St
13	510,953.53	6,096,823	Culvert(s) under Urana St - north of Olympic Hwy
14	510,952.11	6,096,798	Culvert(s) under Olympic Hwy - west cnr The Rock Mangoplah Rd
15	511,003.71	6,096,809	Culvert(s) under Olympic Hwy - east cnr The Rock Mangoplah Rd
16	513,883.67	6,098,682	Culvert(s) under Main Southern railway track
17	513,910.13	6,098,651	Culvert(s) under Olympic Hwy west of Miegels Ln
18	514,768.26	6,099,401	Culvert(s) under Main Southern railway track
19	514,818.00	6,099,395	Culvert(s) under Olympic Hwy

Please provide a quotation for completion of the works described above and an estimate of timeframe for completion of this work by the 21st January 2013.

If you have any questions please call me on (02) 9299 2855 to discuss further.

Yours Sincerely,

Zac Richards
Project Engineer

WMAwater

Webb, McKeown & Associates Pty Ltd (trading as WMAwater)

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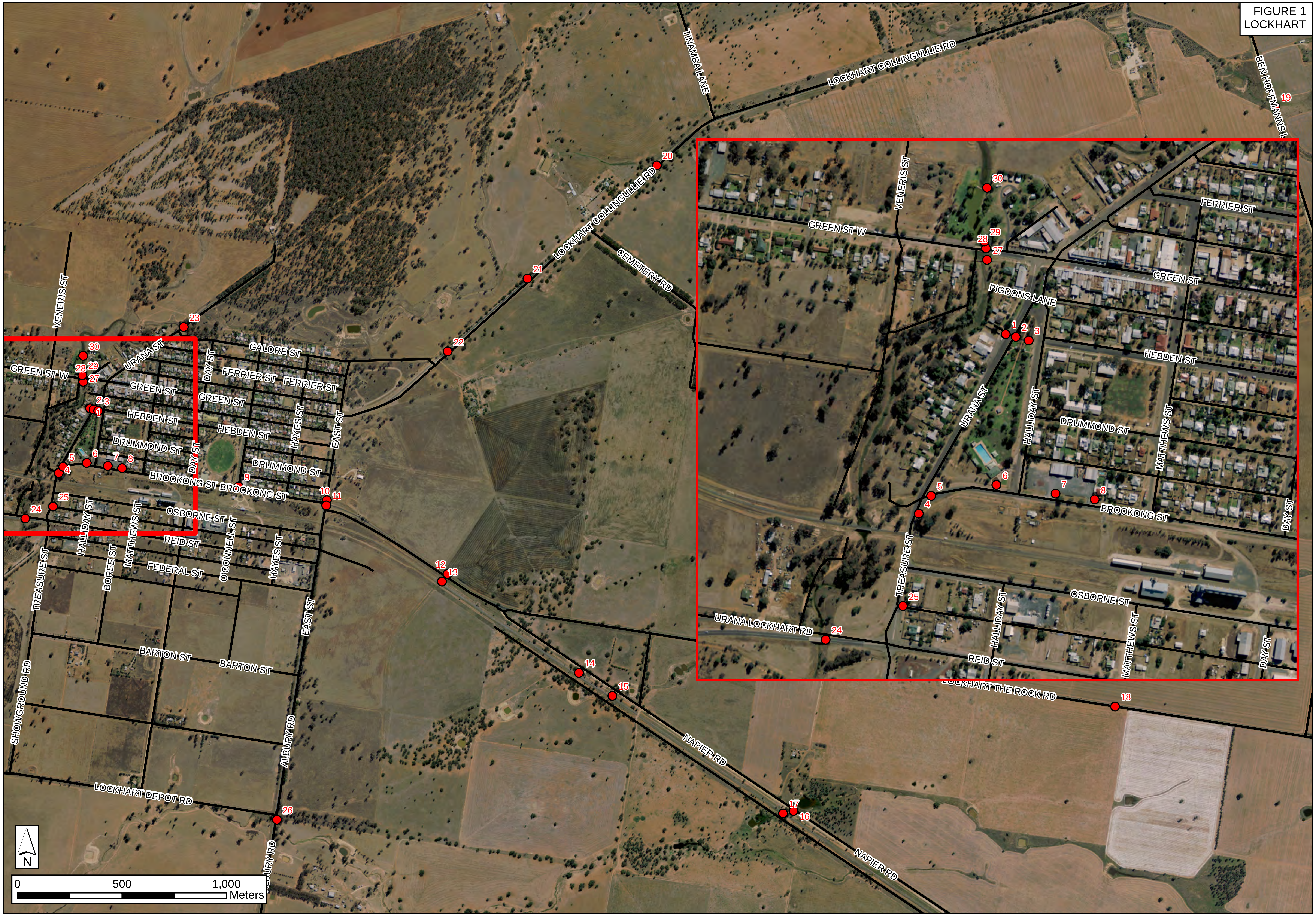
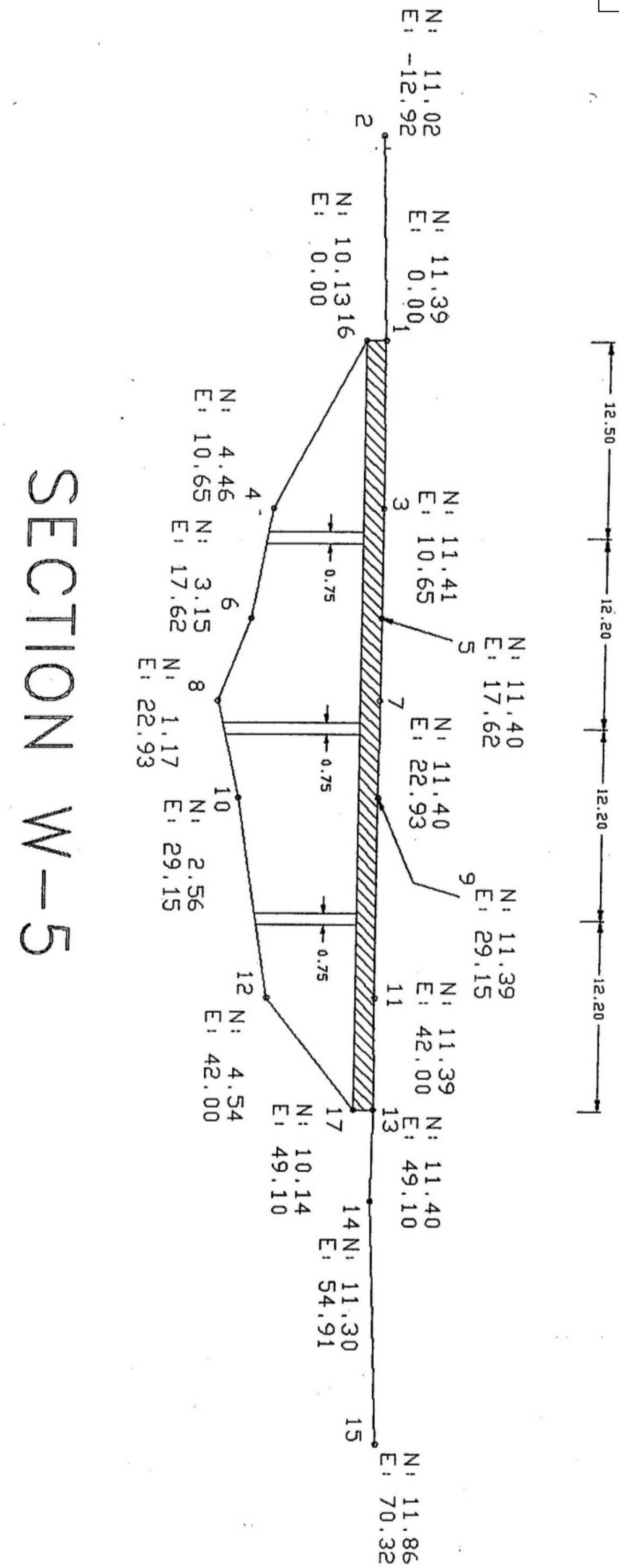


FIGURE 1
LOCKHART
LOCKHART COLLINGULLIE RD
TINAMBA LANE
BEN HOFFMANNS L
CEMETERY RD
VENERIS ST
GREEN ST W
URANA ST
GREEN ST
GALORE ST
FERRIER ST
DAY ST
HEBDEN ST
HAYES ST
EAST ST
DRUMMOND ST
BROOKONG ST
OSBORNE ST
REID ST
FEDERAL ST
O'CONNELL ST
HALLIDAY ST
MATTHEWS ST
BOREE ST
TREASURE ST
SHOWGROUND RD
BARTON ST
ALBURY RD
LOCKHART DEPOT RD
NAPIER RD
LOCKHART THE ROCK RD
PIGDONS LANE
URANA LOCKHART RD
N
0
500
1,000
Meters

FIGURE 2
THE ROCK SURVEY REQUIRED

J:\Jobs\112084\ArcView\ArcMap\TheRock_Survey_marks.mxd

FIGURE 3
EXAMPLE SECTION



FORMAT OF ASCII DATA LISTING OF SECTIONS

Note that the order of points should define the cross-section as if viewed from left to right looking downstream

```
SECTION_NAME
Easting,Northing,Elevation
Easting,Northing,Elevation,
.,.,.
.,.,.
Easting,Northing,Elevations
NEXT_SECTION_NAME
Easting,Northing,Elevation
Easting,Northing,Elevation,
.,.,.
.,.,.
Easting,Northing,Elevation
```

EXAMPLE LISTING

```
UPPER CREEK Xs50
323777.500,1265590.895,56.965
323777.528,1265590.794,56.881
323777.566,1265590.657,56.880
323777.694,1265590.192,55.389
323777.696,1265590.185,55.380
323778.137,1265588.585,55.108
323778.146,1265588.551,55.108
323778.469,1265587.379,55.181
323778.469,1265587.377,55.181
323778.469,1265587.375,55.181
323778.468,1265587.374,55.181
323778.323,1265586.285,56.978
323778.065,1265584.352,57.393
323778.229,1265582.479,57.845
323778.375,1265580.838,58.241
323778.375,1265580.837,58.241
UPPER CREEK Xs60
323799.969,1265589.013,56.186
323799.968,1265589.011,56.186
323799.569,1265587.583,55.025
323799.094,1265585.883,55.074
323799.094,1265585.883,55.074
323799.094,1265585.883,55.074
```

APPENDIX 1: Lockhart


Location 1


Location 2


Location 3


Location 4


Location 5


Location 6


Location 7


Location 8


Location 9


Location 10

Location 11


Location 12


Location 13


Location 14


Location 15


Location 16


Location 17


Location 18


Location 19


Location 20


Location 21


Location 22


Location 23


Location 24


Location 25


Location 26


Location 27


Location 28

Location 29 **No Photo Available**

Location 30 **No Photo Available**

APPENDIX 2: The Rock

Location 3

Location 4

Location 5

Location 6

Location 14

Location 15

 Location 16	 Location 18

FLOOR LEVEL SURVEY FOR THE ROCK AND LOCKHART

1. BACKGROUND

WMAwater are preparing flood and floodplain management studies for towns of The Rock and Lockhart on behalf of Lockhart Shire Council. Part of this work involves obtaining floor levels of all potential flood liable buildings (habitable or commercial buildings but not sheds or garages) within the study area (see Figures 1 and 2). The precise number of building floor levels to be surveyed is unknown but estimates are ~ 350 per town. You are invited to provide a per property price and a lump sum fee to address 350 properties, however the actual number of properties may vary and final budget will be based on a pro-rated amount.

You are invited to provide an email with an attached letter quote, by Friday 17th April 2013, detailing your proposal and timeframe for completion to undertake the works as described above. That is, floor level survey for two towns of The Rock and Lockhart, with approximately 350 floor levels to be picked up in each town.

We have provided the following information to assist with your quotation:

- Figures 1 and 2 showing the properties to be surveyed (properties shown in yellow only),
- Spreadsheet for format of floor level information (Table 1), and
- Sample photograph of each building to be provided.

Should you require further clarification please do not hesitate to contact the undersigned.

Stephen Gray – Associate
WMAwater, Level 2, 160 Clarence Street, SYDNEY NSW 2000
Telephone: (02) 9299 2855 **Email:** gray@wmater.com.au

2. FLOOR LEVEL SURVEY

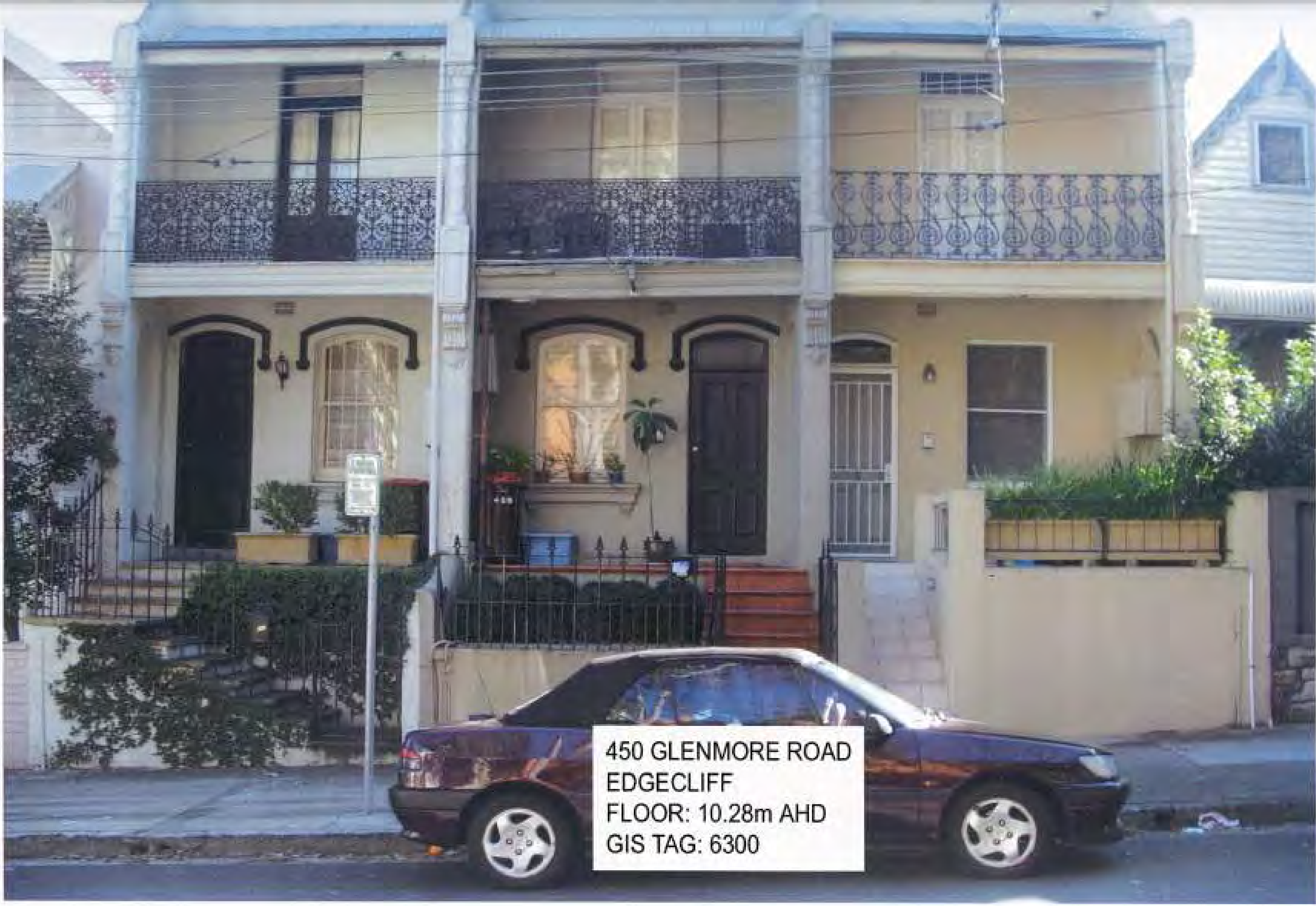
We require floor level information for all buildings (as per the format in Table 1) within the area indicated on Figure 1 and 2) this documentation can be made available in GIS format if required. At each location a digital photograph (suggested max size of photo 500kb) of each building is required (refer to the attached Photo.pdf for details of the required format).

The deliverables from this commission would include:

- Completed Table 1 in a spreadsheet,
- Two hard copy sets of photographs (4 photos per page),
- One digital set of photographs.

Table 1 - Format for Provision of Floor Level Data

						RESIDENTIAL BUILDINGS						NON RESIDENTIAL BUILDINGS					
Property Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Lowest Habitable Floor Level (m AHD)	Single (S) or Double storey (D)	Do people live on the Ground Floor (Y or N)	**House Size** - Small (S), Medium (M), Large (L)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick stone or rendered (B), Clad (C) , Mixed (M)	Type (commercial = C, industrial = I, public = P)	Name and Nature of Use/Business	Lowest Floor Level (m AHD)	Approximate Floor Area (m^2)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick stone or rendered (B), Clad (C) , Mixed (M)
7879	16JohnSt1, 2, 3	3	16	John St	5.25	6.25	S	Y	M	S	B						
												C	Bobs Nursery	6.16	36	S	B
												C	Bobs Fish Stor	6.2	50	S	B
78880	20JohnSt	1	20	John St	5.25	6.56	D	Y	L	S	B						
7671	22JohnSt	1	22	John St	5.25							P	Toilet Block	5.05	50	S	B


450 GLENMORE ROAD
EDGECLIFF
FLOOR: 10.28m AHD
GIS TAG: 6300

Appendix C

							RESIDENTIAL BUILDINGS					
Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Lowest Habitable Floor Level (m AHD)	Single (S) or Double storey (D)	Do people live on the Ground Floor (Y or N)	**House Size -** Small (S), Medium (M), Large (L)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad (C), Mixed (M)
3 4		100-0003	1	107	Orana Street	152.043	152.254	S	Y	M	P	C
6		100-0005	1	110	Osbourne Street	152.501	152.701	S	Y	M	P	C
9		100-0008	1	100	Reid Street	152.647	153.747	S	Y	M	P	C
10		100-0009	2	98	Reid Street	152.895	153.054	S	Y	M	P	C
14 15		100-0013		94	Drummond Street	153.178	153.46	S	Y	S	P	C WB
16 17		100-0014		92	Drummond Street	153.334	153.576	S	Y	S	P	C FC
18 19		100-0015		90	Drummond Street	153.436	153.7	S	Y	M	P	C WB
20 21		100-0016		88	Drummond Street	153.583	153.805	S	Y	L	S	B
22 23		100-0017		86	Drummond Street	153.569	153.826	S	Y	S	P	C FC/WB
24 25		100-0018		82	Drummond Street	153.645	153.691	S	Y	S	P	C WB
27 28		100-0020	2	95	Hebden Street	153.168	153.472	S	Y	M	S	B
29 30		100-0021	1	91	Hebden Street	153.326	153.564	S	Y	M	S	B
31 32		100-022	1	89	Hebden Street	153.294	153.055	S	Y	M	P	C FC

							NON RESIDENTIAL BUILDINGS					
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1 2		100-0001 100-0002	4		Treasure Street	151.181	C	Showground	151.181	360	S	C Iron
5		100-0004	2	98-100	Osbourne Street	152.282	I	HB Primrose M/Vehicle Repairer	152.282	400	S	C Iron Shed
7		100-0006	1	105-111	Treasure Street	152.693	P	Scout Hall	152.693	600	P	C Iron
8		100-0007	2	102-112	Reid Street	152.577	I	Mathews Haulage Service	152.577	1200	S	C Iron Shed
12		100-0011	1		Cnr Brookong & Halliday	153.295	P	Lockhart Swimming Pool	153.295	200	S	B C.B.
26		100-0019	8		Cnr Halliday & Hebden	153.323	P	Lockhart Public School	153.323	1000	S	B
47		100-0028	3	57	Urana Street	153.008	C	Lockhart Roadhouse	153.008	2000	S	M FC/ Metal Shed
101	0.48	100-0039	1	156	Green Street	153.683	C	Crafts	154.163		Wooden P	B
102	0.47	100-0040	1	154	Green Street	154.299	C	Old Bank Bakery	154.769		Wooden P	B
103	0.42	0041	1	152	Green Street	154.366			154.786			B
104		0042	4	140-148	Green Street	153.911	C	IGA	153.911		S	B
105		0043	1	144	Green Street	153.927		Walter Day Building	153.927			B
106		0044	3	134-140	Green Street	154.028	C	Lockhart Building Supplies	154.028		S	B

							RESIDENTIAL BUILDINGS					
Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Lowest Habitable Floor Level (m AHD)	Single (S) or Double storey (D)	Do people live on the Ground Floor (Y or N)	**House Size -** Small (S), Medium (M), Large (L)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad (C), Mixed (M)
33		100-0023	1	4	Halliday Street	153.282	153.488	S	Y	M	S	B
34												
35		100-0024	1	2	Halliday Street	153.475	153.966	S	Y	M	S	B
36												
37		100-0025		158	Green Street	153.188	153.618	D	Y	L	S	B
38												
39						153.078	153.235					
40												
41		100-038		160	Green Street	153.39	153.891	S	Y	M	S	B
42												Rendered
43		100-026	2	51	Urana Street	153.489	154.026	S	Y	M	S	M
44												
45		100-027	3	53	Urana Street	153.258	153.852	S	Y	M	S	C
46												FC/WB
48		100-029	2	61	Urana Street	152.896	153.251	S	Y	S	P	C
49												WB
50		100-030	2	63	Urana Street	152.597	154.201	S	Y	L	S	C
51												FC
52		100-031	2	67	Urana Street	152.48	153.087	S	Y	M	S	C
53												WB
54		100-032	2	69	Urana Street	152.506	153.119	S	Y	M	S	C
55												FC
56		100-033	1	71	Urana Street	152.563	153.213	S	Y	L	S	C
57												FC
58		100-0034	2	73	Urana Street	152.565	153.001	S	Y	M	S	C
59												FC

							NON RESIDENTIAL BUILDINGS					
Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Type (Commercial = C, Industrial = I, Public = P)	Name and Nature of Use/Business	Lowest Floor Level (m AHD)	Approximate Floor Area (m^2)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad
107	0.1	0045	1	132	Green Street	153.852	P	Lockhart Medical Centre	153.952		S	B
108		0046	2	126	Green Street	154.129	C	2nd Hand Shop	154.129		P	B
109	0.2	0047	1	124	Green Street	153.964	C	Red Cross	154.164		P	B
110	0.05	0048	1	122	Green Street	154.055	C	Newsagent	154.155		P	B
111	0.05	0049	2	120	Green Street	154.935	C	Gifts Galore (empty)	154.035		P	B
112	0.24	0050	1	114	Green Street	154.009	C	Empty	154.249		P	B
113	0.37	0051	1	112	Green Street	154.015	C	Hairdresser	154.385		P	B
114	0.25	0052	1	110	Green Street	154.059	C	Jackie's Hair Craft	154.309		P	B
115	0.15	0053	2	108	Green Street	154.095	C	Heaven in Rags	154.245		P	B
116	0.3	0054	1	106	Green Street	154.745	C	Verandah Town Electrical	155.045		P	B
117	0.15	0055	1	104	Green Street	154.015	C	Blue Bird Cafe	154.315		P	B
118	0.05	0056	1	102	Green Street	153.714	C	Empty	154.214		S	B
119	0.1	0057	1	100	Green Street	154.087	C	Empty	154.187		P	B

							RESIDENTIAL BUILDINGS					
Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Lowest Habitable Floor Level (m AHD)	Single (S) or Double storey (D)	Do people live on the Ground Floor (Y or N)	**House Size -** Small (S), Medium (M), Large (L)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad (C), Mixed (M)
60		100-0035	2	75	Urana Street	152.674	153.195	S	Y	M	S	M
61												FC/T
62		100-0036	1	77	Urana Street	152.829	153.517	S	Y	S	S	C
63												FC/WB
64		100-0037	1	79	Urana Street	153.08	153.508	S	Y	L	S	C
65												FC
306		76	1	162	Green Street	153.231	153.534	S	Y	M	P	C
307												
308		77	2	164	Green Street	153.23	153.518	S	Y	M	P	C
309												
310		78	2	166	Green Street	153.588	153.993	S	Y	M	P	C
311												
312		79	3	168	Green Street	153.632	153.736	S	Y	M	P	C
313												
314		80	1	170	Green Street	153.683	153.891	S	Y	M	P	C
315												
324		89	1	15	Urana Street	154.092	154.483	S	Y	M	P	C
325												
326		90	1	13	Urana Street	154.137	154.687	S	Y	M	P	C
327												
328		91	2	11	Urana Street	154.061	154.431	S	Y	M	P	C
329												
330		92	2	9	Urana Street	154.076	154.522	S	Y	M	P	C
331												
332		93	1	5	Urana Street	153.915	154.371	S	Y	M	P	C
333												

Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	NON RESIDENTIAL BUILDINGS Type (Commercial = C, Industrial = I, Public = P)	Name and Nature of Use/Business	Lowest Floor Level (m AHD)	Approximate Floor Area (m^2)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad
119b	0.15	0058	1	98	Green Street	154.078	C	Bendigo Bank	154.378		S	B
121	0.46	0059	1	83-87	Green Street	154.16	C	Lockhart Ex Services Club	154.62		P	B
122	0.05	0060	1		Green Street	154.136	P	Men's Shed	154.186		P	B
123	0.05	0061	1	93	Green Street	154.158	C	SRCC Building (empty)	154.208		P	B
124	0.27	0062	1		Green Street	154.112	C	Dept of Ag	154.382			B
125	0.2	0063	1	109	Green Street	154.509	C	Grain Corp	154.709		P	B
126b	0.28	0064	1	111	Green Street	154.052	C	Commerical Hotel	154.332		P	B
127	0.1	0065	1	125-127	Green Street	153.981	C	Happer Trevaskis	154.081		S	B
128	0.4	0066	1	129	Green Street	153.793	C	Intuition Gifts	154.193		P	B
129	0.28	0067	1	131	Green Street	153.947	C	Collective Healing	154.227		P	B
130	0.25	0068	1	133	Green Street	153.937	C	Latte Da Cafe	154.187		P	B
131	0.35	0069		135	Green Street	153.878			154.228			B
132	0.35	0070	1	137	Green Street	153.89	C	Lollies & Leaves	154.24		P	B

							RESIDENTIAL BUILDINGS					
Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Lowest Habitable Floor Level (m AHD)	Single (S) or Double storey (D)	Do people live on the Ground Floor (Y or N)	**House Size -** Small (S), Medium (M), Large (L)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad (C), Mixed (M)
334		94	1	3	Urana Street	153.828	154.353	S	Y	M	P	C
335												
336		95	3	1	Urana Street	153.723	154.159	S	Y	M	P	C
337												
340		97	1	81	Ferrier Street	153.945	154.254	S	Y	M	P	C
341												
344		99	1	86	Ferrier Street	154.026	154.315	S	Y	M	P	C
345												
346		100	1	79	Ferrier Street	153.869	154.354	S	Y	M	P	C
347												
348		101	3	77	Ferrier Street	154.135	154.411	S	Y	M	P	C
349												
350		102	1	75	Ferrier Street	154.328	154.654	S	Y	M	S	B
351												
362		107	1	58	Galore Street	154.389	154.508	S	Y	M	S	B
363												
364		108	1	56	Galore Street	154.566	154.901	S	Y	M	S	B
365												
370		111	2	48	Galore Street	154.771	155.02	S	Y	M	P	C
371												
372		112	1	55	Galore Street	154.505	155.103	S	Y	M	P	C
373												
374		113	1	53	Galore Street	154.642	155.158	S	Y	M	P	C
375												
376		114	2	51	Galore Street	154.765	155.15	S	Y	M	P	C
377												

							NON RESIDENTIAL BUILDINGS					
Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Type (Commercial = C, Industrial = I, Public = P)	Name and Nature of Use/Business	Lowest Floor Level (m AHD)	Approximate Floor Area (m^2)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad
133	0.42	0071	1		Green Street	153.854			154.274		P	B
134	0.42	0072	1	141	Green Street	153.808	C	Bush & Campbell	154.228		P	B
318		82					P	Bridge	152.069			
319		83				153.341	P	Toilet Caravan Park	153.341		S	B
320		84	3		Green Street	153.582	C	Museum	153.782		S	C
321		86	2		Urana Street	153.692	C	Norwood	153.692		S	C
322		87	2		Urana Street	153.774	C	New	153.954		S	B
323		88	1	17	Urana Street	153.917	I	Shed	153.917		S	Iron
342 343		98	1	84	Ferrier Street	154.135	P	Fire Station	154.282		S	B

							RESIDENTIAL BUILDINGS					
Point No	Parcel Tag as on Council cadastre (GIS Tag)	Photograph name	Total number of buildings	Street Number	Street Name	Indicative Ground Level (m AHD)	Lowest Habitable Floor Level (m AHD)	Single (S) or Double storey (D)	Do people live on the Ground Floor (Y or N)	**House Size -** Small (S), Medium (M), Large (L)	**Floor Construction** Pier (P) or Slab (S) Other - describe	**Wall Construction** Brick, Stone or Rendered (B), Clad (C), Mixed (M)
383		117	1	39	Galore Street	155.373	155.375	S	Y	M	S	C
384												
389		120	1	33	Galore Street	155.63	155.803	S	Y	M	S	B
390												
393		122	1	29	Galore Street	155.644	155.858	S	Y	M	S	B
394												
395		123	2	27	Galore Street	155.748	155.936	S	Y	M	S	B
396												
403		127	1	19	Galore Street	155.772	156.584	S	Y	M	P	C
404												
405		128	1	17	Galore Street	155.856	156.096	S	Y	M	S	B
406												
415		133	1	4	Galore Street	156.117	156.358	S	Y	M	S	B
416												
419		135	2	8	Galore Street	156.045	156.205	S	Y	M	S	C
420												
423		137	1	12	Galore Street	156.007	156.093	S	Y	M	S	B
424												
427		139	1	22	Galore Street	155.694	155.876	S	Y	M	S	B
428												
429		140	1	24	Galore Street	155.538	155.655	S	Y	M	P	C
430												
431		141	1	26	Galore Street	155.576	155.557	S	Y	M	S	B
432												
449		150	1	50	Ferrier Street	155.015	155.181	S	Y	S	S	C
450												

Appendix D

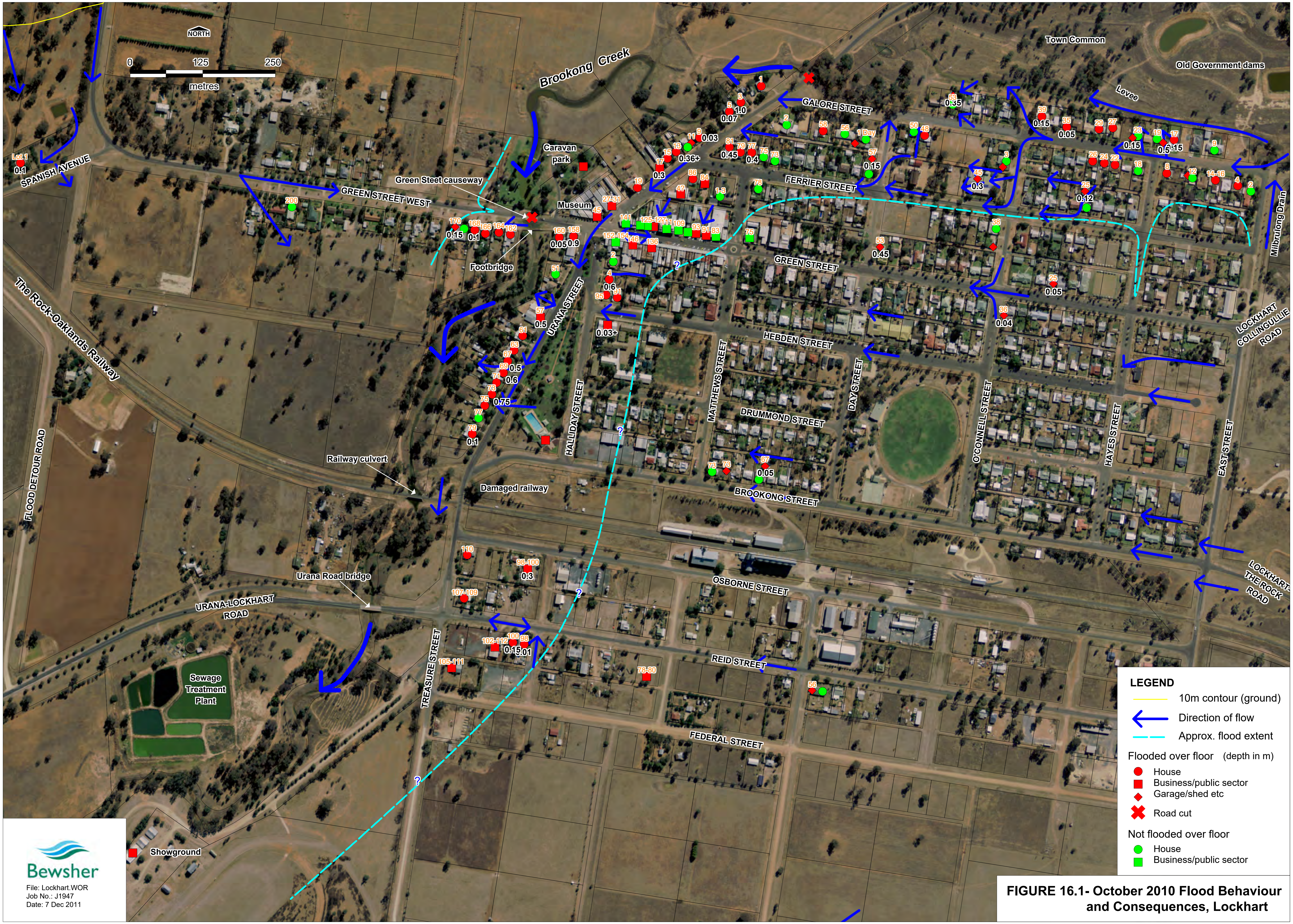


FIGURE 16.1- October 2010 Flood Behaviour and Consequences, Lockhart

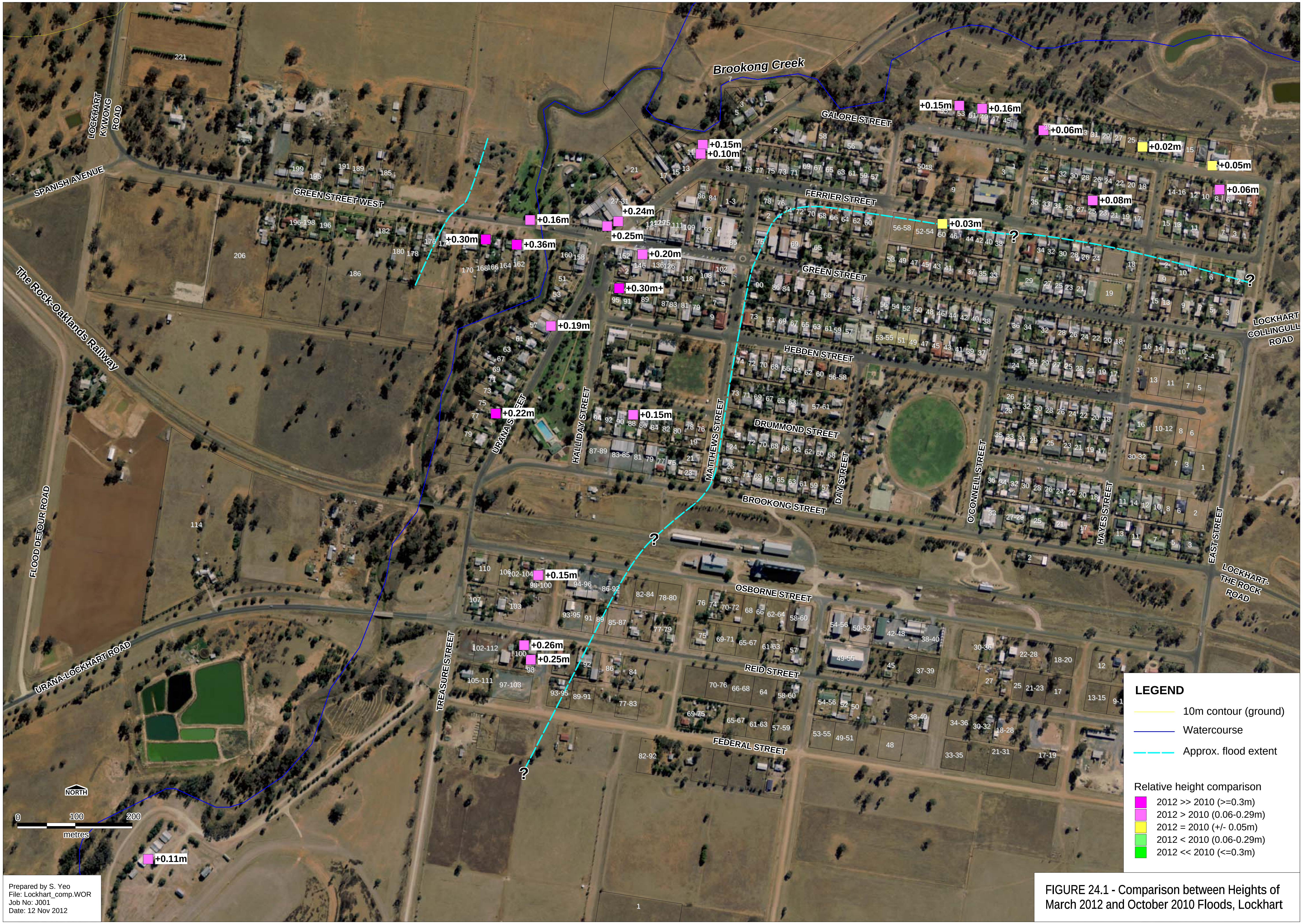


FIGURE 24.1 - Comparison between Heights of March 2012 and October 2010 Floods, Lockhart

Appendix E

LOCKHART

FLOOD AND FLOODPLAIN MANAGEMENT STUDIES

THE ISSUE

Lockhart is a township located in the Lockhart Shire LGA, located 62 km southwest of Wagga Wagga and has a population of 837 at the 2006 census.

Brookong Creek drains on the northern and western sides of Lockhart and has a catchment area of some 150 km² at Lockhart.

Lockhart has been recently affected by major flood events in October 2010 and March 2012. These floods have caused significant disruptions to residents in Lockhart. Floodwaters entered houses, residential and commercial properties causing substantial flood damages and risk to life.

FLOOD STUDY

The flood study aims to describe and understand the nature and extent of flooding at Lockhart. The first stage of the flood study will collect, compile and review all available information that can be valuable to undertake the work. A topographical survey will also be carried out by a sub-consultant to survey hydraulic features in the floodplain (bridges, culverts, levees, etc) that have a significant effect on flood behaviour.

Upon data collection and collation, computer models will be built with the aim of emulating recent flood events (October 2010 and March 2012). Comparison will then be made to observations from residents and data collected in flood intelligence reports. Once the models are able to replicate the observed flood behaviour, we will proceed to carry out design event runs (i.e. 100 year ARI), which will establish design flood levels on the Brookong Creek floodplain as well as other overland flow paths.

FLOODPLAIN MANAGEMENT STUDY AND PLAN

The flood study will provide a robust computer model which will later be used in the Floodplain Management Study. Different flood mitigation alternatives will be assessed showing their advantages and disadvantages. Social, economical and environmental impacts will be assessed to provide the most suitable solution to flood mitigation in Lockhart.

FLOOD MITIGATION

Flood mitigation works aim to reduce or eliminate the severity of existing flooding impacts. Following the Flood Study, the Floodplain Management Study aims to identify suitable flood mitigation works. Suitable flood mitigation works will be cost effective in terms of the benefits they provide versus the cost of implementation and maintenance.

Once the Floodplain Management Study has identified suitable mitigation measures, a Floodplain Management Plan is prepared to recommend implementation of suitable mitigation options.

Preliminary measures are discussed and then those options that could potentially be suitable are modelled to find out in detail what the flood impact is. If the options are shown to reduce flood risk and cost effective, then the Plan will recommend implementation by Council and funding may be available via the State Government.

Flood mitigation works are designed to eliminate flooding for a particular design event, in other cases the severity of flooding is simply reduced.

Mitigation Works will generally fall under the following categories:

STORAGE

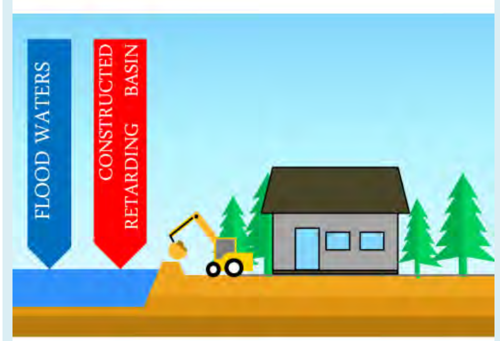
Dams or retarding basins that trap/delay flood waters before they arrive at some critical location.

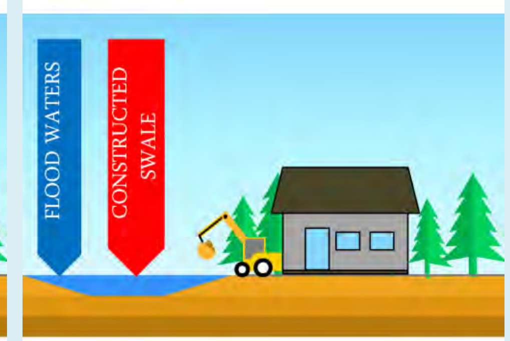
DIVERSION

Move water somewhere else rather than the specific area you do not want flooded.

LEVEES

Typically earthworks that exclude flood waters from a specific area, to provide flood protection.





Whilst flood mitigation measures may reduce flooding in one area they could increase risk in other areas. Flood flows are typically powerful and have large volumes. Flood water must go somewhere and when displaced from one area by a levee or other flood mitigation structure it will end up somewhere else.

The other issue is that whilst flood mitigation works may be designed for one event (say a 5 year ARI event) an event bigger than that could occur. Unless flood mitigation works are designed with larger events in mind they can sometimes make things worse. For example a dam designed to trap flows up to the 5 year ARI that then fails in a larger event could create a powerful flood wave causing flood impacts worse than the original event due to the concentration of flow.

Part of the reason we use models is to identify these other potential impacts of flood mitigation works; to ensure that mitigation has the positive benefits required without causing detrimental impacts in other areas. Sometimes the negative impacts are not foreseen and the hydraulic model helps with that element of prediction.

Using recorded information, such as that from the October 2010 and March 2012 events, can assist is developing accurate flood models.

LOCKHART
Flood and Floodplain Management Studies
NEWSLETTER & QUESTIONNAIRE

Lockhart Shire Council is carrying out two concurrent flood studies within its local government area under the NSW Governments Flood Prone Land Policy. The studies will focus on the towns of Lockhart and The Rock.

Lockhart has recently been affected by two flood events (October 2010 and March 2012). A large number of houses, businesses and public sector buildings were inundated above floor level. The level of damage translated to significant economical losses. In some cases the safety of the residents was also of concern. Some residents had to find alternative accommodation for long periods of time. Additionally, numerous roads had to be closed during these floods and some of them suffered significant damage. Railway tracks were severely affected by floodwater unable to go through culverts. Sewer services were also affected.

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The primary objective of the Policy is to reduce the impact of flooding and flood liability on owners and occupants of flood prone land and to reduce losses from flooding. The Policy provides for technical and financial support by the State Government through four sequential stages:

1. **Flood Study**
   Determine the nature and extent of the flood problem
2. **Floodplain Risk Management**
   Evaluate management options for the floodplain in respect of existing and proposed development.
3. **Floodplain Risk Management Plan**
   Formal adoption by Council of a plan of management for the floodplain
4. **Implementation of the Plan**
   Construction of flood mitigation works to protect existing development and use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

Lockhart Shire Council has commissioned WMAwater to undertake flood and floodplain management studies for both townships. The flood study will define the flood behaviour over a range of flood magnitudes within the two townships. As part of the flood studies computer models describing the flood behaviour will be built. In order to establish the accuracy of such models, input from the public on observed flood behaviour is being sought. We are also interested in residents' suggestions regarding flooding that affects them. So in addition to observations of previous flooding we seek potential solutions, some of which, following acceptance via the Flood Risk Management Committee (FRMC), will be tested via computer model. A questionnaire is provided in the following page which aims in gathering such information.

As well as attempting to obtain information on flooding via this questionnaire **a round of public consultation days will be held on the 8th and 9th of February 2013 at the Lockhart Memorial Hall commencing at 10 am and finishing at 4 pm** to allow members of the Lockhart community to personally provide information on their experiences to the consultant. Community representatives have been selected for each town to provide residents with an additional means of study involvement.

The following people have been appointed as **committee members** for **Lockhart:**

Mayor Peter Yates
Cr Max Day
Cr Roger Schirmer
Mr Laurie Carter
Mr Greg Coombes (SES Rep.)
Mrs Jean Gooden
Mr Ray Lavender
Mr Steven Matthews
Mr John Stevenson

FLOOD STUDY QUESTIONNAIRE

WMAwater is carrying out the study for Council and would like to hear about your experiences of flooding. Please return the completed questionnaire before **15/02/2013 by**:

- **Prepaid self-addressed envelope provided** *or*
- Fax to 9262 6208
- Scan and email to richards@wmawater.com.au

WMAwater is aware of previous work carried out by the SES in regard to flood intelligence data collection for the October 2010 and March 2012 flood events. However, as part of the FRMS+P process WMAwater is required to consult the community in regard to previous experience of flooding. This work will ensure that all possible information that can be used to inform the hydraulic models be available. If you have any photographs of flooding in your area or additional information pertinent to flooding in the region, please email this useful information to richards@wmawater.com.au or include them with the questionnaire in the prepaid envelope. All photos will be copied and returned.

Your Name: ________________________________

Tel No: ________________________________ E-Mail: ________________________________

Property Address: ____

____

☐Residential Property ☐ Non-Residential Property

1. **How long have you lived or worked at this address? _____ years**

2. **Did you experience flooding during October 2010, March 2012 or any other event?**

Location	October 2010		March 2012		Other (date?) ___/___/____	
	Affected?	Water Depth	Affected?	Water Depth	Affected?	Water Depth
Above floor of main building (eg. house)	☐ No ☐ Yes		☐ No ☐ Yes		☐ No ☐ Yes	
Above floor of other buildings (eg. garage)	☐ No ☐ Yes		☐ No ☐ Yes		☐ No ☐ Yes	
Above ground in yard next to main building	☐ No ☐ Yes		☐ No ☐ Yes		☐ No ☐ Yes	
Above road adjacent to property	☐ No ☐ Yes		☐ No ☐ Yes		☐ No ☐ Yes	
Other (please specify): ………………………	☐ No ☐ Yes		☐ No ☐ Yes		☐ No ☐ Yes	

3. **At what time was the highest water level reached during each event?** *(leave blank if unsure)*

Location	October 2010	March 2012	Other (date?) ___/___/____
Date and Time			

4. **If you have any rainfall records or other information that may be useful for better understanding flooding in Lockhart please provide to the above mentioned email or address.**

Appendix F

Appendix F: Calibration \ Validation Trialled Model Approaches

To obtain the best possible fit for the Green Street and Reid Street stage hydrographs (see Section 2.6.1.1) for the calibration/validation events, numerous iterations varying various modelling parameters were tested. These parameters include:

- WBNM lag factor;
- losses;
- baseflow;
- blockage;
- in-bank Manning's 'n'; and
- removal of the Green Street footbridge.

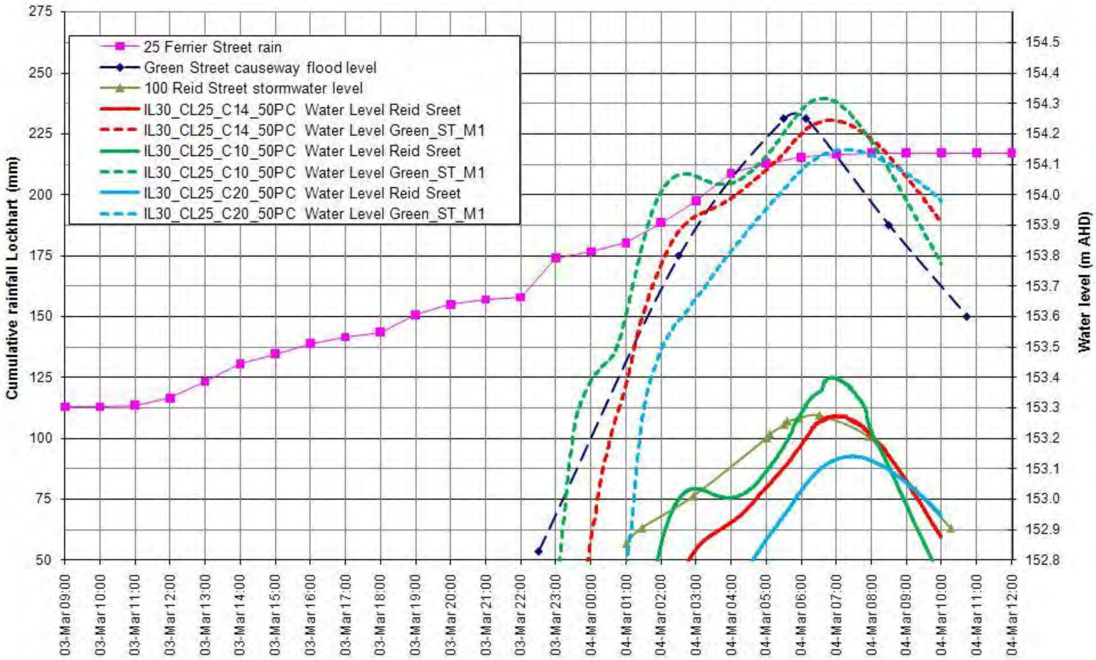
The following sections display a small selection of results from the tested model runs for the March 2012 calibration event. A similar process was undertaken for the October 2010 validation event.

F1.1 WBNM Lag Factor

Chart F1 displays stage hydrographs for various WBNM lag parameters 'C'. The green line has a C of 1.0, the red a C of 1.4 and the blue a C of 2.0 (all other model parameters are the same between each model).

It can be seen that the lower the C value the faster the peak arrives and the more 'peaky' the hydrograph becomes. For the current model a C value of 1.6 has been implemented as is recommended for ungauged catchments (see Section 4.3.1.1). This C value also produced the best match for the stage hydrographs.

Chart F1: Variations to WBNM Lag Factor



F1.2 Losses

Variations to both initial and continuing losses were tested to obtain the best fit to the observed stage hydrographs. Chart F2 displays the variation in stage between tested cases of initial losses ranging from 10 to 40 mm. It can be seen that the smaller the initial loss the sooner the rising limb of the stage hydrograph increases. The initial losses for the calibration/validation events (see Section 4.3.2.1) have been determined via comparison of modelled to observed levels at these stage hydrographs.

Chart F2: Variations to Initial Losses

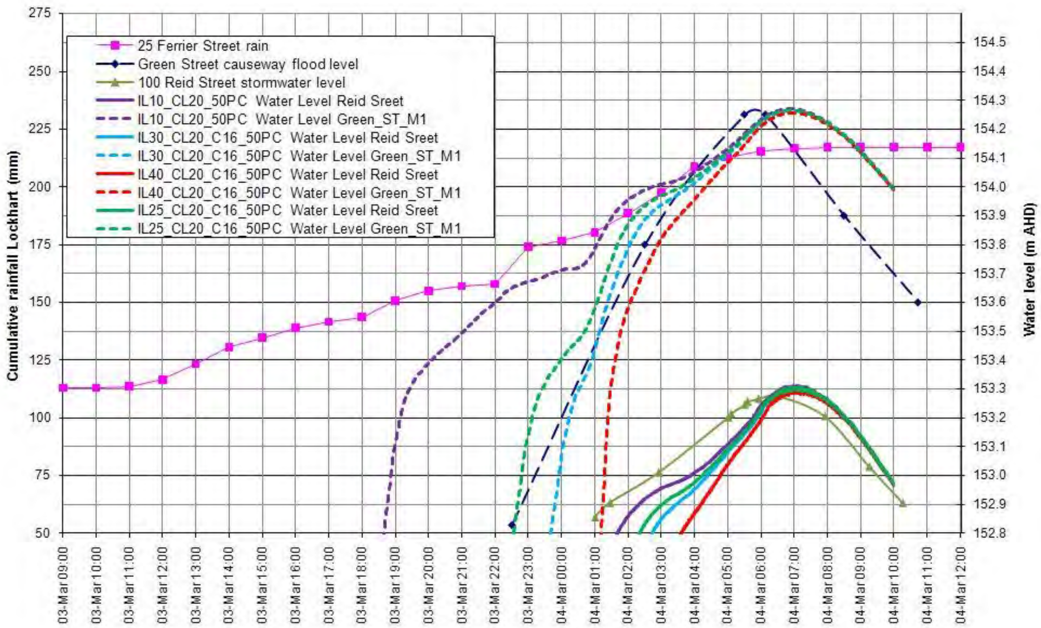


Chart F3: Variations to Continuing Losses

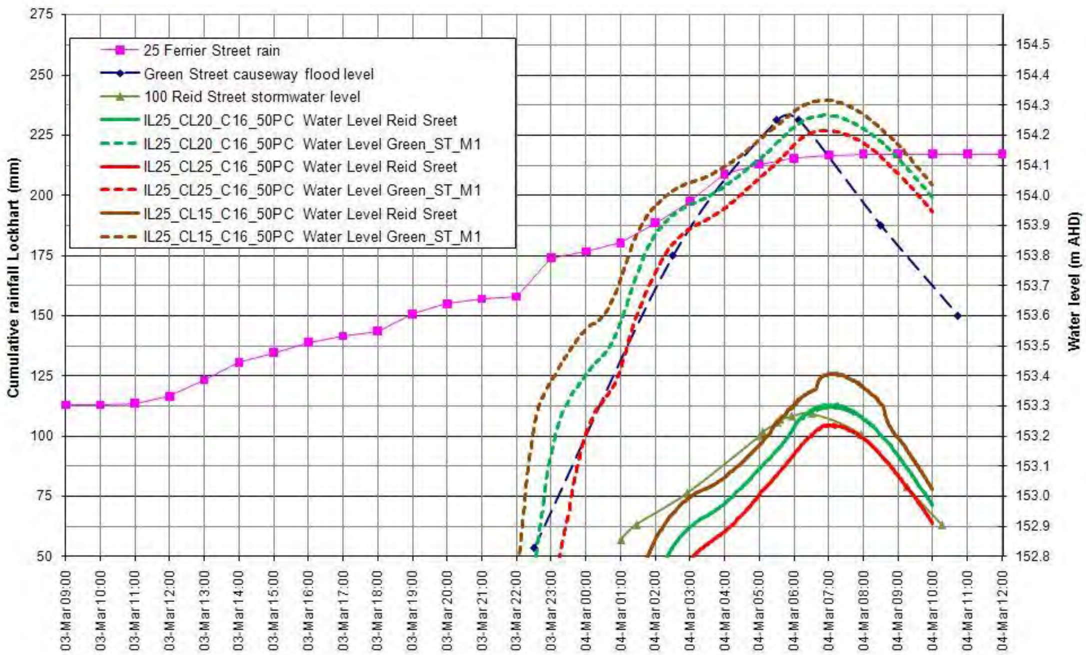
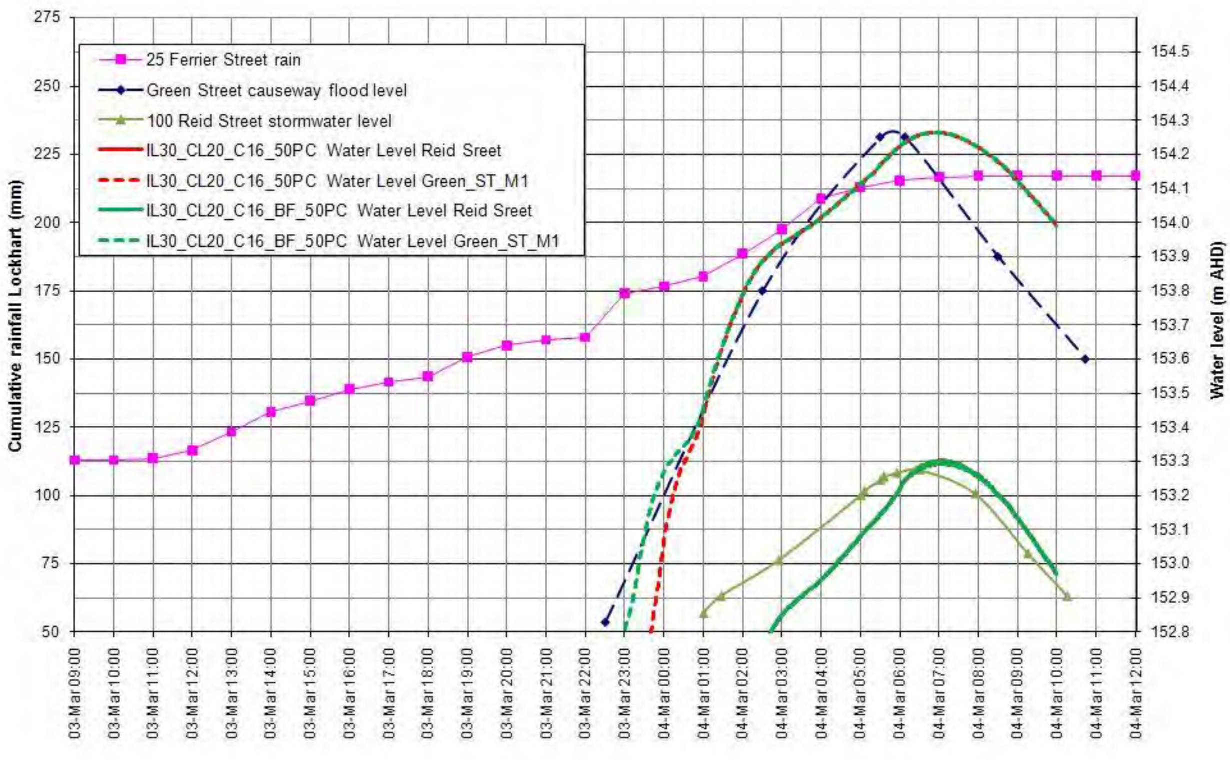


Chart F3 displays the effect of varying continuing losses on levels at the Green and Reid Street hydrographs. Continuing losses of 1.5, 2.0 and 2.5 mm/hr are displayed in the above figure and as expected the larger the selected loss value the lower the peak flood level. A loss of 2.0 mm/hr (see Section 4.3.2.1) was determined to be optimum for the calibration/validation events.

F1.3 Baseflow

Chart F4 displays the effect of adding addition baseflow to the model. With more rainfall data, baseflows would be implicitly incorporated into the hydrologic modelling and thus the need for additional baseflows to be added to the hydraulic model would not be required. However, as mentioned in Section 2.4.1, the available rainfall data was too short in record period to allow for this. As such 10 m³/s of baseflow was added to the model to improve the match on the rising limb. The green line displays the scenario with added baseflow and the red line is without added baseflow. It can be seen that match in improved for lower stages in the stage hydrograph displayed in Chart F4.

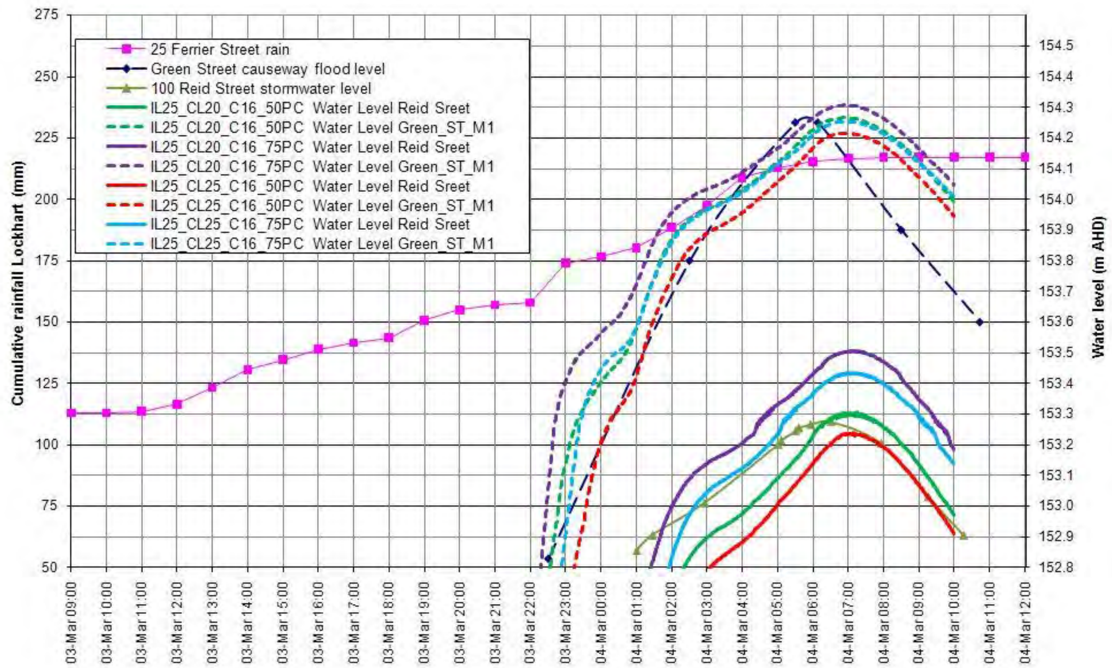
Chart F4: Comparison of Baseflow



F1.4 Blockage

Various blockages were tested on each of the Brookong Creek crossings in Lockhart. Varying this parameter (between 0 – 75%) was shown to impact on both upstream and downstream peak flood levels. The selected blockage assumptions described in Section 4.4.5.2 were determined by comparison of modelled levels to those observed for both the stage hydrographs displayed below in Chart F5 and the surveyed peak flood levels described in Section 2.6.2.

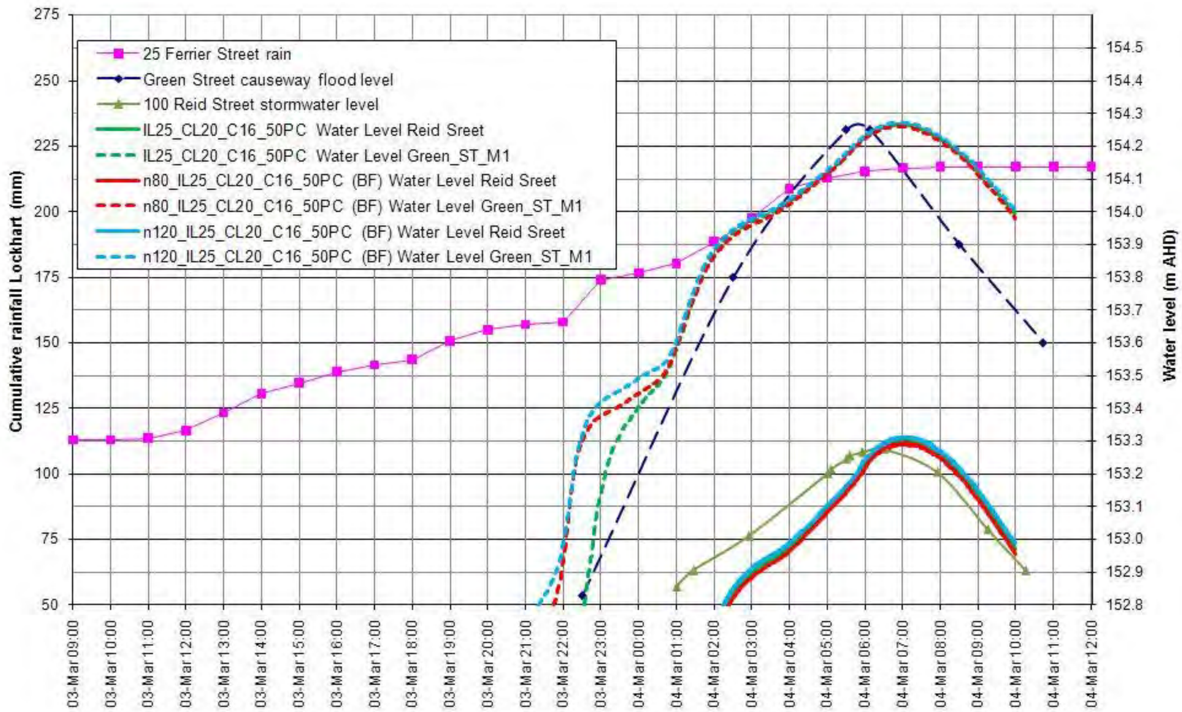
Chart F5: Comparison of Bridge Blockages



F1.5 In-bank Manning's 'n'

The in-bank Manning's 'n' was adjusted by ± 20% and was shown to have no impact on peak flood levels. Flood levels were only affected when the large majority of the flow was contained within the in-bank, thus only impacting on flood levels at lower stages (see Chart F6).

Chart F6: Comparison of In-bank Manning's 'n'

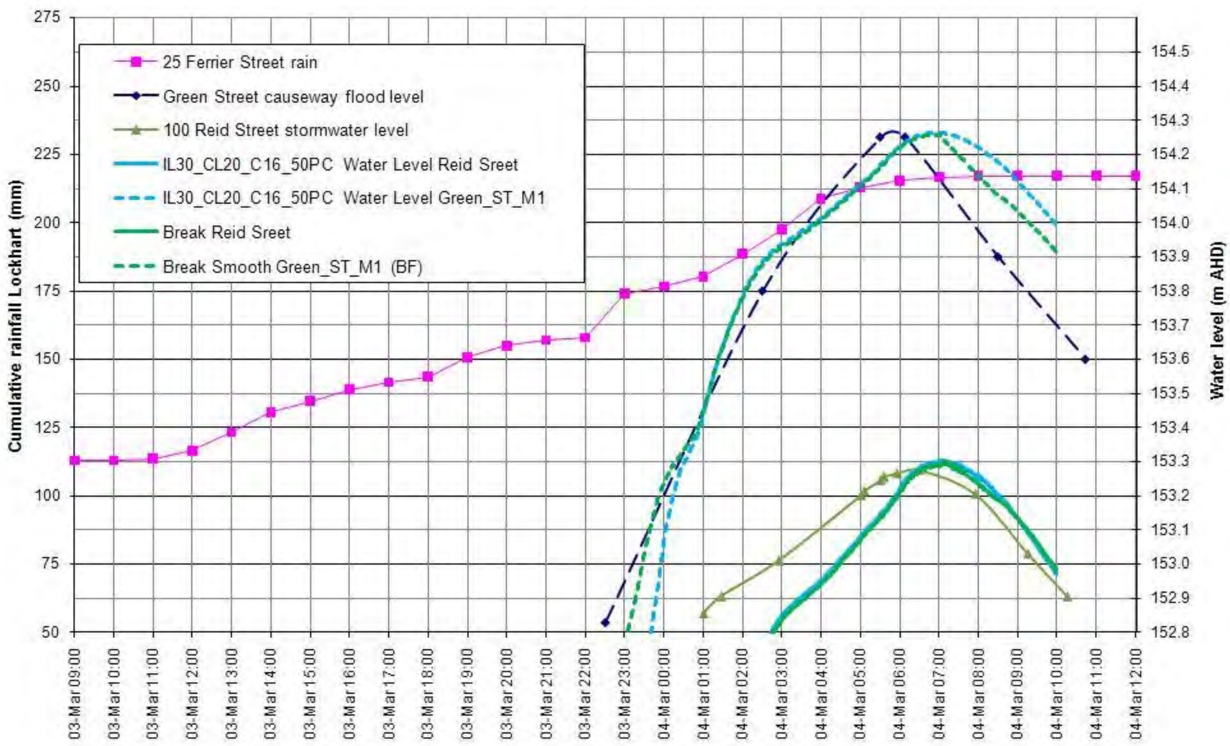


F1.5 Destruction of the Green Street Footbridge

During the March 2012 event the Green Street Footbridge was destroyed (see Section 1.4.2.4). In an attempt to better match the modelled receding limb of Green Street stage hydrograph to that observed the footbridge was removed from the model at the flood peak (it was assumed that this is when the bridge was destroyed). Chart F7 displays a comparison of the stage hydrographs with (green) and without (blue) the removal of the footbridge. It can be seen that with the removal of the footbridge the timing of the receding limb is generally improved by approximately one hour however still remains slightly later then what was observed. This is likely due to the timing of the rainfall data.

Note that in the calibration results (see Section 4.5.3.1) modelling of the removal of the footbridge has not been included. This is because the time of destruction and degree to which the bridge was destroyed is not known.

Chart F7: Removal of Green Street Footbridge



Appendix G

APPENDIX G: Hydraulic Categorisation – Floodway Definition

Introduction

The Lockhart hydraulic categorisation maps are displayed in Figure 24 and Figure 25 for the 1% and 0.5% AEP events respectively.

Hydraulic categorisation is the process by which flood behaviour for a given design event is classified into areas of flood storage, flood fringe and floodway. The NSW Floodplain Development Manual 2005 (Reference 15) provides definitions for all three categories, however these are descriptive definitions and aren't suitable for directly calculating/assessing the categories. The definitions as per Reference 15 are provided below for clarity.

> *Floodway*– areas in the floodplain where significant discharge occurs. Often aligned with natural 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* – those parts of the floodplain important for the temporary storage of floodwaters during a flood. Extent and behaviour of flood storage areas may vary greatly for different events and so a range should be examined.
>
> *Flood Fringe* – remaining areas of land in the floodplain after flood storage and floodway have been defined. (NSW FDM, 2005)

Two further definitions that are suitable for directly calculating/assessing the floodway extent and that are widely used to describe the characteristics of the floodway are described below:

1. The extent which comprises a significant proportion of flow in a flow path (80 to 90% is often used as the portion of flow within the floodway); and

2. The extent which if partially blocked causes impacts in excess of 0.1 m to occur upstream of the partial blockage.

These two definitions have been used to assist in determining the floodway extent at Lockhart.

Defining the floodway is a critical component of the flood risk management work carried out under the NSW Floodplain risk management program. This relates to the fact that the defined floodway extent will typically not be available for further residential development. As such it is imperative that the floodway definition is appropriate and not conservative.

Approach

Generally speaking there is no definitive method and defining a floodway is often an iterative process. In the context of 2D and 1D/2D models, the output used in the mapping tends to be in a raster format. A raster presents flood modelling outputs for each grid cell in a gridded format for the given study area. The velocity depth (VD) product for each cell can, and has in previous studies, been used to define the floodway. For example the Howells et al (Howells) method utilises the VD product and the velocity (V) when assessing hydraulic categories.

The Howells method differentiates the floodway from other hydraulic categories by selecting a VD criteria that exceed a specific threshold. Some subjectivity still exists within the methodology and different regions often require different V and VD criteria to produce suitable results. Testing varying V and VD criteria, to some degree, is comparable to a calibration exercise where the VD product to be used as a threshold for defining floodway is modified until such a time as a suitable floodway is obtained.

Given that the VD product can provide a base for defining the floodway extent for raster results, the next issue with floodway definition is defining what the VD product should be "calibrated" to, to achieve a reasonable floodway definition. In other words, what VD product will define a floodway extent which will satisfy the two floodway definitions mentioned above.

Methodology

In the 2012 paper by Thomas et al., the two previously mentioned floodway definitions were investigated and a remarkable correlation was observed between the 80% flow criteria and a 0.1 m afflux.

The proposed approach builds on the criteria proposed by Howells et al. in their 2004 paper using various VD and V parameters to estimate the floodway and then verifies results using encroachment analysis similar to that found in Thomas et al. (2012).

In the encroachment analysis all areas not defined as floodway via the Howells method have been totally excluded from the modelling domain and the subsequent impact on flood levels is examined. In other words the encroachment run undertaken as a check, conservatively assumes that all areas outside the floodway are blocked and should development occur outside the floodway zone defined herein the impact is likely to be less than 0.1 m

A summary of VD and V values investigated is listed below:

a. VD > 0.25 m^2/s and V>0.25 m/s; or V>1.0 m/s;
b. VD > 0.5 m^2/s and V>0.25 m/s; or V>1.0 m/s;

In addition to this the percentage of flow conveyed in the floodway has been investigated to see if it fits the 80% criteria, further adding to the robustness of results.

Results

Appendix Figure G1 displays the afflux associated with the encroachment analysis testing for Lockhart. Regions displayed in orange satisfy the 2nd floodway definition mentioned previously.

The defined floodway criteria (a) listed above was found on encroachment analysis testing (Appendix Figure G1 displays encroachment region in green) to produce an afflux of approximately 0.1 m in the region upstream of Ferrier Street in Lockhart thus satisfying the 2nd floodway definition.

Further downstream of this region a different criteria was required to further reduce the width of the floodway for encroachment analysis (Appendix Figure G1 displays encroachment region in red) and it was found that criteria (b) produced reasonable results. The tested criteria was found to produce approximately 0.1 m afflux as far downstream as the Railway, again satisfying the 2nd floodway definition listed above.

Downstream of the railway the afflux is less than that required however this is likely due to overland flows from the Milbrulong region being unable to enter the channel due to the modelled encroachment. Therefore regions downstream of the railway are assumed to also be satisfied by criteria (b).

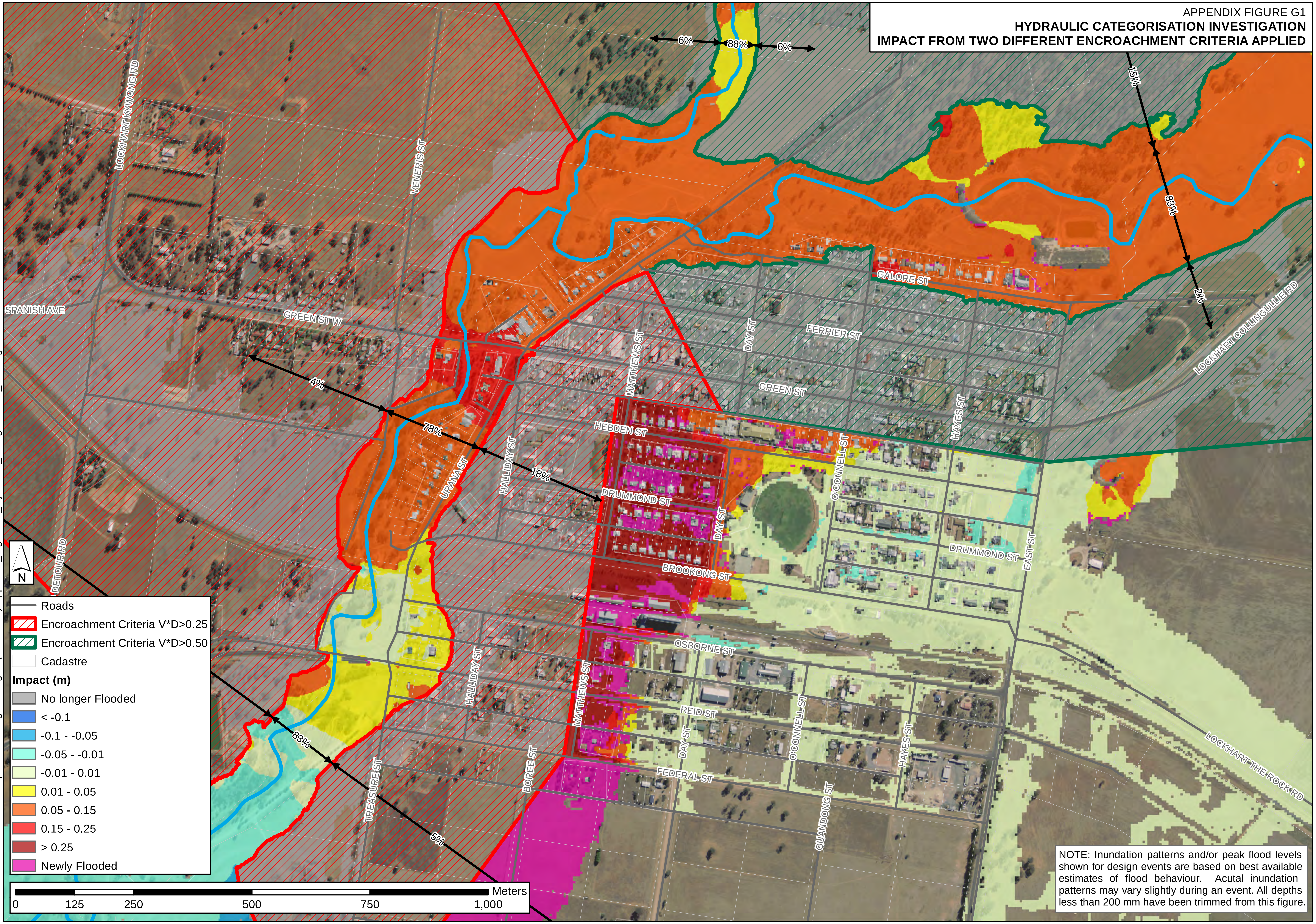
A number of cross sections that measure flow in the model are also displayed in Appendix Figure G1. For each cross section the percentage of flow on either side of and within the floodway are displayed. It can be seen that the percentage of flow contained within the defined floodway is approximately 80% thus satisfying the 1st floodway definition. This adds further robustness to the floodway results.

Conclusions

Defining a floodway is a non-precise process. The goal is to produce floodway extents that match flow behaviour so that the areas which need to be retained for flow are identified whilst other parts of the flood extent can be developed as appropriate. While the allocation of floodway is likely to be a contentious issue that would merit a precise definition, the fact remains that a one size fits all approach still eludes the practitioner. The method presented defines a reasonable floodway extent using VD and V criteria and then confirms the suitability of the defined floodway extent by using afflux testing. The percentage of flow within the floodway was also investigated to see if the 1st floodway definition is satisfied.

The method used in defining the floodway is based on the Howells method but the VD and V thresholds are adjusted according to an encroachment analysis until the 2nd floodway definition is satisfied. When all areas outside the defined floodway are blocked and the resulting afflux is in the region of 0.1 m it can be argued that any development outside this floodway will result in an afflux less than 0.1 m which satisfies our second definition of floodway.

In Lockhart it can be seen that multiple residential lots are defined within the floodway particularly along Urana Street (see Hotspot 6, Section 4.7.6) and Galore Street (see Hotspot 2, Section 4.7.2).



J:\Jobs\112084\ArcView\ArcMap\Lockhart\Figures\Figure(12072013)\Appendix_FigureG1_Hydraulic_Categorisation_Investigation.mxd