ATTACHMENTS

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Ordinary Council Meeting

24 March 2020

NARRABRI SHIRE
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NARRABRI SHIRE COUNCIL

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

DECEMBER 2019

VOLUME 1 – REPORT

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FOREWORD

NSW Government's Flood Policy

The NSW Government's Flood Prone Land Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that 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 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 Policy provides for technical and financial support by the State through the following four sequential stages:

1.	Data Collection and Flood Study	Collects flood related data and undertakes an investigation to determine the nature and extent of flooding.
2.	Floodplain Risk Management Study	Evaluates management measures 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. Improvements to flood emergency management procedures.

Presentation of Study Results

The results of the flood study investigations commissioned by Narrabri Shire Council have been presented in two separate reports:

- *Wee Waa Levee Flood Investigation* dated June 2015.
- ***Wee Waa Levee Risk Management Study & Plan (this present report)***

The studies have been prepared under the guidance of the Floodplain Risk Management Committee comprising representatives from Narrabri Shire Council, the NSW Department of Planning, Industry and Environment, the NSW State Emergency Service and the community.

ACKNOWLEDGEMENT

Narrabri Shire Council has prepared this document with financial assistance from the NSW Government through its Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Department of Planning, Industry and Environment.

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ABBREVIATIONS

AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval (years)
ARR	Australian Rainfall and Runoff (1987 Edition)
BoM	Bureau of Meteorology
Council	Narrabri Shire Council
DECC	Department of Environment and Climate Change
DPIE	Department of Planning, Industry and Environment
FDM	Floodplain Development Manual, 2005
FFA	Flood Frequency Analysis
FRMC	Floodplain Risk Management Committee
FPL	Flood Planning Level (1% AEP flood level + freeboard)
FPA	Flood Planning Area
ICA	Insurance Council of Australia
LRMS	Levee Risk Management Study
LRMP	Levee Risk Management Plan
LRMS&P	Levee Risk Management Study and Plan
LEP	Local Environmental Plan
LiDAR	Light Detection and Ranging (form of aerial based survey)
NSWG	New South Wales Government
NSW SES	New South Wales State Emergency Service
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation

SUMMARY

S1 Study Objectives

Narrabri Shire Council (**Council**) commissioned the *Levee Risk Management Study and Plan* for the township of Wee Waa. The overall objectives of the *Levee Risk Management Study (**LRMS**)* were to assess the impacts of flooding, review existing Council policies as they relate to development of land in flood liable areas, consider measures for the management of flood affected land and to develop a *Levee Risk Management Plan (**LRMP**)* which:

i) Proposes modifications to existing Council policies to ensure that the development of flood affected land is undertaken so as to be compatible with the flood hazard and risk.

ii) Sets out the recommended program of works and measures aimed at reducing over time, the social, environmental and economic impacts of flooding.

iii) Provides a program for implementation of the proposed works and measures.

While the *LRMS* focuses principally on the existing, continuing and future flood risk associated with the urbanised parts of Wee Waa which are bounded by an 8.6 km long earthen ring levee (**Town Levee**), recommendations for managing the flood risk in a 228 ha area which lies to the south-east of Wee Waa which is zoned *R5 Large Lot Residential* are also set out in the report.

S2 Study Activities

The activities undertaken in this *LRMS* included:

1. Undertaking a consultation program over the course of the study to ensure that the Wee Waa community was informed of the objectives, progress and outcomes over the course of the study (**Chapter 1** and **3**, as well as **Appendix A**). Consultation was also undertaken with the insurance industry to gauge the likely reduction in insurance premiums that would be achieved by upgrading the Town Levee (**Chapter 1**).
2. Undertaking of a preliminary geotechnical assessment of the condition of the Town Levee (**Appendix B**).
3. Analysis of historic stream flow data to update the flood frequency relationship that has been derived for WaterNSW's *Namoi River at Mollee* stream gauge (**Chapter 2** and **Appendix C**).
4. Updating of the hydraulic model that was developed as part of the *Wee Waa Levee Flood Investigation* (URS, 2015) (***Flood Study***), as well as the development of a new hydraulic model which was used to define local drainage patterns internal to the Town Levee (**Chapter 2** and **Appendix C**).
5. Assessment of the economic impacts of flooding, including the numbers of affected properties and estimation of flood damages (**Chapter 2** and **Appendix D**).
6. Review of current flood related planning controls for Wee Waa and their compatibility with flooding conditions (**Chapter 2**).
7. Strategic review of potential floodplain management works and measures aimed at reducing flood damages, including a freeboard analysis for the Town Levee and an economic assessment of several measures (**Chapter 3** and **Appendix E**).
8. Ranking of works and measures using a multi-objective scoring system which took into account economic, financial, environmental and planning considerations (**Chapter 4**).
9. Preparation of a draft *LRMP* for Wee Waa (**Chapter 5**).

S3 Summary of Existing Flood Risk

The present study identified that the design standard of the Town Levee is equivalent to about a 5% AEP flood. It also identified that the flood range at Wee Waa is not large and that in the absence of any wind or wave action on the surface of the floodwater, the Town Levee would not be overtopped for floods up to about 0.1% AEP in magnitude.[1]

Figure 2.1 shows the alignment of the Town Levee, while **Figure 2.2** is a longitudinal section showing the elevation of the earth embankment relative to the adjacent floodplain. Also shown on **Figures 2.2** are the design water surface levels along the river side of the Town Levee for floods with AEPs of between 5% and 0.2%, as well as the Extreme Flood. **Figures 2.3** to **2.9** show the indicative extent and depths of inundation both internal and external to the Town Levee for the full range of assessed flood events.

While the Town Levee is likely to prevent major flood damages from being experienced in Wee Waa for floods of up to 0.1% AEP in magnitude (i.e. because the earthen embankment was found to generally be in good condition and is unlikely to fail unless major overtopping occurs), it cannot be relied upon for protecting the local community for floods larger than 5% AEP. This is because the NSW State Emergency Service (**NSW SES**) would deem the Town Levee to be at significant risk of failure during floods larger than 5% AEP and would therefore require the town to be evacuated prior to the arrival of the flood wave.

Should the Town Levee fail or be overtopped during a flood event, then the total flood damages in Wee Waa would be about $117 Million. The "present worth value" of damages resulting from either of these eventualities is estimated to be about $100 Million.

In the event that a 1% AEP storm event occurs over Wee Waa in the absence of elevated water levels in the Namoi River, only one residential and one commercial property would experience above-floor inundation. The number of above-floor inundated properties would increase to four residential and three commercial properties should a 1% AEP storm event occur when the penstock gates that are fitted to the fourteen stormwater pipes which extend through the Town Levee are closed and the six stormwater evacuation pumps are operational. The total flood damages that would be experienced in Wee Waa at the 1% AEP level of flooding under the latter conditions is about $0.9 Million, while the "present worth value" of damages resulting from all localised storms up to 1% AEP in intensity at a seven per cent discount rate and 50 year economic life is $0.4 Million. This number represents the amount of capital spending that would be justified if a particular stormwater upgrade scheme prevented flooding <u>for all</u> properties in Wee Waa up to the 1% AEP event.

S4 Development Controls

The key issue for Wee Waa is that given the design standard of the Town Levee is only equivalent to a 5% AEP flood, Council's current planning documents, namely its *Interim Floodplain Management Policy* referred to in Council's *Exempt & Complying Development DCP* are inconsistent with the NSW Government's Section 9.1 Direction given they allow development in the town to occur below the peak 1% AEP flood level on the Namoi River floodplain plus an allowance for freeboard (which in areas subject to riverine flooding is generally set at 0.5 m).

[1] The AEP of the flood that would first overtop the Town Levee and is based on interpolation between peak flood levels resulting from a 0.2% AEP flood event and the Extreme Flood.

As it is not practical to set floor levels in Wee Waa above the peak 1% AEP Namoi River flood level (i.e. because the floor level of most dwellings would need to be set more than 1.5 m above natural ground levels), development in the town could only proceed if the design standard of the Town Levee is upgraded to 1% AEP.

Should the Town Levee be upgraded to a 1% AEP standard, then the controls that would need to be applied to future development need only amount to a minimum floor level control which is equal to the Flood Planning Level (**FPL**).[2] Note that the FPL would be based on depths of inundation resulting from runoff that is generated internal to the Town Levee, not Namoi River flooding. **Figure 3.7**, sheet 1 shows the extent of the Flood Planning Area (**FPA**)[3] internal to the Town Levee under post-upgrade conditions, as well as the corresponding FPLs.

In regards the large parcel of land that is zoned *R5 Large Lot Residential* south-east of Wee Waa, it is recommended that the portion that is classified as either *Floodway* or *High Hazard Flood Storage* at the 1% AEP level of flooding (refer **Figure 2.23**, sheet 1) be rezoned not to permit future residential and commercial type development. As the remainder of the area either lies above the 1% AEP flood level or is classified as *Flood Fringe*, then future development located within the extent of the FPA need only be subject to a minimum floor level control set equal to the FPL. **Figure 3.7**, sheet 2 shows the extent of the FPA in this area, as well as the corresponding FPLs.

S5 The Floodplain Risk Management Plan

The *LRMP* setting out recommended flood management measures for Wee Waa is presented in **Chapter 5**, with the recommended works and measures summarised below. The recommended works and measures have been given a provisional priority ranking, confirmed by the Floodplain Risk Management Committee, according to a range of economic, social, environmental and other criteria set out in **Table 4.1** of the report.

The draft *LRMP* includes four management measures which could be implemented by Council with the assistance of New South Wales State Emergency Service (**NSW SES**), all of which would not require State Government funding. The four measures are as follows:

- **Measure 1** – Council to consider updating its flood related development controls so as to recognise that the town is subject to inundation as a result of local catchment runoff which is generated internal to the Town Levee. While application of these controls by Council would ensure that future development in flood liable areas in Wee Waa is compatible with the flood risk, in relation to residential type development they can only be applied after the design standard of the Town Levee is increased to 1% AEP.[4]
- **Measure 2** – Council to consider making minor amendments to the wording of clause 6.2 of the *Narrabri Local Environmental Plan 2012*, as well as the inclusion of a new floodplain risk management clause which would apply to land which lies between the FPA and the Extreme Flood.
- **Measures 3** - Improvements in the NSW SES's emergency response planning, including use of the flood related information contained in this study to update the *Narrabri Shire Local Flood Plan*.

[2] The FPL is defined as the peak 1% AEP flood level plus an allowance of 500 mm for freeboard.

[3] The FPA is defined as land that lies at or below the FPL.

[4] In order to comply with the NSW Government's Section 9.1 Direction, no new residential type development should occur in Wee Waa below the peak 1% AEP Namoi River flood level plus an allowance of 500 mm for freeboard until such time as the Town Levee has been upgraded.

- **Measure 4** - Council should take advantage of the information on flooding presented in this report, including the flood mapping, to inform occupiers of the floodplain of the flood risk. This could be achieved through the preparation of a *Flood Information Brochure* which could be prepared by Council with the assistance of NSW SES containing both general and site specific data and distributed with rate notices.

Measure 5 of the *LRMP* comprises the investigation and concept design of the Town Levee upgrade, while **Measure 6** comprises the detailed design and construction of the works.

While the upgrade of the Town Levee cannot be justified on economic grounds unless the impacts of a potential levee failure condition are taken into account, its upgrade would provide significant social benefits such as:

- allowing Council to approve future residential development which is set below the peak 1% AEP flood level external to the Town Levee plus 0.5 m freeboard;
- reduce the likelihood of major overtopping and/or a possible partial failure of the earthen embankment;
- reduce annual insurance premiums, which based on preliminary advice received from the Insurance Council of Australia could be around $250 per household; and
- improve provisions for the timely and safe evacuation of people by air should they not self-evacuate prior to the closure of the road network by rising floodwater.

Measures 1 to **5** have been assigned a **Priority 1** ranking in the *LRMP*, while **Measure 6** has been assigned a **Priority 2** ranking given its medium to long term nature.

S6 Timing and Funding of LRMP Measures

The total estimated cost to implement the preferred floodplain management strategy is **$7.55 Million**, exclusive of Council and NSW SES Staff Costs. The timing of the measures will depend on Council's overall budgetary commitments and the availability of both Local and State Government funds.

Assistance for funding qualifying projects included in the *LRMP* may be available upon application under the Commonwealth and State funded floodplain management programs, currently administered by the NSW Department of Planning, Industry and Environment.

S7 Council Action Plan

1. Council finalises the *LRMS* report and approves the draft *LRMP* according to the procedure recommended in **Section 5.13**.
2. Council and NSW SES commence work on the "non-structural" measures in the *LRMP* (**Measures 1**, **2**, **3** and **4**).
3. Council apply for Government Funding to undertake the investigation and concept design of the Town Levee upgrade (**Measure 5** of the *LRMP*).
4. Following the completion of the investigation and concept design of the upgrade requirements for the Town Levee, Council to apply for Government Funding to undertake the detailed design and construction of the levee upgrade works (**Measure 6** of the *LRMP*).

1 INTRODUCTION

1.1 Study Background

Narrabri Shire Council (**Council**) commissioned the preparation of the *Levee Risk Management Study and Plan* (***LRMS&P***) for the township of Wee Waa in accordance with the New South Wales Government's Flood Prone Land policy. This report sets out the findings of the *LRMS&P* investigation which utilises an updated set of flood models that were originally developed as part of the *Wee Waa Levee Flood Investigation* (***Flood Study***) (URS, 2015). **Figure 1.1** shows the location of Wee Waa, which lies about 34 km to the west of Narrabri on the Namoi River floodplain.

The *Levee Risk Management Study (**LRMS**)* reviewed baseline flooding conditions, including an assessment of economic impacts and the feasibility of potential measures aimed at reducing the impact of both local catchment and riverine flooding on both existing and future development at Wee Waa. This process allowed the formulation of the *Levee Risk Management Plan* (***LRMP***) for Wee Waa.

1.2 Background Information

The following documents were used in the preparation of this report.

- *Audit of Flood Levees for New South Wales – Town of Wee Waa* (Public Works (**PW**), 1992)
- *Narrabri – Wee Waa Flood Study* (Department of Infrastructure, Planning & Natural Resources (**DIPNR**), 2003)
- *Floodplain Development Manual* (New South Wales Government, 2005)
- *Narrabri-Wee Waa Floodplain Management Plan (Department of Natural Resources, 2005)*
- *Narrabri Local Environmental Plan, 2012* (*Narrabri LEP 2012*)
- *Wee Waa Levee Flood Investigation* (URS, 2015) (***Flood Study***)
- *Narrabri Shire Local Flood Plan, 2015* (NSW State Emergency Service (**NSW SES**), 2015)
- *Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully* (WRM Water & Environment (**WRM**), 2016)

1.3 Overview of LRMS Report

The results of the *LRMS* and the *LRMP* are set out in this report. Contents of each Chapter of the report are briefly outlined below:

- **Chapter 2**, **Baseline Flooding Conditions**. This Chapter includes a description of the existing drainage system, as well as the earthen ring levee which was built following the damaging February 1971 flood to protect Wee Waa from riverine flooding (herein denoted the "**Town Levee**"). The Chapter also includes a review of existing flood behaviour at Wee Waa, summarises the economic impacts of flooding on existing urban development, reviews Council's existing flood planning controls and management measures and NSW SES's flood emergency planning.

- **Chapter 3**, **Potential Floodplain Management Measures**. This Chapter reviews the feasibility of floodplain management measures for their possible inclusion in the *LRMP*. The list of measures considered is based on input from the Community Consultation process, which sought the views of residents and business owners in Wee Waa in regards to potential flood management measures which could be included in the *LRMP*. The measures are investigated at the strategic level of detail, including an indicative cost estimate of the upgrade of the Town Levee and benefit/cost analysis.
- **Chapter 4**, **Selection of Floodplain Management Measures**. This Chapter assesses the feasibility of potential floodplain management strategies using a multi-objective scoring procedure which was developed in consultation with the Floodplain Risk Management Committee (**FRMC**) and outlines the preferred strategy.
- **Chapter 5** presents the *LRMP* which comprises a number of structural and non-structural measures which are aimed at increasing the flood awareness of the community and ensuring that future development is undertaken in accordance with the local flood risk.
- **Chapter 6** contains a glossary of terms used in the study.
- **Chapter 7** contains a list of References.

Six appendices provide further information on the study results:

Appendix A – Community Consultation summarises residents' and business owners' views on potential flood management measures which could be incorporated in the *LRMP*.

Appendix B – Preliminary Geotechnical Assessment contains a copy of a report which sets out the findings of a preliminary assessment which was undertaken by Michael Adler & Associates Pty Ltd on the condition of the Town Levee and the proposed methodology for its upgrade.

Appendix C – Updated Flood Modelling sets out the approach which was adopted for updating the flood frequency analysis and hydraulic modelling that was undertaken as part of the *Flood Study*, as well as the development of new hydrologic and hydraulic models that were used to define the nature of local catchment flooding internal to the Town Levee.

Appendix D – **Flood Damages** is an assessment of the economic impacts of both riverine and local catchment flooding to existing residential, commercial and industrial development, as well as public buildings in Wee Waa. The damages have been assessed using the results of the flood modelling which was undertaken as part of the present study, an estimate of floor levels and characteristics of affected development derived from a 'drive-by' survey to estimate floor heights above a natural surface level derived from Light Detecting and Ranging (**LiDAR**) survey data. A damages assessment was also carried out assuming a partial failure of the Town Levee, as well as a scenario where the pumps that are used to evacuate local catchment runoff internal to the Town Levee also fail.

Appendix E – Levee Freeboard Analysis sets out the results of a preliminary analysis which was undertaken to derive the freeboard allowance which has been incorporated in the concept design of the Town Levee.

Appendix F - Details of Town Levee Upgrade Requirements contains a set of figures showing the plan layout and cross sections of the assessed levee upgrade requirements.

1.4 Community Consultation

Following the Inception Meeting of the FRMC which included representatives from Council, NSW Department of Planning, Industry and Environment (**DPIE**), NSW SES and the community, a *Community Newsletter* was prepared by the Consultants and distributed by Council to residents and business owners in Wee Waa. The *Community Newsletter* contained a *Community Questionnaire* seeking details from the community of flood experience and attitudes to potential floodplain management measures. The views of the community on potential flood management measures to be considered in the study were also taken into account in the assessment presented in **Chapter 3** of the report, with supporting information in **Appendix A.**

The FRMC reviewed the potential flood management measures developed in **Chapter 3** and assessed the measures using the proposed scoring system of **Chapter 4**. The *LRMS* and accompanying *LRMP* were also reviewed by the FRMC and amended prior to public exhibition.

The draft *LRMS&P* was placed on public exhibition in late 2019 with only one submission received from DPIE by the closing date. Council ran a workshop with the Wee Waa business chamber during the exhibition period, while a community workshop was held in Wee Waa on 18 December 2019. All those that attended the community workshop were strongly in favour of the recommendation to upgrade the Town Levee.

1.5 Insurance Industry Consultation

During the early phase of the present study the Insurance Council of Australia (**ICA**) was contacted and asked to contact its members to seek a comparison of insurance premiums under pre- and post-Town Levee upgrade conditions. GIS data showing the nature of flooding at Wee Waa based on the findings of the *Flood Study* were provided to ICA at the time.

Prior to contacting its members ICA undertook an unsophisticated assessment of the potential reduction in Average Annual Damages as a very rough proxy for the premium reductions that may be possible if the Town Levee was to be upgraded. ICA's initial analysis indicated that reducing the risk of the 1% AEP flood event for median sum-insureds behind the Town Levee could result in a reduction of between $150 and $250 in annual premiums.

The results of the analysis were forwarded by ICA to its members. ICA later advised Council that no responses were received from its members that would alter its initial findings.

1.6 Flood Frequency and Terminology

In this report, the frequency of floods is referred to in terms of their Annual Exceedance Probability (**AEP**). The frequency of floods may also be referred to in terms of their Average Recurrence Interval (**ARI**). The approximate correspondence between these two systems is:

Annual Exceedance Probability (AEP) – %	Average Recurrence Interval (ARI) – years
0.2	500
0.5	200
1	100
10	10
20	5

The AEP of a flood represents the percentage chance of its being equalled or exceeded in any one year. Thus a 1% AEP flood, which is equivalent to a 100 year ARI, has a 1% chance of being equalled or exceeded in any one year and would be experienced, on the average, once in 100 years; similarly, a 20 year ARI flood has a 5% chance of exceedance, and so on.

Reference is also made in the report to the Extreme Flood. This flood is much rarer than the 1% AEP flood, which is usually adopted for planning purposes. It approximates the Probable Maximum Flood (**PMF**) and defines the upper limit of flooding that could reasonably be expected to occur. The discharge hydrographs of the Extreme Flood were derived by applying a multiplication factor of three (3) to the corresponding 1% AEP discharge hydrographs.

2 BASELINE FLOODING CONDITIONS

2.1 Physical Setting

Wee Waa has a population of about 1,650 and is located on the Namoi River about 34 km west (downstream) of Narrabri. Since the construction of the Town Levee the main impacts of flooding have been the inundation of agricultural land on the floodplain and the closure of local access roads.

The following local roads traverse the study area:

- Kamilaroi Highway which runs in an east-west direction linking Wee Waa with Narrabri to the east and the village of Burren Junction to the west. The Kamilaroi Highway is generally located on the northern side of the Namoi River where it runs between Wee Waa and Narrabri. A new bridge has recently been constructed by NSW Roads and Maritime Services on the Kamilaroi Highway where it crosses the Namoi River immediately to the west of Wee Waa.
- Culgoora Road also links Wee Waa with Narrabri, but is located on the southern side of the Namoi River. A new bridge has recently been constructed on Culgoora Road where it crosses Wee Waa Lagoon.
- Vera Leap Road which runs south from Wee Waa where it crosses Wee Waa Lagoon via a low level concrete causeway. Vera Leap Road becomes Pilliga Road south of its intersection with old Pilliga Road.

While development within Wee Waa is generally located internal to the Town Levee, there are a number of rural homesteads that are located in close proximity to the town which are impacted by riverine flooding.

Wee Waa Airport is located to the south of the town on Pilliga Road on the Namoi River floodplain. An earthen levee has been built around the perimeter of the airport to protect it from Namoi River Flooding. The present study has identified that in the absence of any wind or wave action the ring levee would be overtopped during floods larger than 1% AEP in magnitude. The airport is principally used by private charter companies and local land holders and businesses as part of their agricultural activities.

2.2 Drainage System

2.2.1 Namoi River Floodplain

Figures 1.1 and **2.1** (2 sheets) show the layout of the drainage system in the vicinity of Wee Waa.

Flooding patterns at Wee Waa are largely dependent on the source of the flow. For example, floodwater originating from the upper Namoi River catchment commences to spread out across the wider Namoi River floodplain near the Myall Vale homestead which is located about 10 km upstream of the township. At this location major outflows occur from the river, with the largest breakout occurring toward the north.

The floodwater that moves north from Myall Vale inundates large tracts of land on the north-western floodplain, through Spring Plains to the Doreen area and eventually into Pian Creek, while the floodwater which breaks to the south develops a flood runner along the side of the Kamilaroi Highway. The flow which breaks out to the south initially runs alongside the road before entering O'Briens Channel and then Wee Waa Lagoon. Wee Waa is effectively isolated by road once this flow breakout develops.

Immediately upstream and downstream of Wee Waa flood flows leave the Namoi River via a number of effluent streams, the most significant of which are Gunidgera and Pian Creeks. With the exception of 'high' ridges which are located adjacent to and to the north of Pian Creek, virtually all of the land to the west of Wee Waa is inundated during a major flood.

An alternative flood pattern is caused by local catchment runoff from the streams draining the south-western slopes of the Nandewar Ranges. Spring, Bobbiwaa and Galathera Creeks form the main drainage patterns of this region. All have quite small channels and when in flood, spread over wide areas of agricultural land. The majority of the flood flow generated by the local catchment does not join the Namoi River, but rather turns to the north-west where it ultimately joins flow in the Thalaba Creek system.

While the Pilliga Road can be cut by backwater flooding from the Namoi River, runoff from the Pilliga Scrub area (Bundock, Middle or Nuble Creeks) can be sufficient to inundate the low level causeway crossing of Wee Waa Lagoon.

A summary of the WaterNSW operated stream gauges in the vicinity of Wee Waa is presented in **Table 2.1**. Water levels recorded by the Namoi River at Glencoe stream gauge (GS 419900) (**Glencoe stream gauge**) which is located about 4.3 km to the north-east of the township near the Kamilaroi Highway crossing of the Namoi River are used by NSW SES to assess the consequences of flooding at Wee Waa (refer **Section 2.4** for further details). The annual series of flood peaks that have been recorded by the Namoi River at Mollee stream gauge (GS 419039) (**Mollee stream gauge**) since September 1965 was used as part of the present study to derive design peak flow estimates for the Namoi River for later input to the hydraulic model (refer **Section 2.5** for further details).

TABLE 2.1
STREAM GAUGE DATA AT WEE WAA(1)

Station Number	Gauge Name	Period of Record
419002	Namoi River at Narrabri	January 1982 to date
419003	Narrabri Creek at Narrabri	August 1891 to date
419039	Namoi River at Mollee	September 1965 to date
419900	Namoi River at Glencoe	May 1995 to date
419060	Namoi River at Gunidgera Weir – Storage Gauge	November 1975 to date
419059	Namoi River at Downstream Gunidgera Weir	April 1976 to date
419061	Gunudgera Creek at Downstream Regulator	July 1975 to date

1. Refer **Figure 1.1** for location of stream gauges that are currently in operation at Wee Waa.

2.2.2 Rural Floodways

Since the completion of Keepit Dam in 1960, significant irrigation development has occurred within the Narrabri-Wee Waa floodplain system. During the flood events of 1964, 1971 and 1974, the area suffered several major setbacks during its period of growth with large crop and stock losses. This triggered the development of several guideline documents ('original guidelines') around 1975 to coordinate the construction of flood control works. The 'original guidelines' served as the main reference document when reviewing development applications up until 2005, when the *Narrabri-Wee Waa Floodplain Management Plan* (DNR, 2005) replaced them.

DNR, 2005 aims to provide a floodway network that will improve the current drainage of the floodplain system and allow the orderly passage of flood flows, while balancing the expressed requirements of landholders with the requirement to minimise the impact of floodplain development on natural flood flow patterns and ecological functions. **Figure 2.1**, sheet 1 shows the location of the rural levees which presently form part of the floodway network near Wee Waa.

A study undertaken by the NSW Department of Natural Resources (now DPIE) in 2003 found that while the rural levees would be overtopped by a 1% AEP flood on the Namoi River, they would protect the agricultural land from a 1971 type flood. While levee works on the floodplain are subject to a licencing agreement under the Water Act 1912, DPIE advised that in many cases, but not all, this licence agreement does not restrict the height to which the levees can be built. This is contrary to the requirements of the DNR, 2005 which states that all existing levees must be maintained at their current height.

2.3 Town Levee

As mentioned, the Town Levee was built in response to the damaging flooding that was experienced in February 1971. Construction of the Town Levee, which is approximately 8.6 km in length, was completed in 1978. The Town Levee is an earth embankment which generally varies in height between about 2 m and 4 m. The river side of the earth embankment generally has a slope of 3:1 (Horizontal:Vertical), while the town side has a slope of 2:1 (Horizontal:Vertical). The crest of the Town Levee, which was originally set 1 m above the peak of the 1971 flood, is typically 3 m in width. The side slopes of the earth embankment are grassed, while its crest typically comprises a gravel surface. **Figure 2.1**, sheet 2 shows the alignment of the Town Levee, while **Figure 2.2** is a long section showing its elevation relative to the adjacent floodplain.[5]

There are fourteen penstock gated stormwater drainage pipes and six stormwater evacuation pumps located around the perimeter of the Town Levee, the locations of which are shown on **Figure 2.1**, sheet 2. **Figure 2.2** shows the diameters of the fourteen penstock gated stormwater drainage pipes, as well as their approximate invert levels, while **Table 2.2** sets out the details of the six stormwater evacuation pumps.

In addition to the six stormwater evacuation pumps located along the Town Levee, Council also maintains a number of small trailer mounted pumps which are mobilised on an as-needs basis following heavy rainfall events. The trailer mounted pumps are used to reduce the depth of ponding in several areas where the rate at which stormwater runoff drains toward the penstock gated pipes is considered by affected residents and business owners to be too slow.

[5] The chainages shown on **Figures 2.1**, sheet 2 and **Figure 2.2** are identical to those adopted in the *Flood Study* and are based on a survey which was undertaken by Council in 2010.

TABLE 2.2
EXISTING STORMWATER EVACUATION PUMP DETAILS

Pump Identifier	Maximum Pump Rate (m^3/s)	Pump Ownership	Pump Type
P_01	1.0	Council	2001 Deutz Lift Pump
P_02	1.0	Council	2001 Deutz Lift Pump
P_03	0.1	Council	2006 Ford Water Cooled Lift Pump
P_04	1.0	Council	2001 Deutz Lift Pump
P_05	0.15	Namoi Cotton Alliance	40 Isuzu Turbo
P_06	0.1	Namoi Cotton Alliance	22 Isuzu

Design drawings prepared by Water Resources Consulting Services in 1993 entitled "*Wee Waa Levee Rehabilitation*" set out requirements for the upgrade of the Town Levee. While the *Investigation Stage Report* referred to on the design drawings was not available at the time of writing, it is assumed that the planned upgrade was required to reinstate the 1 m freeboard to peak 1971 flood levels. Council were also unable to confirm that the works as set out in the design drawings have been implemented.[6]

DNR, 2005 states that a comparison between the design crest profile and a crest survey which was conducted in 2002 identified that while no major slumping of the Town Levee had occurred, its crest height was not consistent with the original design parameters. A recommendation was included in DNR, 2005 for Council to review the available freeboard to peak 1971 flood levels and to carry out any remedial work. It also included a recommendation for Council to determine whether the adoption of the 1971 flood as the design event in combination with 1 m freeboard was still appropriate.

By comparison of the original design and current crest heights shown on **Figure 2.2**, there is a 1 km long section between about Chainage 3500 and Chainage 4500 which lies below the original design height of the Town Levee.[7]

A geotechnical investigation was undertaken by Michael Adler & Associates as part of the present study, the findings of which are set out in a letter style report, a copy of which is contained in **Appendix B** of this report. The geotechnical investigation, which comprised a review of the available documentation and a visual inspection of the Town Levee found that the embankment was in good condition, with the following minor defects/aspects requiring rectification:

- There are a number of uncontrolled crossings which should be either closed off or upgraded to a formed/engineered surface such as a gravel of bitumen sealed roadway. These crossings should also be checked on a regular basis for damage and repair as required.

[6] There is a reference on NSW SES's *Wee Waa (Glencoe) Flood Intelligence Card* against the 1984 peak flood height that the Town Levee was audited and upgraded in 1992. It is noted that while this matches the date of an audit undertaken by the then Public Works, it pre-dates the design of the levee upgrade.

[7] Original design heights taken from the report entitled "*Audit of Flood Levees for New South Wales – Town of Wee Waa*" (PW, 1992).

- Tension cracks are present in the embankment at a number of locations. The cracks should be scarified to a depth of at least 300 mm and re-compacted to the specification set out in the report.
- Areas of dense vegetation should be removed before the roots start to form potential drainage pipes.
- The local drainage system should be cleared to prevent water ponding along the toe of the embankment on the town side at Chainages 2900, 3400 and 7500.

Recommendations are also contained in the geotechnical report regarding the approach which is to be adopted should the decision be made to raise the crest height of the Town Levee. These are discussed in more detail in **Section 3.4.1**.

The Imminent Failure Flood (**IFF**) of a levee is typically set equal to the flood for which it was designed to protect. As mentioned, the original intent of the design of the Town Levee was to protect Wee Waa from a flood approximating the February 1971 event, which based on the information contained in **Table 2.3** over had an AEP of about 4 per cent. However. based on the flood modelling undertaken as part of the present study (refer **Section 2.5** for details), the IFF for the Town Levee is actually equal to a flood which is slightly smaller than the February 1971 flood and has an AEP slightly greater than 5 per cent. The prediction of a flood higher than the IFF would trigger the evacuation of Wee Waa, as NSW SES would have deemed the Town Levee to be at significant risk of failure.

2.4 Flood History

The following discussion is based on information contained in Annex A of NSW SES, 2015 and has been reproduced verbatim in some instances. **Table 2.3** sets out the historic discharge data that are available for the Namoi River at Narrabri and Mollee, while **Table 2.4** gives the peak heights that are set out on NSW SES's Flood Intelligence Card for the Glencoe stream gauge (***Wee Waa (Glencoe) Flood Intelligence Card***).[8]

As shown in **Table 2.3**, the February 1955 flood was the largest event to have been recorded in the Namoi Valley near Wee Waa in over 100 years and was equivalent to about a 1.2% AEP flood event. Flow in the Namoi River during this flood was increased by contributions from the Manilla and Mooki Rivers, as well as significant inflows from the Peel River. NSW SES, 2015 states that the water level at the Glencoe stream gauge peaked at 9.12 m, which is 0.86 m higher than the peak height noted on NSW SES's *Wee Waa (Glencoe) Flood Intelligence Card*.[9,10]

Water level data recorded by the Mollee stream gauge indicates that prior to the February 1955 flood, major flooding was experienced in the Namoi Valley near Wee Waa in March 1908, January 1910 and July 1920. There is also reference in a newspaper article of major flooding that was experienced in Wee Waa in February 1874.

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[8] Note that the gauge zero given on the *Wee Waa (Glencoe) Flood Intelligence Card of RL 204.38 m* AHD is incorrect. WaterNSW gives the gauge zero as RL 188.5 m AHD.

[9] The reference to 8.26 m on the *Wee Waa (Glencoe) Flood Intelligence Card* for the February 1955 flood includes a note to check and confirm this level.

[10] By reference to the design flood levels set out in **Table 2.4**, the gauge height of 8.26 m given on the *Wee Waa (Glencoe) Flood Intelligence Card* is the more likely level reached by the 1955 flood.

TABLE 2.3
HISTORIC DISCHARGE DATA
NAMOI RIVER AT NARRABRI AND MOLLEE(1,2)

Rank	Date of Flood	Narrabri(3)	Namoi River at Mollee (GS 419039)			
		Peak Discharge (m^3/s)	Peak Height (m)	Peak Discharge(4,5) (m^3/s)		Approximate AEP(6) (%)
				WaterNSW Rating Table Current at Time of Flood	Present study	
1	February 1955	5,336	8.94	3,704	[4,183]	1.2
2	January 1910	5,315	-	-	(4,103)	1.3
3	July 1920	3,840	-	-	(2,984)	3.6
4	February 1971	3,637	8.43	2,431	[2,898]	3.8
5	March 1908	2,901	-	-	(2,272)	6.5
6	January 1974	2,758	8.16	2,394	[2,154]	7.1
7	1956(7)	2,700	-	-	(2,119)	7.2
8	February 1984	2,479	8.04	2,217	[1,884]	8.9
9	January 1976	2,858	8.02	2,176	[1,828]	9.6
10	July 1998	2,574	8.01	2,280	[1,807]	9.8

1. Only the ten largest flood events to have been recorded by the gauge are listed. Refer **Tables A1** and **A2** in **Annexure A** of **Appendix C** for the full record of annual maximums.
2. "-" indicates stream gauge was not in operation during flood event.
3. Taken from WRM, 2016. Derived by summing the peak annual discharges recorded by the Namoi River at Narrabri (GS 419002) and Narrabri Creek at Narrabri (GS 419003) stream gauges.
4. Numbers in () represent peak discharge derived based on correlation between annual peak flows at Narrabri and Mollee (refer **Figure C1.1** in **Appendix C**).
5. Numbers in [] represent peak discharge derived using *Pre-* or *Post-1971 DPIE Rating Curves* shown on **Figure C1.2** in **Appendix C**.
6. Approximate frequency based on the findings of the flood frequency analysis which incorporated the annual peak discharges for the period 1908-2016, but omitted low flows (refer **Section C1.3.2** of **Appendix C** for discussion).
7. Exact date of flood unknown.

TABLE 2.4
COMPARISON OF HISTORIC AND DESIGN FLOOD LEVELS
GLENCOE STREAM GAUGE[1,2]

Historic/Design Flood Event	Peak Height on Gauge (m)
MINOR	5.30
12 July 1978	6.01
15 April 1978	6.31
MODERATE	6.40
MAJOR	6.70
February 1997	6.77
9 August 1990	6.79
12 August 1998	6.82
14 February 1992	6.86
29 July 1998	6.93
22 January 1977	7.02
9 September 1998	7.15
1 August 1998	7.16
17 May 1977	7.17
27 January 1976	7.26
25 July 1998	7.36
February 1984	7.51
5% AEP	7.61
2% AEP	7.87
1% AEP	8.04
0.5% AEP	8.11
0.2% AEP	8.26
February 1955	8.26 [9.12][3]
Extreme Flood	9.29

1. Source of historic flood data: *NSW SES's Wee Waa (Glencoe) Flood Intelligence Card*
2. Gauge zero = RL 188.50 m AHD
3. Peak height of 9.12 m stated as being the peak of the February 1955 in Annex A of NSW SES, 2015

The February 1971 flood was not only a major flood, but it also caused significant damage due to its long duration. Downstream of Narrabri flooding was exacerbated by concurrent flooding in the Pilliga streams. The height to which the February 1971 flood reached on the Glencoe stream gauge is not given on NSW SES's *Wee Waa (Glencoe) Flood Intelligence Card*.

The January 1974 flood differed in that there was limited contributions from the upper Namoi River and only moderate flows on the Manilla River, with significant contributions originating from the Peel and Mooki Rivers, with the latter being the major source of flood flows. At Mollee there were two flood peaks. While the Pilliga Scrub contributed significant runoff, mainly in Cox's Creek, the resulting floodwater had largely drained by the time the main flood peak from up-river arrived. The height to which the January 1974 flood reached on the Glencoe stream gauge is not given on NSW SES's *Wee Waa (Glencoe) Flood Intelligence Card*.

The January 1976 flood was similar in peak flood level to that of the January 1974 flood at Narrabri and Mollee and reached 7.26 m on the Glencoe stream gauge. While floodwaters originated mainly from the Peel and upper Namoi systems, a major flood was experienced in the Mooki River and contributions from the Manilla and Cockburn Rivers were also significant.

While not mentioned in Annex A of NSW SES, 2015, NSW SES's *Wee Waa (Glencoe) Flood Intelligence Card* states that a flood with a peak height of 7.17 m occurred in May 1977.

Major flooding was experienced in late January and early February 1984 after above-average rainfalls which had saturated the catchment lead to rapid rates of runoff when the flood producing rain occurred. The catchment in the vicinity of and downstream of Narrabri had experienced wet conditions right through the latter half of 1983 and into 1984. Flooding was made worse by the arrival of significant inflows from Bohena Creek which filled the main channel of the Namoi River prior to the arrival of the main flood peak. Dense vegetation on the floodplain, the poor condition of many floodways and obstructions in the entrances to floodways all contributed to the unique behaviour of this flood. Breakouts were hampered, floodways did not begin to operate until levels above those for which they were designed and some areas of the floodplain stored more floodwater than was expected. These factors meant that in some areas higher than expected flood levels were experienced and an unusual redistribution of flows occurred. For example, a peak discharge almost 35 per cent greater than expected for a flood of this magnitude was experienced in Wee Waa Lagoon and to the south-west of Wee Waa. Although the flood was estimated to be only one third of the total volume of the February 1971 flood, it produced similar flood heights in some locations such as immediately upstream of Collins Bridge.

NSW SES's *Wee Waa (Glencoe) Flood Intelligence Card* states that the water level reached 7.51 m during the 1984 flood. While it also states that the water level was only 300 mm below the levee crest due to contributions from the Pilliga Scrub and high wave action, it also includes a note to say that the levee was subsequently upgraded to an equivalent height of 8.5 m on the gauge in 1992.[11]

Major flooding occurred in the valley in 1998 which lasted several months. The largest flood peak was recorded at the Glencoe stream gauge on 25 July 1998, when water levels peaked at 7.36 m. This flood peak was caused by a rain band which crossed the central eastern parts of NSW on the 18 July and included some unusual thunderstorm activity for mid-winter. As in the 1976 flood, floodwaters originated mainly from the Peel and upper Namoi systems which combined with a major flood in the Mooki River, as well as with contributions from the Manilla and Cockburn Rivers. Wee Waa was isolated on four occasions from late July to early September.

[11] Note that the nominated date of construction pre-dates the design drawings that were prepared by Water Resources Consulting Services in 1993.

2.5 Design Flood Behaviour

2.5.1 Background

The *Flood Study* defined the nature of flooding on the Namoi River floodplain in the vicinity of Wee Waa for the 1% AEP and Extreme floods based on a design 1% AEP discharge hydrograph that was extracted from a quasi-two-dimensional cross sectional based MIKE 11 hydraulic model that is presently being maintained by DPIE. The design discharge hydrographs were used as input to a two-dimensional (in plan) hydraulic model that was developed based on the TUFLOW software (**Flood Study TUFLOW Model**). The Flood Study TUFLOW Model was calibrated to the floods that occurred in 1971, 1984 and 1998.

Table 2.5 provides a comparison of the design peak 1% AEP flow estimate that was adopted by the *Flood Study* compared to those derived as part of WRM, 2016 and the present study at the Mollee stream gauge and Wee Waa.

TABLE 2.5
COMPARISON OF PEAK 1% AEP FLOWS
(m^3/s)

Location	*Flood Study*	WRM, 2016	Present Study
Narrabri	-	4,860	-
Mollee stream gauge	6,672	-	4,400
Wee Waa	4,302	-	2,935

By inspection of the values set out in **Table 2.5**, the *Flood Study* adopted a peak flow for the 1% AEP flood event which is about 40% higher than the flow that was derived as part of WRM, 2016 at Narrabri, noting that previous studies have shown that significant attenuation occurs to the flood wave as it travels from Narrabri to Wee Waa.

As discussed in **Section C1.2.4** of **Appendix C**, WRM, 2016 undertook a flood frequency analysis based on an annual series of total peak flows for a 116 year period between 1890 and 2015 at Narrabri. A set of design discharge hydrographs were then generated by factoring the ordinates of the discharge hydrograph that was recorded during the January 1974 flood.

Based on the findings of WRM, 2016, DPIE requested that a flood frequency analysis be undertaken as part of the present study for the Mollee stream gauge (refer **Section C1.3** of **Appendix C** for details). The findings of the flood frequency analysis were used to factor the ordinates of the 1% AEP discharge hydrograph that is presented in DIPNR, 2003 at the Mollee stream gauge to the peak 1% AEP flow estimate of 4,400 m^3/s. DPIE then routed the design 1% AEP discharge hydrograph from Mollee to the Glencoe stream gauge using its MIKE 11 model.

The structure of the Flood Study TUFLOW Model was updated as part of the present study in order to more accurately define flooding behaviour in the vicinity of Wee Waa (**Namoi River TUFLOW Model**). **Chapter C3** in **Appendix C** provides details of the changes that were made to the structure of the Flood Study TUFLOW Model as part of the present study.

In addition to updating the Flood Study TUFLOW Model, a second TUFLOW model was developed as part of the present study to define drainage patterns internal to the Town Levee (**Wee Waa TUFLOW Model**). The direct-rainfall-on-grid approach was adopted for defining drainage patterns in the town due to the very flat nature of the area and the ill-defined nature of the drainage paths. Background to the development of the Wee Waa TUFLOW Model is provided in **Chapter C3** of **Appendix C**.

Both the Namoi River and Wee Waa TUFLOW Models were used to define flooding and drainage patterns on either side of the Town Levee for design events with AEPs of 5, 2, 1, 0.5 and 0.2 per cent, as well as the Extreme Flood.

2.5.2 Design Flooding and Drainage Patterns

Figures 2.3 to **2.8** show the nature of both Namoi River and local catchment flooding at Wee Waa for the 5, 2, 1, 0.5 and 0.2% AEP flood events, as well as the Extreme Flood for present day rural floodplain conditions.

The extents and depths of inundation shown on the figures are a combination of Namoi River flooding on the river side, and local catchment flooding on the protected side of the Town Levee. For presentation purposes it has been assumed that the penstock gates are in their closed positon and floodwater cannot backwater into town in the case of Namoi River flooding. Conversely, in the case of local catchment flooding, it has been assumed that river levels are not elevated and the penstock gates are in their open position. Refer **Section 2.10** for discussion on the impact coincident Namoi River and local catchment flooding would have on the depth and extent of ponding behind the Town Levee.

In order to demonstrate the impact the occurrence of extreme rainfall directly over Wee Waa would have on flooding behaviour internal to the Town Levee, depths of inundation resulting from Probable Maximum Precipitation are shown on **Figure 2.9**.

Figure 2.2 shows design water surface profiles and the available freeboard along the length of the Town Levee for the full range of assessed design flood events, while **Figure 2.10** (3 sheets) shows stage hydrographs at low points along the roads that traverse the floodplain. **Table 2.4** includes the design flood levels at the Glencoe stream gauge and provides a comparison with historic flood levels, while **Table 2.6** sets out the minimum freeboard which is available to the crest of the Town Levee for the design flood events that were assessed as part of the present study.

TABLE 2.6
MINIMUM AVAILABLE FREEBOARD TO CREST OF TOWN LEVEE

AEP (%)	Present Day Floodplain Conditions	Raised Rural Levee Floodplain Conditions	
	Available Freeboard (m)	Available Freeboard (m)	Reduction in Available Freeboard (m)
5	0.87	0.81	0.06
2	0.67	0.47	0.20
1	0.52	0.26	0.26
0.5	0.45	-	-
0.2	0.34	-	-
Extreme	-0.51 (1)	-	-

1. Represents the maximum height to which the crest of the Town Levee would in the absence of any wind or wave action be overtopped.

Namoi River Flooding

The key features of Namoi River flooding at Wee Waa are as follows:

- While floodwater would generally not exceed 1.2 m depth along the northern side of the Town Levee during a 5% AEP flood, it would exceed 2 m depth along its southern side.
- Flood levels would exceed the IFF level of the Town Levee at its eastern end by up to 130 mm in a 5% AEP flood.
- Floodwater would pond up against the flood protection barriers on the Narrabri-West Walgett railway crossings at Chainage 4700 by about 0.3 m in a 5% AEP flood event and at Chainage 7000 by about 0.2 m in a 2% AEP flood event.
- The minimum available freeboard to the crest of the Town Levee reduces from about 0.9 m at the 5% AEP level of flooding to about 0.5 m at the 1% AEP level of flooding. **Table 2.7** gives the height on the Glencoe stream gauge which corresponds with the existing low points along the Town Levee, noting that these corresponded with the existing road and rail crossings.
- The Town Levee would in the absence of any wind or wave action not be overtopped for floods up to a 0.2% AEP in magnitude.
- Peak flood levels are about 0.5-1.0 m higher in the Extreme Flood when compared to those at the 1% AEP level of flooding. As a result, floodwater would overtop the Town Levee at five locations, where it would inundate the town to depths of between 0.7 m and 3.5 m.

TABLE 2.7
PEAK HEIGHTS ON GLENCOE STREAM GAUGE CORRESPONDING WITH LOW POINTS ALONG TOWN LEVEE

Location	Chainage	Peak Height on Glencoe Stream Gauge when Low Point First Overtopped (m)
Narrabri West Walgett Railway	4700	7.40(1)
Narrabri West Walgett Railway	7000	7.89(1)
Kamilaroi Highway	2200	8.70
Vera Leap Road	5600	8.78
Myalla Lane	8600	8.98

1. Gauge level corresponds to the level of the rail line. Concrete flood barriers which are about 1.5 m in height are installed at the location of the rail crossings during a flood event.

Local Catchment Flooding

The key features of local catchment flooding at Wee Waa are as follows:

- Runoff generated by the catchment which is bounded by Boolcarrol Road, Warrior Street and the Narrabri-West Walgett Railway ponds on the northern side of the railway before being conveyed in a westerly direction via a table drain to the 1800 mm diameter pipe that extends through the Town Levee at about Chainage 7200 (refer FG_01).

- Water ponds to a maximum depth of about 600 mm in the rear of existing residential and industrial allotments that are located adjacent to the northern side of the Town Levee during a 1% AEP storm event (i.e. between Chainages 0 and 500, and Chainages 7100 and 8600).
- An overland flow path develops along Mitchell Street which extends into residential development and Department of Education owned land that is located along its northern side. Flow conveyed along this overland flow path drains to the Namoi River via the 750 mm diameter pipe that extends through the Town Levee at about Chainage 8210 (refer FG_02).
- Water ponds to a maximum depth of about 400 mm in the rear of existing residential allotments that are located on the southern side of Alma Street between Maitland and River streets during a 1% AEP storm event (i.e. between Chainages 3400 and 3600 m). Water also ponds in parts of the Wee Waa District Health Service to depths exceeding 0.8 m, albeit that the deeper ponding water is located at the toe of the Town Levee where a drainage swale is located.
- The pipes extending through the Town Levee south of the Narrabri-West Walgett railway have sufficient capacity to prevent major flooding from occurring in the Namoi Cotton Co-op during storms with AEPs up to 1 per cent in intensity.

2.6 Impact of Flooding on Vulnerable Development and Critical Infrastructure

Figure 2.11 (2 sheets) shows the location of vulnerable development and critical infrastructure relative to the extent of flooding for events with AEPs of 5 and 1 per cent , as well as the Extreme Flood, while **Table 2.8** over the page summarises the impact that flooding has on this type of development/infrastructure.[12]

While the Town Levee would in the absence of any wind or wave action not be overtopped for Namoi River Floods of up to 0.2% AEP in magnitude, the telephone exchange, RFS Brigade and Mainway Caravan Park would be impacted by local catchment runoff during a 5% AEP storm. The Wee Waa District health Service and Wee Waa Community Child Centre and Pre School, as well as the Fire and Rescue NSW station will also be affected by local catchment runoff during slightly more intense storm events.

The Wee Waa Sewerage Treatment Plant which is located to the south of the township is impacted by riverine flooding during a 5% AEP event.

2.7 Hydrologic Standard of Existing Road Network

As set out in **Table 2.8**, all but Yarrie Lake Road near its crossing of the Narrabri-West Walgett Railway would be inundated by floodwater during a 5% AEP Namoi River Flood. **Figure 2.5** shows the time or rise of floodwater, as well as the maximum depth and duration of inundation at the location of the road markers that are shown on sheet 1 of **Figures 2.3** to **2.9**. **Table 2.9** gives the maximum depth of inundation for each road marker, as well as the peak height on the Glencoe stream gauge when the road would first be overtopped by floodwater.

[12] Critical infrastructure has been split into two categories; community assets and emergency services.

TABLE 2.8
IMPACT OF FLOODING ON CRITICAL INFRASTRUCTURE AND VULNERABLE DEVELOPMENT[(1)]

Type	Development/Structure	Location Identifier	Design Flood Event					
			5% AEP	2% AEP	1% AEP	0.50%	0.20%	Extreme
Vulnerable Development	Hospital (Wee Waa District Health Service)	-	0	LCF-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Educational Facility (Namoi Valley Christian School)	EF1	0	0	0	0	0	NRF
	Educational Facility (St Joseph's Primary School)	EF2	0	0	0	0	0	NRF
	Educational Facility (Wee Waa High School)	EF3	0	LCF-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Educational Facility (Wee Waa Public School)	EF4	0	0	0	0	0	NRF
	Educational Facility (Wee Waa & Disctrict Pre-School)	CC1	0	LCF-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Child Care Facility (Wee Waa Community Child Centre & Pre School)	CC2	0	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Caravan Park / Camping Ground (Mainway Caravan Park)	CP1	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Caravan Park / Camping Ground (Waioma Caravan Park)	CP2	0	0	0	LCF-GCP	LCF-GO-GCP	NRF
	Aged Care Facilities (The Whiddon Group Wee Waa)	-	0	LCF-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
Emergency Services	NSW SES Headquarters	-	0	LCF-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	RFS Brigade	-	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Police Station	-	0	0	0	0	0	NRF
	Fire & Rescue NSW Station	-	0	LCF-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Ambulance	-	0	0	0	0	0	NRF
	Evacuation Centre (Wee Waa Public School)	EC1	0	0	0	0	0	NRF
	Evacuation Centre (Wee Waa High School)	EC2	0	LCF-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Evacuation Centre (Sports Complex)	EC3	0	0	0	0	0	NRF
	Evacuation Centre (Church Hall)	EC4	0	0	0	0	0	NRF
	Evacuation Centre (CWA Rooms)	EC5	0	0	0	0	0	NRF
	Evacuation Centre (Cotton Growers Services)	EC6	0	0	0	0	0	NRF

Refer over for footnotes

Cont'd Over

TABLE 2.8 (Cont'd)
IMPACT OF FLOODING ON CRITICAL INFRASTRUCTURE AND VULNERABLE DEVELOPMENT

Type	Development/Structure	Location Identifier	Design Flood Event					
			5% AEP	2% AEP	1% AEP	0.50%	0.20%	Extreme
Community Assets	Electricity Substation	-	0	0	0	0	0	NRF
	Telephone Exchange	-	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	LCF-GO-GCP	NRF
	Sewage Treatment Plant	-	NRF	NRF	NRF	NRF	NRF	NRF
	Culgoora Road	RC01	NRF	NRF	NRF	NRF	NRF	NRF
	Yarrie Lake Road	RC02	0	NRF	NRF	NRF	NRF	NRF
	Culgoora Road	RC03	NRF	NRF	NRF	NRF	NRF	NRF
	Culgoora Road	RC04	NRF	NRF	NRF	NRF	NRF	NRF
	Kamilaroi Highway	RC05	NRF	NRF	NRF	NRF	NRF	NRF
	Tulladunna Lane	RC06	NRF	NRF	NRF	NRF	NRF	NRF
	Cotton Lane	RC07	NRF	NRF	NRF	NRF	NRF	NRF
	Vera Leap Road	RC08	NRF	NRF	NRF	NRF	NRF	NRF
	Old Pilliga Road	RC09	NRF	NRF	NRF	NRF	NRF	NRF
	Sandy Hook Lane	RC10	NRF	NRF	NRF	NRF	NRF	NRF
	Kamilaroi Highway	RC11	NRF	NRF	NRF	NRF	NRF	NRF
	Kamilaroi Highway	RC12	NRF	NRF	NRF	NRF	NRF	NRF
	Kamilaroi Highway	RC13	NRF	NRF	NRF	NRF	NRF	NRF
	Kamilaroi Highway	RC14	NRF	NRF	NRF	NRF	NRF	NRF
	Cudgewa Lane	RC15	NRF	NRF	NRF	NRF	NRF	NRF

Refer **Figure 2.11** for location of vulnerable development and critical infrastructure

"O" = Vulnerable development and critical infrastructure not impacted by flooding.

"NFR" = Vulnerable development and critical infrastructure impacted by Namoi River Flooding

"LCF-GCP" = Vulnerable development and critical infrastructure impacted by local catchment flooding in the situation when the flood gates are closed and the stormwater evacuation pumps are operational.

"LCF-GO-GCP" = Vulnerable development and critical infrastructure impacted by local catchment flooding in the situation when the flood gates are open or when the flood gates are closed and the stormwater evacuation pumps are operational.

TABLE 2.9
DETAILS OF NAMOI RIVER FLOODING OF ROADS AT WEE WAA

Identifier[(1)]	Road Name	Maximum Depth of Inundation (m)				Peak Height on Glencoe Stream Gauge when Road First Overtopped (m)
		5% AEP	2% AEP	1% AEP	Extreme	
RC01	Culgoora Road	0.13	0.39	0.53	1.49	7.44
RC02	Yarrie Lake Road	0.07	0.16	0.24	1.22	7.56
RC03	Culgoora Road	0.25	0.47	0.62	1.59	7.39
RC04	Culgoora Road	1.70	1.97	2.15	3.15	6.78
RC05	Kamilaroi Highway	1.08	1.28	1.41	2.39	6.20
RC06	Tulladunna Lane	1.12	1.29	1.39	2.13	6.63
RC07	Cotton Lane	0.96	1.12	1.24	1.96	6.57
RC08	Vera Leap Road	2.54	2.77	2.92	3.95	6.69
RC09	Old Pilliga Road	0.97	1.15	1.27	2.13	6.99
RC10	Sandy Hook Lane	0.59	0.91	1.09	2.08	7.09
RC11	Kamilaroi Highway	0.82	1.07	1.23	1.97	7.06
RC12	Kamilaroi Highway	0.54	0.78	0.93	1.65	7.37
RC13	Kamilaroi Highway	0.52	0.71	0.87	1.77	7.14
RC14	Kamilaroi Highway	0.65	0.79	0.90	1.67	7.08
RC15	Cudgewa Lane	5.05	5.13	5.18	5.56	6.73

1. Refer sheet 1 of **Figures 2.3** to **2.8** for identifiers.

2.8 Potential Impact of a Partial Levee Failure

While the present study found that in the absence of any wind or wave action the Town Levee would only be overtopped during very rare and extreme flood events, its design freeboard of 1 m is compromised by floods that are larger than about a 5% AEP event. While investigations have shown that the embankment is in good condition, there is still the potential for it to fail prior to it being overtopped.

The Namoi River TUFLOW Model was used to assess the impact a partial failure of the Town Levee would have on depths of inundation in the town for a 1% AEP Namoi River flood event. **Figure 2.12** (2 sheets) shows the three locations where short sections of the Town Levee were assumed to fail, as well as the resulting depths of inundation within the town.

Peak flood levels in Wee Waa should the Town Levee partially fail are controlled by the height of the earth embankment at the western end of town, as floodwater would pond to this height before discharging back onto the Namoi River floodplain. This results in depths of inundation occurring at the western end of town of over 2 m, reducing to less than 0.2 m at the toe of the Town Levee at the eastern end of town.

2.9 Potential Impact of Raising Rural Levees

As mentioned, the majority of the licences held by the landowners on the rural floodplain do not place height restrictions on the elevation of the rural levees. It is therefore possible that these levees could be raised in the future, thereby impacting flooding behaviour in the vicinity of the Town Levee.

Figure 2.13 (2 sheets) shows the nature of Namoi River Flooding at Wee Waa should the unrestricted levees be raised to prevent overtopping during a 1% AEP flood event, while **Figure 2.14** (2 sheets) shows the impact that their raising would have on flooding behaviour for a 1% AEP flood event.

The investigation found that raising the levees upstream of Wee Waa diverts floodwater to the south into Wee Waa Lagoon, thereby reducing the volume of floodwater that enters Quinns Billabong. The raised levees also reduce the volume of floodwater that can enter Pian Creek and also Gundigera Creek near the Cudgewa Road crossing, with the result that floodwater discharges in a southerly direction between the raised rural levee which lies to the west of Cottons Lane and the Town Levee.

As shown in **Table 2.6**, the available freeboard to the crest of the Town Levee would be reduced from 0.52 m under current floodplain conditions to 0.26 m should all the unrestricted levees be raised to prevent overtopping in a 1% AEP flood event.

2.10 Potential Impact of Coincident Namoi River and Local Catchment Flooding

During periods when water levels in the Namoi River are elevated, Council closes the fourteen penstock gates which are fitted to the stormwater drainage pipes which are located around the perimeter of the Town Levee. If a rainfall event coincides with the closure of the penstock gates, then stormwater runoff is forced to pond behind the Town Levee until water levels in the river recede, or alternatively the six stormwater evacuation pumps are used to pump water to the river side of the Town Levee.

Figure 2.15 shows the depth of inundation that would occur behind the Town Levee should a 1% AEP storm occur over Wee Waa while the penstock gates are in their closed position and the stormwater evacuation pumps are operating at full capacity. **Figure 2.16** shows that the depth and extent of inundation would generally be less for the case where the six stormwater evacuation pumps are operating at full capacity when compared to the 'penstock gates open' case. This is because the rate at which the pumps evacuate water ponding behind the Town Levee is faster than it can drain to the river side of the Town Levee under gravity. The exception is the area near the Wee Waa District Health Service, where the pump rate of stormwater evacuation pump P_04 is less than the rate at which stormwater can discharge to Wee Waa Lagoon under gravity. In this case, peak 1% AEP flood levels are between 20-50 mm higher than for the 'penstock gates open' case.

An assessment was also made of the impact not starting the stormwater evacuation pumps during a 1% AEP storm event in the case when the penstock gates are in their closed position would have on flooding behaviour. **Figure 2.17** shows the resulting depth and extent of inundation that would occur under these conditions. **Figure 2.18** shows that depths of ponding would be increased by up to about 0.3 m in the vicinity of the Wee Waa District Health Service and on the northern side of the Narrabri-West Walgett railway, while they would be increased by up to about 0.5 m south of the railway line within the Namoi Cotton Co-op. The extent of ponding would also increase significantly in these three areas.

2.11 Potential Impact of a Change in Hydraulic Roughness

The sensitivity of flooding behaviour to variations in hydraulic roughness was assessed. The main purpose of the assessment was to give some guidance on the freeboard to be adopted when setting the crest height of the Town Levee.

Figure 2.19 shows the difference in peak flood levels for the 1% AEP flood event resulting from an assumed 20% increase in hydraulic roughness on the Namoi River floodplain when compared to the values set out in **Table C3.2** of **Appendix C**. The typical increase in peak flood level along the Namoi River in the vicinity of the Town Levee was found to be in the range 90 to 180 mm.

2.12 Potential Impact of a Partial Blockage of Major Hydraulic Structures

The mechanism and geometrical characteristics of blockages in hydraulic structures and piped drainage systems are difficult to quantify due to a lack of recorded data and would no doubt be different for each system and also vary with flood events. Realistic scenarios would be limited to waterway openings becoming partially blocked during a flood event (no quantitative data are available on instances of blockage of the drainage systems which may have occurred during historic flood events).

EA, 2013 includes guidance on modes of blockage which are likely to be experienced for different hydraulic structures. In regards bridge structures, those with clear opening heights less than 3 m are said to be susceptible to blockage in streams where large floating debris is conveyed by floodwater, presumably due to large woody debris becoming lodged in the clear opening of the bridge. For bridges of all heights, EA, 2013 considers that debris is likely to also wrap around the bridge piers.

The impact an accumulation of floating debris on the Kamilaroi Highway and Narrabri-West Walgett railway crossings of the Namoi River immediately west of Wee Waa, as well as the Culgoora Road crossing of Wee Waa Lagoon would have on flood behaviour was assessed as part of the present study assuming the following three modes of blockage:

- **Blockage Mode 1**: Assumes a 1 m thick raft of debris lodges beneath the underside of the bridge deck.
- **Blockage Mode 2**: Assumes a 4 m wide raft of debris lodges on the upstream side of each bridge pier over the full height of the clear opening.
- **Blockage Mode 3**: Combination of Blockage Modes 1 and 2.

A 50% blockage was also applied to the box-culverts which are located under the Kamilaroi Highway on the eastern side of the Namoi River crossing.

Figure 2.20 shows that a partial blockage of the three bridges and two box culvert structures would result in less than a 50 mm increase in peak 1% AEP flood levels. In regards the potential blockage of the local stormwater drainage system would have on internal drainage patterns, reference is made to **Section 2.10** which sets out the increase that would occur in the depth of inundation in the area protected by the Town Levee for the case where the penstock gates are closed and the stormwater evacuation pumps are inoperable.

2.13 Potential Impacts of Future Urbanisation

Future urbanisation has the potential to increase the rate and volume of runoff conveyed along the various overland flow paths which drain toward the low points which are located behind the Town Levee. This in turn would require the installation of larger stormwater evacuation pumps if depths of ponding internal to the Town Levee are not to be increased.

While there is presently limited pressure for new largescale development to occur in Wee Waa, it will be necessary for Council to consider the implications the introduction of new hard stand and roof areas would have on internal drainage patterns and possible pump rate requirements when assessing future development applications.

2.14 Potential Impacts of Climate Change

Consideration was given to the impacts on design flood levels of future climate change when estimating the freeboard requirements for the Town Levee and minimum floor levels in future development at Wee Waa.

DPIE recommends that its guideline *Practical Consideration of Climate Change, 2007* be used as the basis for examining climate change in projects undertaken under the State Floodplain Management program and the *FDM, 2005*. The guideline recommends that until more work is completed in relation to the climate change impacts on rainfall intensities, sensitivity analyses should be undertaken based on increases in rainfall intensities ranging between 10 and 30 per cent.

On current projections the increase in rainfalls within the service life of developments or flood management measures is likely to be around 10 per cent, with the higher value of 30 per cent representing an upper limit which may apply near the end of the century. Under present day climatic conditions, increasing the 1% AEP design rainfall intensities by 10 per cent would produce about a 0.5% AEP flood; and increasing those rainfalls by 30 per cent would produce about a 0.2% AEP event.

For the purpose of the present study, the impact 10% and 30% increases in design 1% AEP rainfall intensities would have on flooding behaviour was assessed by comparing the peak flood levels which were derived from the flood modelling for design events with AEPs of 1, 0.5 and 0.2 per cent.

Figure 2.21 shows the afflux data (i.e. increase in peak flood levels compared with present day conditions) derived from the hydraulic modelling that was undertaken as part of the present study for the 1 and 0.5% AEP events. The potential impact of a 10% increase in rainfall intensity on flooding and drainage patterns at Wee Waa may be summarised as follows:

- Peak 1% AEP flood levels resulting from Namoi River flooding would be increased in the range 50-100 mm around the full perimeter of the Town Levee, with the exception of a short section of the earth embankment in the vicinity of Quinns Billabong where the increases would be slightly less than 50 mm.
- By reference to **Table 2.6**, the available freeboard to the crest of the Town Levee would be a minimum of 0.45 m.

- Depths of inundation due to direct rainfall over Wee Waa would result in an increase in the depth of local catchment flooding east of Warrior Street of between 10 and 50 mm, with greater increases of between 50 and 200 mm shown to occur in a number of properties that are located along the southern side of Alma Street, including the Wee Waa District Health Service. Similar increases in the depth of inundation would occur to the west of Warrior Street in land currently zoned *B4 Mixed Use* and *IN1 General Industrial*.

Figure 2.22 shows the afflux data derived from the hydraulic modelling that was undertaken as part of the present study for the 1 and 0.2% AEP events. The potential impact of a 30% increase in rainfall intensity on flooding and drainage patterns at Wee Waa may be summarised as follows:

- Peak 1% AEP flood levels resulting from Namoi River Flooding would be increased in the range 100-200 mm along the northern and western sides of the Town Levee between Chainage 0 and 1700, as well as between Chainage 5200 and 8600, while they would be increased in the range 200-300 mm along its eastern and southern sides between Chainage 1700 and 5200.
- By reference to **Table 2.6**, the available freeboard to the crest of the Town Levee would be a minimum of 0.34 m.
- Depths of inundation due to direct rainfall over Wee Waa would generally result in an increase in the depth of local catchment flooding east of Warrior Street of between 10 and 100 mm, with greater increases of between 100 and 300 mm shown to occur in a number of properties that are located along the southern side of Alma Street, including the Wee Waa District Health Service. Similar increases in the depth of inundation would occur to the west of Warrior Street in the *B4 Mixed Use* and *IN1 General Industrial* zoned land.

Note that the assessment of the impact future climate change could have on the extent and depth of flooding internal to the Town Levee is based on the case where the Namoi River is not in flood and the flood gates are in their open position.

2.15 Economic Impacts of Flooding

The economic consequences of floods are discussed in **Appendix D**, which assesses flood damages to residential, commercial and industrial property, as well as public buildings that are located in Wee Waa. There was only limited quantitative data available on historic flood damages in Wee Waa since major flooding in the town has not occurred since construction of the Town Levee was completed in 1978. Accordingly it was necessary to use data on damages experienced as a result of historic flooding in other urban centres. The residential flood damages were based on the publication *Floodplain Risk Management Guideline No. 4, 2007* (**Guideline No. 4**) published by the Department of Environment and Climate Change (**DECCW**) (now DPIE). Damages to industrial and commercial development, as well as public buildings were evaluated using data from previous floodplain management investigations in NSW.

It is to be noted that the principle objectives of the damages assessment were to gauge the severity of urban flooding likely to be experienced at Wee Waa and also to provide data to allow the comparative economic benefits of upgrading the Town Levee and the local stormwater drainage system. As explained in **Appendix D**, it is not the intention to determine the depths of inundation or the damages accruing to *individual properties*, but rather to obtain a reasonable estimate of damages experienced over the extent of the urban area in the town for the various design flood events. The estimation of damages using *Guideline No. 4* (in lieu of site specific data determined by a loss adjustor) also allows a uniform approach to be adopted by Government when assessing the relative merits of measures competing for financial assistance in flood prone centres in NSW.

Damages were estimated for the design flood levels determined from the hydraulic modelling that was undertaken as part of the present study, while the elevations of the floors of affected properties were estimated by a "drive-by" survey which assessed the height of the floor above local natural surface elevations. These natural surface elevations were derived from the LiDAR survey used to construct the Namoi River and Wee Waa TUFLOW Models. Flood damages in Wee Waa resulting from the following five scenarios were assessed as part of the present study:

Damage due to local stormwater runoff

- No river flooding and gravity drainage of the protected area via the fourteen penstock gated stormwater drainage pipes that control ponding levels behind the Town Levee (**Damage Scenario 1**).
- Pumping of stormwater runoff to the Namoi River floodplain via the six permeant stormwater evacuation pumps and assuming the fourteen penstock gates are in their closed position and the Town Levee is not overtopped (**Damage Scenario 2**).
- Failure of the six permanent stormwater evacuation pumps to operate during a storm event and assuming the fourteen penstock gates are in their closed position and the Town Levee is not overtopped (**Damage Scenario 3**).

Damage due to riverine flooding

- No coincident rainfall over Wee Waa during a Namoi River Flood (**Damage Scenario 4**).
- No coincident rainfall over Wee Waa during a Namoi River Flood that causes a partial failure of the Town Levee (**Damage Scenario 5**).

The number of flood affected properties and the estimated damages which would occur for the five damage scenarios are summarised in **Tables 2.10** and **2.11** over the page.

It is estimated that only one dwelling and one commercial/industrial property would experience above-floor inundation should a 1% AEP storm event occur over Wee Waa during a period when the flood gates are open. The fact that there are only two properties that would experience above-floor flooding due to local catchment runoff for storms up to 1% AEP in intensity probably dates back to the pre-Town Levee era, when buildings would have been built off the ground to reduce the likelihood that they would be inundated by riverine flooding. While a large number of respondents to the questionnaire were in favour of upgrading the local stormwater drainage system (refer **Section 3.2** and **Appendix A** for further details), this finding indicates that the issue is likely related more to nuisance flooding, rather than damaging above-floor flooding.

While the number of properties that would experience above-floor flooding should a 1% AEP storm occur over Wee Waa when the penstock gates are closed would increase slightly, should the six stormwater evacuation pumps fail or not be started up during a storm of this intensity the total number of properties that would experience above-floor inundation would increase to only 30 properties (15 dwellings and 15 commercial/industrial buildings).

The "present worth value" of damages in Wee Waa resulting from rain falling directly over Wee Waa up to the 1% AEP event assuming the stormwater evacuation pumps are operational is $0.4 Million. This value represents the amount of capital spending which would be justified if a particular stormwater drainage upgrade scheme prevented flooding for all properties up to this event.

TABLE 2.10
FLOOD DAMAGES AT WEE WAS RESULTING FROM LOCAL STORMWATER RUNOFF[(1)]

Design Flood Event (% AEP)	Number of Properties																		Total Damage ($ Million)		
	Residential						Commercial/Industrial						Public								
	Flood Affected			Flood Damaged			Flood Affected			Flood Damaged			Flood Affected			Flood Damaged					
	DS1	DS2	DS3	DS1	DS2	DS3	DS1	DS2	DS3	DS1	DS2	DS3	DS1	DS2	DS3	DS1	DS2	DS3	DS1	DS2	DS3
5	17	18	31	1	1	2	3	3	14	0	0	3	2	2	2	0	0	0	0.39	0.40	0.9
2	20	24	45	1	1	6	4	5	18	0	2	9	2	2	2	0	0	0	0.45	0.56	1.53
1	26	33	55	1	4	15	6	10	23	1	3	15	5	4	5	0	0	0	0.58	0.90	2.43
0.5	31	40	61	2	6	19	8	20	28	2	7	17	5	5	5	0	0	0	0.76	1.36	3.94
0.2	50	60	73	6	14	25	20	25	34	7	14	21	5	5	5	0	0	0	1.51	2.50	6.54
PMF	215	221	221	119	137	137	54	54	54	46	48	48	19	20	19	10	13	13	22.29	26.14	26.14

1. DS1 – Damage Scenario 1 DS2 – Damage Scenario 2 DS3 – Damage Scenario 3

TABLE 2.11
FLOOD DAMAGES AT WEE WAS RESULTING FROM RIVERINE FLOODING[(1)]

Design Flood Event (% AEP)	Number of Properties												Total Damage ($ Million)	
	Residential				Commercial/Industrial				Public					
	Flood Affected		Flood Damaged		Flood Affected		Flood Damaged		Flood Affected		Flood Damaged			
	DS4	DS5	DS4	DS5	DS4	DS5	DS4	DS5	DS4	DS5	DS4	DS5	DS4	DS5
5	0	674	0	560	0	133	0	123	0	36	0	29	0	109.9
2	0	678	0	585	0	135	0	126	0	37	0	30	0	114.6
1	0	681	0	595	0	135	0	126	0	37	0	32	0	116.5
0.5	0	681	0	596	0	135	0	126	0	37	0	32	0	116.8
0.2	0	682	0	601	0	135	0	129	0	38	0	33	0	118.1
0.1[(2)]	681	-	594	-	129	-	126	-	42	-	33	-	117.8	-
Extreme Flood	703	703	696	696	135	135	135	135	42	42	42	42	163.3	163.3

1. DS4 – Damage Scenario 4 DS5 – Damage Scenario 5
2. Approximate AEP when overtopping of the Town Levee first occurs.

While damages due to overtopping of the Town Levee are limited to floods with AEPs less than about 0.1 per cent, once overtopping does occur, all but a small number of buildings would experience above-floor inundation. A similar situation would arise were the Town Levee to partially fail during a flood. The total damages in Wee Waa were the Town Levee to either be overtopped or fail during a major flood event is estimated to be about $117 Million. The present worth value of damages under a Town Levee failure scenario (i.e. Damage Scenario 5) is about $100 Million. This is the amount that could be spent upgrading the Town Levee to ensure that it is geotechnically stable, free of defects and arguably incorporates the required 1 m freeboard to the 1% AEP flood.

2.16 Flood Hazard and Hydraulic Categorisation of the Floodplain

2.16.1 General

According to Appendix L of *NSWG, 2005*, in order to achieve effective and responsible floodplain risk management, it is necessary to divide the floodplain into areas that reflect:

1. The impact of flooding on existing and future development and people. To examine this impact it is necessary to divide the floodplain into *"flood hazard"* categories, which are provisionally assessed on the basis of the velocity and depth of flow. This task was undertaken in the *Flood Study* where the floodplain was divided into *Low Hazard* and *High Hazard* zones. In this present report, a *final determination* of hazard was undertaken which involved consideration of a number of additional factors which are site specific to Wee Waa. **Section 2.16.2** below provides details of the procedure adopted.
2. The impact of future development activity on flood behaviour. Development in active flow paths (i.e. *"floodways"*) has the potential to adversely re-direct flows towards adjacent properties. Examination of this impact requires the division of flood prone land into various *"hydraulic categories"* to assess those parts which are effective for the conveyance of flow, where development may affect local flooding patterns. Hydraulic categorisation of the floodplain was also undertaken in the *Flood Study* and was reviewed in this present study. **Section 2.16.3** below summarises the procedure adopted.

2.16.2 Flood Hazard Categorisation

As mentioned above, flood prone areas may be *provisionally* categorised into *Low Hazard* and *High Hazard* areas depending on the depth of inundation and flow velocity. A flood depth of 1 m in the absence of significant flow velocity represents the boundary between *Low Hazard* and *High Hazard* conditions. Similarly, a flow velocity of 2.0 m/s but with a small flood depth around 200 mm also represents the boundary between these two conditions. Interpolation may be used to assess the hazard for intermediate values of depth and velocity. Flood hazards categorised on the basis of depth and velocity only are *provisional*. They do not reflect the effects of other factors that influence hazard.

These other factors include:

1. Size of flood – major floods though rare can cause extensive damage and disruption.
2. Effective warning time – flood hazard and flood damage can be reduced by sandbagging entrances, raising contents above floor level and also by evacuation if adequate warning time is available.

3. Flood awareness of the population – flood awareness greatly influences the time taken by flood affected residents to respond effectively to flood warnings. The preparation and promotion by Council of Flood Studies and Floodplain Risk Management Studies and Plans increases flood awareness, as does the formulation and implementation of response plans by NSW SES (Local Flood Plans) for the evacuation of people and possessions.
4. Rate of rise of floodwaters – situations where floodwaters rise rapidly are potentially more dangerous and cause more damage than situations in which flood levels increase slowly.
5. Duration of flooding – the duration of flooding (or length of time a community is cut off) can have a significant impact on costs associated with flooding. This duration is shorter in smaller, steeper catchments.
6. Evacuation problems and access routes – the availability of effective access routes from flood prone areas directly influences flood hazard and potential damage reduction measures.

Provisional hazard categories may be reduced or increased after consideration of the above factors in arriving at a final determination. A qualitative assessment of the influence of the above factors on the *provisional flood hazard* (i.e. the hazard based on velocity and depth considerations only) is presented in **Table 2.12** over the page.

Figure 2.23 (2 sheets) shows the division of the floodplain into high and low hazard areas following consideration of the factors set out in **Table 2.12**. While the *provisional flood hazard* classification has been adopted for the majority of the floodplain, pockets of low hazard floodway areas have been identified as *high hazard* areas.

2.16.3 Hydraulic Categorisation of the Floodplain

According to the *NSWG, 2005*, the floodplain may be subdivided into the following zones:

- ***Floodways*** are those areas where a significant volume of water flows during floods and are often aligned with obvious natural channels. They are areas that, even if partially blocked, would cause a significant increase in flood level and/or a significant re-distribution of flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.
- ***Flood Storage*** areas are those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.
- ***Flood Fringe*** is the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

TABLE 2.12
INFLUENCE OF FLOOD RELATED PARAMETERS ON PROVISIONAL FLOOD HAZARD

Parameter	Flood Characteristics	Influence on Provisional Hazard	
		Namoi River Floodplain	Internal to Town Levee
Size of flood	Flooding is generally confined to the Namoi River floodplain and the risk to existing development is minor given the Town Levee is not overtopped for all but an extreme flood events. There is only one residential and one commercial/industrial property that experience above-floor inundation due to local catchment flooding a 1% AEP storm, and only then to relatively shallow depths.	-1	-1
Effective warning time	The flood wave takes between about 12-24 hours to travel from Narrabri to Wee Waa. While BoM and NSW SES maintain an effective and proven Flood Warning System for the Namoi River, high flows from the Pilliga Scrub area can cause unexpected flooding in the rural area south of Wee Waa. While there is presently no formal weather warning service in place for Wee Waa, there is only one residential and one commercial/industrial property that would experience above-floor inundation as a result of local catchment flooding in a 1% AEP storm and only then to relatively shallow depths.	0	-1
Flood awareness	Flood awareness would generally be quite high on the unprotected side of the Town Levee due to the relatively frequent nature of flooding in the rural areas. An awareness that the Town Levee could be overtopped during an extreme flood event is likely to be low in the community. An awareness for the need to evacuate during a flood that exceeds the IFF level would also likely be low in the community Landowners are aware of the deficiencies in the local stormwater drainage system, as evidenced by the strong response to the *Community Questionnaire*.	+1	0
Rate of rise and velocity of floodwaters	Flooding rises to a peak over a number of days, which in conjunction with the Flood Warning System, would provide sufficient warning for Council to close the penstock gates and check the stormwater evacuation pumps to make sure that they are fully functional. Overtopping or a partial failure of the Town Levee would result in a rapid increase in water levels.	0	0
Duration of flooding	Flooding of medium to major events may be maintained for up to one week. While local catchment flooding would be of a relatively short duration nature, it does cause disruption to movements around parts of Wee Waa and also the operation of some businesses.	0	+1
Evacuation problems	While the Town Levee is only overtopped during extreme flood events, the evacuation of people during a flood that exceeds the IFF level for the Town Levee would be costly should they not self-evacuate by vehicle prior to the local roads being inundated by floodwater. This is because the evacuation of people who did not self-evacuate would likely need to be carried out by air.	0	-1
	OVERALL SCORE	**0**	**-2**

Legend 0 = neutral impact on provisional hazard
+ 1 = tendency to increase provisional hazard
– 1 = tendency to reduce provisional hazard

Floodplain Risk Management Guideline No. 2 Floodway Definition, offers guidance in relation to two alternative procedures for identifying floodways. They are:

- **Approach A**. Using a *qualitative approach* which is based on the judgement of an experienced hydraulic engineer. In assessing whether or not the area under consideration was a floodway, the qualitative approach would need to consider; whether obstruction would divert water to other existing flow paths; or would have a significant impact on upstream flood levels during major flood events; or would adversely re-direct flows towards existing development.

- **Approach B**. Using the hydraulic model, in this case TUFLOW, to define the floodway based on *quantitative experiments* where flows are restricted or the conveyance capacity of the flow path reduced, until there was a significant effect on upstream flood levels and/or a diversion of flows to existing or new flow paths.

One quantitative experimental procedure commonly used is to progressively encroach across either floodplain towards the channel until the designated flood level has increased by a significant amount (for example 0.1 m) above the existing (un-encroached) flood levels. This indicates the limits of the hydraulic floodway since any further encroachment will intrude into that part of the floodplain necessary for the free flow of flood waters – that is, into the floodway.

The *quantitative assessment* associated with **Approach B** is technically difficult to implement. Restricting the flow to achieve the 0.1 m increase in flood levels can result in contradictory results, especially in unsteady flow modelling, with the restriction actually causing reductions in computed levels in some areas due to changes in the distribution of flows along the main drainage line.

Accordingly the *qualitative approach* associated with **Approach A** was adopted, together with consideration of the portion of the floodplain which conveys approximately 80% of the total flow. The findings of *Howells et al, 2004* who defined the floodway based on velocity of flow and depth were also taken into consideration. For example, Howells et al suggested the following criteria for defining those areas which operate as a "floodway" in a 1% AEP flood event:

- Velocity x Depth greater than 0.25 m^2/s **and** Velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

Flood storage areas on the Namoi River floodplain were identified as those areas which do not operate as floodways in a 1% AEP flood event but where the depth of inundation exceeds 1 m. The remainder of the flood affected area outside the Town Levee was classified as flood fringe.

No floodway areas are present internal to the Town Levee. Rather flood storage areas were defined as areas where the depth of inundation exceeds 0.3 m, while the remainder was classified as flood fringe.

Figure 2.23 (2 sheets) shows the division of the Namoi River floodplain and the area internal to the Town Levee into floodway, flood storage and flood fringe areas at the 1% AEP level of flooding.

2.17 Council's Existing Planning Instruments and Policies

2.17.1 General

The *Narrabri Local Environmental Plan 2012* (***Narrabri LEP 2012***) is the principal statutory planning document used by Council for controlling development by defining zoning provisions, establishing permissibility of land use and regulating the extent of development in Wee Waa.

Council does not maintain a consolidated development control plan, but rather maintains fourteen individual development control plans which deal with specific types of development.

2.17.2 Land Use Zoning – Narrabri Local Environmental Plan 2012

Figure 2.24 shows the zonings incorporated in *Narrabri LEP 2012* at Wee Waa. The area that is bounded by the Town Levee and lies to the east of Warrior Street is zoned *B2 Local Centre*, *B4 Mixed Use*, *IN2 Light Industrial*, *R1 General Residential*, *RE1 Public Recreation* and *SP2 Infrastructure*, while the area to the west of Warrior Street is zoned *B4 Mixed Use* and *IN1 General Industrial*.

The area surrounding the township is zoned *RU1 Primary Production*, with the exception of a 228 ha area which lies to the south-east which is zoned *R5 Large Lot Residential*.

2.17.3 Flood Provisions – Narrabri LEP 2012

Clause 6.2 of *Narrabri LEP 2012* entitled "Flood planning" outlines its objectives in regard to development of land that is at or below the Flood Planning Level (**FPL**). It is similar to the standard Flood Planning Clause used in recently adopted LEPs in other NSW country centres and applies to land at or below the FPL.

The FPL referred to is the 1:100 ARI (or 1% AEP) flood plus an allowance for freeboard of 500 mm. The area encompassed by the FPL (i.e. the FPA) denotes the area subject to flood related development controls, such as locating development outside high hazard areas and setting minimum floor levels for future residential development. It is now standard practice for the residential FPL to be based on the 1% AEP flood plus an appropriate freeboard unless exceptional circumstances apply.

While Clause 6.2 also applies to land identified as the FPA on the "*Flood Planning Map*", the flood related mapping attached to *Narrabri LEP 2012* does not cover the township of Wee Waa. For the *Flood Planning Map* to be modified, a formal amendment would need to be made to *Narrabri LEP 2012*, which would take considerable time. It is therefore recommended that the *Flood Planning Map* not be attached to *Narrabri LEP 2012*, as this way it can be updated without the need to update the LEP. Recommended amendments to the wording of clause 6.2 are set out in **Section 3.5.1.4** of the report.

2.17.4 Flooding and Stormwater Controls

Schedule 2 of Council's *Exempt & Complying Development Development Control Plan* (***DCP***) under Section 4 titled "Dwelling house (single storey)" and the heading "Bulk and scale" contains the following flood related controls:

> *"(1) The ground floor level of the structure is located at least 150 mm. for raft construction or 650 mm. for timber frame flooring but not more than 700 millimetres above the natural ground level (except where the dwelling complies with the Narrabri Shire Interim Floodplain Management Policy.)*
>
> *(2) The Finished Floor Level of all habitable areas of the dwelling are constructed 500mm higher than the 1:100 year flood event, for the subject land, in accordance with Narrabri Shire Council's Interim Floodplain Management Policy. Note: Written verification of the finished floor level is to be provided to Council after the establishment of the flooding system.*
>
> *(3) The height of any landfill placed on the land is no more than 225mm."*

Under Section 5 of Schedule 2 titled "Extensions" and the heading "Bulk and scale", the following flood related controls are also set out:

> *"(1) The ground floor level of the structure at any point is not more than 700 millimetres above the natural ground level (except where the dwelling complies with the Narrabri Shire Interim Floodplain Management Policy.)*
>
> *(2) The Finished Floor Level of all habitable areas of the dwelling extension are constructed 500mm higher than the 1:100 year flood event, for the subject land, in accordance with Narrabri Shire Council's Interim Floodplain Management Policy. Note: Written verification of the finished floor level is to be provided to Council after the establishment of the flooding system."*

Council's *Landfill Development DCP* states that the aims and objectives of the document are to set reasonable environmental standards in respect to flood liable land, privacy, on-site drainage, streetscape and other impacts on adjoining land uses. The *Landfill Development DCP* requires that a Statement of Environmental Effects be prepared which demonstrates that consideration has been given to the environmental impact of the development, including the probable effect on natural and stormwater drainage, flood water flows, privacy, soil erosion and management, and any other identifiable impacts on adjoining lands. It also requires that all batters of the landfill edges are to be stabilised in a manner to prevent surface erosion from storm or flood water events.

Council's *Subdivision Code DCP* under Section 4.6.1 titled "Flooding" states the following:

> *"Where a subdivision is undertaken within urban areas which are subject to flooding, the applicant is required to provide Council with the level of water on the property in a 1:100 year flood.*
>
> *With rural subdivisions, the applicant is required to supply Council with evidence that an area suitable for the construction of a dwelling is available which is in a low flood risk area. Where the subdivision is not for a residential purpose, evidence should be submitted to Council showing that the proposed used* [sic] *will not be adversely effected* [sic] *by a foreseeable flood event."*

The *Interim Floodplain Management Policy* referred to in Council's *Exempt & Complying Development DCP* was first adopted in October 1987 and later updated in March 1988 and October 1998. The interim policy states the following (**bold** and <u>underlined</u> text has been added for emphasis):

1. *All habitable rooms as described under clause A1.1 of the Building Code of Australia, for new houses and residential flat buildings are to be constructed at least 0.5 of a metre above the 1:100 ARI flood level.* ***This <u>does not</u> apply in the Town of Wee Waa, which is protected by the flood levee.***
2. *Alterations and additions to dwelling houses constructed prior to the enactment date for Council's current flood policy adopted in 1987 and requiring the floor levels of houses and residential flat buildings to be 0.5 of a metre above the 1:100 ARI flood level will be considered on an individual merit basis up to an area equal to 50% of the existing floor area of habitable rooms.* ***This provision <u>does not</u> apply to the Town of Wee Waa, which is protected by the flood levee.***

3 *All Commercial and Industrial buildings whether new or additions, are considered on merit generally.*

4 *All building materials, for all types of development, that are to be utilised below the 1:100 ARI flood level, must be floodwater tolerant or resistant. Further, Council recommends that all electrical fittings and equipment be installed above the 1:100 ARI flood height for that land.*

5 *In the areas which may be affected by the 1:100 ARI flood landholders land filling in excess of 225mm.of material will be required to provide a permanent drain to the street from backyard run off and the backyard be graded to a sump which is to be drained by permanent piping to the street or by concrete dish drains or other approved drainage systems of permanent material, Such provisions must not restrict natural drainage from adjoining lands. Where the installation of land filling adversely affects the drainage of the adjoining site or sites a provision for drainage of the adjoining site or sites shall be incorporated in the drainage system provided by the person carrying out land filling.* ***This provision <u>also applies</u> to the Town of Wee Waa.***

6 *Where, in the opinion of the Director of Environmental Services or Council Planner, Council holds insufficient information to provide reasonably accurate flood information to enable compliance with Item 1 of this Policy, any applicant for the erection of new dwellings or residential flat buildings must provide to Council accurate information as to the level of the land, where the development is to occur and the 1955 flood level for that particular area.*

7 *With respect to new dwellings and residential buildings, where, in the opinion of Council, a proposed development could sustain structural damage by flooding, no work on the development will be allowed to commence until the applicant obtains and submits a Certificate of Structural Adequacy of the proposed dwelling or residential building from a qualified Structural/Civil Engineer.*

8 *With respect to commercial and industrial development, new and existing, in flood liable areas, applications for development are to be accompanied by a Certificate from a qualified practising Structural or Civil Engineer stating that the building will not sustain structural damage from the forces and impact of debris associated with flood waters equal to the 1:100 ARI flood, except - with respect to extensions and alterations to commercial buildings, shops, offices, motels, hotels, and the like having a floor area of 50 m^2 or less or industrial buildings including workshops, stores associated with such workshops, warehouses and bulk stores having an area of 100 m^2 or less.*

NOTE: *Major residential and rural areas of this Shire were affected by the 1955 flood peak. The Council has details of the depth of flooding in Narrabri Township (Narrabri Shire Council 1:100 ARI Flood Contour Map, Town of Narrabri) and the extent of flooding with respect to the 1955 flood at the Town of Boggabri. Council's records relating to Narrabri and Boggabri may be inspected by any interested person.* ***With respect to the residue of the Shire, the Town of Wee Waa is protected by a levee bank which at the time of construction was***

> ***designed in accordance with the requirements of the then Water Resources Commission of New South Wales, The integrity of the Wee Waa levee bank depends on the future nature of flooding In the area.***

With respect to rural areas, Council holds very little information regarding the depth of flooding in portions of the Shire affected by the 1955 flood event and reference should be made to the Department of Land and Water Conservation who may hold useful Information in this regard.

THE FILLING OF LAND AT NARRABRI WITH FILL OF A GREATER DEPTH THAN 225mm IN AREAS AFFECTED BY THE 1:100 ARI YEAR FLOOD EVENT REQUIRES COUNCIL'S DEVELOPMENT CONSENT PRIOR TO WORK BEING COMMENCED.

DEFINITION AS PER BCA

Habitable room means a room used for normal domestic activities, and–

(a) includes a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room and sunroom; but

(b) excludes a bathroom, laundry, water closet, pantry, walk–in wardrobe, corridor, hallway, lobby, photographic darkroom, clothes–drying room, and other spaces of a specialised nature occupied neither frequently nor for extended periods.

Based on the controls set out in Council's *Exempt & Complying Development DCP* and the *Interim Floodplain Management Policy*, there is no requirement to set the floor level of any new development or extension in Wee Waa above the peak 1% AEP flood level. This requirement does not take into account the depth to which stormwater will pond behind the Town Levee during a 1% AEP storm event and assumes that it has the required freeboard to protect new development from inundation by a 1% AEP Namoi River flood (which it presently doesn't provide given insufficient freeboard).

In the knowledge that the Town Levee does not have the required 1 m freeboard and therefore does not protect development for a 1% AEP flood, the provisions set out in *Interim Floodplain Management Policy* allow development to occur in Wee Waa below the level of the FPL. The policy is therefore inconsistent with the NSW Government's Section 9.1 Direction which states that unless there are exception circumstances[13] the residential FPL is the 1% AEP plus an appropriate freeboard (which in areas subject to riverine flooding is generally set at 0.5 m). Further discussion on this issue is contained in **Chapter 3**.

Development Design Specification D5 titled "*Stormwater Drainage*" sets out Council's requirements for the design of new stormwater drainage systems. It adopts the "major/minor" system concept set out in the 1987 version of Australian Rainfall & Runoff (IEAust, 1987).

[13] In this context, exception circumstances relate to the adoption of a higher flood standard, not a lower flood standard which is presently the case at Wee Waa where development is allowed to occur based on a maximum height above ground.

2.18 Flood Warning and Flood Preparedness

The NSW SES is nominated as the principal combat and response agency for flood emergencies in NSW. NSW SES is responsible for the issuing of relevant warnings (in collaboration with BoM), as well as ensuring that the community is aware of the flood threat and how to mitigate its impact.

The *Narrabri Local Flood Plan*, 2015 (herein referred to as the ***Local Flood Plan***) published by NSW SES covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures for all levels of flooding within the Narrabri Shire area. The *Local Flood Plan* is administered by the NSW SES Narrabri Local Controller who controls flood operations within the Narrabri Shire area and is based in Narrabri. A NSW SES unit is also based in Wee Waa and assists the Narrabri Local Controller administer the *Local Flood Plan* in relation to the township. The NSW SES Wee Waa unit is located at No. 52 Rose Street, Wee Waa.

The main body of the *Local Flood Plan* follows the standard NSW SES template and is divided into the following sections:

- ***Introduction****;* this section of the *Local Flood Plan* identifies the responsibilities of the NSW SES Local Controller, Unit Controllers and NSW SES members, as well as supporting services such as the Police, BoM, Ambulance, Country Energy, Fire Brigades, Department of Community Services, Council, etc. The *Local Flood Plan* identifies the importance for NSW SES and Council to coordinate the development and implementation of a public education program to advise the population of the flood risk.
- ***Preparedness****;* this section deals with activities required to ensure the *Local Flood Plan* functions during the occurrence of the flood emergency. The Plan will devote considerable attention to flood warning and emergency response.
- ***Response***. The NSW SES maintains an operation centre at the NSW SES Local Headquarters in Reid Street, Narrabri. Response operations will commence: on receipt of a Preliminary Flood Warning, Flood Warning, Flood Watch, Severe Thunderstorm Warning or a Severe Weather Warning for flash flooding from BoM, on receipt of a dam failure or when other evidence leads to an expectation of flooding within the Narrabri Shire area. Sources of Flood Intelligence identified will include BoM, NSW Office of Water, the Keepit Dam Storage Monitoring System, NSW SES Namoi Regional Headquarters and Council.

  The *Local Flood Plan* states that the Wee Waa Public School on Cowper Street, Wee Waa High School on Purcell Street, the Church Hall on Cowper Street, the Sports Complex on the Kamilaroi Highway, the Country Women's Association Rooms in Rose Street, and the Namoi Cotton Co-Op and Cotton Grower Services on Boolcarrol Road are suitable flood evacuation centres. The location of the nominated flood evacuation centres are shown on **Figure 2.11**, sheet 2.
- ***Recovery****,* involving measures to ensure the long term welfare for people who have been evacuated, recovery operations to restore services and clean up and de-briefing of emergency management personnel to review the effectiveness of the *Local Flood Plan*.

Annexes A and B of the *Local Flood Plan* describe the flood threat and impact that flooding has on the community in the Narrabri Shire area, respectively. **Sections 2.4** and **2.5** of this report contain a description of flooding behaviour at Wee Waa, as well as the impact that flooding has on the local community which is based partially on the information contained in Annexes A and B of the *Local Flood Plan*.

Annex F of the *Local Flood Plan* which deals with evacuation arrangements in the Narrabri Shire area states that up to eighteen residences that are located outside the Town Levee may require evacuation into Wee Waa during a flood. The *Local Flood Plan* also states that the most likely event to trigger the decision to undertake a large-scale evacuation of Wee Waa would be evidence of a possible failure or overtopping of the Town Levee.

In the event of actual levee failure or overtopping, the *Local Flood Plan* states that all essential services would be cut and the town would almost certainly have to be completely evacuated. As Wee Waa usually has up to three days warning of a peak flood height, as well as up to two days warning of when the town may be isolated by road, some preliminary evacuations may be possible.

In the event that predicted flood heights indicate a threat of levee overtopping, the NSW SES Narrabri Local Controller, Wee Waa Unit Controller and the Narrabri Local Emergency Operations Controller will consider preliminary road evacuation of the aged, infirm and children. It is thought that this could reduce the population by up to 40 per cent.[14]

In the case where the town is isolated by road, the *Local Flood Plan* states that evacuees will be flown to a transit area at “The Pines”. If the Bohena Creek crossing on the Narrabri to Yarrie Lake Road is open, the evacuees could be moved out of “The Pines” by bus. If not, they will need to be moved by air from Nicholson’s Airport, which is located adjacent to ‘The Pines” and is flood free.

2.19 Environmental Considerations

The river and creek systems at Wee Waa are largely in their natural state where they run to the north and south of the township. Given the relatively wide floodplain at Wee Waa and the fact that there are a limited number of properties affected by Namoi River Flooding, modifications to the main arm of the river would not result in a significant reduction in flood damages. As a result, channel modifications and stream clearing do not form part of the recommended set of flood mitigation measures at Wee Waa.

Consideration would need to be given to the impact the upgrade of the Town Levee would have on existing vegetation and Wee Waa Lagoon as its footprint would increase as a result of an increase in the elevation of its crest. **Section 3.4.1** of this report sets out the requirements for the upgrade of the Town Levee.

[14] Note that this would still leave about 1,000 people in Wee Waa who would need to be evacuated during a flood emergency by air.

3 POTENTIAL FLOODPLAIN MANAGEMENT MEASURES

3.1 Range of Available Measures

A variety of floodplain management measures can be implemented to reduce flood damages. They may be divided into three categories, as follows:

Flood modification measures change the behaviour of floods in regard to discharges and water surface levels to reduce flood risk. This can be done by the construction of levees, detention basins, channel improvements and upgrades of piped drainage systems in urban areas. Such measures are also known as "structural" measures as they involve the construction of engineering works. Vegetation management is also classified as a flood modification measure.

Property modification measures reduce risk to properties through appropriate land use zoning, specifying minimum floor levels for new developments, voluntary purchase of residential property in high hazard areas, or raising existing residences in the less hazardous areas. Such measures are largely planning (i.e. "non-structural") measures, as they are aimed at ensuring that the use of floodplains and the design of buildings are consistent with flood risk. Property modification measures could comprise a mix of structural and non-structural methods of damage minimisation to individual properties.

Response modification measures change the response of flood affected communities to the flood risk by increasing flood awareness, implementation of flood warning and broadcast systems and the development of emergency response plans for property evacuation. These measures are entirely non-structural.

3.2 Community Views

Comments on potential flood management measures were sought from the Wee Waa community by way of the *Community Questionnaire* which was distributed at the commencement of the study. The responses are summarised in **Appendix A** of this report. Question 13 in the *Community Questionnaire* outlined a range of potential flood management measures. The responses are shown on **Table 3.1** over the page together with initial comments on the feasibility of each measure. The measures are discussed in more detail in later sections of this Chapter.

The Community favoured the following measures:

- Raising of the Town Levee
- Improvements in the stormwater system within Wee Waa.
- Advice of flood affectation via Planning Certificates for properties located within the *Flood Planning Area*.
- Flood related controls over future development in flood liable areas.
- Improved flood warning, evacuation and flood response procedures.
- Community education to promote flood awareness.

TABLE 3.1
COMMUNITY VIEWS ON POTENTIAL FLOOD MANAGEMENT MEASURES

Flood Management Measure		Classification[1]	Respondent's Views			Comments
			Yes	No	Don't Know	
a)	Raising of the existing earthen levee using the same construction methodology	FM	52	2	3	The community is strongly in favour of this measure, which is an essential part of the *LRMP*. Details of the upgrade requirements for the Town Levee are set out in **Section 3.4.1**.
b)	Raising of the existing earthen levee during times of flood using temporary/relocatable flood barriers	FM	12	20	5	The community is not in favour of this measure. Nonetheless, a brief discussion on this approach is contained in **Section 3.4.1**.
c)	Improvements to the internal drainage system	FM	45	1	1	This measure is strongly supported by the community and needs to be considered as part of the *LRMP*. While the present study shows that the severity of flooding internal to the Town Levee is reduced by the operation of the stormwater evacuation pumps, there is merit in increasing the temporary flood storage in several areas. This flood management measure and the technical requirements associated with the upgrade of the existing stormwater system are discussed in **Section 3.4.2**.
d)	Removal of floodplain obstructions, such as rural levees	FM	12	18	7	This measure is not supported by the community. This is likely due to the reliance of the town on the surrounding agricultural industry, namely cotton farms which rely on the rural levees to protect crops from inundation by floodwater.
e)	Voluntary purchase of the most severely affected flood-liable properties	PM	7	17	11	The community is not in favour of this measure, which is often adopted to remove residential property in high hazard areas of the floodplain. As there are no dwellings internal to the Town Levee located in the High Hazard Floodway area, this measure was not assessed.
f)	Provide funding or subsidies to raise houses above major flood level in low hazard areas	PM	19	13	6	The community is not in favour of this measure. As there are no more than four residential properties that would experience above-floor inundation during a 1% AEP storm event other than for the case where the stormwater evacuation pumps were inoperable, and only then to relatively shallow depths, this measure by inspection could not be justified economically. As a result, it was not considered further.
g)	Flood proofing of individual properties by waterproofing walls, putting shutters across doors, etc.	PM	4	21	12	The community is not in favour of this measure, which should only be adopted as a means by which to mitigate the impact of flooding on existing development. As a result, this measure was not assessed.
h)	Improve flood warning and evacuation procedures both before and during a flood	RM	34	8	1	NSW SES is responsible for the issuing of relevant warnings (in collaboration with BoM), as well as ensuring that the community is aware of the flood threat and how to mitigate its impact. BoM operates a flood warning system which provides predictions of gauge heights along the Namoi River, including at Wee Waa. Improvements to flood emergency response planning (using information contained in this study) are supported by the community and are considered in **Section 3.6.3**.
i)	Community education, participation and flood awareness programs	RM	29	4	5	Ensuring the community is aware of the flood risk in Wee Waa is favoured by the questionnaire respondents. This measure is reviewed in **Section 3.6.3**.
j)	Ensuring all residents and business owners have Flood Action Plans	RM	33	6	4	Ensuring the community knows what actions to take during a flood event is favoured by the questionnaire respondents. This measure is reviewed in **Section 3.6.3**.
k)	Specify controls on future development in flood-liable areas (e.g. controls on extent of filling, minimum floor levels, etc.)	PM	27	5	11	The community supports this measure, which is an essential part of the *LRMP*. The issue is covered in **Section 3.5.1**.
l)	Provide a Planning Certificate to purchasers in flood prone areas, stating that the property is flood affected	PM	38	2	3	Provision of information on flood affection of properties is strongly favoured by the community. This may be achieved by notation of flood affectation of allotments on Section 10.7 Planning Certificates. This measure is discussed in **Section 3.5.1.3**.
m)	Ensuring all information about the potential risks of flooding is available to all residents and business owners	PM	47	1	0	Ensuring the community is aware of the flood risk in Wee Waa is favoured by the questionnaire respondents. This measure is reviewed in **Section 3.6.3**.

1. FM = Flood Modification Measure
PM = Property Modification Measure
RM = Response Modification Measure

3.3 Outline of Chapter

Several of the measures set out in **Table 3.1** were examined at the strategic level of detail in **Chapter 3** and then tested for feasibility on a range of assessment criteria in **Chapter 4**. Following consideration of the results by the FRMC, selected measures were included in the *LRMP* in **Chapter 5**.

Only two flood modification measures were assessed as part of the present study given the two principal issues are:

i) the design standard of the Town Levee is currently equivalent to about a 5% AEP flood, and

ii) parts of the town are subject to nuisance flooding that occurs during periods of heavy and/or prolonged rainfall.

In the economic analysis, the damages prevented by the upgrade of the Town Levee represent its benefits. The damages were computed for present day and post-scheme conditions for a range of flood events. By integrating the area beneath the damage–frequency curve up to the "design standard" of the scheme (in this case the 1% AEP), the long term "average annual" value of benefits were calculated (by subtraction of post-scheme from present day damages). These average annual benefits were then converted to an equivalent present worth value for each of the three discount rates nominated by NSW Treasury Guidelines for the economic analysis of public works (i.e. 4, 7 and 11 per cent), over an economic life of 50 years. These present worth values of benefits were then divided by the capital costs of the Town Levee upgrade scheme to give benefit/cost ratios for the three discount rates. An economic analysis was not undertaken of the assessed stormwater drainage upgrade scheme as by inspection, it could not be justified on economic grounds (i.e. because its benefit cost ration would be significantly less than one).

Given the limited number of properties in Wee Waa that would experience above-floor inundation during a 1% AEP storm event and the low hazard nature of the stormwater which ponds behind the Town Levee, property modification measures such as voluntary purchase of residential properties and house raising were not considered. Flood related development controls over future development in the protected part of town could be limited to a minimum fill height and floor level control based on peak 1% AEP local catchment flood levels. However, until such time as the Town Levee is upgraded, this requirement would be deemed not to protect new development from a 1% AEP Namoi River flood (i.e. because the Town Levee does not incorporate sufficient freeboard to protect against a flood of this magnitude). Response modification measures such as improvements to emergency planning and responses, and public awareness programs have been considered for Wee Waa.

3.4 Flood Modification Measures

3.4.1 Town Levee Upgrade

While the Town Levee would not be overtopped for all but extreme flood events, the analysis set out in **Appendix E** of the report confirms the 1 m freeboard requirement that was adopted as part of its original design. Based on this finding, the design standard of the Town Levee is only equivalent to about a 5% AEP flood, which is slightly less than the level of flooding that it was originally designed to protect against (As previously mentioned, the original design adopted the February 1971 flood as the design standard which had an AEP of about 4 per cent).

Upgrading the Town Levee to provide a 1% AEP level of flood protection would require its crest to be raised over about a 6.2 km length. **Figure 3.1** shows the eight sections of the Town Levee that would need to be raised by a maximum height of about 0.5 m in order to provide the required 1 m freeboard to peak 1% AEP flood levels, while **Figure 3.2** is a long section showing the upgraded crest relative to existing ground and peak 1% AEP and Extreme flood levels.

While temporary relocatable flood barriers could be used to achieve the required 1 m freeboard to peak 1% AEP flood levels, reasons for not adopting this approach include:

- the logistics associated with installing the temporary measures over such a long length of levee prior to the arrival of the flood peak;
- the large flood damages that would result should these temporary measures fail or not be installed either correctly or in time;
- the hazardous nature of the flooding that would result from an overtopping event; and
- this type of approach to protecting the town is not favoured by the community.

The preferred option for upgrading the Town Levee is to raise its crest similar to the design which was prepared by Water Resources Consulting Services as part of the previous levee upgrade in 1993. This would require the removal of topsoil from the crest and front face of the embankment and the placement of a new engineered skin and associated toe arrangement. **Figure 3.3** is a typical section showing the scope of the upgrade works, while **Figures F1.1** (7 sheets) and **F1.2** (10 sheets) in **Appendix F** provide details of the upgrade requirements along the full length of the Town Levee.

The geotechnical report contained in **Appendix B** also provides recommendations associated with the upgrade of the Town Levee which includes a requirement to undertake further more detailed subsurface investigations to ascertain the condition of its core.

Table 3.2 gives a breakdown of the estimated $7.55 Million that it would cost to upgrade the Town Levee to a 1% design flood standard, noting that this does not include the cost of purchasing any easements over the Town Levee which at this point in time has been assumed not to be required.

If it is assumed that major overtopping of the Town Levee does not occur for all floods up to the 1% AEP (which could occur for reasons such as wind and wave action in the flow), then on economic grounds its upgrade could not be justified as there are no damages to prevent.

If it costs the community say $1 Million to evacuate people by air and relocate them to Narrabri for all floods between 5 and 1% AEP, then the present worth value of costs that would be saved by its upgrade would be about $0.6 Million, resulting in a benefit cost ratio of about 0.08.

In addition to the above, if the cost of flood insurance was to reduce by $250 on average in the 707 residential and say $500 on average in the 135 commercial/industrial properties that are protected by the Town Levee should it be upgraded, then the present worth value of costs that would be saved by its upgrade would increase to about $0.9 Million, resulting in a slight increase in the benefit cost ratio to about 0.1.

If the Town Levee is deemed not to protect property in Wee Waa for floods larger than 5% AEP in magnitude (i.e. equal to or larger than the IFF), then the present worth value of flood damages saved by its upgrade increases to about $100 Million. This results in a benefit cost ratio of about 13.

TABLE 3.2
BREAKDOWN OF CAPITAL COST ESTIMATE
TOWN LEVEE UPGRADE
1% AEP PLUS 1 m FREEBOARD

Item	Description	Unit	Rate	Quantity	Amount
1	Geotechnical Testing along levee route	Item	\$100,000	1	\$100,000
2	Preliminaries (Site Establishment, Sediment Control, etc)	Item	\$50,000	1	\$50,000
3	Clear and Grub along Route of Levee, including tree removal	m^2	\$2.00	87,000	\$174,000
4	Strip and Store Topsoil (150 mm) for later spreading over levee batters	m^2	\$1.50	87,000	\$130,500
5	Excavate additional 150 mm below adjacent natural surface to form foundation of new levee	m^3	\$10.00	48,000	\$480,000
6	Roll and Compact Levee Foundation	m^2	\$5.00	87,000	\$435,000
7	Supply and compact suitable impervious fill to form levee embankment	m^3	\$40.00	71,000	\$2,840,000
8	Excavate from stockpile and spread topsoil over face of levee	m^2	\$1.00	87,000	\$87,000
9	Grass seed levee batters	m^2	\$5.00	87,000	\$435,000
10	Road Crossing (Bitumen)	Item	\$50,000	5	\$ 250,000
11	Road Crossing (Dirt)	Item	\$10,000	1	\$10,000
12	Railway Crossing	Item	\$20,000	2	\$40,000
13	Drainage Works	Item	\$10,000	10	\$100,000
14	Un-estimated items and contingencies (40%)				\$1,892,600
	Sub-total				\$7,024,100
	Survey, Investigation and design (7.5%)				\$526,808
	Total Estimated Cost (Rounded to nearest \$10,000)				**\$7,550,000**

As mentioned in **Section 2.17.4**, as the design standard of the Town Levee is only equivalent to about a 5% AEP flood, Council's *Interim Floodplain Management Policy* is not consistent with the NSW Government's Section 9.1 Direction which states that unless there are exception circumstances the residential FPL is the 1% AEP plus an appropriate freeboard (which in areas subject to riverine flooding is generally set at 0.5 m) (i.e. because it allows development to occur based on a maximum height of 700 mm above the natural ground level, which is below the peak 1% AEP flood level in the river for which the Town Levee does not protect against).

This finding is a major issue for Council and the Wee Waa community, as unless the Town Levee is upgraded to incorporate the required 1 m freeboard, future development can only be approved if its floor level is set 0.5 m above the peak 1% AEP flood level on the Namoi River floodplain, which in most areas would place it more than 1.5 m, and in some areas more than 2.5 m above natural surface levels.

3.4.2 Upgrade of Stormwater Drainage System

Stormwater drainage systems are an effective means of preventing frequent flooding of urban areas by local catchment runoff. Stormwater drainage systems are usually designed to convey flows associated with more frequent rainfall events. Flows resulting from rarer events will usually exceed the capacity of the stormwater drainage system and travel along flow paths as local overland flow. While upgrading key elements of a stormwater drainage system may prevent nuisance flooding in low lying properties or inundation of low points in roads due to small storms that occur frequently, it is generally not a cost effective or practical way to mitigate damaging flooding that results from intense, rare storm events.

While major upgrades to the stormwater drainage system at Wee Waa could not be economically justified (i.e. because the present worth value of flood damages in Wee Waa for all localised storms up to 1% AEP is only $0.4 Million and a scheme costing more than this would have a benefit cost ratio less than 1), three options for reducing flooding resulting from the major flow path that develops through the centre of Wee Waa were assessed as part of the present study.

Figures 3.4, **3.5** and **3.6** show the impact three options for upgrading the existing stormwater drainage system on the northern side of Mitchell Street between George Street and the existing 750 mm diameter pipe which extends through the Town Levee at Chainage 8200 would have on drainage patterns for storms with AEPs of 5, 2 and 1 per cent. While all three stormwater drainage upgrade schemes would reduce the depth and extent of inundation, most of the benefits would be confined to land which is low lying and presently undeveloped. The exception is on the northern side of Boolcarrol Road, west of Warrior Street where the depth and extent of ponding in several industrial properties would be reduced.

Given the stormwater drainage upgrade schemes would be relatively expensive to construct and do not remove flooding in Wee Waa, they could not be justified on either economic or social grounds. Based on this finding, they were not considered further.

3.5 Property Modification Measures

3.5.1 Controls over Future Development

3.5.1.1 Considerations for Setting Flood Planning Level

Selection of the FPL for an area is an important and fundamental decision as the standard is the reference point for the preparation of floodplain risk management plans. It is based on adoption of the peak level reached by a particular flood plus an appropriate allowance for freeboard. It involves balancing social, economic and ecological considerations against the consequences of flooding, with a view to minimising the potential for property damage and the risk to life and limb. If the adopted FPL is too low, new development in areas outside the FPA (particularly where the difference in level is not great) may be inundated relatively frequently and damage to associated public services will be greater. Alternatively, adoption of an excessively high FPL will subject land that is rarely flooded to unwarranted controls.

Councils are responsible for determining the appropriate FPLs within their local government area. While *Narrabri LEP 2012* nominates the "*1:100 ARI (average recurrence interval) flood event plus 0.5 m freeboard*" as the FPL, the *Interim Floodplain Management Policy* allows development in Wee Waa to proceed subject to it being built no more than 700 mm above the natural ground surface, even though the design standard of the Town Levee is only equivalent to about a 5% AEP flood.

As it is not practical to apply the 1% AEP Namoi River flood level plus 0.5 m freeboard to development in Wee Waa given the height to which floor levels would need to be set above natural ground levels, the only means by which development can occur at a lower level is if the design standard of the Town Levee is increased to 1% AEP. <u>The following discussion on flood related planning controls for Wee Waa therefore assumes that the Town Levee is upgraded to achieve a 1% AEP level of protection from Namoi River Flooding</u>.

3.5.1.2 Current Government Policy

The circular issued by the Department of Planning on 31 January 2007 contained a package of changes clarifying flood related development controls to be applied on land in low flood risk areas (land above the 1% AEP flood). The package included an amendment to the Environmental Planning and Assessment Regulation 2000 in relation to the questions about flooding to be answered in Section 149 planning certificates (now referred to as Section 10.7 planning certificates), a revised ministerial direction (Direction 15 – now Direction 4.3 issued of 1 July 2009) regarding flood prone land (issued under Section 9.1 of the EP&A Act, 1979) and a new Guideline concerning flood-related development controls in low flood risk areas. The Circular advised that councils will need to follow NSWG, 2005, as well as the Guideline to gain the legal protection given by Section 733 of the Local Government Act.

The Department of Planning Guideline confirmed that unless exceptional circumstances applied, councils should adopt the 1% AEP flood with appropriate freeboard as the FPL for residential development. In proposing a case for exceptional circumstances, a council would need to demonstrate that a different FPL was required for the management of residential development due to local flood behaviour, flood history, associated flood hazards or a particular historic flood. Unless there were exceptional circumstances, Council should not impose flood-related development controls on residential development on land with a low probability of flooding, that is land above the residential FPL.

Nevertheless, the safety of people and associated emergency response management needs to be considered in low flood risk areas, which may result in:

- Restrictions on types of development which are particularly vulnerable to emergency response, for example, developments for aged care and schools.
- Restrictions on critical emergency response and recovery facilities and infrastructure. These aim to ensure that these facilities and the infrastructure can fulfil their emergency response and recovery functions during and after a flood event. Examples include evacuation centres and routes, hospitals and major utility facilities.

While typically this would lead to a recommendation to locate the abovementioned types of development off the floodplain (i.e. on land which lies above the Extreme Flood in the case of Wee Waa), this is not necessarily practical given there would be the potential for the upgraded Town Levee to be overtopped in an Extreme Event. Controls on this type of development should therefore be limited to a minimum floor level control above the peak 1% AEP local catchment flood event (in this case 0.5 m). An added requirement in the case of the Wee Waa District Health Service would be to provide rising pedestrian access to the crest of the Town Levee from the floor level of the main building.

3.5.1.3 Proposed Planning Controls

Figure 3.7 (2 sheets) is an extract from the *Flood Planning Map* covering the area which is bounded by the Town Levee, as well as the 228 ha area that lies to the south-east of Wee Waa which is zoned *R5 Large Lot Residential*. The extent of the FPA (the area subject to flood related development controls) is shown in a solid red colour in **Figure 3.7** and has been defined as land which lies at or below the 1% AEP plus 500 mm freeboard.[15,16]

It is proposed that properties intersected by the extent of the FPA would be subject to S10.7 flood affectation notification and planning controls graded according to flood. NSWG, 2005 suggests wording on S10.7 (2) Planning Certificates along the following lines:

> *"Council considers the land in question to be within the Flood Planning Area and therefore subject to flood related development controls. Information relating to this flood risk may be obtained from Council. Restrictions on development in relation to flooding apply to this land as set out in Council's Flood Policy which is available for inspection at Council offices or website."*

As the flooding internal to the Town Levee is of a low hazard ponding nature, controls applied to future development need only amount to a minimum floor level control which is equal to the height of the FPL shown on **Figure 3.7**.

In regards the 228 ha area which lies to the south-east of Wee Waa which is zoned *R5 Large Lot Residential*, it is recommended that Council consider rezoning the portion that is classified as either Floodway or High Hazard Flood Storage at the 1% AEP level of flooding (refer **Figure 2.23**, sheet 1) so as not to permit future residential and commercial type development. As the remainder of the area either lies above the 1% AEP flood level or is classified as Flood Fringe, then future development need only be subject to a minimum floor level control set equal to the FPL.

3.5.1.4 Revision of Narrabri LEP 2012 by Council

To improve Council's approach to floodplain risk management, clause 6.2 of *Narrabri LEP 2012* would require minor amendments, namely in regards the wording of sub clause (2) and (5). It is recommended that Council consider updating the wording in the existing clause 6.2 of *Narrabri LEP 2012* as follows:

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[15] When defining the extent of the FPA internal to the Town Levee, it has been assumed that the levee has been upgraded to provide a 1% AEP level of protection from Namoi River Flooding

[16] Internal to the Town Levee, the higher of the peak 1% AEP flood levels resulting from the 'penstock gates open' and the 'penstock gates closed and stormwater evacuation pumps operational' scenarios were adopted for setting the FPL's, while external to the Town Levee the higher of the 'present day' and 'raised rural levee' scenarios were adopted for setting the FPL's.

*"6.2 **Flood planning***

(1) The objectives of this clause are as follows:

(a) to minimise the flood risk to life and property associated with the use of land,

(b) to allow development on land that is compatible with the land's flood hazard, taking into account projected changes as a result of climate change,

(c) to avoid significant adverse impacts on flood behaviour and the environment.

(2) This clause applies to land at or below the flood planning level.

(3) Development consent must not be granted for development on land to which this clause applies unless the consent authority is satisfied that the development:

(a) is compatible with the flood hazard of the land, and

(b) will not significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and

(c) incorporates appropriate measures to manage risk to life from flood, and

(d) will not significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and

(e) is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

(4) A word or expression used in this clause has the same meaning as it has in the Floodplain Development Manual, unless it is otherwise defined in this Plan."

In order to support the proposed changes to clause 6.2 of *Narrabri LEP 2012*, it would be necessary to include the following definitions in the Dictionary:

- ***Flood planning level*** means the level of a 1% AEP (annual exceedance probability) flood event plus 0.5 metre freeboard, or other freeboard as determined by any floodplain risk management plan adopted by the Council in accordance with the Floodplain Development Manual.

- ***Floodplain Development Manual*** means Floodplain Development Manual (ISBN 0 7347 5476 0) published by the NSW Government in April 2005.

While not strictly relevant to Wee Waa, it is also recommended that Council consider incorporating a new floodplain risk management clause in *Narrabri* LEP *2012* as follows:

"Floodplain risk management

(1) The objectives of this clause are as follows:

(a) in relation to development with particular evacuation or emergency response issues, to enable evacuation of land subject to flooding in events exceeding the flood planning level,

(b) to protect the operational capacity of emergency response facilities and critical infrastructure during extreme flood events.

(2) This clause applies to land which lies between the flood planning level and the level of the probable maximum flood, but does not apply to land at or below the flood planning level.

(3) Development consent must not be granted to development for the following purposes on land to which this clause applies unless the consent authority is satisfied that the development will not, in flood events exceeding the flood planning level, affect the safe occupation of, and evacuation from, the land:

(a) child-based child care facility

(b) correctional centre

(c) educational establishment

(d) emergency services facility

(e) extractive industry

(f) group homes

(g) mining

(h) place of public worship

(i) residential care facilities

(j) respite day care centre

(k) senior housing

(l) tourist and visitor accommodation

(m) waste or resource management facility

(4) A word or expression used in this clause has the same meaning as it has in the Floodplain Development Manual, unless it is otherwise defined in this Plan."

In order to support the inclusion of the new clause in *Narrabri LEP 2012*, it would be necessary to include the following definitions in the Dictionary:

- ***probable maximum flood*** means the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation.

The steps involved in Council's amending *Narrabri LEP 2012* following the finalisation and adoption of the *LRMS&P* are:

1. Council Planning Staff consider the conclusions of the *LRMS&P* and suggested amendments to *Narrabri LEP 2012*.
2. Council resolves to amend *Narrabri LEP 2012* in accordance with the *LRMS&P*.
3. Council prepares a Planning Proposal in accordance with NSW Planning and Environment Guidelines. Planning Proposal submitted to NSW Planning and Environment in accordance with section 3.33 of the EP&A Act, 1979.
4. Planning Proposal considered by NSW Planning and Environment and determination made in accordance with section 3.34 of the EP&A Act, 1979 as follows:
   (a) whether the matter should proceed (with or without variation),
   (b) whether the matter should be resubmitted for any reason (including for further studies or other information, or for the revision of the planning proposal),
   (c) community consultation required before consideration is given to the making of the proposed instrument (the community consultation requirements),
   (d) any consultation required with State or Commonwealth public authorities that will or may be adversely affected by the proposed instrument,
   (e) whether a public hearing is to be held into the matter by the Planning Assessment Commission or other specified person or body,
   (f) the times within which the various stages of the procedure for the making of the proposed instrument are to be completed.
5. Planning Proposal exhibited for public comment.
6. Planning Proposal reviewed following public submissions and submissions from relevant State and Commonwealth authorities.
7. Final Local Environmental Plan with proposed amendments drafted.
8. Amending Local Environmental Plan made by the Minister and gazetted.

3.6 Response Modification Measures

3.6.1 Improvements to Flood Warning System

Improvements to the flood warning and response procedures were strongly favoured by the community during the consultation process. An effective flood warning system has three key components, i.e. a flood forecasting system, a flood warning broadcast system and a response/evacuation plan. All systems need to be underpinned by an appropriate public flood awareness program.

As mentioned in **Section 2.13**, BoM currently operates a well-established and proven flood warning system which provides predictions of gauge heights along the Namoi River, including at Wee Waa. BoM's system is based on the conversion of rainfalls recorded at telemetered gauges within the catchments to predicted peak flood levels at the gauges, which are updated and conveyed to NSW SES Local Units during a flood emergency. The flood warning system includes the Glencoe stream gauge.

To improve flood response it is recommended that the *Local Flood Plan* be updated (see **Section 3.6.2**) to provide the most up to date information on the nature of flooding at Wee Waa.

3.6.2 Improved Emergency Planning and Response

As mentioned in **Section 2.18**, the *Local Flood Plan* provides detailed information regarding preparedness measures, conduct of response operations and coordination of immediate recovery measures for all levels of flooding.

NSW SES should ensure information contained in this report on the impacts of flooding on urban development, as well as recommendations regarding flood warning and community education are used to update the *Narrabri Local Flood Plan*:

1 – The Flood Threat includes the following sub-sections:

1.1 Land Forms and River Systems – ref. **Sections 2.1** and **2.2** of the report for information on these topics.

1.4 Characteristics of Flooding – The elevation to which peak flood levels reach relative to the crest height of the Town Levee for floods ranging between 5% and 0.2% AEP, as well as the PMF is shows on **Figure 2.2**, while the indicative extent and depth of inundation both internal to the Town Levee for the assessed flood events are shown on **Figures 2.3** to **2.8**. **Figure 2.10** shows the rate of rise and duration of inundation at several locations along the roads which lead into Wee Waa. **Table 2.4** provides a comparison between historic and design peak heights on the Glencoe stream gauge, while **Table 2.8** summarises the impact Namoi River and Local Catchment Flooding has on vulnerable development and critical infrastructure at Wee Waa. The location of vulnerable development and critical infrastructure relative to the flood extents is shown on **Figure 2.11**.

1.5 Flood History – Recent flood experience at Wee Waa is discussed in **Section 2.4** of the report.

1.6 Flood Mitigation Systems – The Town Levee forms the major flood mitigation system at Wee Waa, a description of which is contained in **Section 2.3**.

1.7 Extreme Flood Events – An Extreme Flood on the Namoi River was modelled and the indicative extent and depth of inundation is presented on **Figure 2.8**. The Probable Maximum Flood was also assessed in order to define the upper limit of flooding internal to the Town Levee, the results of which are shown on **Figure 2.9**.

2 – Effects on the Community

The depth and extent of inundation in individual properties resulting from both a 1% AEP Namoi River and Local Catchment Flood are shown on **Figure 2.5**.

Table 2.7 gives the peak heights on the Glencoe stream gauge which correspond with the existing low points in the Town Levee, noting that these correspond with existing road and rail crossings.

Figure 2.10 shows stage hydrographs at several locations along the roads which lead into Wee Waa. The figure contains information such as the assessed minimum road/bridge level, times to peak flood levels, times to overtopping of the road crossing, and maximum depth of inundation. In addition to giving the maximum depth of inundation at the road locations shown on **Figure 2.10**, **Table 2.8** also gives the corresponding height on the Glencoe stream gauge when the road is first overtopped.

Figure 2.11 shows the location of vulnerable development and critical infrastructure at Wee Waa relative to the flood extents of the 5% and 1% AEP flood events, as well as the Extreme Flood/PMF. Refer **Section 2.6** and **Table 2.8** for details of affected infrastructure.

Figures 3.8 and **3.9** show the flood emergency response planning classifications for the 1% AEP and Extreme Flood/PMF events, respectively, based on the definitions set out in the *Floodplain Risk Management Guideline – Flood Emergency Response Classification of Communities* (DECC, 2007).[17]

At the 1% AEP level of flooding (refer **Figure 3.5**), areas internal to the Town Levee that are not classified as *Low Hazard Hydraulic Flooding* are classified as *Low Flood Island*. This is because in an overtopping event there would be insufficient high ground to which people could safely evacuate. This finding demonstrates that it would be necessary to evacuate Wee Waa if flood levels are predicted to exceed the crest height of the Town Levee.

3.6.3 Public Awareness Programs

Community awareness and appreciation of the existing flood hazards in the floodplain would promote proper land use and development in flood affected areas. A well informed community would be more receptive to requirements for flood proofing of buildings and general building and development controls imposed by Council. Council should also take advantage of the information on flooding presented in this report, including the flood mapping, to inform occupiers of the floodplains of the flood risk.

One aspect of a community's preparedness for flooding is the "flood awareness" of individuals. This includes awareness of the flood threat in their area and how to protect themselves against it. The overall level of flood awareness within the community tends to reduce with time, as memories fade and as residents move into and out of the floodplain. The improvements to flood warning arrangements described above, as well as the process of disseminating this information to the community, would represent a major opportunity for increasing flood awareness in Wee Waa.

Means by which community awareness of flood risks can be maintained or may be increased include:

- displays in Wee Waa using the information contained in the present study; and
- talks by NSW SES officers with participation by Council and longstanding residents with first-hand experience of flooding in the area.
- preparation of a *Flood Information Brochure* which could be prepared by Council with the assistance of NSW SES containing both general and site specific data and distributed with rate notices.

The community should also be made aware that a flood greater than historic levels or the planning level can, and will, occur at some time in the future.

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[17] Note that the flood emergency response planning classifications for the 1% AEP flood event are based on the envelope of ideal flow and partially blocked conditions, since either condition may arise during a major flood event.

As mentioned in **Section 3.6.1**, it is recommended that a community awareness programme be developed which specifically targets residents and business owners in Wee Waa. The community awareness program would be aimed at ensuring that residents and business owners are aware of the existing flood risk at Wee Waa and understand the need to respond to evacuation orders when issued by NSW SES.

4 SELECTION OF FLOODPLAIN MANAGEMENT MEASURES

4.1 Background

NSWG, 2005 requires a Council to develop a *LRMP* based on balancing the merits of social, environmental and economic considerations which are relevant to the community. This chapter sets out a range of factors which need to be taken into consideration when selecting the mix of works and measures that should be included in the *LRMP*.

The community will have different priorities and, therefore, each needs to establish its own set of considerations used to assess the merits of different measures. The considerations adopted by a community must, however, recognise the State Government's requirements for floodplain management as set out in NSWG, 2005 and other relevant policies. A further consideration is that some elements of the *LRMP* may be eligible for subsidy from State and Federal Government sources and the requirements for such funding must, therefore, be taken into account.

Typically, State and Federal Government funding is given on the basis of merit, as judged by a range of criteria:

- The magnitude of damage to property caused by flooding and the effectiveness of the measure in mitigating damage and reducing the flood risk to the community.
- Community involvement in the preparation of the *LRMP* and acceptance of the measure.
- The technical feasibility of the measure (relevant to structural works).
- Conformance of the measure with Council's planning objectives.
- Impacts of the measure on the environment.
- The economic justification, as measured by the benefit/cost ratio of the measure.
- The financial feasibility as gauged by Council's ability to meet its commitment to fund its part of the cost.
- The performance of the measure in the event of a flood greater than the design event.
- Conformance of the measure with Government Policies (e.g. NSWG, 2005 and Catchment Management objectives).

4.2 Ranking of Measures

A suggested approach to assessing the merits of various measures is to use a subjective scoring system. The chief merits of such a system are that it allows comparisons to be made between alternatives using a common "currency". In addition, it makes the assessment of alternatives "transparent" (i.e. all important factors are included in the analysis). The system does not, however, provide an absolute "right" answer as to what should be included in the *LRMP* and what should be left out. Rather, it provides a method by which Council can re-examine the measures and if necessary, debate the relative scoring given to aspects of the *LRMP*.

Each measure is given a score according to how well the measure meets the considerations discussed above. In order to keep the scoring simple, the following system is proposed:

+2	Measure rates very highly
+1	Measure rates well
0	Measure is neutral
- 1	Measure rates poorly
- 2	Measure rates very poorly

The scores are added to get a total for each measure.

Based on considerations outlined in this chapter, **Table 4.1** presents a suggested scoring matrix for the measures reviewed in **Chapter 3** at Wee Waa. This scoring has been used as the basis for prioritising the components of the *LRMP*.

4.3 Summary

Table 4.1 indicates that there are good reasons to consider including the following elements into the draft *LRMP*:

- Planning controls for future development in Wee Waa.
- An update of the *Narrabri LEP 2012* to allow better management of the floodplain
- Incorporation of the catchment specific information on flooding impacts contained in this Study in NSW SES Response Planning and Flood Awareness documentation for the study area.
- Improved public awareness of flood risk in the community.
- Upgrade of the Town Levee

TABLE 4.1
ASSESSMENT OF POTENTIAL FLOODPLAIN MANAGEMENT MEASURES FOR INCLUSION IN THE FLOODPLAIN RISK MANAGEMENT PLAN

Measure	Impact on Flooding/ Reduction in Flood Risk	Community Acceptance	Technical Feasibility	Planning Objectives	Environ. Impacts	Economic Justification	Financial Feasibility	Extreme Flood	Government Policies and TCM Objectives	Score
Flood Modification										
Upgrade of the Town Levee	+2	+2	+2	+2	0	-2	-1	0	+2	+7
Stormwater Upgrade Scheme 1	+1	+2	+1	0	0	-2	0	0	0	+3
Stormwater Upgrade Scheme 2	+1	+2	+1	0	0	-2	0	0	0	+3
Stormwater Upgrade Scheme 3	+1	+2	+1	0	0	-2	0	0	+2	+3
Property Modification										
Controls over Future Development	+2	+2	+2	+2	0	0	0	+1	+2	+11
Response Modification										
Improved Emergency Planning and Response	+2	+2	+2	+1	0	0	0	+2	+2	+11
Public Awareness Programs	+1	+2	+2	+1	0	0	0	+1	+2	+9

5 DRAFT LEVEE RISK MANAGEMENT PLAN

5.1 The Floodplain Risk Management Process

The *Levee Risk Management Study (**LRMS**)* and draft *Levee Risk Management Plan* (***LRMP***) have been prepared for Wee Waa as part of a Government program to mitigate the impacts of major floods and reduce the hazards in the floodplain. The *LRMP* which is set out in this Chapter has been prepared as part of the Floodplain Risk Management Process in accordance with NSW Government's Flood Prone Land Policy.

The first steps in the process of preparing the *LRMP* were the collection of flood data and the review and update of the flood modelling which was originally undertaken as part of the *Wee Waa Levee Flood Investigation* (URS, 2015) (***Flood Study***). The updated flood modelling for Wee Waa formed the formal starting process of defining management measures for flood liable land and represented a detailed technical investigation of flood behaviour for Wee Waa.

5.2 Purpose of the Plan

The overall objectives of the *LRMS* were to assess the impacts of flooding, review policies and measures for management of flood affected land and to develop a *LRMP* which:

- Sets out the recommended program of works and measures aimed at reducing over time, the social, environmental and economic impacts of flooding and establishes a program and funding mechanism for the *LRMP*.
- Proposes amendments to Narrabri Shire Council's (**Council's**) existing policies to ensure that the future development of flood affected land at Wee Waa is undertaken so as to be compatible with the flood hazard and risk.
- Ensures that the *LRMP* is consistent with NSW SES's local emergency response planning procedures.
- Ensures that the *LRMP* has the support of the community.

5.3 The Study Area

The study area for this *LRMP* comprises the town of Wee Waa and its immediate environs. The *LRMP* applies to the urbanised parts of Wee Waa that are protected by an existing earthen ring levee (Town Levee), as well as a 228 ha area which lies to the south-east of the town which is zoned *R5 Large Lot Residential*.

5.4 Community Consultation

The Community Consultation process provided valuable direction over the course of the investigations, bringing together views from key Council staff, other departments and agencies, and importantly, the views of the community gained through:

- the delivery of a *Community Newsletter* and *Community Questionnaire* to property occupiers located in the floodplain which allowed the wider community to gain an understanding of the issues being addressed as part of the study; and
- meetings of the Floodplain Risk Management Committee to discuss results as they became available.

The views of the community on potential flood management measures to be considered in the study were also taken into account in the assessment presented in **Chapter 3** of the report, with supporting information in **Appendix A**.

5.5 Town Levee

The Town Levee, the alignment of which is shown on **Figure 2.1**, was constructed in response to the damaging flooding that was experienced in Wee Waa as a result of the February 1971 flood. The Town Levee, which is about 8.6 km in length, is an earth embankment which generally varies in height between about 2 m and 4 m. **Figure 2.2** is a long section showing the elevation of the Town Levee relative to the adjacent floodplain.

There are fourteen penstock gated stormwater drainage pipes and six stormwater evacuation pumps located around the perimeter of the Town Levee, the locations of which are shown on **Figure 2.1**, sheet 2. These pipes allow stormwater runoff which is generated internal to the Town Levee to discharge to the Namoi River floodplain.

The Town Levee was originally designed to protect against a February 1971 type flood event and incorporated a 1 m freeboard to peak flood levels that were recorded at the time of the event. While a design was prepared in 1992 which was aimed at reinstating the design freeboard to February 1971 flood levels, there are no records of this work having been completed. By inspection of **Figure 2.2**, there is a 1 km long section between about Chainage 3500 and Chainage 4500 which lies below the original design height of the Town Levee.

A geotechnical investigation was undertaken as part of the present study, the findings of which are set out in a letter style report, a copy of which is contained in **Appendix B**. The geotechnical investigation, which comprised a review of the available documentation and a visual inspection of the Town Levee found that the embankment was generally in good condition, with only a few minor defects/aspects requiring rectification.

The Imminent Failure Flood (**IFF**) of the Town Levee is slightly smaller than the February 1971 flood and corresponds with a flood with an Annual Exceedance Probability (**AEP**) of about 5 per cent. The prediction of a flood higher than the IFF would trigger the evacuation of Wee Waa, as NSW SES would have deemed the Town Levee to be at significant risk of failure.

The present study found that the available freeboard between the crest of the Town Levee and a 1% AEP Namoi River flood is a minimum of about 0.5 m, reducing to less than 0.3 m if the surrounding network of rural levees were to be raised in the future. While there is some freeboard to the crest of the Town Levee, it is likely that it would be overtopped at the 1% AEP level of flooding due to wave set up and run up, albeit to an extent that would likely not inundate the whole of the town. The present study confirmed that the design freeboard for the Town Levee should be 1 m (refer **Appendix E** for details). This accounts for factors such as wave action, local water surge, inaccuracies in the design flood level estimates, levee settlement, defects in the levee and future climate change.

5.6 Indicative Flood Extents

Figures 2.3 to **2.8** show the indicative extent and depths of inundation on the Namoi River floodplain for floods with AEPs of between 5 and 0.2%, as well as the Extreme Flood. The figures also show the indicative extent and depths of inundation that would result from direct rain falling over Wee Waa with the same AEP. For presentation purposes, it has been assumed that the aforementioned penstock gates are in their closed positon and floodwater cannot backwater into town in the case of Namoi River flooding. Conversely, in the case of local catchment flooding, it has been assumed that river levels are not elevated and the penstock gates are in their open position.

The 1% AEP design flood which has been adopted as the "planning flood" for the purposes of specifying flood related controls over future development. The extent of flooding is indicative only, being based on hydrologic and hydraulic models that were developed as part of the present study.

5.7 Economic Impacts of Flooding

Flood damages in Wee Waa were assessed for the following five scenarios:

- No river flooding and gravity drainage of the protected area via the fourteen penstock gated stormwater drainage pipes that control ponding levels behind the Town Levee (**Damage Scenario 1**).
- Pumping of stormwater runoff to the Namoi River floodplain via the six permeant stormwater evacuation pumps and assuming the fourteen penstock gates are in their closed position and the Town Levee is not overtopped (**Damage Scenario 2**).
- Failure of the six permanent stormwater evacuation pumps to operate during a storm event and assuming the fourteen penstock gates are in their closed position and the Town Levee is not overtopped (**Damage Scenario 3**).

Damage due to riverine flooding

- No coincident rainfall over Wee Waa during a Namoi River Flood (**Damage Scenario 4**).
- No coincident rainfall over Wee Waa during a Namoi River Flood that causes a partial failure of the Town Levee (**Damage Scenario 5**).

Table 5.1 over shows the number of properties that would be flooded to above-floor level for the various classes of property in Wee Waa, as well as the total flood damages for the five damage scenarios.

It is estimated that only one dwelling and one commercial/industrial property would experience above-floor inundation should a 1% AEP storm event occur over Wee Waa during a period when the flood gates are open. The fact that there are only two properties that would experience above-floor flooding due to local catchment runoff for storms up to 1% AEP in intensity probably dates back to the pre-Town Levee era, when buildings would have been built off the ground to reduce the likelihood that they would be inundated by riverine flooding. While a large number of respondents to the questionnaire were in favour of upgrading the local stormwater drainage system, this finding indicates that the issue is likely related more to nuisance flooding, rather than damaging above-floor flooding.

While the number of properties that would experience above-floor flooding should a 1% AEP storm occur over Wee Waa when the penstock gates are closed would increase slightly, should the six stormwater evacuation pumps fail or not be started up during a storm of this intensity the total number of properties that would experience above-floor inundation would increase to about 30 properties (15 dwellings and 15 commercial/industrial buildings).

The "present worth value" of damages in Wee Waa resulting from rain falling directly over Wee Waa up to the 1% AEP event assuming the stormwater evacuation pumps are operational is $0.4 Million. This value represents the amount of capital spending which would be justified if a particular stormwater drainage upgrade scheme prevented flooding for all properties in Wee Waa up to this event.

TABLE 5.1
ECONOMIC IMPACTS OF FLOODING AT WEE WAA

Design Flood Event (% AEP)	No. of Flood Damaged Properties															Total Damage ($ Million)				
	Residential					Commercial/Industrial					Public									
	DS1	DS2	DS1	DS4	DS5	DS1	DS2	DS1	DS4	DS5	DS1	DS2	DS1	DS4	DS5	DS1	DS2	DS1	DS4	DS5
5	1	1	2	0	560	0	0	3	0	123	0	0	0	0	29	0.39	0.40	0.9	0	109.9
2	1	1	6	0	585	0	2	9	0	126	0	0	0	0	30	0.45	0.56	1.53	0	114.6
1	1	4	15	0	595	1	3	15	0	126	0	0	0	0	32	0.58	0.90	2.43	0	116.5
0.5	2	6	19	0	596	2	7	17	0	126	0	0	0	0	32	0.76	1.36	3.94	0	116.8
0.2	6	14	25	0	601	7	14	21	0	129	0	0	0	0	33	1.51	2.50	6.54	0	118.1
Extreme Flood/PMF	119	137	137	696	696	46	48	48	135	135	10	13	13	42	42	22.29	26.14	26.14	163.3	163.3

1. DS1 – Damage Scenario 1 DS2 – Damage Scenario 2 DS3 – Damage Scenario 3 DS4 – Damage Scenario 4 DS5 – Damage Scenario 5

Once major overtopping of the Town Levee occurs, all but a small number of buildings would experience above-floor inundation. A similar situation would arise were the Town Levee to partially fail during a flood. The total damages in Wee Waa were the Town Levee to either be overtopped or fail during a major flood event is estimated to be about $117 Million. The present worth value of damages under a Town Levee failure scenario (i.e. Damage Scenario 5) is about $100 Million. This is the amount that could be spent upgrading the Town Levee to ensure that it is geotechnically stable, free of defects and arguably incorporates the required 1 m freeboard to the 1% AEP flood.

5.8 Structure of Floodplain Risk Management Study and Plan

The *LRMS* and *LRMP* are supported by Appendices which provide additional details of the investigations. A summary of the *LRMP* proposed for the study area along with broad funding requirements for the recommended measures are shown in **Table 5.2**. These measures comprise preparation of planning documentation by Council, improvements to the flood warning system and community education on flooding by Council and NSW SES to improve flood awareness and response, and the upgrade of the Town Levee to increase its design standard to 1% AEP. The measures will over time achieve the objectives of reducing the flood risk to existing and future development for the full range of floods.

The *LRMP* is based on a mix of measures which have been given a provisional priority ranking according to a range of economic, social, environmental and other criteria set out in **Table 4.1** of the report:

TABLE5.2
MEASURES COMPRISING THE WEE WAA FLOODPLAIN RISK MANAGEMENT PLAN

Measure	Required Funding	Priority
Measure 1 - Planning and development controls for future development in flood prone areas	Council staff costs	1[(1)]
Measure 2 – Update wording in *Narrabri LEP 2012*	Council's staff costs	1
Measure 3 – Improvements to emergency response planning	NSW SES costs	1
Measure 4 – Increase public awareness of the risks of flooding in the community	Council staff costs	1
Measure 5 – Investigation and concept design of Town Levee upgrade works	$350,000	1
Measure 6 – Detailed design and construction of Town Levee upgrade works	$7.2 Million	2[(2)]

1. Only controls on development other than residential type development could be implemented in the short-term, as the Town Levee would need to be upgraded before minimum floor levels for residential type development could be set below the peak 1% AEP Namoi River flood level plus an allowance of 500 mm freeboard.
2. Because of its medium to long term nature, this measure has been given a **Priority 2** ranking.

5.9 Planning and Development Controls

The results of the *LRMS* indicate that an important measure (**Measure 1**) for Council to consider adopting in the floodplain would be strong floodplain management planning applied consistently by all branches of Council.

The key issue for Wee Waa is that given the design standard of the Town Levee is less than 1% AEP, Council's current planning documents, namely the *Interim Floodplain Management Policy* referred to in Council's *Exempt & Complying Development DCP* is inconsistent with the NSW Government's Section 9.1, as it allows development to occur below the 1% AEP plus an appropriate freeboard (which in areas subject to riverine flooding is generally set at 0.5 m).

As it is not practical to set the floor levels of residential type development in Wee Waa above the peak 1% AEP Namoi River flood level (i.e. because the floor level of most dwellings would need to be set more than 1.5 m above natural ground levels), it is recommended that Council consider that this type of development should only proceed if the design standard of the Town Levee is upgraded to 1% AEP. This would require the crest of the Town Levee to be raised to a height of no less than 1 m above the peak 1% AEP Namoi River flood level.

Should the Town Levee be upgraded to a 1% AEP standard, then it is recommended that Council consider that the controls that would need to be applied to future residential type development would amount to a minimum floor level control which is equal to the Flood Planning Level (**FPL**).[18] Note that the FPL would be based on depths of inundation resulting from runoff that is generated internal to the Town Levee, not Namoi River flooding. **Figure 3.7**, sheet 1 shows the extent of the Flood Planning Area (**FPA**)[19] under post-Town Levee upgrade conditions, as well as the corresponding FPLs.

In regards the 228 ha area which lies to the south-east of Wee Waa which is zoned *R5 Large Lot Residential*, it is recommended that Council consider rezoning the portion that is classified as either *Floodway* or *High Hazard Flood Storage* at the 1% AEP level of flooding (refer **Figure 2.23**, sheet 1) so as not to permit future residential and commercial type development. As the remainder of the area either lies above the 1% AEP flood level or is classified as *Flood Fringe*, then future development located within the extent of the FPA need only be subject to a minimum floor level control set equal to the FPL. **Figure 3.7**, sheet 2 shows the extent of the FPA in this area, as well as the corresponding FPLs.

Measure 2 recommends that Council consider updating the wording in the *Narrabri LEP 2012* concerning flood planning. Clause 6.2 of *Narrabri LEP 2012* entitled "Flood planning" outlines its objectives in regard to development of flood prone land. It is similar to the standard Flood Planning Clause used in recently adopted LEPs in other NSW country centres and applies to land at or below the Flood Planning Level (**FPL**). The FPL referred to is the 1% AEP flood plus an allowance for freeboard of 500 mm. The area encompassed by the FPL is known as the FPA and denotes the area subject to flood related development controls, such as setting minimum floor levels for future residential development. Suggested amendments to Clause 6.2 of *Narrabri LEP 2012* are given in **Section 3.5.1.4**.

While not strictly relevant to Wee Waa, it is also recommended that Council consider incorporating a new floodplain risk management clause in *Narrabri LEP 2012*. The objectives of the new clause are as follows:

- in relation to development with particular evacuation or emergency response issues (e.g. group homes, residential care facilities, etc.) to enable evacuation of land subject to flooding in events exceeding the flood planning level; and

[18] The FPL is defined as the peak 1% AEP flood level plus an allowance of 500 mm for freeboard.
[19] The FPA is defined as land that lies at or below the FPL.

- to protect the operational capacity of emergency response facilities and critical infrastructure during extreme flood events.

The new clause would apply to land which lies between the FPA and the extent of the Extreme or Probable Maximum Flood. Suggested wording in relation to this new clause is given in **Section 3.5.1.4**.

5.10 Improvements to Flood Warning, Emergency Response Planning and Community Awareness

Two measures are proposed in the *LRMP* to improve flood warning, emergency response planning and community awareness to the threat posed by flooding.

Measure 3 involves the update by NSW SES of the *Narrabri Shire Local Flood Plan* using information on flooding patterns, times of rise of floodwaters and flood prone areas identified in this report. Figures have been prepared showing indicative extents of flooding, high hazard areas, expected rates of rise of floodwaters in key areas and locations where flooding problems would be expected. **Section 3.6.2** references the locations of key data within this report.

Council should also take advantage of the information on flooding presented in this report, including the flood mapping, to inform occupiers of the floodplains of the flood risk (included as **Measure 4** of the *LRMP*). This information could be included in a *Flood Information Brochure* to be prepared by Council with the assistance of NSW SES containing both general and site specific data and distributed with the rate notices. The community should also be made aware that a flood greater than historic levels or the planning level can, and will, occur at some time in the future. The *LRMP* should be publicised and exhibited at community gathering places to make residents aware of the measures being proposed.

5.11 Flood Modification Works

While the present study found that the design standard of the Town Levee is equivalent to about a 5% AEP flood, the earth embankment is generally in good condition and therefore is unlikely to fail unless major overtopping occurs. While wind and wave action could result in minor overtopping of the Town Levee during larger floods, it is estimated that major overtopping would only occur during floods with AEPs less than about 0.1 per cent.

While it is only under a levee failure or a major overtopping scenario that the upgrade of the Town Levee can be justified economically (the resulting benefit cost ratio is 13), there are two significant social reasons supporting its upgrade. These are:

i) As mentioned in **Section 5.9**, the minimum floor level requirements for future development in Wee Waa should, contrary to Council's current planning documents, be set equal to the peak 1% AEP Namoi River flood level plus an allowance of 500 mm for freeboard. As this in impractical given the height to which future development would need to be built above natural ground level, there is a need to upgrade the design standard of the Town Levee to 1% AEP so that future development can be set closer to the ground.

ii) The Imminent Failure Flood (**IFF**) for a flood protection levee is equal to its design standard, which in the case of the Town Levee is 5% AEP. During larger flood events, NSW SES would need to evacuate the town as the Town Levee would be deemed to be at significant risk of failure. As identified in the *Narrabri Shire Local Flood Plan* and confirmed by the present study, the local road network which is relied upon for flood evacuation purposes would be inundated by floods that are more frequent than 5% AEP. As a result, it would be necessary to evacuate the whole of Wee Waa should a flood larger than 5% AEP be predicted at the town. As not everyone would self-evacuate in a flood emergency, NSW SES would be forced to air lift those people that remained. As the area internal to the Town Levee is classified as a Low Flood Island, there is insufficient high ground available for people to safely reside while awaiting to be evacuated in the case of a very rare or extreme flood event.

For these reasons there is merit in upgrading the Town Levee to incorporate a 1 m freeboard to peak 1% AEP Namoi River flood levels. **Figure 3.1** shows the sections of the Town Levee which would need to be raised, while **Figure 3.2** shows a typical section of the upgrade requirements. Further details of the upgrade requirements are shown on **Figures F1.1** (7 sheets) and **F1.2** (10 sheets) in **Appendix F**. The capital cost associated with upgrading the Town Levee is estimated to be $7.55 Million, which includes investigation and design. A breakdown of the cost to design and construct the Town Levee upgrade works is given in **Table 3.2**.

The investigation and concept design of the Town Levee upgrade works has been included as **Measure 5**, while its detailed design and construction has been included as **Measure 6** in the LRMP.

While the present study showed that upgrading the existing stormwater drainage system would have a beneficial effect on reducing nuisance flooding in parts of Wee Waa, improvements to the existing drainage system cannot be economically justified given the relatively small flood damages that would be saved by implementing the works. The flooding that occurs internal to the Town Levee is also of a low hazard nature given its relatively shallow and slow moving nature. This also means that the upgrade of the stormwater drainage system at Wee Waa, while beneficial to affected land owners, would not rank highly when competing for funds under the NSW Government's floodplain management program.

5.12 Mitigating Effects of Future Development

While there is presently limited pressure for new development to occur in Wee Waa, it will be necessary for Council to consider the implications the introduction of new hard stand and roof areas would have on internal drainage patterns, as well as the pump capacity requirements of the six stormwater evacuation pumps which are located around the perimeter of the Town Levee when assessing future development applications.

5.13 Implementation Program

The steps in progressing the floodplain management process from this point onwards are:

1. Floodplain Risk Management Committee to consider and adopt recommendations of this study. In particular, the Committee should review the basis for ranking floodplain management measures (as set out in **Table 4.1** of the *LRMS* and the proposed works and measures to be included in the *LRMP* as set out in **Table 5.2**); exhibit the *draft LRMS* and *LRMP* and seek community comment.
2. Consider public comment, modify the document if and as required, and submit to Council.
3. Council adopts the *LRMP* and submits application(s) for funding assistance in the next funding round for qualifying projects. Assistance for funding qualifying projects included in the *LRMP* may be available upon application under the Commonwealth and State funded floodplain management programs, currently administered by NSW Department of Planning, Industry and Environment.

4. As funds become available from Government agencies and/or Council's own resources, implement the measures in accordance with the established priorities.

The *LRMP* should be regarded as a dynamic instrument requiring review and modification over time. The catalysts for change could include new flood events and experiences, legislative change, alterations in the availability of funding, reviews of Council's planning strategies and importantly, the outcome of some of the studies proposed in this report as part of the *LRMP*. In any event, a thorough review every five years is warranted to ensure the ongoing relevance of the *LRMP*.

6 GLOSSARY OF TERMS

Note: For expanded list of definitions, refer to Glossary contained within the NSW Government Floodplain Development Manual, 2005.

TERM	DEFINITION
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, for a flood magnitude having five per cent AEP, there is a five per cent probability that there would be floods of greater magnitude each year.
Australian Height Datum (AHD)	A common national surface level datum corresponding approximately to mean sea level.
Extreme Flood	An extremely rare event analogous to the PMF, which in the case of the present study is assumed to have a peak flow 3 times the 1% AEP flood event.
Flood Frequency Analysis	A statistical methodology to estimate peak flood levels and discharge of design flood events based on a record of historic flood data.
Floodplain	Area of land which is subject to inundation by floods up to and including the Probable Maximum Flood (**PMF**) event, that is, flood prone land.
Flood Planning Area	The area of land that is shown to be in the Flood Planning Area on the *Flood Planning Map*. The Flood Planning Area is the area of land which lies at or below the Flood Planning Level.
Flood Planning Map	The *Flood Planning Map* shows the extent of land on which flood related development controls apply, extracts of which is shown on **Figure 3.7** (2 sheets).
Flood Planning Level (FPL)	The combinations of flood levels and freeboards selected for planning purposes, as determined in floodplain risk management studies and incorporated in floodplain risk management plans. For land within the Flood Planning Area at Wee Waa, the Flood Planning Level (**FPL**) is the level of the 1% Annual Exceedance Probability (**AEP**) flood event plus 500 mm freeboard.
Flood Prone/Flood Liable Land	Land susceptible to flooding by either the Extreme Flood in the case of riverine type flooding or the PMF in the case of local catchment flooding at Wee Waa. Flood Prone land is synonymous with Flood Liable land.
Floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Flood Storage Area	Those parts of the floodplain that may be important for the temporary storage of floodwaters during the passage of a flood. Loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding a particular flood chosen as the basis for the FPL and setting minimum floor level requirements 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 derivation of the FPL and the setting of minimum floor level requirements.

TERM	DEFINITION
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location. 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. For the study area, the extent of the PMF has been trimmed to include depths greater than 100 mm.

7 REFERENCES

BoM (Bureau of Meteorology), 2003. ***"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"***.

DECCW (Department of Environment, Climate Change and Water, NSW), 2007. ***"Floodplain Risk Management Guideline – Flood Emergency Response Classification of Communities"***.

DECCW (Department of Environment, Climate Change and Water, NSW), 2007. ***"Floodplain Risk Management Guideline – Practical Considerations of Climate Change"***.

DECCW (Department of Environment, Climate Change and Water, NSW), 2008. ***"Floodplain Risk Management Guideline No 4. Residential Flood Damage Calculation"***.

DIPNR (Department of Infrastructure, Planning & Natural Resources), 2003. ***"Narrabri – Wee Waa Flood Study"***

DNR (Department of Natural Resources), 2005. ***"Narrabri-Wee Waa Floodplain Management Plan"***

EA (Engineers Australia), 2013. **"Project 11 – Blockage of Hydraulic Structures – Stage 2 Report"**

Howells et al, 2004. ***"Defining the Floodway - Can One Size Fit All?"*** FMA NSW Annual Conference, Coffs Harbour, February 2004.

IEAust (The Institution of Engineers Australia), 1987. ***"Australian Rainfall and Runoff – A Guide to Flood Estimation"***, Volumes 1 and 2.

NSWG (New South Wales Government), 2005. ***"Floodplain Development Manual: the Management of Flood Liable Land"***.

NSW SES (NSW State Emergency Service), 2015. ***"Narrabri Shire Local Flood Plan"***

PW (Public Works), 1992. ***"Audit of Flood Levees for New South Wales – Town of Wee Waa"***

URS, 2015. ***"Wee Waa Levee Flood Investigation"***

WRM (WRM Water & Environment), 2016. ***"Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully"***

APPENDIX A

COMMUNITY CONSULTATION

TABLE OF CONTENTS

ATTACHMENTS

A1. INTRODUCTION

At the commencement of the *LRMS,* the Consultants prepared a *Community Newsletter* and a *Community Questionnaire*, both of which were distributed by Council to the residents and business owners in Wee Waa (refer to **Attachment 1**).

The purpose of the *Community Newsletter* was to introduce the objectives of the study and set the scene on flooding conditions so that the community would be better able to respond to the *Community Questionnaire* and contribute to the study process.

The *Newsletter* contained the following information:

- A plan showing the layout of the existing levee and stormwater drainage system at Wee Waa.
- A statement of the objectives of the *LRMS&P*; namely to assess the requirements for the upgrade of the existing levee in order to ensure that it will protect the town from floods up to the 1% AEP flood event.

The *Community Questionnaire* was structured with the objectives of:

- Obtaining local information on flood experience and behaviour at residents' and business owners' properties.
- Determining residents' and business owners' attitudes to controls over future development in flood liable areas.
- Inviting community views on possible flood management options which could be considered for further investigation in the *LRMS* and possible inclusion in the resulting *LRMP*.
- Obtaining feedback on any other flood related issues and concerns which the residents and business owners cared to raise.

This **Appendix** to the *LRMS&P* report discusses the responses to the 13 questions that were included in the *Community Questionnaire* and comments made by respondents.

Chapter A2 deals with the residents' and business owners' experience with historic flooding, as well as determining their views on the relative importance of classes of development over which flood-related controls should be imposed by Council.

Chapter A3 identifies residents' and business owners' views on the suitability of the various options which could be considered in more detail in the *LRMS*.

Chapter A4 discusses the best methods by which the community could provide feedback to the consultants over the course of the study.

Chapter A5 summarises the findings of the community consultation process.

A2 RESIDENT PROFILE AND FLOOD AWARENESS

A2.1 General

Residents were requested to complete the *Community Questionnaire* and return it to the Consultants by 23 December 2016. The deadline was extended to include any submissions that were received after this date. The Consultants received 59 responses in total out of the 850 that had been distributed.[1]

The Consultants have collated the responses, which are shown in graphical format in **Attachment 2**.

A2.2 Experiences of Flooding

The first four questions of the *Community Questionnaire* canvassed resident information such as length of time at the property, the type of property (e.g. house, unit/flat), whether the respondent had any experience of flooding and if so which particular flood. Of those who replied to the question, nine respondents had lived in Wee Waa for less than 5 years, twenty-one respondents had lived there for between 5 and 20 years and twenty-eight for more than 20 years (**Question 2**).

Forty-six respondents occupied a house, three respondents occupied a unit/flat and five respondents owned a shop / retail property (**Question 3**). Three respondents occupied an industrial unit in a larger complex, while five respondents owned a standalone warehouse or factory.

In response to **Question 4**, thirteen respondents reported that they had experienced flooding on their property. Flooding was reported at respondents properties during flood events that occurred prior to the construction of the levee in 1955 (two), 1970 (one), 1971 (six), 1974 (five) and 1976 (three). Two respondents reported flooding on their property in flood events that occurred after the construction of the levee (1986 and 2011/2012). As the levee did not overtop in these years, the respondents are likely referring to local stormwater issues.

A2.3 Controls over Development in Flood Prone Areas

The respondents were also asked to rank from 1 to 6 the classes of development which they consider should receive protection from flooding (**Question 5**). Rank 1 was the most important and rank 6 the least.

The classes in decreasing order of importance to respondents, ranged from residential property, critical utilities (e.g. medical facilities, emergency services), essential community facilities (e.g. schools, evacuation centres), commercial/business, new residential subdivisions and lastly, minor developments/additions to existing buildings.

[1] Note that two of the respondents were both a resident and business owner in Wee Waa, while one respondent was a caretaker of the property.

Respondents were asked in **Question 6** about the level of control Council should place on new development to minimise flood-related risks. The most popular response (twenty-two) was to advise of the flood risks, but allow the individual the choice as to whether they develop or not provided they take steps to minimise the potential flood risks. The next most favoured responses were placing restrictions on developments to reduce the potential for flood damage (e.g. minimum floor level controls or the use of compatible building materials) (fifteen) and prohibiting all new development only in those locations that would be extremely hazardous to persons or property due to the depth and/or velocity of floodwaters, or evacuation difficulties (thirteen). Eleven respondents felt that Council should prohibit all development on land with any potential to flood.

In **Question 7**, respondents were asked what notifications Council should give about the flood affectation of individual properties. The community was strongly in favour of advising existing residents and prospective purchasers of the known potential flood threat, with only two residents not in favour of providing flood related notifications.

A2.3 Home and Contents Insurance

Respondents were asked in **Question 8** if they currently maintain a home and contents insurance policy on their property, and what the annual premium was. Thirty-four respondents currently maintain building and contents insurance, while seven maintain building-only insurance and eleven maintain contents-only insurance. The annual premium range generally range between $500 and $5000.

In **Question 9**, respondents were asked if their home and contents insurance premiums had increased significantly in the last few years (since adoption of URS, 2015), and if so, by how much. Of the fifty-two respondents that currently maintain building and/or contents insurance, forty-two have experienced an increase in their premiums in recent years. Their premiums generally increased by less than $1,000.

It was noted that seven of the respondents to the questionnaire are not covered for flood as part of the insurance policy as the insurance company will not cover them or the costs were too high (one respondent’s insurer quoted an additional $4,000 for flood insurance). Two respondents do not have building and contents insurance due to the cost of flood cover.

It is noted that one respondent’s insurance premiums reduced by $2,000 between 2013 and 2016.

A3 INPUT TO THE STUDY AND FEEDBACK FROM THE COMMUNITY

In **Question 10,** residents were asked for their view on the best methods of their providing input to the study and feedback to the Consultants over the course of the investigation. Articles in the local newspaper was the most popular method, followed by communication via Council's website and public meetings. Other suggestions raised by respondents included a letter drop (similar to the *Community Newsletter* and *Community Questionnaire* distributed as part of the present investigation), and announcements on local radio and Council's Facebook page as methods of community engagement.

A4 POTENTIAL FLOOD MANAGEMENT MEASURES

The respondents were asked for their opinion on potential flood management measures which could be evaluated in the *LRMS* (and if found to be feasible included in the *LRMP*), by ticking a "yes" or "no" to the thirteen potential options identified in **Question 13**.

The options comprised a range of *structural flood management measures* (e.g. programs by Council to manage vegetation in the creek system to maintain hydraulic capacity; improving the stormwater system; levees to contain floodwaters; widening of watercourses; removal of floodplain obstructions), as well as various *non-structural management measures* (e.g. voluntary purchase of residential properties in high hazard areas; raising floor levels of houses in low hazard areas; flood related controls over new developments; improvements to flood warning and evacuation procedures; community education on flooding; flood advice certificates). The options were not mutually exclusive, as the adopted *LRMP* could, in theory, include all of the options set out in the *Community Questionnaire*, or indeed, other measures nominated by the respondents or the FRMC.

The most popular structural measures was the raising of the existing ring levee and the improvement of the internal drainage system within the town.

Of the non-structural measures, improvement of flood warning and evacuation procedures and community flood awareness programs received the strongest support, followed by provision of a Planning Certificate to purchasers in flood prone areas. Other popular measures included specifying controls on future development in flood-prone areas.

A mostly negative response was given to the temporary raising of the ring levee during times of flood and removal of floodplain obstructions. Providing subsidies for raising the floor level of properties and the implementation of a residential Voluntary Purchase scheme were also unpopular.

A5 SUMMARY

Fifty-nine responses were received to the *Community Questionnaire* which was distributed by Council to residents and business owners. The responses amounted to about seven per cent of the total distributed. About twenty per cent of respondents had experienced flooding at their property prior to the construction of the ring levee in the early 1980's.

A5.1 Issues

The issues identified by the responses to the *Community Questionnaire* support the objectives of the study as nominated in the attached *Community Newsletter,* and the activities nominated in the Study Brief. There was strong support amongst the community for raising the existing ring levee.

The main issue facing the community was increased insurance premiums relating to flood insurance. A number of respondents identified that insurance costs had increased by up to $4,000 in recent years, and seven respondents had to forego flood insurance due to the increase in costs.

A5.2 Flood Management Measures

Of the *structural measures* which could be incorporated in the *LRMP*, the most popular were raising the existing ring levee and the improvement to the internal drainage system within the town.

Improvements to flood warning and emergency management measures and community flood awareness programs appeared to be the most popular of the potential *non-structural measures* set out in the *Community Questionnaire*. Planning controls and providing Planning Certificates were also widely popular. There does not appear to be any new measures raised by the respondents.

ATTACHMENT 1

COMMUNITY NEWSLETTER AND QUESTIONNAIRE

WEE WAA LEVEE
RISK MANAGEMENT STUDY &
DRAFT PLAN

COMMUNITY QUESTIONAIRE

This Questionnaire is part of the *Wee Waa Levee Risk Management Study and Draft Plan*, which is currently being prepared by Narrabri Shire Council with the financial and technical support of the NSW Office of Environment & Heritage. Your responses to the questionnaire will help us determine the flood issues that are important to you.

Please return your completed Questionnaire in the reply paid envelope provided by **Friday 23 December 2016**. No postage stamp is required. If you have misplaced the supplied envelope or wish to send an additional submission the address is:

Lyall & Associates
Reply Paid 85163
NORTH SYDNEY NSW 2060

About your property

1. Please tick as appropriate:

☐	I am a resident
☐	I am a business owner
☐	I own the property
☐	I rent the property
☐	Other (please specify_________________)

2. How long have you been at this address?

- ☐ Less than a year
- ☐ 1 year to 5 years
- ☐ 5 years to 20 years
- ☐ More than 20 years (____ years)

3. What is your property?

- ☐ House
- ☐ Villa/Townhouse
- ☐ Unit/Flat/Apartment
- ☐ Vacant land
- ☐ Industrial unit in larger complex
- ☐ Standalone warehouse or factory
- ☐ Shop/Retail
- ☐ Community building
- ☐ Other

4. Have you experienced flooding at your property and if so, in what year(s)?

____

5. Please rank the following development types according to which you think are the most important to protect from floods (1=highest priority to 6= least priority)

- ☐ Commercial
- ☐ Residential
- ☐ Essential community facilities
- ☐ Critical Utilities
- ☐ Minor developments and additions
- ☐ New residential subdivisions

Your attitudes to Council's development controls

6. What level of control do you consider Council should place on new development to minimise flood-related risks?
(Tick only one box)
(In addition to being favoured by the Community, these options would also need to comply with legislation)

- ☐ Prohibit all new development on land with any potential to flood
- ☐ Prohibit all new development only in those locations that would be extremely hazardous to persons or property due to the depth and/or velocity of floodwaters, or evacuation difficulties.
- ☐ Place restrictions on developments which reduce the potential for flood damage (e.g. minimum floor level controls or the use of flood compatible building materials)
- ☐ Advise of the flood risks, but allow the individual a choice as to whether they develop or not, provided steps are taken to minimise potential flood risks
- ☐ Provide no advice regarding the potential flood risks or measures that could minimise those risks
- ☐ Don't know

7. What notifications do you consider Council should give about the potential flood affectation of individual properties?
(Tick one or more boxes)

- ☐ Advise every resident and property owner on a regular basis of the known potential flood threat
- ☐ Advise only those who enquire to Council about the known potential flood threat
- ☐ Advise prospective purchasers of property of the known potential flood threat.
- ☐ Provide no notifications
- ☐ Other (________________________)

Other Information

8. **Do you currently maintain a Home and Contents Insurance policy and if so, what is the annual premium (to the nearest $100).**

Building Only - Yes / No	$____________
Contents Only - Yes / No	$____________
Building and Contents - Yes / No	$____________

9. **Has your Home and Contents Insurance premiums increased substantially in the last few years and if so, by approximately how much? (Circle Yes or No and Write $ Amount)**

Building Only - Yes / No	$____________
Contents Only - Yes / No	$____________
Building and Contents - Yes / No	$____________

10. **What do you think is the best way for us to get input and feedback from the local community about the results and proposals from this study?**
(Tick one or more boxes)

- ☐ Council's website
- ☐ Articles in local newspaper
- ☐ Open days or drop-in days
- ☐ Community workshops
- ☐ Public Meetings
- ☐ Through Council's Floodplain Management Committee
- ☐ Other (please specify _______________)

11. **If you wish us to contact you so you can provide further information, please provide your details below:**

Name: ________________________________

Address: ________________________________

____

Phone: ________________________________

Best time to call is ________________________

Fax No: ________________________________

Email: ________________________________

Other (________________________________)

12. **If you have any photographs of historic flooding at Wee Waa you are welcome to drop into Council's office in Maitland Street, Narrabri to have them photocopied. Council will then forward the photocopy onto the Consultant on your behalf.**

Your opinions on floodplain risk management measures and controls

13. **Below is a list of possible options that may be looked at to try to minimise the effects of flooding in the Study Area (see plan at back of questionnaire).**

This list is not in any order of importance and there may be other options that you think should be considered. For each of the options listed, please indicate "yes", or "no" to indicate if you favour the option or "don't know" if undecided. (In addition to being favoured by the Community, management options would also need to comply with legislation and be capable of being funded).

Option	Yes	No	Don't Know
Raising of the existing earthen levee using the same construction methodology			
Raising of the existing earthen levee during times of flood using temporary/relocatable flood barriers			
Improvements to the internal drainage system (e.g. upgrade of the stormwater evacuation pumps which are located around the perimeter of the existing levee)			
Removal of floodplain obstructions, such as rural levees			
Voluntary purchase of the most severely affected flood-liable properties			
Provide funding or subsidies to raise houses above major flood level in low hazard areas.			
Flood proofing of individual properties by waterproofing walls, putting shutters across doors, etc.			
Improve flood warning and evacuation procedures both before and during a flood.			
Community education, participation and flood awareness programs.			
Ensuring all residents and business owners have Flood Action Plans - these outline WHAT people should do, WHERE they should go and WHO they should contact in a flood			
Specify controls on future development in flood-liable areas (e.g. controls on extent of filling, minimum floor levels, etc.)			
Provide a Planning Certificate to purchasers in flood prone areas, stating that the property is flood affected.			
Ensuring all information about the potential risks of flooding is available to all residents and business owners			

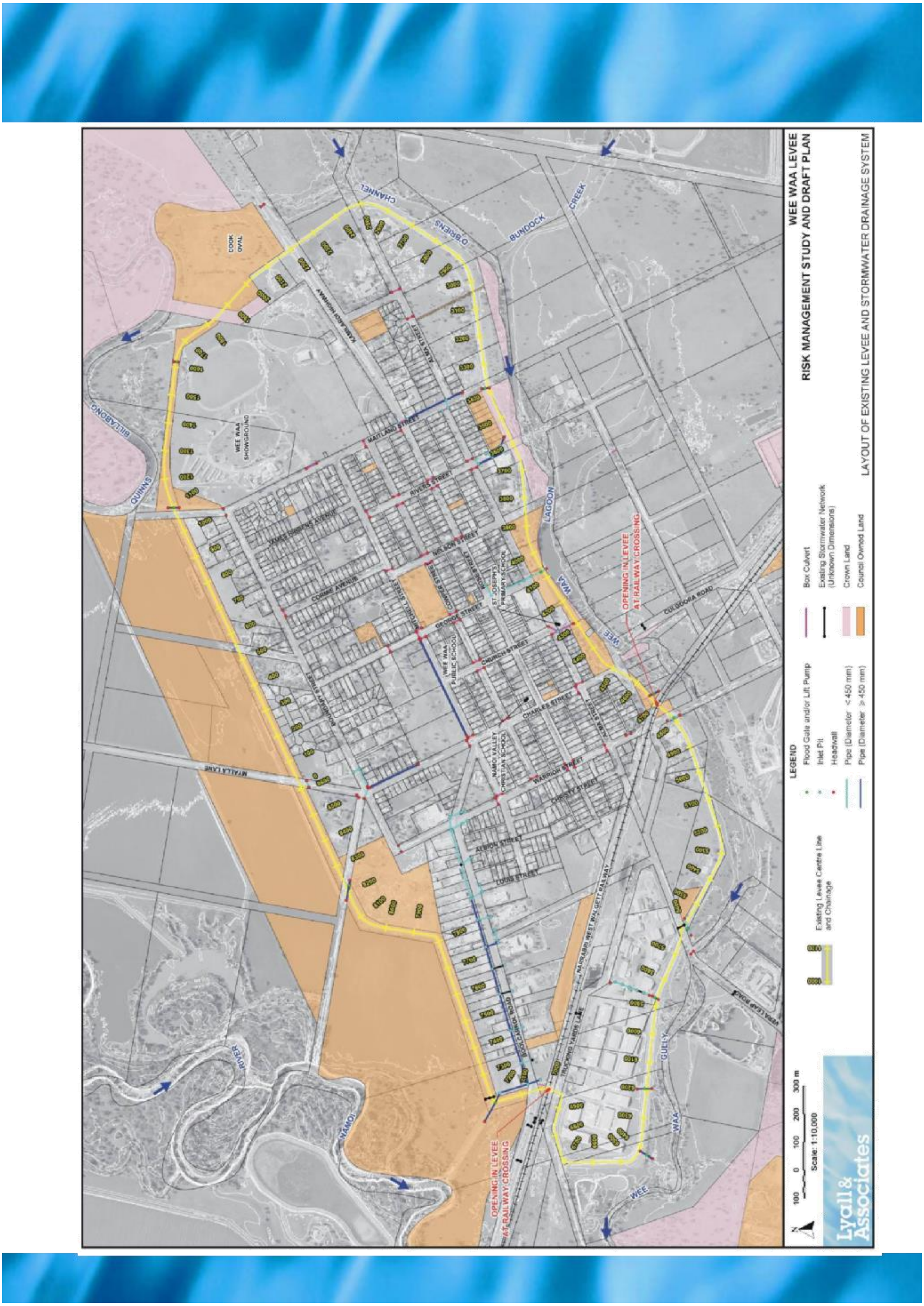
Who can I contact for further information?

Narrabri Shire Council
Cara Stoltenberg – Town Planner
Phone: (02) 6799 6817
Email: caras@narrabri.nsw.gov.au

Copies of this Questionnaire can be obtained from:
www.narrabri.nsw.gov.au

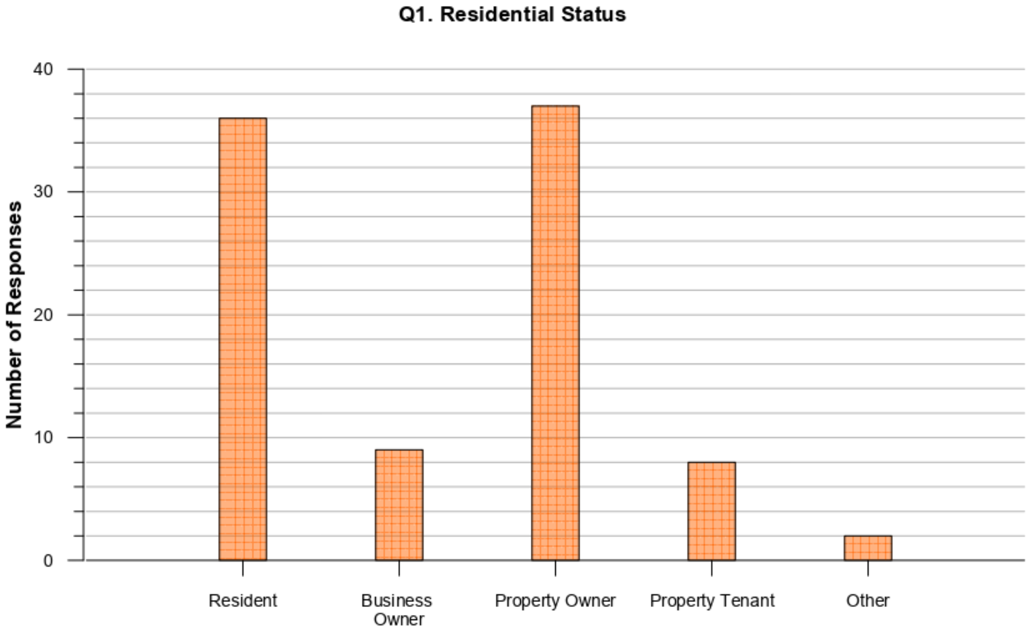
COMMENTS

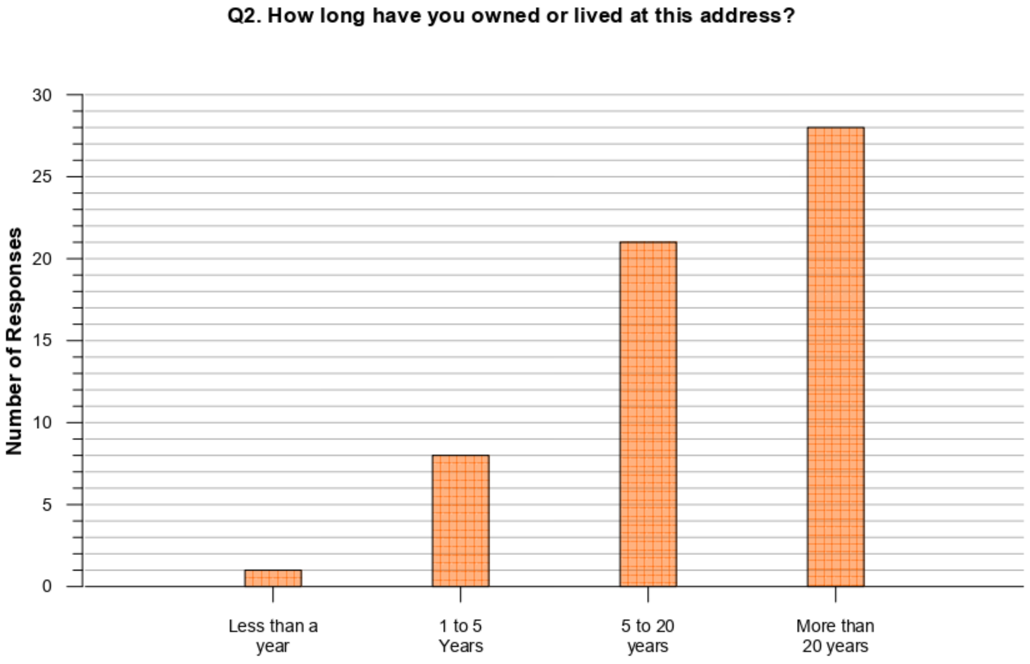
Please write your comments here:


WEE WAA LEVEE
RISK MANAGEMENT STUDY AND DRAFT PLAN
LAYOUT OF EXISTING LEVEE AND STORMWATER DRAINAGE SYSTEM
LEGEND
Existing Levee Centre Line and Chainage
Flood Gate and/or Lift Pump
Inlet Pit
Headwall
Pipe (Diameter < 450 mm)
Pipe (Diameter ≥ 450 mm)
Box Culvert
Existing Stormwater Network (Unknown Dimensions)
Crown Land
Council Owned Land
Scale: 1:10,000
Lyall & Associates
OPENING IN LEVEE AT RAILWAY CROSSING
OPENING IN LEVEE AT RAILWAY CROSSING
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
MAITLAND STREET
RIVERS STREET
WILSON STREET
GEORGE STREET
CHURCH STREET
CHARLES STREET
WARRIOR STREET
CHRISTY STREET
ALBION STREET
LOUIS STREET
COMBE AVENUE
MYALLA LANE
CULGOORA ROAD
BUNDOCK CREEK
O'BRIENS CHANNEL
QUINNS BILLABONG
NAMOI RIVER
WEE WAA LAGOON
WEE WAA GULLY
NARRABRI WEST WALGETT RAILWAY

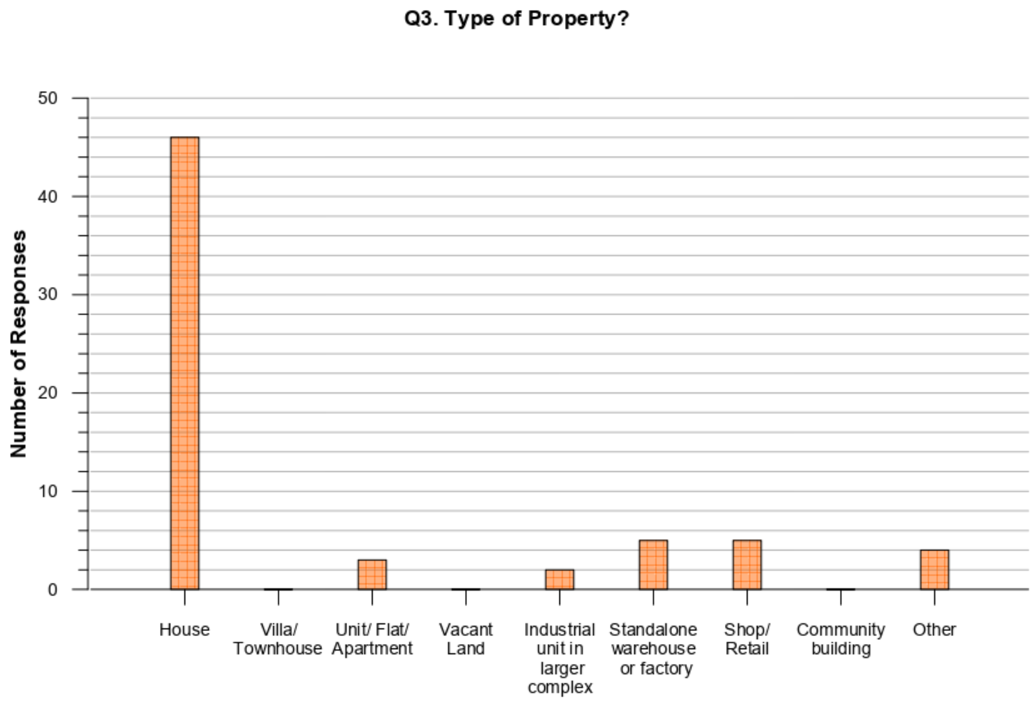
ATTACHMENT 2

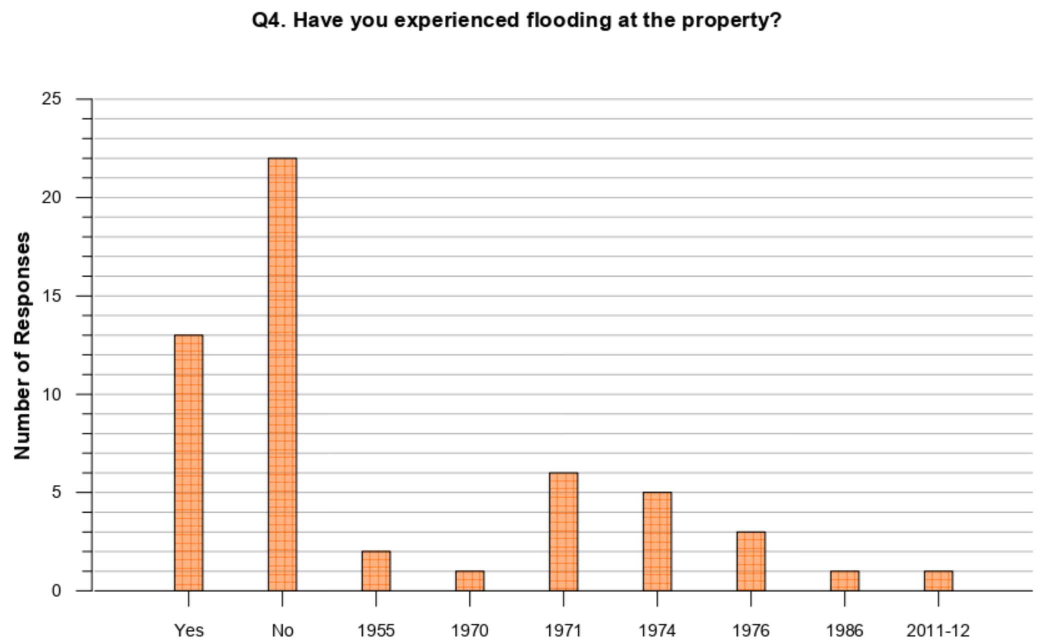
RESPONSES TO COMMUNITY QUESTIONNAIRE



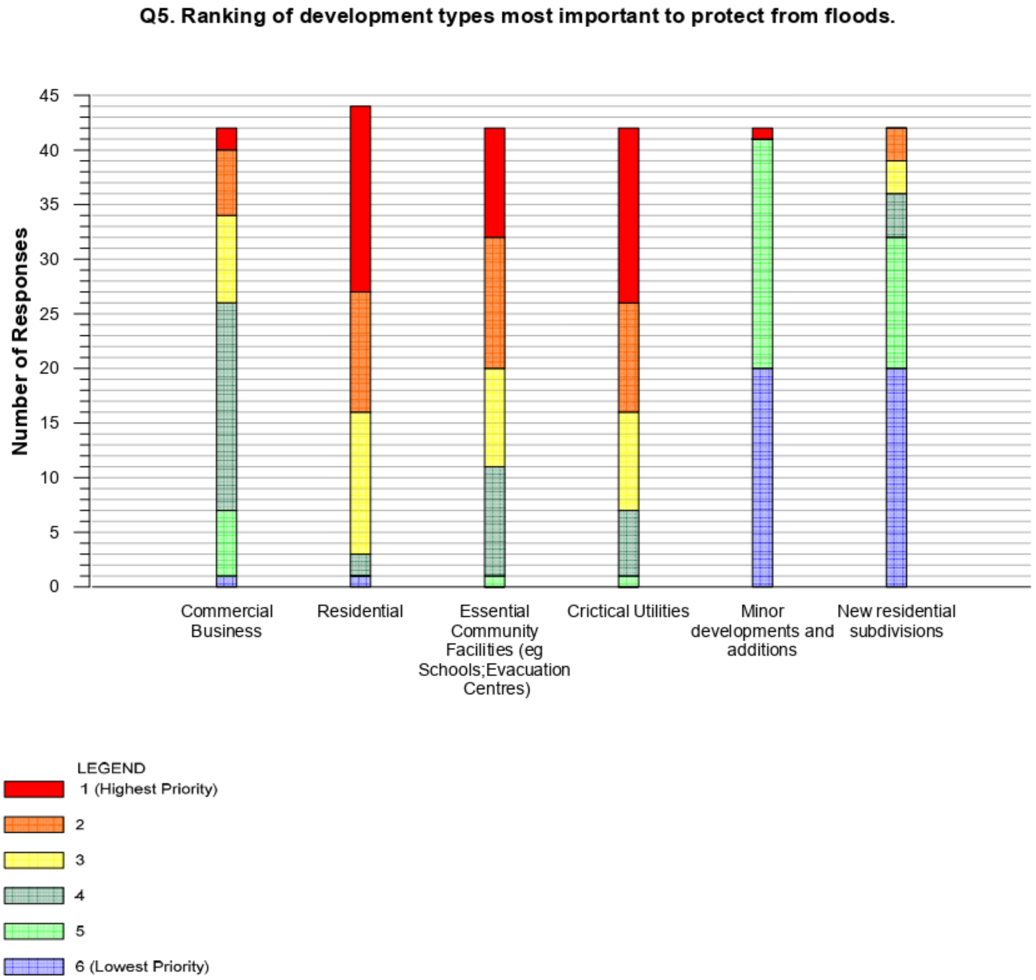


RESPONSE TO COMMUNITY QUESTIONNAIRE



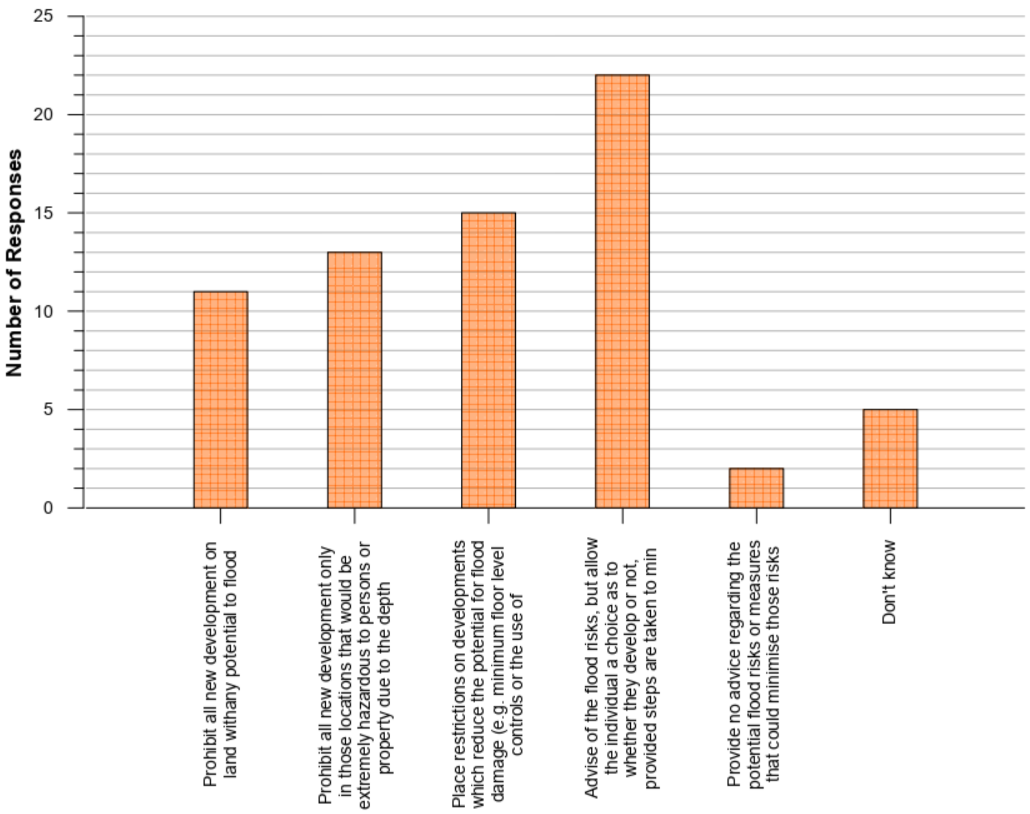


RESPONSE TO COMMUNITY QUESTIONNAIRE

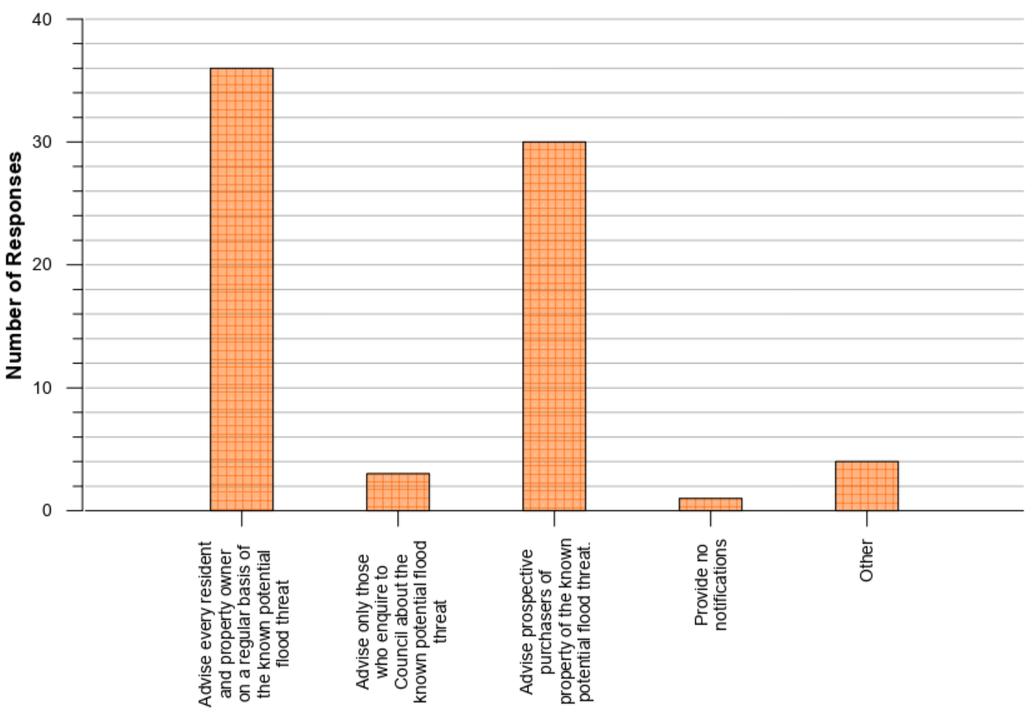


RESPONSE TO COMMUNITY QUESTIONNAIRE

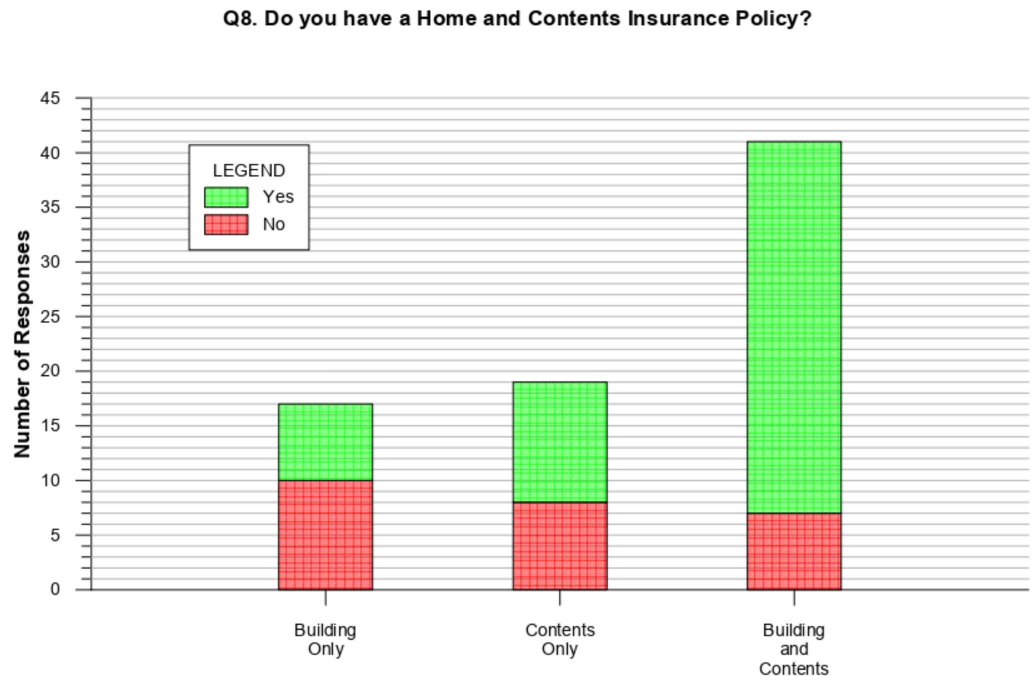
Q6. What level of control should be placed over new development?

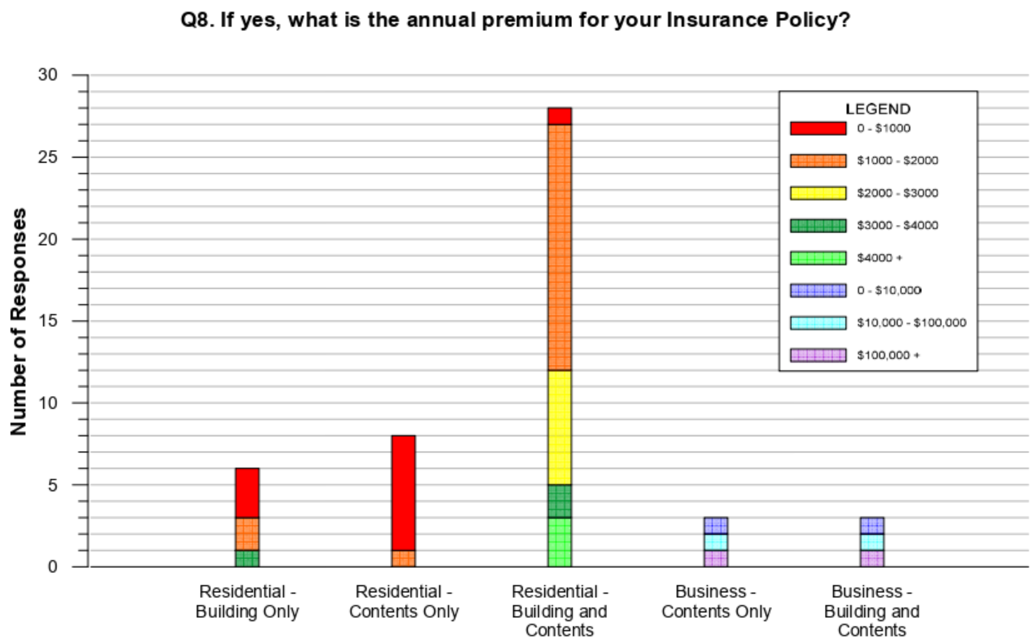


Q7. What notifications should be given by Council about the potential flood affectation of individual properties?



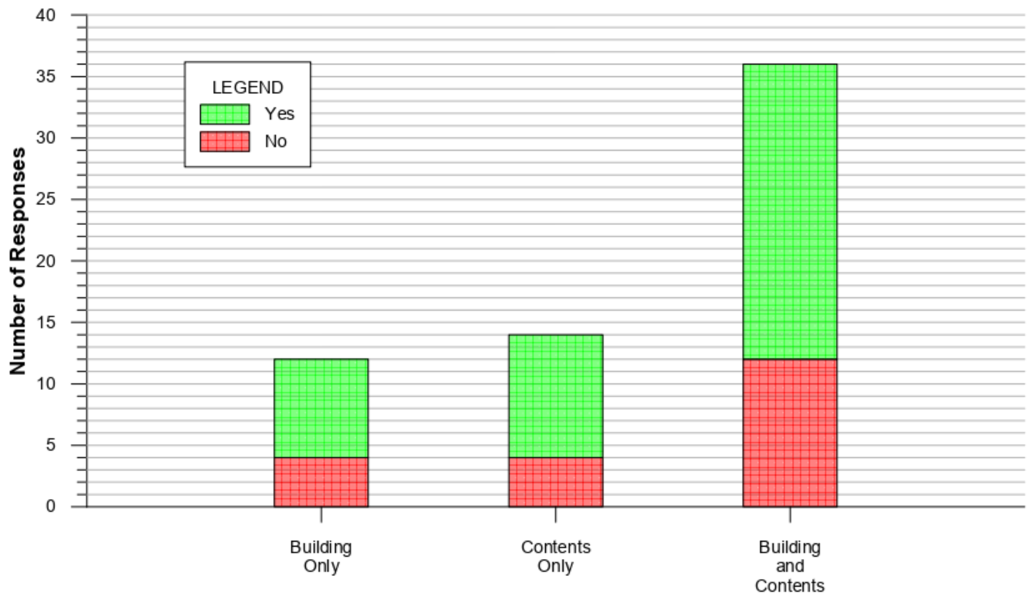
RESPONSE TO COMMUNITY QUESTIONNAIRE



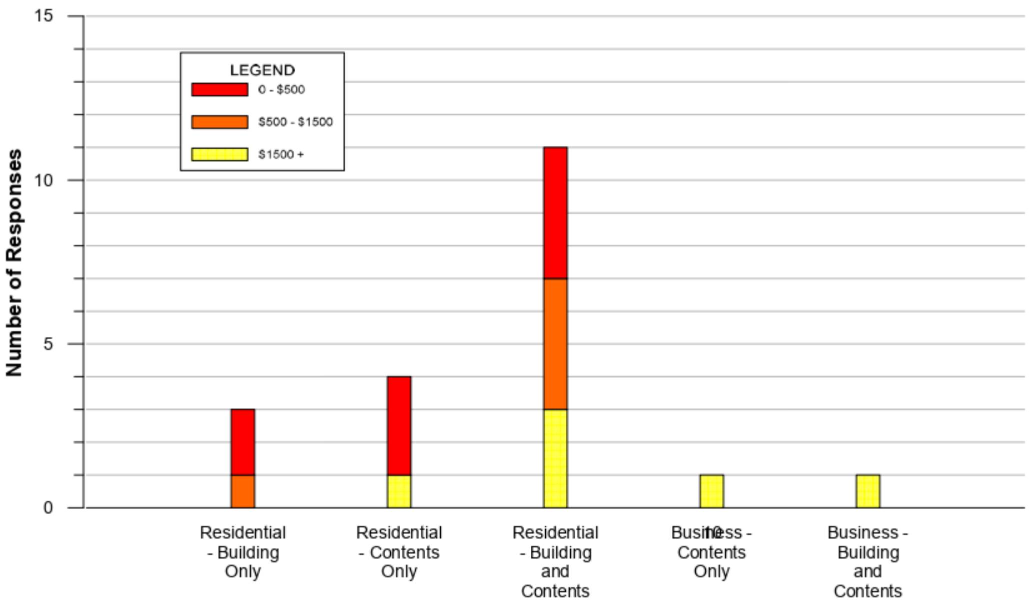


RESPONSE TO COMMUNITY QUESTIONNAIRE

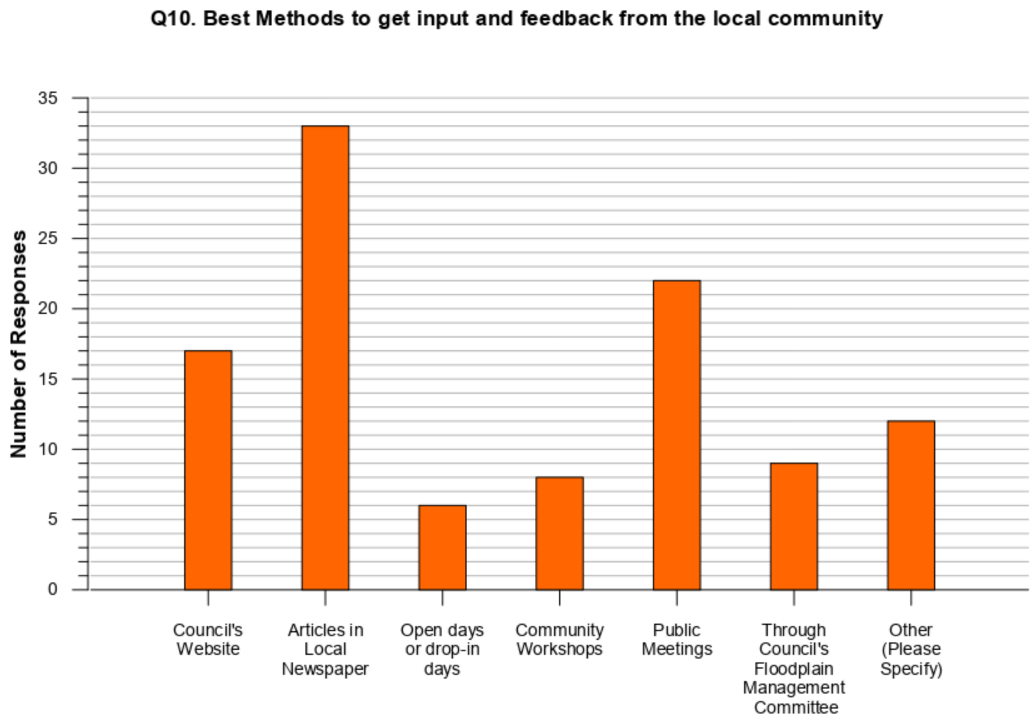
Q9. Have your Home and Contents Insurance premiums increased substantially in the last few year?



Q9. If yes, how much have premiums increased by?

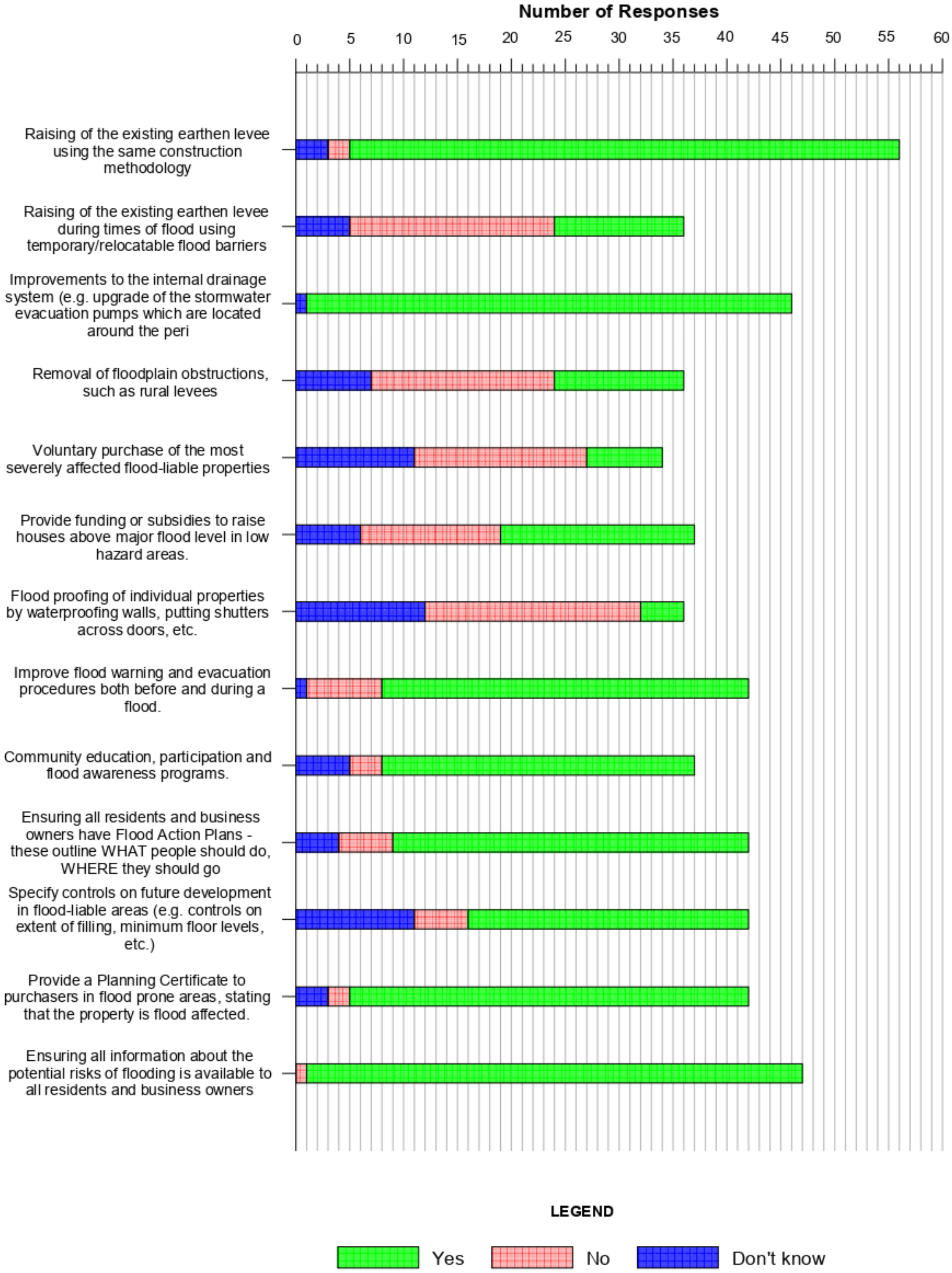


RESPONSE TO COMMUNITY QUESTIONNAIRE



RESPONSE TO COMMUNITY QUESTIONNAIRE

Q13. Possible Flood Management Options



RESPONSE TO COMMUNITY QUESTIONNAIRE

APPENDIX B

PRELIMINARY GEOTECHNICAL ASSESSMENT

MICHAEL ADLER AND ASSOCIATES
Consulting Geotechnical Engineer

PO Box 91
Church Point, NSW 2105
AUSTRALIA

Tel: +61 412 904 349
Fax: (02) 9999 5770
Mobile: 0412 904 349
EMAIL: michael@madler.com.au

Wednesday, January 29, 2020
Our Reference: 15/03650

Lyall and Associates
Level 1, 26 Ridge Street
NORTH SYDNEY, NSW 2060

Attention: **Tom Rooney**

Dear Sir

Preliminary Geotechnical Assessment for
Wee Waa Levee Risk Management Study & Draft Plan
Proposed Raising of Levee
Wee Waa, New South Wales

1) Introduction

This report presents the results of a preliminary geotechnical assessment undertaken as part of the preparation of the Wee Waa Levee Risk Management Study & Draft Plan. The draft plan includes concept design for the proposed raising of various sections of the levee at Wee Waa, north western New South Wales.

Lyall and Associates (LA) are preparing this study and draft plan for the Narrabri Shire Council. They have commissioned Michael Adler and Associates (MAA) to undertake a preliminary geotechnical assessment for the proposed new works.

It is important to note that no subsurface investigations have been undertaken to date. This report is solely based on a walk over inspection of the existing levee, available reports and our experience with similar structures.

The purpose of the investigation was to provide *preliminary* information on:

- The condition of the existing levee
- Methodology for the proposed raising of the structure
- Geotechnical related specifications for the new works
- Further geotechnical investigation requirements.

A number of photographs of the existing levee are attached in the appendices to this report and referred to in the following text. When referring to individual photographs, the appendix letter is quoted first before the photo number, e.g., Photo B7418 refers to a Photo No. 7418 in Appendix B.

It should be noted that this is not a contamination assessment.

2) Background

Wee Waa is a small country town on the north western slopes of New South Wales. It is 30 km west of Narrabri and approximately 420 km north west of Sydney. It has a population of just over 2000. The immediate general area is a relatively flat flood plain.

Wee Waa is situated on the Namoi River flood plain, see Figure 1. The Namoi River flows in a general south west direction on the north side of the town. The Wee Waa Gully forms the towns south western boundary with the Wee Waa Lagoon to the south. Obriens Channel is on the eastern side of Wee Waa with Quinns Billlabong to the north.

There is an existing levee running around the entire perimeter of the town. Appendix A presents a series of Photographs of the general condition of the structure. These are taken at between 150 and 500 m intervals along the levee alignment. Figure 2 details the chainage locations noted on the photographs. Construction of the levee was completed in 1978. There was a 'significant' upgrade proposed and designed in 1993. Narrabri Shire Council owns, controls and maintains this structure. Council were unable to confirm that the 1993 proposed works were implemented.

The levee is 8.6 km in length and varies in height from 2.5 m to 7.0 m. It is an earth embankment. The upstream/river side slopes vary from 2:1 to 3.5:1 (Horizontal:Vertical), generally at 3:1, down stream slopes are in the order of 1.6:1 to 5:1, generally 2:1 with a typical crest width of 3 m. The side slopes are grassed and the crest typically has a gravel surface.

There are a number of road and railway crossings over and through the levee. Appendix B presents photographs of each crossing, they are detailed below;

Type of Crossing	Details	Approx. Chainage.
Sealed Roads	Kamilaroi Highway	2200
	Culgoora Road	4550
	Leaps Road	5600
	Western Narrabri Walgett Road	6900
	Boolcarrol Road	7100
Unsealed Roads	Substation access	2150
	Alama Road	2450
	Myalla Lane	8600
Unformed Crossings		1250, 3600, 6700 & 8200
Railway Cuttings	Removable flood gates	4700 & 6900

The removable flood gates for the rail crossings (Photos B7390 & B7421) are stored adjacent to the rail cuttings. During a flood event they are lowered into slots in the concrete abutment walls either side of the railway line (Photos B7391 & B7420).

We understand that there are no spillways either designed for, or constructed along the length of the levee.

3) Local Geology

Reference to Geological Sheet SH 55-12, Narrabri, 1971 at a scale of 1:250,000 indicates that the site is underlain by Quaternary age alluvium. The map states that these materials comprise gravel, sand, silt and clay.

Our experience in the general Wee Waa area is that these alluvial deposits can extend to considerable depth. They typically comprise high plasticity silty clays that are potentially highly dispersive and usually reactive. There are also some clayey sands and sandy clays.

4) D J Douglas Investigation, 1993

The only available report that is particularly relevant to this geotechnical assessment is a geotechnical investigation carried out by D J Douglas & Partners Pty. Ltd (Consulting Geotechnical Engineers) in 1993 (Ref. No. 18045, 22 September, 1993). Eight test pits, two pits at four different locations, were excavated through the levee fill and the underlying insitu soils. Laboratory testing was undertaken on samples taken from the pits.

The results indicate that at the four test locations the levee in its then condition comprised an outer 0.3 m to 0.7 m thick layer of poorly compacted silty clay over an inner core of 'relatively well compacted' clay. In one pit 0.6 m of dense clayey sand was encountered. The natural soils below the levee comprised similar silty clay to the levee filling. This insitu soil was hard.

Laboratory dispersion testing indicated that the clays are all either dispersive or potentially dispersive.

The Douglas report discussed the work required for the then proposed raising of the levee by up to approximately 0.3 m. Construction methodology and specifications were presented for this work. Essentially this involved forming a new skin of well compacted clay fill over the river side slope with a 1 m deep key excavated into the natural ground out the front. A minimum thickness of 1.5 m was recommended for this new skin. It was also recommended that the new clay fill should be stabilised with 3 to 5% gypsum. This was to minimise the potential for adverse dispersive type erosion through the embankment.

It is reported that in 1995 it was intended to undertake a significant upgrade of the levee. As previously mentioned this work may not have been completed.

5) Proposed New Works

The present proposal is to ensure that the entire levee is provided with a minimum 1m of free board above the 1% AEP flood level, and with a minimum crest width of 3 m. In places the existing crest level will be raised by up to 0.6 m. This will result in an increased in height of up to 1 m above the side slopes at some locations. In other locations the height is already at or above the required level. The present proposal is not to lower the height of the sections that are above the required level.

The basic assumption being made is that the internal condition of the existing embankment, especially in areas where no new work is proposed, is in an acceptable state from a geotechnical stability point of view. As already noted this current preliminary geotechnical assessment has not involved any subsurface investigation and hence this basic assumption must be read in that light. Unless there is recorded information about the state of the levee from the upgrade works proposed in 1995, the internal condition of the embankment is currently only known at the four individual locations investigated in 1993. It's worth noting that the levee has experienced significant flood events on at least nine occasions and there have been no collapses or adverse behaviour reported.

As part of the proposed new works a 1.5 m thick skin of well compacted gypsum stabilised clay will be formed on the river side face in the areas where the levee needs to be raised. A 1 m deep key will extend into the natural soils below the upstream toe. The new face will be formed at a slope of 2.5:1 with a 3 m width crest, see Figure 3. Further comment on the construction of this skin is presented later in this report.

6) Existing Levee Condition

The following comments only address the condition of the existing levee from a geotechnical stability point of view. No comment is made at this time regarding the various hydraulic structures which pass through the embankment or any erosion adjacent to or in the vicinity of these structures. A recent visual audit by Public Works in late 2017 identifies some possible defects associated with these structures as well as elsewhere along the levee ('Visual Audit of Wee Waa Levee', Public Works, Report No. DO/17/07, dated 20/11/2017). Some of the identified defects/issues may need to be assessed at a later date if they have not already been rectified by Council.

We inspected the levee on March 9, 2018. The general conditions observed are shown in the series of photographs in Appendix A. In summary, we consider from a visual inspection that the embankment appears to be in good condition. There are no obvious signs of instability, generally it is well maintained and appears from a geotechnical point of view to be fit for purpose. The sealed road crossings and the railway cuttings are currently performing as expected (Photos B7348, B7386, B7391, B7430, B7418 & B7420). There is Reno mattress toe protection along the river side of the embankment adjacent to the Wee Waa Lagoon in the vicinity of Ch. 4050 (Photos D7372 to D7374). This appears to be performing adequately.

Some minor defects or aspects requiring attention are discussed below. A number of these recommendations may be superfluous if the new works are proposed in the immediate area.

There are a number of unformed crossing used by local vehicles. These are detailed in Section 2) above and shown in Appendix B. There is the potential that these uncontrolled vehicle movements will over time damage the levee locally. Photo B7352 shows the early stages of the type of damage that can occur where there is an uncontrolled crossing adjacent to a formed road. It would be appropriate to either close off these crossings or possibly control the movements so that vehicles cross over a formed/engineered surface such as a gravel pavement or even a sealed roadway. There are also some unsealed crossings that comprise either formed or engineered gravel pavements. These are also detailed in Section 2) and shown in Appendix B. These should be checked on a regular basis for damage and repaired if required. Vehicles using these should be restricted to using only the formed gravel pavement. Consideration could be given to sealing these crossings, this may reduce the maintenance costs.

In some locations obvious tension cracks have formed along the crest, examples are Ch. 0 to 200, 400 to 450, 1400 to 2150, 2500 to 2600, 4200 to 4250 & 8200 to 8600. Appendix C presents examples of the some significant cracking. Tension cracking in the highly reactive clays found in this area can develop to considerable depth. Such cracking is usually not acceptable in a water retaining structure. It would be good practice to scarify these cracks, and any damage caused by vehicle or cattle movements, down to a depth of at least 300 mm and recompact the fill to the specifications discussed below. A good well maintained vegetation cover helps reduce the cracking.

In some areas the vegetation on the side slopes is starting to become significant. Examples are shown on Photos D7343, D7363, D7372, D7393 & D7395. These should be removed before the roots start to form potential drainage pipes.

There was water observed ponding at the toe of the town side of the embankment at three locations, Ch. 2900, 3400 and 7500 (Photos D7358, D7363 & D7315). It would be good practice to clear the local drainage system in these area to allow the water to drain.

7) Comments on Proposed New Construction

Both the assumed condition of the existing Wee Waa levee and the natural subgrade below are typical of those found in this part of north western New South Wales. The vast majority of the soils likely used to form levees in this area will essentially behave as a fine grained clayey soil. We consider that they can be successfully used for construction of the new works as long as good engineering practice is followed as discussed below. Attention to compaction and moisture conditions is vital, this is discussed below.

7.1) DISPERSION

This western part of the state is sometimes referred to as "black soil country" because it is prone to large shrink/swell reactive soil movements due to seasonal changes in soil moisture conditions (when the clayey soils wet up and dry out on a cyclic seasonal basis). The depth of these changes can be over 4 m. During the "drying out cycle" of the seasonal change, cracking and fissures can therefore extend to significant depths. This can occur not only in natural soil deposits, but also in fill placed above the ground.

The concept of dispersive behaviour in geotechnical terms, originated with the study of piping failures of small earth dams in Australia in about 1963. These dams constructed of homogeneous fill with minimal or no compaction control generally failed within a short period. The average failure rates of about 20% – 25% have been reported for such dams built in dispersive areas.

The failure mechanism is an interaction of certain chemical properties of the clay fraction of the soil and seepage water (causing dispersion) with the existence of macro (or micro) channels in the embankment soil. The process involves the stored/retained water seeping through the channels in the embankment, contacting the dispersive clay that then breaks down to colloidal sized particles (disperses) and the resulting suspension moving with the flow. In this manner the macro channel, or 'pipe', rapidly increase in size (erodes) until complete piping failure occurs.

If dams and levees are designed and built to acceptable engineering standards, with both material and compaction control, then the incidence of dispersive failure is very much smaller, probably less than 1%. This is mainly due to the fact that controlled compaction of clayey soil results in a relatively impermeable mass that does not facilitate movement of dispersed particles. Furthermore, these 'properly' engineered structures generally exhibit a self healing property whereby swelling of the clay fabric closes any small channels that may exist. Failures of well engineered dams have generally been associated with interface problems, such as leakage along culverts or foundations, which can be minimised by appropriate design measures.

In summary, dispersive soils are particularly prone to erosion if there is a flow path through the material in its natural state, say when placed as a fill in a water retaining embankment. These flow paths can be formed by cracking in the soil due to drying out or by fissures. They can also form in poorly compacted soil, especially when it has been placed relatively dry of optimum. The optimum moisture content is the moisture condition at which it is possible to obtain the maximum level of compaction when placing the soil as a fill, such as in a dam embankment.

7.2) DEALING WITH DISPERSIVE SOILS

One of the best ways of dealing with dispersive soils in a fill situation is to mix in lime or gypsum when placing the clay. Typically only some 0.5% is required, but because of the extreme difficulty of obtaining a consistent well mixed material, 1% to 2% has to be added, and well mixed in, to ensure any success. On levees the treated soil often only needs to extend over a horizontal width of say 2 m from the upstream face. Given the minimal size of the Wee Waa levee the most practical solution would be to treat all the new fill. Of course the treated soil must be properly compacted.

Another less certain method that has been used on dams is to place and compact the soil wet of optimum, say between 0 and +2% or +3%. In this situation it is even more vital to ensure that all soil is well and thoroughly compacted in order to form a consistent mass of impervious fill.

7.3) NEW LEVEE WORKS

The proposed cross section details shown on Figure 3 are considered reasonable. Given the typical size of available earth moving equipment, in some locations it may be more practical to remove the entire embankment and rebuild it, rather that attempting to form a well engineered skin using conventional construction equipment. It will not be practical to construct a zoned embankment. The structure will likely be built of one homogeneous fill material. This material must be clayey in nature and won from a local borrow area. In some situations it may be practical to reuse existing levee material as long as all vegetation, deleterious material and topsoil are discarded.

A large proportion of the new fill will be highly dispersive. It is recommended that serious consideration is given to gypsum stabilising all new engineered fill placed in the new works. A minimum of 2% lime or gypsum should be added and well mixed prior to placing the fill. A 300 mm thick topsoil skin can be provided over the top of the levee to allow vegetation to establish. This should be appropriately vegetated to ensure that there is no unacceptable erosion during flood events.

7.4) CONSTRUCTION

The following present the minimum work that is required to meet the level of good engineering construction discussed above:

- Only clayey fill can be used to construct the new works. An engineer should ensure that acceptable material is used.
- All structural fill should be lime or gypsum stabilised with a minimum of 2%.
- **All** structural filling should be compacted to at least 98% of the maximum Standard dry density at a moisture content between Standard optimum and optimum +3%. A sheep or pad foot roller must be used, it is expected that eight to ten passes of a suitable sized roller may be sufficient. A smooth drum roller should not be used.
- All fill must be placed in thin layers. The maximum loose layer thickness should not exceed 200 mm.
- All new fill must be benched in layers into the sides of the existing embankment for a horizontal distance of at least 1 m.
- Prior to building any part of the embankment all vegetation, topsoil, loosened or soft soil should be removed before placing any fill. The exposed surface is to be scarified to a depth of at least 300 mm and compacted as noted above. This includes the sides of the existing levee.
- A cut off trench should be formed into the natural soils below the river side toe as shown on Figure 3. An experienced engineer will need to inspect the exposed subgrade at the bottom of the toe.

- All pipe work through the embankment is to be provided with cut off collars. All trenches are to be back filled with compacted clayey fill well mixed, with 2% lime or gypsum. Sand backfill must **not** be used.

It would be normal practice on a civil engineering project of a similar magnitude to undertake full time supervision and earth works testing during the construction. Consideration could be given to carrying out similar testing while building the proposed new works at Wee Waa.

8) Additional Investigation

Given that there is very little information available about the internal conditions of the existing levee it is recommended that a detailed subsurface investigation is carried out during the detailed design phase particularly for the sections of embankment where there will be no new earthworks undertaken, or where the new works do not form an impervious skin for the full height of the levee.

This investigation will likely include boreholes at say 500 m centers along these sections together with appropriate laboratory testing.

It may also be necessary to investigate the proposed borrow pit area to ensure that the new fill is acceptable. Discussions will need to be held with Council regarding potential borrow areas.

9) Concluding Remarks

To date only an extremely limited subsurface investigation was undertaken in 1993. Significant works were proposed in 1995 but the final extent is unknown. The above preliminary geotechnical assessment has been provided on the basis that little is known about the internal condition of the existing level. It has been assumed that is in an acceptable condition.

Our observation of the external condition of the levee suggests that it is in good condition. There are some minor defects/aspects that will need rectification. The proposal to form a new engineered skin in areas where the levee needs to be raised is considered reasonable as long as the works follow the recommendations presented in this report.

The attached *Notes Relating To Geotechnical Report* are an intrinsic part of this report.

We do note that we have assumed in our costing for this investigation that you, the client, will contact us by phone on a number of occasions to discuss the proposed works, especially in regards to the finding presented in this report. Please do not hesitate to ring our office.

Yours Sincerely

Michael A Adler BSc, BE, MSc, DIC, MIEAust, CPEng

NOTES RELATING TO GEOTECHNICAL REPORTS
Michael Adler & Associates

Introduction

These notes outline some of the methodology and limitations inherent in geotechnical reporting. The issues discussed are not relevant to all reports and further advice should be sought if there are any queries regarding any advice or report.

When copies of reports are made, they should be reproduced in full.

Geotechnical Reports

Geotechnical reports are prepared by qualified personnel using information supplied or obtained. They are based on current engineering standards of interpretation and analysis.

Information may be gained from limited subsurface testing, surface observations, previous work often supplemented by knowledge of the local geology and experience of the range of properties that may be exhibited by the materials present. For this reason, geotechnical reports should be regarded as interpretative rather than factual documents, limited to some extent by the scope of information on which they rely.

Where the report has been prepared for a specific purpose (e.g.. design of a three-storey building), the information and interpretation may not be appropriate if the design is changed (e.g.. a twenty storey building). In such cases, the report and the sufficiency of the existing work should be reviewed by Michael Adler & Associates in the light of the new proposal.

Every care is taken with the report content, however, it is not always possible to anticipate or assume responsibility for all situations such as:

- Unexpected variations in ground conditions. The potential for this depends on the amount of investigative work undertaken.
- Changes in policy or interpretation by statutory authorities.
- The actions of contractors responding to commercial pressures.
- Interpretation by others of this report.

If these occur, Michael Adler & Associates would be pleased to resolve the matter through further investigation, analysis or advice.

Unforeseen Conditions

Should conditions encountered on site differ markedly from those anticipated from the information contained in the report, Michael Adler & Associates should be notified immediately. Early identification of site anomalies generally results in most problems being more readily resolved, and allows reinterpretation and assessment of the implications for future work.

Subsurface Information

Logs of a borehole, rock core, test pit, excavated face or cone penetration test are an engineering and/or geological interpretation of the subsurface conditions. The reliability of the logged information depends on the drilling/testing method, sampling and/or observation spacing and the ground conditions. It is not always possible or economic to obtain continuous high quality data. It should also be recognised that the volume or material observed or tested is only a fraction of the total subsurface profile.

Interpretation of the available subsurface information and application to design/ construction should take into consideration the spacing of the test locations, the frequency of observations and testing, and the possibility that geological boundaries may vary between observation points.

Groundwater observations and measurements not based on specially designed and constructed piezometers should be treated with care for the following reasons:

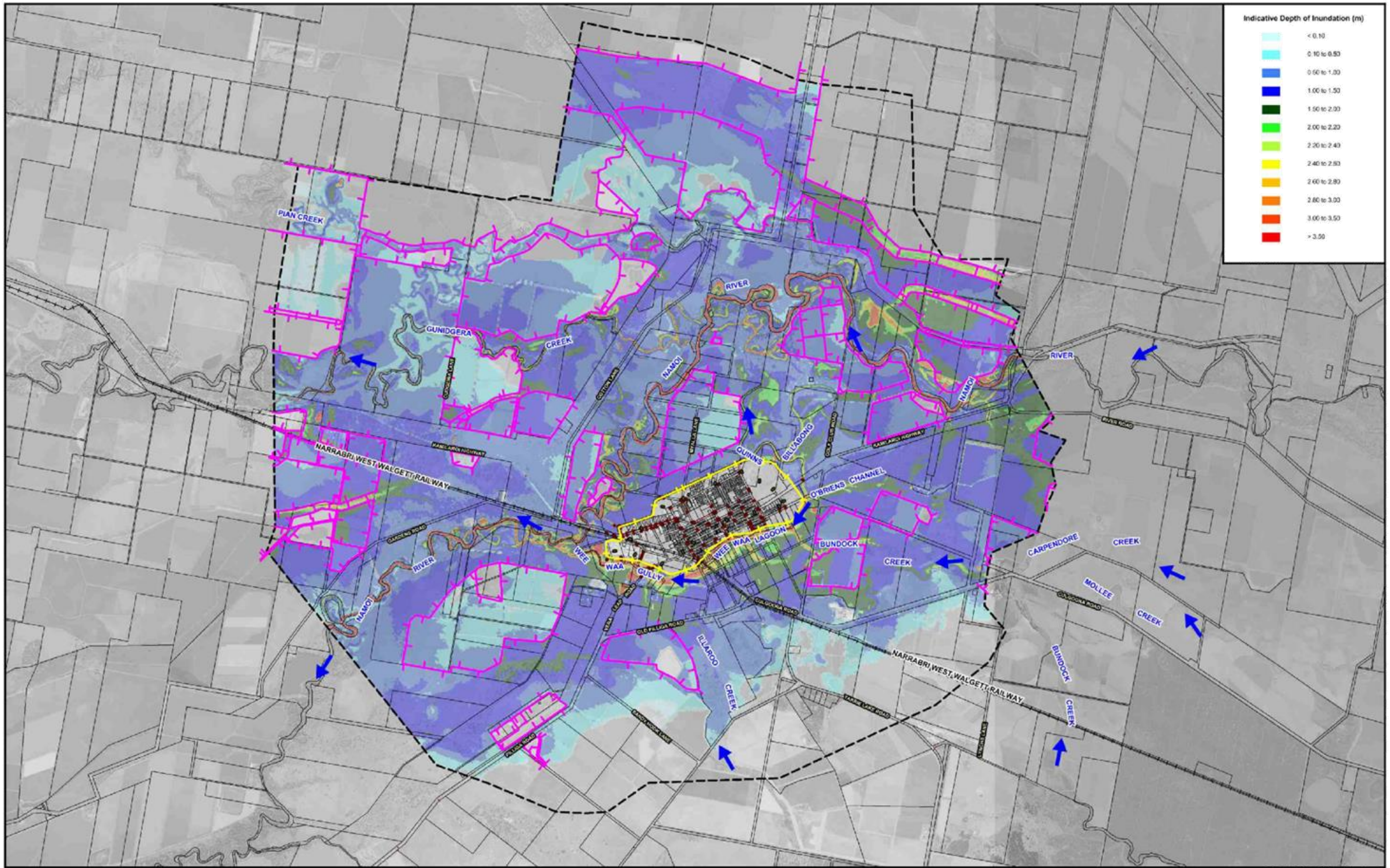
- In low permeability soils groundwater may not seep into an excavation or bore in the short time it is left open.
- A localised perched water table may not represent the true water table.
- Groundwater levels vary according to rainfall events or season.
- Some drilling and testing procedures such as rock coring or penetration testing mask or prevent groundwater inflow.

The installation of piezometers and long term monitoring of groundwater levels may be required to adequately identify groundwater conditions.

Supply of Geotechnical Information For Tendering Purposes

It is recommended that tenderers are provided with as much geological and geotechnical information as there is available. It is best practice to provide copies of all geotechnical related reports, opinions and data.

michael@madler.com.au



N

600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

LEGEND

Existing Stormwater Network (Not Modelled)

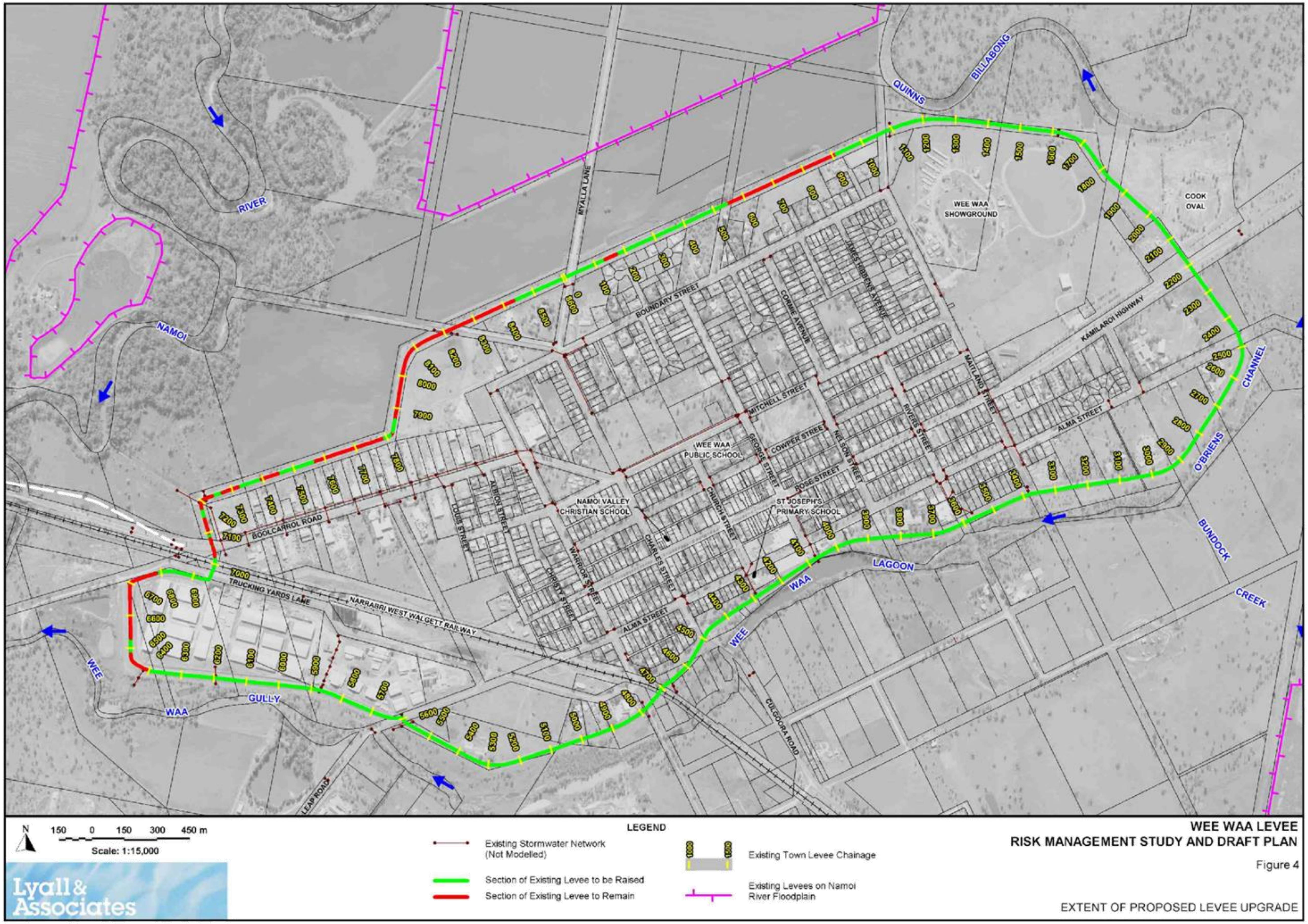
Existing Town Levee Centre Line and Chainage

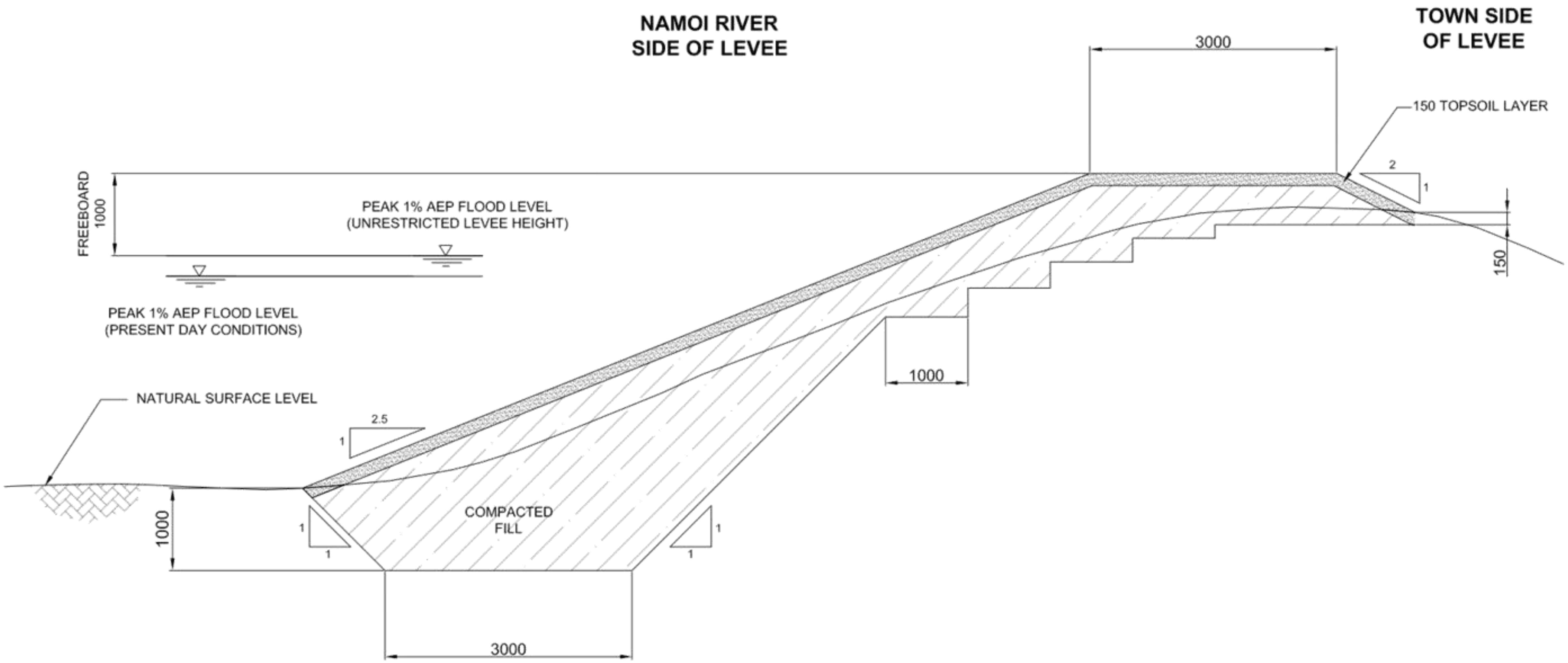
Existing Levees on Namoi River Floodplain

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND DRAFT PLAN

Figure 1

INDICATIVE EXTENT AND DEPTHS OF INUNDATION
1% AEP - EXISTING RURAL LEVEE HEIGHTS


LEGEND
Existing Stormwater Network (Not Modelled)
Section of Existing Levee to be Raised
Section of Existing Levee to Remain
Existing Town Levee Chainage
Existing Levees on Namoi River Floodplain
Scale: 1:15,000
150 0 150 300 450 m
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND DRAFT PLAN
Figure 4
EXTENT OF PROPOSED LEVEE UPGRADE



WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Lyall & Associates

Note:
Vertical Scale: 1:50
Horizontal Scale: 1:50
All dimensions in millimetres.

Figure 3

TYPICAL SECTION SHOWING TOWN LEVEE UPGRADE REQUIREMENTS

APPENDIX A

General Photographs

Ch. 0 – Looking North East

Ch 500 – Looking South West

Ch. 500 – Looking North East

Ch 800 – Looking South West

Ch. 800 – Looking North East

Ch 950 – Looking South West

Ch. 950 – Looking North East

Ch. 1100 – Looking South West

Ch. 1100 – Looking East

Ch 1250 –Looking East

Ch. 1250 – Looking West

Ch 1650 –Looking East

Ch. 1650 – Looking West

Ch 2100 – Looking North West

Ch 2100 – Looking South East

Ch 2150 – Looking South East

Ch. 2150 – Looking South East

Ch 2250 – Looking South East

Ch. 2450 – Looking North West

Ch 2450 – Looking South East

Ch. 2500 – Looking South

Ch 2600 – Looking North East

Ch. 2900 – Looking North East

Ch 2900 – Looking South West

Ch. 2900 – Looking North East

Ch 2900 – Looking South West

Ch. 3100 – Looking West

Ch 3100 – Looking East

Ch. 3400 – Looking North East

Ch 3400 – Looking South West

Ch. 3600 – Looking South West

Ch 3650 – Looking North East

Ch. 3650 – Looking West

Ch 4000 – Looking North East

Ch. 4000 – Looking South West

Ch 4100 – Looking South West

Ch. 4100 – Looking North East

Ch 4200 – Looking South West

Ch. 4200 – Looking North East

Ch 4300 – Looking South West

Ch. 4250 – Looking South West

Ch 4250 – Looking North East

Ch. 4300 – Looking South West

Ch 4300 – Looking North East

Ch. 4400 – Looking South West

Ch 4400 – Looking North East

Ch. 4550 – Looking South West

Ch 4700 – Looking South West

Ch. 4700 – Looking North East

Ch 4770 – Looking South West

Ch. 4800 – Looking South West

Ch 4900 – Looking South West

Ch. 4900 – Looking North East

Ch 5200 – Looking North East

Ch. 5200 – Looking South West

Ch 5350 – Looking North West

Ch. 5350 – Looking East

Ch 5600 – Looking West

Ch. 5600 – Looking East

Ch 5900 – Looking East

Ch. 5900 – Looking West

Ch 6200 – Looking East

Ch. 6200 – Looking West

Ch 6400 – Looking East

Ch. 6400 – Looking North

Ch 6650 – Looking South

Ch. 6650 – Looking North

Ch 6700 – Looking South

Ch. 6700 – Looking East

Ch 6900 – Looking East

Ch. 6900 – Looking West

Ch 6900 – Looking North

Ch. 6950 – Looking West

Ch 7050 – Looking North

Ch. 7100 – Looking North

Ch 7150 – Looking South

Ch. 7150 – Looking North

Ch 7200 – Looking North East

Ch. 7200 – Looking North East

Ch 7350 – Looking South West

Ch. 7350 – Looking North East

Ch 7500 – Looking North East

Ch. 7500 – Looking South West

Ch 7800 – Looking South West

Ch. 7800 – Looking North East

Ch 8100 – Looking North East

Ch. 8100 – Looking South West

Ch 8600 – Looking South West

APPENDIX B

Crossing Photographs

Ch. 1250 – Unformed Crossing

Ch 2150 – Access to Substation, Formed Crossing

Ch. 2150– Access to Substation, Formed Crossing

Ch 2200– Kamilaroi Highway, Sealed Crossing

Ch. 2450 – Alama Road Unsealed Crossing

Ch 2450 – Damage Adjacent to Alama Road

Ch. 3600 – Unformed Crossing, S End of River Rd.

Ch. 3600 – Unformed Crossing, S End of River Rd.

Ch. 4550 – Culgoora Road, Sealed Crossing

Ch 4700 –Eastern Narrabri/Walgett Rail Crossing

Ch. 4700– Flood Gate for Eastern Rail Crossing

Ch 4700 –Eastern Narrabri/Walgett Rail Crossing

Ch. 5600 – Leap Road, Sealed Crossing

Ch 6700 – Trucking Yard Lane, Unsealed Crossing

Ch 6700 – Trucking Yard Lane, Unsealed Crossing

Ch 6900 – Western Narrabri Walgett Rail Crossing

Ch 6900 – Western Narrabri Walgett Rail Crossing

Ch 6900 – Western Narrabri Walgett Rail Crossing

Ch. 6700 – Flood Gate for Western Rail Crossing

Ch. 7100 – Boolcarrol Road, Sealed Crossing

Ch. 8200 – Unformed Crossing

Ch 8200 –Unformed Crossing

Ch. 8600 – Myalla Lane, Unformed Crossing

APPENDIX C

Cracking Photographs

Ch. 7950 – Crack River Side of Crest

Ch 50.– Crack Town Side of Crest

Ch. 50 – Crack River Side of Crest

Ch. 1600 – Crack Town Side of Crest

APPENDIX D

Vegetation Photographs

Ch. 2000 – Large Vegetation

Ch 2900 – Ponding Water at Town Side Toe

Ch. 3400 – Ponding Water at Town Side Toe

Ch 4030 – Lagoon at River Side Toe

Ch. 4050 – Reno Mattress at River Side Toe

Ch 4050 – Lagoon at River Side Toe

Ch. 4770 – Large Vegetation

Ch. 4900 – Large Vegetation

Ch. 7500 – Ponding Water on Town Side Toe

APPENDIX C

UPDATED FLOOD MODELLING

TABLE OF CONTENTS

Page No.

ANNEXURES

FIGURES
(BOUND IN VOLUME 2)

C1. BACKGROUND INFORMATION

C1.1. Summary of Available Data

Data collected for the purpose of the present study included:

- Stream flow data recorded at seven telemetered stream gauges that are operated by WaterNSW. The location of the seven stream gauges are shown on **Figure 1.1** of the Main Report, while their commencement dates are set out in **Table C1.1**. **Annexure A** of this Appendix contains annual maximum peak flow data for the Mollee stream gauge.

TABLE C1.1
DETAILS OF AVAILABLE STREAM FLOW GAUGES

Gauge Number	Gauge Name	Commencement Date
419002	Namoi River at Narrabri	January 1982
419003	Narrabri Creek at Narrabri	August 1891
419039	Namoi River at Mollee	September 1965
419900	Namoi River at Glencoe	May 1995
419060	Namoi River at Gunidgera Weir – Storage Gauge	November 1975
419059	Namoi River at Downstream Gunidgera Weir	April 1976
419061	Gunudgera Creek at Downstream Regulator	July 1975

- **Figure 1.1** of the Main Report shows the extent of the five sets of LiDAR survey data that were relied upon as part of the present study, the capture dates of which are set out in **Table C1.2**. The data comprising each set were captured to the *International Committee on Surveying and Mapping Level 3* standard with a 95% confidence interval on horizontal accuracy of ±800 mm and a 95% confidence interval on vertical accuracy of ± 150 mm.

TABLE C1.2
LiDAR SURVEY DATA SPECIFICATIONS

Data Set	Date of Capture
Wee Waa Town	July 2012
AAMHATCH(1)	February 2009
Narrabri North West	June 2014
GA_5m(2,3)	October 2013
GA_1m(2,3)	

1. The AAMHATCH LiDAR survey data was used to defined natural surface levels as part of URS, 2015.
2. Geoscience Australia LiDAR survey data provided by DPIE at commencement of study.
3. The GA_5m and GA_1m LiDAR survey data were raised by 270 and 290 mm, respectively in order to provide a better fit with the Wee Waa Town, AAMHATCH and Narrabri North West data sets.

- Field survey provided by Council which was undertaken in 2002 along the crest of the Town Levee. The survey was used to set the crest elevation of the Town Levee in the Flood Study TUFLOW Model. Field survey along the crest undertaken by Public Works in 2013 was also provided by DPIE.

  A review of the data found that the crest levels captured by the 2002 field survey are about 200 mm lower when compared with the Wee Waa Town and AAMHATCH LiDAR survey data, while the crest elevations contains in the 2013 field survey closely match the LiDAR survey data. Based on this finding, the 2002 field survey is not considered suitable for use in defining the crest level of the Town Levee.

- Aerial photography provided by Council covering a 240 km^2 area of the Namoi River floodplain in the vicinity of Wee Waa captured on 24 July 1998 when water levels reached RL 7.39 m of the Glencoe stream gauge.
- GIS based data sets including cadastre and watercourse information that were extracted from the NSW Government's *Spatial Information Exchange* website. **Figure 1.1** of the Main Report shows the layout of the drainage system in the vicinity of Wee Waa.
- GIS based data sets including land ownership and stormwater pit and pipe data as compiled by Council. **Figure 2.1** (2 sheets) of the Main Report shows the layout of the drainage system at Wee Waa, as well as the extent of Crown and Council Owned land.
- A number of previous studies which contain flood related information at Wee Waa (refer **Section C2.2** for further details).

C1.2. Previous Investigations

C1.2.1. General

A number of reports which deal with flooding on the Namoi River floodplain in the vicinity of Wee Waa have been commissioned by the NSW Government and Council. **Sections C1.2.2** to **C1.2.5** provide a brief summary of the reports that were relied upon for the hydrologic and hydraulic modelling undertaken as part of the present study.

Additional reports reviewed as part of the study include:

- *NSW Inland Rivers Flood Plain Management Studies - Namoi Valley* (Laurie, Montgomerie & Pettit Pty. Ltd. (**LM&P**), 1982)
- *Audit of Flood Levees for NSW – Town of Wee Waa* (PW, 1992)
- *Report on Geotechnical Investigation – Wee Waa Flood Levee* (Douglas & Partners (**D&P**), 1993)
- *Wee Waa Levee Rehabilitation* (DWR, 1994)
- *Wee Waa Flood Levee – Review of Levee Design* (Patterson Consulting Pty. Ltd., 1995)
- *Narrabri - Wee Waa Floodplain Management Study* (Department of Infrastructure, Planning & Natural Resources (**DIPNR**), 2005)
- *Wee Waa Inspection Report* (PW, 2012)
- *Visual Audit of Wee Waa Levee* (PW, 2013)

C1.2.2. Narrabri - Wee Waa Flood Study (DIPNR, 2003)

The *Narrabri – Wee Waa Flood Study* (DIPNR, 2003) contains a detailed description of flooding patterns on the Namoi River floodplain between the Mollee stream gauge and a location about 14 km west (downstream) of Wee Waa based on the results of modelling that was developed using the MIKE 11 Software.

The MIKE 11 model was run for the February 1955, January 1964, February 1971, February 1984 and July 1998 flood events, as well as a design flood event with an AEP of1 per cent.[1]

C1.2.3. Wee Waa Levee Flood Investigation (URS, 2015)

The *Wee Waa Levee Flood Investigation* prepared by URS in 2015 (***Flood Study***) defined flooding patterns along a 16 km reach of the Namoi River in the vicinity of Wee Waa in order to assess the level of protection that the Town Levee provides the town. **Figure 1.1** of the Main Report shows the extent of Flood Study TUFLOW Model. Discharge hydrographs were extracted from the MIKE 11 model that was developed as part of DIPNR, 2003 and input at the upstream boundary of the Flood Study TUFLOW Model.

The Flood Study TUFLOW Model was calibrated to flood marks that were recorded during the February 1971, February 1984 and July 1998 floods. The calibrated Flood Study TUFLOW Model was then used to define flooding patterns at Wee Waa for the 1% AEP and Extreme Flood events. The hydraulic modelling that was undertaken as part of the Flood Study assumed that the existing rural levees on the Namoi River floodplain were elevated above the Extreme Flood level.

Table C1.3 sets out the peak flow estimates at Mollee and Wee Waa for the historic and design flood events modelled as part of the *Flood Study*. For comparative purposes the corresponding peak flows relied upon for the present study are also given.

The *Flood Study* found that crest of the Town Levee would be overtopped at multiple locations during a 1% AEP flood event, with floodwater shown to pond at the western end of the township to depths of up to about 1.0 m.

C1.2.4. Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully (WRM, 2016)

The *Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully* (WRM, 2016) defines flooding behaviour along the Namoi River and its anabranch at Narrabri (known as Narrabri Creek), as well as the Mulgate Creek and Long Gully tributaries.

WRM, 2016 derived an annual series of total peak flows for a 116 year period between 1890 and 2015[2] at Narrabri by combining the recorded peak flows at the Narrabri Creek and Namoi River at Narrabri stream gauges. **Table C1.4** gives the design peak flow estimates that were derived by a flood frequency analysis that was undertaken as part of WRM, 2016 for the total peak flow at Narrabri using the aforementioned 116 years of annual peak flow data.

[1] Note that DIPNR, 2003 doesn't provide any background to the derivation of the 1% AEP discharge hydrograph at the Mollee stream gauge. Based on DIPNR, 2003, a flow rate of 6,672 m^3/s was adopted as the peak 1% AEP flow on the Namoi River at Mollee.

[2] Annual peak flows were not derived for the period between 1900 and 1907, as well as 1909 and 1911.

TABLE C1.3
PREVIOUSLY DERIVED DESIGN PEAK FLOW ESTIMATES
AT MOLLEE AND WEE WAA

Flood Event	*Flood Study*		Present Study	
	Mollee Stream Gauge(1)	Wee Waa(2)	Mollee Stream Gauge(1)	Wee Waa(3)
February 1971	2,847	2,022	2,898(4)	-
February 1984	2,234	1,655	1,884(4)	-
July 1998	2,280	1,681	1,807(4)	-
1% AEP	6,672	4,302	4,400(5)	2,935
Extreme Flood(6)	20,016	12,907	13,200	8,805

1. Derived as part of DIPNR, 2003.
2. Derived using the MIKE 11 model that was developed as part of DIPNR, 2003.
3. Derived using the MIKE 21 model that was developed as part of DPIW, 2017.
4. Derived using the DPIE Derived Rating Curve shown on **Figure C1.2** (refer **Section C1.3.1** for discussion).
5. Peak 1% AEP discharge at Mollee derived from flood frequency analysis undertaken as part of present study (refer **Section C1.3.2** for discussion).
6. Derived by increasing the 1% AEP peak flow by factor of three.

TABLE C1.4
PREVIOUSLY DERIVED DESIGN PEAK FLOW ESTIMATES
AT NARRABRI AND MOLLEE

AEP (%)	Narrabri (WRM, 2016)	Mollee Stream Gauge (Present Study)
20	1,070	910
10	1,980	1,740
5	2,920	2,600
2	4,090	3,700
1	4,860	4,400
Extreme Flood	14,580	13,200

A set of design discharge hydrographs were then generated by factoring the ordinates of the discharge hydrograph that was recorded during the January 1974 flood. The design discharge hydrographs were input to a MIKE Flood FM model that was developed as part of the study and routed along a 23 km reach of the Namoi River to the location of the Mollee Stream gauge.

Figure C1.1 shows the relationship of annual peak flows at Narrabri and Mollee for the period 2015 to 1971. Also included on the figure is a comparison of the peak flow that was recorded for the February 1955 flood. By inspection, with the exception of a few years, in general the peak flow in the Namoi River at Mollee is less than that at Narrabri for a given flood event. Based on the findings of WRM, 2016 which estimated the peak 1% AEP flow at Narrabri to be 4,860 m³/s, it follows that the peak 1% AEP flow at Mollee should be less than this value. This finding indicates that the previously adopted peak 1% AEP flow rate of 6,672 m³/s at Mollee is too high, which in turn has resulted in an over-estimate of peak 1% AEP flood levels along the Town Levee. Based on this finding, DPIE requested that a flood frequency analysis be undertaken as part of the present study for the Mollee stream gauge (refer **Section C2.3** for details).

C1.2.5. Floodplain Management Plan for the Lower Namoi Valley Floodplain 2018 (DPIW, 2017)

The *Floodplain Management Plan for the Lower Namoi Valley Floodplain* (Department of Primary Industries – Water (**DPIW**), 2017) was undertaken to inform local landholders and the wider community about how the rural floodplain management planning approach presented in the *Rural Floodplain Management Plans: Technical manual for plans developed under the Water Management Act 2000* has been applied across the Lower Namoi Valley floodplain.

The MIKE 11 model developed as part of DIPNR, 2003 was updated using the MIKE 21 software and extended about 120 km west (downstream) along the Namoi River to Walgett. DPIE provided the MIKE 21 results for the February 1984 flood, as well as a flood that occurred in December 2004 which was equivalent to about a 13% AEP flood at Mollee. The MIKE 21 results were used to determine the downstream boundary condition (i.e. flood slope) of the Namoi River TUFLOW Model that was developed as part of the present study.

C1.3. Analysis of Available Stream Gauge Data

C1.3.1. General

A manually-read stream gauge was first installed on the Namoi River at Mollee in September 1965, while WaterNSW installed a telemetered stream gauge at the same location in October 1972. Annual maximum data for the February 1955 and February 1971 floods were provided by DPIE at the commencement of the present study, while the correlation between annual flood peaks at Narrabri and Mollee (refer **Figure C12.1**) was used to derive the annual maximum flow data for the 63 years between 1908 and when the telemetered gauge was first installed.

Figure C1.2 shows historic rating tables representing pre- and post-1971 floodplain conditions in the vicinity of the stream gauge which were derived from the MIKE 21 model developed as part of DPIW, 2017. **Figure C1.2** also shows the then current rating table which was downloaded from WaterNSW's website (WaterNSW Rating Table No. 314.05). The pre- and post-1971 rating curves were used to derive annual maximum flows from the recorded heights at the stream gauge.

Figure C1.2 also shows the 429 gaugings that have been undertaken at the gauge site since 1965. The highest gauged <u>height</u> at the site was taken on 2 February 2012 when the water level reached RL 7.84 m, when the gauged flow in the river at the time was 1,169 m³/s. However, the highest gauged <u>discharge</u> of 1,574 m³/s was recorded on 24 November 2000 when the water level reached RL 7.63 m on the gauge.

Table 2.3 in the Main Report lists the ten largest floods that have occurred in the Namoi River at Narrabri and Mollee since records commence in 1890. Included in the table are the corresponding peak flows based on the rating curve that was current at the time of the flood, as well as the DPIE rating curves shown on **Figure C1.2** and the correlation shown on **Figure C1.1**.[3] **Table 2.3** shows that three of the five largest floods to occur in the Namoi River occurred prior to the commencement of records at the Mollee stream gauge.

C1.3.2. Annual Flood Frequency Analysis

A log-Pearson Type 3 (**LP3**) distribution was fitted to the annual series of flood peaks for the 46 year period of continuous record since installation of the telemetered stream gauge at Mollee (i.e. 1971-2016) using the FLIKE software. The resulting frequency curves, along with 5% and 95% confidence limits are shown on **Figure C1.3** (refer left hand side (**LHS**) of Sheet 1).

As the recorded flood peaks are only a small sample of peaks actually occurring over a longer period, an expected probability adjustment was made using the procedure set out in *Australian Rainfall and Runoff* (***ARR***) (Geoscience Australia (**GA**), 2016). GA, 2016 recommends implementing the expected probability adjustment to remove bias from the estimate. **Column B** in **Table C1.5** at the end of this chapter gives the peak flow estimates for a range of AEP's as derived from the above analysis.

Values at the low end of the observed range of flood peaks can distort the fitted probability distribution and affect the estimates of large floods. Deletion of these low values may improve the fit to the remaining data. The right hand side (**RHS**) of **Figure C1.3**, sheet 1 and **Column C** in **Table C1.5** shows the results of omitting the 32 annual flows less than 500 m^3/s from the analysis and applying the expected probability adjustment to the remaining data.

The flood of record at the gauge site occurred prior to the establishment of the telemetered gauge in February 1955. The inclusion of this flood in the flood frequency analysis increased the estimate of the 1% AEP flood from 5,800 m^3/s to 7,700 m^3/s (refer LHS of **Figure C1.3**, sheet 2 and **Column D** of **Table C1.5**). The RHS of **Figure C1.3**, sheet 2 and **Column E** of **Table C1.5** show the result of omitting flows less than 500 m^3/s from the data set that includes the February 1955 flood event.

It is noted that estimates of the peak 1% AEP flow at Mollee set out in columns B, D and E of **Table C1.5** are higher than the peak 1% AEP flow estimate that was derived as part of WRM, 2016 at Narrabri. This finding is inconsistent with the historic flow record which shows that the flood wave is typically attenuated between Narrabri and Mollee, resulting in lower peak flows at the downstream gauge site. The reason for the higher flow estimate at Mollee is attributed to the relatively short period of record and the fact that three of the five largest floods to have occurred in the Namoi River in the past 100 plus years occurred prior to the February 1955 flood event.

[3] Refer **Annexure A** which contains a list of the adopted annual series of flood peaks. Note that the "*Pre-1971 DPIE Rating Curve*" in **Figure C1.2** has been used for deriving peak flow estimates for 1955 and 1971 and the "*Post-1971 DPIE Rating Curve*" has been used for the period between 1972 and 2016. The correlation between peak flows at Narrabri and Mollee shown on **Figure C1.1** was used to derive peak flow estimates for the remaining years between 1908 and 1970.

Estimates were derived of the peak flow at Mollee based on the recorded flow at Narrabri and the relationship shown in Figure C2.1 for the period 1908 to 1970. The LHS of **Figure C1.3**, sheet 3 and **Column F** of **Table C1.5** shows that including the annual series of flood peaks for the 109 year period of continuous record from 1908 to 2016 reduced the peak 1% AEP flow estimate to 4,800 m^3/s. Omission of the 73 annual flows less than 500 m^3/s from the analysis and applying the expected probability adjustment to the remaining data further reduced the peak 1% AEP flow estimate to 4,400 m^3/s (refer RHS of **Figure C1.3**, sheet 3 and **Column G** of **Table C1.5**).

The results of the LP3 analysis show that the inclusion of low flows leads to a degree of positive skew in the fitted distribution which increases the estimate of peak flows for the larger, less frequent floods. By comparison, the fitted probability distribution for the case where low flows were omitted provides a better fit to the historic data.

An analysis was also carried out by fitting the annual series of flood peaks to the General Extreme Value (**GEV**) distribution using LH moments. **Figure C1.4** shows the results for both the 109 year period of record and after the 73 annual flows less than 500 m^3/s are omitted from the analysis.

The GEV distribution was found to be very sensitive to the inclusion of low flows for the larger, less frequent floods. The estimated peak discharge when low flows are included (refer **Column H** of **Table C1.5**) are almost double those derived when the 73 annual flows less than 500 m^3/s are omitted (refer **Column I** of **Table C1.5**) for AEP's less than 1 per cent. Comparison of **Columns G** and **I** of **Table C1.5** show that fitting the annual series of flood peaks for the 109 year period of record but omitting flows less than 500 m^3/s to the LP3 and GEV distribution gives similar design peak flow estimates at Mollee.

Based on the above findings, the peak flow estimates given in **Column G** of **Table C1.5**, as well as those derived from the relationship shown on the RHS of **Figure C1.3**, sheet 3 have been given greatest weight when deriving design discharge hydrographs for input to the hydraulic model. **Table C1.2** shows that the peak 1% AEP flow estimate derived as part of the present study is two-thirds that derived as part of DIPNR, 2003 and utilised in the *Flood Study*.

TABLE C1.5
ESTIMATES OF DESIGN PEAK FLOWS AT MOLEE STREAM GAUGE
VALUES IN m^3/s

Annual Exceedance Probability % AEP	LP3 Distribution						GEV Distribution	
	1971-2016 Full Period of Record	1971-2016 Low Flows Omitted(1)	1971-2016 Plus Historic (1955) Full Period of Record	1971-2016 Plus Historic (1955) Low Flows Omitted(1)	1908-2016(2) Full Period of Record	1908-2016(2) Low Flows Omitted(1)	1908-2016(2) Full Period of Record	1908-2016(2) Low Flows Omitted(1)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]
20	870	940	920	940	910	910	870	990
5	2,300	2,500	2,750	3,100	2,200	2,600	2,400	2,450
2	3,900	3,300	4,950	4,900	3,500	3,700	4,600	3,450
1	5,800	3,850	7,700	6,700	4,800	4,400	7,400	4,300
0.5	8,600	-	11,700	9,300	6,600	5,000	11,900	5,300
0.2	14,700	-	21,000	14,500	9,750	5,850	23,000	7,000

1. Peak flows lower than 500 m^3/s omitted.
2. Peak discharge for the period 1908 to 1971 (excluding 1955) derived from the correlation between peak flows at Narrabri and Mollee shown on **Figure C1.1**.

C2. HYDROLOGIC MODEL DEVELOPMENT AND CALIBRATION

C2.1. Hydrologic Modelling Approach

The present study required the use of a hydrologic model that is capable of representing the rainfall-runoff processes that occur within the area that is protected by the Town Levee. Given its flat nature and the ill-defined nature of the existing drainage paths, the hydrologic response of the protected area was simulated using the direct-rainfall-on-grid approach which is built into the TUFLOW software.

C2.2. Hydrologic Model Tuning

There were no historic data on peak flows and flood levels that have been experienced in the protected area post the construction of the Town Levee to allow the TUFLOW model to be calibrated. The procedure adopted for the testing of the hydrologic model therefore involved an iterative process sometimes referred to as “tuning”.

The process usually involves adjusting the hydrologic parameters until the peak flows generated by the model give a good match to those derived using the Probabilistic Rational Method (**PRM**) Model, procedures for which are set out in IEAust, 1987. However, as the protected area is so flat, it was not possible to obtain a reasonable match with peak flow estimates derived using the PRM.

As a result, an initial loss of 15 mm and a continuing loss of 2.5 mm/hr were adopted in order to derive discharge hydrographs for design storms which were then used as input to the TUFLOW model.

C3. HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

C3.1. General

The present study required the use of a hydraulic model which is capable of analysing the time varying effects of flow in the Namoi River and the local stormwater drainage system and the two-dimensional nature of flow on both the floodplain and in the area behind the Town Levee. The TUFLOW modelling software was adopted as it is one of only a few commercially available hydraulic models which contain all the required features.

This chapter deals with the development of the Namoi River and Wee Waa TUFLOW Models that were used to define flooding behaviour on either side of the Town Levee.

C3.2. Brief Review of TUFLOW Modelling Approach

TUFLOW is a true two-dimensional hydraulic model which does not rely on a prior knowledge of the pattern of flood flows in order to set up the various fluvial and weir type linkages which describe the passage of a flood wave through the system.

The basic equations of TUFLOW involve all of the terms of the St Venant equations of unsteady flow. Consequently the model is "fully dynamic" and once tuned will provide an accurate representation of the passage of the flood wave through the drainage system (both surface and piped) in terms of extent, depth, velocity and distribution of flow.

TUFLOW solves the equations of flow at each point of a rectangular grid system which represent overland flow on the floodplain. The choice of grid point spacing depends on the need to accurately represent features on the floodplain which influence hydraulic behaviour and flow patterns (e.g. buildings, streets, changes in channel and floodplain dimensions, hydraulic structures which influence flow patterns, etc.).

Pipe drainage and channel systems can be modelled as one-dimensional elements embedded in the larger two-dimensional domain which typically represents the wider floodplain. Flows are able to move between the one and two-dimensional elements of the model depending on the capacity characteristics of the drainage system being modelled.

The Namoi River and Wee Waa TUFLOW Models also allow for the assessment of potential flood management measures, such as the upgrade of the Town Levee and the existing stormwater drainage system.

C3.3. TUFLOW Model Setup

The extent of the Flood Study TUFLOW Model matched that of the AAMHATCH LiDAR survey data which only covered Wee Waa and its immediate environs. The plan extent of the Flood Study TUFLOW Model was increased to form the Namoi River TUFLOW Model as follows:

- The two-dimensional model boundary was extended approximately 1.0 km to the east and 4.0 km to the north so that the flow in the flood runners to the north of Wee Waa were included in the model.
- The two-dimensional model boundary was extended approximately 3.5 km to the west in order to reduce the impact the downstream boundary condition has on flooding patterns nearer the town.

The layout of the Namoi River TUFLOW Model is shown on **Figure C3.1**. The model comprises a 26 km reach of the Namoi River within the two-dimensional (in plan) model domain using a grid based approach. A 40 m grid spacing was found to provide the appropriate balance between the need to define features along the various flow paths versus model run times.

The layout of the Wee Waa TUFLOW Model is shown on **Figure C3.2**. The model comprises the area which lies on the protected side of the Town Levee. A 5 m grid spacing was adopted for the Wee Waa TUFLOW Model in order to more accurately define the passage of overland flow through the urbanised parts of town.

Ground surface elevations for model grid points were initially assigned using a Digital Terrain Model (**DTM**) derived from the LiDAR survey data sets out in **Table C1.2**. Ridge and gully lines were added to the model where the grid spacing was considered too coarse to accurately represent important topographic features. Ridge lines were added to the model to define the crest elevations of the Town Levee, as well as those of the network of rural levees.[4]

The footprints of a large number of the individual buildings protected by the Town Levee were incorporated in the Wee Waa TUFLOW Model and assigned an artificially high hydraulic roughness value which accounted for their blocking effect on flow while maintaining storage in the model. Individual allotments where development is present were also digitised and assigned an artificially high hydraulic roughness value (although not as high as for individual buildings) to account for the reduction in conveyance capacity which will result from fences and other obstructions stored on these properties.

Figure C3.2 shows the piped drainage system that were incorporated in the Wee Waa TUFLOW Model based on information contained in Council's asset database. The dimensions of the piped elements were taken from the Council's database where available and supplemented by field measurements. Limited information was available on pipe invert levels. Therefore an assumed cover of 700 mm was adopted for those drainage elements where invert levels or depth measurements were not available. Adjustments were made to the assumed invert levels where this approach resulted in a negatively graded reach of pipe or culvert.

Several types of pits are also identified on **Figure C3.2**, including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. Council's asset database did not contain any information in regard to inlet pit types and dimensions. Therefore, inlet capacity relationships for incorporation in the TUFLOW model were derived based on visual inspection of the pit.

Pit losses throughout the various piped drainage networks were modelled using the Engelhund approach in TUFLOW. This approach provides an automatic method for determining time-varying energy loss coefficients at pipe junctions that are recalculated each time step based on a range of variables including the inlet/outlet flow distribution, the depth of water within the pit, expansion and contraction of flow through the pit, and the horizontal deflection and vertical drop across the pit.

Table C3.1 summarises the pit and pipe data that were incorporated into the TUFLOW model.

[4] The majority of the licences held by the landowners on the rural floodplain do not place height restrictions on the elevation of the rural levees. Therefore it is possible that these levees could be raised above the height of the PMF in the future. A sensitivity analysis to assess the impact that the potential raising of these levees would have on peak flood levels at Wee Waa is presented in **Section 2.9** of the Main Report.

TABLE C3.1
SUMMARY OF MODELLED DRAINAGE STRUCTURES

Element	Number	Length (m)
Pipes	148	4000
Box Culverts	59	950
Headwalls	246	-
Inlet Pits	58	-
Junction Pits	24	-

Figure C3.2 shows the plan location of the fourteen (14) penstock gates and six (6) permanent stormwater evacuation pumps that were also incorporated in the Wee Waa TUFLOW Model.[5]

C3.4. Model Boundary Conditions

The design discharge hydrographs derived as part of the present study at the Mollee stream gauge were run through the MIKE 21 model that was developed as part of DPIW, 2017 (refer **Chapter C4** for details). The locations where discharge hydrographs were extracted from the MIKE 21 model results and input to the Namoi River TUFLOW Model is shown on **Figure C3.1**.

As mentioned, rainfall was directly applied to the grid of the Wee Waa TUFLOW Model. TUFLOW converted the rainfall to runoff and routed the resulting overland flow to the fourteen (14) penstock gated pipes which extend through the Town Levee. Direct application of rainfall to the natural surface is a recent development and is part of the TUFLOW modelling system. While direct application should be used with caution as it has the potential to over-attenuate overland flows, it has considerable advantages in situations where the flow paths are relatively indistinct and are difficult to "map" by eye. In effect, the grid of the TUFLOW geometric model of the floodplain defines the flow paths automatically.

The downstream boundaries of the two models comprised a "free discharge" outlet, where a TUFLOW derived normal depth calculation was used to define hydraulic conditions at the outlet of both models.

C3.5. Model Roughness

The main physical parameter for TUFLOW is the hydraulic roughness. Hydraulic roughness is required for each of the various types of surfaces comprising the overland flow paths. In addition to the energy lost by bed friction, obstructions to flow also dissipate energy by forcing water to change direction and velocity and by forming eddies. Hydraulic modelling traditionally represents all of these effects via the surface roughness parameter known as "Mannings n".

[5] The effect of that trailer mounted pumps which are mobilised on an as needs basis during local catchment flood events have on flooding patterns in Wee Waa was not assessed as part of the present investigation.

Table C3.2 presents the set of hydraulic roughness values that were found by the *Flood Study* to give reasonable correspondence with observed flood behaviour for the February 1971, February 1984 and July 1998 floods. These same values have been applied to the Namoi River TUFLOW Model.

In regards the definition of flooding behaviour in the protected area of Wee Waa, hydraulic roughness values that have been found to give reasonable correspondence with observed flooding behaviour in other rural towns were used as input to the Wee Waa TUFLOW Model (refer **Table C3.2** for values).

TABLE C3.2
"BEST ESTIMATE" OF HYDRAULIC ROUGHNESS VALUES
ADOPTED FOR TUFLOW MODELLING

TUFLOW model	Surface Treatment	Mannings n Value
Flood Study TUFLOW Model and Namoi River TUFLOW Model	Bushes	0.15
	Namoi River Floodplain	0.075
	Namoi River and Watercourses	0.05
	Wetlands / Lagoons	0.045
Wee Waa TUFLOW Model	Grassed Areas	0.045
	Roads	0.02
	Grassed / Paved Inter Allotment Area	0.1
	Buildings	10

Figure C3.3 is a typical example of flow patterns derived from the above roughness values. This example applies for the 1% AEP flood event and shows flows through existing development in the vicinity of Charles Street and Boundary Street.

The left hand side of the figure shows the roads and inter-allotment areas, as well as the outlines of buildings, which have been individually digitised in the model. The right hand side shows the resulting flow paths in the form of scaled velocity vectors and the depths of inundation. The buildings with their high values of hydraulic roughness block the passage of flow, although the model recognises that they store floodwater when inundated and therefore correctly accounts for flood storage. The flow is conveyed via the road reserves and through the open parts of the allotments. Similar information to that shown on **Figure C3.3** may be presented at any location within the model domain (which is shown on **Figures C3.1** and **C3.2**) and will be of assistance to Council in assessing individual flooding problems in the floodplain.

C4. DERIVATION OF DESIGN DISCHARGE HYDROGRAPHS

C4.1. Namoi River Flooding

A set of design discharge hydrographs at Mollee (refer **Figure C4.1**) were derived by factoring the ordinates of the 1% AEP design discharge hydrograph presented in DIPNR, 2003 so that their peaks matched the values given in **Column G** of **Table C2.5**. The design discharge hydrographs were then input to the MIKE 21 model that was developed as part of DPIW, 2017 and routed downstream to Wee Waa. **Figure C4.2** shows the design discharge hydrographs that were extracted from the MIKE 21 model and used as input to the Namoi River TUFLOW model. The locations where these hydrographs were input to the Namoi River TUFLOW Model are shown on **Figure C3.1**, sheet 1.

As required by the Study Brief, the Extreme Flood was assumed to have a peak flow three (3) times that of the 1% AEP flood at Wee Waa.

C4.2. Local Catchment Flooding

C4.2.1. Rainfall Intensity

The procedures used to obtain temporally and spatially accurate and consistent Intensity-Frequency-Duration (**IFD**) design rainfall curves for the assessment of local catchment flooding behind the Town Levee are presented in IEAust, 1987. Design storms for frequencies of 5, 2, 1, 0.5 and 0.2% AEP were derived for storm durations ranging between 25 minutes and three days. The IFD dataset was downloaded from the BoM's *1987 Rainfall IFD Data System*.

C4.2.2. Areal Reduction Factors

The rainfalls derived using the processes outlined in IEAust, 1987 are applicable strictly to a point. In the case of a catchment of over tens of square kilometres area, it is not realistic to assume that the same rainfall intensity can be maintained. An Areal Reduction Factor (**ARF**) is typically applied to obtain an intensity that is applicable over the entire catchment.

However, as the local catchment at Wee Waa is relatively small, the reduction in rainfall intensity would be quite small. Accordingly, no reduction in design point rainfalls was made for this present study (i.e. an ARF of 1.0 was adopted).

C4.2.3. Temporal Patterns

Temporal patterns for various zones in Australia are presented in IEAust, 1987. These patterns are used in the conversion of a design rainfall depth with a specific AEP into a design flood of the same frequency. Patterns of average variability are assumed to provide the desired conversion. The patterns may be used for AEP's up to 0.2 per cent where the design rainfall data is extrapolated for storms with an AEP less than 1 per cent.

The derivation of temporal patterns for design storms are discussed in Volume 1 of IEAust, 1987 and separate patterns are presented in Volume 2 of IEAust, 1987 for AEP's ≥ 3.3 per cent and AEP's < 3.3 per cent. The second pattern is intended for use for rainfalls with AEP's down to 1 per cent, and down to 0.2 per cent in those cases where the design rainfall data in IEAust, 1987 are extrapolated for larger AEP's.

C4.2.4. Probable Maximum Precipitation

Estimates of PMP were made using the Generalised Short Duration Method (**GSDM**) as described in BoM, 2003. This method is appropriate for estimating extreme rainfall depths for catchments up to 1,000 km^2 in area and storm durations up to six hours.

The steps involved in assessing PMP for each study catchment are briefly as follows:

- Calculate PMP for a given duration and catchment area using depth-duration-area envelope curves derived from the highest recorded US and Australian rainfalls.
- Adjust the PMP estimate according to the percentages of the catchment which are meteorologically rough and smooth, and also according to elevation adjustment and moisture adjustment factors.
- Assess the design spatial distribution of rainfall using the distribution for convective storms based on US and world data, but modified in the light of Australian experience.
- Derive storm hyetographs using the temporal distribution contained in BoM, 2003, which is based on pluviographic traces recorded in major Australian storms.

C5. REFERENCES

BoM (Bureau of Meteorology), 2003. ***"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"***.

DECCW (Department of Environment, Climate Change and Water, NSW), 2007b. ***"Floodplain Risk Management Guideline – Practical Considerations of Climate Change"***.

D&P (Douglas & Partners), 1993. ***"Report on Geotechnical Investigation – Wee Waa Flood Levee"***

DIPNR (Department of Infrastructure, Planning and Natural Resources), 2003. ***"Narrabri-Wee Waa Flood Study"***

DIPNR, 2005. ***"Narrabri - Wee Waa Floodplain Management Study"***

DPIW (NSW Department of Primary Industries – Water), 2018. ***"Floodplain Management Plan for the Lower Namoi Valley Floodplain"***

Department of Water Resources (DWR), 1994. ***"Wee Waa Levee Rehabilitation"***

EA (Engineers Australia), 2013. ***"Australian Rainfall & Runoff - Revision Projects – Project 11 – Blockage of Hydraulic Structures"***. Stage 2 Report P11/S2/021 dated February 2013.

IEAust (The Institution of Engineers Australia), 1987. ***"Australian Rainfall and Runoff – A Guide to Flood Estimation"***, Volumes 1 and 2.

GA (Geoscience Australia), 2016. ***"Australian Rainfall and Runoff, A Guide to Flood Estimation"***.

LM&P (Laurie, Montgomerie & Pettit Pty. Ltd.), 1982. ***"NSW Inland Rivers Flood Plain Management Studies - Namoi Valley"***

O'Loughlin, 1993. ***"The ILSAX Program for Urban Stormwater Drainage Design and Analysis (User's manual for Microcomputer Version 2.13)"***, Civil Engineering Monograph 93/1, University of Technology, Sydney (5th printing, 1st version 1986).

NSWG (New South Wales Government), 2005. ***"Floodplain Development Manual"***

NSW SES (NSW State Emergency Service), 2015. ***"Narrabri Shire Local Flood Plan"***

Patterson Consulting Pty. Ltd., 1995. ***"Wee Waa Flood Levee – Review of Levee Design"***

PW, (Public Works), 1992. ***"Audit of Flood Levees for NSW – Town of Wee Waa"***

PW, 2012. ***"Wee Waa Inspection Report"***

PW, 2013. ***"Visual Audit of Wee Waa Levee"***

URS, 2015. ***"Wee Waa Levee Flood Investigation"***

WRM, 2016. ***"Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully"***

ANNEXURE A

NAMOI RIVER AT MOLLEE
STREAM GAUGE DATA (GS 419039)

TABLE A1
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
NAMOI RIVER AT MOLLEE STREAM GAUGE

Year	Gauge Height[(1)] (m)	Discharge[(2)] (m^3/s)
1908	-	[2272]
1909	-	-[(3)]
1910	-	[4103]
1911	-	-[(3)]
1912	-	[143]
1913	-	[543]
1914	-	[188]
1915	-	[575]
1916	-	[1071]
1917	-	[806]
1918	-	[343]
1919	-	[153]
1920	-	[2984]
1921	-	[1713]
1922	-	[407]
1923	-	[300]
1924	-	[1040]
1925	-	[184]
1926	-	[224]
1927	-	[311]
1928	-	[579]
1929	-	[274]
1930	-	[336]
1931	-	[1523]
1932	-	[206]
1933	-	[541]
1934	-	[743]
1935	-	[446]
1936	-	[359]

Refer over for footnotes to table.

TABLE A1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
NAMOI RIVER AT MOLLEE STREAM GAUGE

Year	Gauge Height(1) (m)	Discharge(2) (m^3/s)
1937	-	[236]
1938	-	[282]
1939	-	[258]
1940	-	[292]
1941	-	[995]
1942	-	[1213]
1943	-	[342]
1944	-	[398]
1945	-	[366]
1946	-	[207]
1947	-	[440]
1948	-	[380]
1949	-	[788]
1950	-	[1490]
1951	-	[321]
1952	-	[1109]
1953	-	[207]
1954	-	[420]
1955	8.94	4,183
1956	-	[2119]
1957	-	[143]
1958	-	[342]
1959	-	[201]
1960	-	[403]
1961	-	[176]
1962	-	[883]
1963	-	[342]
1964	-	[1322]
1965	-	[154]

Refer over for footnotes to table.

TABLE A1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
NAMOI RIVER AT MOLLEE STREAM GAUGE

Year	Gauge Height(1) (m)	Discharge(2) (m^3/s)
1966	-	[180]
1967	-	[121]
1968	-	[496]
1969	-	[291]
1970	-	[304]
1971	8.43	2,898
1972	-	[152]
1973	2.97	123
1974	8.16	2,154
1975	3.53	160
1976	8.02	1,828
1977	7.32	872
1978	6.20	380
1979	3.13	134
1980	1.77	61
1981	3.79	180
1982	2.38	90
1983	4.31	218
1984	8.04	1,884
1985	4.39	225
1986	4.10	203
1987	5.01	275
1988	3.82	182
1989	6.87	551
1990	6.62	424
1991	6.40	398
1992	7.05	663
1993	4.34	221
1994	1.10	21

Refer over for footnotes to table.

TABLE A1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
NAMOI RIVER AT MOLLEE STREAM GAUGE

Year	Gauge Height(1) (m)	Discharge(2) (m^3/s)
1995	3.30	145
1996	5.34	303
1997	7.31	864
1998	8.01	1,807
1999	4.28	216
2000	7.97	1,736
2001	3.50	159
2002	2.10	76
2003	2.40	91
2004	7.67	1,220
2005	6.28	387
2006	1.56	51
2007	2.94	122
2008	6.22	382
2009	2.18	80
2010	7.27	825
2011	7.26	820
2012	7.94	1,666
2013	5.08	281
2014	5.63	328
2015	1.24	29
2016	6.43	401

1. With the exception of 1955 and 1971, gauge height records not available prior to 1973.
2. Numbers in [] represent peak discharge derived using a line of best fit analysis between Narrabri (sourced from WRM, 2016) and the Mollee stream gauge in order to estimate annual maximum discharges prior to the establishment of the Mollee stream gauge.
3. Peak discharge at Narrabri not presented in WRM, 2016. Peak discharge assumed to be 100 m^3/s for the purposes of the flood frequency analysis undertaken as part of the present study.

APPENDIX D

FLOOD DAMAGES

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D1 INTRODUCTION AND SCOPE

D1.1 Introduction

Damages from flooding belong to two categories:

- **Tangible Damages**
- **Intangible Damages**

Tangible damages are defined as those to which monetary values may be assigned, and may be subdivided into direct and indirect damages. Direct damages are those caused by physical contact of floodwater with damageable property. They include damages to commercial/industrial and residential building structures and contents, as well as damages to infrastructure services such as electricity and water supply. Indirect damages result from the interruption of community activities, including traffic flows, trade, industrial production, costs to relief agencies, evacuation of people and contents and clean up after the flood.

Generally, tangible damages are estimated in dollar values using survey procedures, interpretation of data from actual floods and research of government files.

The various factors included in the **intangible damage** category may be significant. However, these effects are difficult to quantify due to lack of data and the absence of an accepted method. Such factors may include:

- inconvenience
- isolation
- disruption of family and social activities
- anxiety, pain and suffering, trauma
- physical ill-health
- psychological ill-health.

D1.2 Scope of Investigation

In the following sections, tangible damages to residential, commercial / industrial and public properties have been estimated resulting from flooding at Wee Waa. Intangible damages have not been quantified. The threshold floods at which damages may commence to infrastructure and community assets have also been estimated, mainly from site inspection and interpretation of flood level data. However, there is no data available to allow a quantitative assessment of damages to be made to this category.

D1.3 Terminology

Definitions of the terms used in this Appendix are presented in **Chapter D8** which also summarises the value of Tangible Flood Damages.

D2 DESCRIPTION OF APPROACH

The damage caused by a flood to a particular property is a function of the depth of inundation above floor level and the value of the property and its contents. The warning time available for residents to take action to lift property above floor level also influences damages actually experienced. A spreadsheet model which has been developed by DPIE for estimating residential damages and an in house spreadsheet model which has been developed for previous investigations of this nature for estimating commercial, industrial and public building damages were used to estimate damages on a property by property basis according to the type of development, the location of the property and the depth of inundation.

Using the results of the hydraulic model, a peak flood elevation for each event was interpolated at each property. The interpolated property flood levels were input to the spreadsheet models which also contained property characteristics and depth-damage relationships. The depth of above-floor inundation was computed as the difference between the interpolated flood level and the floor elevation at each property. The elevations of building floors were assessed by adding the height of floor above a representative natural surface within the allotment (as estimated by visual inspection) to the natural surface elevation determined from LiDAR survey data. The type of structure and potential for property damage were also assessed during the visual inspection.

The depth-damage curves for residential damages were determined using procedures described in *Guideline No. 4*. Damage curves for other categories of development (commercial and industrial, public buildings) were derived from previous floodplain management investigations.

Damages to the non-residential sector depend on the nature of the enterprise, the depth of inundation over the floor area and the time available for owners to take action to mitigate losses to contents. A spreadsheet model was used which was similar to the residential model in terms of both surveyed and estimated floor level and estimation of depths of inundation, but used typical unit damage data which had been adopted in similar studies in NSW in recent years.

It should be understood that this approach is not intended to identify individual properties liable to flood damages and the value of damages in individual properties, even though it appears to be capable of doing so. The reason for this caveat lies in the various assumptions used in the procedure, the main ones being:

- the assumption that computed water levels and topographic data used to define flood extents are exact and without any error;
- the assumption that the water levels as computed by the hydraulic model are not subject to localised influences;
- the estimation of property floor levels by visual inspection rather than by formal field survey;
- the use of "average" stage-damage relationships, rather than a unique relationship for each property;
- the uncertainties associated with assessing appropriate factors to convert *potential damages* to *actual flood damages* experienced for each property after residents have taken action to mitigate damages to contents.

The consequence of these assumptions is that some individual properties may be inappropriately classified as flood liable, while others may be excluded. Nevertheless, when applied over a broad area these effects would tend to cancel, and the resulting estimates of overall damages, would be expected to be reasonably accurate.

For the above reasons, the information contained in the spreadsheets used to prepare the estimates of flood damages for the catchments should not be used to provide information on the depths of above-floor inundation of individual properties.

D3 SOURCES OF DATA

D3.1 General

To estimate A*verage Annual Flood Damages* for a specific area it is necessary to estimate the damages for several floods of different magnitudes, i.e. of different frequencies, and then to integrate the area beneath the damage – frequency curve computed over the whole range of frequencies up to the PMF. To do this, it is necessary to have data on the damages sustained by all types of property over the likely range of inundation. There are several ways of doing this:

- The ideal way would be to conduct specific damage surveys in the aftermath of a range of floods, preferably immediately after each. An example approaching this ideal is the case of Nyngan where surveys were conducted in May 1990 following the disastrous flood of a month earlier (DWR, 1990). This approach would not be practicable at Wee Waa, as the damaging flooding in the town only occurred prior to the construction of the Town Levee in 1978.
- The second best way is for experienced loss adjusters to conduct a survey to estimate likely losses that would arise due to various depths of inundation. This approach is used from time to time, but it can add significantly to the cost of a floodplain management study (LMJ, 1985). It was not used for the present investigation.
- The third way is to use generalised data such as that published by CRES (Centre for Resource & Economic Studies, Canberra) and used in the Floodplain Management Study for Forbes (SKM, 1994). These kinds of data are considered to be suitable for generalised studies, such as broad regional studies. They are not considered to be suitable for use in specific areas, unless none of the other approaches can be satisfactorily applied.
- The fourth way is to adapt or transpose data from other flood liable areas. This was the approach used for the present study. As mentioned, the *Guideline No 4* procedure was adopted for the assessment of residential damages. The approach was based on data collected following major flooding in Katherine in 1998, with adjustments to account for changes in values due to inflation, and after taking into account the nature of development and flooding patterns in the study area. The data collected during site inspection in the flood liable areas assisted in providing the necessary adjustments. Commercial and industrial damages were assessed via reference to recent floodplain management investigations undertaken by Lyall and Associates of a similar nature to the present study.

D3.2 Property Data

The properties were divided into three categories: residential, commercial/industrial and public buildings.

For residential properties, the data used in the damages estimation included:

- the location/address of each property
- an assessment of the type of structure
- natural surface level
- floor level

For commercial/industrial and public properties, the required data included:

- the location of each property
- the nature of each enterprise
- an estimation of the floor area
- natural surface level
- floor level

The property information was used to classify the commercial and public developments into categories (i.e. high, medium or low value properties) which relate to the magnitude of likely flood damages.

Properties lying along the Major Overland Flow paths were included in the database. The total number of residential, commercial, industrial and public properties is shown in **Table D3.1**.

TABLE D3.1
NUMBER OF PROPERTIES INCLUDED IN DAMAGES DATABASE

Development Type	Number of Properties
Residential	707
Commercial / Industrial	135
Public	42
Total	884

D3.3 Flood Levels Used in the Analysis

Damages were computed for the design flood levels determined from the hydraulic model that was set up as part of the present investigation (refer **Appendix B** for details). Damages resulting from both local stormwater runoff and riverine flooding were computed for Wee Waa.

In the case of the damages arising from local stormwater runoff, the following three scenarios were assessed:

- No river flooding and gravity drainage of the protected area via the fourteen (14) penstock gated stormwater drainage pipes that control ponding levels behind the Town Levee (**Damage Scenario 1**).
- Pumping of stormwater runoff to the river side of the Town Levee via the six (6) permeant pumps and assuming the fourteen (14) penstock gates are in their closed position and it is not overtopped (**Damage Scenario 2**).
- Failure of the six (6) permanent pumps to operate during a storm event and assuming the fourteen (14) penstock gates are in their closed position and the Town Levee is not overtopped (**Damage Scenario 3**).

In the case of the damages arising from riverine flooding, the following two scenarios were assessed:

- No coincident rainfall over Wee Waa during river flooding (**Damage Scenario 4**).
- No coincident rainfall over Wee Waa during river flooding that causes a partial failure of the Town Levee (**Damage Scenario 5**).

For the purposes of assessing damages, the 10% AEP was adopted as the "threshold" flood at which damages commence in Wee Waa. While not modelled, a Namoi River flood with a 0.1% AEP was assumed to represent the threshold for overtopping of the Town Levee. Flood damages for this event were computed assuming floodwater would pond to the height of the low point in the Town Levee which has an elevation of about RL 192.4 m AHD.

D4 RESIDENTIAL DAMAGES

D4.1 Damage Functions

The procedures identified in *Guideline No 4* allow for the preparation of a depth versus damage relationship which incorporates structural damage to the building, damage to internals and contents, external damages and clean-up costs. In addition, there is the facility for including allowance for accommodation costs and loss of rent. Separate curves are computed for three residential categories:

- Single storey slab on ground construction
- Single storey elevated floor
- Two storey residence

The level of flood awareness and available warning time are taken into account by factors which are used to reduce "potential" damages to contents to "actual" damages. "Potential" damages represent losses likely to be experienced if no action were taken by residents to mitigate impacts. A reduction in the potential damages to "actual" damages is usually made to allow for property evacuation and raising valuables above floor level, which would reduce the damages actually experienced. The ability of residents to take action to reduce flood losses is mainly limited to reductions in damages to contents, as damages to the structure and clean-up costs are not usually capable of significant mitigation.

The reduction in damages to contents is site specific, being dependent on a number of factors related to the time of rise of floodwaters, the recent flood history and flood awareness of residents and emergency planning by the various Government Agencies (BoM and NSW SES).

While there is a well developed and tested flood warning system for the Namoi River operated by BoM, as well as detailed response procedures incorporated in the *Narrabri Local Flood Plan, 2015* developed by NSW SES which are implemented during flood alerts, actions taken by residents and business owners are unlikely to significantly reduce flood damages resulting from an overtopping event (i.e. because depths of inundation would be too great and they are unlikely to relocate contents to another town or remote evacuation centre during a flood event).

Flooding due to local stormwater runoff is "flash flooding" in nature with a time of rise generally limited to less than one hour. While the duration of peak flooding would be similarly short in the absence of riverine flooding, stormwater could be forced to pond for an extended period of time if river levels are elevated and the pumps are in operation. While Council maintains several truck mounted pumps which are used to reduce depths of ponding in several problem areas, these measures are only implemented after a heavy rainfall event. Consequently, there would be very limited time in advance of a storm event in which to warn residents and for them to take action to mitigate flood losses.

Table D4.1 over sets out the parameters and resulting factors that were adopted for converting potential to actual damages after taking into account the differences between the rate of rise and duration of inundation of local stormwater runoff and riverine flooding.

TABLE D4.1
DAMAGE ADJUSTMENT FACTORS/PARAMETERS FOR RESIDENTIAL DEVELOPMENT SUBJECT TO RIVERINE FLOODING AND LOCAL STORMWATER RUNOFF

Property Damage	Parameter/Factor	Local Stormwater Runoff	Riverine Flooding
Building	Typical Duration of Immersion (hours)	36	168
	Building Damage Repair Limitation Factor	1.0	1.0
	Total Building Adjustment Factor	2.02	3.04
Contents	Contents Damage Repair Limitation Factor	0.9	0.9
	Level of Flood Awareness	Low	High
	Effective Warning Time	0	24[1]
	Typical Table/Bench Height (TTBH) (m)	0.9	0.9
	Total Contents Adjustment Factor (Above-Floor Depth <= TTBH)	1.58	0.7
	Total Contents Adjustment Factor (Above-Floor Depth > TTBH)	1.58	1.58

1. Maximum value permitted in damages spreadsheet.

Table D4.2 shows total flood damages estimated for the three classes of residential property using the procedures identified in *Guideline No. 4*, for typical depths of above-floor inundation of 0.3 m and 1.0 m. A typical ground floor area of 240 m^2 was adopted for the assessment. The values in **Table D4.2** allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

TABLE D4.2
DAMAGES TO RESIDENTIAL PROPERTIES

Type of Residential Construction	0.3 m Depth of Inundation Above Floor Level		1.0 m Depth of Inundation Above Floor Level	
	Local Stormwater Runoff	Riverine Flooding	Local Stormwater Runoff	Riverine Flooding
Single Storey Slab on Ground	$87,868	$71,294	$108,451	$126,702
Single Storey High Set	$79,374	$106,916	$120,605	$144,932
Double Storey	$55,562	$49,906	$75,915	$88,691

Note: These values allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

D4.2 Total Residential Damages

Tables D4.3 and **D4.4** at the end of this Chapter summarise residential damages in Wee Waa resulting from local stormwater runoff and riverine flooding, respectively.

The occurrence of a 1% AEP storm event at Wee Waa in the absence of riverine flooding would result in one dwelling experiencing above-floor inundation (**Damage Scenario 1**). The number of dwellings that would experience above-floor inundation would increase to four should a 1% AEP storm event occur when the fourteen (14) penstock gates are closed due to elevated water levels in the river and the pumps are running at full capacity (**Damage Scenario 2**). The upper limit of potential above-floor inundation should all six permanent pumps not be operational during a 1% AEP storm event is limited to 15 dwellings (**Damage Scenario 3**).

The total residential flood damage at the 1% AEP level of flooding due to local stormwater runoff would generally be between about $0.45 Million (**Damage Scenario 1**) and $0.64 Million (**Damage Scenario 2**), but could be as high as about $1.48 Million (**Damage Scenario 3**) should the aforementioned pumps are not operational during the burst of flood producing rain.

During a riverine flood which just overtops the Town Levee and causes equalisation of water levels on both sides of the earthen embankment, a total of 594 dwellings would experience above-floor inundation, with the total residential damage in Wee Waa amounting to about $65 Million (**Damage Scenario 4**). A partial failure of the Town Levee during a 1% AEP riverine flood would also result in similar residential flood damages at Wee Waa (**Damage Scenario 5**).

An Extreme Flood on the Namoi River would result in all but seven out of a total of the 703 dwellings in Wee Waa experiencing above-floor inundation, with the upper limit of potential residential flood damage estimated to be about $94 million.

TABLE D4.3
RESIDENTIAL FLOOD DAMAGES – LOCAL STORMWATER RUNOFF ONLY

Design Flood Event (% AEP)	Damage Scenario 1			Damage Scenario 2			Damage Scenario 3		
	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)
	Flood Affected	Flood Damaged		Flood Affected	Flood Damaged		Flood Affected	Flood Damaged	
5	17	1	0.31	18	1	0.33	31	2	0.55
2	20	1	0.36	24	1	0.42	45	6	0.96
1	26	1	0.45	33	4	0.64	55	15	1.48
0.5	31	2	0.55	40	6	0.84	61	19	2.00
0.2	50	6	1.00	60	14	1.52	73	25	2.39
PMF	215	119	11.72	221	137	13.77	221	137	13.77

TABLE D4.4
RESIDENTIAL FLOOD DAMAGES - RIVERINE FLOODING ONLY

Design Flood Event (% AEP)	Damage Scenario 4			Damage Scenario 5		
	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)
	Flood Affected	Flood Damaged		Flood Affected	Flood Damaged	
5	0	0	0	674	560	59.31
2	0	0	0	678	585	62.65
1	0	0	0	681	595	64.08
0.5	0	0	0	681	596	64.18
0.2	0	0	0	682	601	64.89
0.1[(1)]	681	594	64.50	-	-	-
PMF	703	696	94.27	703	696	94.27

1. Approximate AEP when overtopping of the Town Levee first occurs.

D5 COMMERCIAL / INDUSTRIAL DAMAGES

D5.1 Direct Commercial / Industrial Damages

The method used to calculate damages requires each property to be categorised in terms of the following:

- damage category
- floor area
- floor elevation

The damage category assigned to each enterprise may vary between "low", "medium" or "high", depending on the nature of the enterprise and the likely effects of flooding. Damages also depend on the floor area.

It has recently been recognised following the 1998 flood in Katherine that previous investigations using stage-damage curves contained in proprietary software tends to seriously underestimate true damage costs. DPIE are currently researching appropriate damage functions which could be adopted in the estimation of commercial and industrial categories as they have already done with residential damages. However, these data were not available for the present study.

On the basis of previous investigations, the following typical damage rates are considered appropriate for potential external and internal damages and clean-up costs for both commercial and industrial properties. They are indexed to a depth of inundation of 2 metres. At floor level and 1.2 m inundation, zero and 70% of these values respectively were assumed to occur:

Low value enterprise	$280/m^2	(e.g. Commercial: small shops, cafes, joinery, public halls. Industrial: auto workshop with concrete floor and minimal goods at floor level, Council or Government Depots, storage areas.)
Medium value enterprise	$420/m^2	(e.g. Commercial: food shops, hardware, banks, professional offices, retail enterprises, with furniture/fixtures at floor level which would suffer damage if inundated. Industrial: warehouses, equipment hire.)
High value enterprise	$650/m^2	(e.g. Commercial: electrical shops, clothing stores, bookshops, newsagents, restaurants, schools, showrooms and retailers with goods and furniture, or other high value items at ground or lower floor level. Industrial: service stations, vehicle showrooms, smash repairs.)

The factor for converting potential to actual damages depends on a range of variables such as the available warning time, flood awareness and the depth of inundation. Given sufficient warning time, a well prepared business will be able to temporarily lift property above floor level. However, unless property is actually moved to flood free areas, floods which result in a large depth of inundation, will cause considerable damage to stock and contents.

For the present study, the above-floor potential damages were converted to actual damages using a multiplier which ranged between 0.5 and 0.8 depending on the depth of inundation above the floor. The multiplier of 0.5 was adopted to convert potential to actual damages for depths of inundation up to 1.2 m, increasing to 0.8 for greater depths.

D5.2 Indirect Commercial and Industrial Damages

Indirect commercial and industrial damages comprise costs of removal of goods and storage, loss of trading profit and loss of business confidence.

Disruption to trade takes the following forms:

- The loss through isolation at the time of the flood when water is in the business premises or separating clients and customers. The total loss of trade is influenced by the opportunity for trade to divert to an alternative source. There may be significant local loss but due to the trade transfer this may be considerably reduced at the regional or state level.
- In the case of major flooding, a downturn in business can occur within the flood affected region due to the cancellation of contracts and loss of business confidence. This is in addition to the actual loss of trading caused by closure of the business by flooding.

Loss of trading profit is a difficult value to assess and the magnitude of damages can vary depending on whether the assessment is made at the local, regional or national level. Differences between regional and national economic effects arise because of transfers between the sectors, such as taxes, and subsidies such as flood relief returned to the region.

Some investigations have lumped this loss with indirect damages and have adopted total damage as a percentage of the direct damage. In other cases, loss of profit has been related to the gross margin of the business, i.e. turnover less average wages. The former approach has been adopted in this present study. Indirect damages have been taken as 50% of direct actual damages. A clean-up cost of $15/metre^2 of floor area of each flooded property was also included.

D5.3 Total Commercial and Industrial Damages

Tables D5.1 and **D5.2** at the end of this Chapter summarise commercial damages in Wee Waa resulting from local stormwater runoff and riverine flooding, respectively.

The occurrence of a 1% AEP storm event at Wee Waa in the absence of riverine flooding would result in one commercial/industrial building experiencing above-floor inundation (**Damage Scenario 1**). The number of buildings that would experience above-floor inundation would increase to three should a 1% AEP storm event occur when the fourteen (14) penstock gates are closed due to elevated water levels in the river and the pumps are running at full capacity (**Damage Scenario 2**). The upper limit of potential above-floor inundation should all six (6) permanent pumps not be operational during a 1% AEP storm event is limited to 15 commercial/industrial buildings (**Damage Scenario 3**).

The total commercial/industrial flood damage at the 1% AEP level of flooding due to local stormwater runoff would generally be between about $0.1 Million (**Damage Scenario 1**) and $0.23 Million (**Damage Scenario 2**), but could be as high as about $0.92 Million (**Damage**

Scenario 3) should the aforementioned pumps are not operational during the burst of flood producing rain.
During a riverine flood which just overtops the Town Levee and causes equalisation of water levels on both sides of the earthen embankment, a total of 126 buildings would experience above-floor inundation, with the total commercial/industrial damage in Wee Waa amounting to about $51 Million (**Damage Scenario 4**). A partial failure of the Town Levee during a 1% AEP riverine flood would also result in similar commercial/industrial flood damages at Wee Waa (**Damage Scenario 5**).

An Extreme Flood on the Namoi River would result in all but three out of a total of the 135 buildings in Wee Waa experiencing above-floor inundation, with the upper limit of potential commercial/ industrial flood damage estimated to be about $64 million.

TABLE D5.1
COMMERCIAL/INDUSTRIAL FLOOD DAMAGES – LOCAL STORMWATER RUNOFF ONLY

Design Flood Event (% AEP)	Damage Scenario 1			Damage Scenario 2			Damage Scenario 3		
	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)
	Flood Affected	Flood Damaged		Flood Affected	Flood Damaged		Flood Affected	Flood Damaged	
5	3	0	0.05	3	0	0.05	14	3	0.31
2	4	0	0.06	5	2	0.12	18	9	0.54
1	6	1	0.10	10	3	0.23	23	15	0.92
0.5	8	2	0.18	20	7	0.47	28	17	1.91
0.2	20	7	0.47	25	14	0.94	34	21	4.11
PMF	54	46	10.11	54	48	11.76	54	48	11.76

TABLE D5.2
COMMERCIAL/INDUSTRIAL FLOOD DAMAGES - RIVERINE FLOODING ONLY

Design Flood Event (% AEP)	Damage Scenario 4			Damage Scenario 5		
	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)
	Flood Affected	Flood Damaged		Flood Affected	Flood Damaged	
5	0	0	0	133	123	48.51
2	0	0	0	135	126	49.62
1	0	0	0	135	126	50.08
0.5	0	0	0	135	126	50.24
0.2	0	0	0	135	129	50.79
0.1(1)	129	126	50.84	-	-	-
PMF	135	135	63.63	135	135	63.63

1. Approximate AEP when overtopping of the Town Levee first occurs.

D6 DAMAGES TO PUBLIC BUILDINGS

D6.1 Direct Damages – Public Buildings

Included under this heading are government buildings, churches, swimming pools and parks. Damages were estimated individually on an area basis according to the perceived value of the property. Potential internal damages were indexed to a depth of above-floor inundation of 2 metres as shown below. At floor level and 1.2 metres depth of inundation, zero and 70% of these values respectively were assumed to occur.

Low value	$280/m^2	
Medium value	$420/m^2	(e.g. council buildings, NSW SES HQ, fire station)
High value	$650/m^2	(e.g. schools)

These values were obtained from the Nyngan Study (DWR, 1990), as well as commercial data presented in the Forbes Water Studies report (WS, 1992). External and structural damages were taken as 4 and 10% of internal damages respectively.

D6.2 Indirect Damages – Public Buildings

A value of $15/metre^2 was adopted for the clean-up of each property. This value is based on results presented in the Nyngan Study and adjusted for inflation. Total "welfare and disaster" relief costs were assessed as 50% of the actual direct costs.

D6.3 Total Damages – Public Buildings

Tables D6.1 and **D6.2** at the end of this Chapter summarise public damages in Wee Waa resulting from local stormwater runoff and riverine flooding, respectively.

The occurrence of a 1% AEP storm event at Wee Waa would not result in any public buildings experiencing above-floor inundation, even if all six (6) permanent pumps were to be inoperable during the storm event.

The total damage to public buildings at the 1% AEP level of flooding due to local stormwater runoff is only about $0.03 Million and is a function of the limited clean-up costs.

During a riverine flood which just overtops the Town Levee and causes equalisation of water levels on both sides of the earthen embankment, a total of 33 buildings would experience above-floor inundation, with the total public damage in Wee Waa amounting to about $2.43 Million (**Damage Scenario 4**). By comparison, a partial failure of the Town Levee during a 1% AEP riverine flood would result in slightly less public flood damages at Wee Waa (**Damage Scenario 5**).

An Extreme Flood on the Namoi River would result in all 42 public buildings in Wee Waa experiencing above-floor inundation, with the upper limit of potential flood damage estimated to be about $5.38 million.

TABLE D6.1
PUBLIC FLOOD DAMAGES – LOCAL STORMWATER RUNOFF ONLY

Design Flood Event (% AEP)	Damage Scenario 1			Damage Scenario 2			Damage Scenario 3		
	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)
	Flood Affected	Flood Damaged		Flood Affected	Flood Damaged		Flood Affected	Flood Damaged	
5	2	0	0.03	2	0	0.03	2	0	0.03
2	2	0	0.03	2	0	0.03	2	0	0.03
1	5	0	0.03	4	0	0.03	5	0	0.03
0.5	5	0	0.03	5	0	0.05	5	0	0.03
0.2	5	0	0.05	5	0	0.05	5	0	0.05
PMF	19	10	0.46	20	13	0.61	20	13	0.61

TABLE D6.2
PUBLIC FLOOD DAMAGES - RIVERINE FLOODING ONLY

Design Flood Event (% AEP)	Damage Scenario 4			Damage Scenario 5		
	Number of Properties		Total Damages ($ Million)	Number of Properties		Total Damages ($ Million)
	Flood Affected	Flood Damaged		Flood Affected	Flood Damaged	
5	0	0	0	36	29	2.12
2	0	0	0	37	30	2.28
1	0	0	0	37	32	2.38
0.5	0	0	0	37	32	2.39
0.2	0	0	0	38	33	2.42
0.1(1)	42	33	2.43	-	-	-
PMF	42	42	5.38	42	42	5.38

1. Approximate AEP when overtopping of the Town Levee first occurs.

D7 DAMAGES TO INFRASTUCTURE AND COMMUNITY ASSETS

No data were available regarding damage of community infrastructure during historic flood events. However, a qualitative matrix of the effects of flooding on important assets in Wee Waa is presented in **Table D7.1**.

TABLE D7.1
QUALITATIVE EFFECTS OF FLOODING ON INFRASTRUCTURE AND COMMUNITY ASSETS[(1)]

Damage Sector	Design Flood Event (% AEP)					
	5	2	1	0.5	0.2	Extreme
Electricity	O	O	O	O	O	X
Telephone	X	X	X	X	X	X
Roads	X	X	X	X	X	X
Bridges	X	X	X	X	X	X
Sewerage	X	X	X	X	X	X
Water Supply	O	O	O	X	X	X
Parks and Gardens	X	X	X	X	X	X

1. Riverine flooding only

Notes: O = No significant damages likely to be incurred.
X = Some damages likely to be incurred.

D8 SUMMARY OF TANGIBLE DAMAGES

D8.1 Tangible Damages

From **Tables D8.1** and **D8.2** at the end of this chapter, considerable flood damages would only be expected in Wee Waa during very rare and extreme riverine floods, or due to a partial failure of the Town Levee. The relatively large flood damages is due to the rapid inundation of Wee Waa during an overtopping or partial failure event, whereby existing buildings would generally be inundated to depths exceeding 1.5 m.

D8.2 Definition of Terms

Average Annual Damages (also termed "expected damages") are determined by integrating the area under the damage-frequency curve. They represent the time stream of annual damages, which would be expected to occur on a year by year basis over a long duration.

Using an appropriate discount rate, average annual damages may be expressed as an equivalent "*Present Worth Value"* of damages and used in the economic analysis of potential flood management measures.

A flood management scheme which has a design 1% AEP level of protection, by definition, will eliminate damages up to this level of flooding. If the scheme has no mitigating effect on larger floods, then these damages represent the benefits of the scheme expressed on an average annual basis and converted to the *Present Worth Value* via the discount rate.

Under current NSW Treasury guidelines, economic analyses are carried out assuming a 50 year economic life for projects and discount rates of 7% pa. (best estimate) and 11% and 4% pa. (sensitivity analyses).

D8.3 Average Annual Damages

The *Average Annual Damages* in Wee Waa for all flood events up to the PMF in the case of local stormwater runoff and the Extreme Flood in the case of riverine flooding are shown in **Tables D8.3 and D8.4**, respectively. Note that values have been quoted to two decimal places to highlight the relatively small recurring damages in the town.

D8.4 Present Worth of Damages

The *Present Worth Value* of damages likely to be experienced in Wee Waa local stormwater runoff and riverine flooding for events up to the 1% AEP and PMF/Extreme Flood events, a 50 year economic life and discount rates of 4, 7 and 11 per cent are shown in **Tables D8.5** and **D8.6**.

For a discount rate of 7% pa and an economic life of 50 years, the *Present Worth Value* of damages for all storm events at Wee Waa up to 1% AEP in intensity is between about $0.8 Million and $1.1 Million. Therefore, one or more stormwater drainage upgrade schemes costing up to these amounts could be economically justified provided they eliminated damages in Wee Waa for all storms up to this level.

While the Town Levee is not overtopped during a 1% AEP Namoi River flood, its IFF level is below the level of a 5% AEP flood. The *Present Worth Value* of damages for all riverine floods between the IFF and the 1% AEP event assuming a partial failure of the Town Levee is about $100 Million. This is the amount that could be spent upgrading the Town Levee to ensure that it is geotechnically stable, free of defects and incorporates the required 1 m freeboard to the 1% AEP flood.

TABLE D8.1
TOTAL FLOOD DAMAGES – LOCAL STORMWATER RUNOFF ONLY - $ MILLION

Design Flood Event (%AEP)	Damage Scenario 1				Damage Scenario 2				Damage Scenario 3			
	Residential	Commercial	Public	Total	Residential	Commercial	Public	Total	Residential	Commercial	Public	Total
5	0.00	0.00	0.00	0.00	0.33	0.05	0.03	0.41	0.55	0.31	0.03	0.89
2	0.31	0.05	0.03	0.39	0.42	0.12	0.03	0.57	0.96	0.54	0.03	1.53
1	0.36	0.06	0.03	0.45	0.64	0.23	0.03	0.90	1.48	0.92	0.03	2.43
0.5	0.45	0.10	0.03	0.58	0.84	0.47	0.05	1.36	2.00	1.91	0.03	3.94
0.2	0.55	0.18	0.03	0.76	1.52	0.94	0.05	2.51	2.39	4.11	0.05	6.55
PMF	1.00	0.47	0.05	1.52	13.77	11.76	0.61	26.14	13.77	11.76	0.61	26.14

TABLE D8.2
TOTAL FLOOD DAMAGES - RIVERINE FLOODING ONLY - $ MILLION

Design Flood Event (%AEP)	Damage Scenario 4				Damage Scenario 5			
	Residential	Commercial	Public	Total	Residential	Commercial	Public	Total
5	0	0	0	0	59.31	48.51	2.12	109.94
2	0	0	0	0	62.65	49.62	2.28	114.55
1	0	0	0	0	64.08	50.08	2.38	116.54
0.5	0	0	0	0	64.18	50.24	2.39	116.81
0.2	0	0	0	0	64.89	50.79	2.42	118.10
0.1	64.5	50.84	2.43	117.77	-	-	-	-
Extreme Flood	94.27	63.63	5.38	163.28	94.27	63.63	5.38	163.28

1. Approximate AEP when overtopping of the Town Levee first occurs.

TABLE D8.3
AVERAGE ANNUAL DAMAGES – LOCAL STORMWATER RUNOFF ONLY - $ MILLION

Design Flood Event (%AEP)	Damage Scenario 1				Damage Scenario 2				Damage Scenario 3			
	Residential	Commercial	Public	Total	Residential	Commercial	Public	Total	Residential	Commercial	Public	Total
5	0.01	0	0	0.01	0.01	0	0	0.01	0.01	0.01	0	0.02
2	0.02	0	0	0.02	0.02	0	0	0.02	0.04	0.02	0	0.06
1	0.02	0	0	0.02	0.02	0.01	0	0.03	0.05	0.03	0	0.08
0.5	0.02	0	0	0.02	0.03	0.01	0	0.04	0.06	0.04	0	0.10
0.2	0.03	0.01	0	0.04	0.03	0.01	0	0.04	0.06	0.04	0	0.10
PMF	0.04	0.02	0	0.06	0.05	0.02	0	0.07	0.08	0.06	0	0.14

TABLE D8.4
AVERAGE ANNUAL DAMAGES - RIVERINE FLOODING ONLY - $ MILLION

Design Flood Event (%AEP)	Damage Scenario 4				Damage Scenario 5			
	Residential	Commercial	Public	Total	Residential	Commercial	Public	Total
5	0	0	0	0	1.48	1.21	0.05	2.74
2	0	0	0	0	3.31	2.68	0.12	6.11
1	0	0	0	0	3.95	3.18	0.14	7.27
0.5	0	0	0	0	4.27	3.43	0.15	7.85
0.2	0	0	0	0	4.46	3.59	0.16	8.21
0.1	0.03	0.03	0	0.06	-	-	-	-
Extreme Flood	0.10	0.08	0	0.18	4.63	3.70	0.17	8.50

1. Approximate AEP when overtopping of the Town Levee first occurs.

TABLE D8.5
PRESENT WORTH VALUE OF DAMAGES - LOCAL STORMWATER RUNOFF ONLY - $ MILLION

Discount Rate (%)	Damage Scenario 1		Damage Scenario 2		Damage Scenario 3	
	All Floods Up to 1% AEP	All Floods Up to PMF	All Floods Up to 1% AEP	All Floods Up to PMF	All Floods Up to 1% AEP	All Floods Up to PMF
4	0.4	1.3	0.6	1.5	1.7	3.0
7	0.3	0.8	0.4	1.0	1.1	1.9
11	0.2	0.5	0.3	0.6	0.7	1.3

TABLE D8.6
PRESENT WORTH VALUE OF DAMAGES - RIVERINE FLOODING ONLY - $ MILLION

Discount Rate (%)	Damage Scenario 4		Damage Scenario 5	
	All Floods Up to 1% AEP	All Floods Up to PMF	All Floods Up to 1% AEP	All Floods Up to PMF
4	0.0	3.9	156.3	182.1
7	0.0	2.5	100.3	116.9
11	0.0	1.6	65.4	76.2

D9 REFERENCES

DECC (Department of Environment and Climate Change, NSW), 2007. ***"Floodplain Management Guideline No 4. Residential Flood Damages"***.

DWR (Department of Water Resources, NSW), 1990. ***"Nyngan April 1990 Flood Investigation"***.

LMJ (Lyall, Macoun and Joy, Willing and Partners Pty Ltd), 1985. ***"Camden Floodplain Management Study"***.

SKM (Sinclair Knight Merz), 1994. ***"Forbes Floodplain Management Report and Draft Floodplain Management Plan, Volume 1"***.

WS (Water Studies), 1986. ***"The Sydney Floods of August 1986"***, Volume I Residential Flood Damage Survey, Report prepared for CRCE Water Studies Pty Ltd for the NSW PWD.

WS (Water Studies), 1992. ***"Forbes Flood Damage Survey, August 1990 Flood"***.

APPENDIX E

LEVEE FREEBOARD ANALYSIS

TABLE OF CONTENTS

FIGURES (BOUND IN VOLUME 2)

SYNOPSIS

This Appendix deals with the derivation of the freeboard allowance which has been incorporated into the design of the Town Levee. As there are presently no formal freeboard standards in Australia, the freeboard requirements for the Town Levee have been based on a joint probability analysis that consisted of an assessment of the possible increase in peak flood levels associated with a range of design variables and their associated probabilities of occurrence.

Design variables that have been incorporated in the derivation of the freeboard for the Town Levee comprised the following:

- increases in peak flood levels due to wind action;
- increases in peak flood levels due to wave action;
- increases in peak flood levels due to local water surge;
- uncertainties in the design flood level estimates due to inaccuracies in the LiDAR survey data and possible variations in key parameters such as hydraulic roughness;
- post-construction settlement of the levee;
- reduction in the crest level due to defects; and
- inaccuracies in peak flood levels as a result of future climate change.

The total freeboard allowance was assessed at four locations along the Town Levee as shown on **Figure E1.1**. **Table ES1** over gives a breakdown of the freeboard allowance which has been derived for each of the design variables and their associated probabilities of occurrence. Based on the findings of the assessment, a freeboard allowance of 1 m has been adopted in the design of the Town Levee.

TABLE ES1
FREEBOARD ALLOWANCE AT WEE WAA(1)

Design Variable	Probability of Occurrence (%)	Location A		Location B		Location C		Location D	
		Maximum Allowance (m)	Joint Probability Allowance (m)	Maximum Allowance (m)	Joint Probability Allowance (m)	Maximum Allowance (m)	Joint Probability Allowance (m)	Maximum Allowance (m)	Joint Probability Allowance (m)
Wave Action (Run-up)	50	0.48	0.24	0.41	0.21	0.38	0.19	0.47	0.23
Wave Action (Set-up)	50	0.30	0.15	0.10	0.05	0.07	0.04	0.09	0.04
Local Water Surge	50	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Uncertainties in Peak Flood Level Estimates	100	0.42	0.42	0.56	0.56	0.53	0.53	0.40	0.40
Levee Settlement	100	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Levee Defects	50	0.10	0.05	0.10	0.05	0.10	0.05	0.10	0.05
Future Climate Change	50	0.17	0.09	0.27	0.14	0.25	0.13	0.17	0.09
Total		**1.50**	**0.98**	**1.47**	**1.04**	**1.36**	**0.97**	**1.25**	**0.83**

1. Refer **Figure E1.1** for location where assessment relates.

E1. FREEBOARD COMPONENTS

E1.1 Wave Action

Where the levee face is exposed to a large expanse of flood water, windy conditions can generate significant waves. When superimposed on the design flood level, these waves may cause the levee to be overtopped.

There are two types of wave action to be considered when assessing this component of the freeboard allowance;

- *Wave Run-up* - When a wave generated over a certain fetch reaches an earth levee, it will run up the embankment based on its slope and surface roughness.
- *Wind Setup* – Wind blowing over a water surface exerts a horizontal shear force driving it in the direction of the wind, which results in a higher water level at the downwind end of the fetch.

The freeboard allowance for wave action is based on the Australian Wind Loading Standard – *AS/NSZ1170.2 (2002)* and guidelines for the estimation of wave run-up in *NSWPW (2010)* and *USDIBR (2012)*. The freeboard allowance for three locations with different approach winds and fetch length are shown below in **Table E1.1**.

TABLE E1.1
WAVE ACTION FREEBOARD ALLOWANCE

Location(1)	Effective Fetch Length (km)	Wind Direction	Design Wind Speed(2) (m/s)	Significant Wave Height (m)	Wave Run-up(3) (m)	Wind Setup (m)
A	3.19	North West	26	0.87	0.48	0.30
B	2.92	East	22	0.68	0.41	0.10
C	2.59	South East	22	0.64	0.38	0.07
D	2.96	West	27	0.87	0.47	0.09

1. Refer **Figure E1.1** for location where assessment relates.
2. Design wind speed taken from *AS/NZS1170.2, 2002*
3. Using embankment slope of 1V:2.5H assuming “rubble-mound slopes” (NSWPW, 2010)

E1.2 Local Water Surge

When the velocity and direction of flow changes abruptly, such as alongside a levee bank, local water levels can become elevated when compared to the broader water surface (commonly referred to as “water surge”). Flow velocities of between 0.2-0.5 m/s adjacent to the Town Levee were extracted from the TUFLOW model results and used to estimate local water surge. The local water surge at each location can be seen in **Table ES1**.

E1.3 Inaccuracies in Design Flood Level Estimates

Uncertainties in the determination of peak flood levels occur if there is doubt about any of the parameters used in the computation process. Confidence in the computed flood levels may be compromised by the following:

- *Model calibration* – A lack of historic flood data to enable the model to be calibrated for a flow which matches the design flood for the levee design (in this case the 1% AEP event). It is noted that the Flood Study TUFLOW model was originally calibrated to the February 1971, February 1984 and July 1998 flood events which had equivalent AEP's of between about 4 and 10 per cent, so estimates of peak flood levels reached by rarer events could be considered to have a greater error band.
- *Availability of detailed survey data* – LiDAR survey data was captured by LPI between February 2009 and June 2014 to a vertical accuracy of ±150 mm and horizontal accuracy of ±800 mm.
- *How accurately flood slope can be calculated given the available data* - The design flood levels were modelled in Namoi River TUFLOW using LiDAR levels sampled on a 40 m grid spacing along the alignment of the levee. The two-dimensional nature of the modelling coupled with the high level of detail used for the underlying topography means that the flood slope can be assessed with a high degree of certainty.
- *Degree of uncertainty in model parameters* – The model parameters adopted for design flood estimation may not reflect contemporaneous conditions at the time of an actual flood (e.g. rainfall losses and hydraulic roughness).

The above factors may result in the underestimation of either design flows or levels. Sensitivity analyses were undertaken to determine the increase in peak flood levels associated with a 20% increase in the 'best estimate' hydraulic roughness and a 30% increase in the peak 1% AEP flow. The computed vertical inaccuracies in the design flood level estimates based on the findings of the sensitivity analyses are given in **Table E1.2**, along with the stated vertical accuracy of the LiDAR survey data.

TABLE E1.2
INACCURACIES IN DESIGN FLOOD LEVEL ESTIMATES
1% AEP

Location[1]	Vertical Error in LiDAR (m)	Impact of 20% Increase in Hydraulic Roughness (m)	Impact of 30% Increase in Peak Flow Estimates (m)	Total (m)
A	0.15	0.10	0.17	0.42
B	0.15	0.14	0.27	0.56
C	0.15	0.13	0.25	0.53
D	0.15	0.08	0.17	0.40

1. Refer **Figure E1.1** for location where assessment relates.

E1.4 Levee Settlement

The existing earthen levee will be raised using material sourced from a local borrow pit, the location of which has yet to be determined. In most cases settlement of an earth embankment occurs post construction as a result of drying, shrinkage and cracking. As stated in the geotechnical report contained in **Appendix B**, a levee of up to 2.5 m height which is constructed of the clayey material sourced from the local borrow pit can be expected to have a maximum settlement of 20 mm.

E1.5 Defects in Levee

The structural integrity of a levee depends on its age, design, construction methodology, fill material and maintenance history. If any of these components are compromised then defects in the levee may cause it to fail. The following will mitigate the likelihood of defects occurring.

- *Design and Construction* – It is envisaged that the raised sections of levee will be designed with a 150 mm thick topsoil layer to allow vegetation to establish which reduces the risk of erosion by direct rainfall.
- *Maintenance* - A levee maintenance program will need to be developed and implemented by WSC in order to identify and repair any defects that may cause a progressive failure of the levee.

The risk of defects occurring in an earthen levee is reduced through the design and construction of a vegetated layer of topsoil and regular inspection and maintenance. Levees that are neglected should allow for an additional 500 mm freeboard to cater for defects. For the purpose of the freeboard assessment, it has been assumed that the Town Levee will be well maintained. Based on this assumption, a freeboard allowance for possible defects in the levee of only 100 mm has been adopted.

E1.6 Climate Change

DPIE recommends that its guideline *Practical Considerations of Climate Change, 2007* be used as the basis for examining climate change induced increases in rainfall intensities in projects undertaken under the State Floodplain Management Program and the FDM. The guideline recommends that until more work is completed in relation to the climate change impacts on rainfall intensities, sensitivity analyses should be undertaken based on increases in rainfall intensities ranging between 10 and 30 per cent. On current projections the increase in rainfalls within the service life of developments or flood management measures is likely to be around 10 per cent, with the higher value of 30 per cent representing an upper limit. Under present day climatic conditions, increasing the 1% AEP design rainfall intensities by 10 per cent would produce a 0.5% AEP flood; and increasing those rainfalls by 30 per cent would produce a 0.2% AEP event.

Along the alignment of the Town Levee, 1% AEP flood levels would be increased by up to 100 mm as a result of a 10 per cent increase in rainfall intensities and by up to 270 mm as a result of a 30 per cent increase in rainfall intensities. **Table ES1** shows the freeboard allowance which has been adopted for uncertainties in the peak flood level estimates due to potential increases in rainfall intensities linked with future climate change.

E2. FREEBOARD ALLOWANCE

E2.1 Joint Probability Analysis

The freeboard allowances set out in **Section E1** represent the maximum increases possible for each design variable. It is highly unlikely that these will compound along the Town Levee during a flood event, therefore each design variable is assigned a probability of occurrence in order to determine a factored freeboard allowance. As shown in **Table ES1**, the factored values are added together at each location to determine the total freeboard allowance along the Town Levee. The total freeboard allowance along the Town Levee ranges from 830 mm to 1040 mm. As such, a freeboard allowance of 1000 mm (or 1 m) has been adopted for the design of the Town Levee.

E3. REFERENCES

NSWG (New South Wales Government), 2005. "Floodplain Development Manual – The Management of Flood Liable Land"

U.S. Department of the Interior Bureau of Reclamation (USDIBR), Design Standard No. 13 – Embankment Dams, Chapter 6: Freeboard, 2012

Standards Australia, Australia/New Zealand standard 1170.2:2002, Structural design action, Part 2 Wind Actions, 2002

NSW Public Works (NSWPW), Wagga Wagga Levee Upgrade – Flood Freeboard, 2010

PJ Hawkes, Department of Environment, Food and Rural Affairs (UK), Use of Joint Probability Methods in Flood Management – A Guide to Best Practice, 2005

Chris Stanton, Stanton Associates, Flood Levee Design based on Progressive Failure Probability

NARRABRI SHIRE COUNCIL

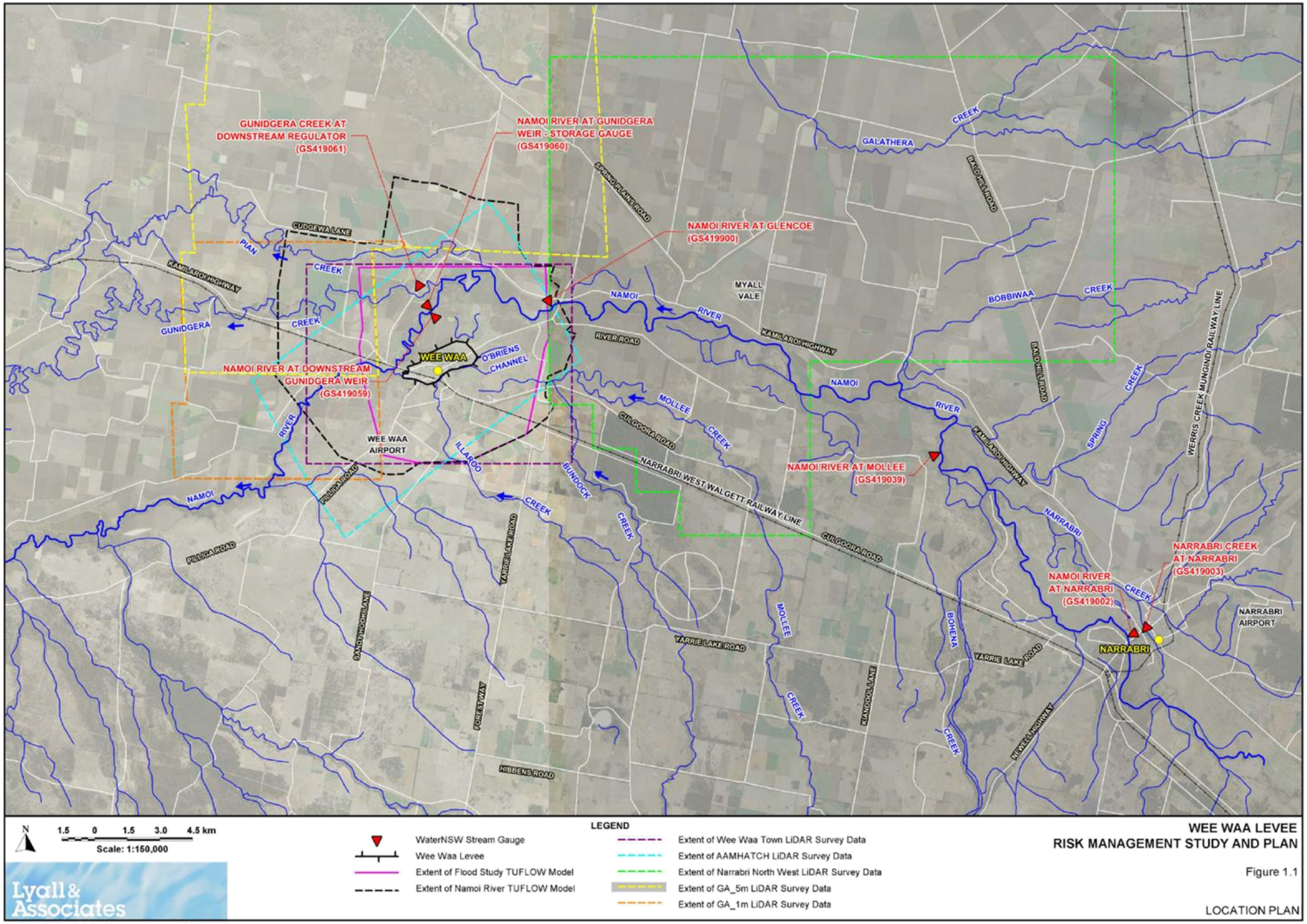
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

DECEMBER 2019

VOLUME 2 – FIGURES

Job No: EE409 File: WWL_V2_Figures_[Rev 1.4].docx	Date: December 2019 Rev No: 1.4	Principal: SAB Authors: SAB/TDR

LIST OF FIGURES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NAMOI RIVER AT GLENCOE (GS419900)
NAMOI RIVER AT DOWNSTREAM GUNIDGERA WEIR (GS419059)
NAMOI RIVER AT MOLLEE (GS419039)
NAMOI RIVER AT NARRABRI (GS419002)
NARRABRI CREEK AT NARRABRI (GS419003)
WEE WAA
WEE WAA AIRPORT
NARRABRI
NARRABRI AIRPORT
MYALL VALE
LEGEND
WaterNSW Stream Gauge
Wee Waa Levee
Extent of Flood Study TUFLOW Model
Extent of Namoi River TUFLOW Model
Extent of Wee Waa Town LiDAR Survey Data
Extent of AAMHATCH LiDAR Survey Data
Extent of Narrabri North West LiDAR Survey Data
Extent of GA_5m LiDAR Survey Data
Extent of GA_1m LiDAR Survey Data
1.5 0 1.5 3.0 4.5 km
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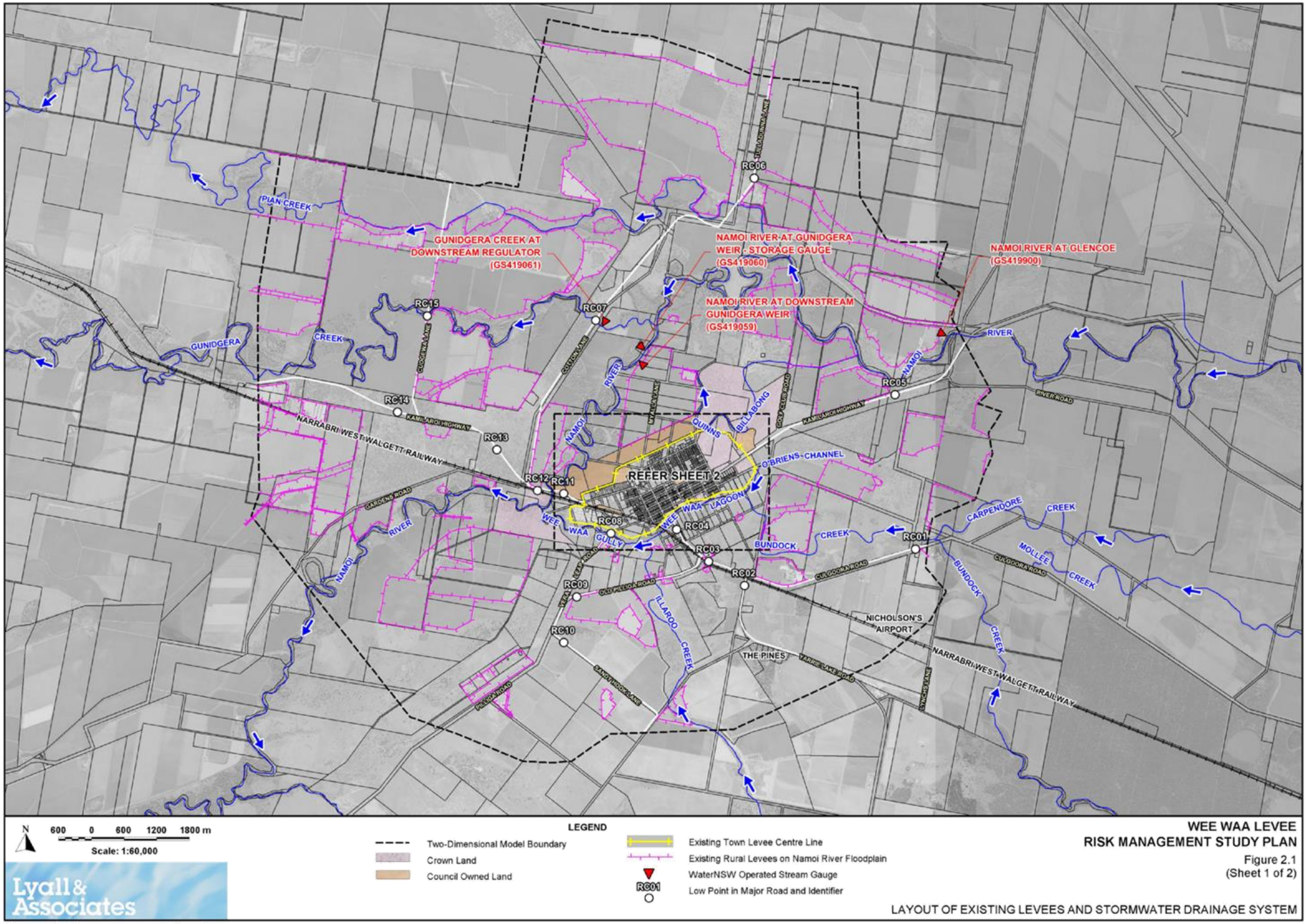
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 1.1
LOCATION PLAN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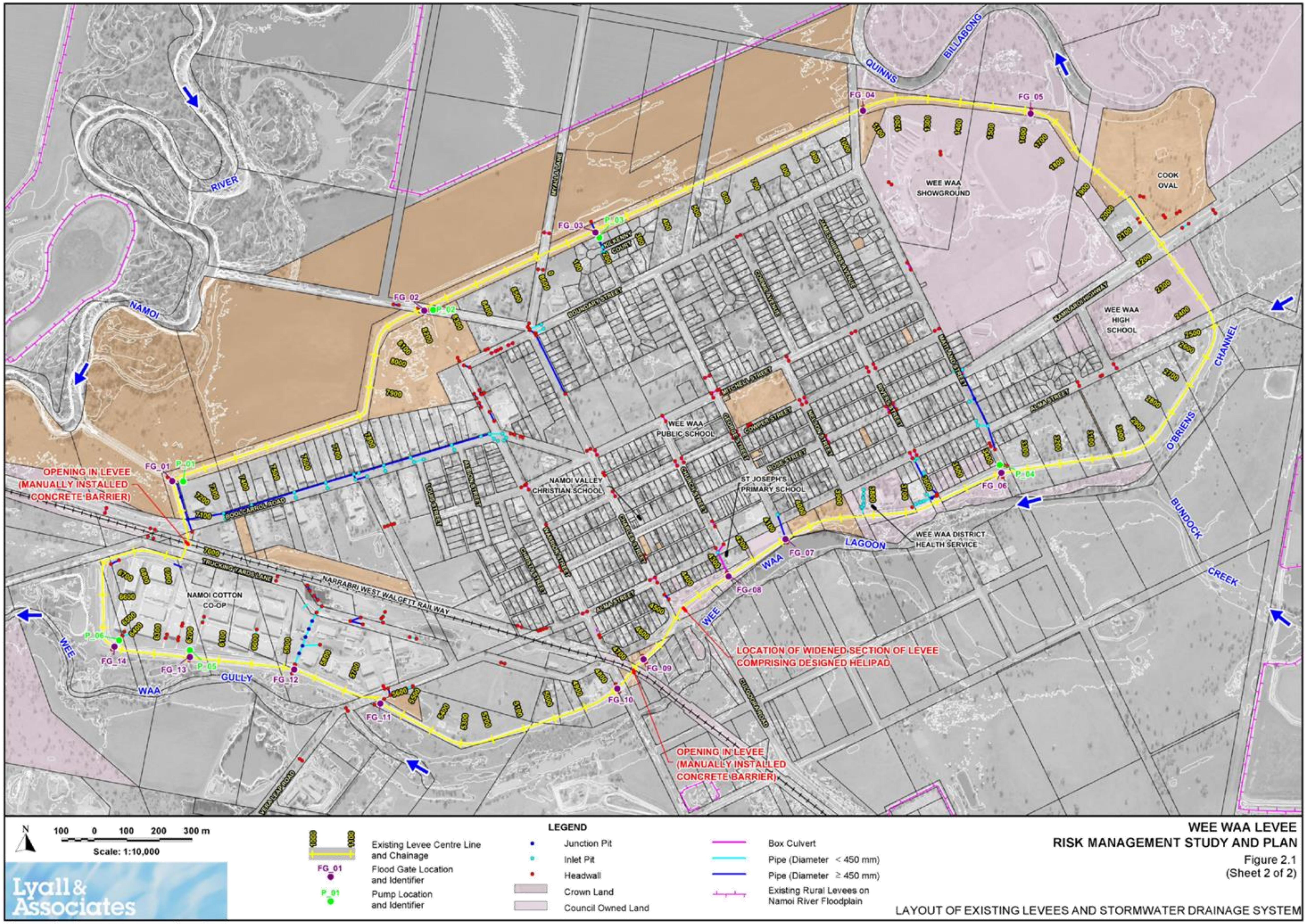
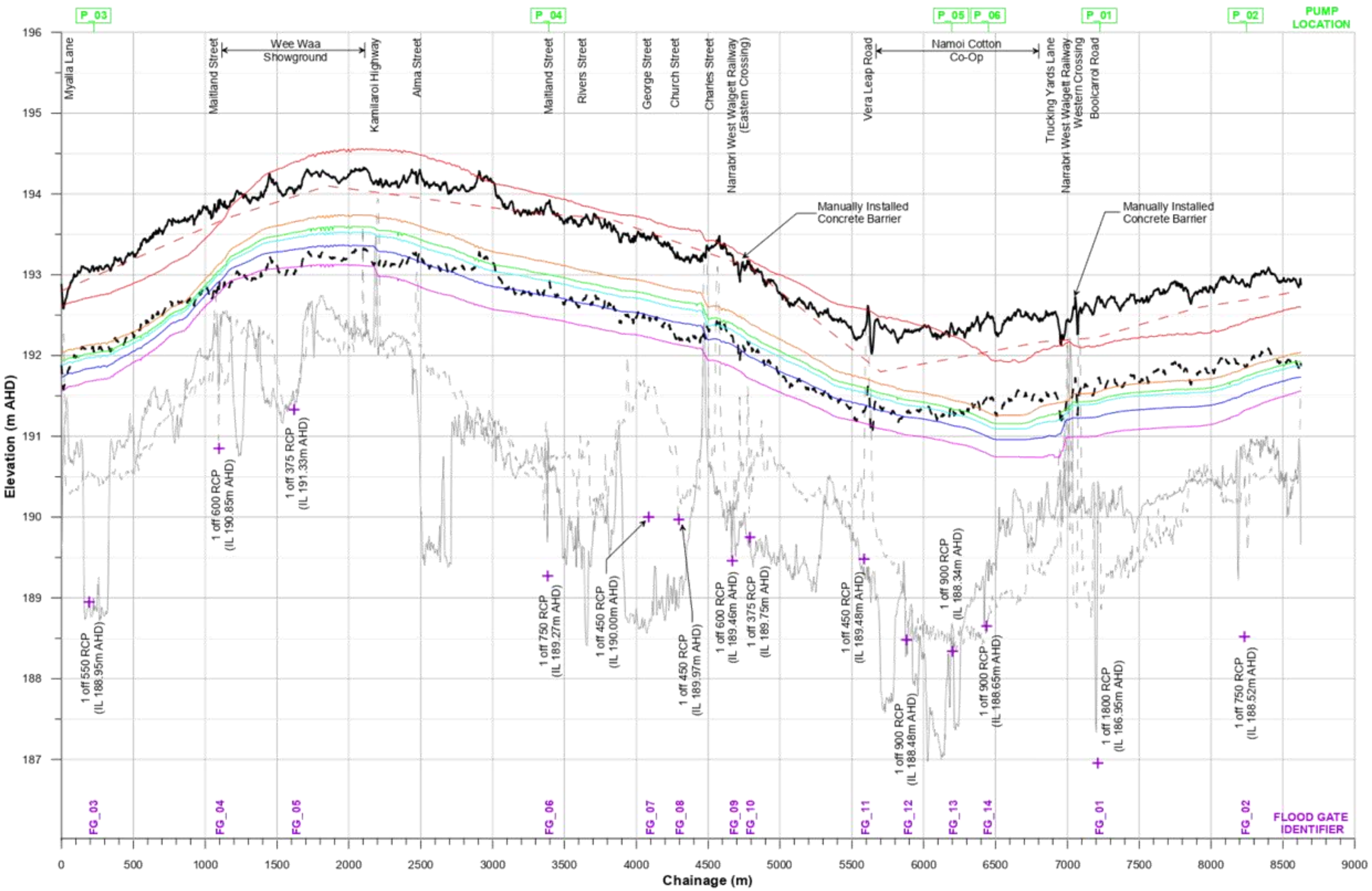
NAMOI RIVER AT GLENCOE (GS419900)
RC06
RC07
RC15
GUNIDGERA
CREEK
RIVER
NAMOI
RC05
RC14
RC13
NARRABRI WEST WALGETT RAILWAY
KAMILAROI HIGHWAY
QUINNS
BILLABONG
REFER SHEET 2
O'BRIENS CHANNEL
RC12
RC11
WEE WAA LAGOON
WEE WAA GULLY
RC08
RC04
RC03
RC02
BUNDOCK CREEK
RC01
CARPENDORE CREEK
MOLLEE CREEK
CULGOORA ROAD
RC09
RC10
ILLAROO CREEK
NICHOLSON'S AIRPORT
THE PINES
NARRABRI WEST WALGETT RAILWAY
RIVER ROAD
GARDENS ROAD
PILLIGA ROAD
SANDY HOOK LANE
OLD PILLIGA ROAD
COTTON LANE
TULLADUNNA LANE
GOLF CLUB ROAD
600 0 600 1200 1800 m
Scale: 1:60,000
LEGEND
Two-Dimensional Model Boundary
Crown Land
Council Owned Land
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WaterNSW Operated Stream Gauge
RC01
Low Point in Major Road and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY PLAN
Figure 2.1
(Sheet 1 of 2)
LAYOUT OF EXISTING LEVEES AND STORMWATER DRAINAGE SYSTEM



WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 2.1
(Sheet 2 of 2)

LAYOUT OF EXISTING LEVEES AND STORMWATER DRAINAGE SYSTEM



WATER SURFACE PROFILES

- Extreme Flood
- 0.2% AEP
- 0.5% AEP
- 1% AEP
- 2% AEP
- 5% AEP

GROUND PROFILES

- Crest of Existing Town Levee
- Imminent Failure Flood Level
- Toe of Levee (River Side)
- Toe of Levee (Town Side)
- Invert of Pipe
- Original Design Height (1971 Flood + 1 m)

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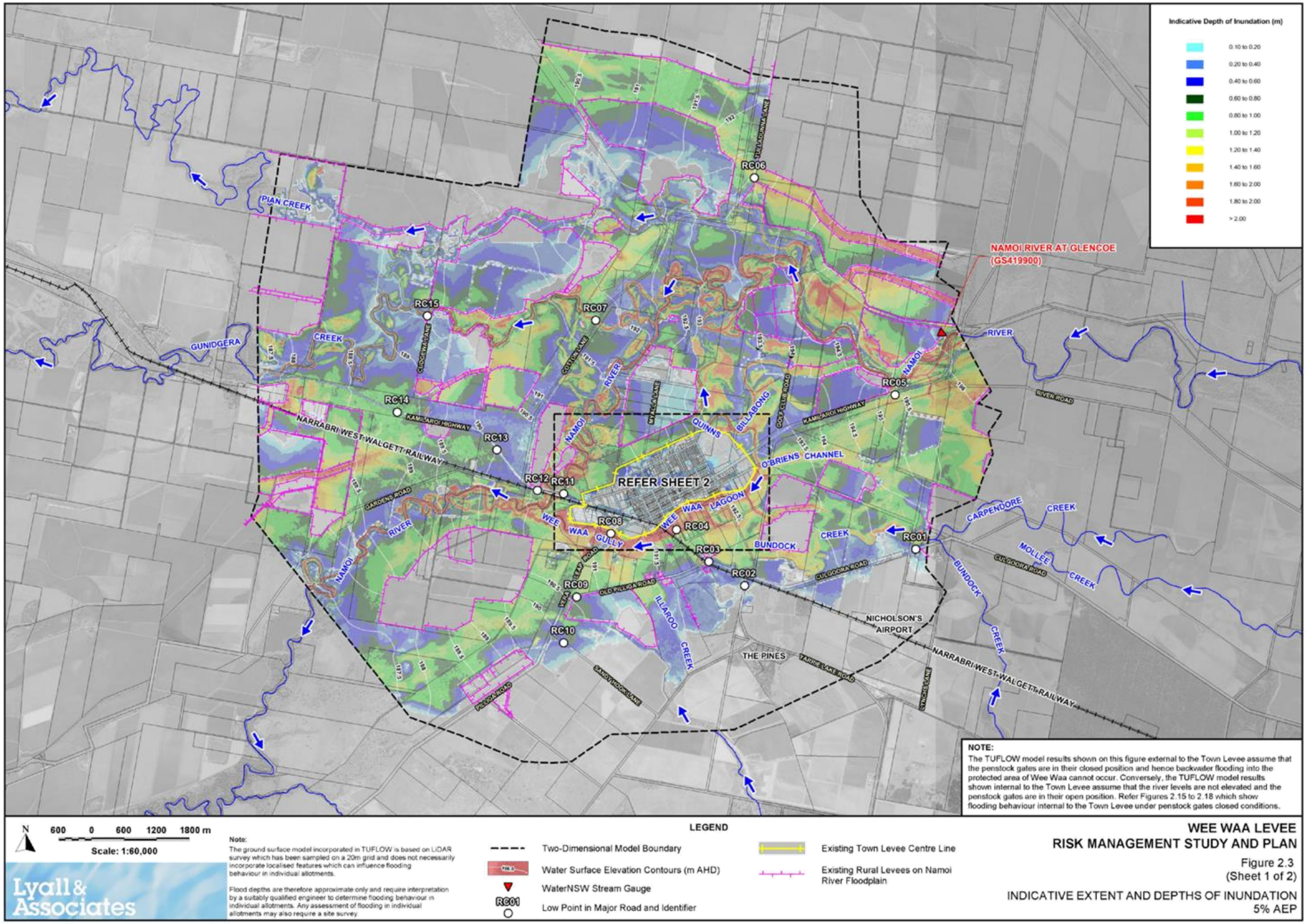
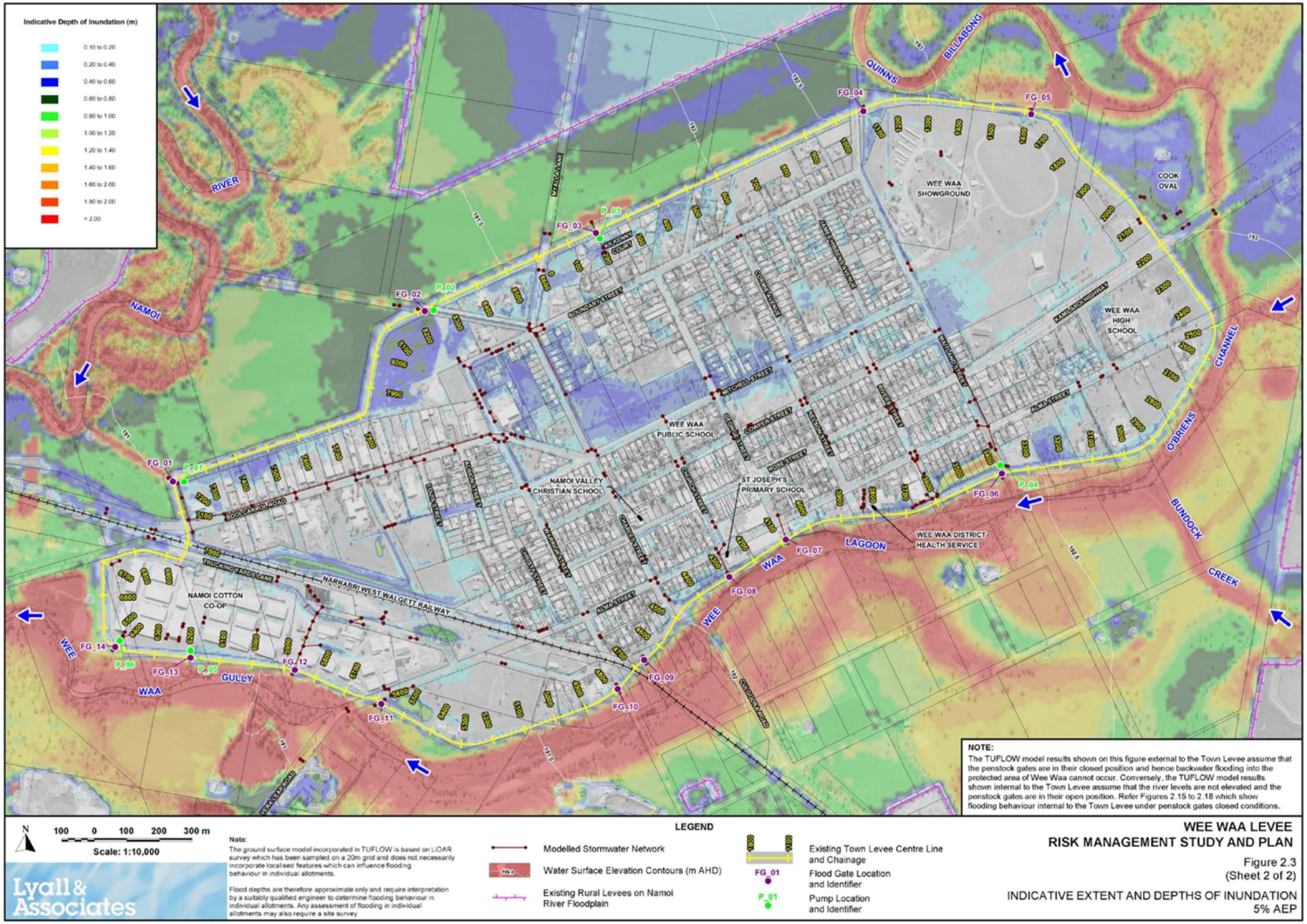
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 2.2

LONGITUDINAL SECTION ALONG CREST OF EXISTING TOWN LEVEE


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER AT GLENCOE (GS419900)
PIAN CREEK
GUNIDGERA CREEK
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
ILLAROO CREEK
REFER SHEET 2
NARRABRI WEST-WALGETT RAILWAY
KAMILAROI HIGHWAY
RIVER ROAD
CULGOORA ROAD
OLD PILLIGA ROAD
GARDENS ROAD
NICHOLSON'S AIRPORT
THE PINES
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
600 0 600 1200 1800 m
Scale: 1:60,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
Water Surface Elevation Contours (m AHD)
WaterNSW Stream Gauge
RC01 Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.3
(Sheet 1 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
5% AEP


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER
QUINNS BILLABONG
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
NARRABRI WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOLCARROL ROAD
KAMILAROI HIGHWAY
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
BOUNDARY STREET
MAITLAND STREET
CULGOORA ROAD
VERA LEAP ROAD
FG_01
FG_02
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FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
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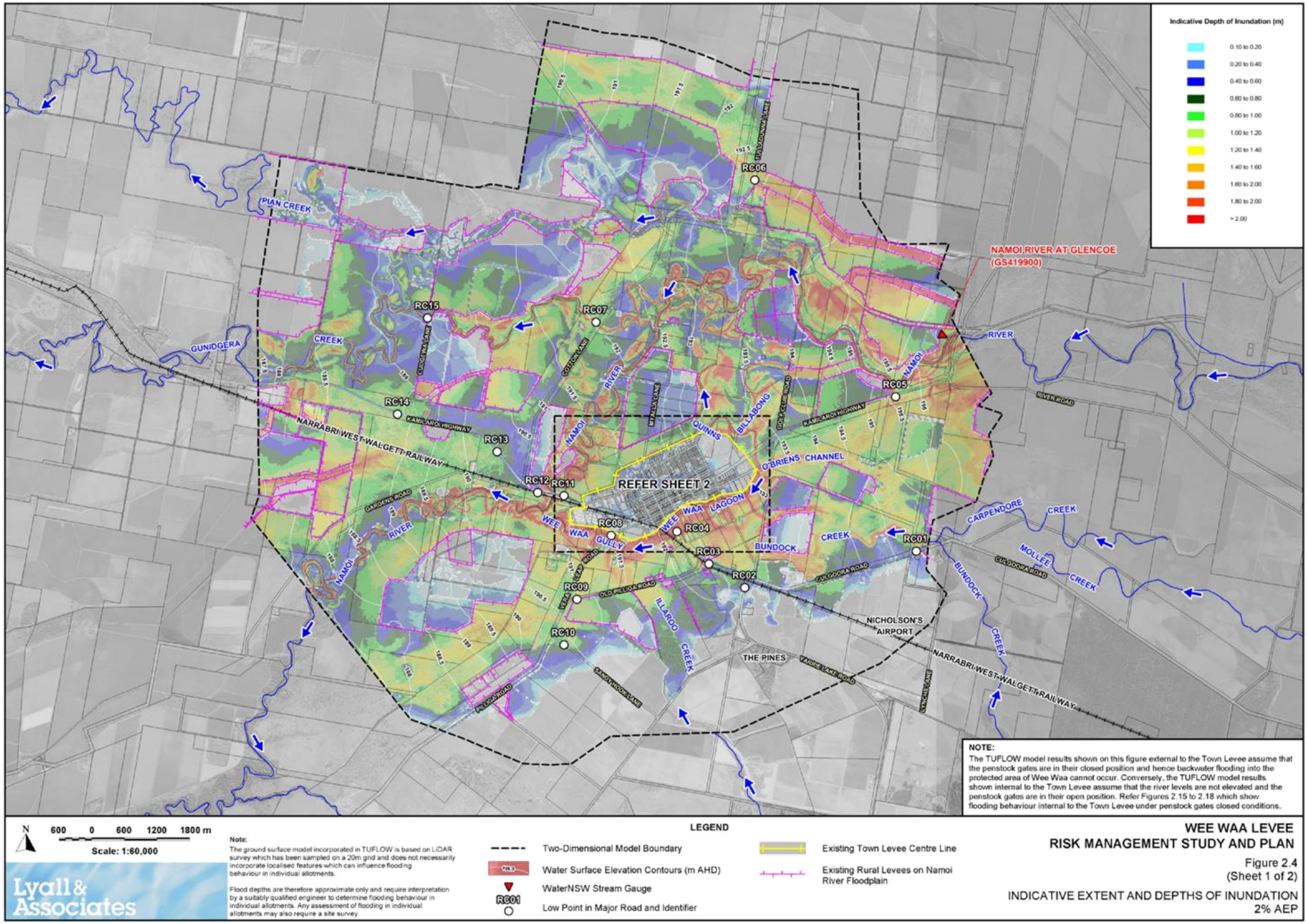
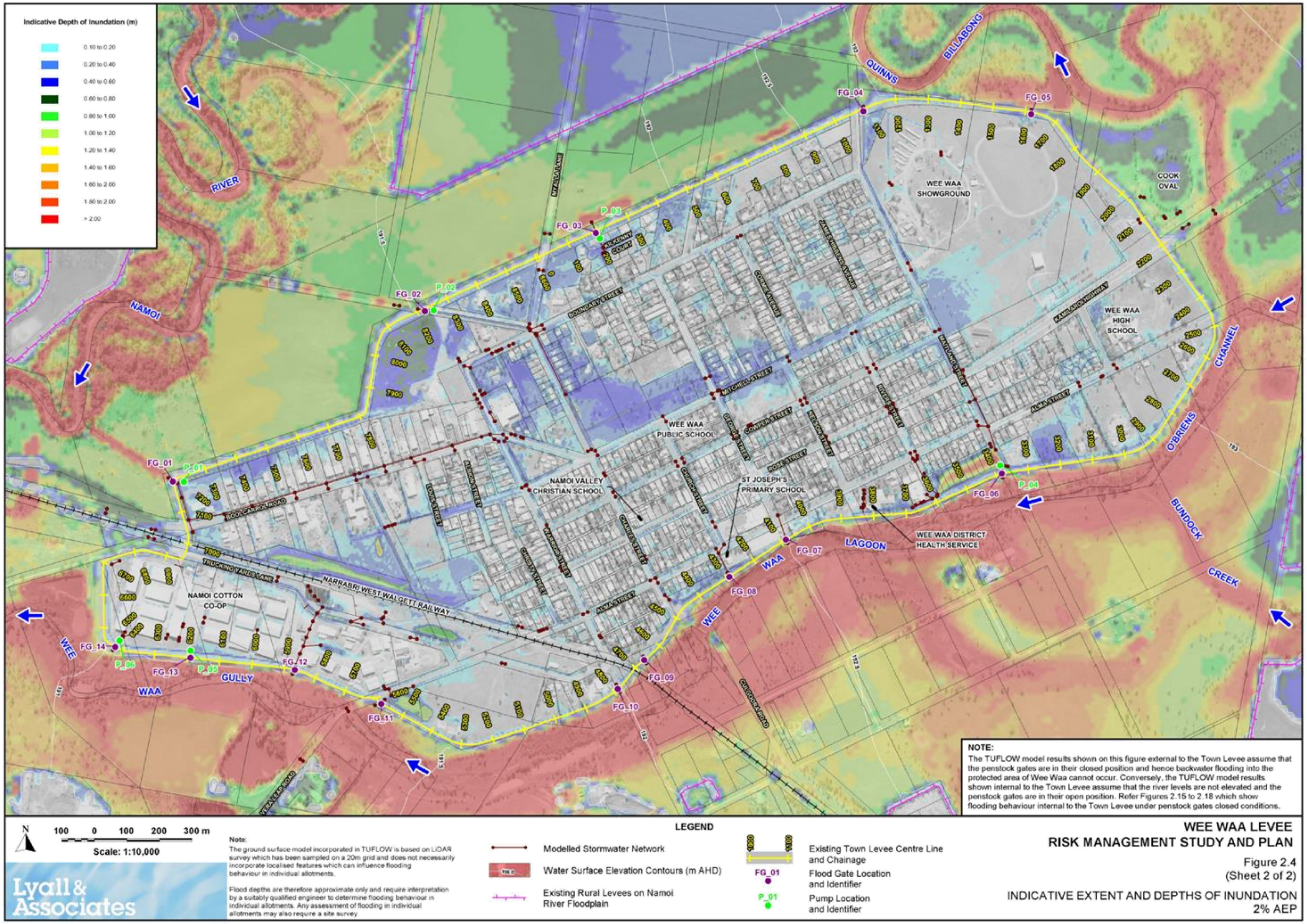
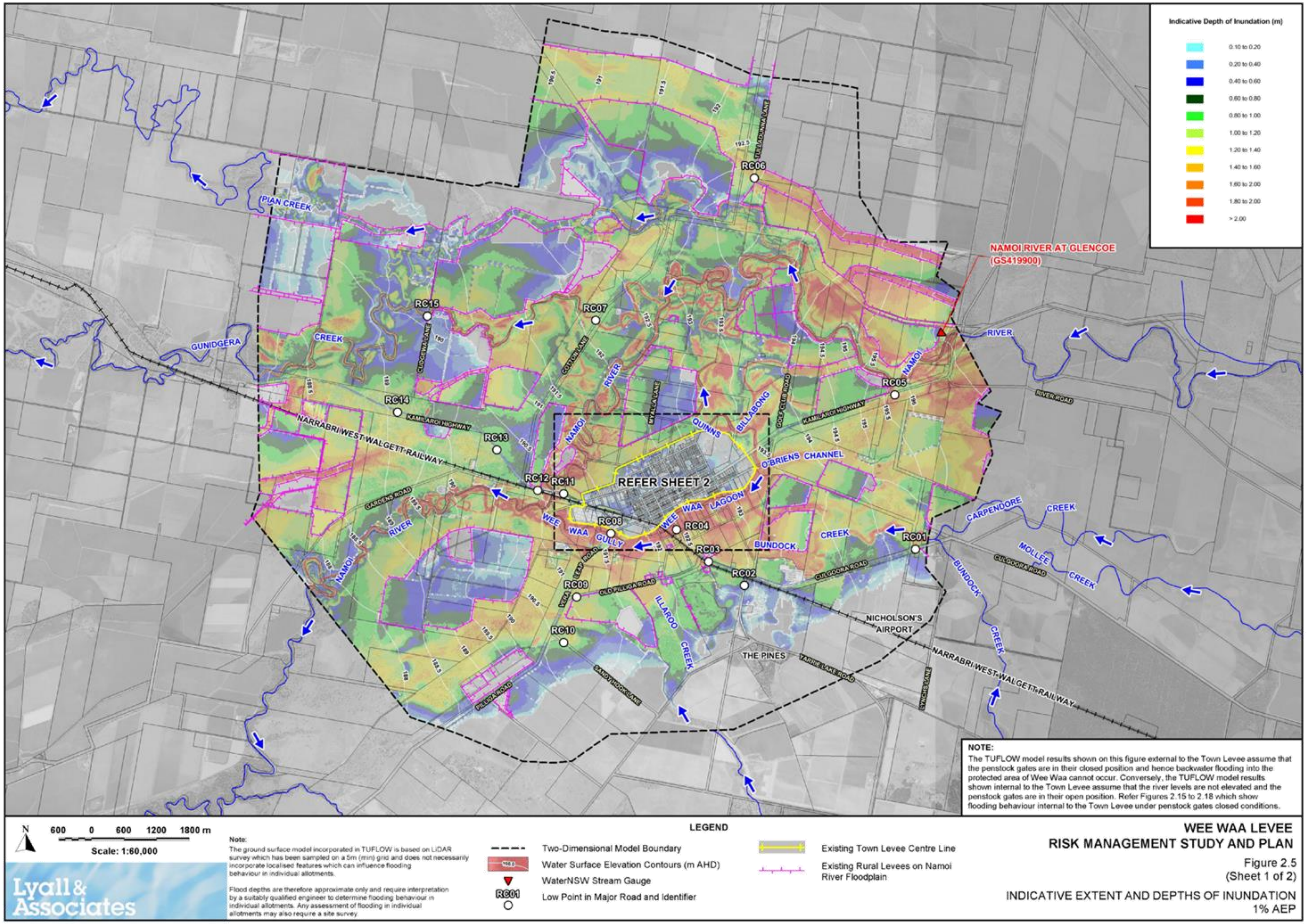
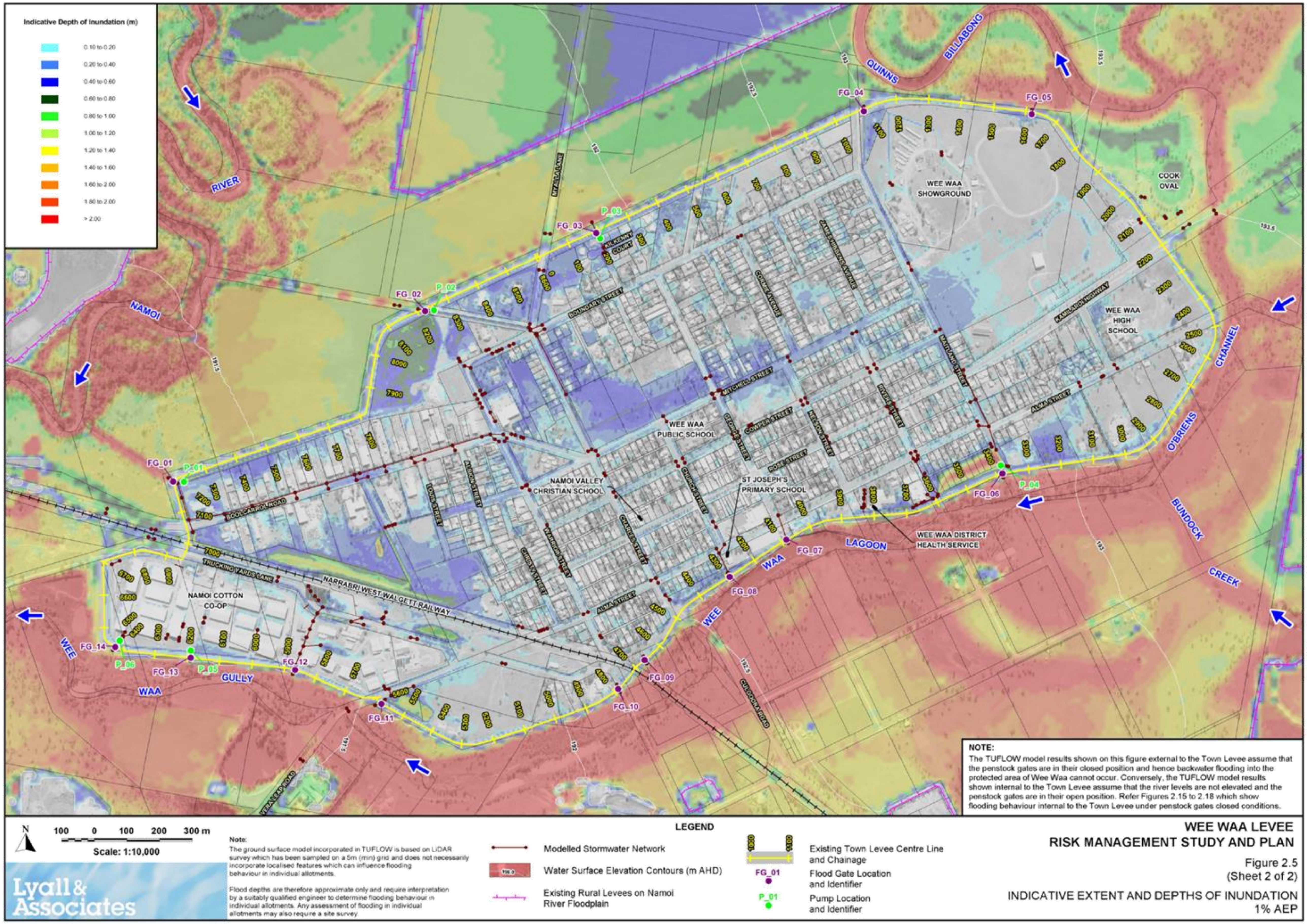
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Water Surface Elevation Contours (m AHD)
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.3
(Sheet 2 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
5% AEP

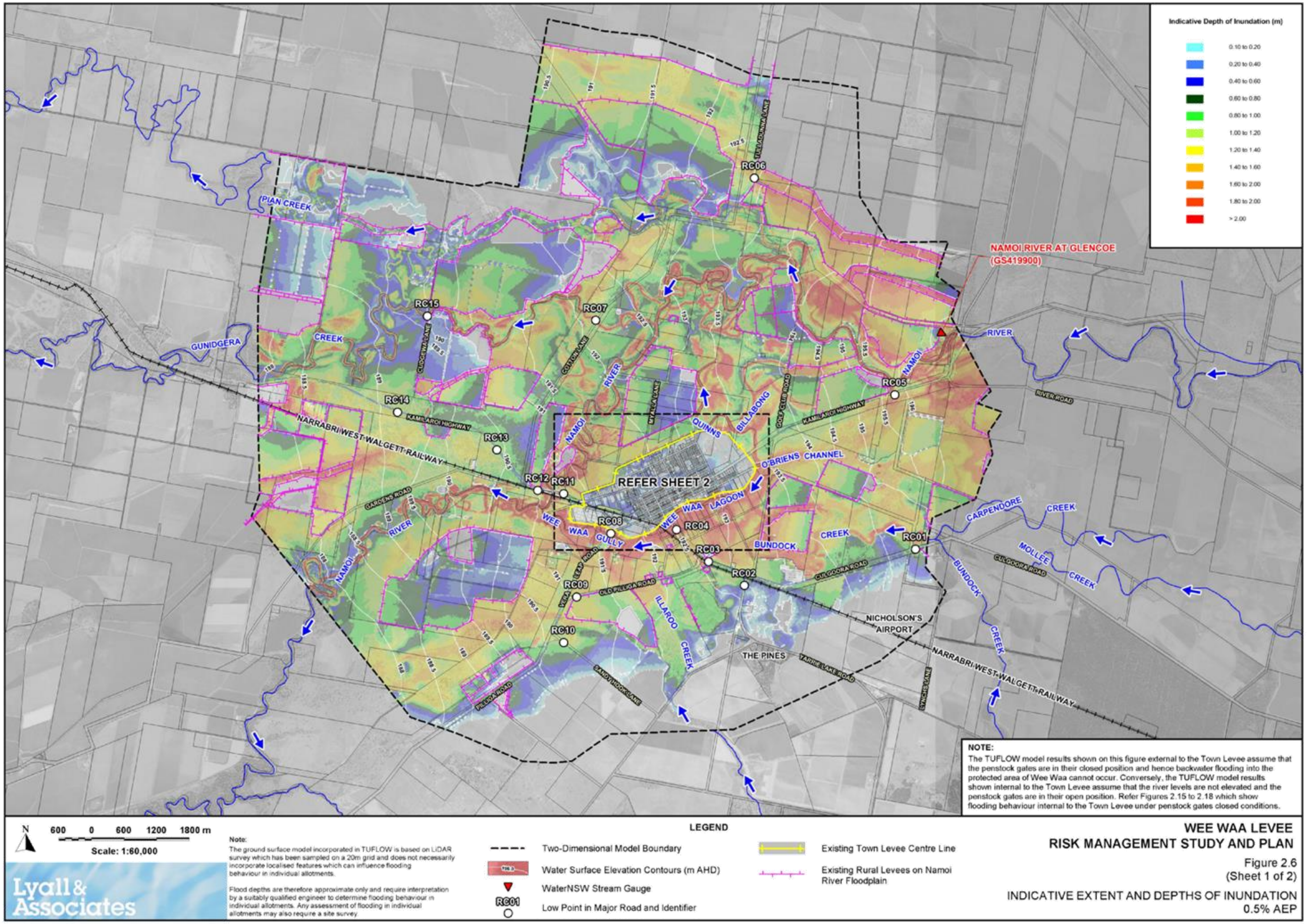

Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER AT GLENCOE (GS419900)
PIAN CREEK
GUNIDGERA CREEK
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
ILLAROO CREEK
REFER SHEET 2
NARRABRI-WEST-WALGETT-RAILWAY
KAMILAROI HIGHWAY
RIVER ROAD
CULGOORA ROAD
OLD PILLIGA ROAD
GARDENS ROAD
COTTON LANE
GOLF CLUB ROAD
SANDY HOOK LANE
PILLIGA ROAD
YARRIE LAKE ROAD
NICHOLSON'S AIRPORT
THE PINES
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
Water Surface Elevation Contours (m AHD)
WaterNSW Stream Gauge
Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.4
(Sheet 1 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
2% AEP

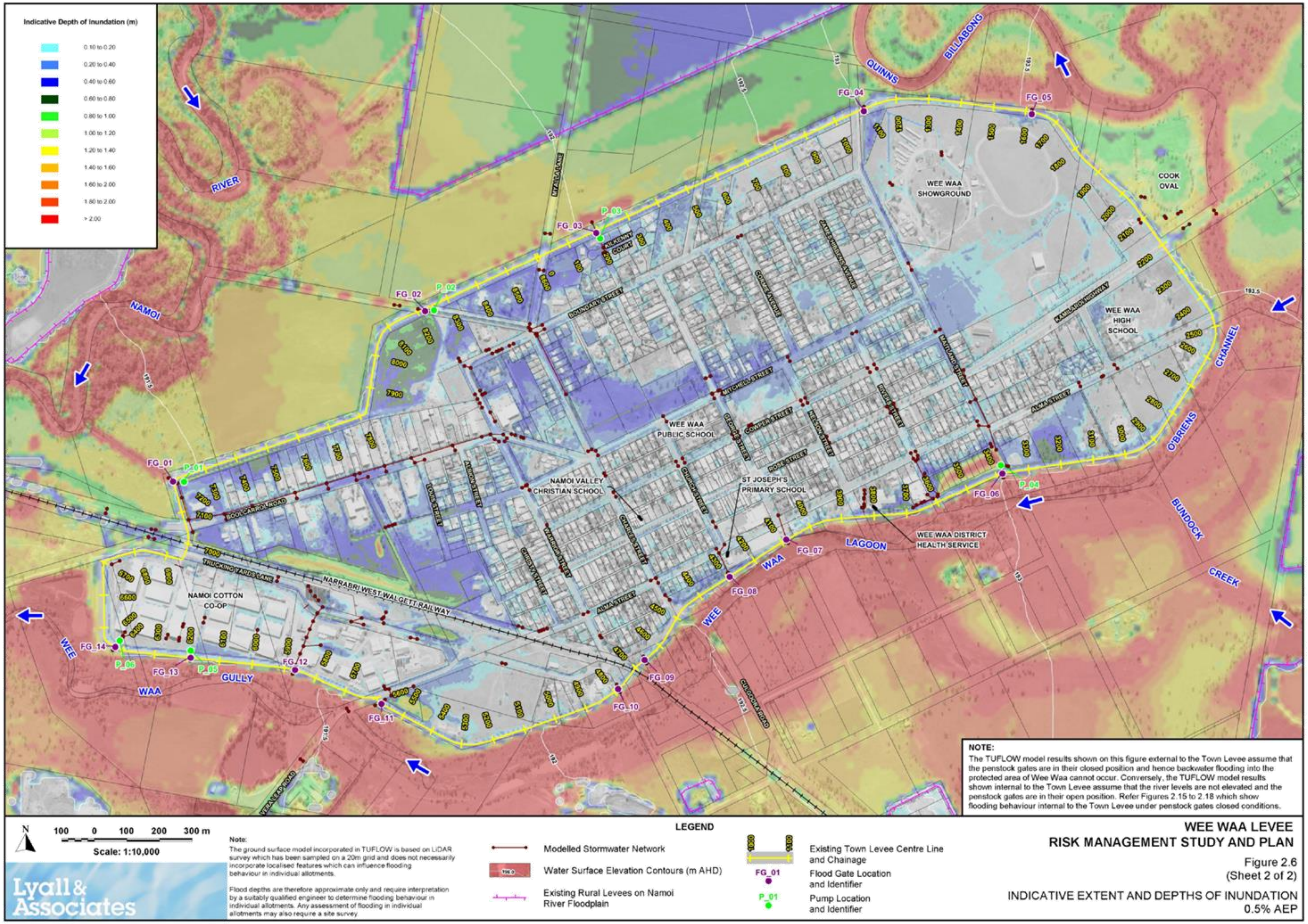


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NARRABRI WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOLCAROL ROAD
KAMILAROI HIGHWAY
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
MAITLAND STREET
CULGOORA ROAD
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Water Surface Elevation Contours (m AHD)
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.4
(Sheet 2 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
2% AEP

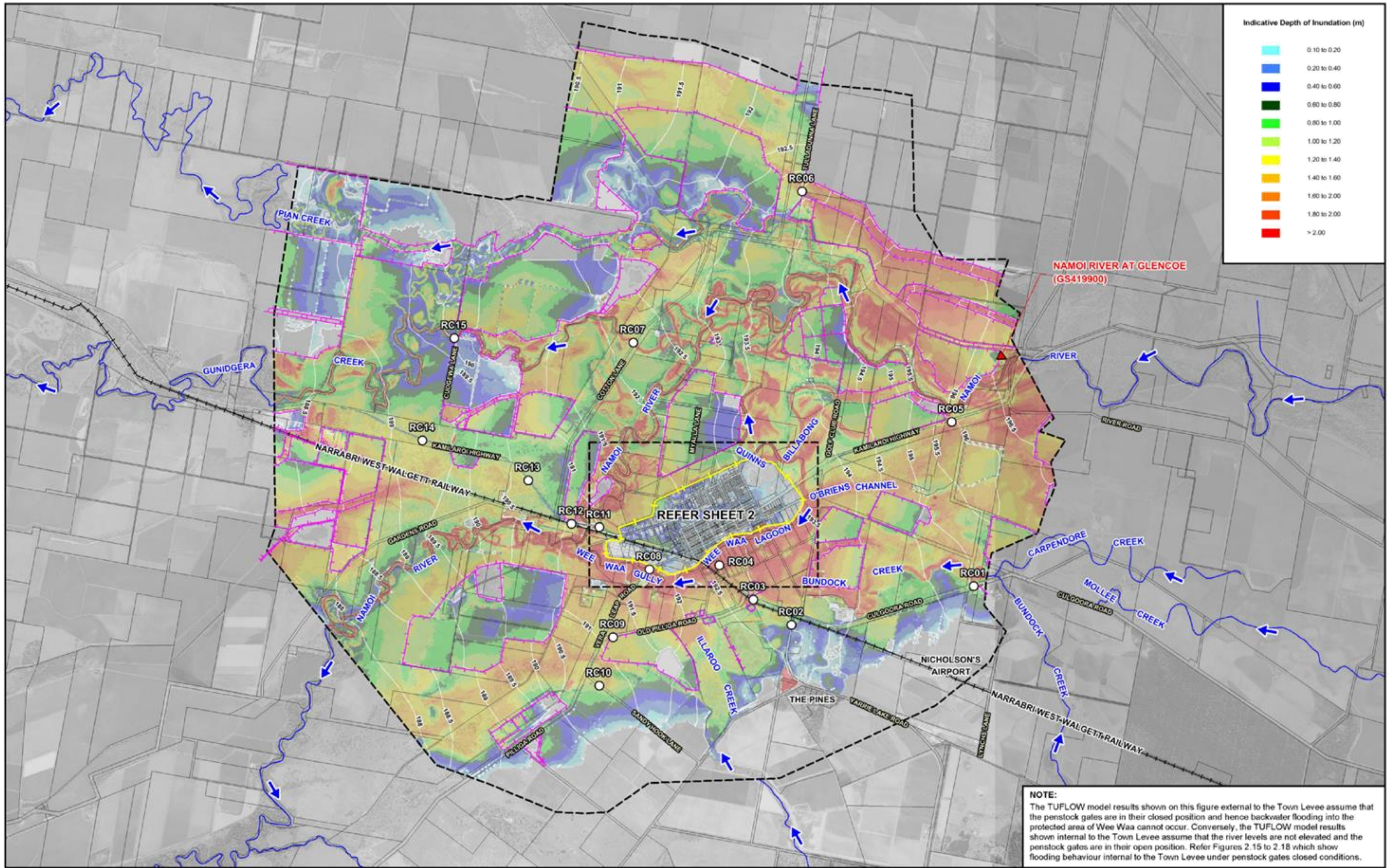

Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER AT GLENCOE (GS419900)
PIAN CREEK
GUNIDGERA CREEK
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
ILLAROO CREEK
REFER SHEET 2
NARRABRI-WEST-WALGETT-RAILWAY
KAMILAROI HIGHWAY
RIVER ROAD
CULGOORA ROAD
OLD PILLIGA ROAD
PILLIGA ROAD
GARDENS ROAD
COTTON LANE
GOLF CLUB ROAD
SANDY HOOK LANE
YARRIE LAKE ROAD
NICHOLSON'S AIRPORT
THE PINES
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
Water Surface Elevation Contours (m AHD)
WaterNSW Stream Gauge
Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.5
(Sheet 1 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
1% AEP


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI
RIVER
QUINNS
BILLABONG
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
CHANNEL
O'BRIENS
BUNDOCK
CREEK
LAGOON
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NARRABRI-WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOLCARROL ROAD
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
KAMILAROI HIGHWAY
WEE
WAA
GULLY
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Water Surface Elevation Contours (m AHD)
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.5
(Sheet 2 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
1% AEP


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER AT GLENCOE (GS419900)
PIAN CREEK
GUNIDGERA CREEK
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
ILLAROO CREEK
REFER SHEET 2
NARRABRI-WEST-WALGETT-RAILWAY
KAMILAROI HIGHWAY
RIVER ROAD
CULGOORA ROAD
OLD PILLIGA ROAD
PILLIGA ROAD
GARDENS ROAD
COTTON LANE
GOLF CLUB ROAD
NICHOLSON'S AIRPORT
THE PINES
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
Water Surface Elevation Contours (m AHD)
WaterNSW Stream Gauge
Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.6
(Sheet 1 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
0.5% AEP



Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI
RIVER
QUINNS
BILLABONG
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
CHANNEL
O'BRIENS
BUNDOCK
CREEK
LAGOON
WEE
WAA
GULLY
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NARRABRI-WEST WALGETT RAILWAY
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
KAMILAROI HIGHWAY
TRUCKING YARDS LANE
BOOLCARROL ROAD
CULGOORA ROAD
KILKENNY COURT
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Water Surface Elevation Contours (m AHD)
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.6
(Sheet 2 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
0.5% AEP



N

600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

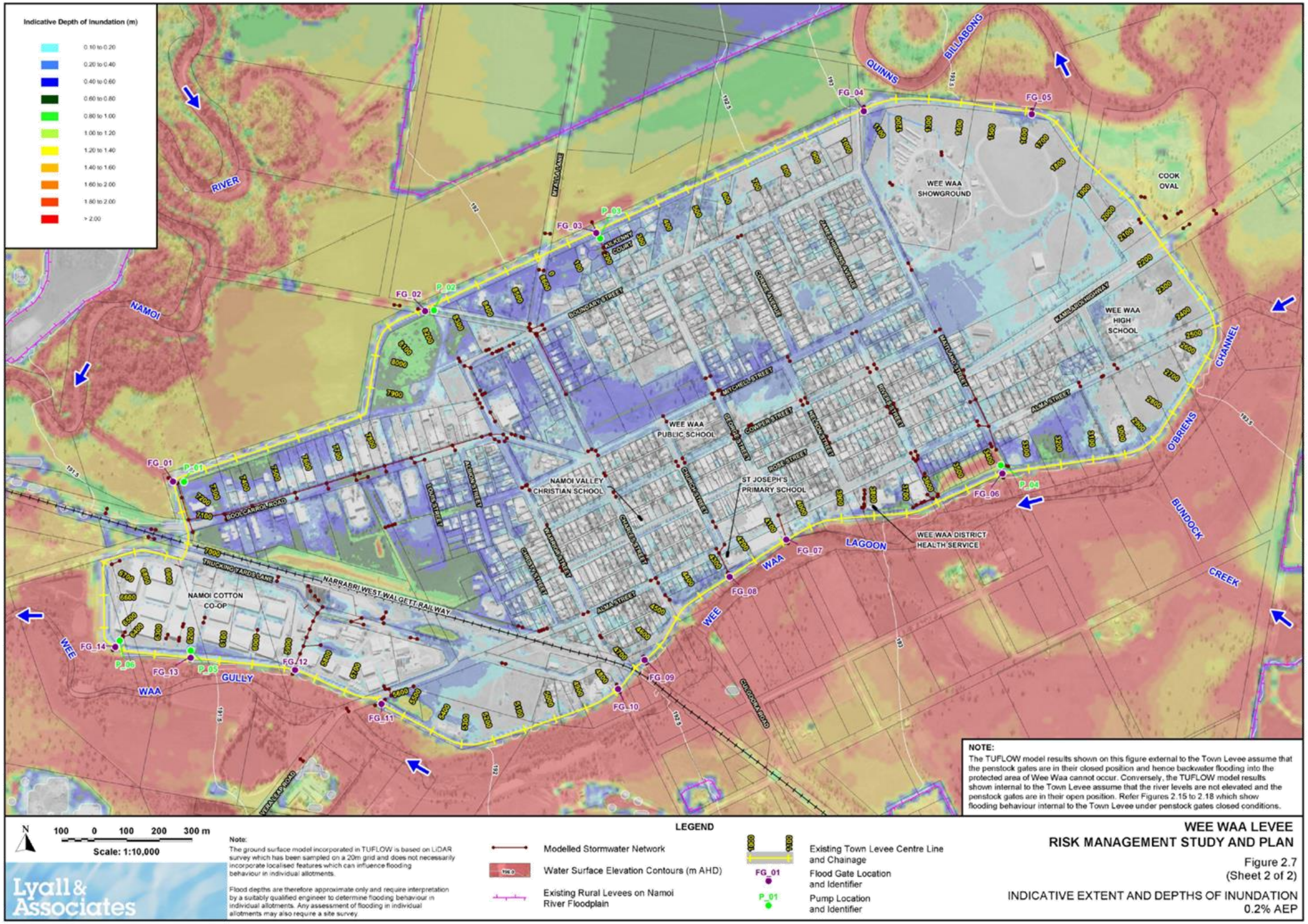
LEGEND

- Two-Dimensional Model Boundary
- Water Surface Elevation Contours (m AHD)
- WaterNSW Stream Gauge
- RC01 Low Point in Major Road and Identifier
- Existing Town Levee Centre Line
- Existing Rural Levees on Namoi River Floodplain

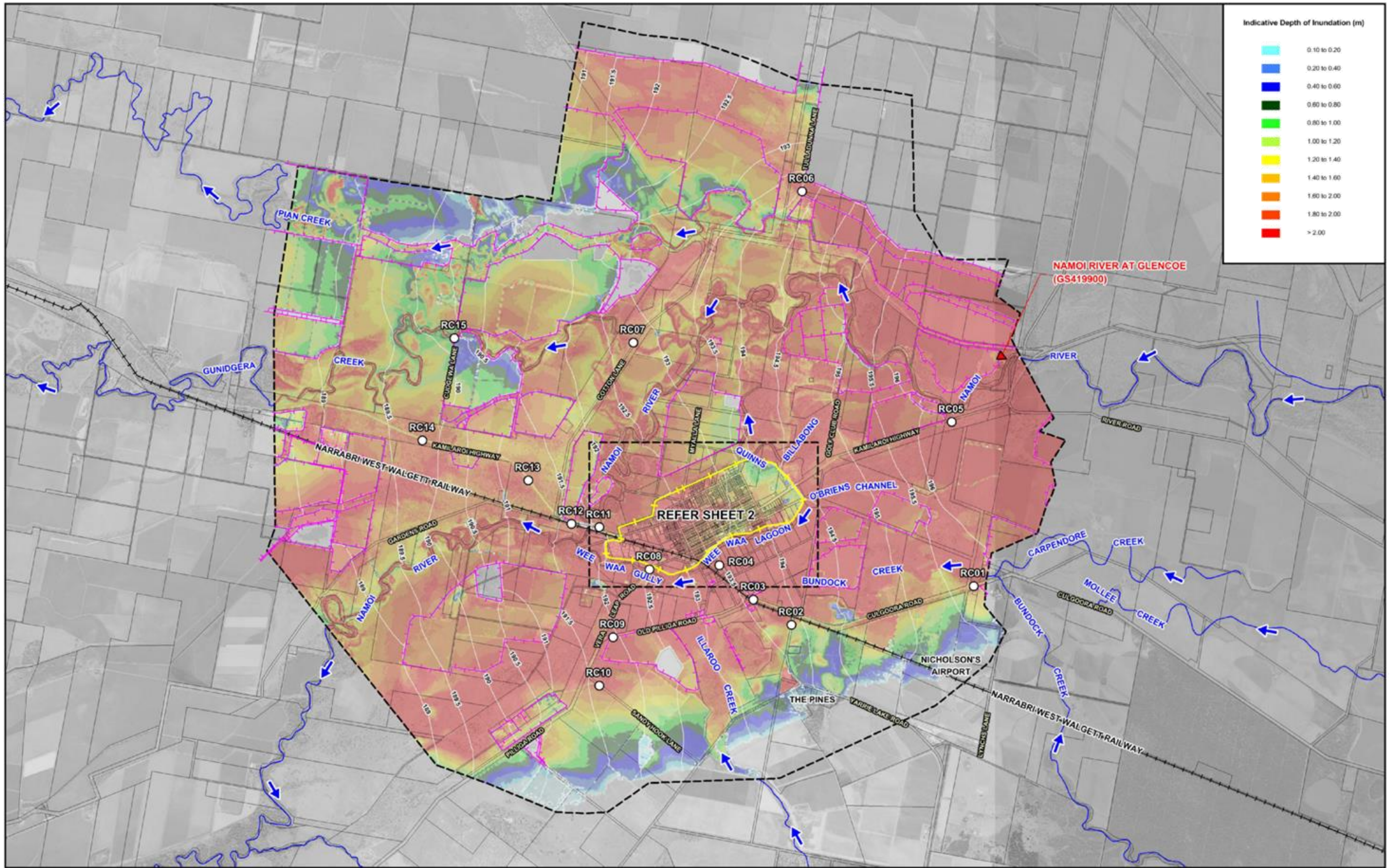
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 2.7
(Sheet 1 of 2)

INDICATIVE EXTENT AND DEPTHS OF INUNDATION
0.2% AEP



Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
BOOLCARROL ROAD
TRUCKING YARDS LANE
NARRABRI-WEST WALGETT RAILWAY
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Water Surface Elevation Contours (m AHD)
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
FG_01 Flood Gate Location and Identifier
P_01 Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.7
(Sheet 2 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
0.2% AEP



N

600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

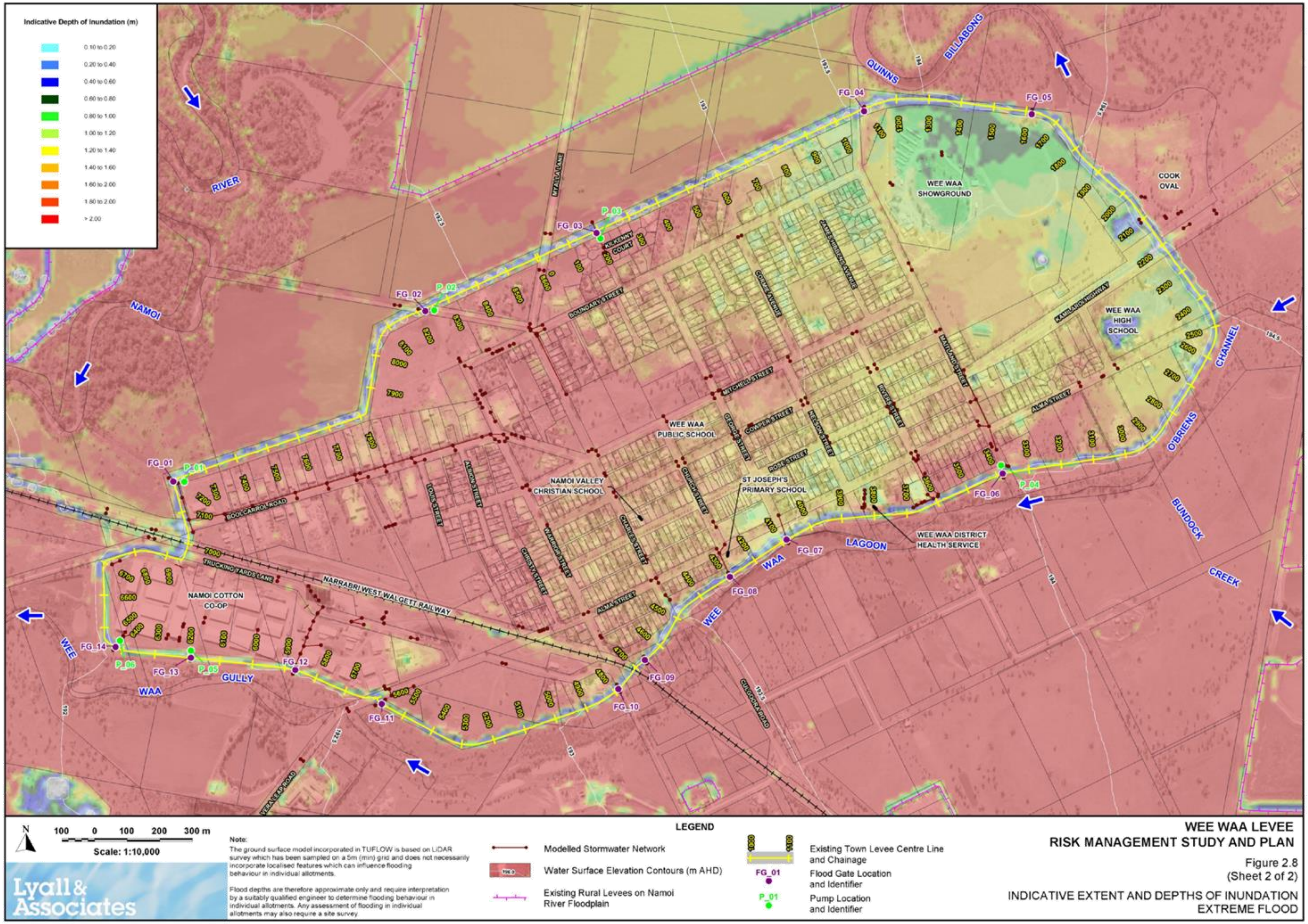
LEGEND

Two-Dimensional Model Boundary
Water Surface Elevation Contours (m AHD)
WaterNSW Stream Gauge
RC01 Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain

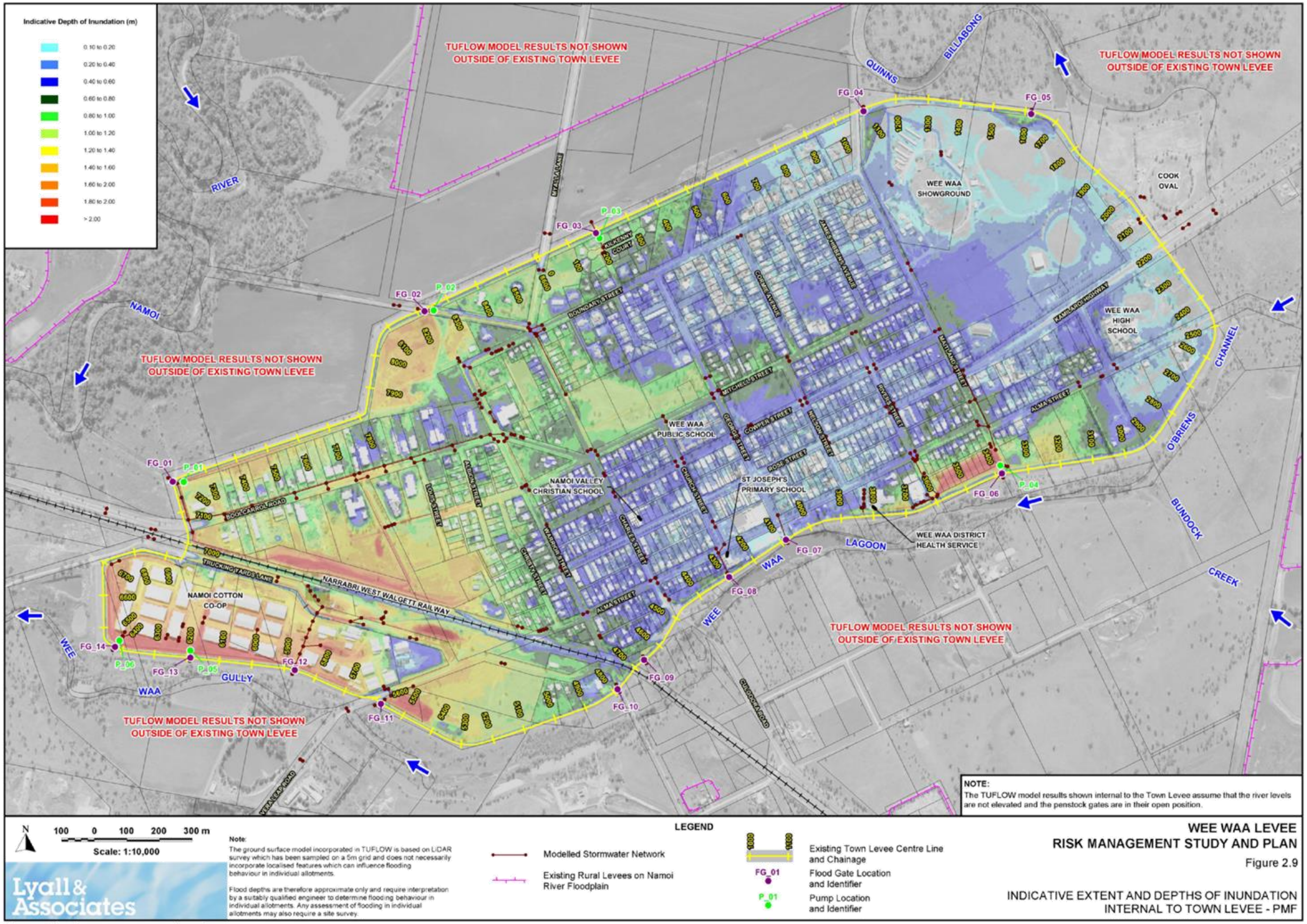
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

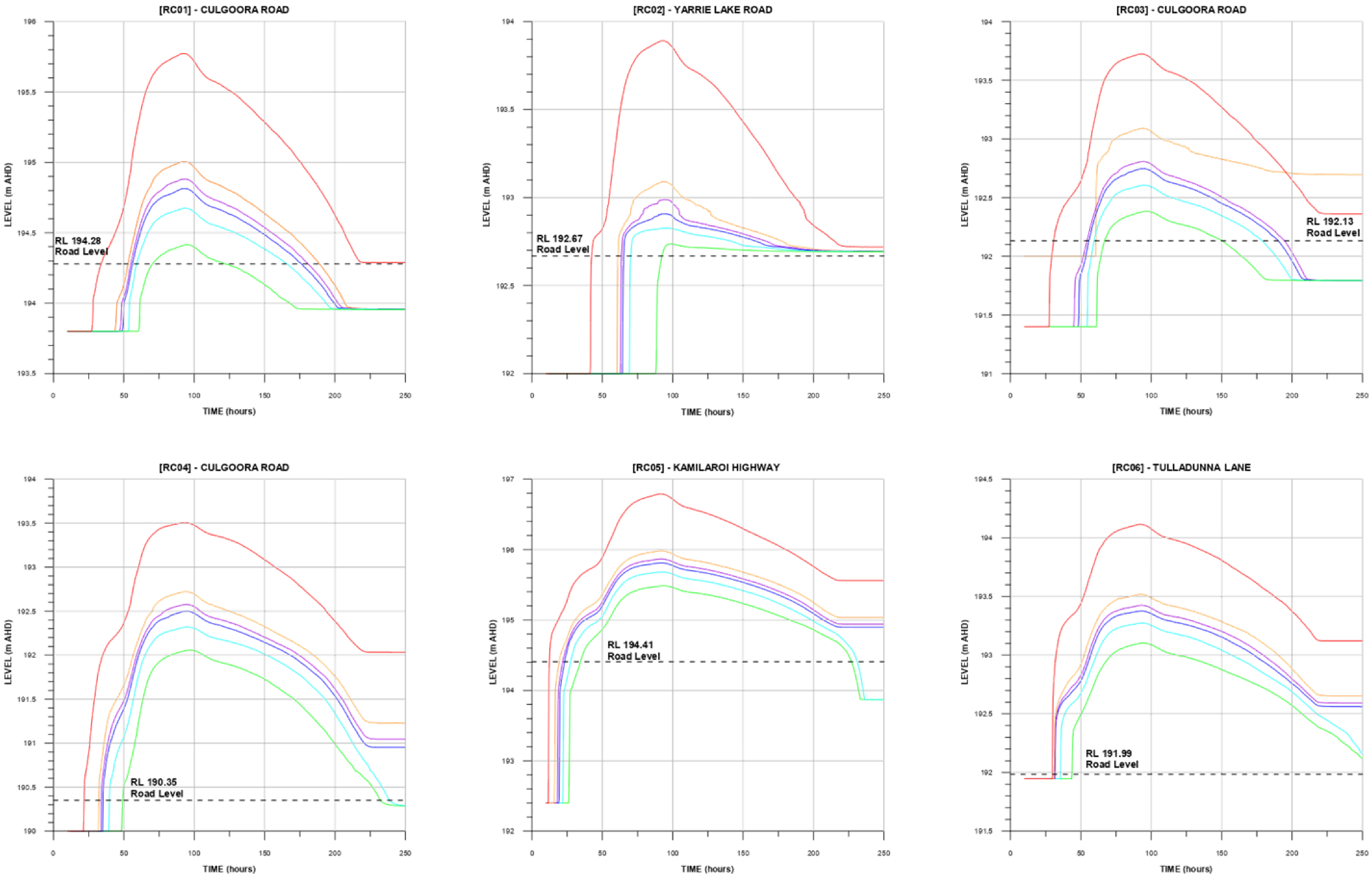
Figure 2.8
(Sheet 1 of 2)

INDICATIVE EXTENT AND DEPTHS OF INUNDATION
EXTREME FLOOD



Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER
QUINNS BILLABONG
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NARRABRI WEST WALGETT RAILWAY
BOOLCARROL ROAD
TRUCKING YARDS LANE
KAMILAROI HIGHWAY
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
CHARLES STREET
CHURCH STREET
GEORGE STREET
NELSON STREET
RIVER STREET
MAITLAND STREET
CRANE STREET
CHRISTY STREET
ALBION STREET
CAMERON AVENUE
VERA LEAP ROAD
CULGOORA ROAD
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Water Surface Elevation Contours (m AHD)
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.8
(Sheet 2 of 2)
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
EXTREME FLOOD


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NARRABRI WEST WALGETT RAILWAY
NAMOI RIVER
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
O'BRIENS CHANNEL
QUINNS BILLABONG
NOTE:
The TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position.
Scale: 1:10,000
100 0 100 200 300 m
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.9
INDICATIVE EXTENT AND DEPTHS OF INUNDATION
INTERNAL TO TOWN LEVEE - PMF



LEGEND

Extreme Flood	1% AEP
0.2% AEP	2% AEP
0.5% AEP	5% AEP

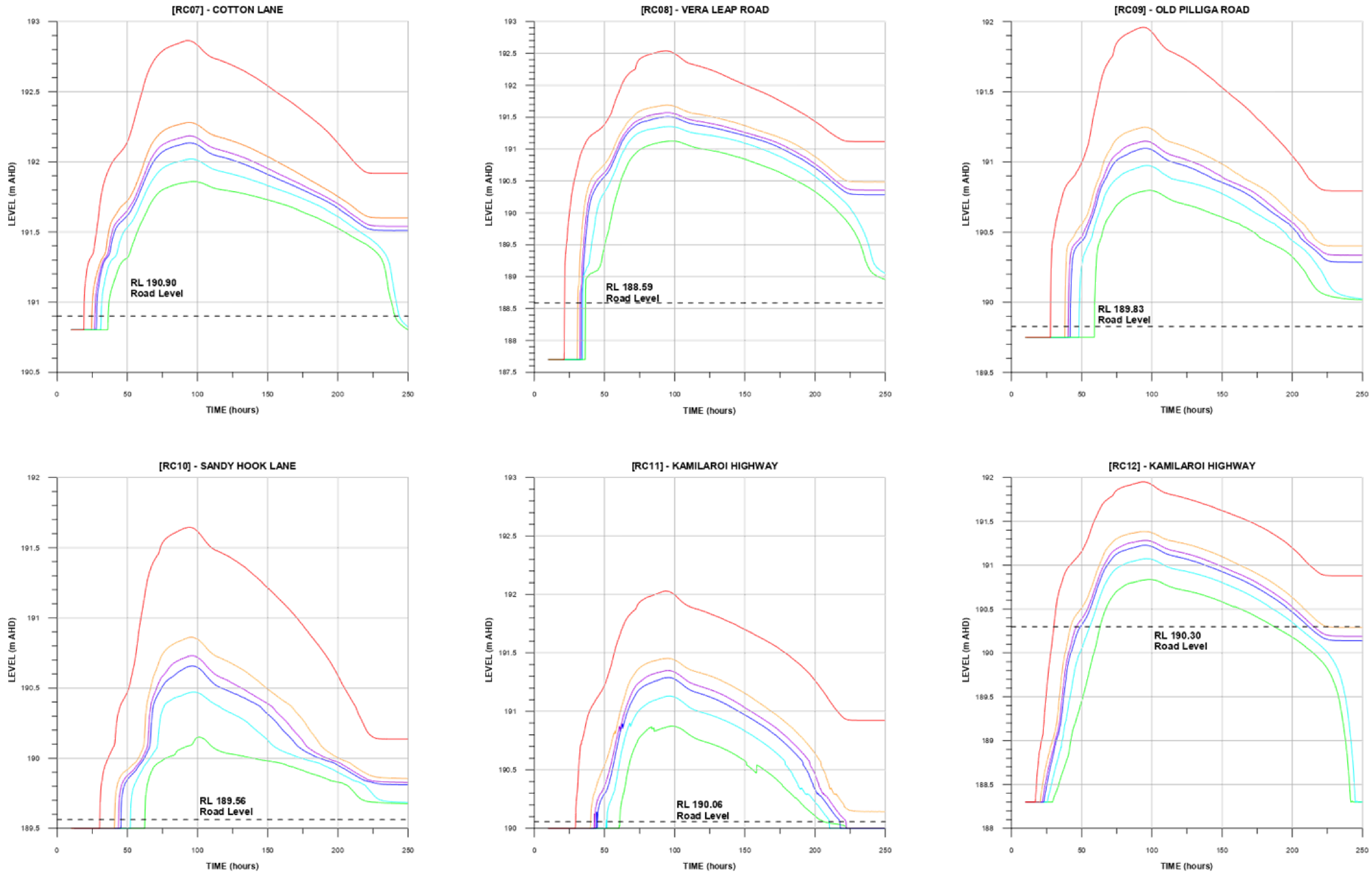
Lyall & Associates

NOTE:
Refer Figure 2.3 Sheet 1 for location of hydrographs.

WEE WAA LEVEE
RISK MANAGEMENT STUDY PLAN

Figure 2.10
(Sheet 1 of 3)

TIME OF RISE OF FLOODWATERS



LEGEND

- Extreme Flood
- 0.2% AEP
- 0.5% AEP
- 1% AEP
- 2% AEP
- 5% AEP

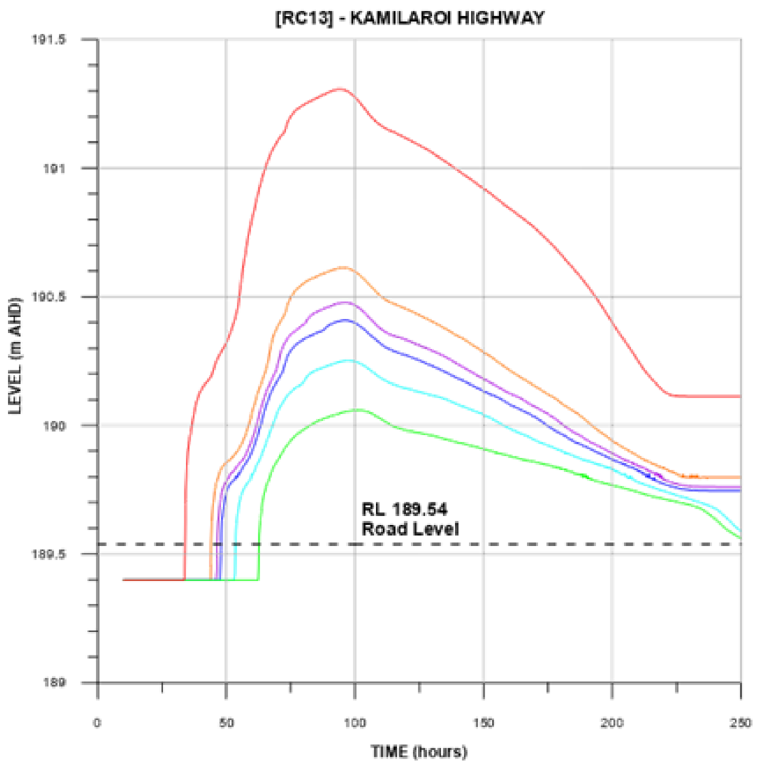
Lyall & Associates

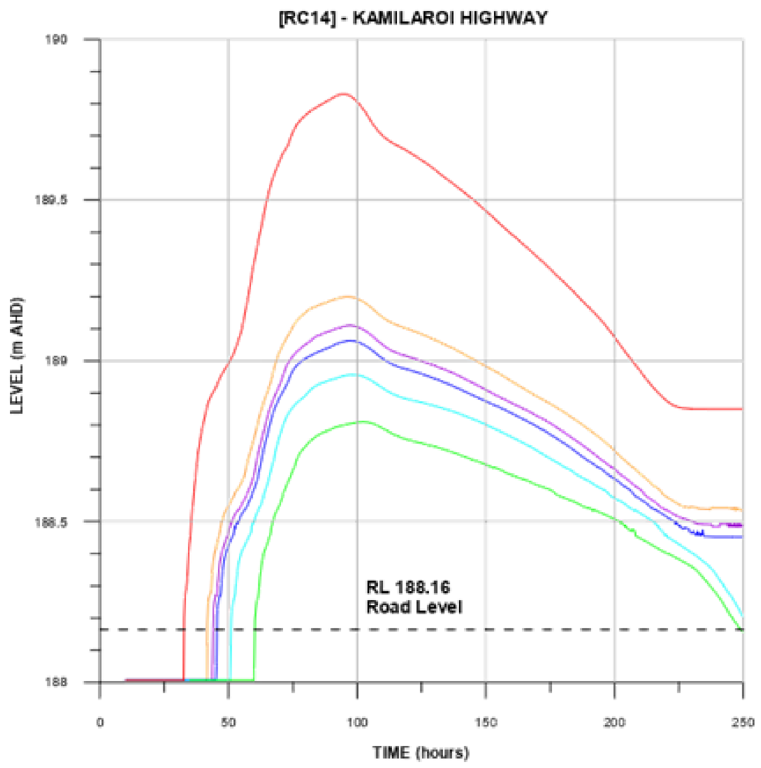
NOTE:
Refer Figure 2.3 Sheet 1 for location of hydrographs.

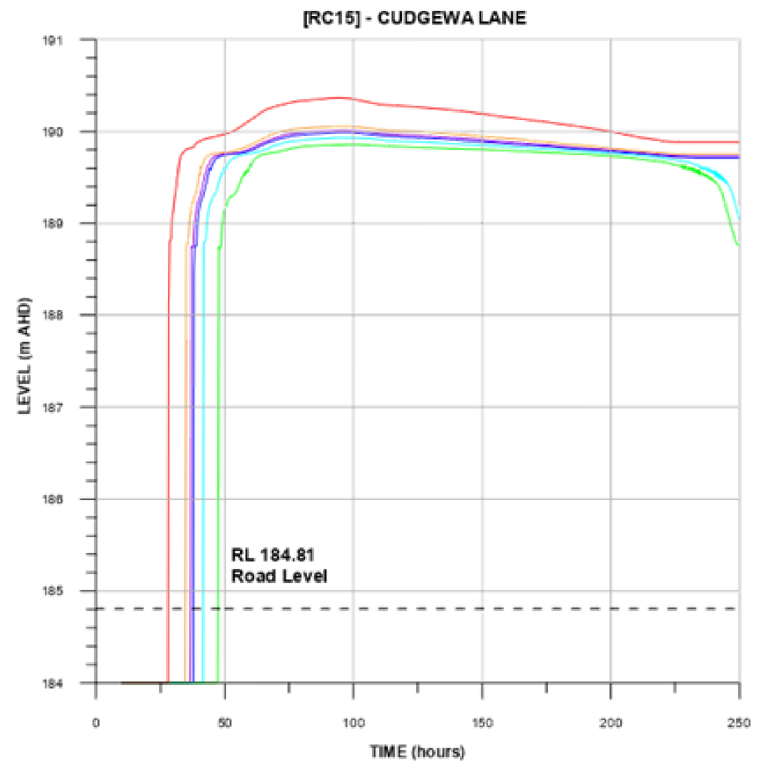
WEE WAA LEVEE
RISK MANAGEMENT STUDY PLAN

Figure 2.10
(Sheet 2 of 3)

TIME OF RISE OF FLOODWATERS





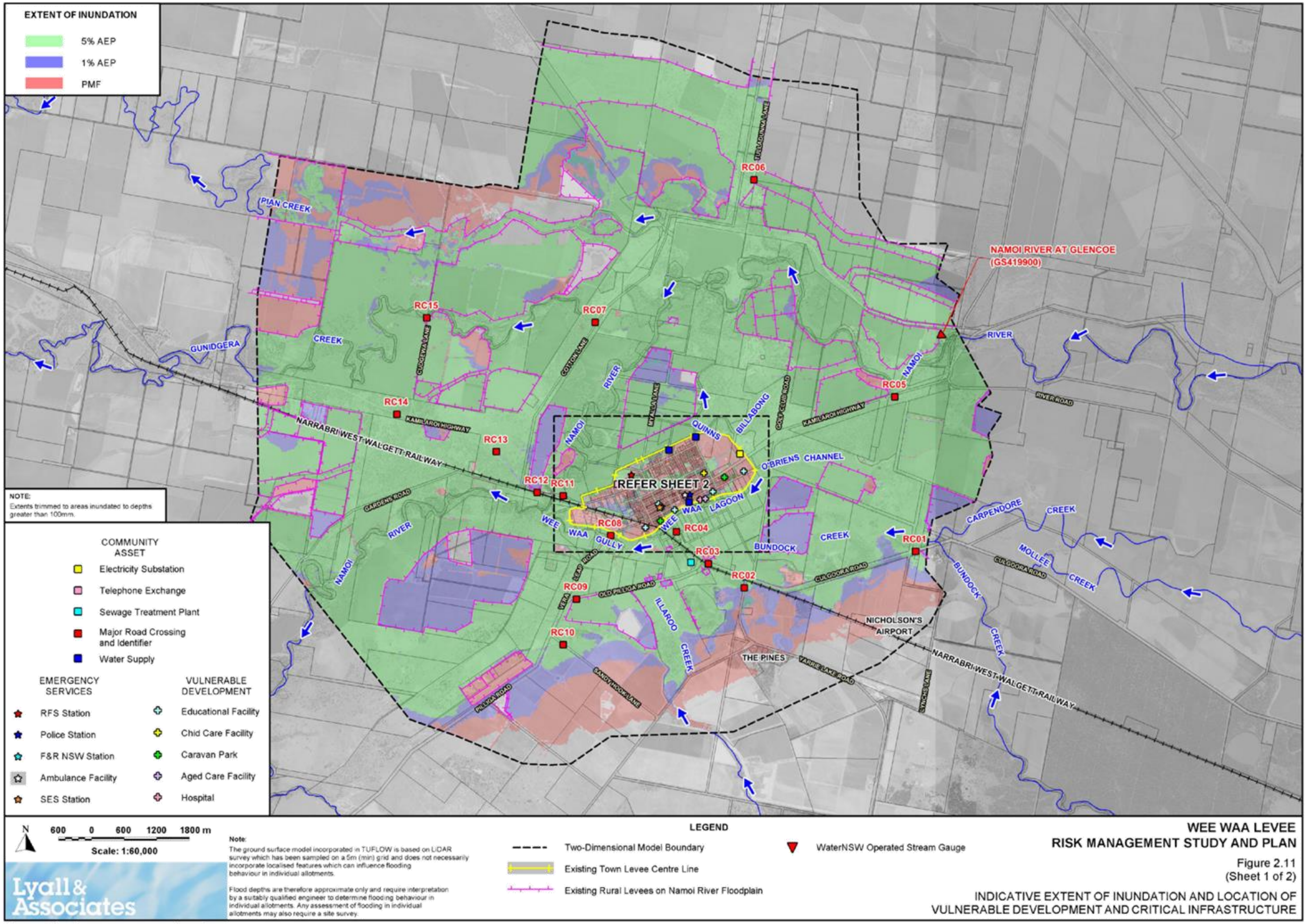


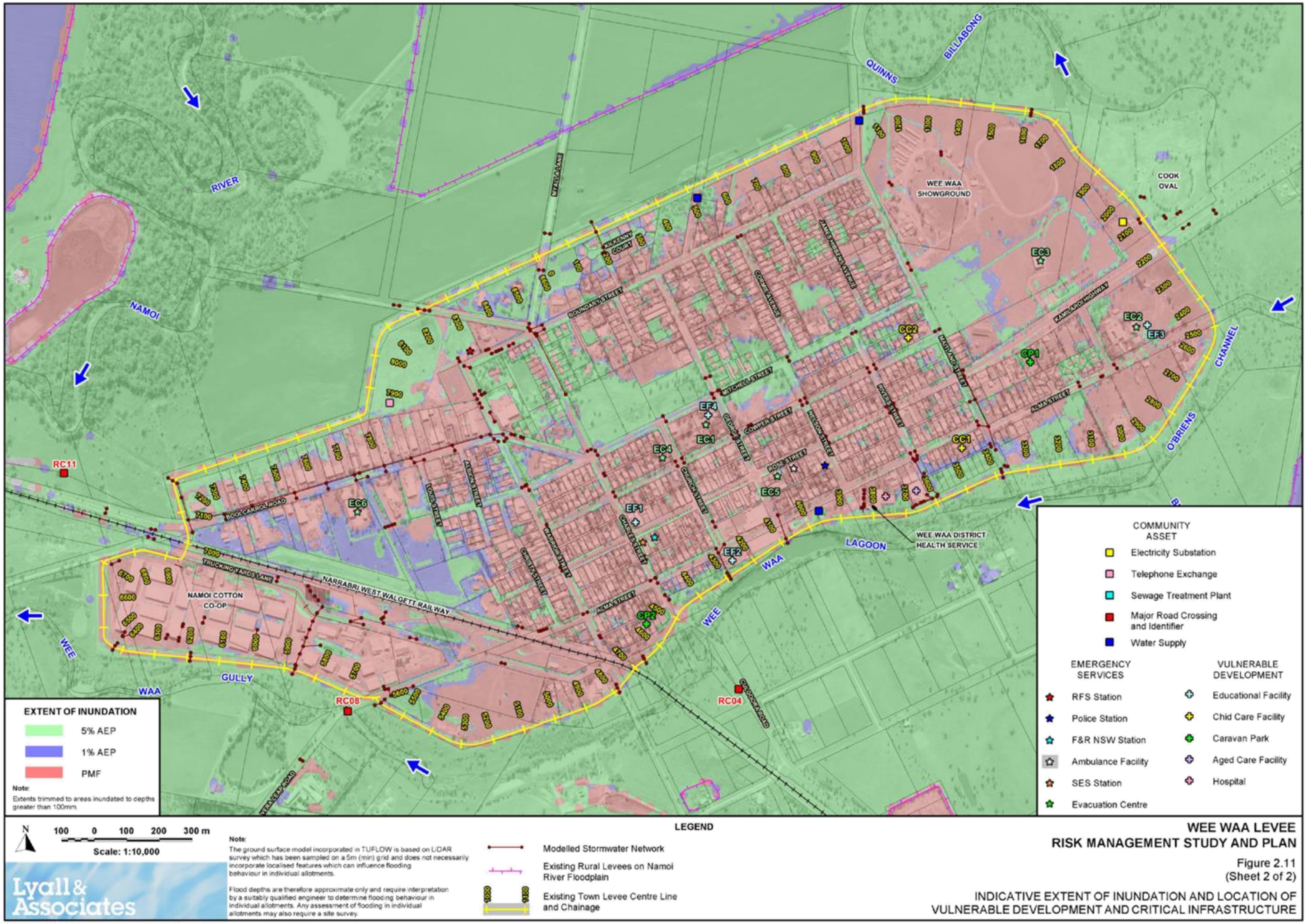
Lyall & Associates

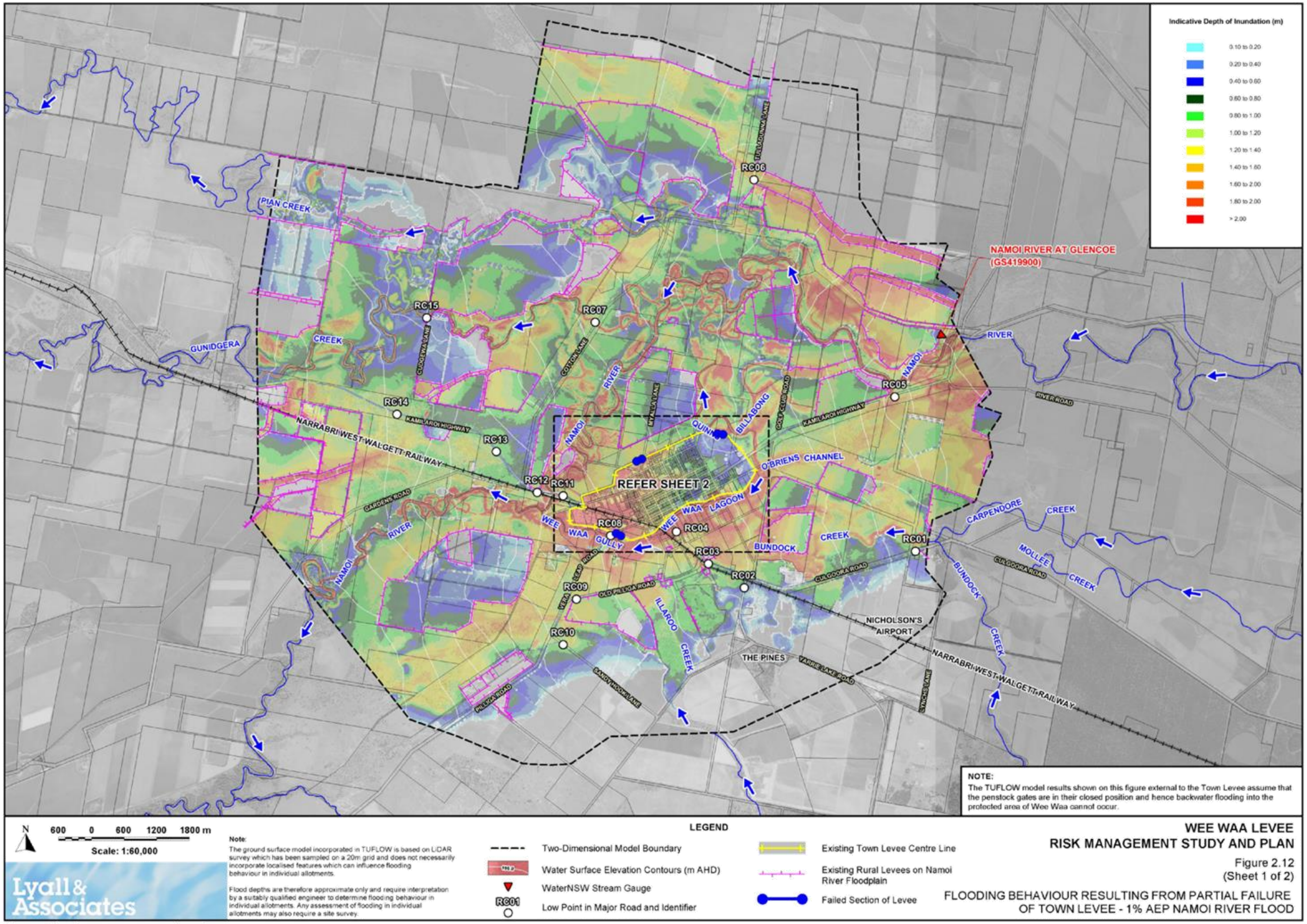
NOTE:
Refer **Figure 2.3 Sheet 1** for location of hydrographs.

WEE WAA LEVEE
RISK MANAGEMENT STUDY PLAN

Figure 2.10
(Sheet 3 of 3)
TIME OF RISE OF FLOODWATERS


EXTENT OF INUNDATION
5% AEP
1% AEP
PMF
NOTE:
Extents trimmed to areas inundated to depths greater than 100mm.
COMMUNITY ASSET
Electricity Substation
Telephone Exchange
Sewage Treatment Plant
Major Road Crossing and Identifier
Water Supply
EMERGENCY SERVICES
RFS Station
Police Station
F&R NSW Station
Ambulance Facility
SES Station
VULNERABLE DEVELOPMENT
Educational Facility
Chid Care Facility
Caravan Park
Aged Care Facility
Hospital
NAMOI RIVER AT GLENCOE (GS419900)
REFER SHEET 2
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
PIAN CREEK
GUNIDGERA
CREEK
NAMOI
RIVER
NARRABRI-WEST-WALGETT RAILWAY
KAMILAROI HIGHWAY
QUINNS
BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK
CREEK
CARPENDORE
MOLLEE
CULGOORA ROAD
ILLAROO
NICHOLSON'S AIRPORT
THE PINES
OLD PILLIGA ROAD
GARDENS ROAD
RIVER ROAD
600 0 600 1200 1800 m
Scale: 1:60,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WaterNSW Operated Stream Gauge
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.11
(Sheet 1 of 2)
INDICATIVE EXTENT OF INUNDATION AND LOCATION OF VULNERABLE DEVELOPMENT AND CRITICAL INFRASTRUCTURE


NAMOI
RIVER
QUINNS
BILLABONG
WEE WAA SHOWGROUND
COOK OVAL
BOUNDARY STREET
KAMILAROI HIGHWAY
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
BOOLCARROL ROAD
TRUCKING YARDS LANE
NARRABRI WEST WALGETT RAILWAY
NAMOI COTTON CO-OP
WEE WAA GULLY
WEE WAA LAGOON
WEE WAA DISTRICT HEALTH SERVICE
O'BRIENS CHANNEL
RC11
RC08
RC04
EXTENT OF INUNDATION
5% AEP
1% AEP
PMF
Note:
Extents trimmed to areas inundated to depths greater than 100mm.
COMMUNITY ASSET
Electricity Substation
Telephone Exchange
Sewage Treatment Plant
Major Road Crossing and Identifier
Water Supply
EMERGENCY SERVICES
RFS Station
Police Station
F&R NSW Station
Ambulance Facility
SES Station
Evacuation Centre
VULNERABLE DEVELOPMENT
Educational Facility
Chid Care Facility
Caravan Park
Aged Care Facility
Hospital
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.11
(Sheet 2 of 2)
INDICATIVE EXTENT OF INUNDATION AND LOCATION OF VULNERABLE DEVELOPMENT AND CRITICAL INFRASTRUCTURE


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER AT GLENCOE (GS419900)
PIAN CREEK
GUNIDGERA CREEK
NAMOI RIVER
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
KAMILAROI HIGHWAY
NARRABRI-WEST-WALGETT RAILWAY
REFER SHEET 2
QUINNS BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
CULGOORA ROAD
RIVER ROAD
GOLF CLUB ROAD
COTTON LANE
GARDENS ROAD
OLD PILLIGA ROAD
ILLAROO CREEK
NICHOLSON'S AIRPORT
THE PINES
YARRIE LAKE ROAD
PILLIGA ROAD
VERA LEAF ROAD
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur.
N
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
Water Surface Elevation Contours (m AHD)
WaterNSW Stream Gauge
RC01
Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
Failed Section of Levee
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.12
(Sheet 1 of 2)
FLOODING BEHAVIOUR RESULTING FROM PARTIAL FAILURE OF TOWN LEVEE - 1% AEP NAMOI RIVER FLOOD

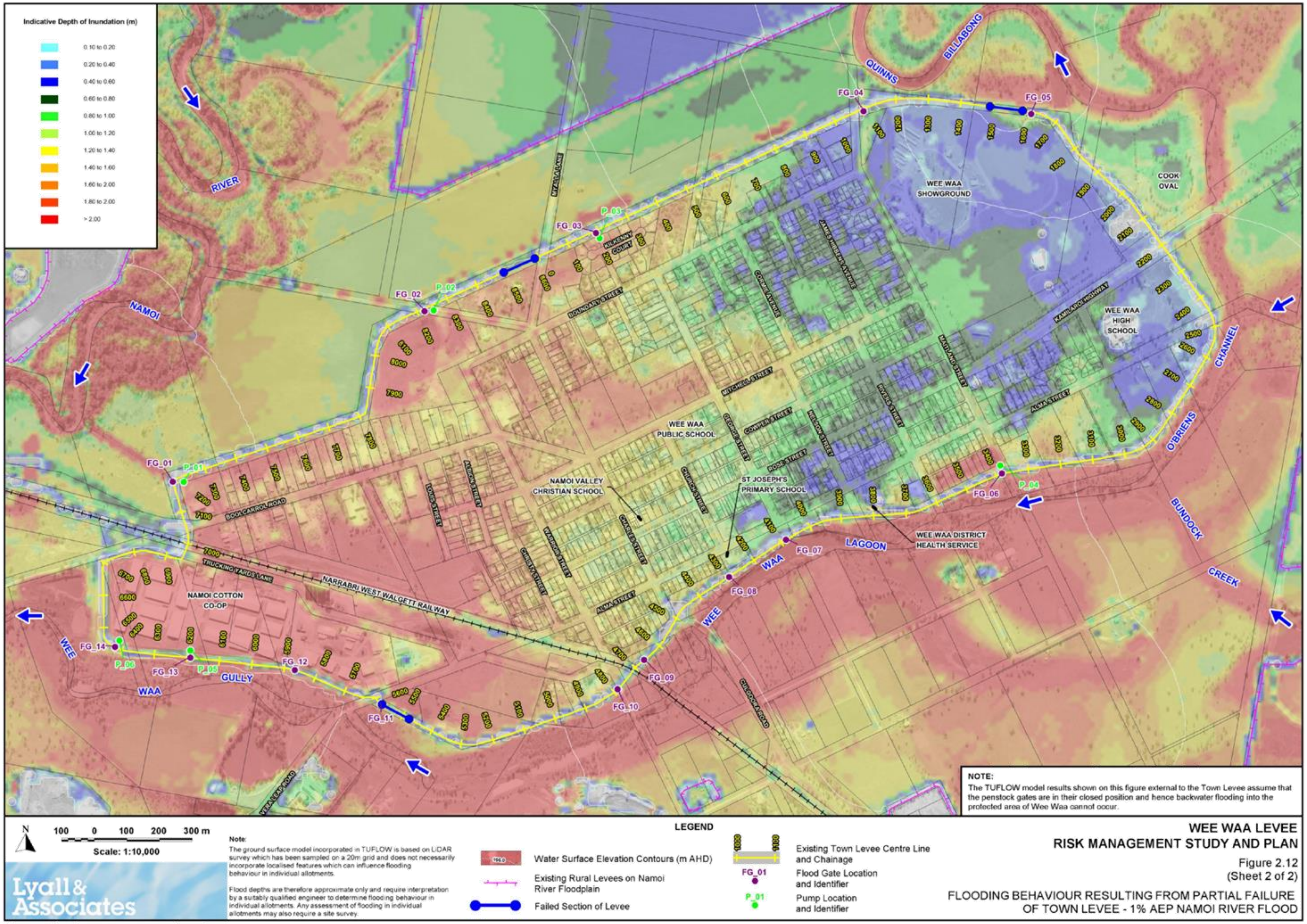
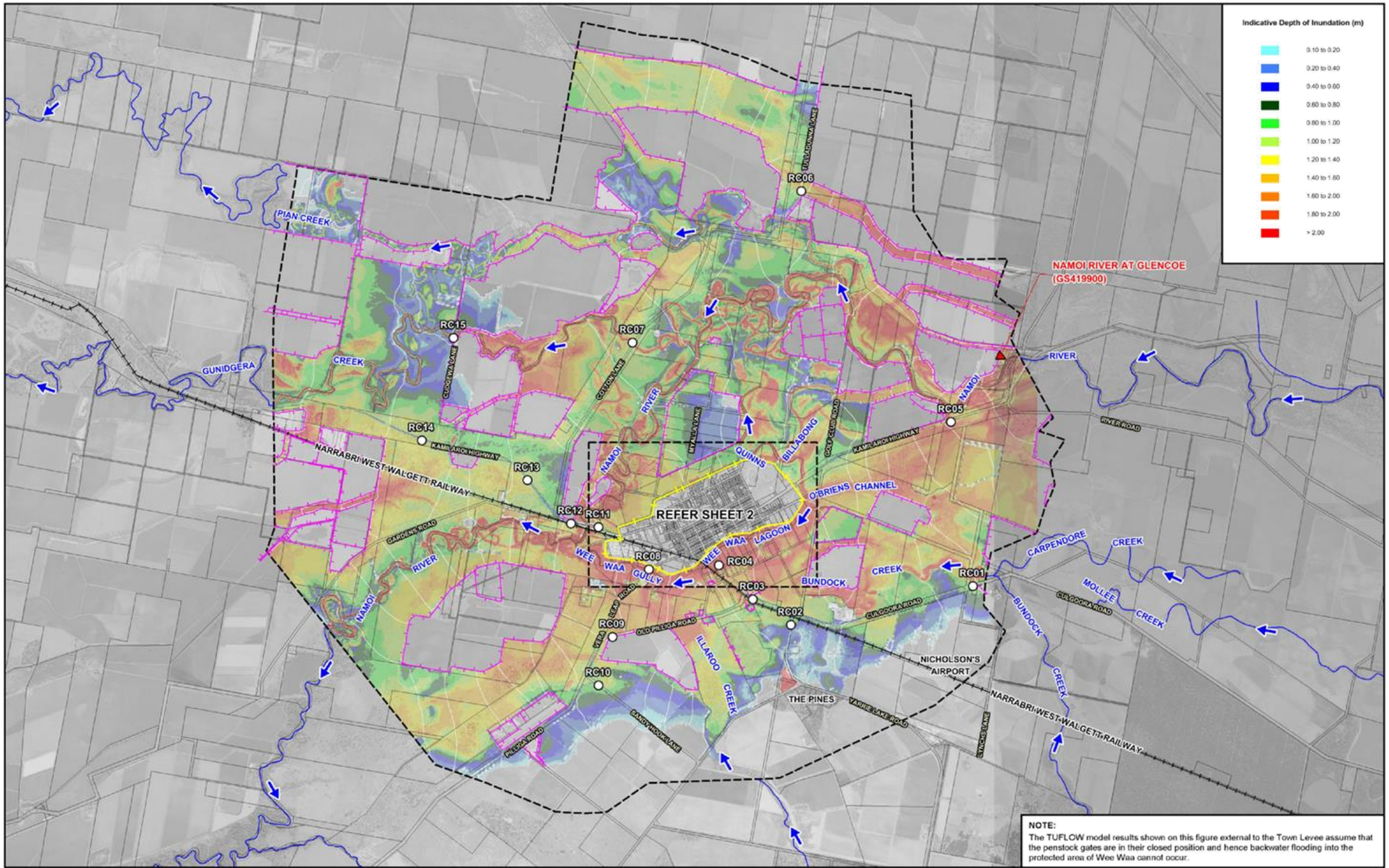


Figure 2.12
(Sheet 2 of 2)

FLOODING BEHAVIOUR RESULTING FROM PARTIAL FAILURE OF TOWN LEVEE - 1% AEP NAMOI RIVER FLOOD



N

600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

Note:

The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

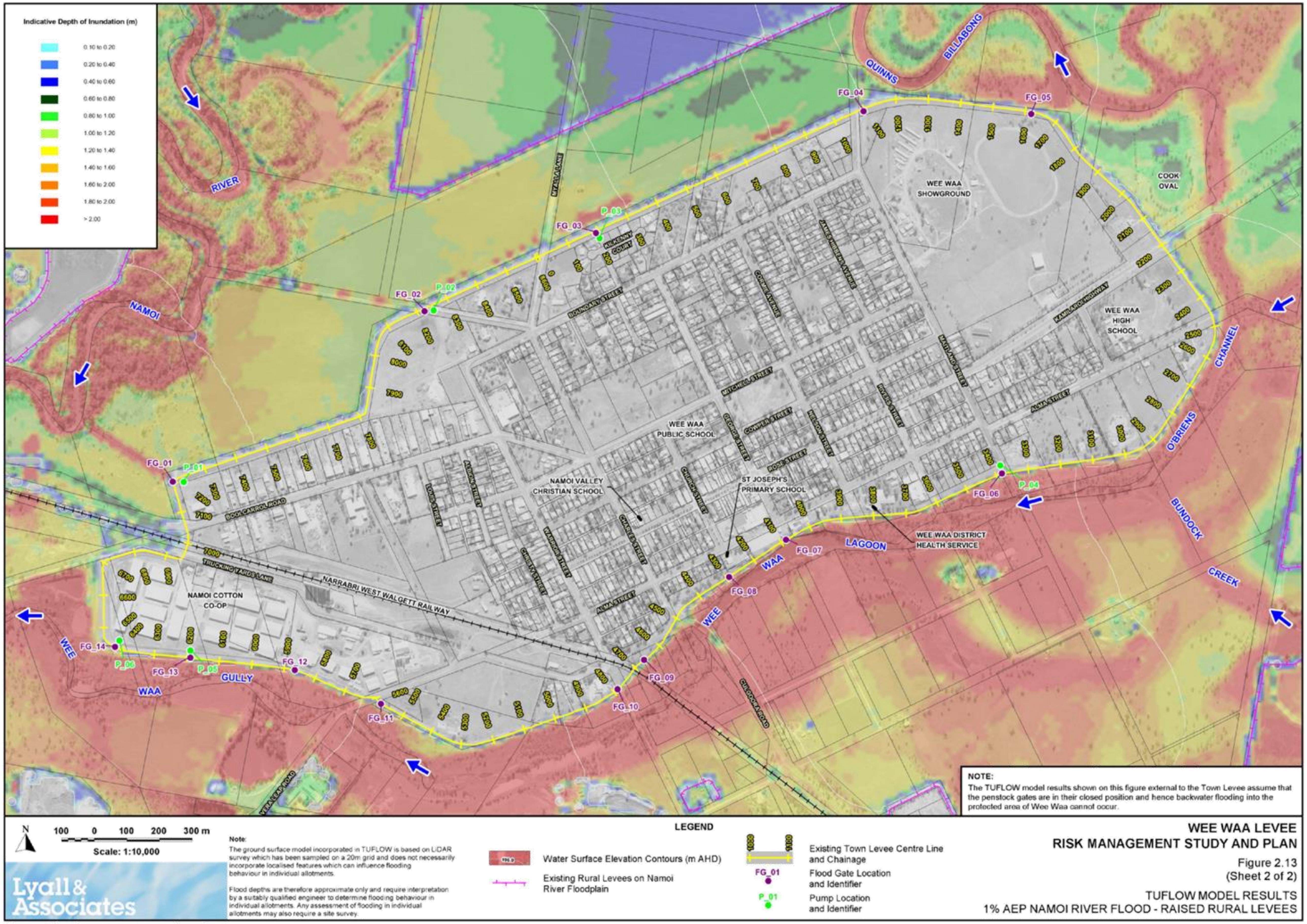
LEGEND

- Two-Dimensional Model Boundary
- Water Surface Elevation Contours (m AHD)
- WaterNSW Stream Gauge
- RC01 Low Point in Major Road and Identifier
- Existing Town Levee Centre Line
- Existing Rural Levees on Namoi River Floodplain

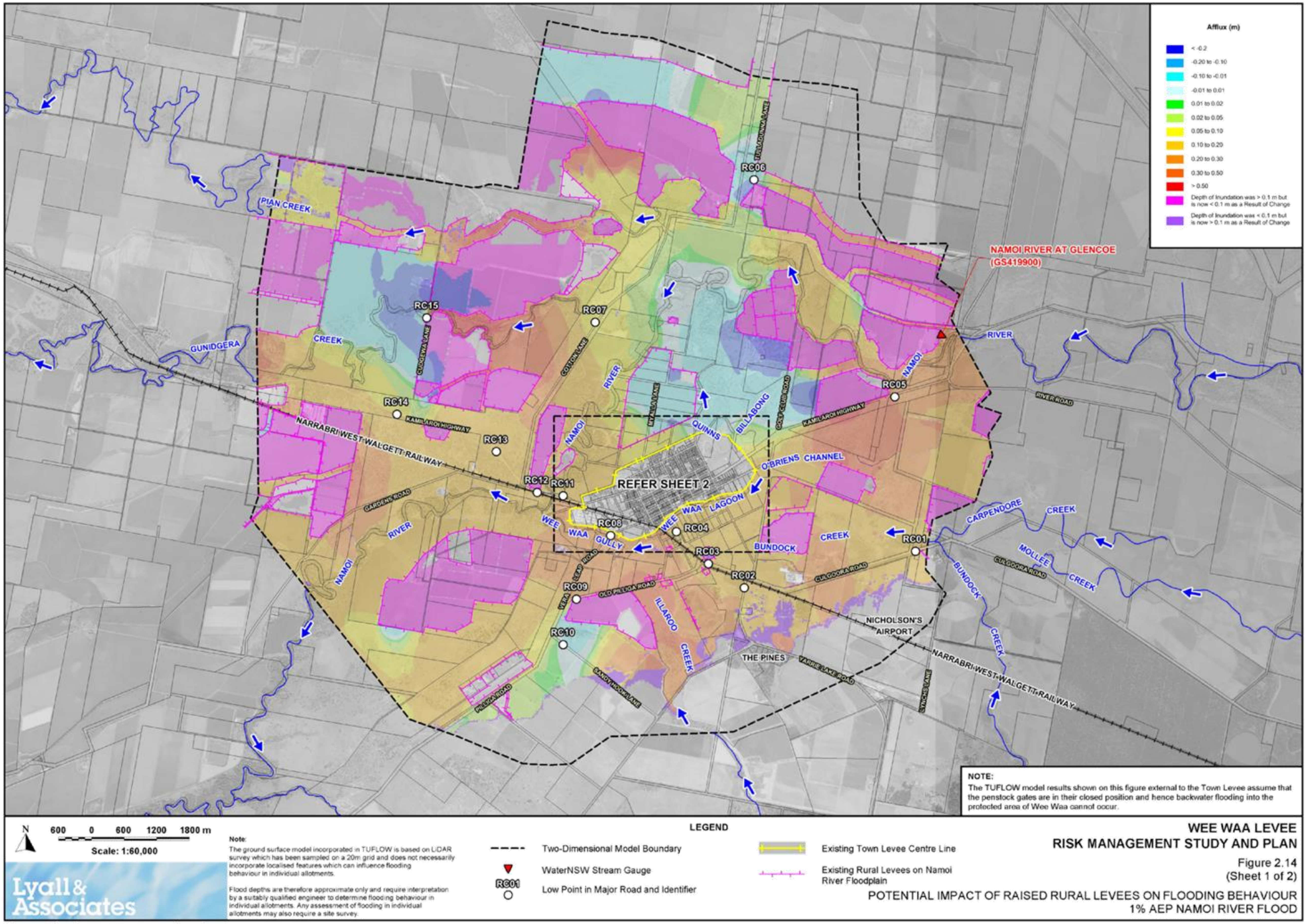
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

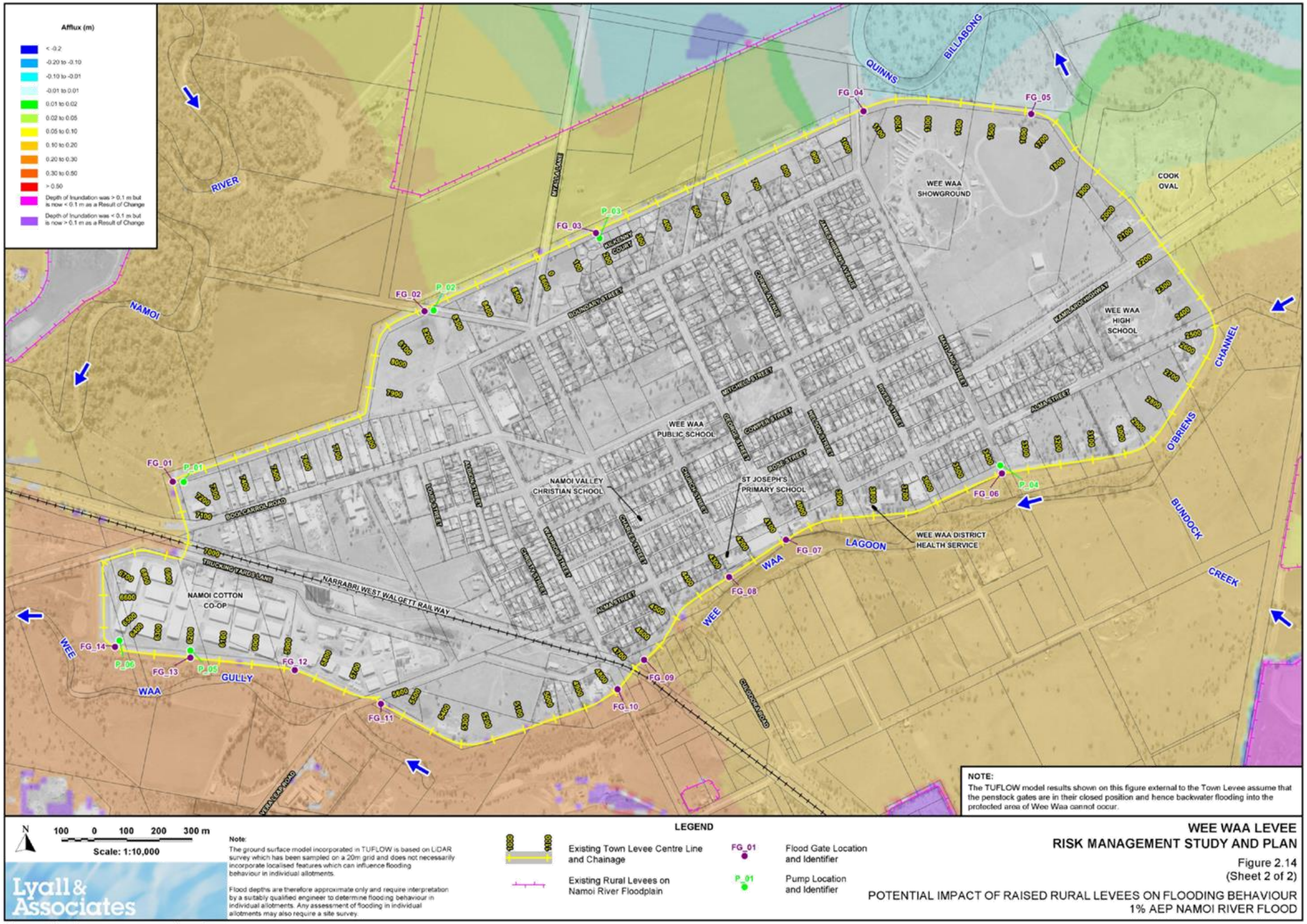
Figure 2.13
(Sheet 1 of 2)

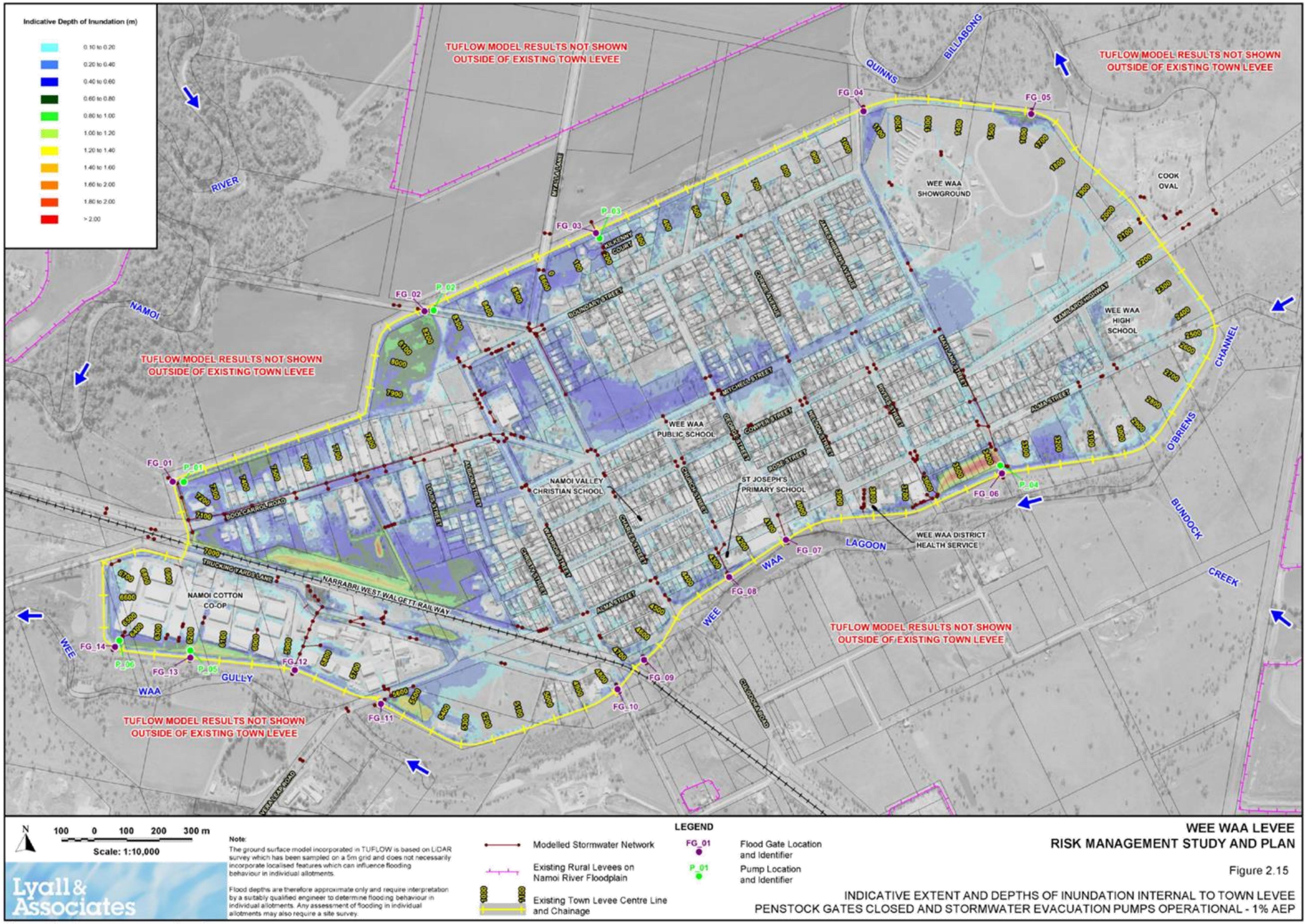
TUFLOW MODEL RESULTS
1% AEP NAMOI RIVER FLOOD - RAISED RURAL LEVEES

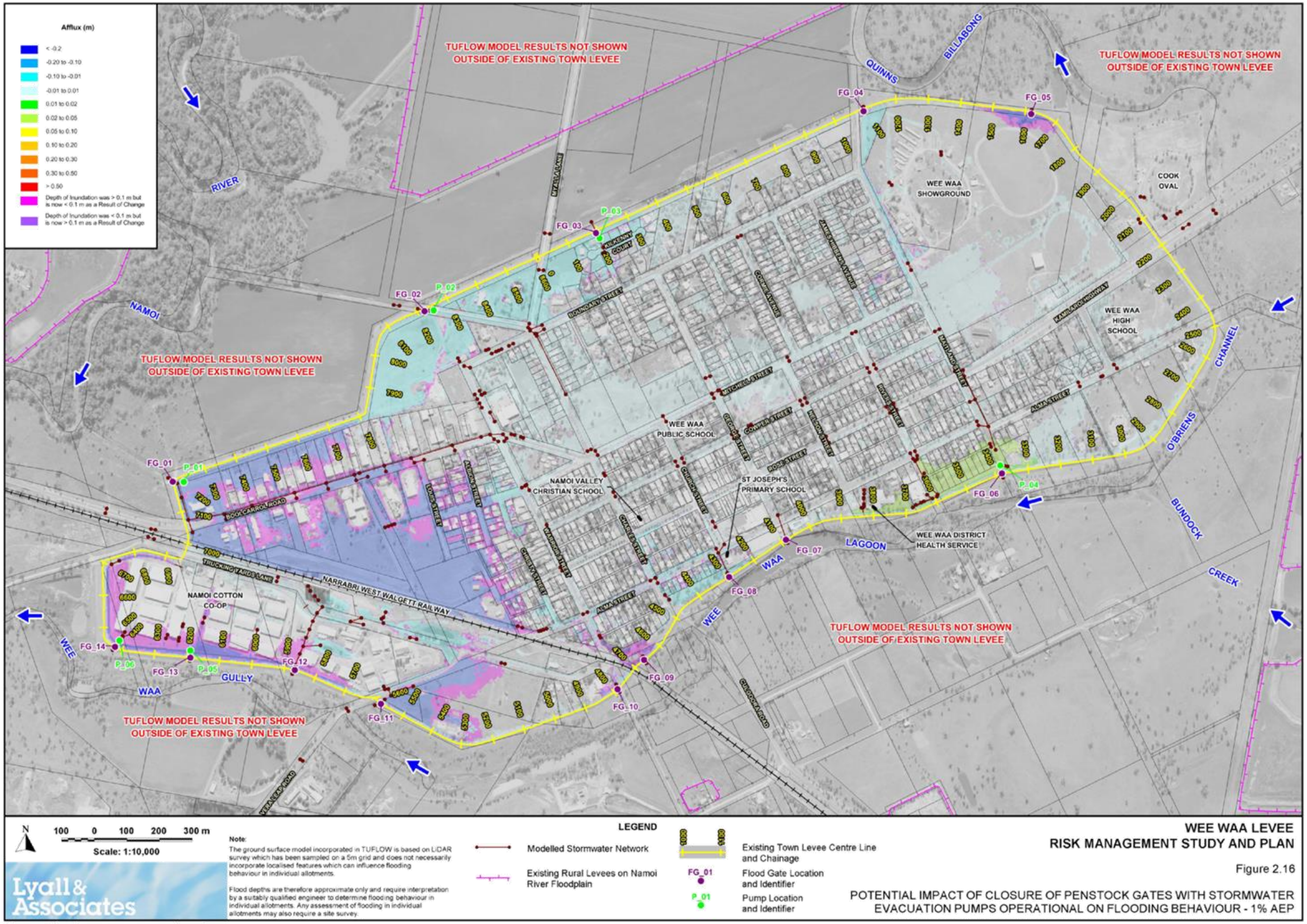


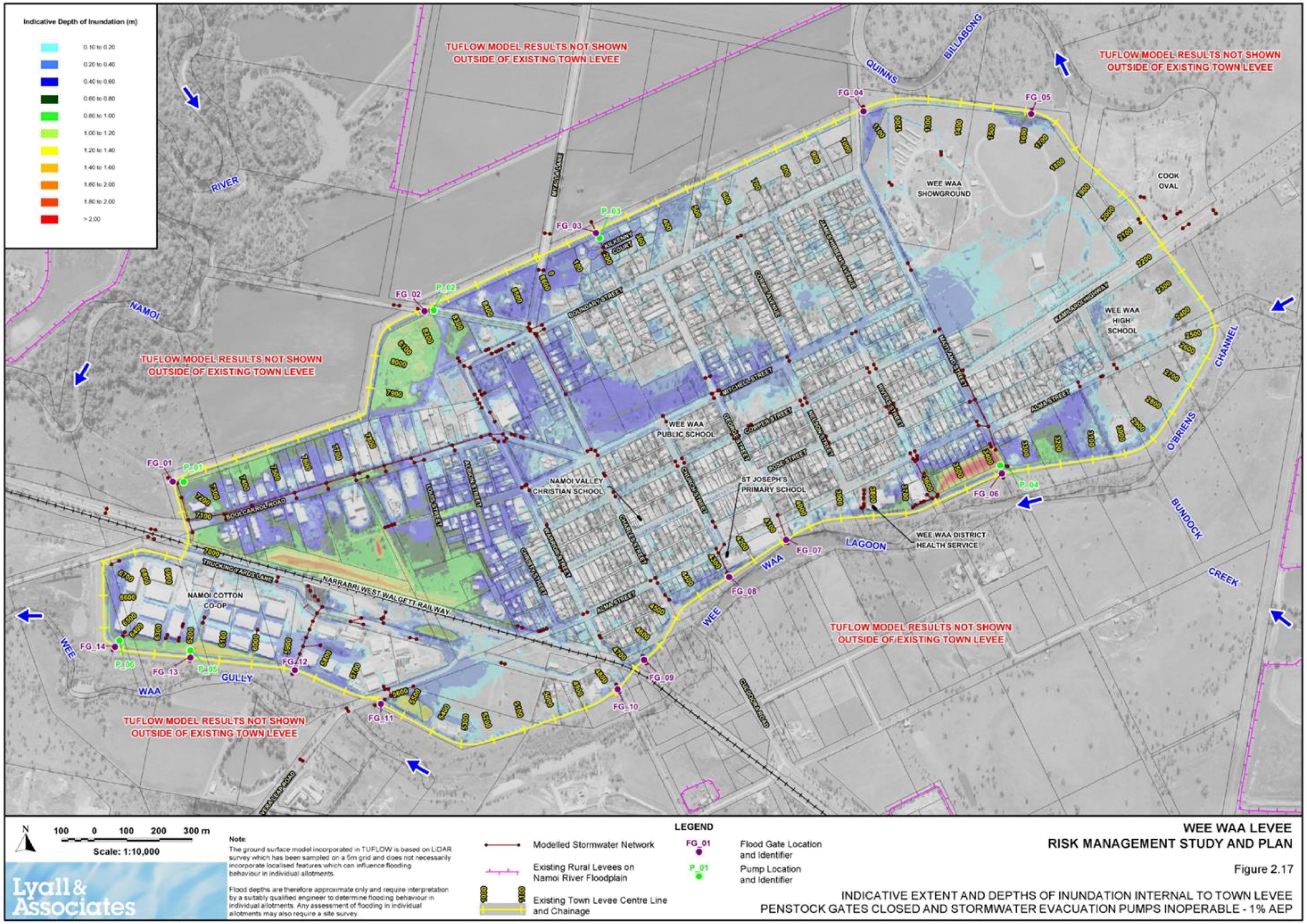
Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
NAMOI RIVER
QUINNS BILLABONG
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
CHANNEL
O'BRIENS
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NARRABRI WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOKCARROL ROAD
BOUNDARY STREET
KAMILAROI HIGHWAY
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
FG_01 FG_02 FG_03 FG_04 FG_05 FG_06 FG_07 FG_08 FG_09 FG_10 FG_11 FG_12 FG_13 FG_14
P_01 P_02 P_03 P_04 P_05 P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur.
100 0 100 200 300 m
Scale: 1:10,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
Lyall & Associates
LEGEND
Water Surface Elevation Contours (m AHD)
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.13
(Sheet 2 of 2)
TUFLOW MODEL RESULTS
1% AEP NAMOI RIVER FLOOD - RAISED RURAL LEVEES


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NAMOI RIVER AT GLENCOE (GS419900)
PIAN CREEK
GUNIDGERA CREEK
NAMOI RIVER
REFER SHEET 2
WEE WAA LAGOON
WEE WAA GULLY
QUINNS BILLABONG
O'BRIENS CHANNEL
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
ILLAROO CREEK
NARRABRI-WEST-WALGETT RAILWAY
KAMILAROI HIGHWAY
RIVER ROAD
CULGOORA ROAD
OLD PILLIGA ROAD
NICHOLSON'S AIRPORT
THE PINES
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur.
N
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
WaterNSW Stream Gauge
RC01 Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.14
(Sheet 1 of 2)
POTENTIAL IMPACT OF RAISED RURAL LEVEES ON FLOODING BEHAVIOUR
1% AEP NAMOI RIVER FLOOD


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NAMOI RIVER
QUINNS BILLABONG
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
NARRABRI WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOKCARROL ROAD
KAMILAROI HIGHWAY
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
1000 1100
Existing Town Levee Centre Line and Chainage
Existing Rural Levees on Namoi River Floodplain
FG_01
Flood Gate Location and Identifier
P_01
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.14
(Sheet 2 of 2)
POTENTIAL IMPACT OF RAISED RURAL LEVEES ON FLOODING BEHAVIOUR
1% AEP NAMOI RIVER FLOOD


Indicative Depth of Inundation (m)
0.10 to 0.20
0.20 to 0.40
0.40 to 0.60
0.60 to 0.80
0.80 to 1.00
1.00 to 1.20
1.20 to 1.40
1.40 to 1.60
1.60 to 2.00
1.80 to 2.00
> 2.00
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
BOOLCARROL ROAD
TRUCKING YARDS LANE
NARRABRI WEST WALGETT RAILWAY
KAMILAROI HIGHWAY
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
KILKENNY COURT
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
FG_01 Flood Gate Location and Identifier
P_01 Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.15
INDICATIVE EXTENT AND DEPTHS OF INUNDATION INTERNAL TO TOWN LEVEE
PENSTOCK GATES CLOSED AND STORMWATER EVACUATION PUMPS OPERATIONAL - 1% AEP

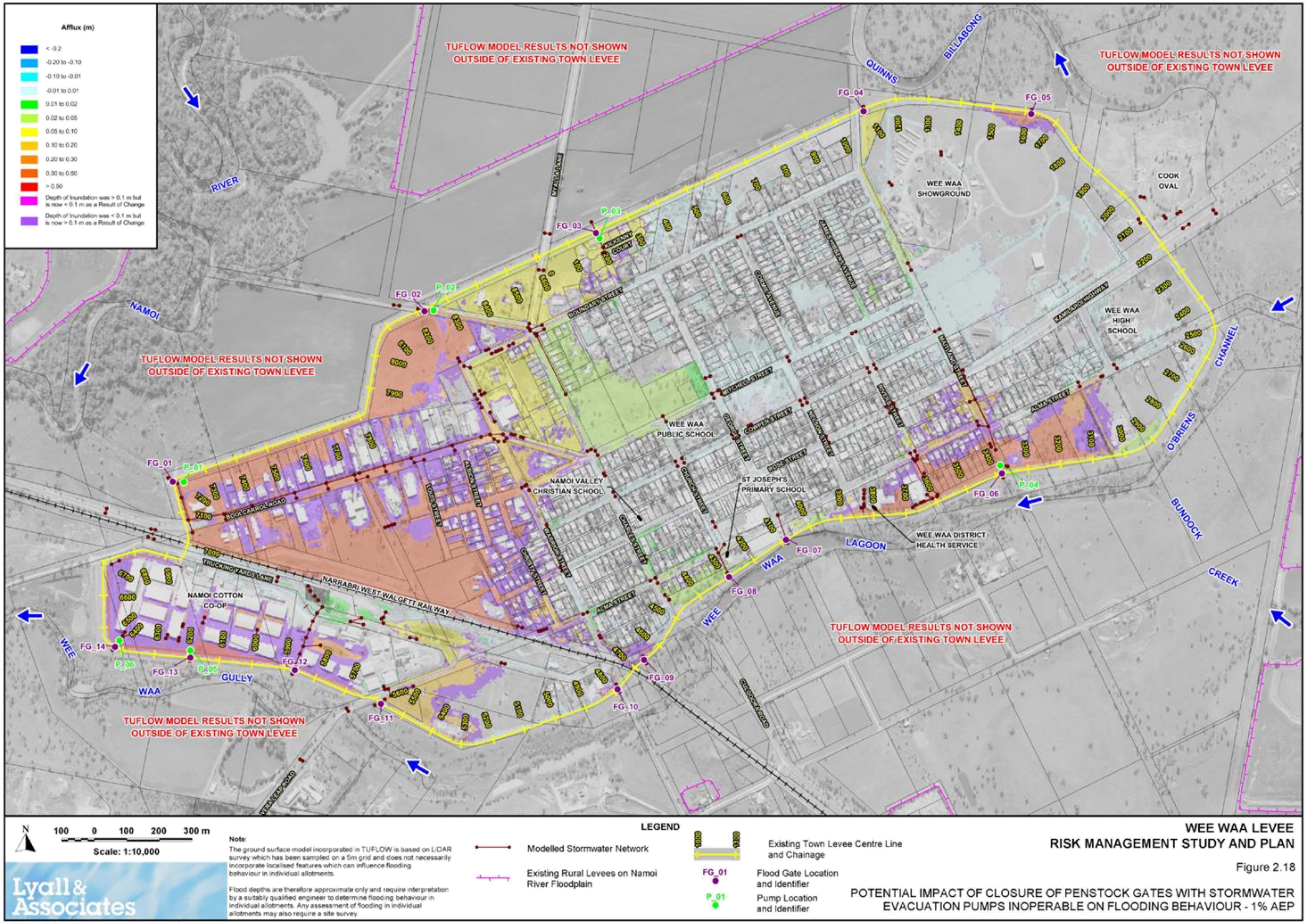

Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
NAMOI
RIVER
QUINNS
BILLABONG
CHANNEL
O'BRIENS
BUNDOCK
CREEK
WEE WAA
LAGOON
GULLY
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
BOOLCARROL ROAD
TRUCKING YARDS LANE
NARRABRI WEST WALGETT RAILWAY
BOUNDARY STREET
KAMILAROI HIGHWAY
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
KILKENNY COURT
VERA LEAP ROAD
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.16
POTENTIAL IMPACT OF CLOSURE OF PENSTOCK GATES WITH STORMWATER EVACUATION PUMPS OPERATIONAL ON FLOODING BEHAVIOUR - 1% AEP

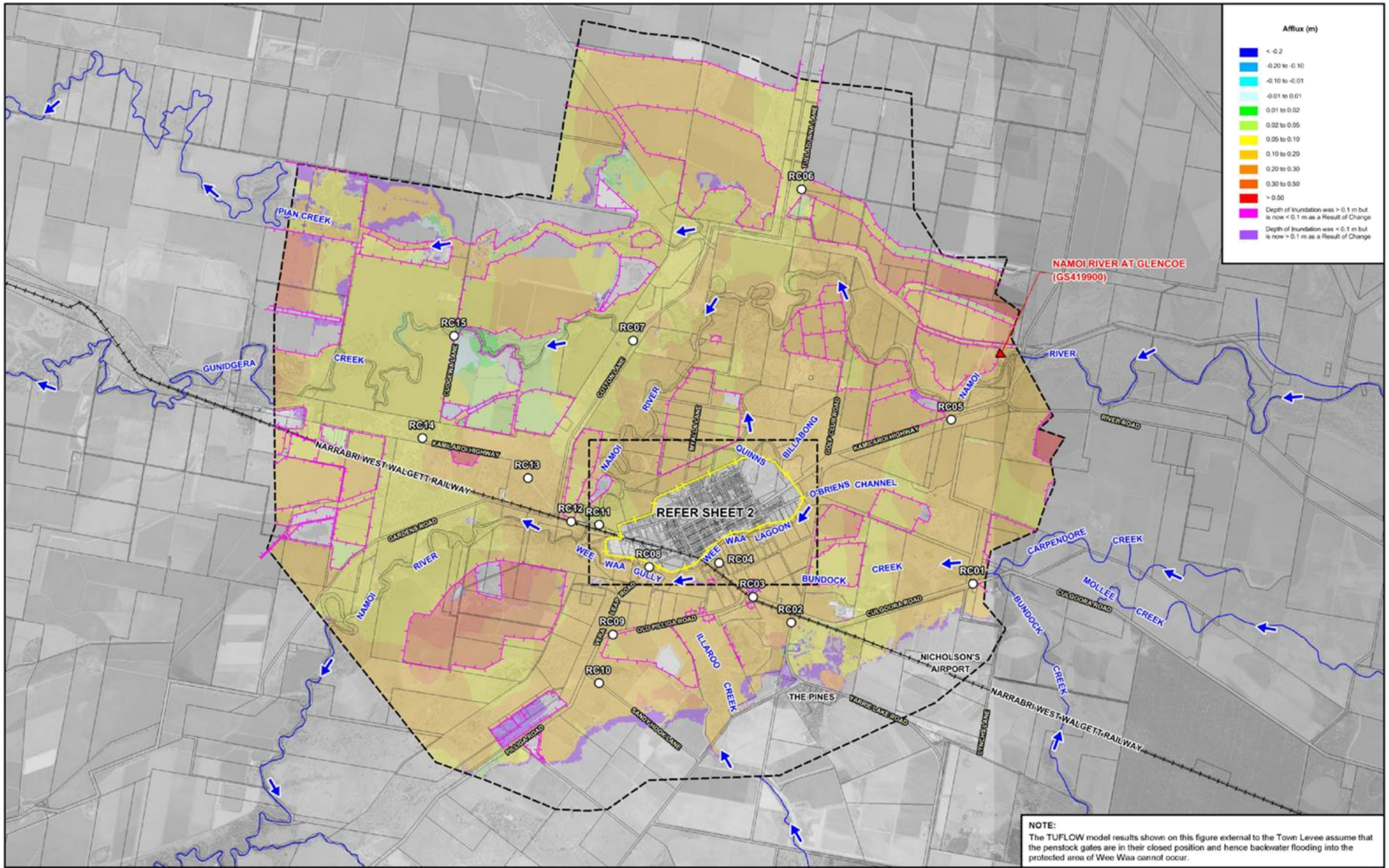


WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 2.17

INDICATIVE EXTENT AND DEPTHS OF INUNDATION INTERNAL TO TOWN LEVEE
PENSTOCK GATES CLOSED AND STORMWATER EVACUATION PUMPS INOPERABLE - 1% AEP


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
NAMOI RIVER
QUINNS BILLABONG
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
CHANNEL
O'BRIENS
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
BOOLCARROL ROAD
TRUCKING YARDS LANE
NARRABRI WEST WALGETT RAILWAY
KAMILAROI HIGHWAY
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
MAITLAND STREET
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
FG_01 Flood Gate Location and Identifier
P_01 Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.18
POTENTIAL IMPACT OF CLOSURE OF PENSTOCK GATES WITH STORMWATER EVACUATION PUMPS INOPERABLE ON FLOODING BEHAVIOUR - 1% AEP



N

600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

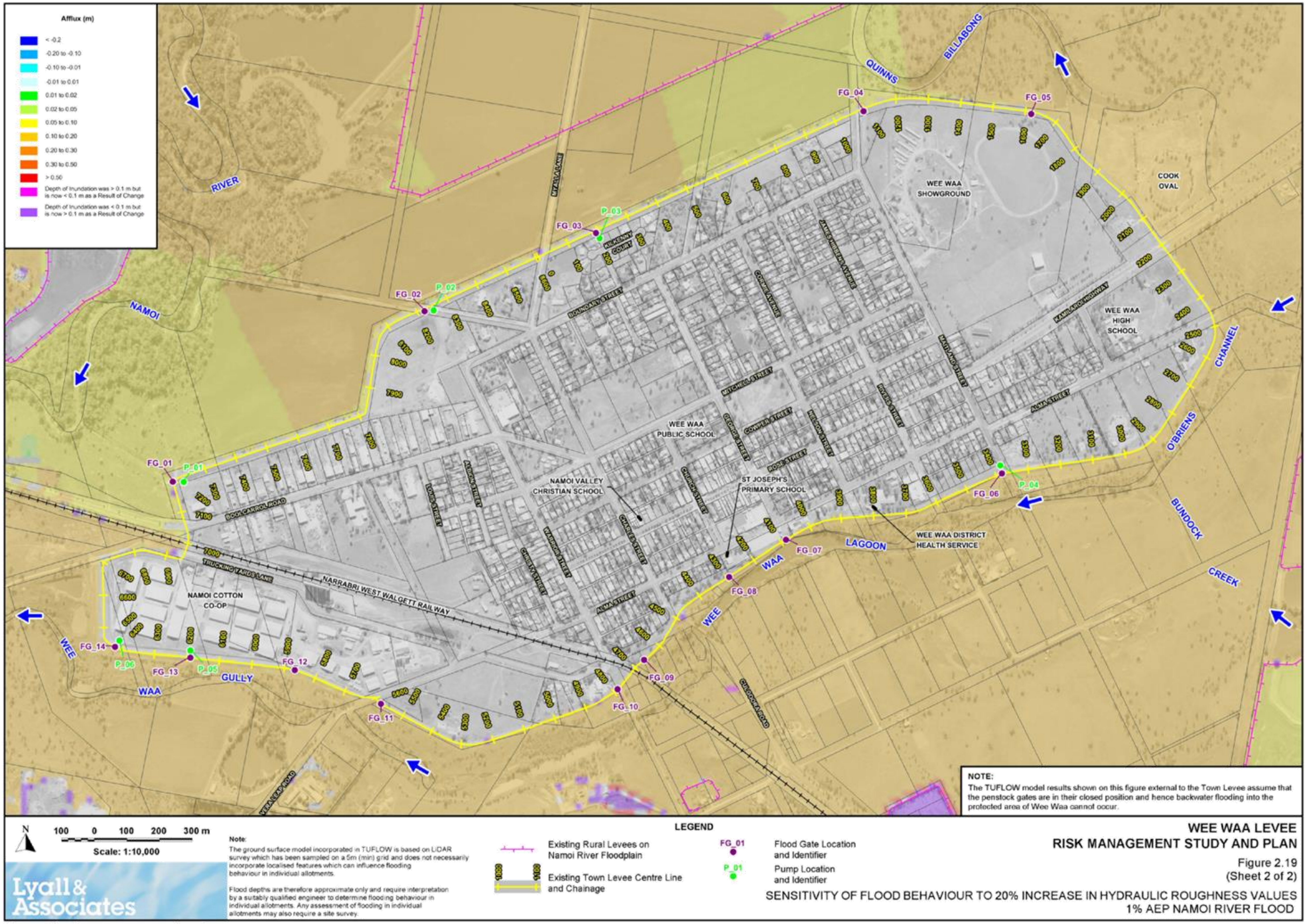
LEGEND

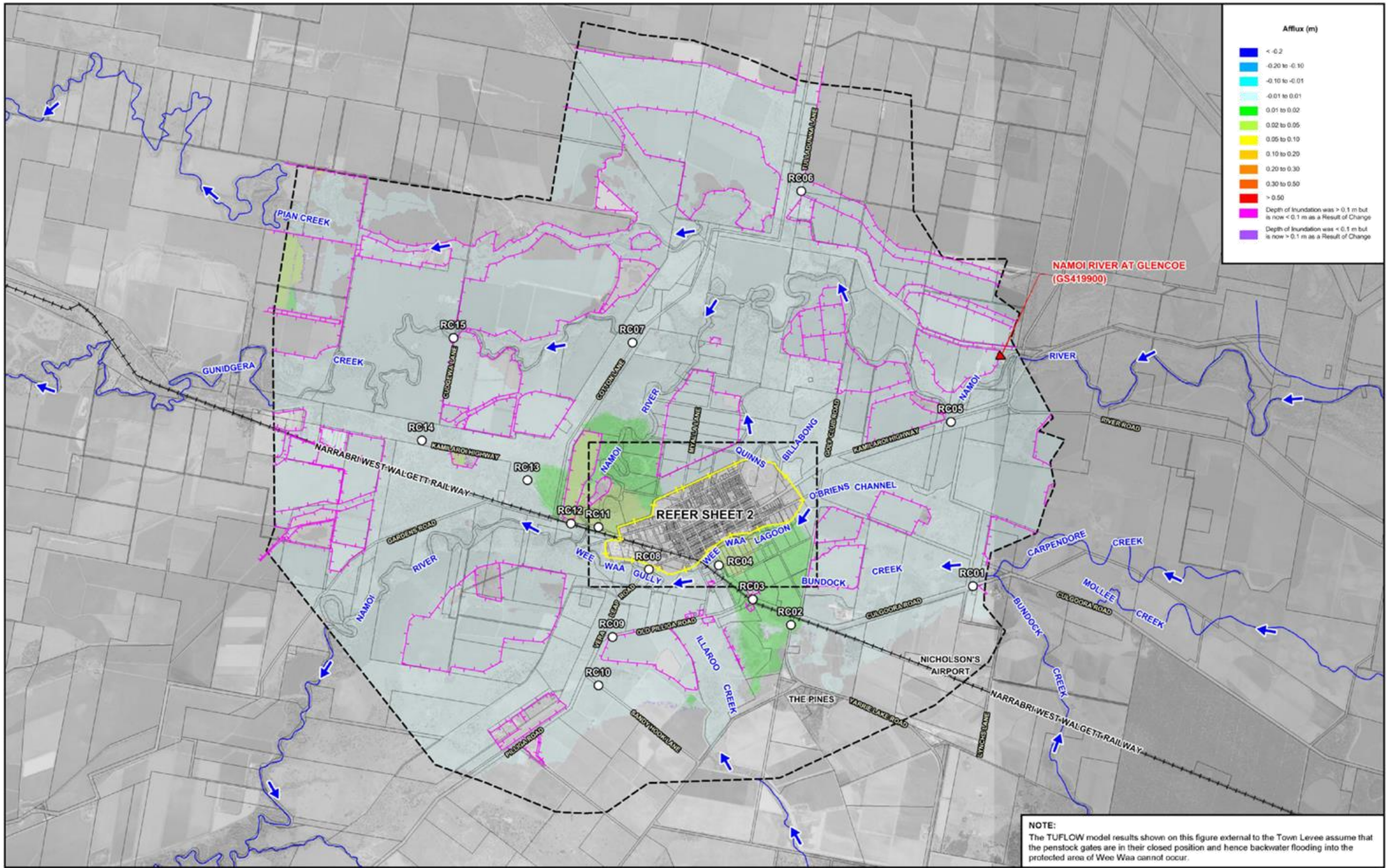
Two-Dimensional Model Boundary
WaterNSW Stream Gauge
RC01 Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 2.19
(Sheet 1 of 2)

SENSITIVITY OF FLOOD BEHAVIOUR TO 20% INCREASE IN HYDRAULIC ROUGHNESS VALUES
1% AEP NAMOI RIVER FLOOD


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NAMOI RIVER
QUINNS BILLABONG
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
NARRABRI WEST WALGETT RAILWAY
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur.
100 0 100 200 300 m
Scale: 1:10,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.19
(Sheet 2 of 2)
SENSITIVITY OF FLOOD BEHAVIOUR TO 20% INCREASE IN HYDRAULIC ROUGHNESS VALUES
1% AEP NAMOI RIVER FLOOD



N

600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

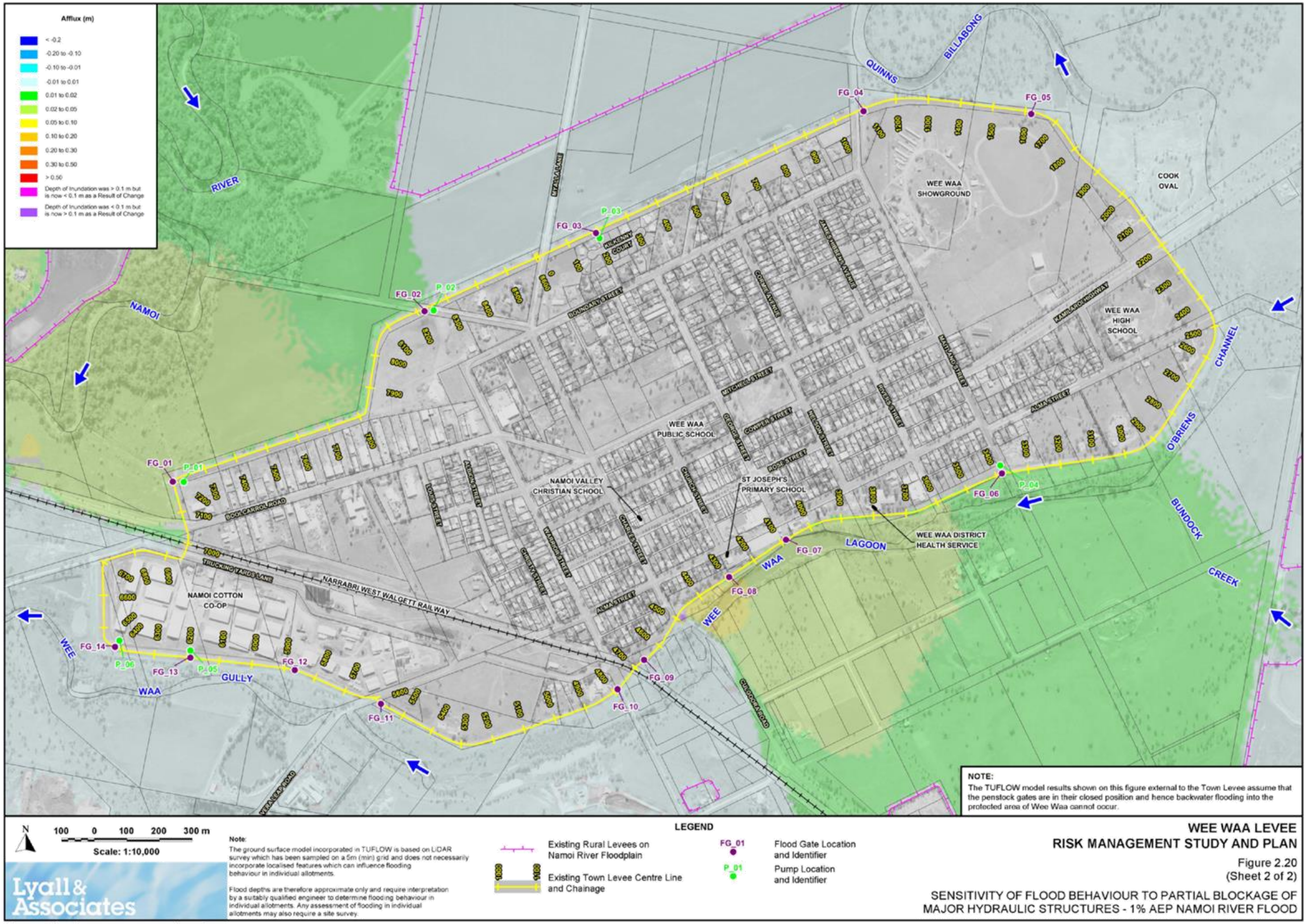
LEGEND

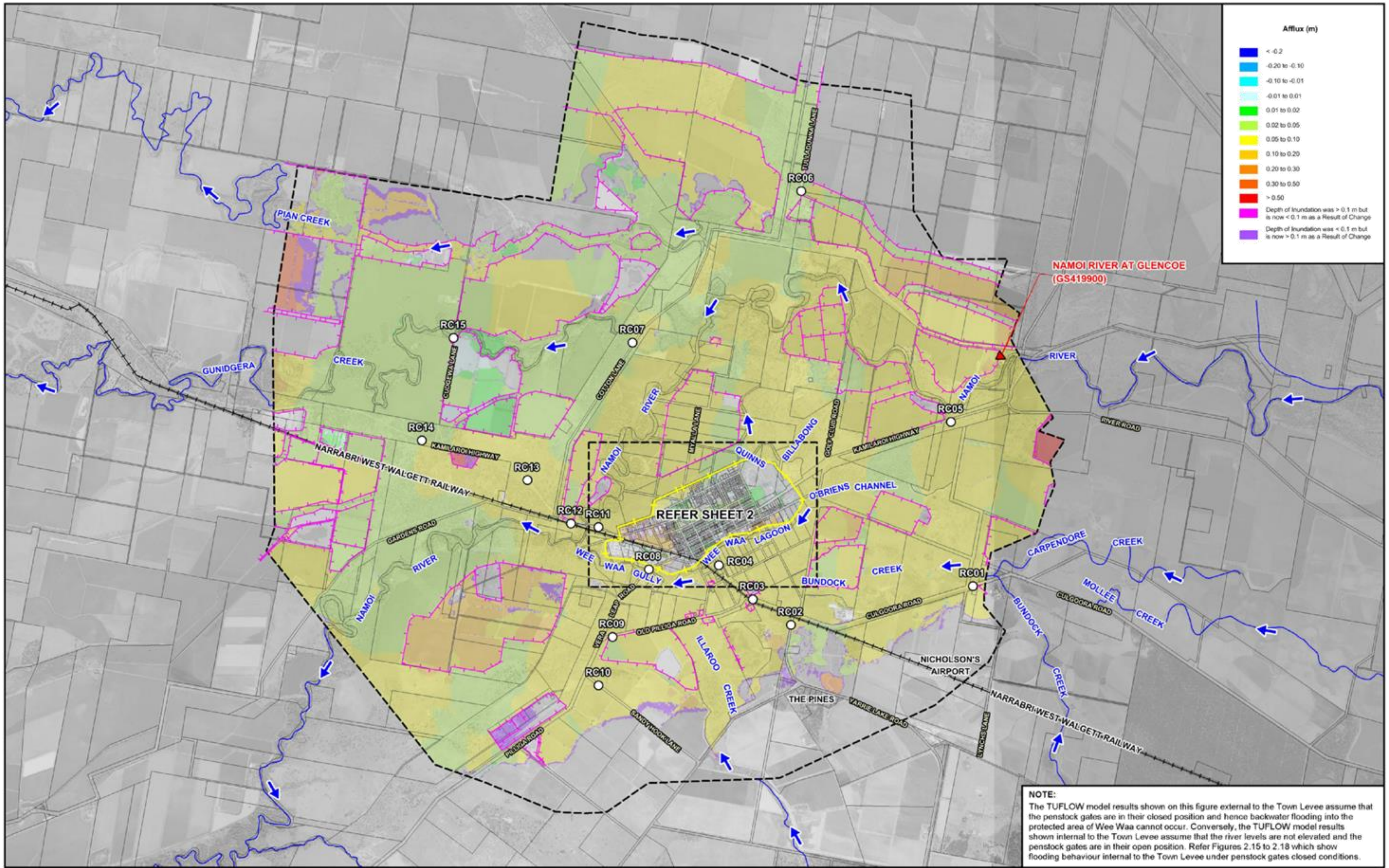
Two-Dimensional Model Boundary
WaterNSW Stream Gauge
RC01 Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 2.20
(Sheet 1 of 2)

SENSITIVITY OF FLOOD BEHAVIOUR TO PARTIAL BLOCKAGE OF MAJOR HYDRAULIC STRUCTURES - 1% AEP NAMOI RIVER FLOOD


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NAMOI RIVER
QUINNS BILLABONG
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
WEE WAA LAGOON
WEE WAA GULLY
O'BRIENS CHANNEL
BUNDOCK CREEK
NARRABRI WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOKCARROL ROAD
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
KAMILAROI HIGHWAY
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
FG_01 Flood Gate Location and Identifier
P_01 Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.20
(Sheet 2 of 2)
SENSITIVITY OF FLOOD BEHAVIOUR TO PARTIAL BLOCKAGE OF MAJOR HYDRAULIC STRUCTURES - 1% AEP NAMOI RIVER FLOOD



N 600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

LEGEND

Two-Dimensional Model Boundary

WaterNSW Stream Gauge

RC01 Low Point in Major Road and Identifier

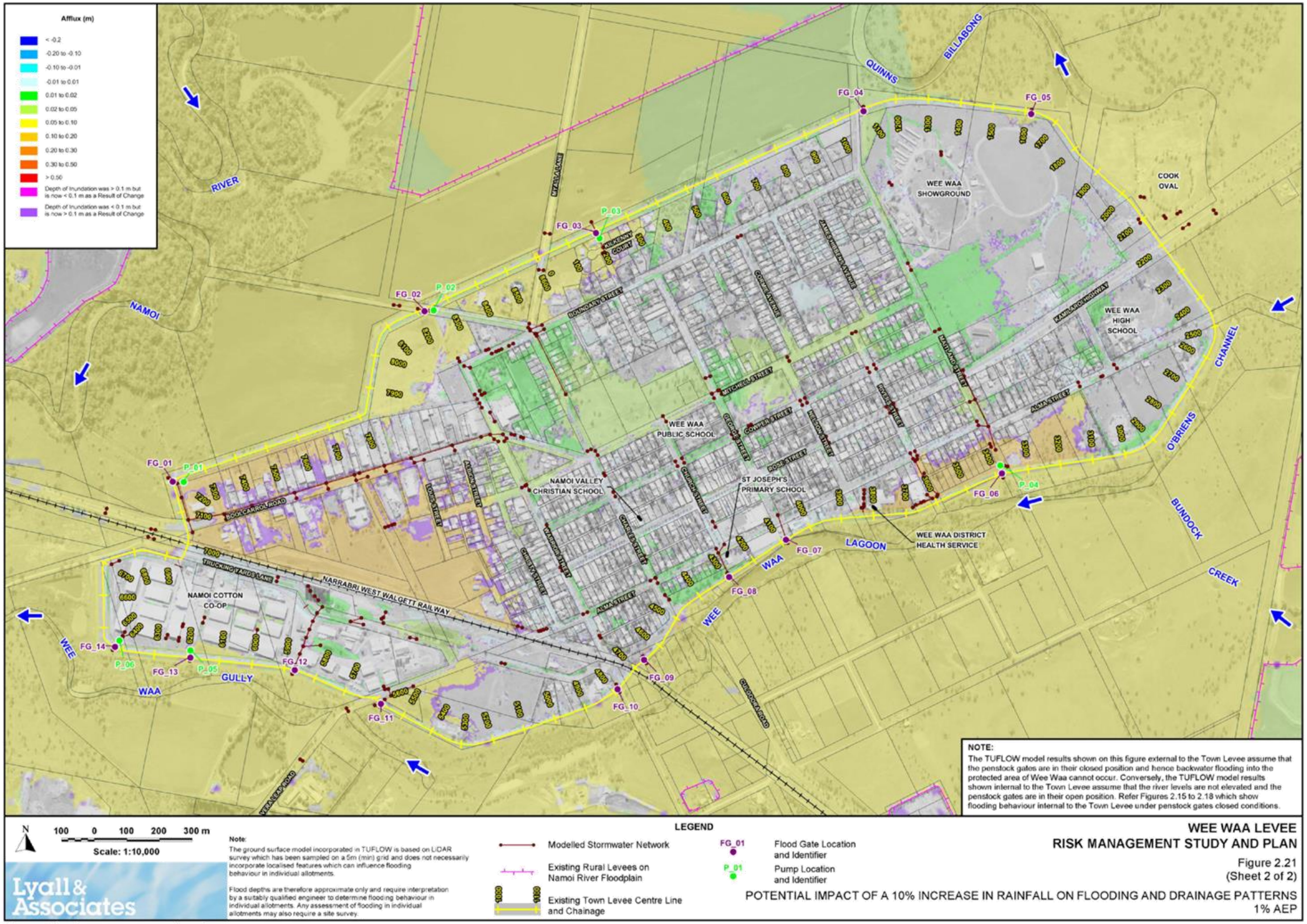
Existing Town Levee Centre Line

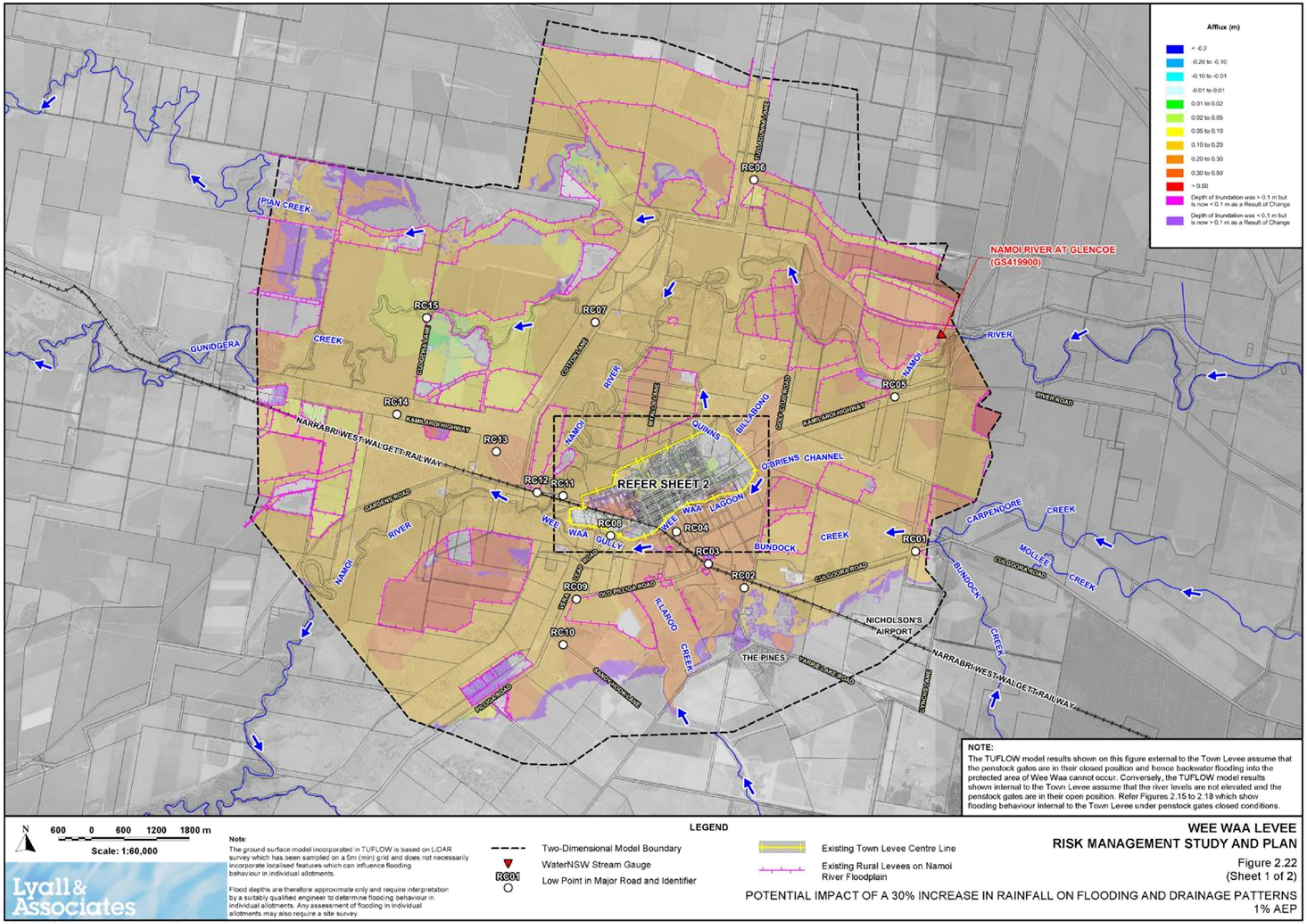
Existing Rural Levees on Namoi River Floodplain

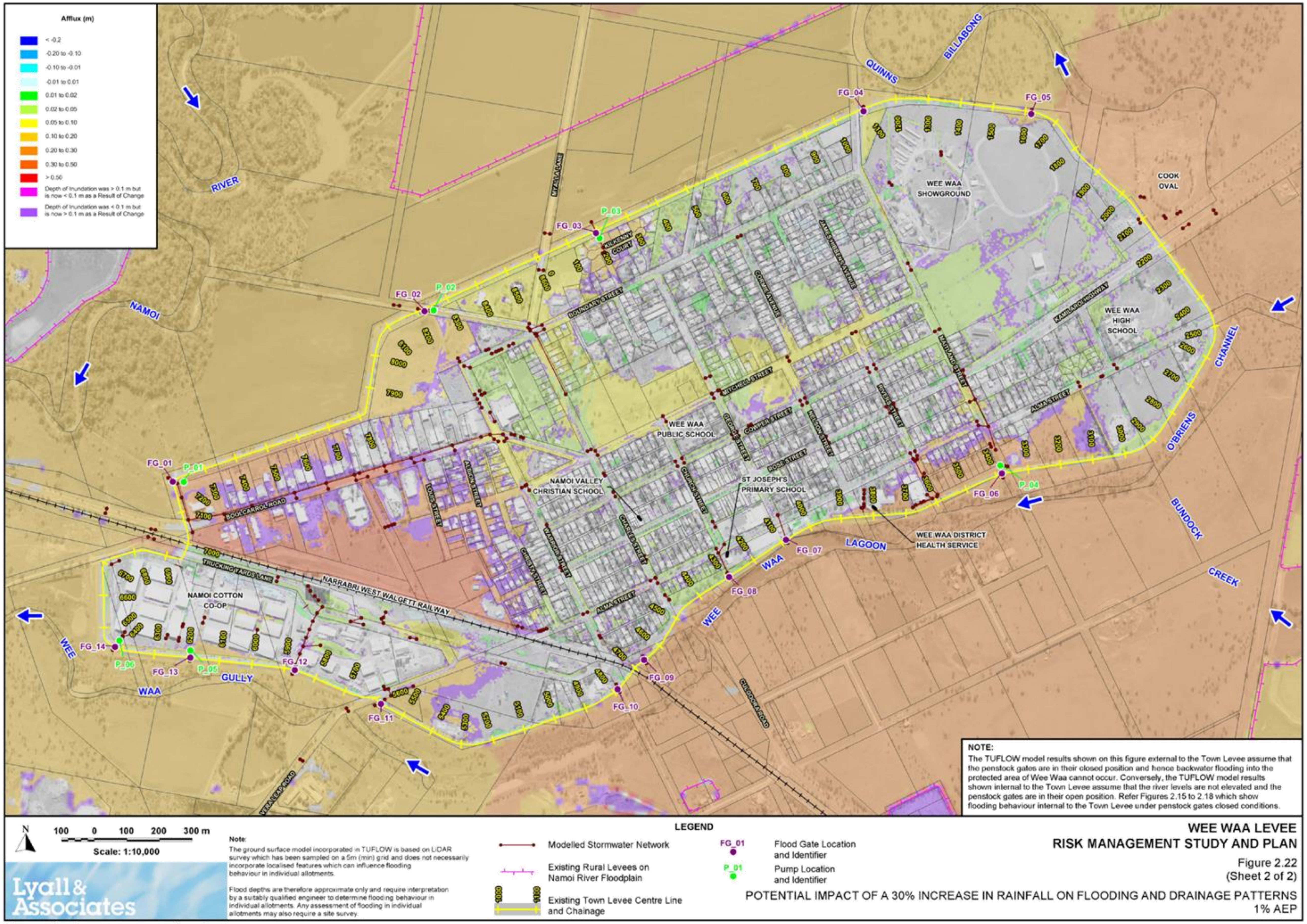
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

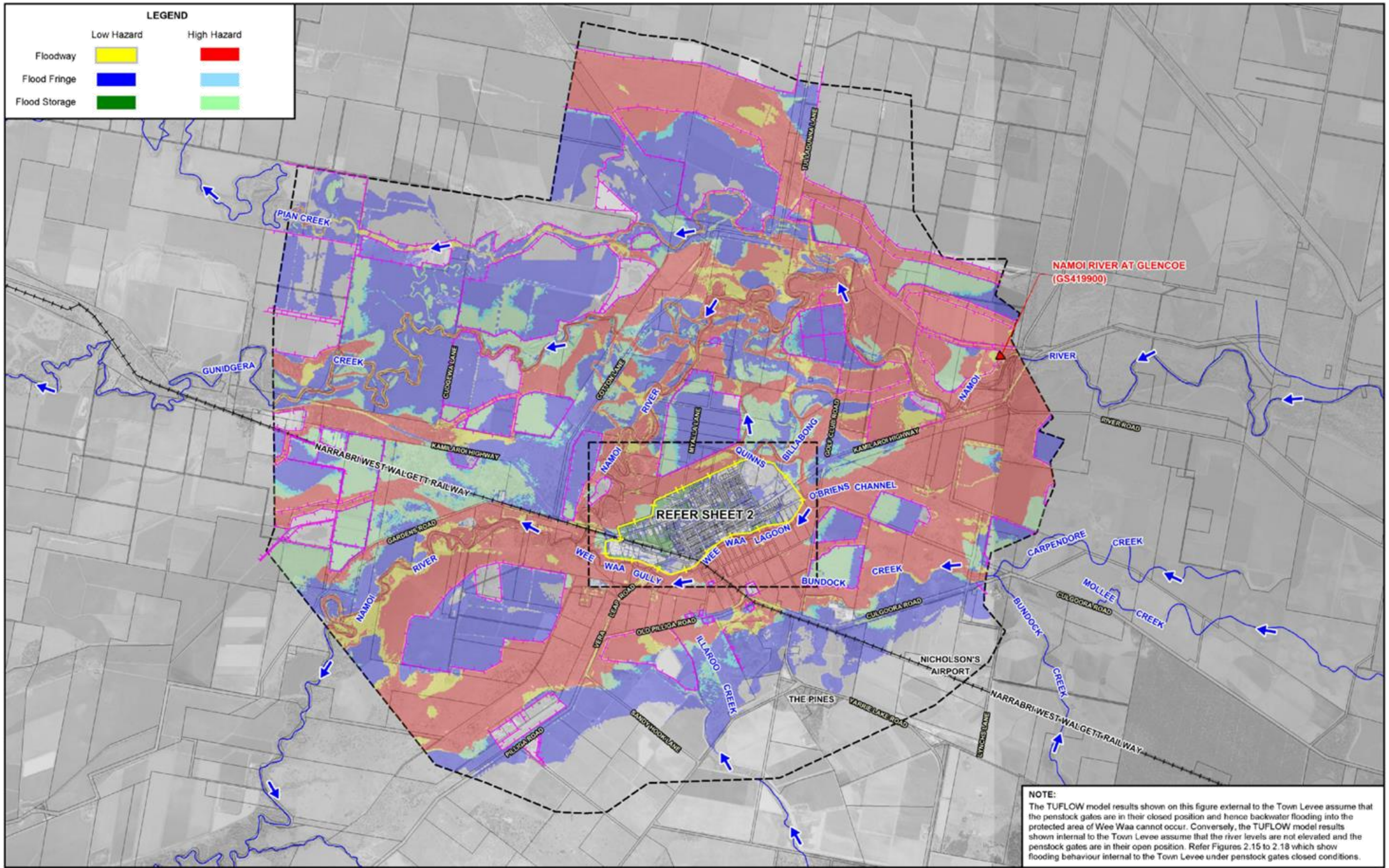
Figure 2.21
(Sheet 1 of 2)

POTENTIAL IMPACT OF A 10% INCREASE IN RAINFALL ON FLOODING AND DRAINAGE PATTERNS
1% AEP


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NAMOI
RIVER
QUINNS
BILLABONG
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
CHANNEL
O'BRIENS
BUNDOCK
CREEK
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
LAGOON
WEE
WAA
NAMOI COTTON CO-OP
NARRABRI WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOLCARROL ROAD
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
KAMILAROI HIGHWAY
WEE
WAA
GULLY
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.21
(Sheet 2 of 2)
POTENTIAL IMPACT OF A 10% INCREASE IN RAINFALL ON FLOODING AND DRAINAGE PATTERNS
1% AEP


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NAMOI RIVER AT GLENCOE (GS419900)
PIAN CREEK
GUNIDGERA CREEK
NAMOI RIVER
REFER SHEET 2
QUINNS BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
ILLAROO CREEK
NICHOLSON'S AIRPORT
THE PINES
KAMILAROI HIGHWAY
NARRABRI-WEST-WALGETT RAILWAY
RIVER ROAD
GARDENS ROAD
COTTON LANE
MYALLA LANE
GOLF CLUB ROAD
CULGOORA ROAD
OLD PILLIGA ROAD
VERA LEAP ROAD
PILLIGA ROAD
SANDY HOOK LANE
YARRIE LAKE ROAD
RC01
RC02
RC03
RC04
RC05
RC06
RC07
RC08
RC09
RC10
RC11
RC12
RC13
RC14
RC15
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
WaterNSW Stream Gauge
RC01 Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.22
(Sheet 1 of 2)
POTENTIAL IMPACT OF A 30% INCREASE IN RAINFALL ON FLOODING AND DRAINAGE PATTERNS
1% AEP


Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
100 0 100 200 300 m
Scale: 1:10,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
FG_01 Flood Gate Location and Identifier
P_01 Pump Location and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.22
(Sheet 2 of 2)
POTENTIAL IMPACT OF A 30% INCREASE IN RAINFALL ON FLOODING AND DRAINAGE PATTERNS
1% AEP



N 600 0 600 1200 1800 m
Scale: 1:60,000

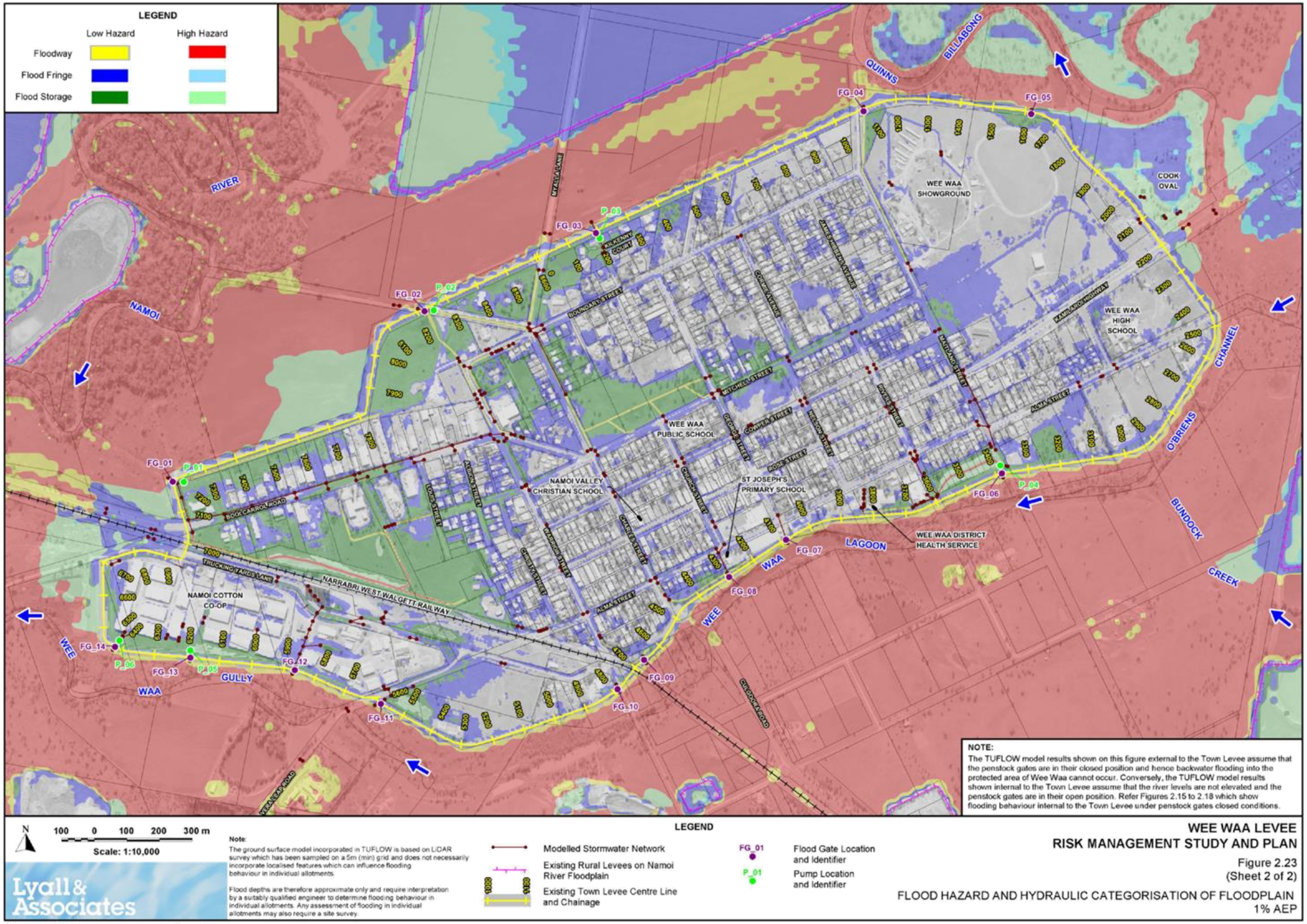
Lyall & Associates

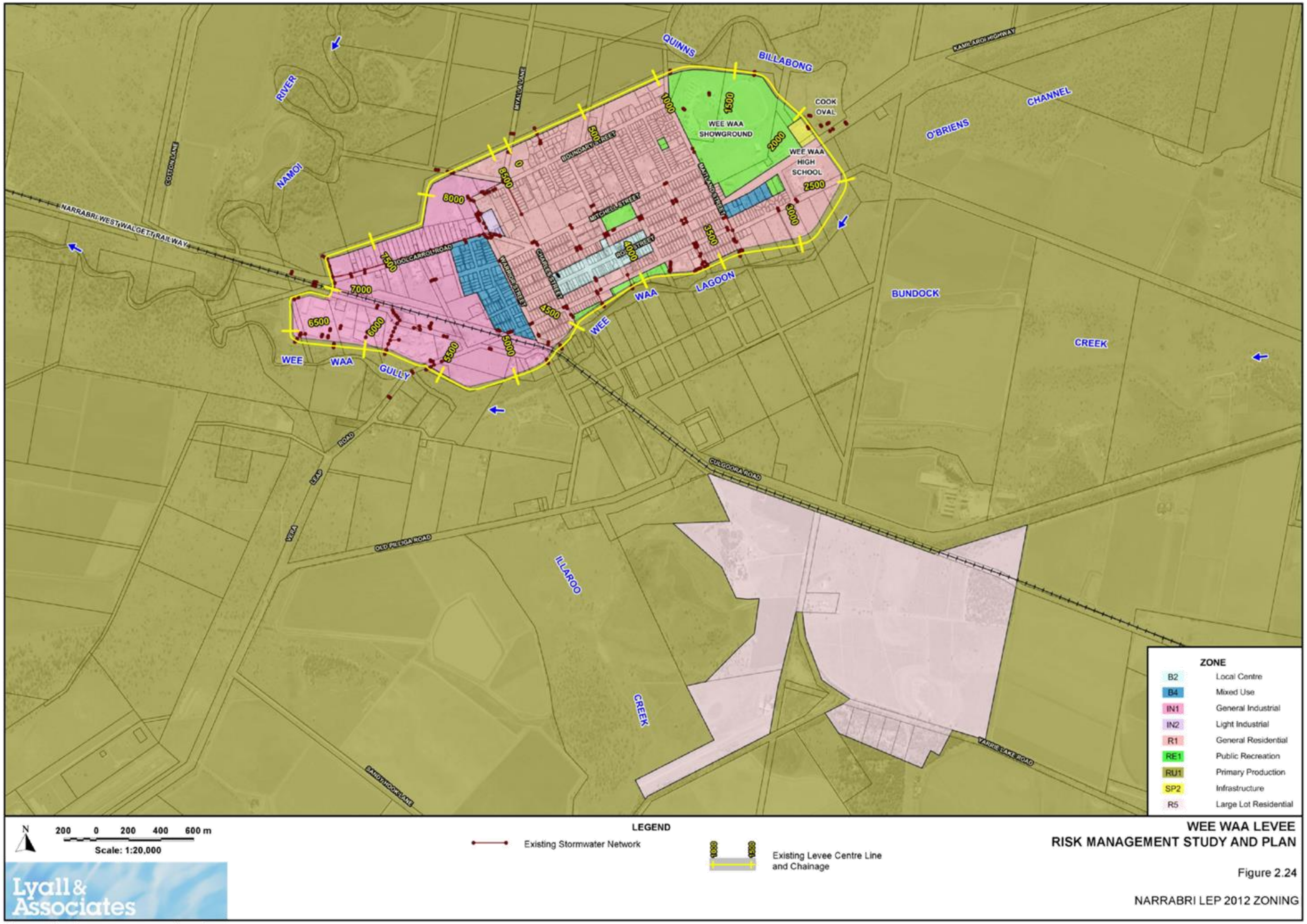
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

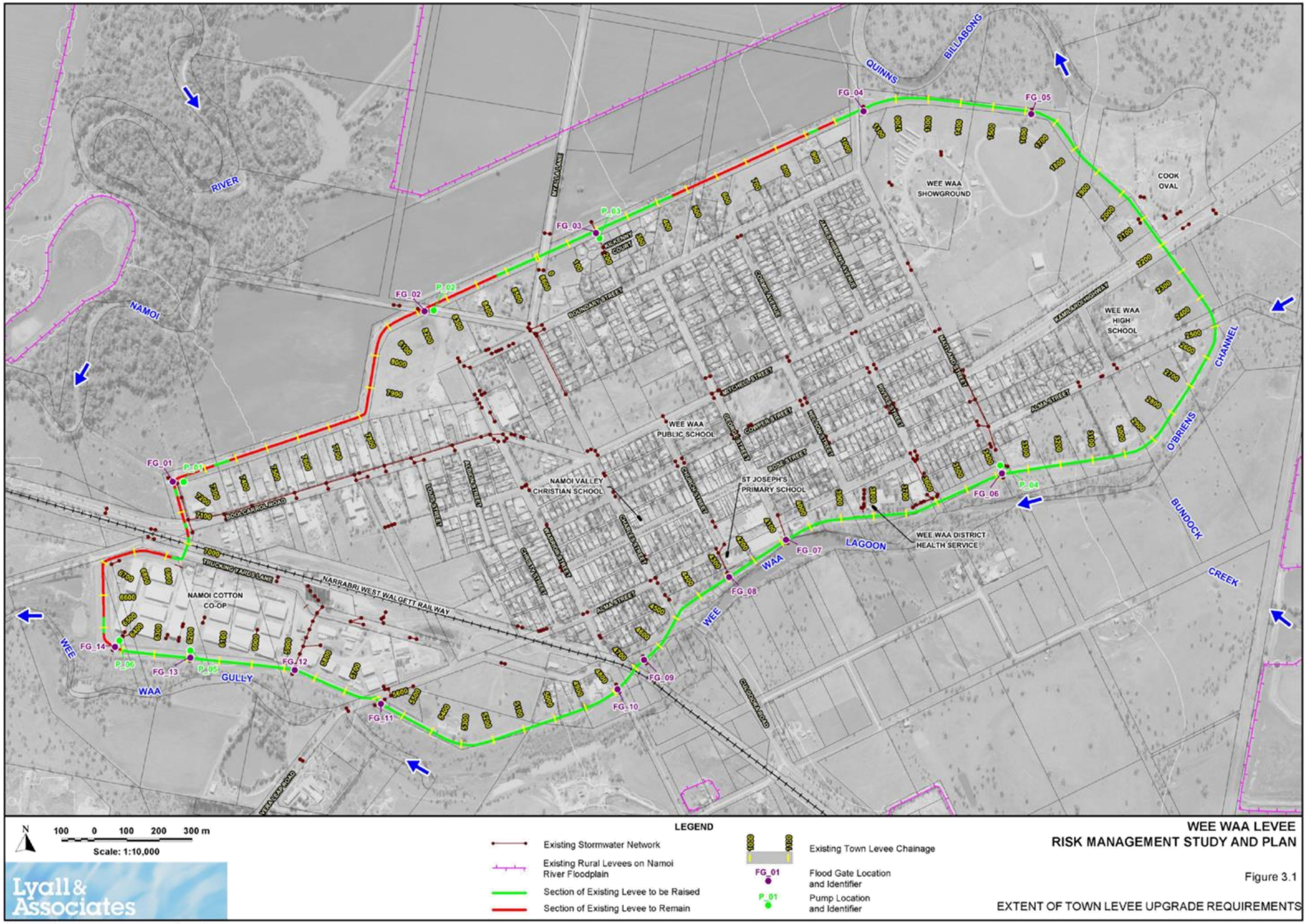
LEGEND
Two-Dimensional Model Boundary
WaterNSW Stream Gauge
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.23
(Sheet 1 of 2)
FLOOD HAZARD AND HYDRAULIC CATEGORISATION OF FLOODPLAIN
1% AEP


LEGEND
Low Hazard
High Hazard
Floodway
Flood Fringe
Flood Storage
QUINNS
BILLABONG
RIVER
NAMOI
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
CHANNEL
O'BRIENS
BUNDOCK
CREEK
LAGOON
WAA
WEE
GULLY
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
MYALL LANE
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
KAMILAROI HIGHWAY
BOOLCARROL ROAD
TRUCKING YARDS LANE
NARRABRI-WEST WALGETT RAILWAY
CHARLES STREET
MAITLAND STREET
NOTE:
The TUFLOW model results shown on this figure external to the Town Levee assume that the penstock gates are in their closed position and hence backwater flooding into the protected area of Wee Waa cannot occur. Conversely, the TUFLOW model results shown internal to the Town Levee assume that the river levels are not elevated and the penstock gates are in their open position. Refer Figures 2.15 to 2.18 which show flooding behaviour internal to the Town Levee under penstock gates closed conditions.
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
FG_01
Flood Gate Location and Identifier
P_01
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.23
(Sheet 2 of 2)
FLOOD HAZARD AND HYDRAULIC CATEGORISATION OF FLOODPLAIN
1% AEP



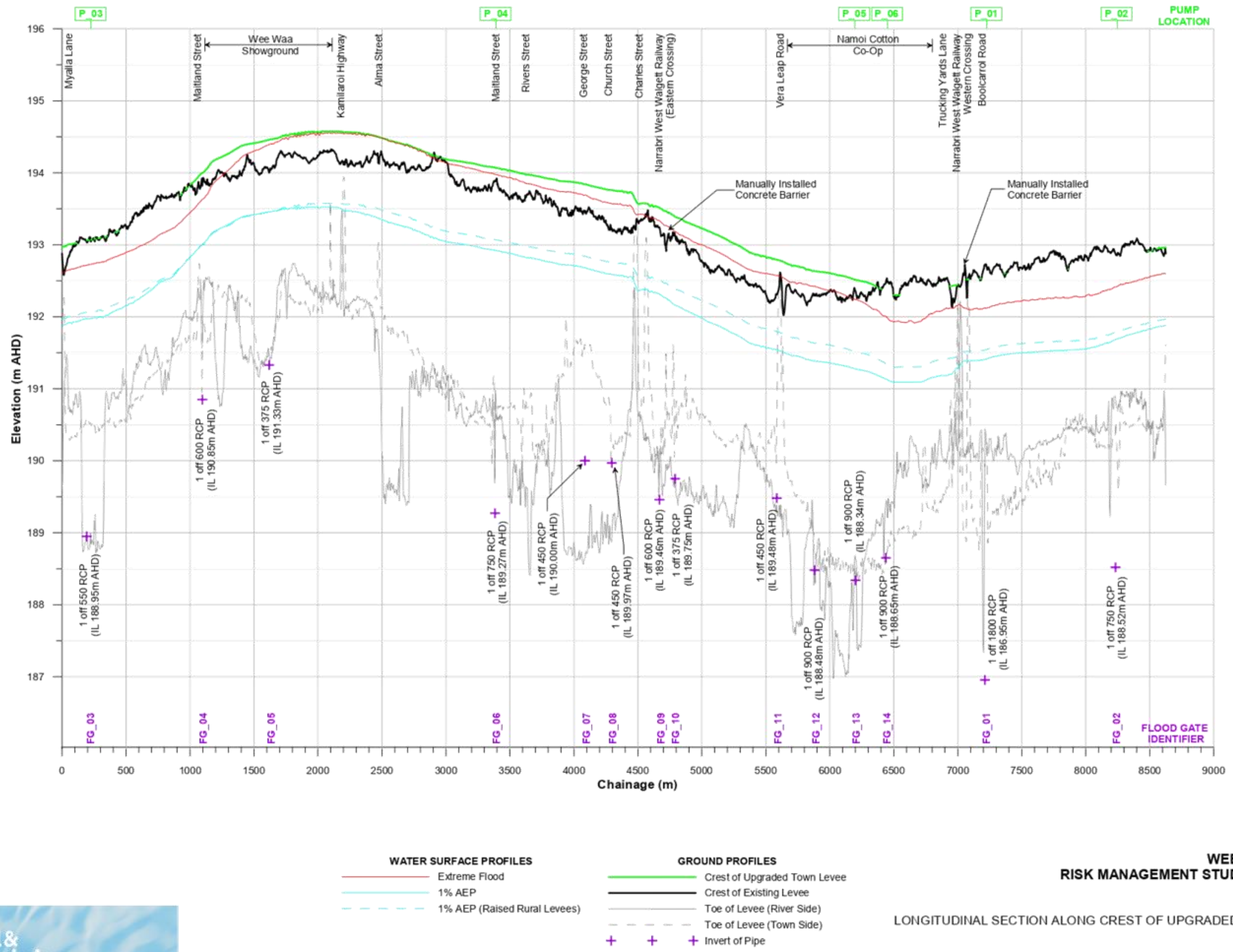
ZONE
B2 Local Centre
B4 Mixed Use
IN1 General Industrial
IN2 Light Industrial
R1 General Residential
RE1 Public Recreation
RU1 Primary Production
SP2 Infrastructure
R5 Large Lot Residential
200 0 200 400 600 m
Scale: 1:20,000
LEGEND
Existing Stormwater Network
Existing Levee Centre Line and Chainage
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 2.24
NARRABRI LEP 2012 ZONING
Lyall & Associates
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
NAMOI RIVER
QUINNS BILLABONG
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
ILLAROO CREEK
NARRABRI-WEST WALGETT RAILWAY
KAMILAROI HIGHWAY
CULGOORA ROAD
OLD PILLIGA ROAD
YARRIE LAKE ROAD
LEAP ROAD
COTTON LANE
MYALL VALE LANE
BOUNDARY STREET
MITCHELL STREET
CHARLES STREET
DOLCARROL ROAD



WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 3.1

EXTENT OF TOWN LEVEE UPGRADE REQUIREMENTS

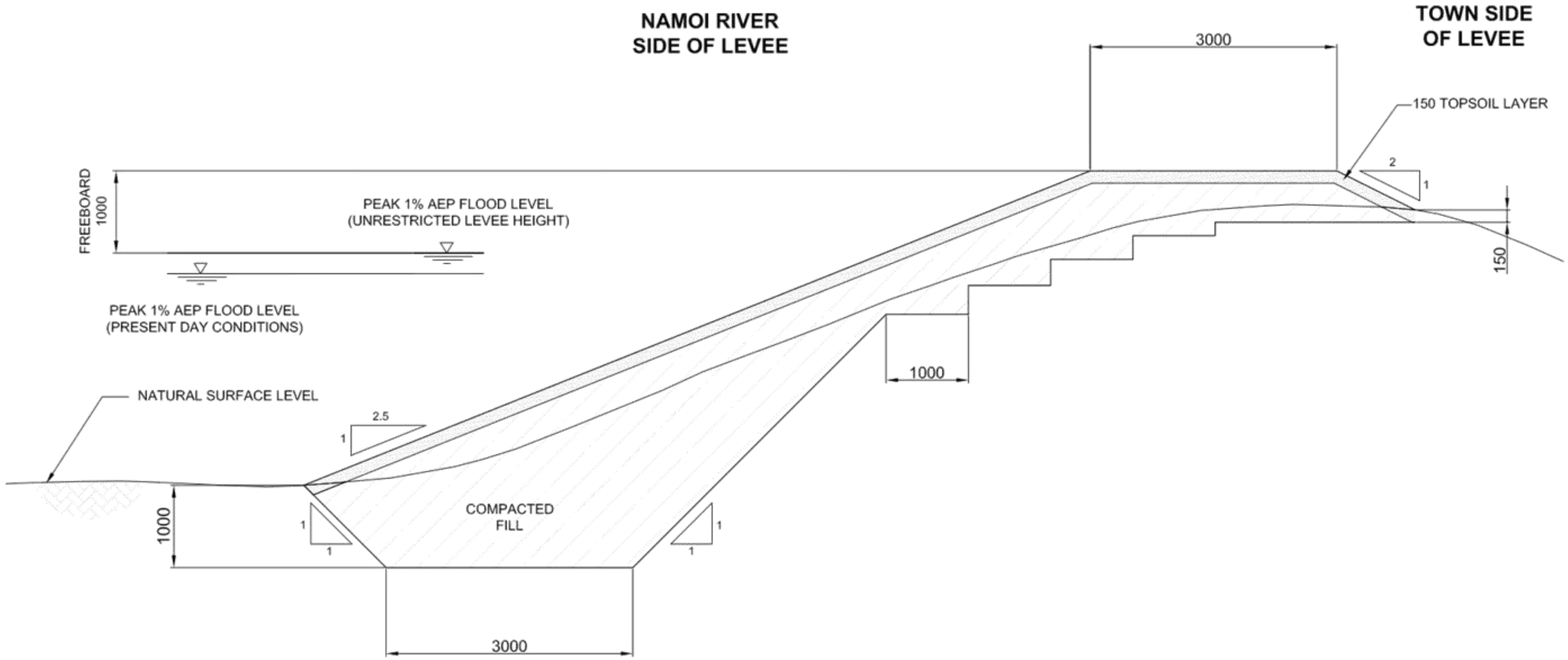


WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 3.2

LONGITUDINAL SECTION ALONG CREST OF UPGRADED TOWN LEVEE

Lyall & Associates



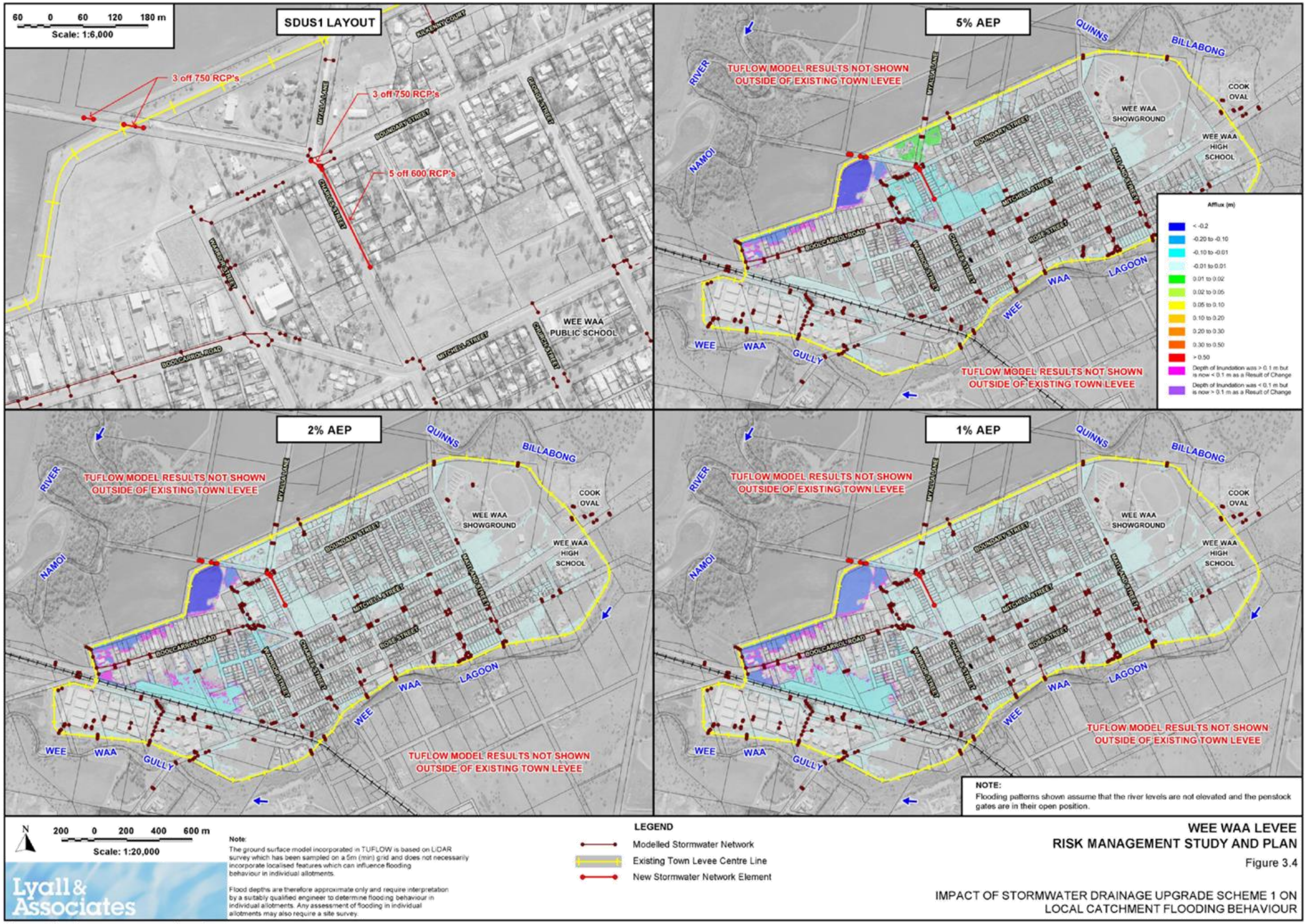
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 3.3

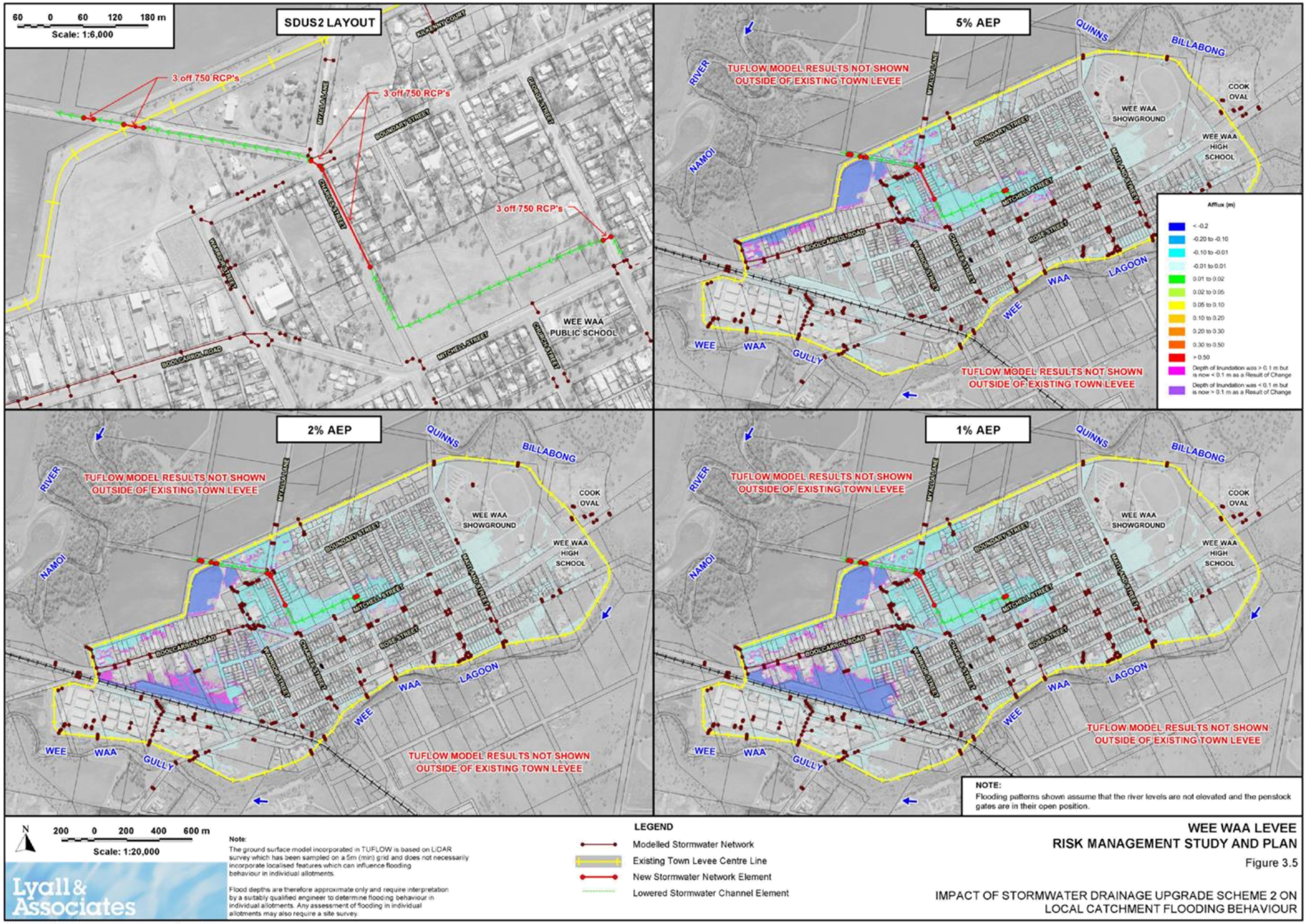
TYPICAL SECTION SHOWING TOWN LEVEE UPGRADE REQUIREMENTS

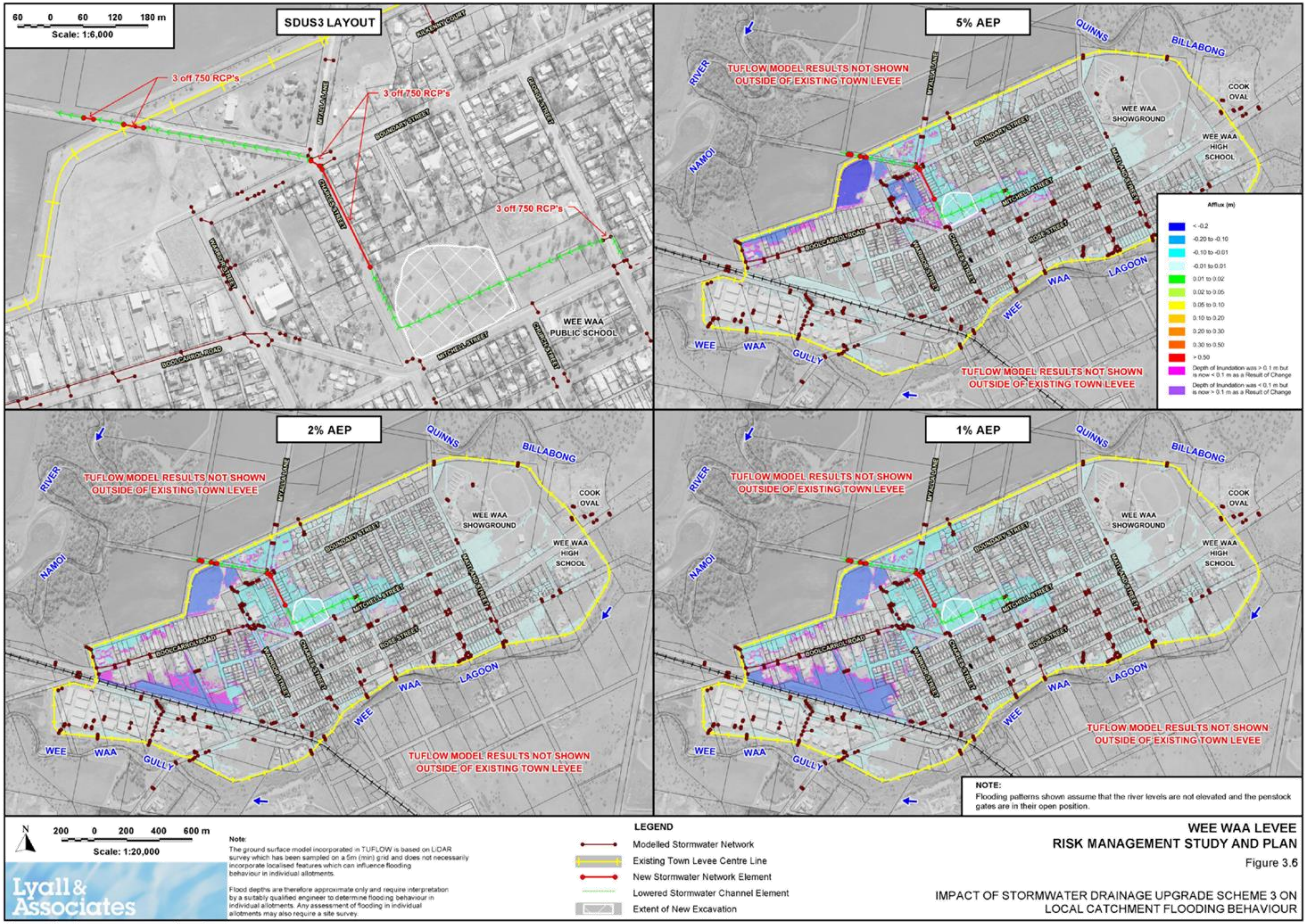
Lyall & Associates

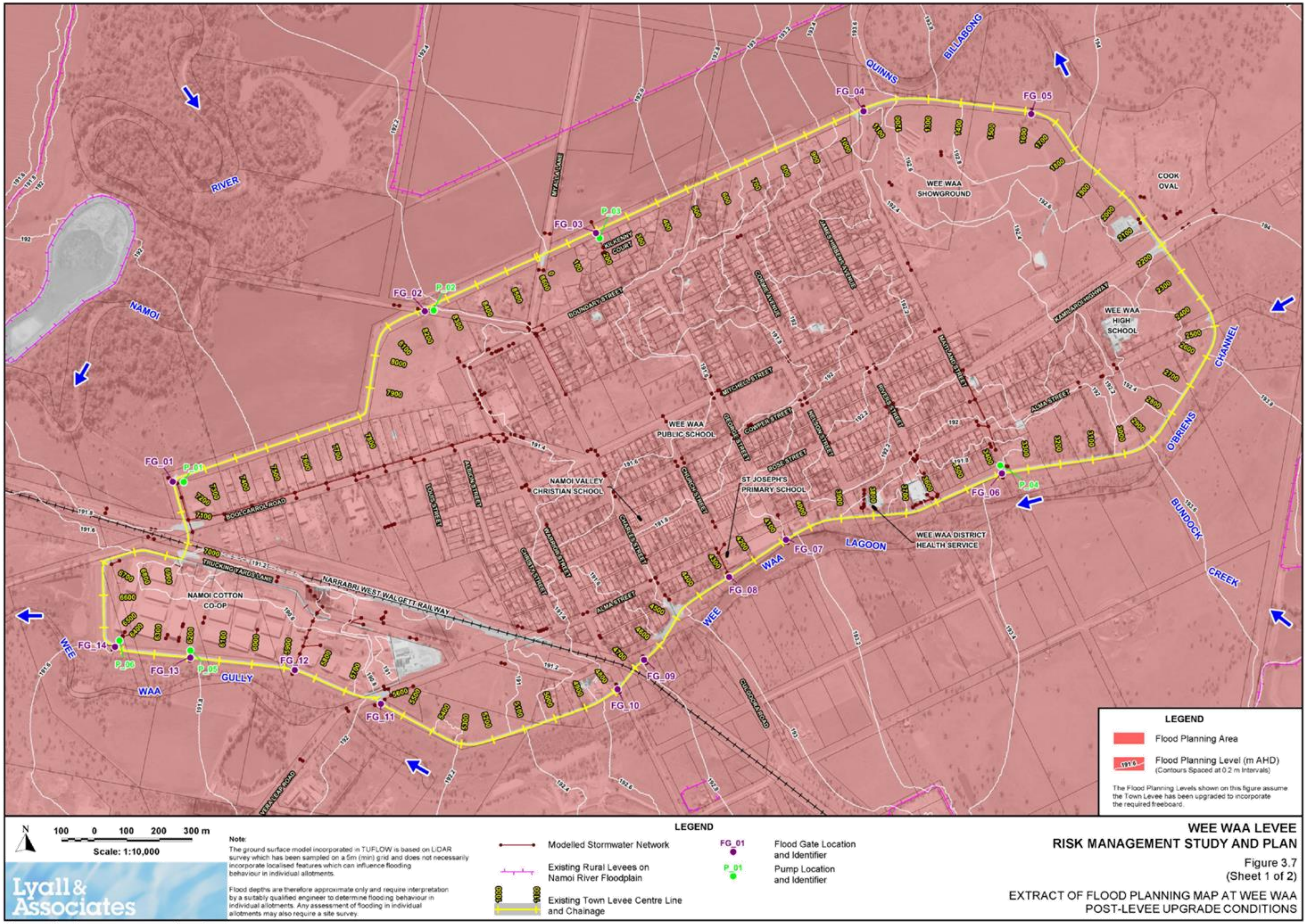
Note:
Vertical Scale: 1:50
Horizontal Scale: 1:50
All dimensions in millimetres.



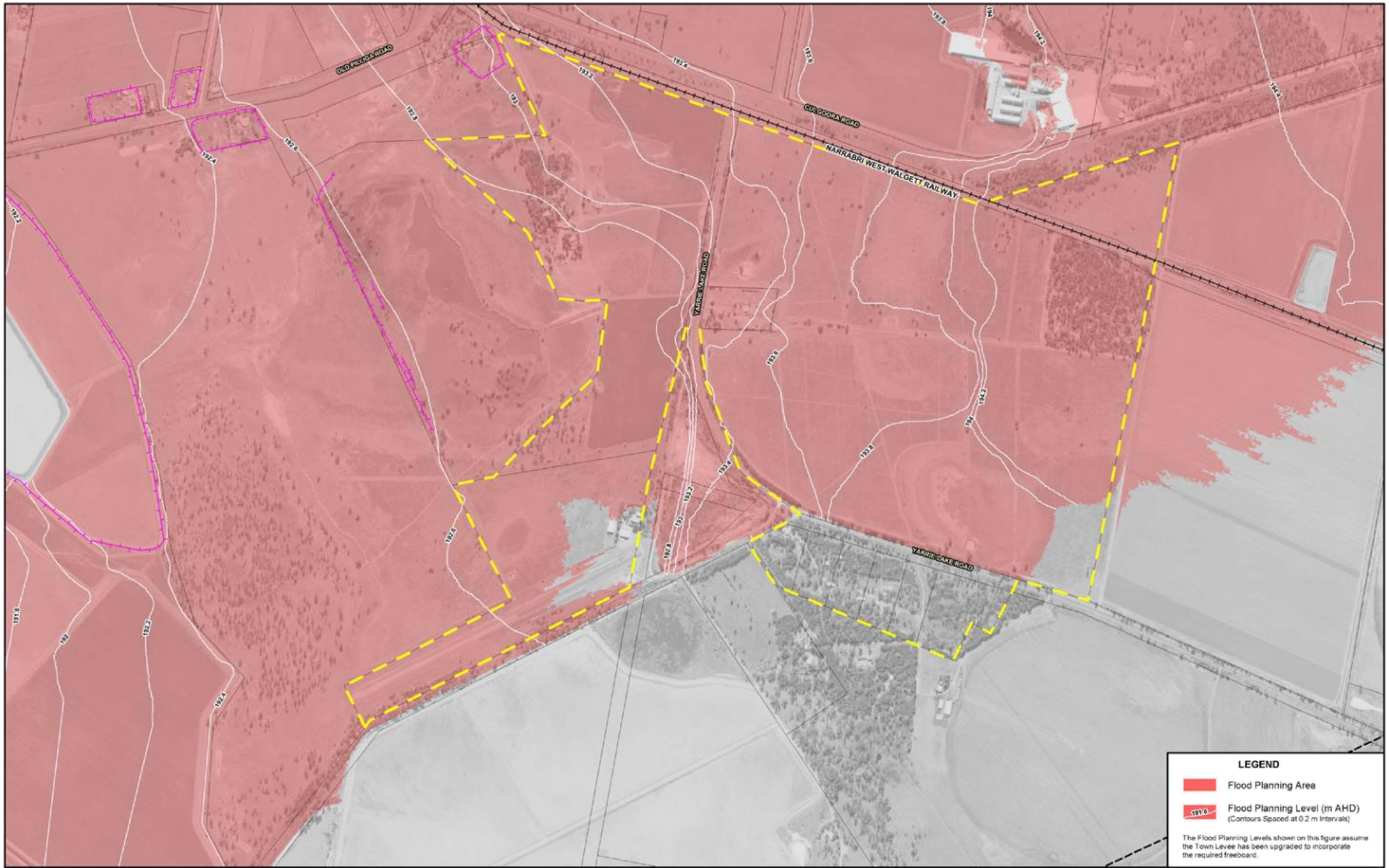
SDUS1 LAYOUT
60 0 60 120 180 m
Scale: 1:6,000
3 off 750 RCP's
3 off 750 RCP's
5 off 600 RCP's
KILKENNY COURT
MYALL LANE
BOUNDARY STREET
GEORGE STREET
CHARLES STREET
WARREGO STREET
BOOLCARROL ROAD
MITCHELL STREET
CHURCH STREET
WEE WAA PUBLIC SCHOOL
5% AEP
2% AEP
1% AEP
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
QUINNS BILLABONG
NAMOI RIVER
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
ROSE STREET
MAITLAND STREET
WEE WAA LAGOON
WEE WAA GULLY
Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NOTE:
Flooding patterns shown assume that the river levels are not elevated and the penstock gates are in their open position.
N
200 0 200 400 600 m
Scale: 1:20,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Town Levee Centre Line
New Stormwater Network Element
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 3.4
IMPACT OF STORMWATER DRAINAGE UPGRADE SCHEME 1 ON LOCAL CATCHMENT FLOODING BEHAVIOUR


60 0 60 120 180 m
Scale: 1:6,000
SDUS2 LAYOUT
3 off 750 RCP's
3 off 750 RCP's
3 off 750 RCP's
WEE WAA PUBLIC SCHOOL
5% AEP
2% AEP
1% AEP
QUINNS
BILLABONG
RIVER
NAMOI
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
WEE WAA LAGOON
WEE WAA GULLY
Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NOTE:
Flooding patterns shown assume that the river levels are not elevated and the penstock gates are in their open position.
200 0 200 400 600 m
Scale: 1:20,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
Lyall & Associates
LEGEND
Modelled Stormwater Network
Existing Town Levee Centre Line
New Stormwater Network Element
Lowered Stormwater Channel Element
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 3.5
IMPACT OF STORMWATER DRAINAGE UPGRADE SCHEME 2 ON LOCAL CATCHMENT FLOODING BEHAVIOUR


SDUS3 LAYOUT
60 0 60 120 180 m
Scale: 1:6,000
3 off 750 RCP's
3 off 750 RCP's
3 off 750 RCP's
WEE WAA PUBLIC SCHOOL
BOUNDARY STREET
CHARLES STREET
MITCHELL STREET
BOOLCARROL ROAD
MYALLA LANE
5% AEP
2% AEP
1% AEP
TUFLOW MODEL RESULTS NOT SHOWN OUTSIDE OF EXISTING TOWN LEVEE
NAMOI RIVER
QUINNS BILLABONG
COOK OVAL
WEE WAA SHOWGROUND
WEE WAA HIGH SCHOOL
WEE WAA LAGOON
WEE WAA GULLY
Afflux (m)
< -0.2
-0.20 to -0.10
-0.10 to -0.01
-0.01 to 0.01
0.01 to 0.02
0.02 to 0.05
0.05 to 0.10
0.10 to 0.20
0.20 to 0.30
0.30 to 0.50
> 0.50
Depth of Inundation was > 0.1 m but is now < 0.1 m as a Result of Change
Depth of Inundation was < 0.1 m but is now > 0.1 m as a Result of Change
NOTE:
Flooding patterns shown assume that the river levels are not elevated and the penstock gates are in their open position.
200 0 200 400 600 m
Scale: 1:20,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
Lyall & Associates
LEGEND
Modelled Stormwater Network
Existing Town Levee Centre Line
New Stormwater Network Element
Lowered Stormwater Channel Element
Extent of New Excavation
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 3.6
IMPACT OF STORMWATER DRAINAGE UPGRADE SCHEME 3 ON LOCAL CATCHMENT FLOODING BEHAVIOUR



LEGEND
Flood Planning Area
Flood Planning Level (m AHD)
(Contours Spaced at 0.2 m Intervals)
The Flood Planning Levels shown on this figure assume the Town Levee has been upgraded to incorporate the required freeboard.
Scale: 1:10,000
100 0 100 200 300 m
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 3.7
(Sheet 1 of 2)
EXTRACT OF FLOOD PLANNING MAP AT WEE WAA
POST-LEVEE UPGRADE CONDITIONS
NAMOI RIVER
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
QUINNS BILLABONG
O'BRIENS CHANNEL
BUNDOCK CREEK
WEE WAA LAGOON
WEE WAA GULLY
NARRABRI WEST WALGETT RAILWAY
BOOLCARROL ROAD
TRUCKING YARDS LANE
KAMILAROI HIGHWAY
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06



N

100 0 100 200 300 m

Scale: 1:10,000

Lyall & Associates

Note:

The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

LEGEND

Modelled Stormwater Network

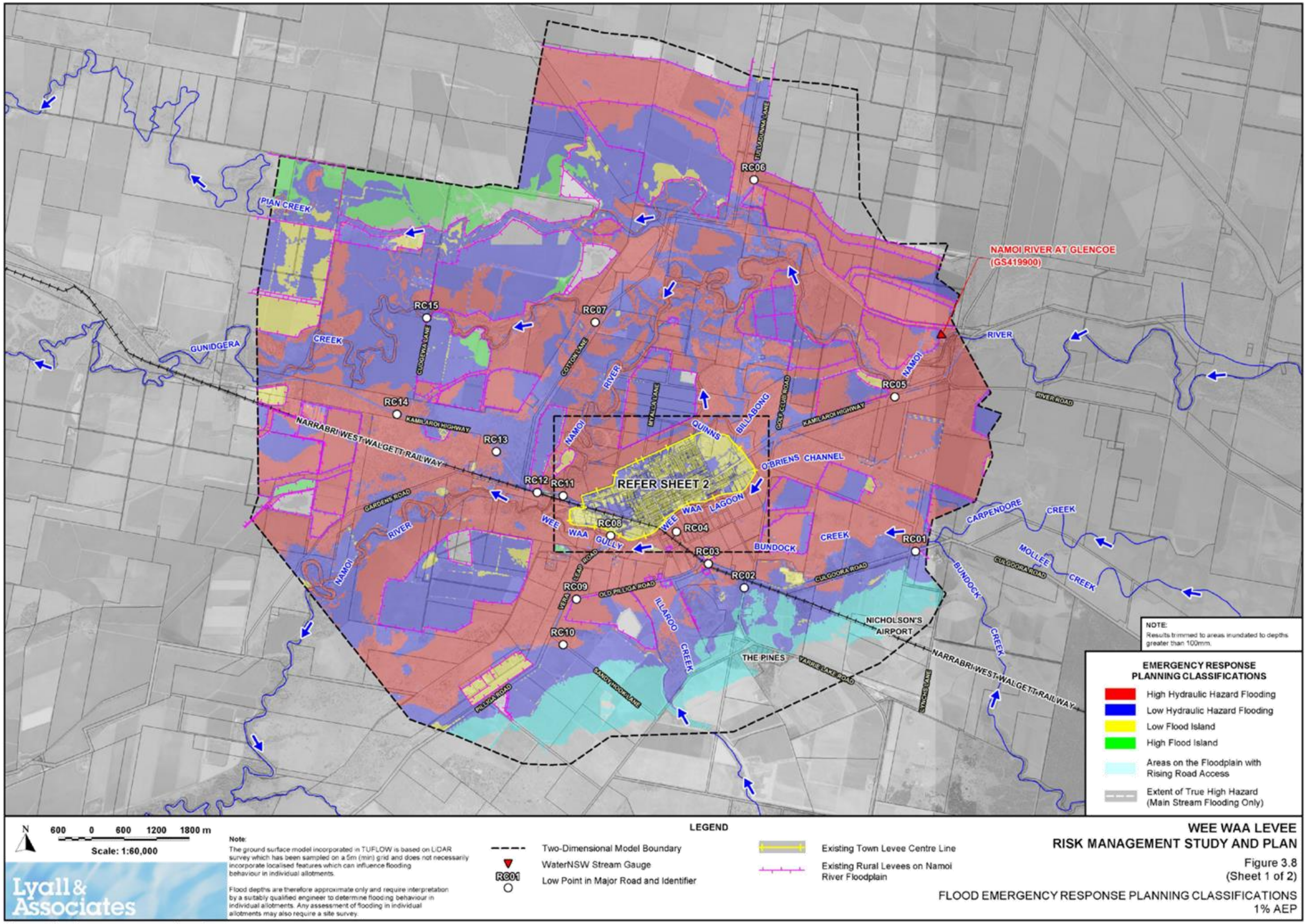
Existing Rural Levees on Namoi River Floodplain

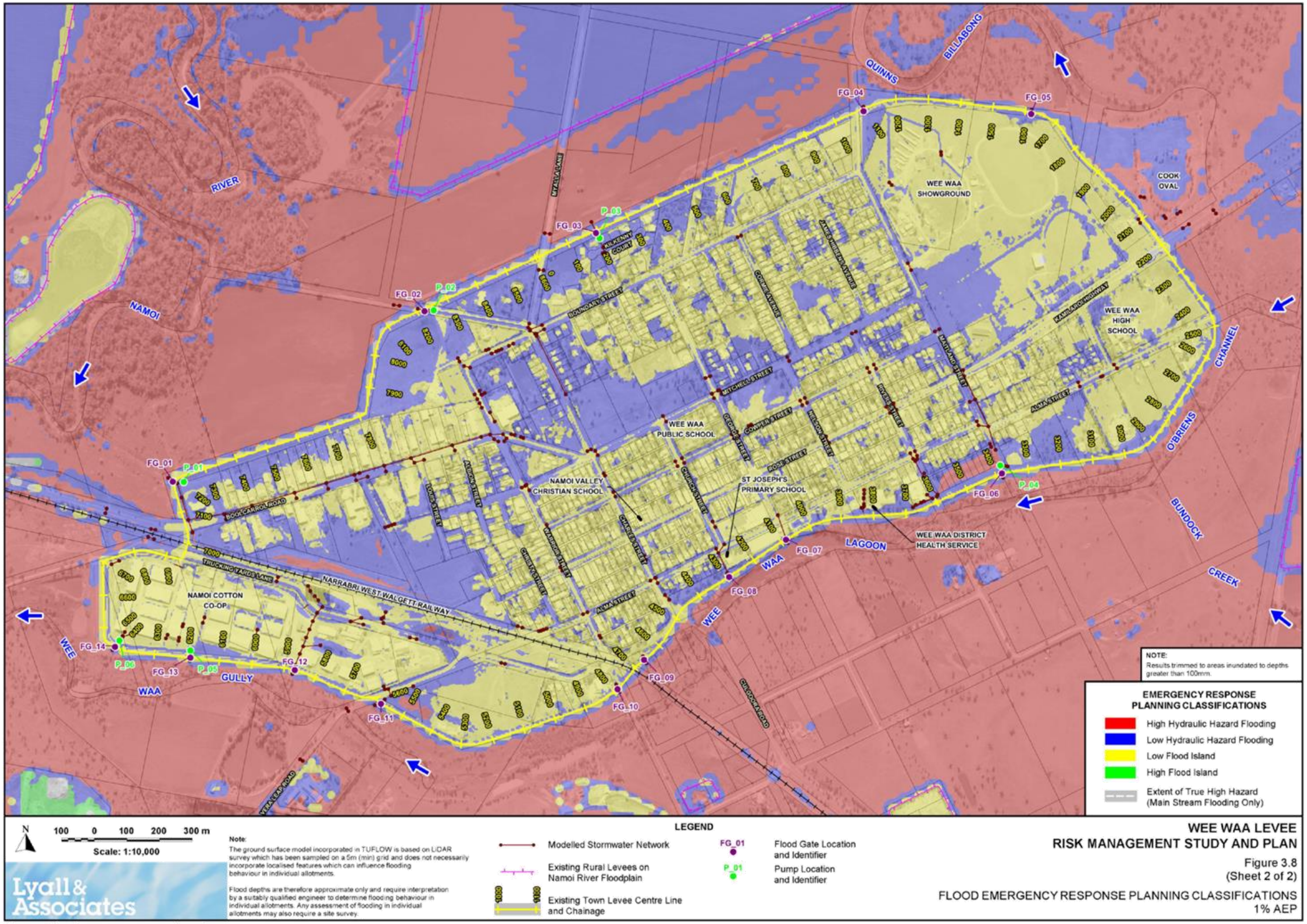
Land Zoned R5 - Large Lot Residential

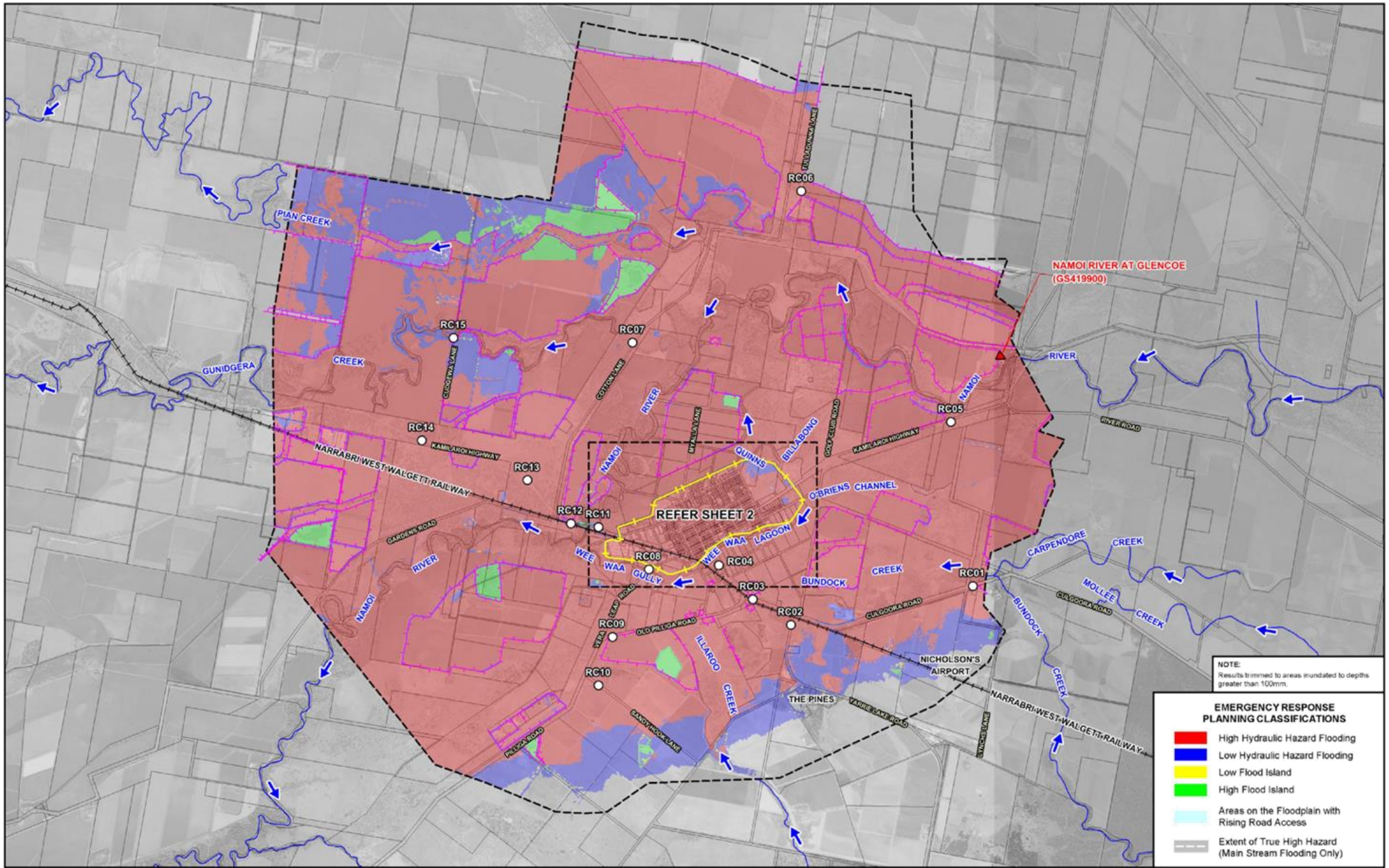
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 3.7
(Sheet 2 of 2)

EXTRACT OF FLOOD PLANNING MAP AT WEE WAA
POST-LEVEE UPGRADE CONDITIONS


PIAN CREEK
GUNIDGERA
CREEK
RC15
RC07
RC06
RC14
RC13
RC12
RC11
RC08
RC04
RC03
RC02
RC01
RC05
RC09
RC10
NAMOI RIVER AT GLENCOE
(GS419900)
RIVER
NAMOI
RIVER ROAD
KAMILAROI HIGHWAY
NARRABRI-WEST-WALGETT RAILWAY
GARDENS ROAD
COTTON LANE
MYALLA LANE
QUINNS
BILLABONG
GOLF CLUB ROAD
O'BRIENS CHANNEL
REFER SHEET 2
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK
CREEK
CARPENDORE
CREEK
MOLLEE
CREEK
BUNDOCK
CREEK
CULGOORA ROAD
NICHOLSON'S AIRPORT
THE PINES
YARRIE LAKE ROAD
ILLAROO
CREEK
OLD PILLIGA ROAD
VERA LEAP ROAD
SANDY HOOK LANE
PILLIGA ROAD
NARRABRI-WEST-WALGETT RAILWAY
NOTE:
Results trimmed to areas inundated to depths greater than 100mm.
EMERGENCY RESPONSE PLANNING CLASSIFICATIONS
High Hydraulic Hazard Flooding
Low Hydraulic Hazard Flooding
Low Flood Island
High Flood Island
Areas on the Floodplain with Rising Road Access
Extent of True High Hazard (Main Stream Flooding Only)
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
WaterNSW Stream Gauge
RC01 Low Point in Major Road and Identifier
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 3.8
(Sheet 1 of 2)
FLOOD EMERGENCY RESPONSE PLANNING CLASSIFICATIONS
1% AEP


NAMOI RIVER
QUINNS BILLABONG
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
NAMOI COTTON CO-OP
WEE WAA LAGOON
WEE WAA GULLY
O'BRIENS CHANNEL
BUNDOCK CREEK
NARRABRI WEST-WALGETT RAILWAY
TRUCKING YARDS LANE
BOOLCARROL ROAD
KAMILAROI HIGHWAY
BOUNDARY STREET
MITCHELL STREET
COWPER STREET
ROSE STREET
ALMA STREET
MAITLAND STREET
KILKENNY COURT
FG_01 FG_02 FG_03 FG_04 FG_05 FG_06 FG_07 FG_08 FG_09 FG_10 FG_11 FG_12 FG_13 FG_14
P_01 P_02 P_03 P_04 P_05 P_06
NOTE:
Results trimmed to areas inundated to depths greater than 100mm.
EMERGENCY RESPONSE PLANNING CLASSIFICATIONS
High Hydraulic Hazard Flooding
Low Hydraulic Hazard Flooding
Low Flood Island
High Flood Island
Extent of True High Hazard (Main Stream Flooding Only)
N
100 0 100 200 300 m
Scale: 1:10,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
FG_01 Flood Gate Location and Identifier
P_01 Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 3.8
(Sheet 2 of 2)
FLOOD EMERGENCY RESPONSE PLANNING CLASSIFICATIONS
1% AEP



N 600 0 600 1200 1800 m

Scale: 1:60,000

Lyall & Associates

Note:

The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.

Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.

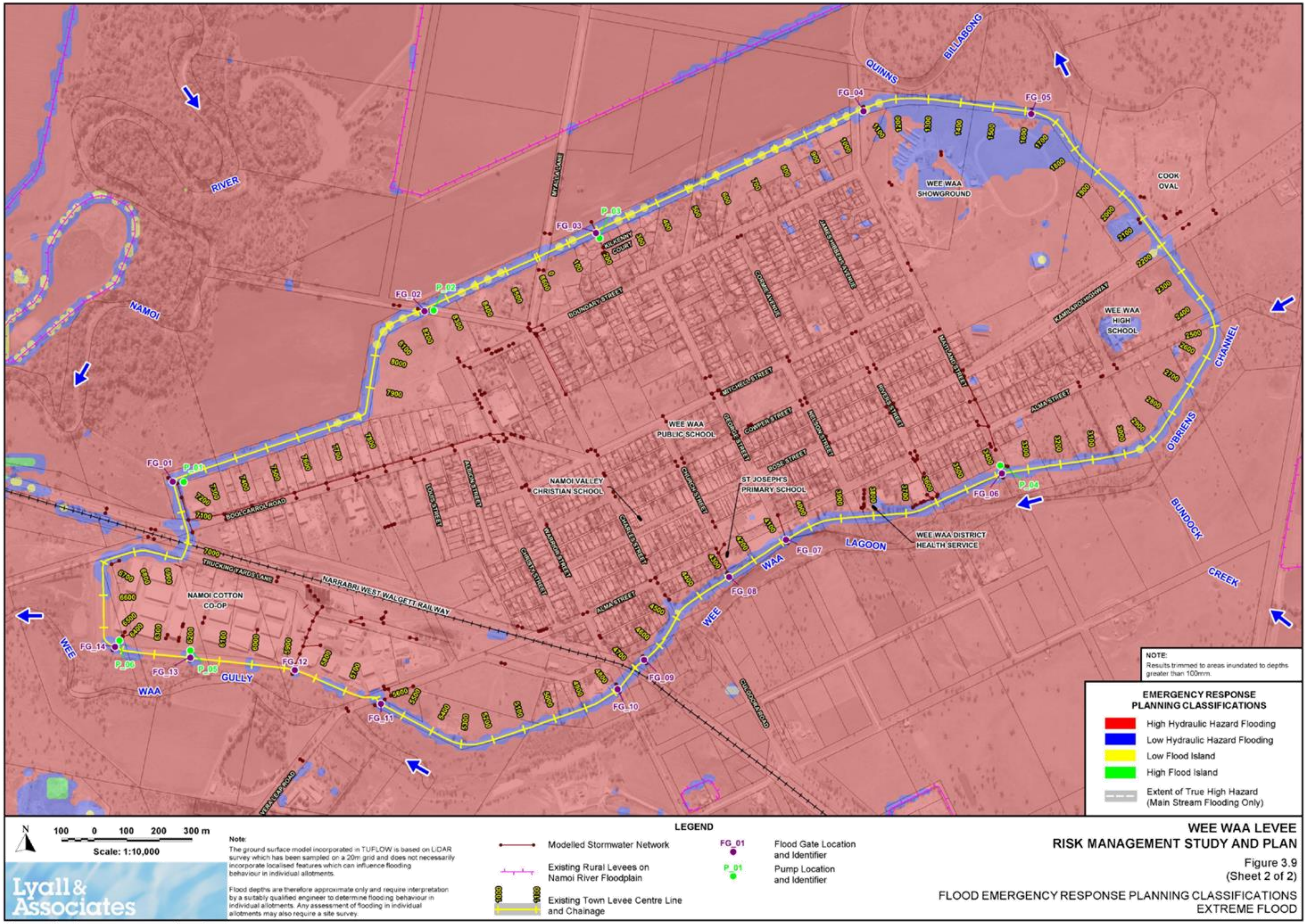
LEGEND

- Two-Dimensional Model Boundary
- WaterNSW Stream Gauge
- RC01 Low Point in Major Road and Identifier
- Existing Town Levee Centre Line
- Existing Rural Levees on Namoi River Floodplain

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure 3.9
(Sheet 1 of 2)

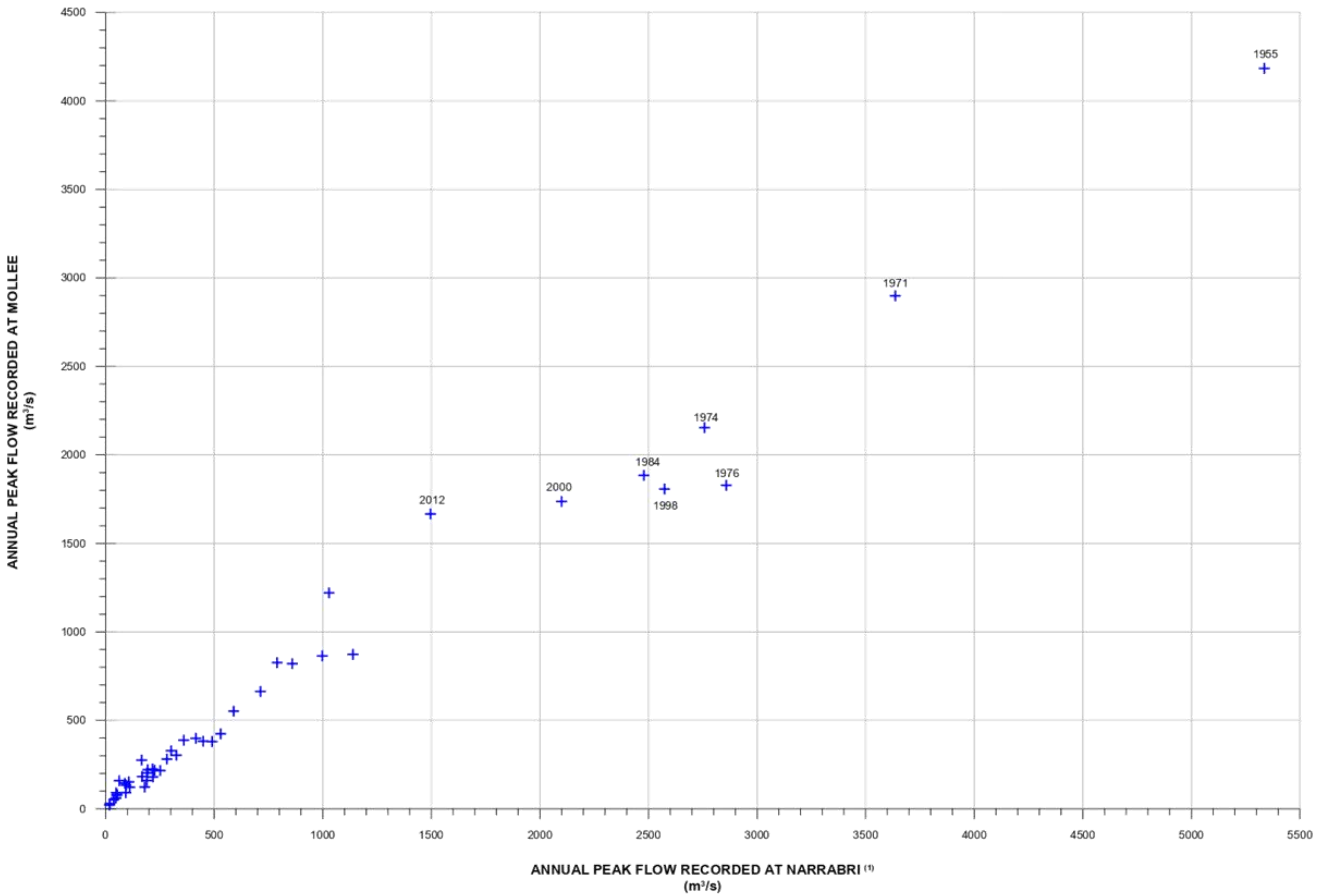
FLOOD EMERGENCY RESPONSE PLANNING CLASSIFICATIONS
EXTREME FLOOD


QUINNS
BILLABONG
NAMOI
RIVER
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
CHANNEL
O'BRIENS
BUNDOCK
CREEK
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
LAGOON
WEE WAA
NAMOI COTTON CO-OP
NARRABRI WEST WALGETT RAILWAY
TRUCKING YARDS LANE
BOOLCARROL ROAD
KAMILAROI HIGHWAY
WEE
WAA
GULLY
FG_01
FG_02
FG_03
FG_04
FG_05
FG_06
FG_07
FG_08
FG_09
FG_10
FG_11
FG_12
FG_13
FG_14
P_01
P_02
P_03
P_04
P_05
P_06
NOTE:
Results trimmed to areas inundated to depths greater than 100mm.
EMERGENCY RESPONSE PLANNING CLASSIFICATIONS
High Hydraulic Hazard Flooding
Low Hydraulic Hazard Flooding
Low Flood Island
High Flood Island
Extent of True High Hazard (Main Stream Flooding Only)
100 0 100 200 300 m
Scale: 1:10,000
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 20m grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Modelled Stormwater Network
Existing Rural Levees on Namoi River Floodplain
Existing Town Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure 3.9
(Sheet 2 of 2)
FLOOD EMERGENCY RESPONSE PLANNING CLASSIFICATIONS
EXTREME FLOOD

APPENDIX C

FLOOD STUDY UPDATE

LIST OF FIGURES (APPENDIX C)



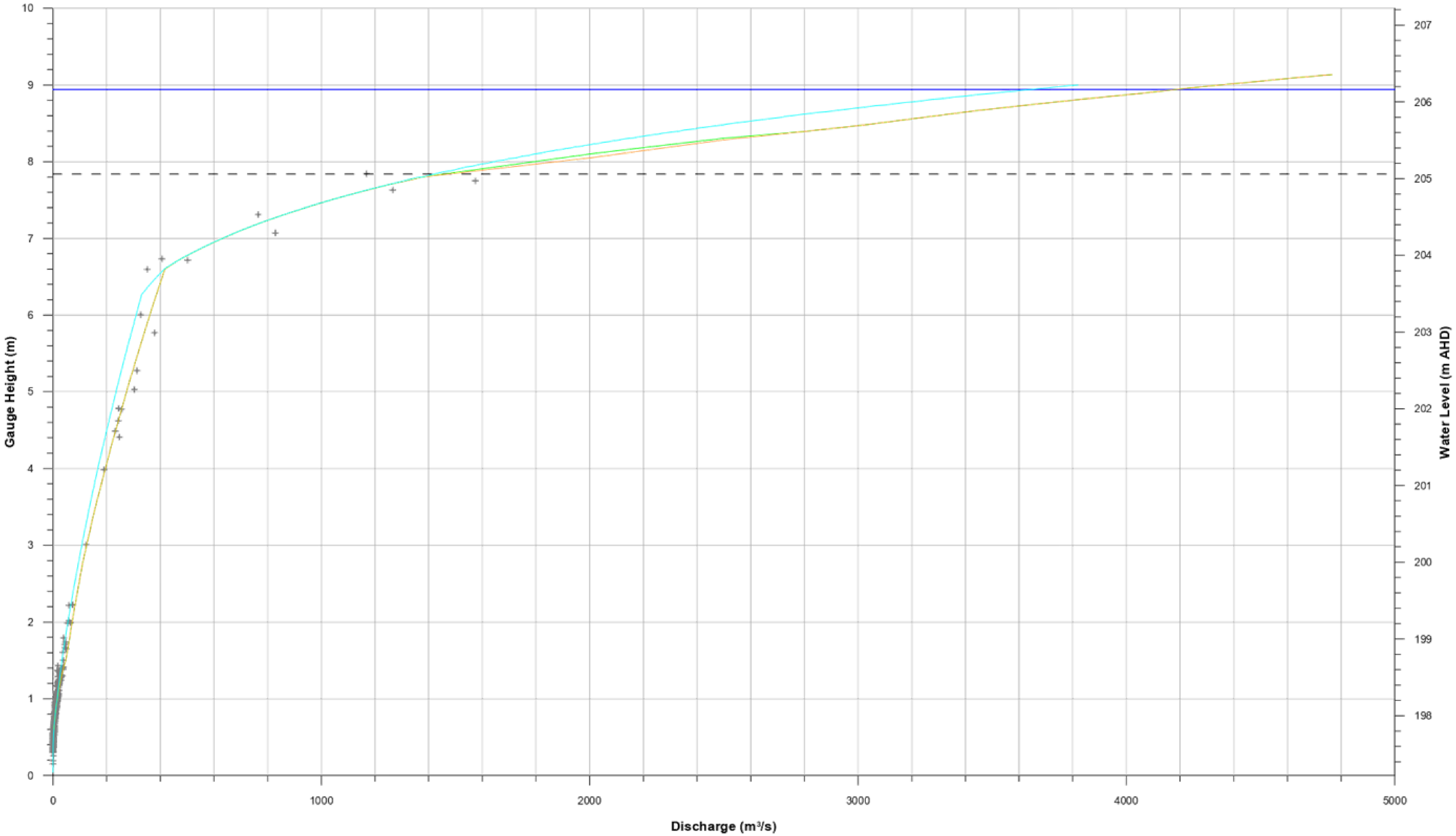
Lyall & Associates

NOTE:
1. Source: WRM, 2016.

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C1.1

COMPARISON OF ANNUAL PEAK FLOWS
MOLLEE VERSUS NARRABRI STREAM GAUGES
PERIOD 1971-2015 AND 1955



NOTE:
Gauge zero = 197.22 m AHD.

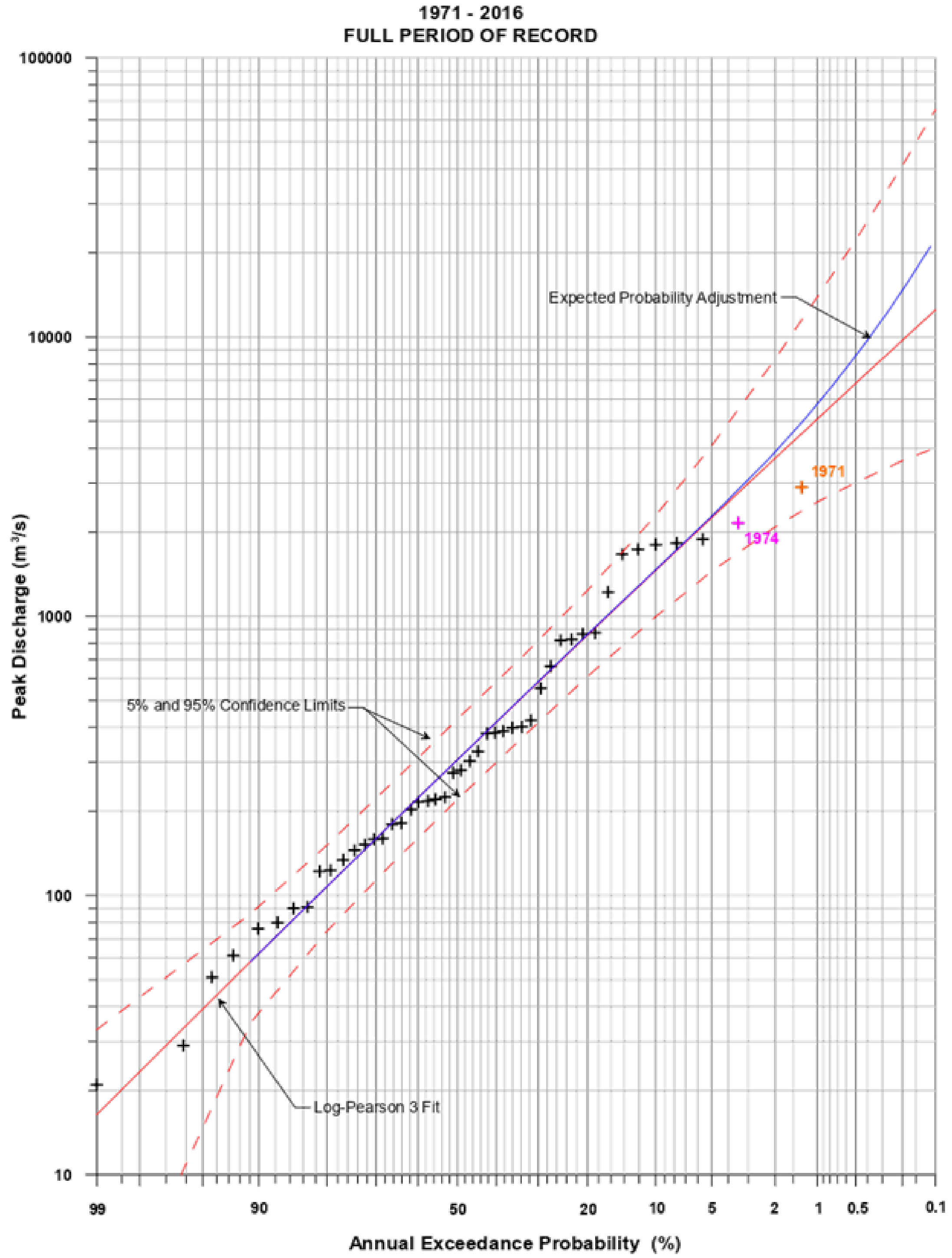
LEGEND

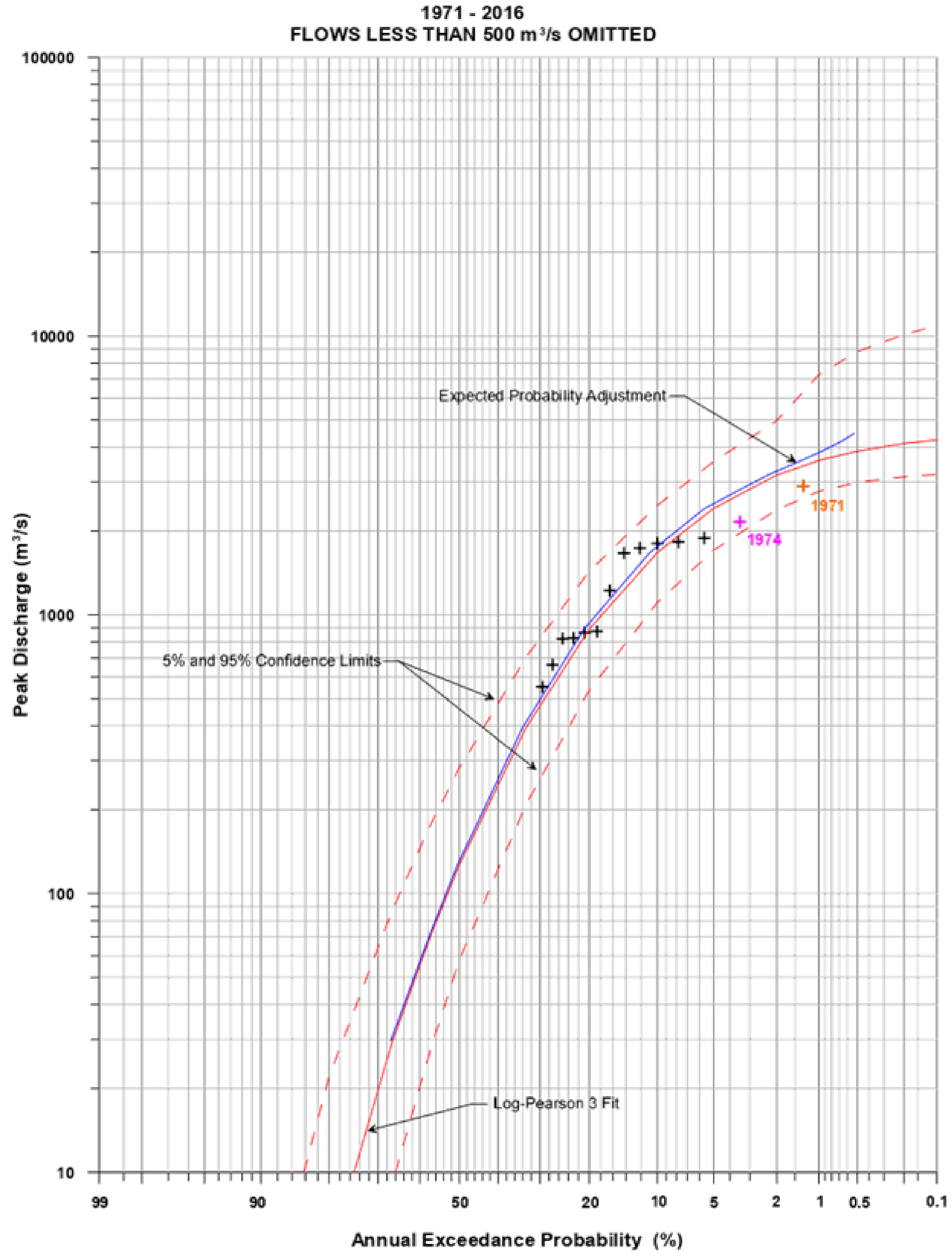
- February 1955 Peak Height - 8.94 m (206.16 m AHD)
- Max Gauged Height - 7.84 m (205.06 m AHD)
- Gauged River Height and Discharge
- Pre-1971 DPIE Rating Curve
- Post-1971 DPIE Rating Curve
- WaterNSW No. 314.05 Rating Curve

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C1.2

RATING CURVES
NAMOI RIVER AT MOLLEE STREAM GAUGE (GS 419039)



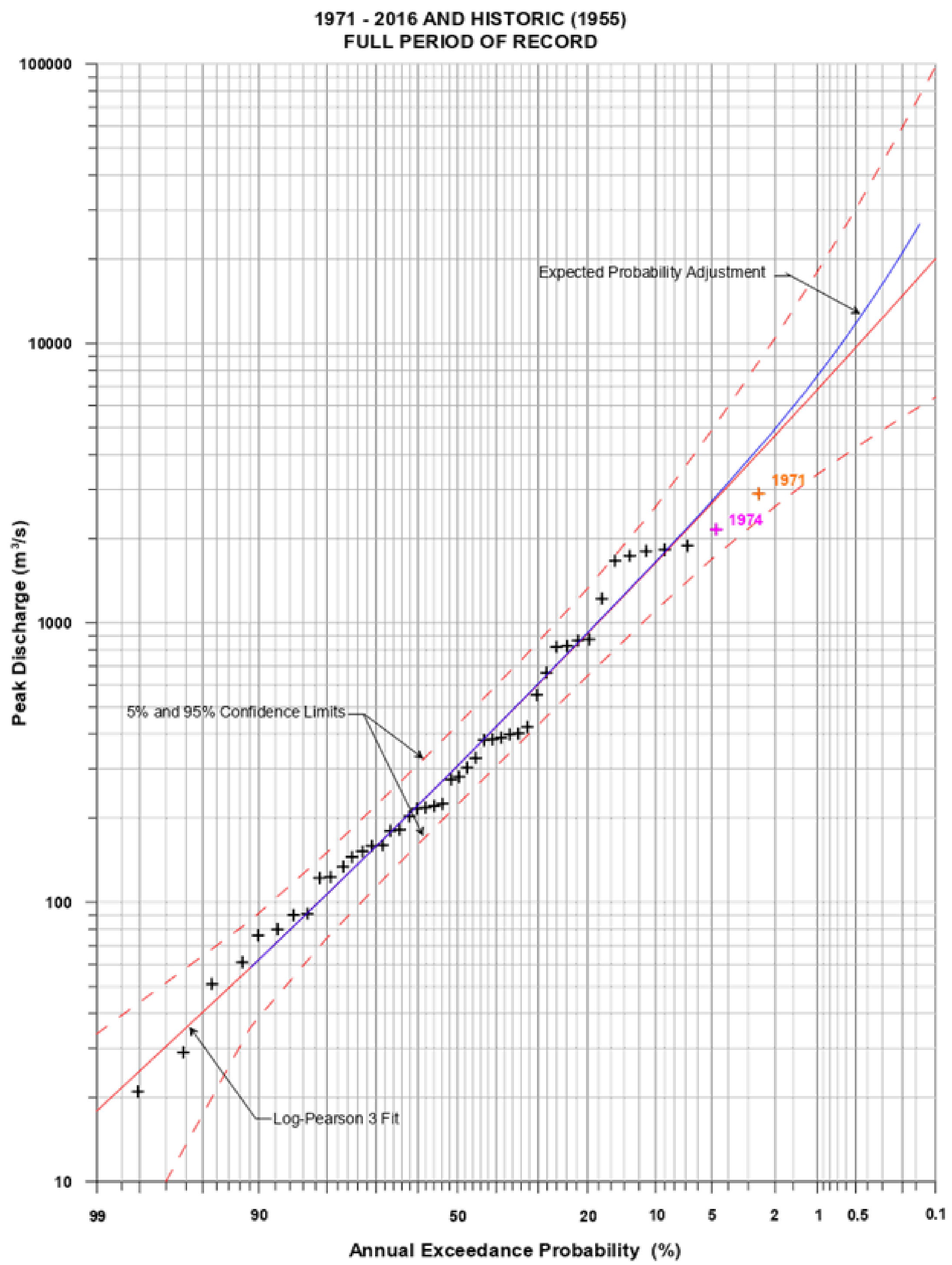


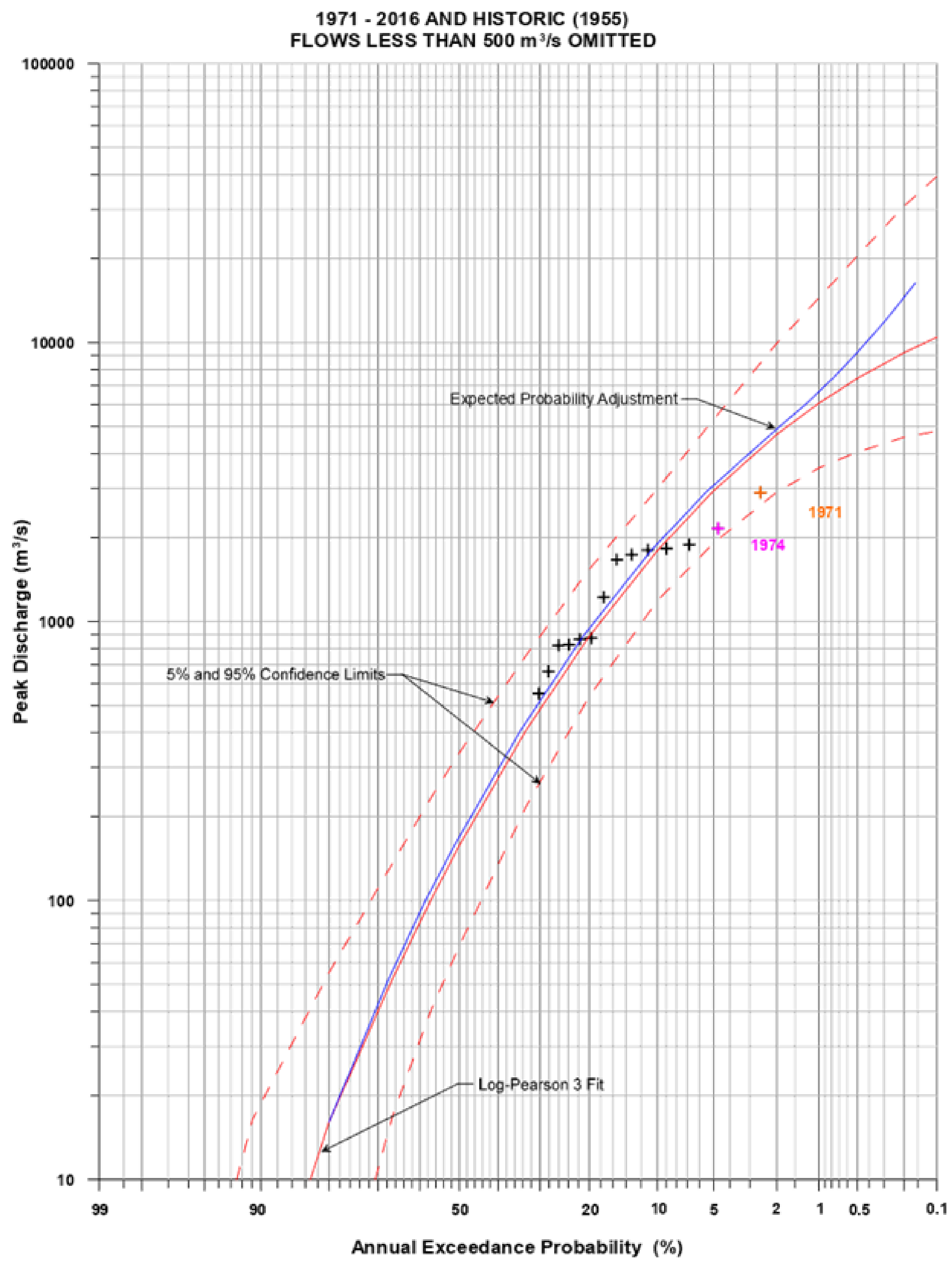
Lyall & Associates

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C1.3
(Sheet 1 of 3)

FLOOD FREQUENCY RELATIONSHIP
LOG-PEARSON 3 ANNUAL SERIES 1971-2016
NAMOI RIVER AT MOLLEE STREAM GAUGE (GS 419039)



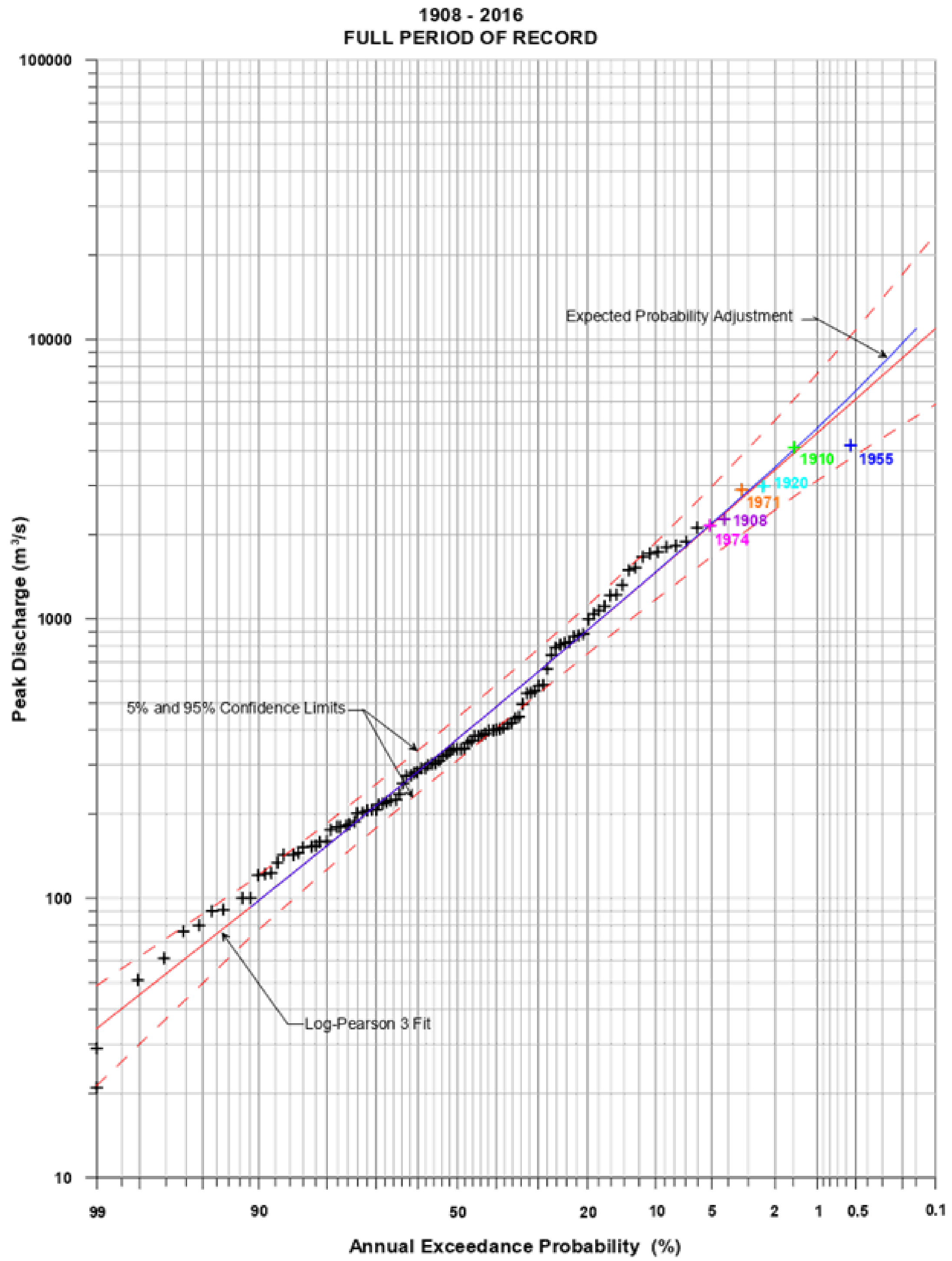


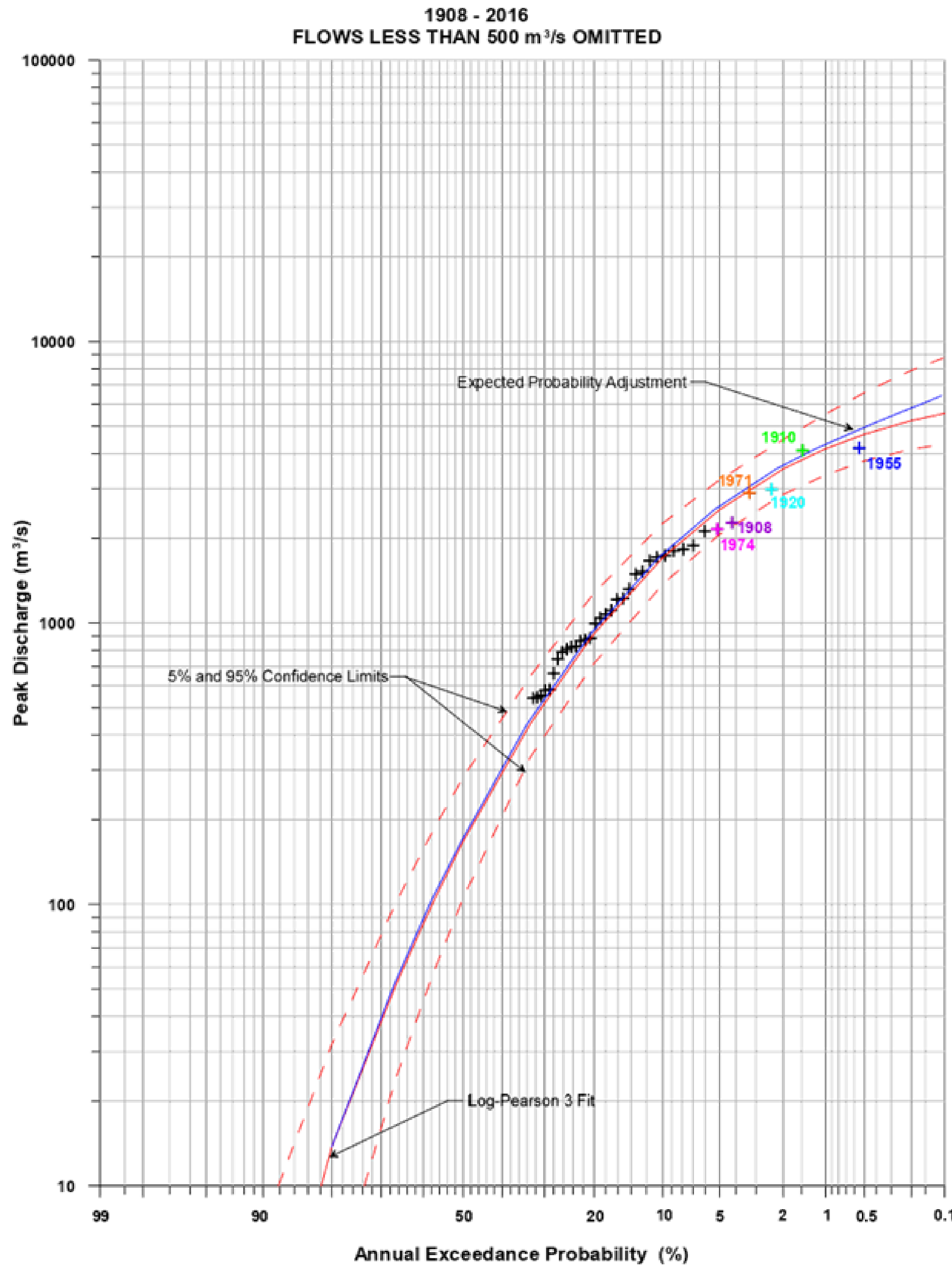
Lyall & Associates

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C1.3
(Sheet 2 of 3)

FLOOD FREQUENCY RELATIONSHIP
LOG-PEARSON 3 ANNUAL SERIES 1971-2016
NAMOI RIVER AT MOLLEE STREAM GAUGE (GS 419039)



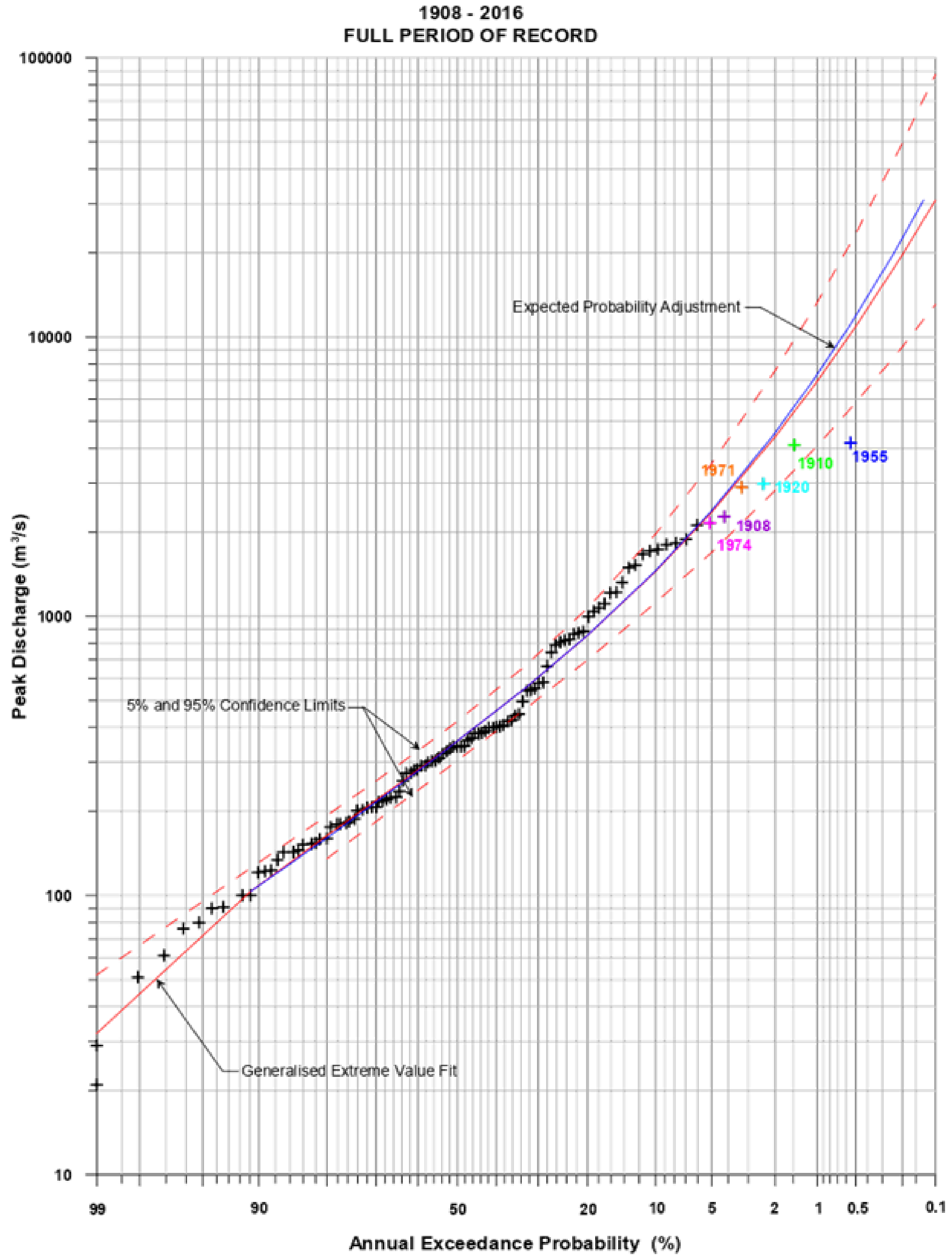


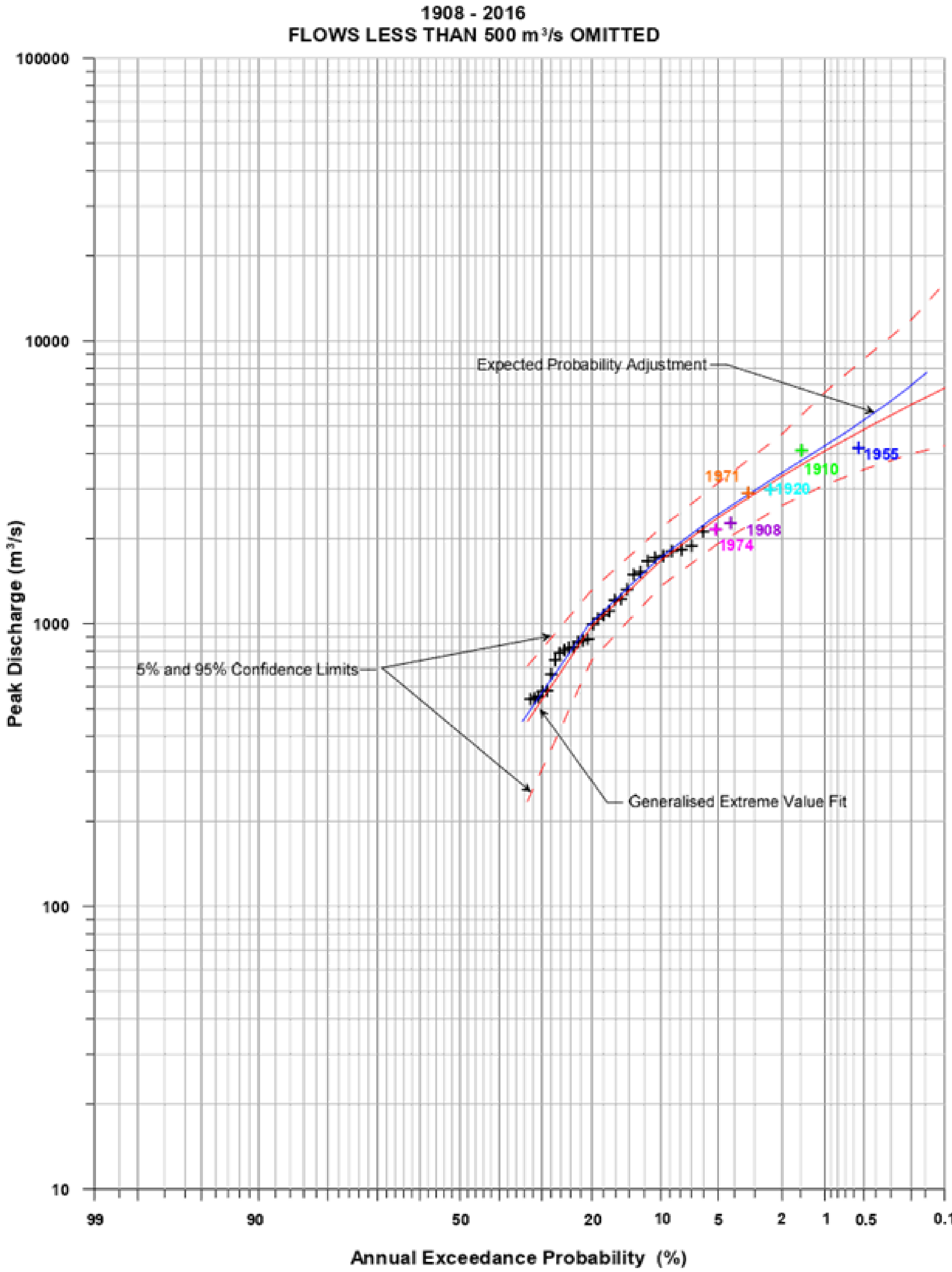
Lyall & Associates

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C1.3
(Sheet 3 of 3)

FLOOD FREQUENCY RELATIONSHIP
LOG-PEARSON 3 ANNUAL SERIES 1971-2016
NAMOI RIVER AT MOLLEE STREAM GAUGE (GS 419039)



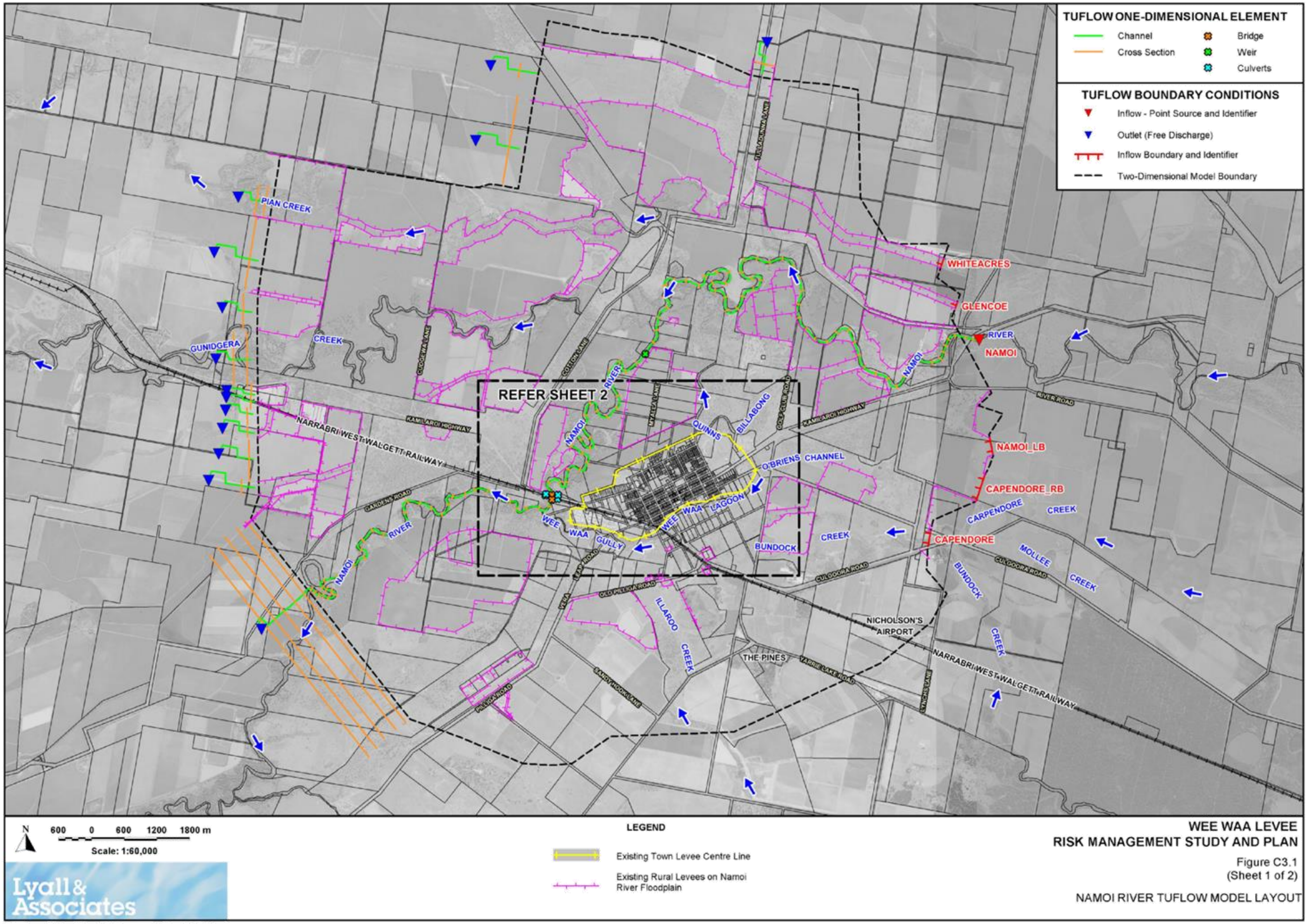


Lyall & Associates

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C1.4

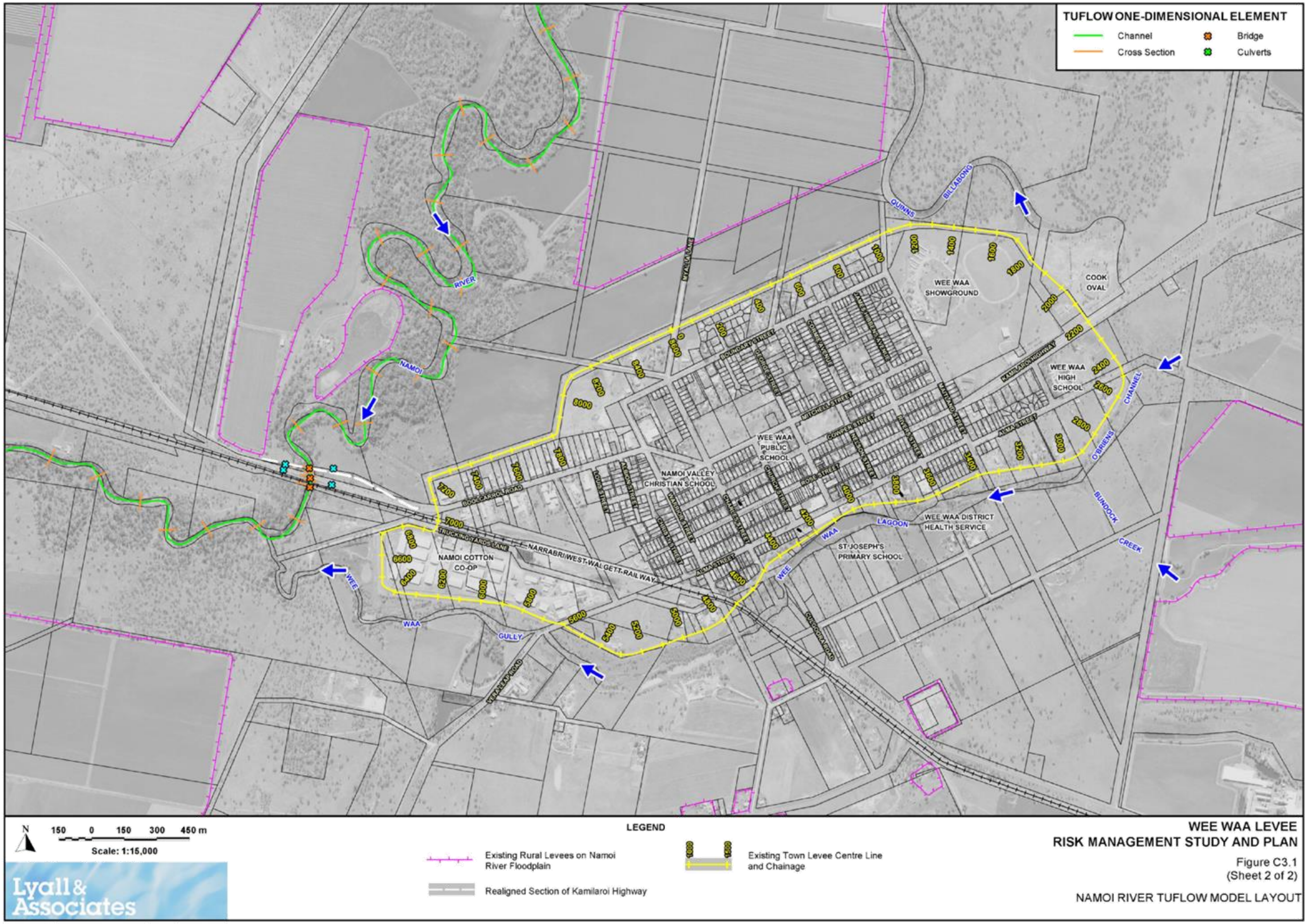
FLOOD FREQUENCY RELATIONSHIP
GENERALISED EXTREME VALUE ANNUAL SERIES 1971-2016
NAMOI RIVER AT MOLLEE STREAM GAUGE (GS 419039)

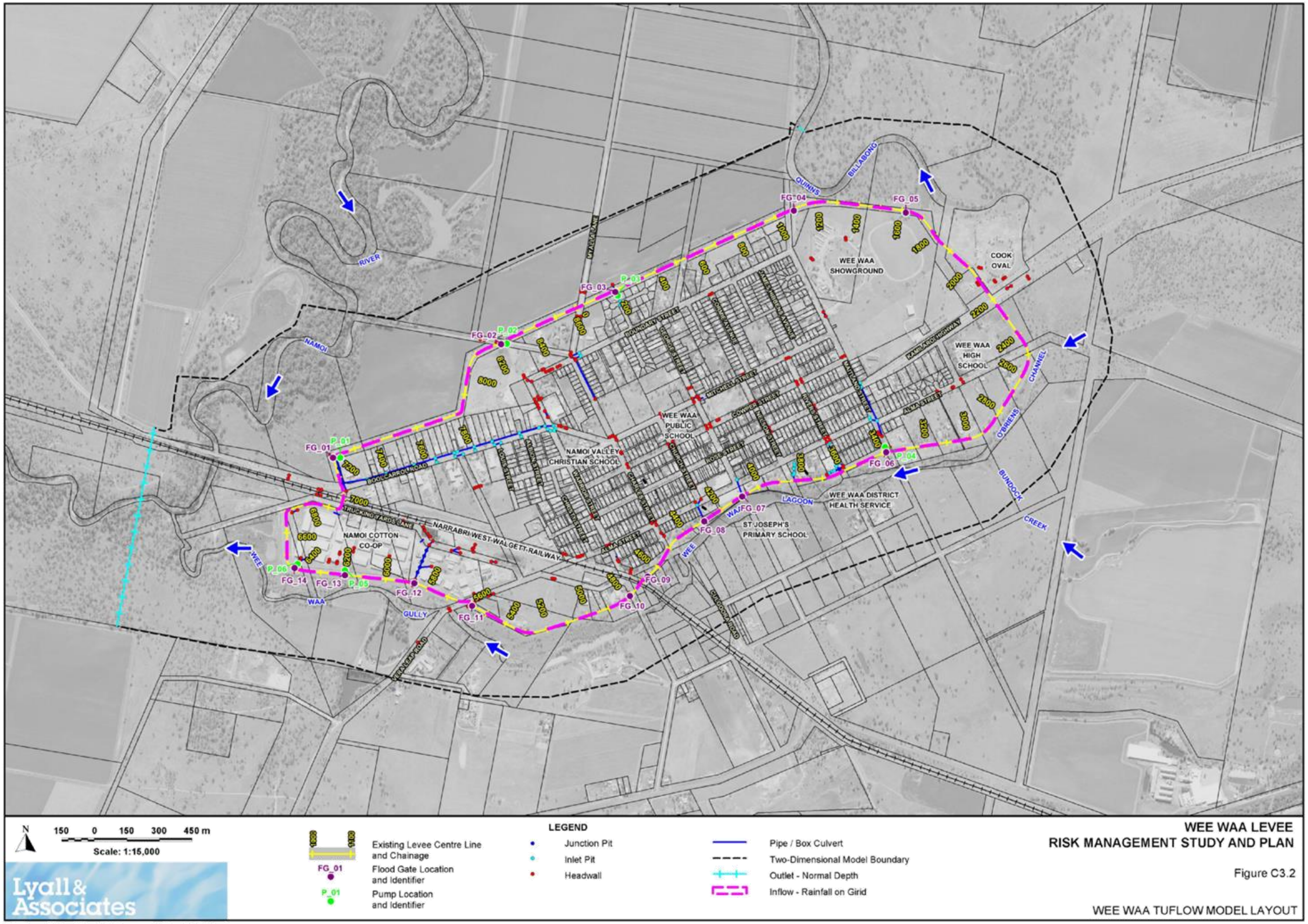


WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C3.1
(Sheet 1 of 2)

NAMOI RIVER TUFLOW MODEL LAYOUT


TUFLOW ONE-DIMENSIONAL ELEMENT
Channel
Cross Section
Bridge
Culverts
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
ST JOSEPH'S PRIMARY SCHOOL
NAMOI COTTON CO-OP
NAMOI RIVER
QUINNS BILLABONG
CHANNEL
O'BRIENS
BUNDOCK CREEK
LAGOON
WEE WAA
WEE WAA GULLY
KAMILAROI HIGHWAY
NARRABRI-WEST-WALGETT RAILWAY
BOOLCARROL ROAD
TRUCKING YARDS LANE
Scale: 1:15,000
150 0 150 300 450 m
LEGEND
Existing Rural Levees on Namoi River Floodplain
Realigned Section of Kamilaroi Highway
Existing Town Levee Centre Line and Chainage
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure C3.1
(Sheet 2 of 2)
NAMOI RIVER TUFLOW MODEL LAYOUT
Lyall & Associates


WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure C3.2
WEE WAA TUFLOW MODEL LAYOUT
LEGEND
Existing Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
Junction Pit
Inlet Pit
Headwall
Pipe / Box Culvert
Two-Dimensional Model Boundary
Outlet - Normal Depth
Inflow - Rainfall on Grid
Scale: 1:15,000
150 0 150 300 450 m
Lyall & Associates
WEE WAA SHOWGROUND
COOK OVAL
WEE WAA HIGH SCHOOL
WEE WAA PUBLIC SCHOOL
NAMOI VALLEY CHRISTIAN SCHOOL
WEE WAA DISTRICT HEALTH SERVICE
ST JOSEPH'S PRIMARY SCHOOL
NAMOI COTTON CO-OP
NARRABRI-WEST-WALGETT-RAILWAY
NAMOI
RIVER
QUINNS
BILLABONG
O'BRIENS
CHANNEL
BUNDOCK
CREEK
WEE
WAA
LAGOON
GULLY

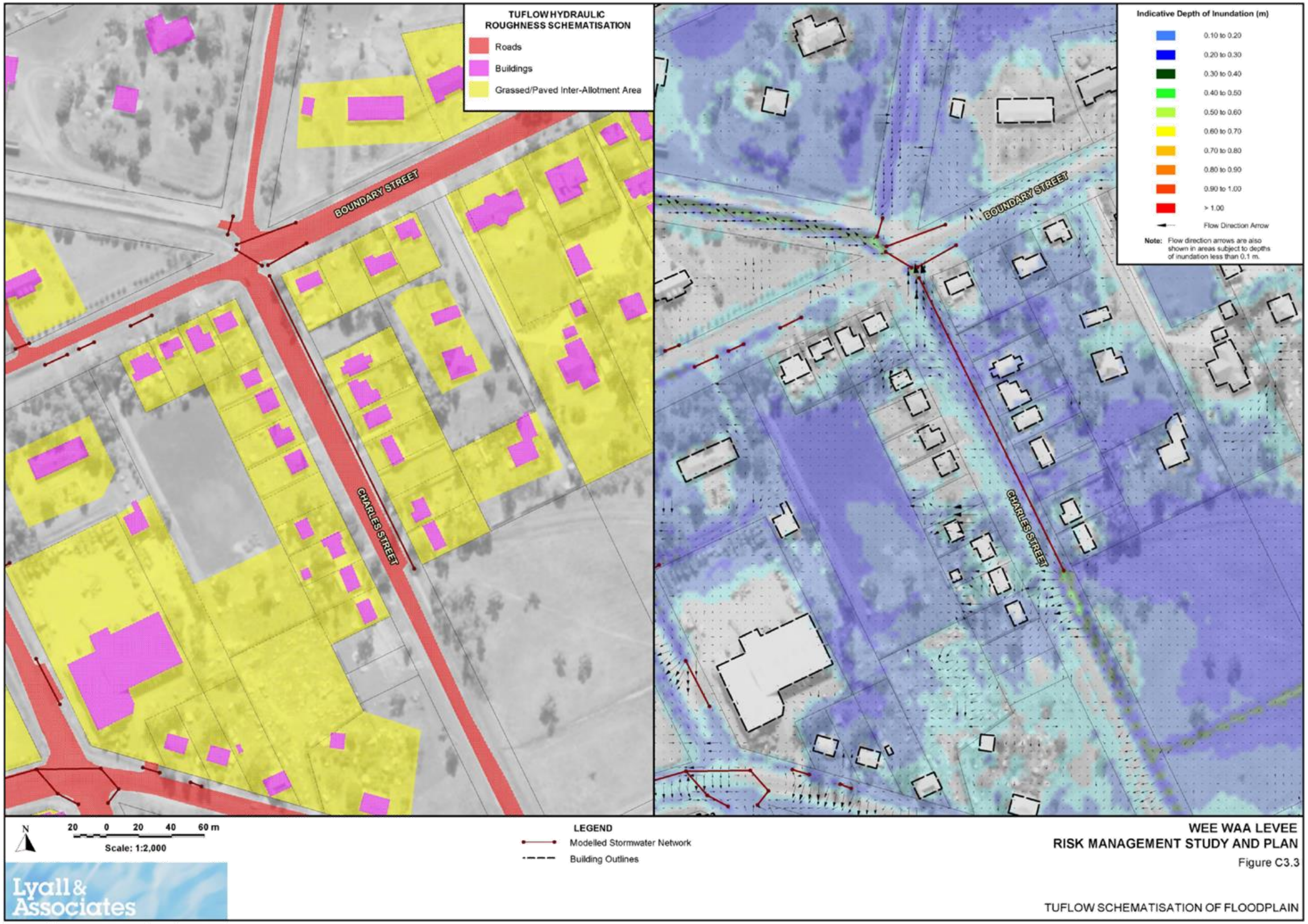
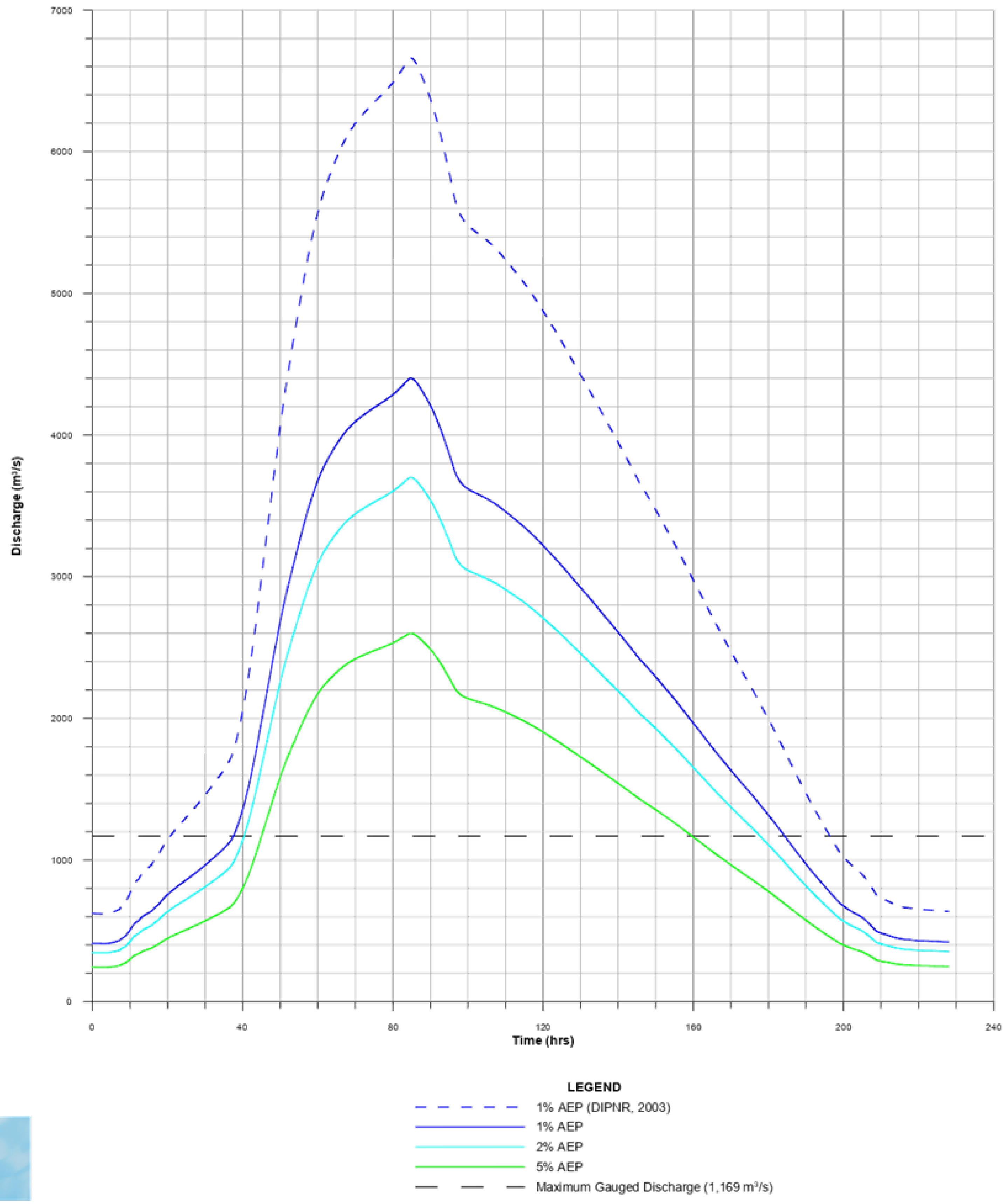


Figure C3.3

TUFLOW SCHEMATISATION OF FLOODPLAIN

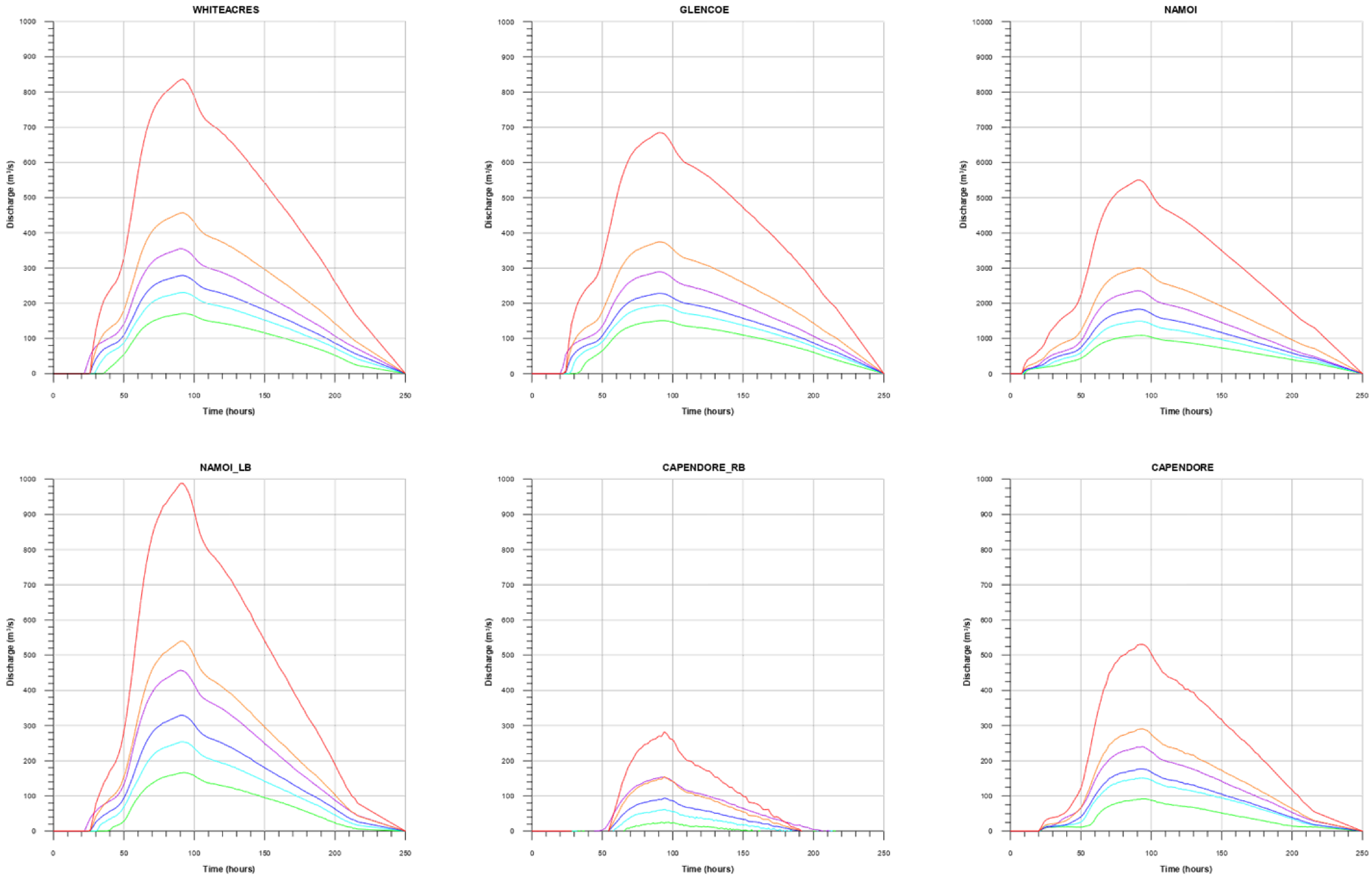


Lyall & Associates

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure C4.1

DESIGN DISCHARGE HYDROGRAPHS
NAMOI RIVER AT MOLLEE STREAM GAUGE (GS 419039)



NOTE:
Refer **Figures B4.1** for location of discharge hydrographs.

LEGEND

Extreme Flood	1% AEP
0.2% AEP	2% AEP
0.5% AEP	5% AEP

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

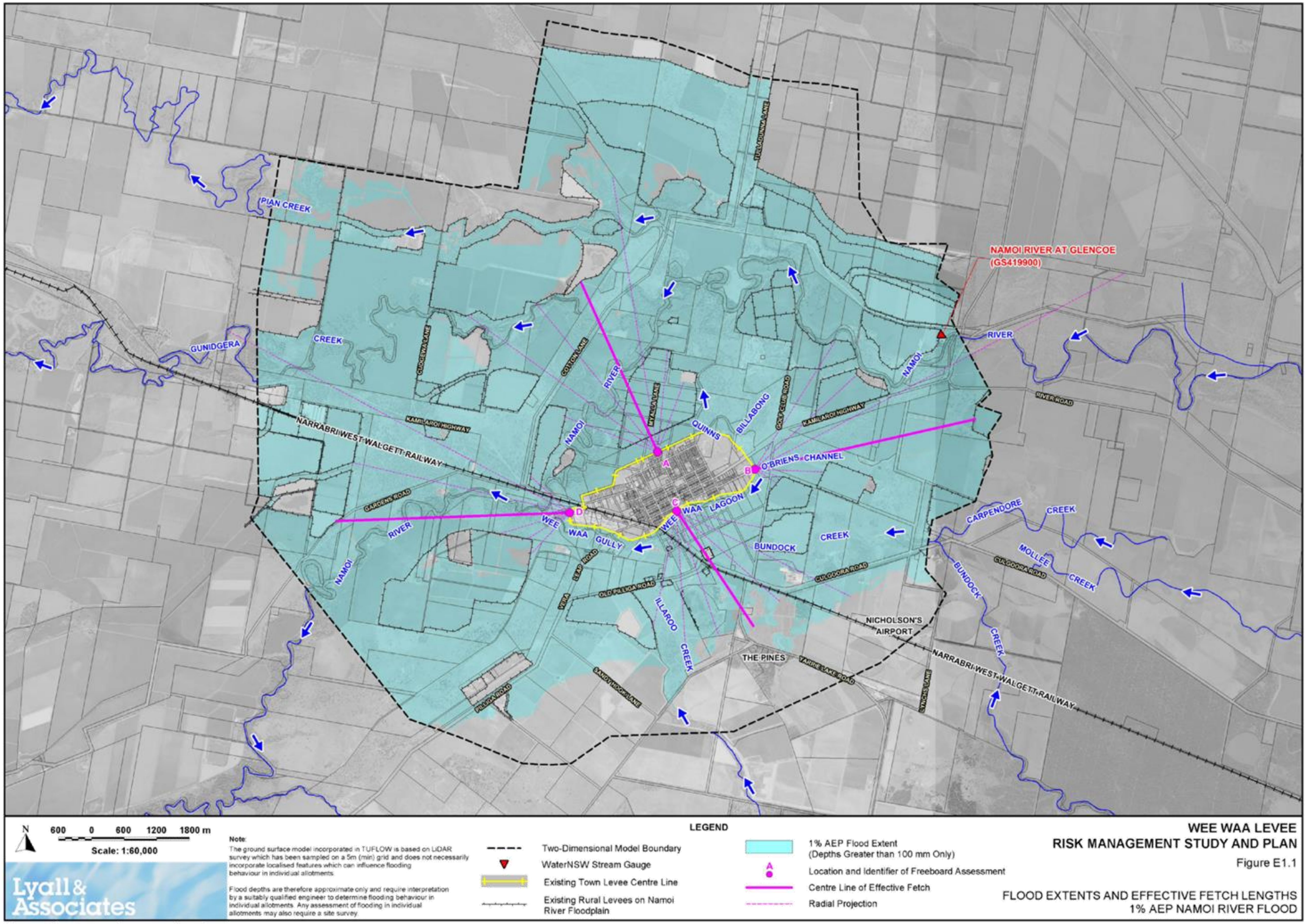
Figure C4.2

DESIGN DISCHARGE HYDROGRAPHS
NAMOI RIVER FLOODPLAIN UPSTREAM OF WEE WAA

APPENDIX E

FREEBOARD ANALYSIS

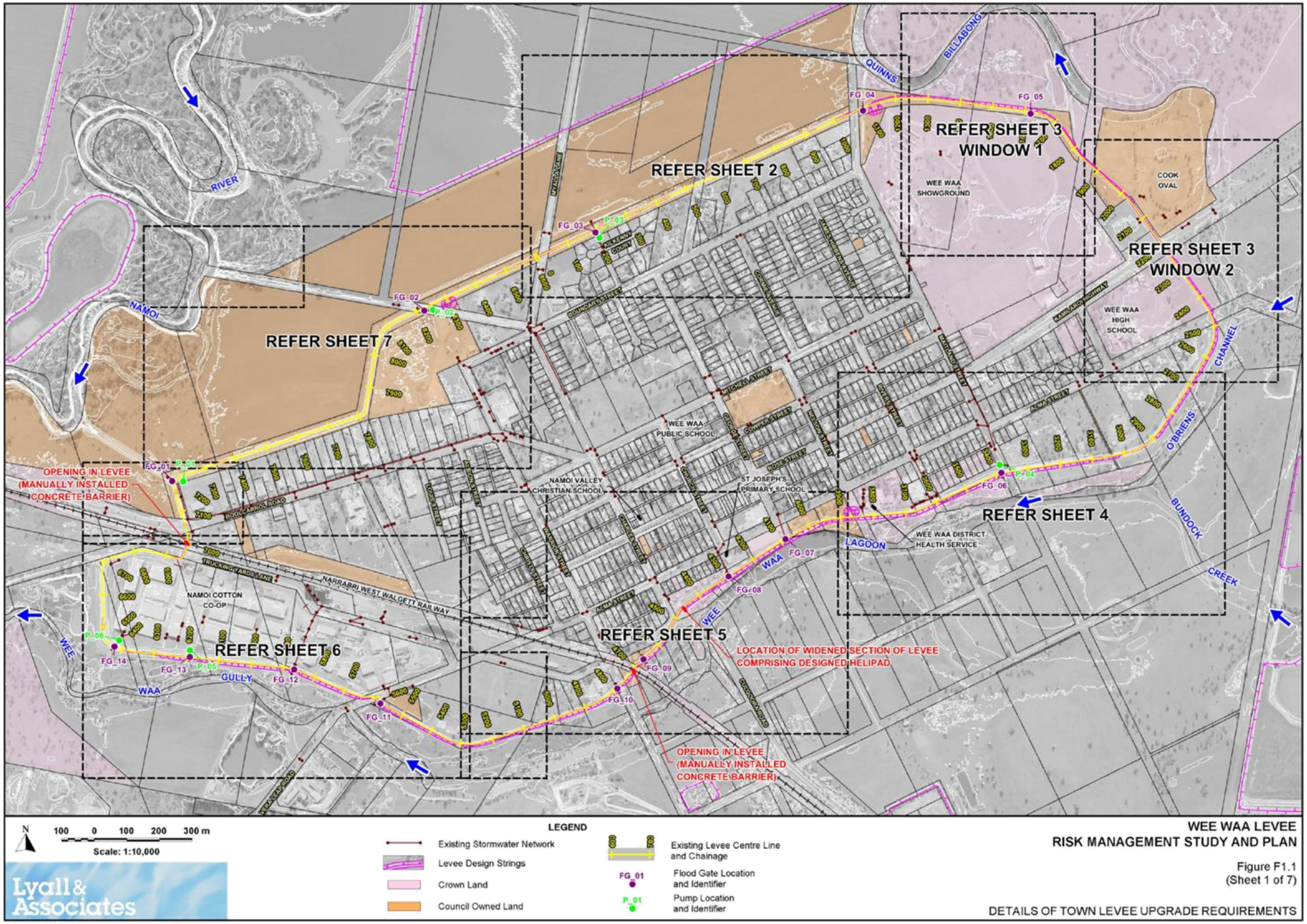
LIST OF FIGURES (APPENDIX E)


PIAN CREEK
GUNIDGERA
CREEK
NAMOI RIVER AT GLENCOE
(GS419900)
RIVER
NAMOI
RIVER ROAD
KAMILAROI HIGHWAY
NARRABRI-WEST-WALGETT RAILWAY
QUINNS
BILLABONG
O'BRIENS CHANNEL
WEE WAA LAGOON
WEE WAA GULLY
BUNDOCK CREEK
CARPENDORE CREEK
MOLLEE CREEK
CULGOORA ROAD
NICHOLSON'S AIRPORT
THE PINES
ILLAROO CREEK
GARDENS ROAD
OLD PILLIGA ROAD
PILLIGA ROAD
COTTON LANE
MYALLA LANE
GOLF CLUB ROAD
A
B
C
D
600 0 600 1200 1800 m
Scale: 1:60,000
Lyall & Associates
Note:
The ground surface model incorporated in TUFLOW is based on LiDAR survey which has been sampled on a 5m (min) grid and does not necessarily incorporate localised features which can influence flooding behaviour in individual allotments.
Flood depths are therefore approximate only and require interpretation by a suitably qualified engineer to determine flooding behaviour in individual allotments. Any assessment of flooding in individual allotments may also require a site survey.
LEGEND
Two-Dimensional Model Boundary
WaterNSW Stream Gauge
Existing Town Levee Centre Line
Existing Rural Levees on Namoi River Floodplain
1% AEP Flood Extent (Depths Greater than 100 mm Only)
Location and Identifier of Freeboard Assessment
Centre Line of Effective Fetch
Radial Projection
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure E1.1
FLOOD EXTENTS AND EFFECTIVE FETCH LENGTHS
1% AEP NAMOI RIVER FLOOD

APPENDIX F

PRELIMINARY DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS

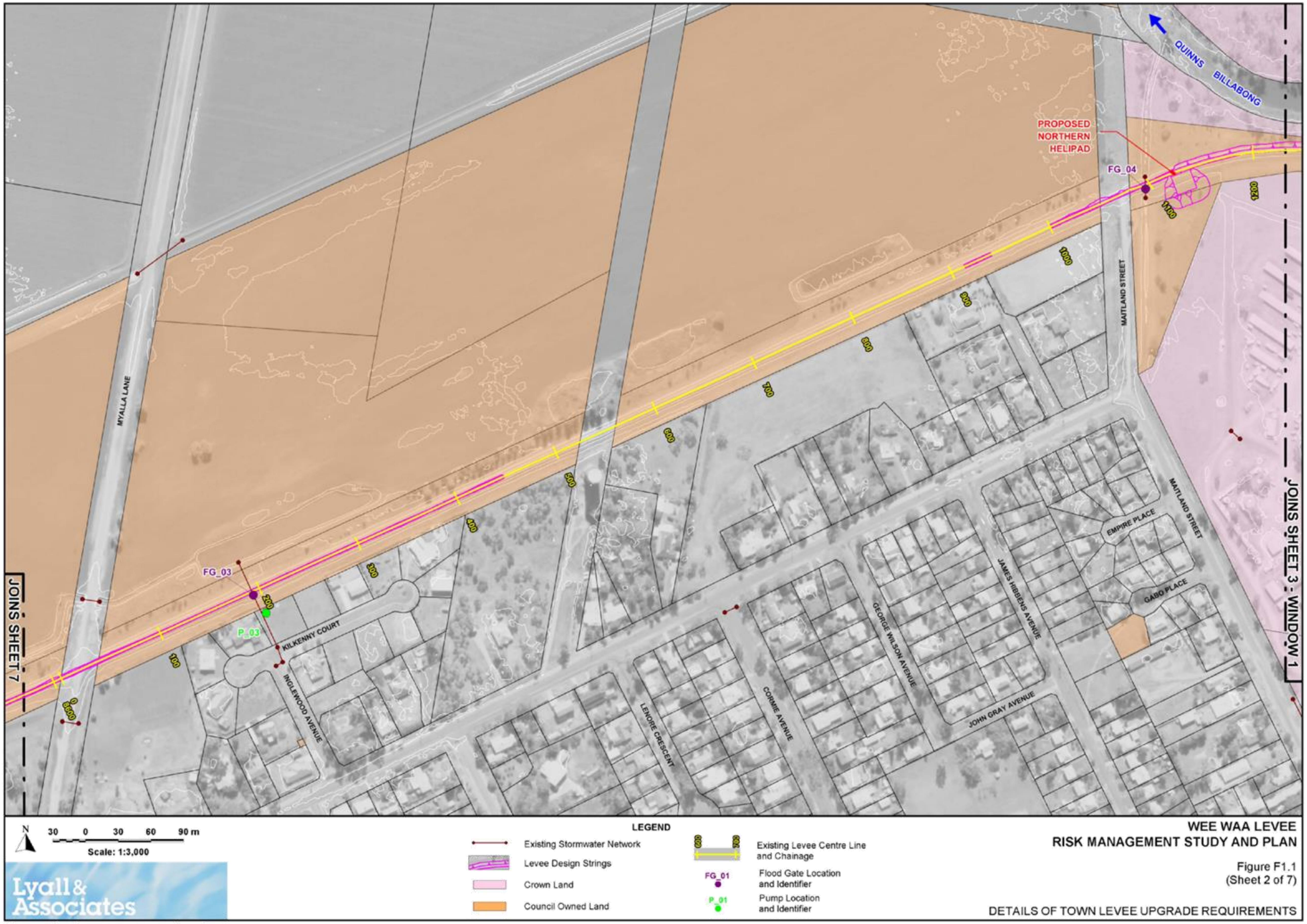
LIST OF FIGURES (APPENDIX F)

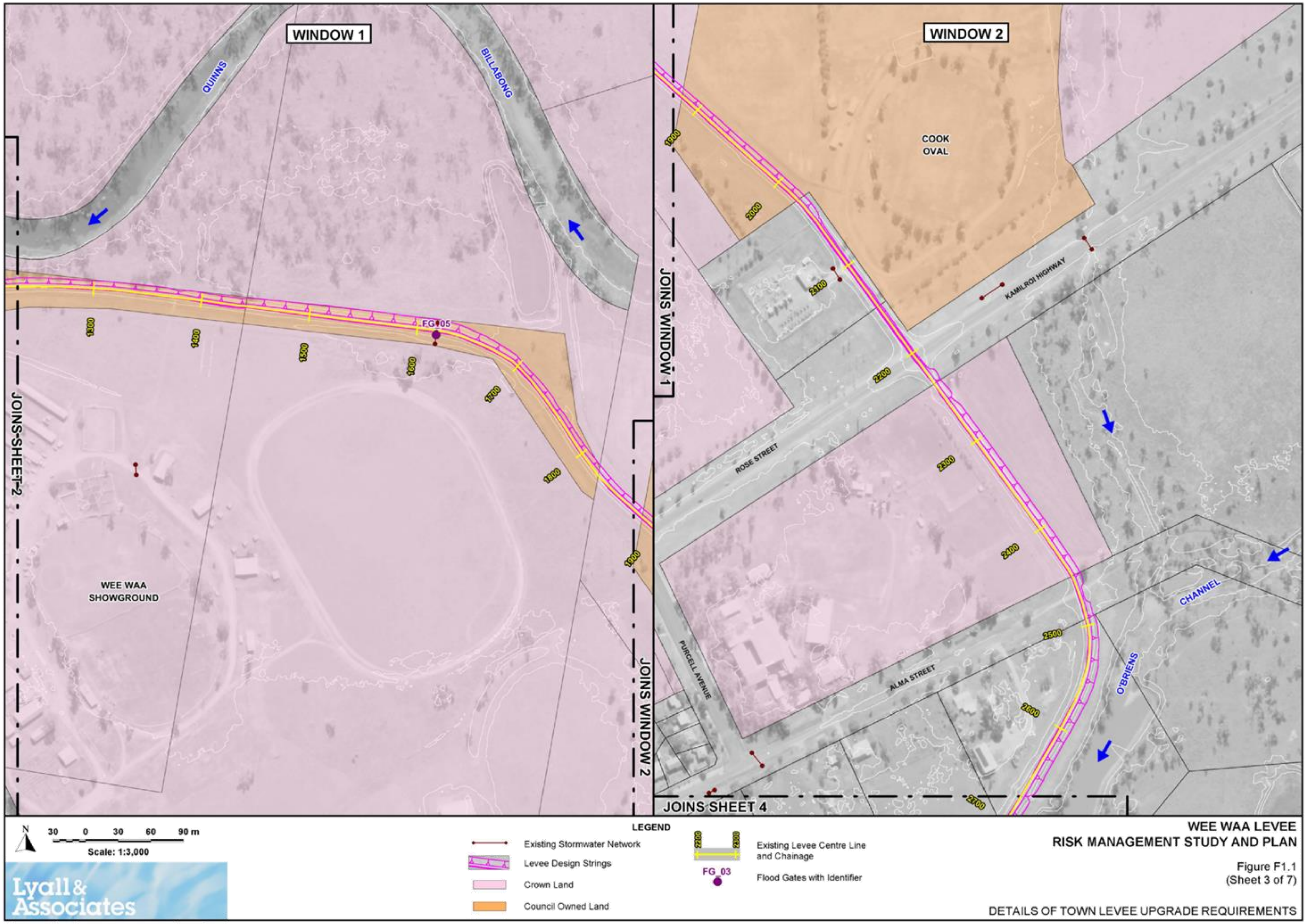


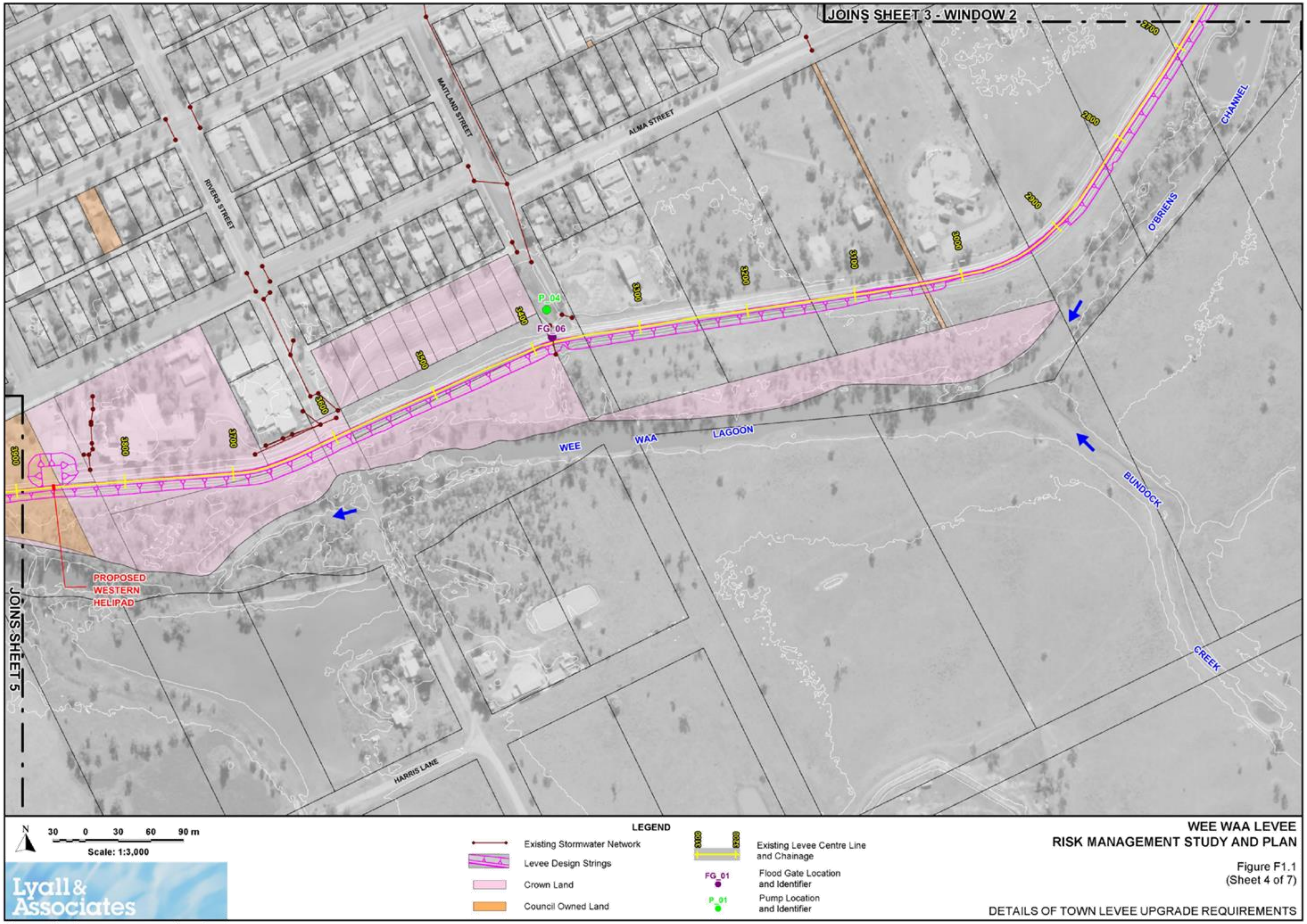
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

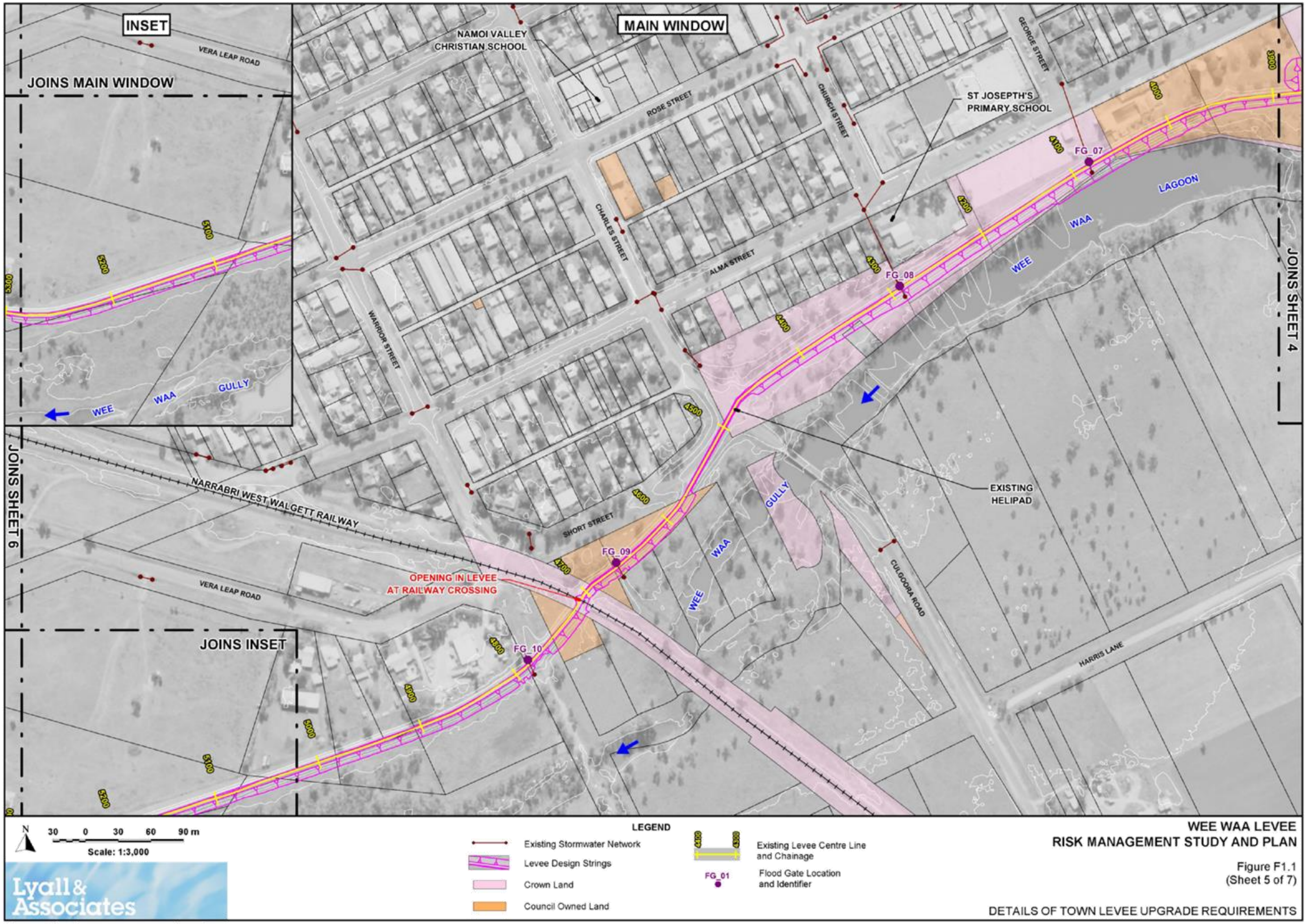
Figure F1.1
(Sheet 1 of 7)

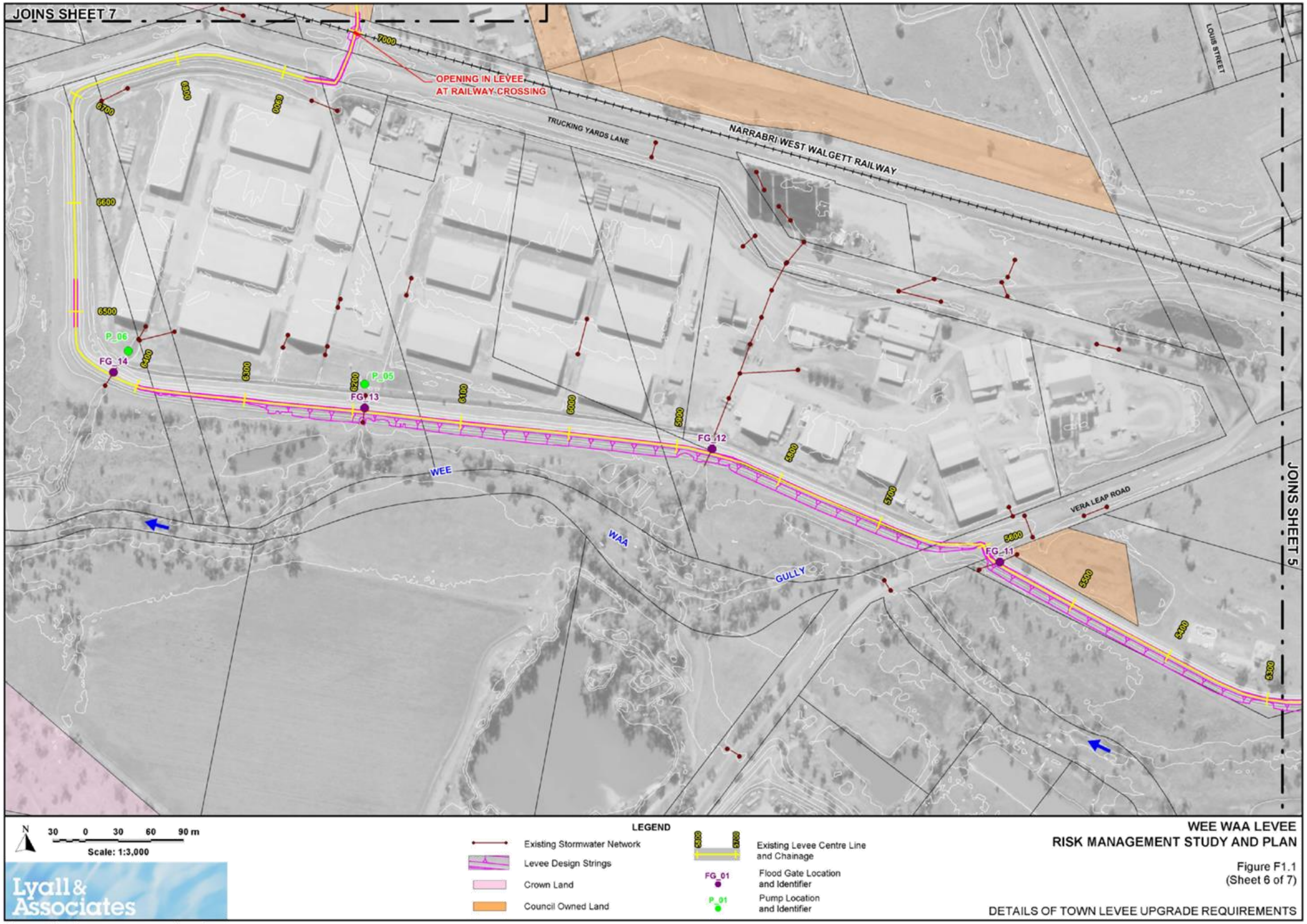
DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS

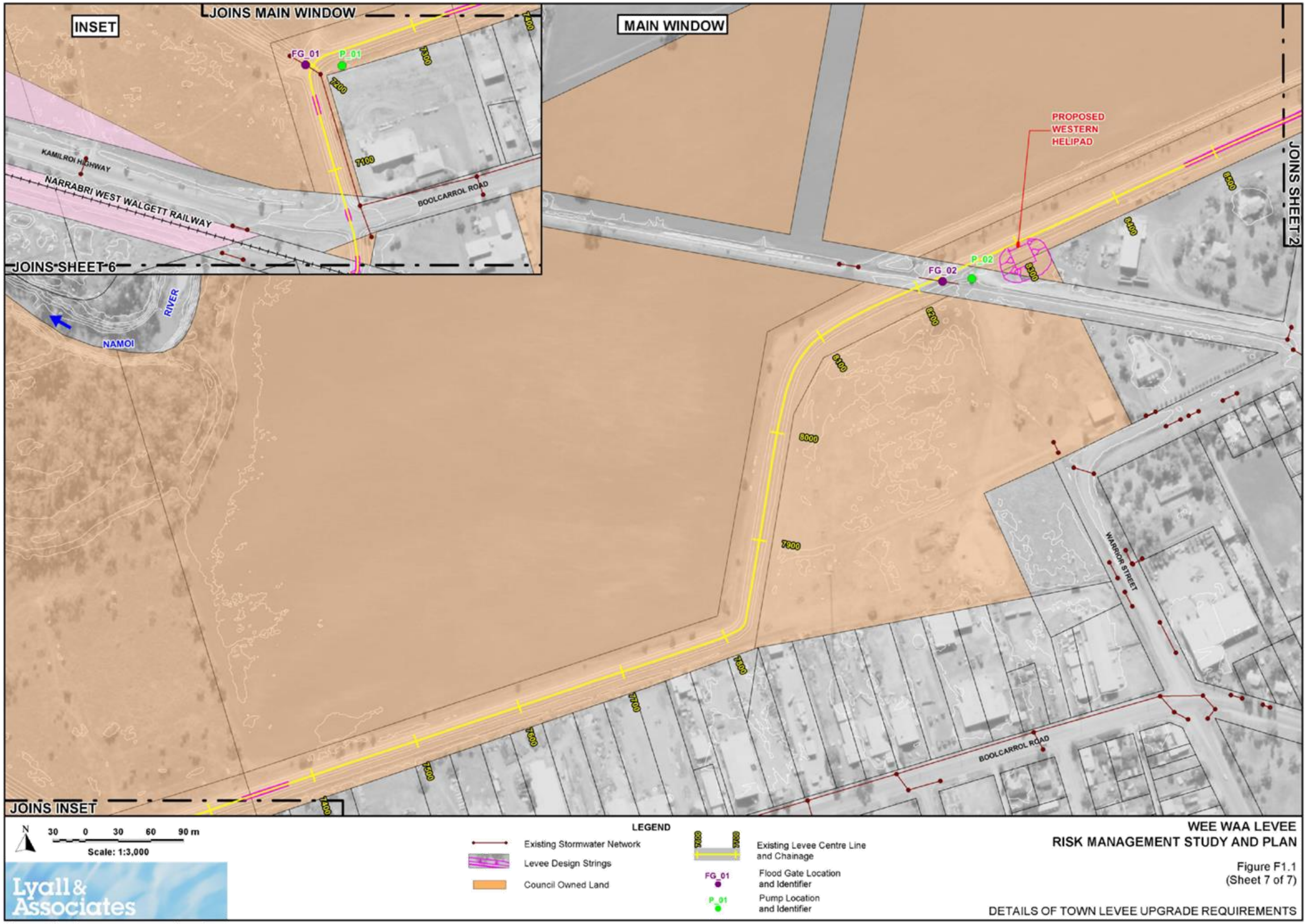

QUINNS BILLABONG
PROPOSED NORTHERN HELIPAD
FG_04
FG_03
P_03
MYALLA LANE
MAITLAND STREET
KILKENNY COURT
INGLEWOOD AVENUE
LENORE CRESCENT
CORMIE AVENUE
GEORGE WILSON AVENUE
JAMES HIBBENS AVENUE
JOHN GRAY AVENUE
EMPIRE PLACE
GABO PLACE
JOINS SHEET 7
JOINS SHEET 3 : WINDOW 1
100
200
300
400
500
600
700
800
900
1000
1100
Scale: 1:3,000
30 0 30 60 90 m
LEGEND
Existing Stormwater Network
Levee Design Strings
Crown Land
Council Owned Land
Existing Levee Centre Line and Chainage
FG_01
Flood Gate Location and Identifier
P_01
Pump Location and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.1
(Sheet 2 of 7)
DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS

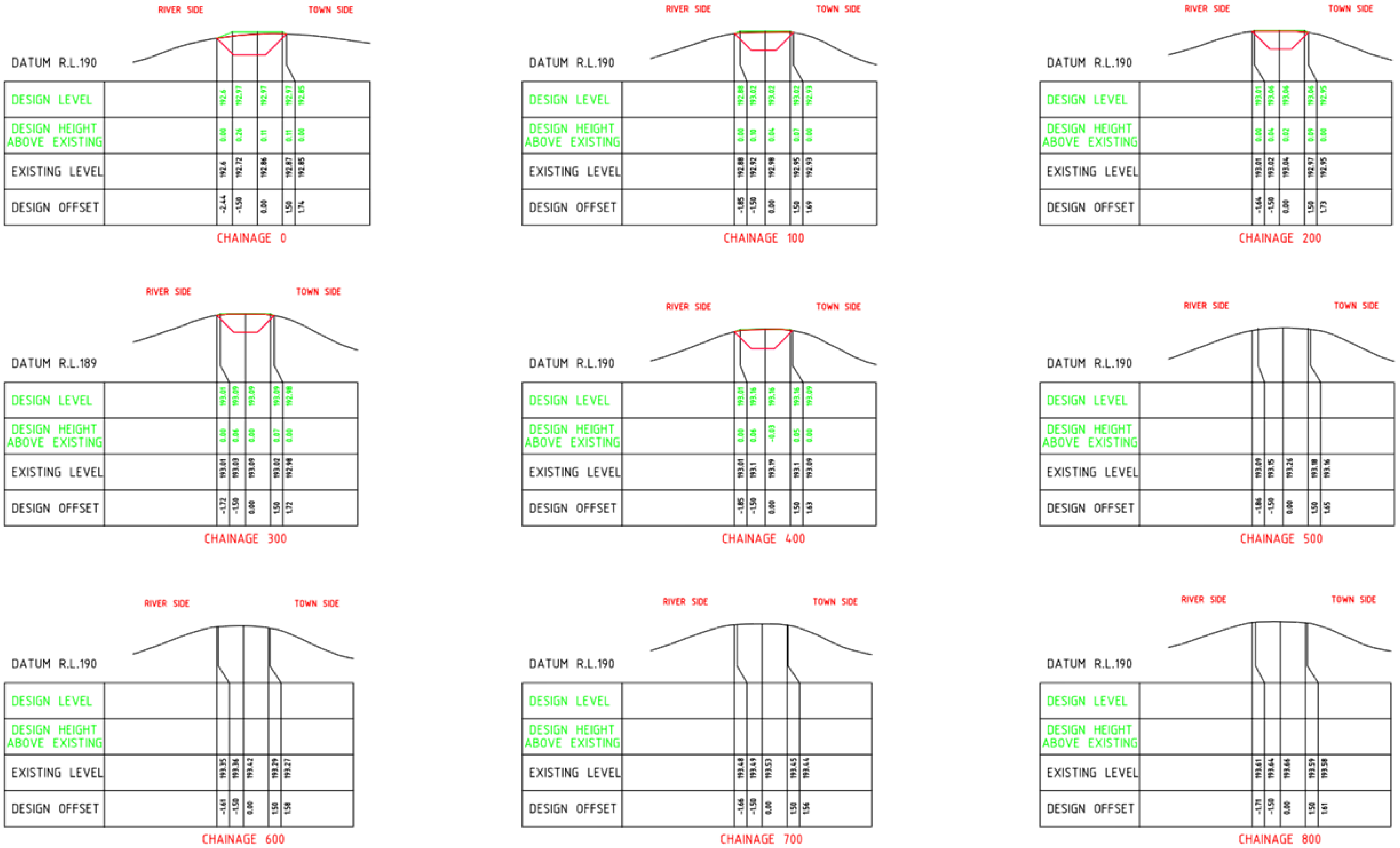

WINDOW 1
QUINNS
BILLABONG
FG 05
1300
1400
1500
1600
1700
1800
1900
WEE WAA SHOWGROUND
JOINS SHEET 2
JOINS WINDOW 2
WINDOW 2
COOK OVAL
JOINS WINDOW 1
2000
2100
2200
2300
2400
2500
2600
2700
KAMILROI HIGHWAY
ROSE STREET
CHANNEL
O'BRIENS
ALMA STREET
PURCELL AVENUE
JOINS SHEET 4
30 0 30 60 90 m
Scale: 1:3,000
LEGEND
Existing Stormwater Network
Levee Design Strings
Crown Land
Council Owned Land
Existing Levee Centre Line and Chainage
FG 03
Flood Gates with Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.1
(Sheet 3 of 7)
DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS


JOINS SHEET 3 - WINDOW 2
JOINS SHEET 5
MAITLAND STREET
ALMA STREET
RIVERS STREET
HARRIS LANE
WEE WAA LAGOON
O'BRIENS CHANNEL
BUNDOCK CREEK
P_04
FG_06
PROPOSED WESTERN HELIPAD
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
LEGEND
Existing Stormwater Network
Levee Design Strings
Crown Land
Council Owned Land
Existing Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
FG_01
P_01
30 0 30 60 90 m
Scale: 1:3,000
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.1
(Sheet 4 of 7)
DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS


INSET
MAIN WINDOW
JOINS MAIN WINDOW
JOINS INSET
JOINS SHEET 4
JOINS SHEET 6
VERA LEAP ROAD
NAMOI VALLEY CHRISTIAN SCHOOL
ST JOSEPH'S PRIMARY SCHOOL
ROSE STREET
CHURCH STREET
GEORGE STREET
CHARLES STREET
ALMA STREET
WARRIOR STREET
SHORT STREET
CULGOORA ROAD
HARRIS LANE
NARRABRI WEST WALGETT RAILWAY
OPENING IN LEVEE AT RAILWAY CROSSING
EXISTING HELIPAD
LAGOON
WEE WAA GULLY
FG_07
FG_08
FG_09
FG_10
3900
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
5100
5200
30 0 30 60 90 m
Scale: 1:3,000
LEGEND
Existing Stormwater Network
Levee Design Strings
Crown Land
Council Owned Land
Existing Levee Centre Line and Chainage
Flood Gate Location and Identifier
FG_01
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.1
(Sheet 5 of 7)
DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS


JOINS SHEET 7
OPENING IN LEVEE AT RAILWAY CROSSING
TRUCKING YARDS LANE
NARRABRI WEST WALGETT RAILWAY
LOUIS STREET
VERA LEAP ROAD
JOINS SHEET 5
WEE
WAA
GULLY
FG_14
FG_13
FG_12
FG_11
P_06
P_05
7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
30 0 30 60 90 m
Scale: 1:3,000
LEGEND
Existing Stormwater Network
Levee Design Strings
Crown Land
Council Owned Land
Existing Levee Centre Line and Chainage
FG_01
Flood Gate Location and Identifier
P_01
Pump Location and Identifier
Lyall & Associates
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.1
(Sheet 6 of 7)
DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS


INSET
JOINS MAIN WINDOW
MAIN WINDOW
JOINS SHEET 6
JOINS SHEET 2
JOINS INSET
FG_01
P_01
FG_02
P_02
KAMILROI HIGHWAY
NARRABRI WEST WALGETT RAILWAY
BOOLCARROL ROAD
NAMOI
RIVER
PROPOSED
WESTERN
HELIPAD
WARRIOR STREET
7100
7200
7300
7400
7500
7600
7700
7800
7900
8000
8100
8200
8300
8400
8500
30 0 30 60 90 m
Scale: 1:3,000
Lyall & Associates
LEGEND
Existing Stormwater Network
Levee Design Strings
Council Owned Land
Existing Levee Centre Line and Chainage
Flood Gate Location and Identifier
Pump Location and Identifier
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.1
(Sheet 7 of 7)
DETAILS OF TOWN LEVEE UPGRADE REQUIREMENTS



Lyall & Associates

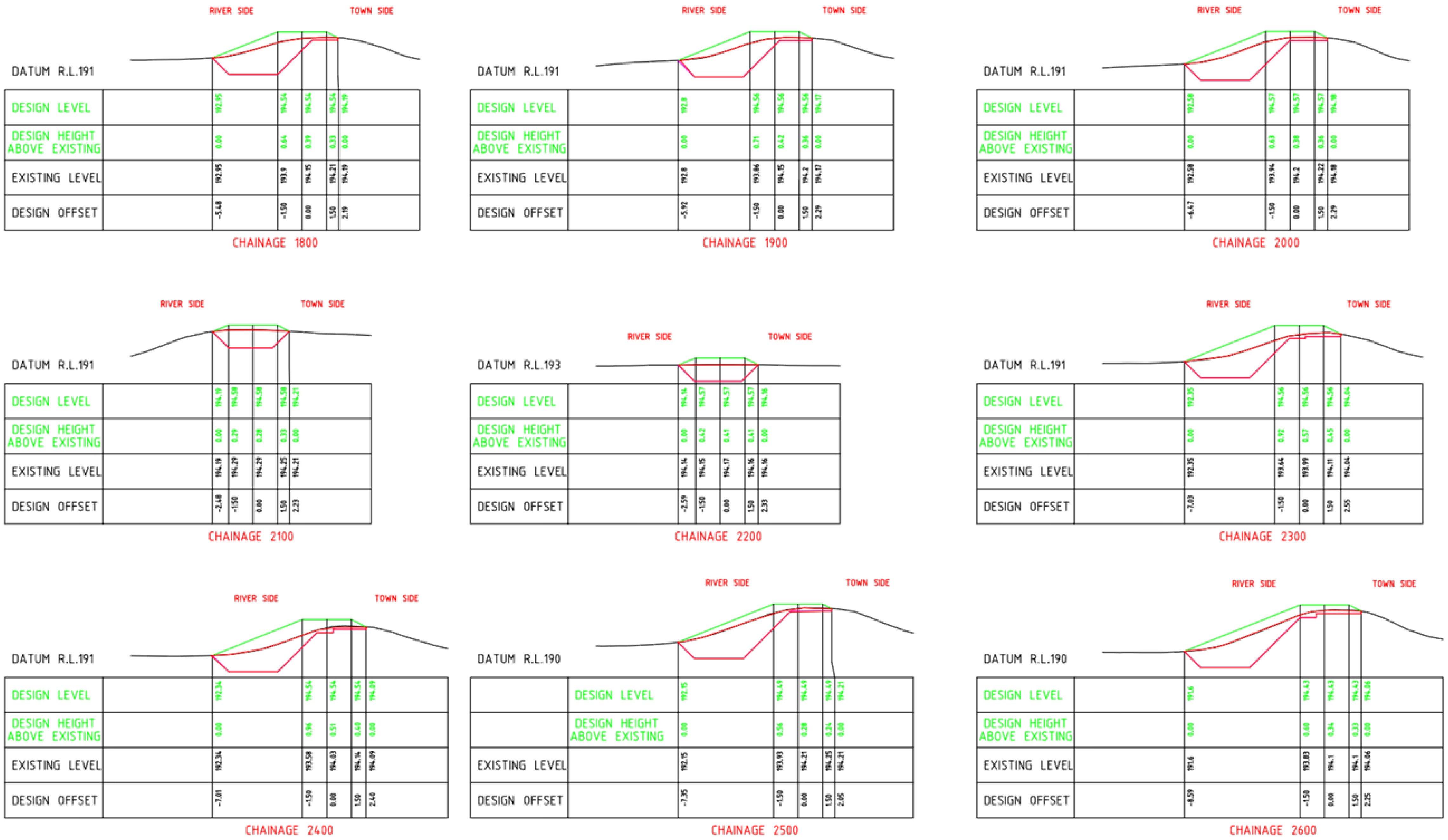
Scale
Vertical 1:250
Horizontal 1:250

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 1 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS


DATUM R.L.191
DESIGN LEVEL
DESIGN HEIGHT ABOVE EXISTING
EXISTING LEVEL
DESIGN OFFSET
RIVER SIDE
TOWN SIDE
CHAINAGE 900
CHAINAGE 1000
CHAINAGE 1100
CHAINAGE 1200
CHAINAGE 1300
CHAINAGE 1400
CHAINAGE 1500
CHAINAGE 1600
CHAINAGE 1700
Lyall & Associates
Scale
Vertical 1:250
Horizontal 1:250
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.2
(Sheet 2 of 10)
CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS



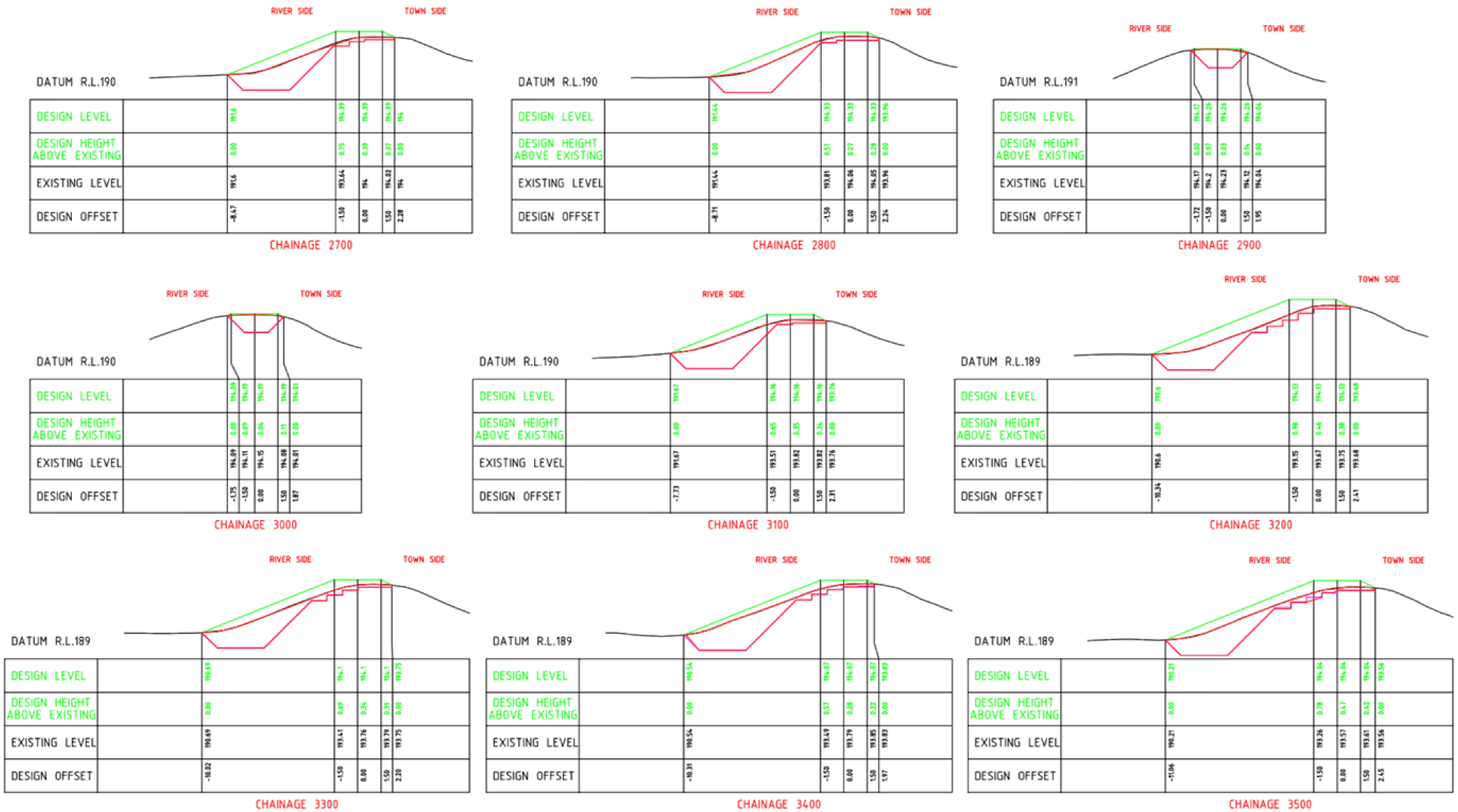
Lyall & Associates

Scale
Vertical 1:250
Horizontal 1:250

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 3 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS



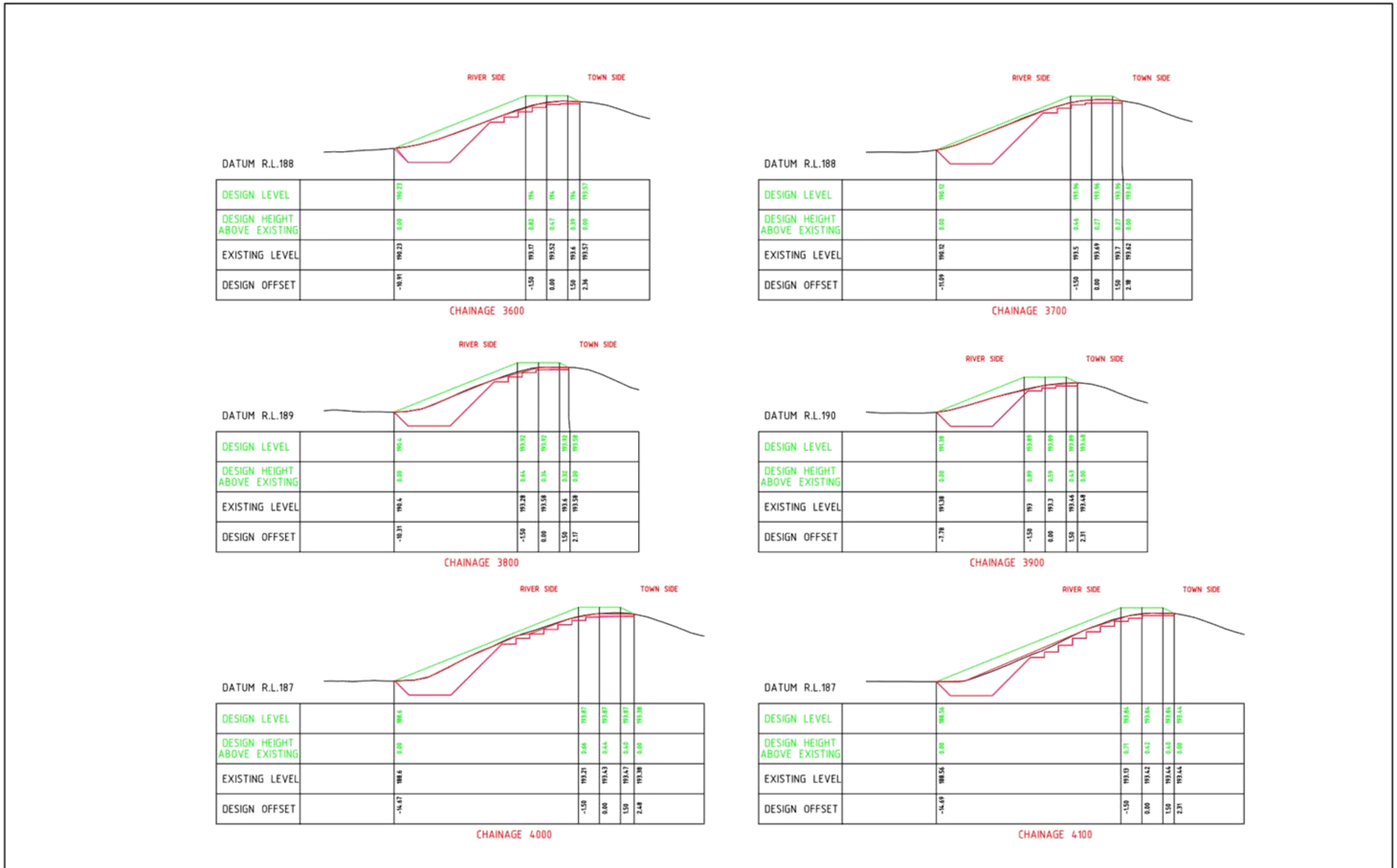
Lyall & Associates

Scale
Vertical 1:250
Horizontal 1:250

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 4 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS



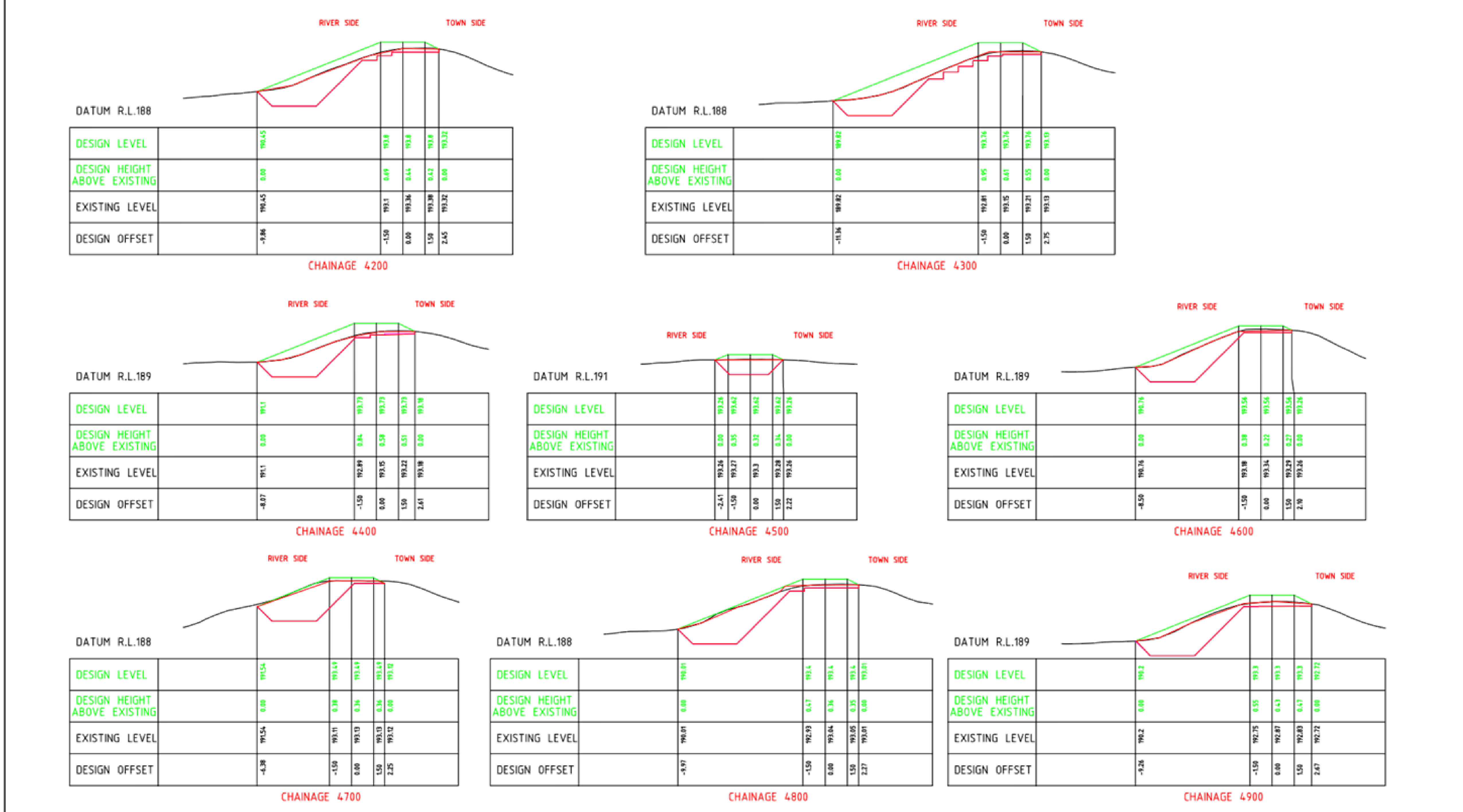
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 5 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS

Lyall & Associates

Scale
Vertical 1:250
Horizontal 1:250



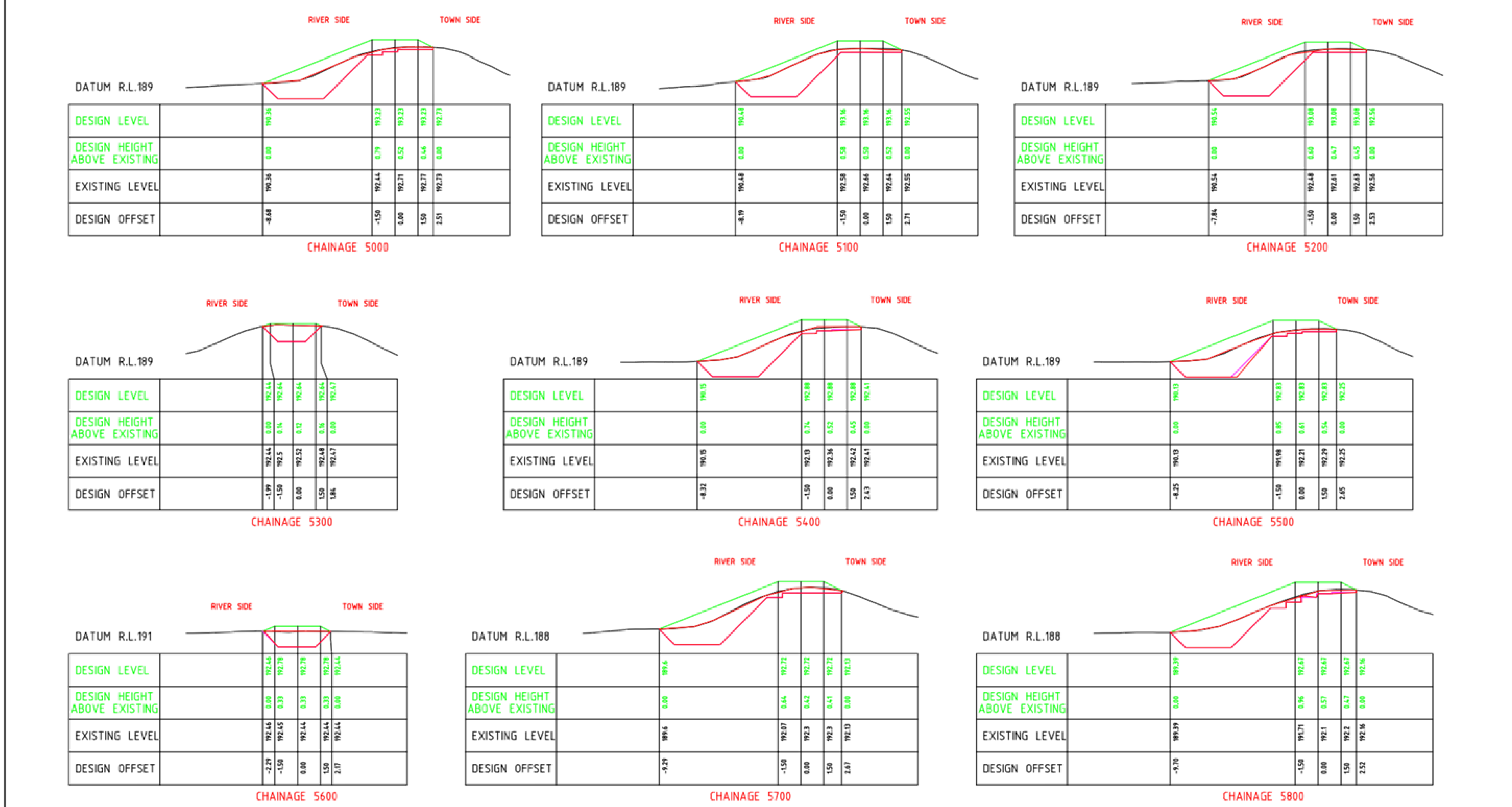
Lyall & Associates

Scale
Vertical 1:250
Horizontal 1:250

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 6 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS



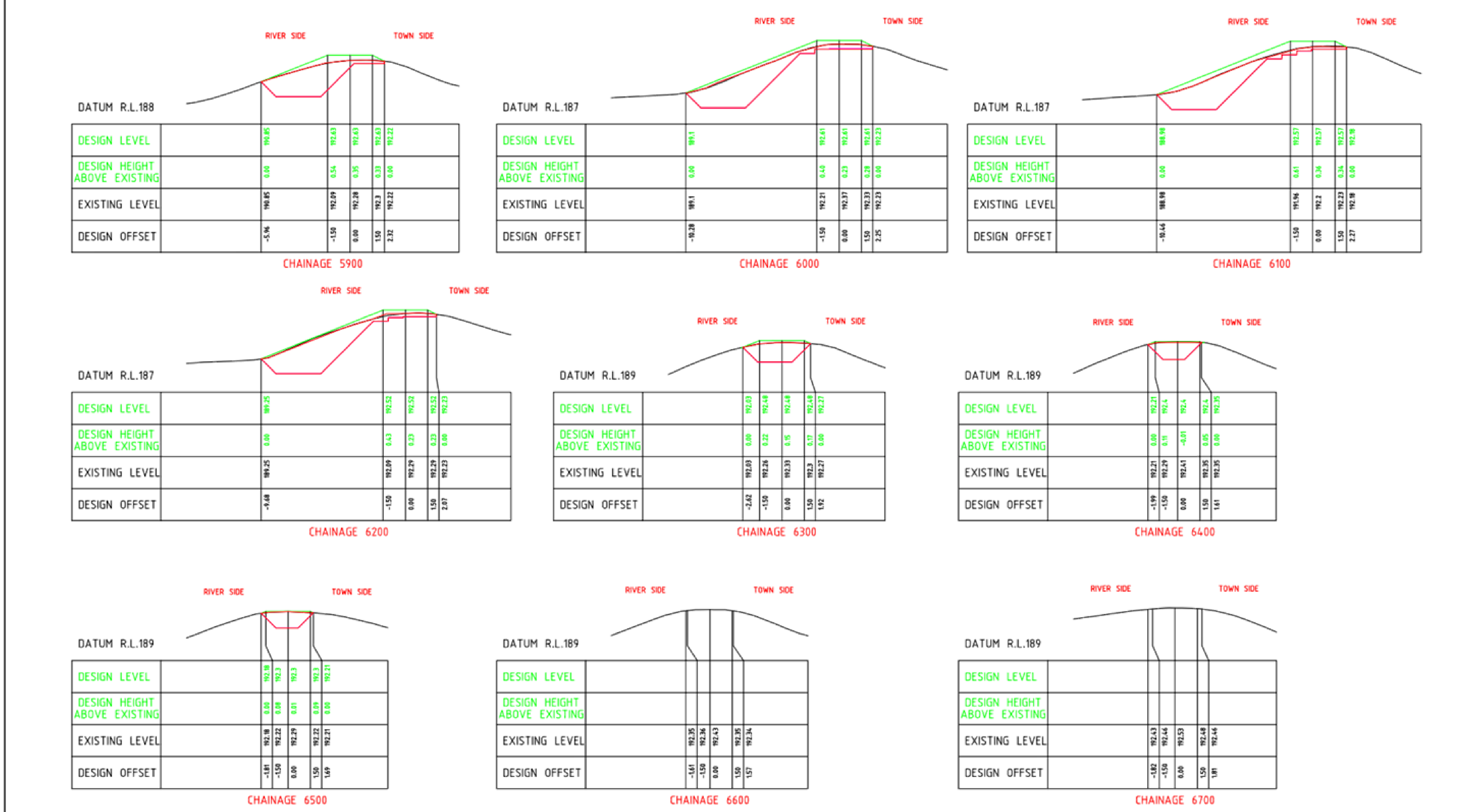
Lyall & Associates

Scale
Vertical 1:250
Horizontal 1:250

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 7 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS



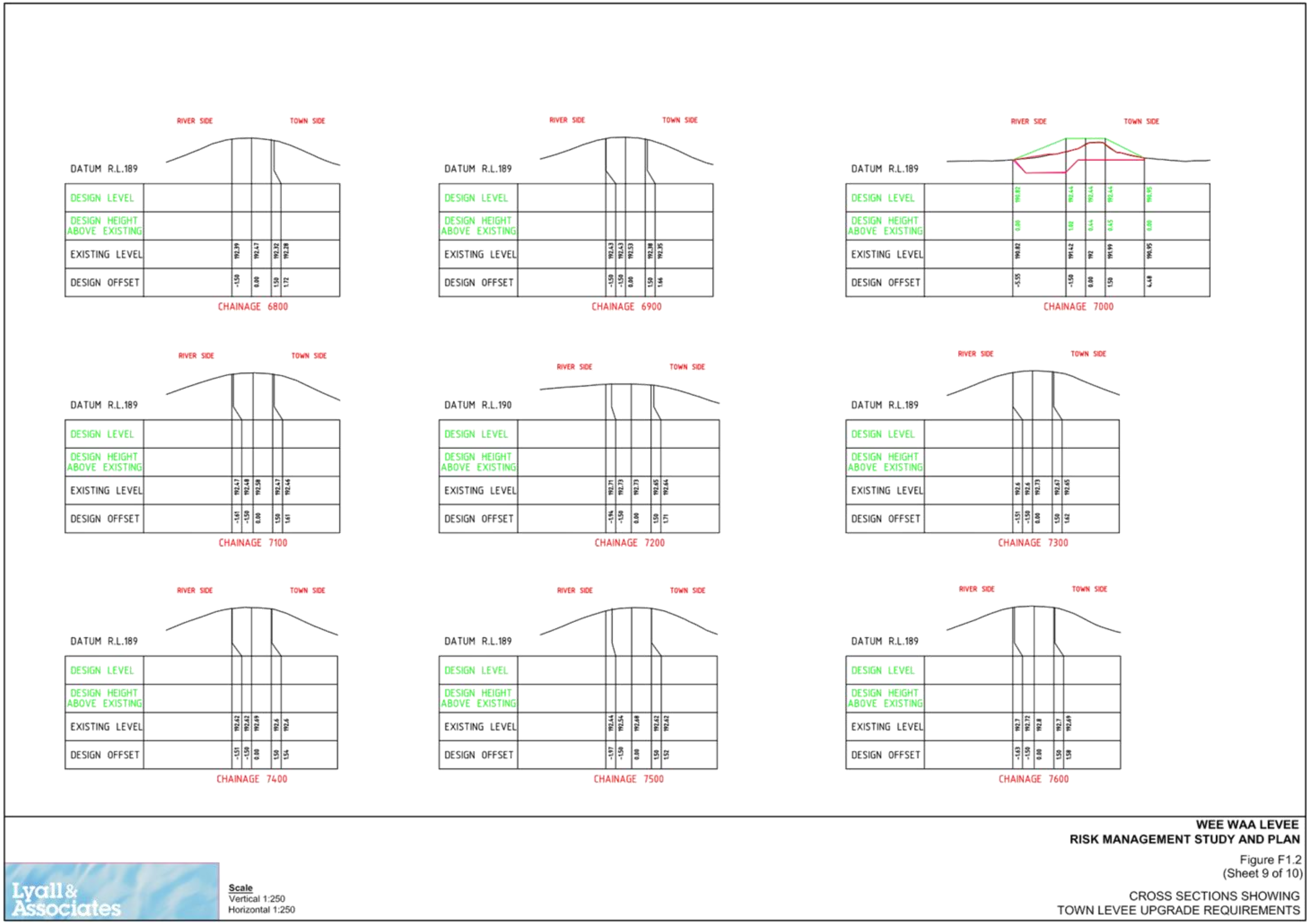
Lyall & Associates

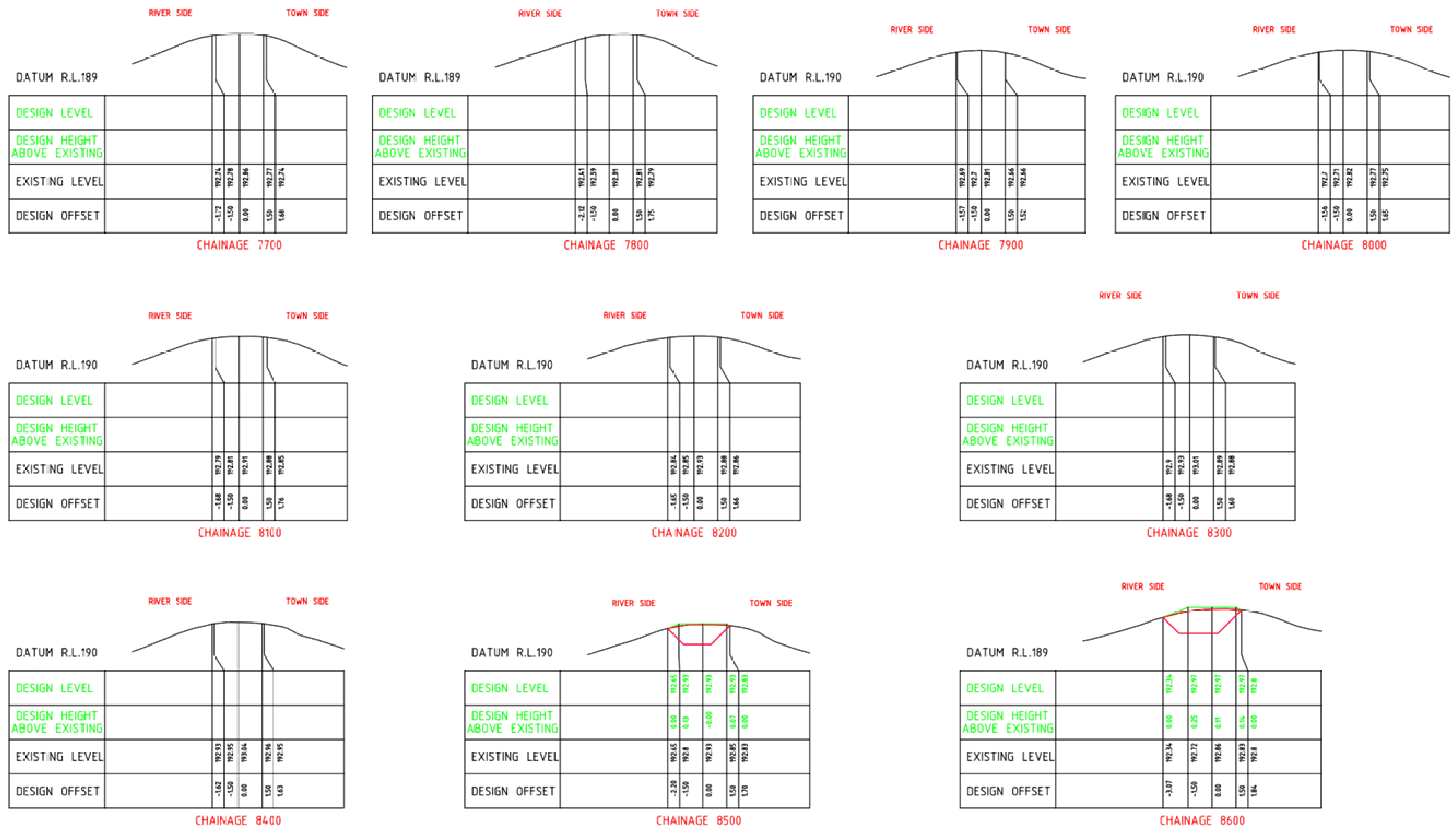
Scale
Vertical 1:250
Horizontal 1:250

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 8 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS


RIVER SIDE
TOWN SIDE
DATUM R.L.189
DESIGN LEVEL
DESIGN HEIGHT ABOVE EXISTING
EXISTING LEVEL
DESIGN OFFSET
CHAINAGE 6800
CHAINAGE 6900
CHAINAGE 7000
CHAINAGE 7100
DATUM R.L.190
CHAINAGE 7200
CHAINAGE 7300
CHAINAGE 7400
CHAINAGE 7500
CHAINAGE 7600
Lyall & Associates
Scale
Vertical 1:250
Horizontal 1:250
WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN
Figure F1.2
(Sheet 9 of 10)
CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS



Scale
Vertical 1:250
Horizontal 1:250

WEE WAA LEVEE
RISK MANAGEMENT STUDY AND PLAN

Figure F1.2
(Sheet 10 of 10)

CROSS SECTIONS SHOWING
TOWN LEVEE UPGRADE REQUIREMENTS

SUMMARY OF THE NARRABRI SHIRE FLOODPLAIN RISK MANAGEMENT COMMITTEE MEETING HELD IN THE NARRABRI SHIRE COMMITTEE ROOM, 46-48 MAITLAND STREET, NARRABRI, ON WEDNESDAY, 12 FEBRUARY 2020.

The meeting was opened at 11:35am by CS.

ATTENDANCE:
Cara Stoltenberg – Council Representative (Strategic and Major Projects Planner)
Daniel Boyce – Council Representative (Executive Manager Planning and Environment)
Cr. Robert Kneale - Narrabri Shire Councillor
Tony Battam – SES Representative
Conrad Bolton – Resident Representative
Jim Purcell – Resident Representative

APOLOGIES:
Heath Stimson – SES Representative
Jono Phelps – Resident Representative
Craig Ronan – SES Representative
Frank Hadley – Resident Representative
Ivan Rivas - DPIE Representative

DECLARATION OF PECUNIARY AND NON-PECUNIARY INTERESTS
CB requested that "Declaration of Pecuniary and Non- Pecuniary Interests" be included at the start of the meetings from now on similarly to how the Council meeting is run. It was agreed that this would be included from now on. CB declared a pecuniary interest in discussing the Wee Waa Levee Risk Management Plan and Study due to the recommendation to re-zone R5 Large Lot Residential land to the south east of Wee Waa not to permit future residential or commercial type development, as CB thought land he owned was in this area. However, it was confirmed that the recommendation was for land outside the levee, not inside the levee, which is land that CB does not own and so the declaration was withdrawn.

CONFIRMATION OF MINUTES FROM 9 OCTOBER 2019
A motion was put forward to move the minutes of the 9 October 2019 meeting without changes.

Moved:	**Conrad Bolton**	**Seconded:**	**Cr Kneale**	**Carried**

BOGGABRI FLOOD STUDY
CS advised that WRM Water + Environment were currently liaising with Fyfe Surveying regarding the survey of properties within Boggabri. 66 properties are affected by the 1% flood and 341 additional properties are affected by the PMF flood. It was agreed to have all 407 properties surveyed to ensure we have all the available data for input into WaterRide for the purposes of generating flood information for each property.

A motion was put forward to survey all 407 properties.

Moved:	**Daniel Boyce**	**Seconded:**	**Cr Kneale**	**Carried**

WEE WAA LEVEE RISK MANAGEMENT PLAN AND STUDY
CS advised that since the 30 July 2019 Committee meeting the draft Wee Waa Levee Risk Management Plan and Study was edited as per the Committee's recommendations regarding the recommendations in the study be changed to say that "Council consider" rather than be bound by doing. The document was then put on public exhibition for 28 days in which one submission was received from the Department of Planning, Industry & Environment (DPIE). DPIE's comments were fundamentally to do

with changing reference throughout the document to reflect the Department's new name, and advice to Council that the recommendation to rezone the R5 large Lot residential area to the south east of Wee Waa can potentially create issues with the owners of the subject land. The submission concluded that instead of downzoning, consideration could be given to ensuring any potential lot configuration / sizing during subdivision within the subject R5 area is compatible with the flood risk through appropriate development controls.

A motion was put forward to recommend that Narrabri Shire Council adopt the final version of the Wee Waa Levee Risk Management Plan and Study completed by Lyall and Associates and dated December 2019. It was further recommended that if a benefit/cost analysis is required to apply for funding for the Feasibility Study for the next stage of the Wee Waa Levee Flood Investigation then it should be expanded to include the social impacts as well as financial.

Moved: **Jim Purcell** **Seconded:** **Conrad Bolton** **Carried**

Actions;

1. *CS to provide SES with the flood data from this study when everything is received, and the project acquitted.*
2. *TB to bring updated SES evacuation brochures to the Committee for discussion when drafted, before finalisation.*
3. *CB to obtain a copy of the current Wee Waa Evacuation schedule from the retirement home in Wee Waa and bring it to the next meeting.*
4. *CS to obtain a copy (from Jono) of a study that had previously been done in 97 which looked at surrounding infrastructure outside the levee and its impact on flooding within the levee at Wee Waa.*
5. *CS to follow-up with DPIE's grants unit when funding is available for the Feasibility Study.*

NARRABRI RISK MANAGEMENT PLAN AND STUDY

CS advised that the "Narrabri Floodplain Risk Management Study and Plan – Volume 1: Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully", dated 13 June 2019 needed to be adopted by Council prior to the draft Narrabri Risk Management Plan and Study being finalized. The Supplementary study was an update of the 2016 flood study completed by WRM Water + Environment and had been discussed at last year's July committee meeting. It then formed part of the exhibition documents for 2 months last year with no submissions being received, however it was never adopted by Council.

A motion was put forward to recommend that Council adopt the Narrabri Floodplain Risk Management Study and Plan – Volume 1: Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully, dated 13 June 2019.

Moved: **Cara Stoltenberg** **Seconded:** **Tony Battam** **Carried**

Structural mitigation options currently being considered by WRM Water + Environment were discussed and include the following:

- Voluntary purchase.
- House-raising.
- Narrabri flood bypass channel.
- Narrabri North Industrial Estate proposed levee/channel upgrades.
- Flash flooding of the eastern parts of the 'Narrabri Town South'
- Cleaning out debris from Namoi River/Narrabri Creek.
- The removal of the wall at the northern end of Narrabri West Lake.
- Namoi River 5% AEP levee and channel upgrades.

It was agreed that all the above measures should be included in the final Narrabri Floodplain Risk Management Plan and Study. However, with regards to the Narrabri flood bypass channel; the return to the river at the northern end of the proposed channel should be further north than it is currently proposed in the map below (near the model aero club).

CS advised that the flood risk management recommendations in the extract of the Draft Narrabri Floodplain Management Study prepared by WRM Water + Environment needed to be discussed, however due to the extended timeframe of the current meeting it was agreed to defer this discussion to the next meeting.

Actions;

1. *CS to advise WRM Water + Environment of the requested change to the proposed bypass channel.*
2. *CS to table the flood risk management recommendations in the extract of the Draft Narrabri Floodplain Management Study prepared by WRM Water + Environment for discussion at the next meeting.*

The next meeting was scheduled for Wednesday 11th March 2020 at 11:30am at Council's Administration Building, Maitland Street, Narrabri.

There being no further business the meeting closed at 2:44pm.

wrm
water + environment

Narrabri Floodplain Risk Management Study and Plan

Volume I: Supplementary Flood Study - Namoi River, Mulgate Creek and Long Gully

Narrabri Shire Council

0328-08-G, 13 Jun 2019

Report Title	Narrabri Floodplain Risk Management Study and Plan: Volume I: Supplementary Flood Study - Namoi River, Mulgate Creek and Long Gully
Client	Narrabri Shire Council 45-48 Maitland St, Narrabri, NSW, 2390
Report Number	0328-08-G

Revision Number	Report Date	Report Author	Reviewer
DRAFT	13 Jun 2019	HG	GR

For and on behalf of WRM Water & Environment Pty Ltd
Level 9, 135 Wickham Tce, Spring Hill
PO Box 10703 Brisbane Adelaide St Qld 4000
Tel 07 3225 0200

Greg Roads
Director

Acknowledgements and limitations

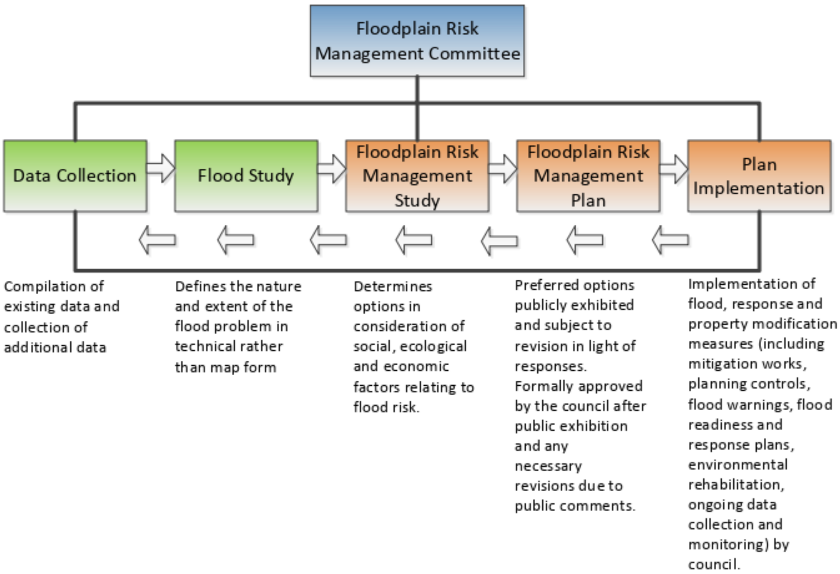
This project was prepared with financial assistance from the NSW Government's Floodplain Management Program. This document does not necessarily represent the opinions of the NSW Government or the Office of Environment and Heritage.

While all due effort has been made to ensure the reliability of flood model results, all models have limitations (Ball et al., 2019). The accuracy of any model is a function of the quality of the data used in the model development including topographical data, drainage structure data and calibration data. Modelling is by nature a simplification of very complex systems and results of flood model simulations should be considered as a best estimate only. There is, therefore, an unknown level of uncertainty associated with all model results that should be considered when utilising the outputs from this study.

Foreword

The NSW Government's Flood Prone Land Policy provides a framework for managing development on the floodplain. The primary objective of the policy is to develop sustainable strategies for managing human occupation and use of the floodplain using risk management principles. 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 NSW Government's Floodplain Development Manual (2005) (the Manual) has been prepared to support the NSW Government's Flood Prone Land Policy. The Manual provides council's with a framework for implementing the policy to achieve the policies primary objective. The framework is shown below.



The Narrabri Flood Study constituted the first stage of the Floodplain Risk Management process and assessed the risk of regional flooding from the Namoi River and local flooding from its tributaries, Mulgate Creek and Long Gully. It was prepared by consultants WRM Water & Environment Pty Ltd and the Narrabri Shire Floodplain Risk Management Committee for Narrabri Shire Council.

Modelling conducted for the Narrabri Flood Study was updated as part of the Floodplain Risk Management process, with this report presenting the results of the updated Flood Study modelling. The results presented herein supersede the Narrabri Flood Study and will be used throughout the remainder of the Floodplain Risk Management process.

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1 Introduction

1.1 OVERVIEW

The township of Narrabri is located on the Namoi River floodplain and is drained by a number of smaller tributaries including Mulgate Creek, Horsearm Creek and Long Gully. In the past Narrabri has experienced above floor flooding from each of these sources on a regular basis posing a significant risk to property and life. The location of Narrabri and the drainage characteristics of the area of interest are shown in Figure 1.1.

There have been several studies prepared to define the flood risk from the Namoi River but minimal investigations have been undertaken to define the flood risk from its minor tributaries Mulgate Creek and Long Gully. The most recent of these studies was the Narrabri Flood Study, completed by WRM Water & Environment Pty Ltd (WRM) in December 2016 which addressed flooding from both regional (Namoi River) and local (Mulgate Creek and Long Gully) sources. This report is referred to as the 2016 flood study herein.

WRM have been commissioned by Narrabri Shire Council (NSC), with funding assistance administered by the NSW Office of Environment and Heritage (OEH), to prepare a Floodplain Risk Management Study and Plan (FRMP), which in conjunction with the previously prepared flood study will continue the floodplain risk management process. This Supplementary Flood Study updates the flood modelling conducted during the FRMP process to bring the modelling up to date with the latest revision of Australian Rainfall and Runoff (AR&R) (Ball et al., 2019) while utilising updated versions of modelling software.

1.2 ADOPTED APPROACH

The approach of this Supplementary Flood Study is consistent with the previous 2016 flood study (WRM, 2016), hence only the changes made since the completion of the 2016 flood study are outlined in this report. As such, this report should be read in conjunction with the 2016 flood study. However the results presented in this report supersedes all results presented in the 2016 flood study.

1.3 REPORT STRUCTURE

The report is structured as follows:

- Section 2 describes the configuration of the XP-RAFTS hydrological model;
- Section 3 describes the configuration of the MIKE-FLOOD hydraulic model;
- Section 4 outlines the model calibration against five historical flood events;
- Section 5 presents the design discharge estimates for both local and regional flooding;
- Section 6 presents the results from the design flood modelling and the sensitivity analysis undertaken, as well as a description of the local flooding behaviour;
- Section 7 describes the hydraulic hazard category analysis and provides the provisional hydraulic hazard categories proposed for the study area;
- Section 8 provides a summary of the findings for the study;
- Section 9 is a list of references; and
- Section 10 is a glossary of technical terms used in this report.

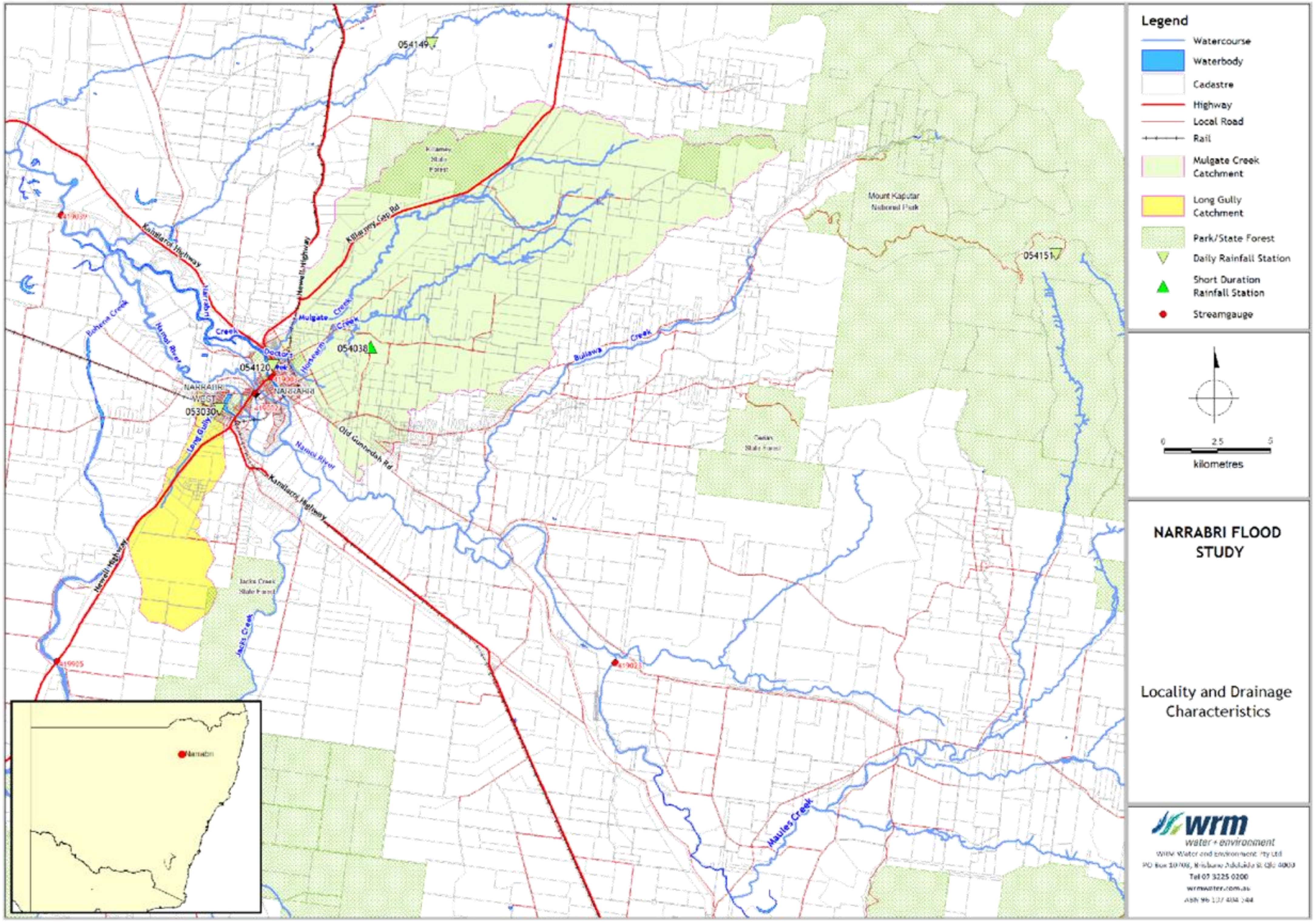


Figure 1.1 - Narrabri locality and drainage characteristics

2 Hydrological modelling (local catchments)

2.1 CHANGES FROM THE 2016 FLOOD STUDY

The XP-RAFTS hydrologic model developed for the 2016 flood study was updated to the latest version of the software and updated to incorporate new design rainfalls and methodology from AR&R (Ball et al., 2019). The model configuration and adopted model parameters have not been changed.

3 Hydraulic model development

3.1 CHANGES FROM THE 2016 FLOOD STUDY

The MIKE-FLOOD hydraulic model developed for the 2016 flood study was updated to a more recent version of the software. Minor changes were also made to the adopted hydraulic resistance parameters and hydraulic structure representation to improve model calibration and improve model stability.

3.2 MODEL CONFIGURATION

3.2.1 MIKE-21FM mesh properties

The MIKE-21 module is the two dimensional component of the hydrodynamic model. Figure 3.1 shows the extent of the Narrabri MIKE-21 model. The flexible mesh version of MIKE-21 (MIKE-21FM) uses triangular and/or trapezoidal elements to create a computational mesh on which the element-centred two-dimensional shallow water equations are solved. An adaptive time step is used by the computational engine to maintain simulation stability.

Any number of regions can be digitised within the model domain. Each distinct region can have a unique set of mesh properties that includes element type, maximum element area, smallest allowable angle and maximum number of nodes. The ability to subdivide the model domain allows greater topographic definition to be implemented in critical study areas, while limiting the computational resources being used in non-critical areas. Mesh orientation can also be controlled by digitising points and lines within the model domain.

For this study, important flow locations, structures, topographical features, watercourses, water bodies, roads, railways and the 1D structure alignments were digitised in a GIS package to define the mesh orientation at these hydraulically significant locations. MIKE-21FM was then used to generate and refine a computational mesh.

Table 3.1 details the six sets of mesh properties that were used to create the flexible mesh. The spatial locations of the six mesh regions are shown in Figure 3.2.

Table 3.1 - Mesh generation inputs

Region	Maximum Element Area (m^2)	Smallest Allowable Angle	Maximum Number of Nodes
Important flow path	75	26°	6,000,000
Developed area	100		
Secondary flow path	200		
General floodplain / rural land	400		
Intensive cropping	600		
Non floodplain	1200		

The adopted mesh parameters were aimed at optimising run times while providing sufficient model definition in critical areas flow areas. The following is of note:

- The non-floodplain area is not inundated during flooding events (i.e. the hill slope areas on the fringe of the hydraulic model);
- The intensive cropping regions have been applied to land found behind levee banks and earthen bunds and are likely to be laser levelled. The relatively constant topography requires little model definition to fully capture flow behaviour;

- The general floodplain / rural land regions are modelled at an element size sufficient to simulate the flow distribution while not detracting from model performance and run times;
- The secondary flow path regions have been applied around breakouts from the one-dimensional representation of Narrabri Creek to the Namoi River. The smaller element being applied to these regions have been used to simulate the terrain of flood runners that break out from the main channel;
- The developed areas of Narrabri have been modelled at 100 m^2 element size to capture sufficient detail on the flow obstructions, as well as capture the varying hydraulic resistance; and
- The important flow path regions have been applied to ill-defined channels as well as some of the smaller flow paths to adequately capture channel capacity.

The end result was a flexible mesh of 1,015,397 elements covering an area of 22,820 ha. A single coupled MIKE-FLOOD model was created that covers the combined study areas for both the local and regional flooding investigations, hence large portions of the model remain dry when simulating only local or only regional flooding.

Each mesh node was assigned an elevation using the project DTM. Manual changes to the element elevations were made to match the invert levels of the 1D and 2D domains at the coupling locations. Some manual variation of mesh topography was also undertaken to improve the definition of the crest levels of levees and bunds. Survey of the levees and bunds were not available for the study. It was also assumed that the levees/bunds do not fail during flood events.

A single hydraulic model mesh based on the project DTM (derived from LiDAR data captured in 2014) was used for all calibration and design simulations. A review of model calibration showed that historical topographical changes over the past 70 years have been minor and would not significantly change the overall distribution of flow across the floodplain. Any impacts on flooding of recent developments would occur in the local area only.

3.2.2 Hydraulic resistance

The model uses Manning's 'n' values to represent hydraulic resistance (notionally channel or floodplain roughness). Discrete regions of continuous vegetation types and land uses were mapped, and appropriate roughness values assigned to each region. Vegetation and land use mapping were based on ortho-photograph imagery obtained from SixMaps online mapping tool provided by NSW Land and Property Information as well as the project DTM. The Manning's 'n' values were selected during model calibration and were applied to all model scenarios. Table 3.2 shows the adopted Manning's 'n' values used in the model and Figure 3.3 shows the locations of the Manning's 'n' regions.

Table 3.2 - Manning's roughness parameters

Region	Manning's 'n' Value
Floodplain	0.080
Flood channel	0.045
Open water/airport	0.034
Buildings	0.300
Road/rail	0.025

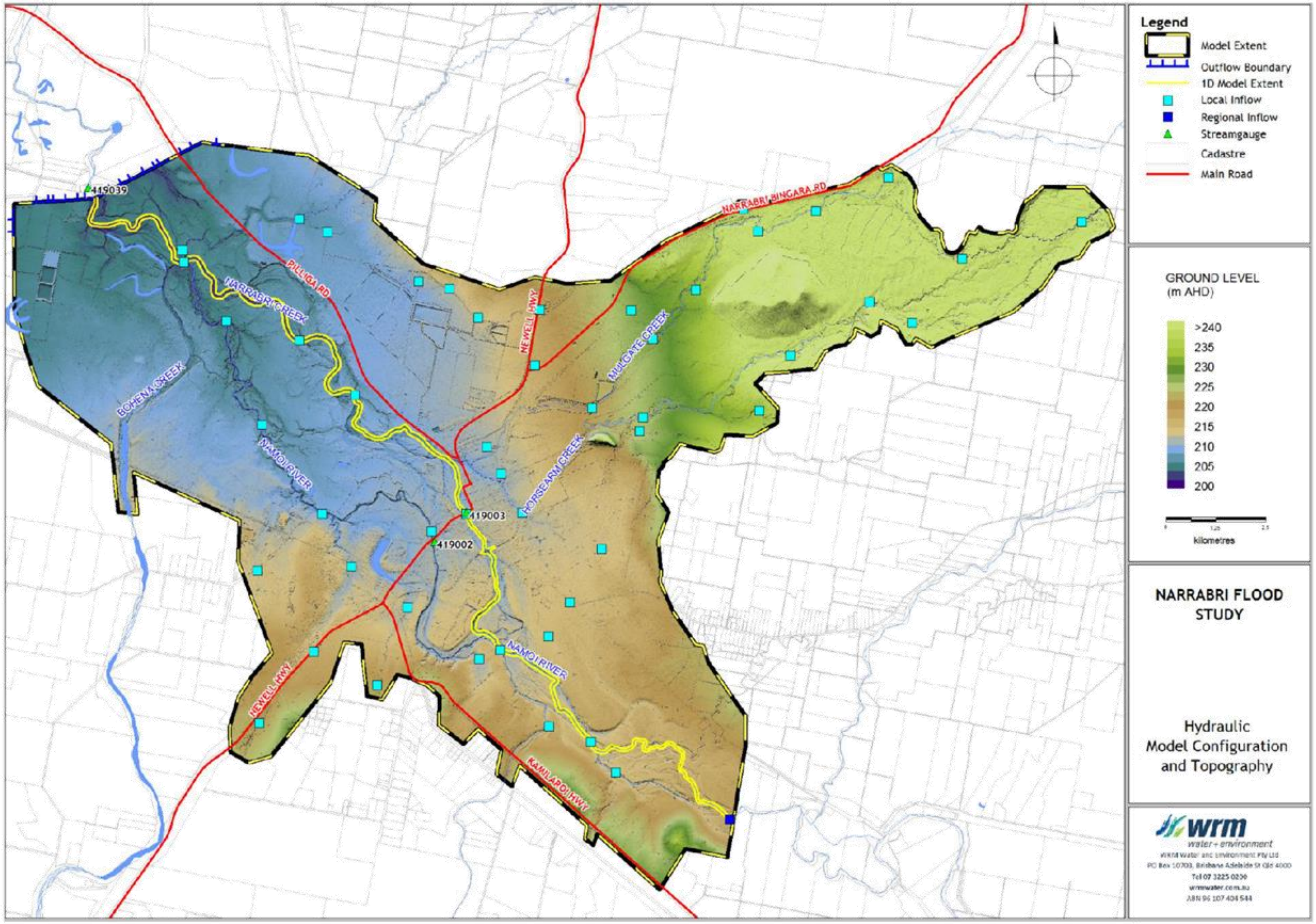


Figure 3.1 - MIKE-FLOOD model configuration and topography

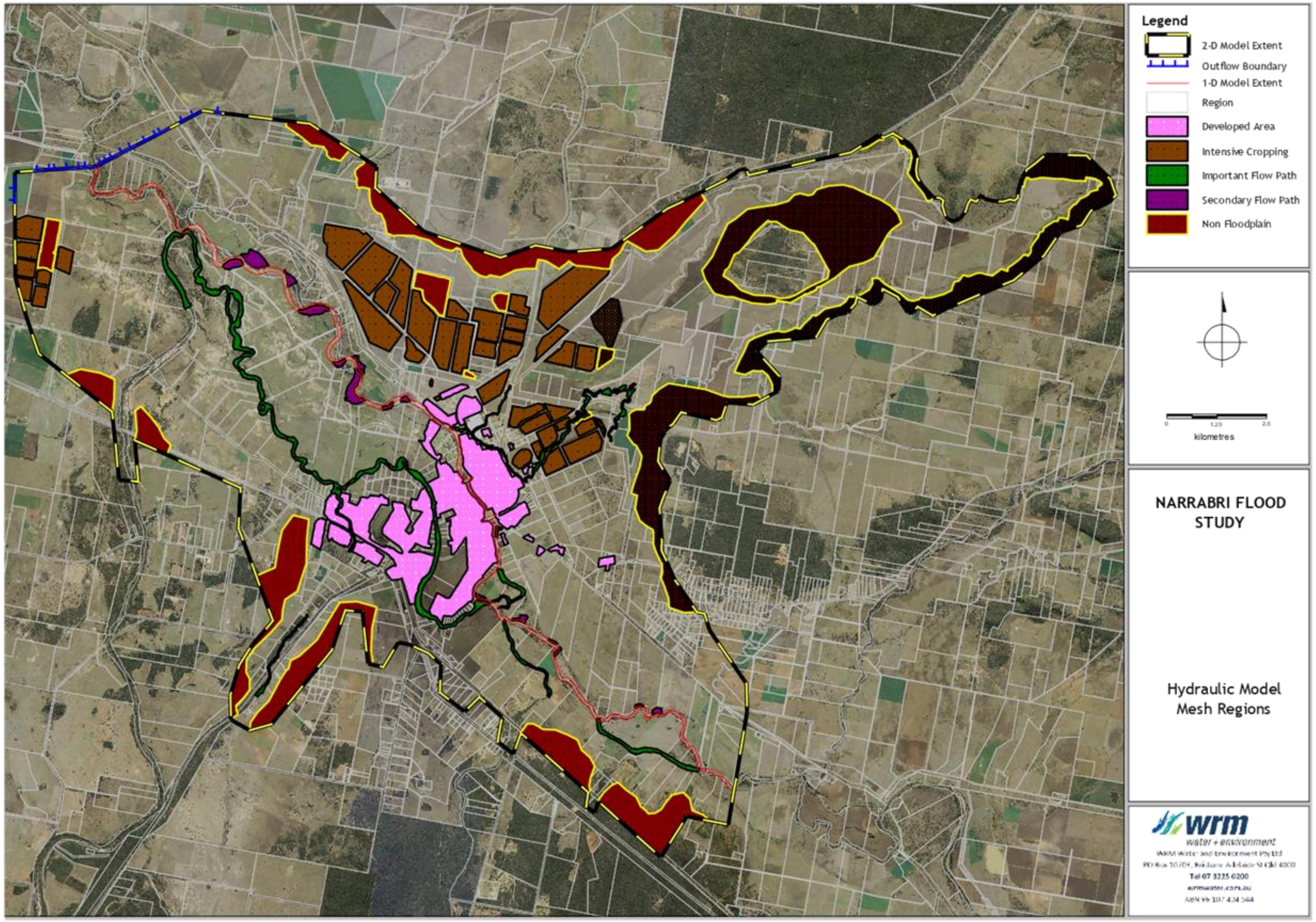


Figure 3.2 - MIKE-21FM mesh regions

3.2.3 Model boundaries

Figure 3.1 shows the locations of the inflow and outflow boundaries of the hydraulic model. A single upstream inflow was used to represent the flows from the Namoi River for regional modelling. All other inflows were associated with local catchment modelling of Mulgate Creek and Long Gully.

A total of 15 outflow boundaries were used at the downstream end of the model. The 14 outflow boundaries in the 2D domain were specified as Q-H rating curves derived using separate HEC-RAS models. The 1D outflow boundary was also specified as a Q-H rating curve calculated by MIKE-11. The outflow boundary Q-H rating curve was verified against the Namoi River at Mollee stream gauge (GS419039) rating curve, which is located approximately 300 m downstream of the boundary. Gauging records show that the DPI Water rating curve for this gauge is a good representation of flows up to around 1,500 m^3/s. Further discussion of the rating curve of this gauge is given in the WRM Flood Study (2016).

3.2.4 Model parameters

A number of model parameters were varied from default values to aid simulation stability and keep run times manageable. Parameters that were varied are shown in Table 3.3.

Table 3.3 - Adopted MIKE modelling parameters

Model Parameter	Adopted Value
MIKE Software Version	2017 Service Pack 2
MIKE-FLOOD	
Momentum conservation through couples	Yes
Standard link smoothing factor	0.28 - 0.30
MIKE-21FM	
Courant-Friedrichs-Levy (CFL) number	0.8
Maximum Timestep	2.0 s
Computation	Hydrodynamic - inland flooding
Time and Space Discretisation	Higher order
Flooding and Drying	Advanced flood and dry (floodplain)
Drying depth	0.005 m
Flooding depth	0.025 m
Wetting depth	0.05 m
Eddy viscosity formulation	Smagorinsky
Smagorinsky coefficient	0.28 (constant)
Computing approach	Single Precision GPU
MIKE-11	
Solution Engine	MIKE-11
FroudeMax	1
FroudeExp	2
Delta	0.85
MaxIterSteady	120

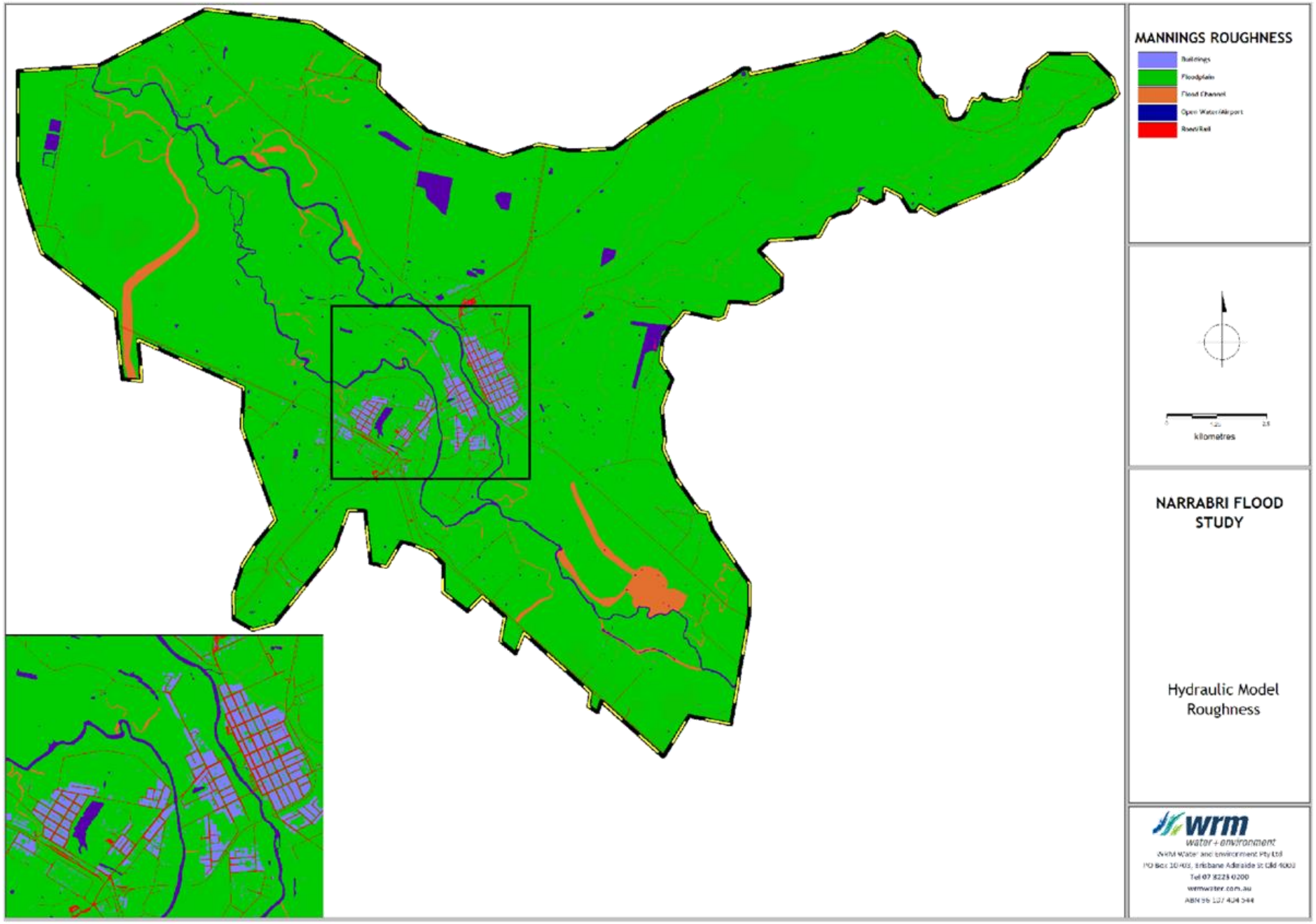


Figure 3.3 - Manning's roughness distribution

3.2.5 Bridge, culvert and levee structures

The bridge and culvert structures were modelled within the 1D (MIKE-11) and 2D (MIKE-21FM) numerical schemes. Details of the bridge and culvert structures included in the study area are given in Table 3.4. The remaining hydraulic structures within the study area were deemed to be too small to affect flood levels or the distribution of flow. Those structures that weren't explicitly modelled in MIKE-11 or MIKE-21FM were handled in the two-dimensional mesh by lowering element topography (effectively leaving a gap to maintain the flow path).

A number of earthen levees and bunds were defined within the 2D domain using MIKE-21FMs dike regime. The dike regime creates a string of nodes along the crest of the levee/bund so that its hydraulic properties can be properly represented. In addition to the earthen structures, the road and rail embankments were also modelled as dikes to improve the definition of the crest levels of these structures. The concrete wall weir at the northern end of Narrabri Lake was also modelled as a dike in the 2D domain.

Table 3.4 - Culvert and bridge details

MIKE Name	Road/Rail Crossing	Dimension[a]	U/S Invert (mAHD)	D/S invert (mAHD)	Length (m)	Source	Representation
K Hwy 01	Kamilaroi Hwy	1 RCP 0.525	210.05	210.04	13.50	WRM Inspection	MIKE-21FM culvert
K Hwy 05	Kamilaroi Hwy	4 box 0.9x1.8	209.09	209.08	9.60	RMS Structure Plan	MIKE-11 culvert
K Hwy 25	Kamilaroi Hwy	4 box 1.2x2.4	213.52	213.51	9.60	RMS Structure Plan	MIKE-21FM culvert
Misc 03	Stoney Creek Rd	3 box 1.8x2.75	220.10	220.09	9.60	NSC Spreadsheet	MIKE-21FM culvert
Misc 14	Old Cemetery Rd	3 span	208.23	209.31	5.20	Detailed Survey	MIKE-21FM culvert
Misc 19	Namoi St	3 box 1.8x2.44	207.45	207.44	7.00	NSC Spreadsheet	MIKE-21FM culvert
Misc 22	Saleyards Ln	2 box 0.6x0.4	211.60	211.59	10.00	WRM Inspection	MIKE-11 culvert
Misc 36	Old Turrawan Rd	3 box 1.3x0.9	212.20	212.19	10.00	WRM Inspection	MIKE-21FM culvert
Misc 40	Violet St	4 span	200.80	200.70	11.00	NSC Structure Plan	MIKE-11 bridge
Misc 45	Ugoa St	3 box 1.8x0.9	209.85	209.84	10.00	WRM Inspection	MIKE-21FM culvert
Misc 53	Yarrie Lake Rd	2 box 2.1x2.1	208.58	208.51	7.96	Detailed Survey	MIKE-11 culvert
Misc 54	Mooloobar St	2 span	210.49	210.27	14.20	Detailed Survey	MIKE-21FM culvert
Misc 80	Gould Street	4 box 1.2x0.75	211.21	211.20	10.00	WRM Inspection	MIKE-11 culvert
Misc 86	Ugoa Street	3 box 1.8x0.9	209.9	209.89	10.00	WRM Inspection	MIKE-21FM culvert
N Hwy 01	Newell Hwy	4 box 2.4x1.2 2 box 2.4x1.35	217.55	217.54	16.00	WRM Inspection	MIKE-11 culvert
N Hwy 03	Newell Hwy	1 span	215.58	215.57	10.20	RMS Structure Plan	MIKE-21FM culvert
N Hwy 06	Newell Hwy	1 RCP 1.05	211.05	211.04	25.00	WRM Inspection	MIKE-11 culvert
N Hwy 07	Newell Hwy	2 box 2.1x2.1	210.00	209.99	28.50	-	MIKE-11 culvert
N Hwy 08	Newell Hwy	5 span	206.00	206.00	9.4	RMS Structure Plan	MIKE-11 culvert
N Hwy 09	Newell Hwy	2 box 2.1x2.1	210.20	210.19	19.00	-	MIKE-21FM culvert
N Hwy 10	Newell Hwy	7 span	201.54	201.89	13.2	RMS Structure Plan	MIKE-11 bridge
N Hwy 12	Newell Hwy	5 span	205.428	205.428	13.2	RMS Structure Plan	MIKE-11 culvert
N Hwy 13	Newell Hwy	9 span	210.88	210.88	18.00	RMS Structure Plan	MIKE-21FM culvert
N Hwy 14	Newell Hwy	4 span	210.13	210.13	13.85	RMS Structure Plan	MIKE-21FM culvert
N Hwy 29	Newell Hwy	2 box 1.2x0.6	218.90	218.89	17.00	WRM Inspection	MIKE-21FM culvert
N Hwy 30	Newell Hwy	4 box 3.2x1.8	218.45	218.44	17.50	WRM Inspection	MIKE-21FM culvert
Rail 01	Werris Creek Mungindi Railway	30 CMP 0.6	217.57	217.56	10.00	WRM Inspection	MIKE-11 culvert
Rail 02	Werris Creek Mungindi Railway	1 CMP 1.2	217.55	217.54	7.50	WRM Inspection	MIKE-11 culvert
Rail 05	Werris Creek Mungindi Railway	23 box 0.9x3.8	214.62	214.61	5.00	URS Model	MIKE-11 culvert
Rail 06	Werris Creek Mungindi Railway	9 span	208.53	208.69	2.60	Detailed Survey	MIKE-21FM culvert
Rail 07	Werris Creek Mungindi Railway	12 span	202.03	202.07	4.50	NSC Structure Plan	MIKE-11 bridge
Rail 08	Werris Creek Mungindi Railway	15 box 2.74x4.98	212.31	212.32	8.00	Detailed Survey	MIKE-21FM culvert
Rail 10	Werris Creek Mungindi Railway	28 span	205.64	205.64	5.50	NSC Structure Plan	MIKE-11 bridge
Rail 12	Werris Creek Mungindi Railway	4 box 2.56x4.8	210.90	210.88	4.42	Detailed Survey	MIKE-21FM culvert
Rail 15	Narrabri West Walgett Railway	5 CMP 2.1	210.88	210.87	7.20	WRM Inspection	MIKE-21FM culvert
Rail 24	Werris Creek Mungindi Railway	2 box 1.95x2.95	212.47	212.23	6.70	Detailed Survey	MIKE-21FM culvert
Rail 99	Narrabri West Walgett Railway	1 RCP 1.5	211.56	211.17	26.00	-	MIKE-21FM culvert

[a] - RCP = reinforced concrete pipe, box = box culvert, 3 span = 3 span bridge, CMP = corrugated metal pipe

4 Model calibration

4.1 OVERVIEW

The MIKE-FLOOD model was calibrated to the available data for:

- three regional (Namoi River) flood events:
  - February 1955;
  - February 1971; and
  - July 1998.
- two local (Mulgate Creek/Long Gully) flood events:
  - December 2004; and
  - February 2012.

No major flood events have occurred since 2016, hence the calibration events adopted for the 2016 flood study were re-run.

The purpose of model calibration was to match as close as possible the predicted and recorded flood levels across the floodplain in Narrabri for all the historical events using a single set of hydraulic model parameters. No changes were made to the hydrology model or the regional discharge estimates for the historical events.

4.2 REGIONAL FLOODING

4.2.1 February 1955 event

The February 1955 flood event was calibrated to the peak flood level data obtained from the NSW Department of Environment and Heritage (NSW OEH). The 1955 peak flood level data originated from a survey of floodmarks completed in April 1980.

Figure A.1 in Appendix A shows the predicted 1955 flood depths, levels and extent. Comparisons of the recorded and predicted peak flood levels at the available stream gauges and at the surveyed flood marks are also shown.

The overall calibration of the model to the 1955 flood marks is good with predicted peak flood levels in reasonable agreement with the recorded values. Of the 46 surveyed peak flood level marks available, the median difference is 0.00 m with 80th percentile values between 0.14 m low and 0.10 m high. There are two levels along Eathers Creek near the Newell Highway where the model predictions are 0.62 m and 0.36 m low. There are also two levels immediately downstream of Narrabri Township (along the Kamilaroi Highway and Lagoon Creek) that are 0.30 m and 0.49 m high. It was not possible to calibrate the model to these levels without significantly impacting on the calibration at the other points.

Overall a good calibration has been achieved for the February 1955 flood.

4.2.2 February 1971 event

The February 1971 flood event was calibrated to the surveyed peak flood level data obtained from the NSW OEH. The 1971 peak flood level data also originated from a survey of floodmarks completed in April 1980.

Figure A.2 in Appendix A shows the predicted 1971 flood depths, levels and extent. Comparisons of the recorded and predicted peak flood levels at the available stream gauges and at the surveyed flood marks are also shown.

The overall calibration of the model to the 1971 flood is good. Of the 58 surveyed peak flood level marks available, the median difference is 0.05 m with 80th percentile values between 0.19 m low and 0.07 m high.

4.2.3 July 1998 event

The July 1998 flood event was calibrated to the recorded water levels at the two stream gauges together with the flood extent shown in the aerial imagery of this event obtained from Narrabri Shire Council. There was no metadata supplied with the aerial photograph so it is uncertain whether the photograph captured the peak of the flood event.

Figure A.3 in Appendix A shows the predicted 1998 flood depths, levels and extent and Figure A.4 in Appendix A compares the predicted and actual flood extents given in the aerial imagery. Figure A.3 also shows a comparison of the recorded and predicted peak flood levels at the Narrabri Creek stream gauge is also shown. The recorded and predicted peak flood level at the Narrabri gauge is within 0.01 m for this event.

The flood extent comparison map in Figure A.4 in Appendix A shows that the model accurately predicts the flood extent for this event with the exception of the Francis Street industrial area. The hydrodynamic model underestimates the flood extent in this area. It appears that some filling has occurred between 1998 and the capture of the LiDAR data in 2014, which prevents this area being inundated during this event. Note that predicted flood levels would only have to be about 0.1 m higher to inundate this area as shown in the aerial photograph. Overall a good calibration has been achieved for the July 1998 flood.

4.3 LOCAL FLOODING

4.3.1 December 2004 event

Figure A.5 and Figure A.6 in Appendix A show the predicted December 2004 flood extents for Mulgate Creek and Long Gully derived by the MIKE-FLOOD model. The XP-RAFTS model inflows were used to represent the local catchment flows and the recorded Narrabri Creek at Narrabri (GS419003) discharge hydrograph was factored and input into the upstream end of the model to represent the Namoi River/Narrabri Creek flow that occurred during the event. The peak recorded Namoi River discharge during the December 2004 event was approximately 720 m^3/s, which has an AEP of less than 20%.

Mulgate Creek and Long Gully drain into Narrabri Creek and the Namoi River respectively, downstream of the Narrabri gauges and therefore the recorded Narrabri Creek flows are a good representation of the flows from the Namoi River catchment that potentially impact on peak flood levels at the downstream boundary of Mulgate Creek and Long Gully.

Figure 4.1 shows the recorded and predicted water levels at the Narrabri Creek at Narrabri stream gauge as well as the predicted water levels in Mulgate Creek upstream of the Newell Highway (Newell reporting location - see Figure A.5) and Long Gully upstream of the Narrabri West Walgett Rail (Burt St reporting location - see Figure A.6).

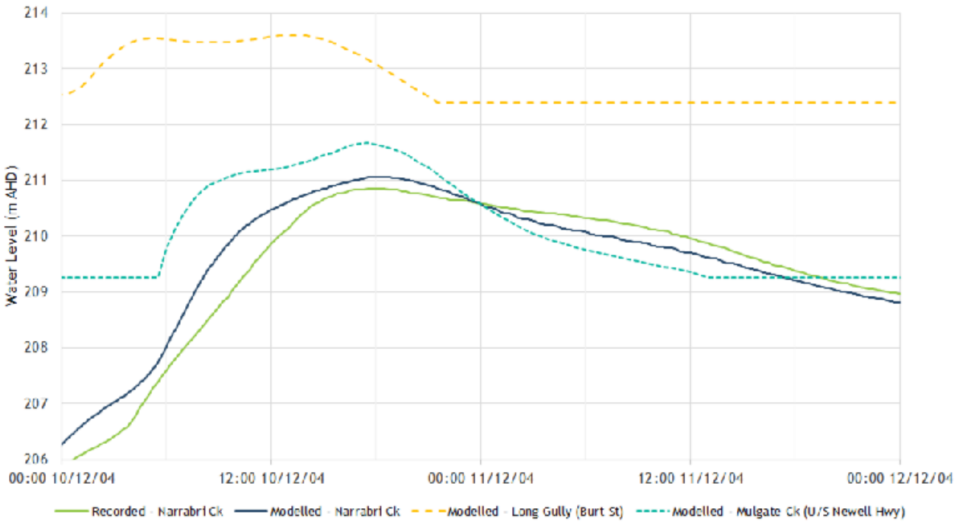


Figure 4.1 - Recorded and predicted water level hydrographs, December 2004 event

The Narrabri Creek water level comparison shows that the MIKE-FLOOD model adequately represents the Narrabri Creek flows for this event at that location. The figure also shows that the Namoi River peaks at a similar time to the Mulgate Creek peak for this event. However, Namoi River flows of this magnitude are generally confined to the Narrabri Creek and Namoi River channels at Narrabri and do not significantly impact on flooding in Mulgate Creek. Long Gully is not impacted by Namoi River flows for this event.

Table 4.1 compares the model results to the anecdotal flooding information provided during the community consultation process. The locations of the anecdotal information are shown in Figure A.5 and Figure A.6 in Appendix A.

Overall, the model provides a reasonably good representation of the 2004 flood along Mulgate Creek. The flood extents are generally consistent with the oblique aerial photography supplied by OEH as shown by Figure 4.2 and Figure 4.3. The model well represents flooding upstream of the rail (see Figure 4.2) and slightly overestimates the flood extent along Mulgate Creek downstream of the rail (see Figure 4.2 and Figure 4.3). The model could not reproduce the flooding at reporting locations 10, 13 and 14.

Overall the model provides a reasonable representation of the 2004 flood along Long Gully. There is anecdotal information on SES call outs in the vicinity of Long Gully, which suggests that the flood extent may have been higher than what has been predicted. However, no information was available as to why the SES were called out to these locations. Given that the URS study (2011) reports much higher anecdotal rainfalls in the upper catchment of Long Gully (higher than what was officially recorded and subsequently used in the hydrologic model), some underestimation of flood extent would be expected.

Table 4.1 - Comparison of anecdotal flood information and modelling results, December 2004 event

ID	Anecdotal information	Modelling results	Comment
2	Office and house inundated	Parts of lot inundated up to 0.65 m depth	Consistent
4	House inundated	Lot inundated up to 2.90 m depth	Consistent
5	Paddocks inundated. Breakout locations and detailed account of flooding provided	Surrounding area inundated. Mulgate Creek breakouts replicated	Consistent
6	Paddocks flooded to many metres depth	Many paddocks inundated, some to great depth	Consistent
7	Yard inundated up to 0.4 m depth	Parts of lot inundated to shallow depth	Consistent
10	Inundated to up 2.5 m depth	No inundation of property (resident may be referring to Namoi River flood earlier in the year)	Inconsistent
11	Flood water present for more than 5 hours	Duration of surrounding inundation greater than 5 hours, no inundation of property	Consistent
13	Yard inundated up to 0.6 m	No inundation of property. Model predicts inundation in street up to 0.40 m depth	Inconsistent
14	Yard inundated up to 0.6 m	Parts of lot inundated up to 0.20 m depth	Inconsistent
16	Water in street	Inundation in street and inundation into lot up to 0.20 m depth	Consistent
17	Yard inundated up to 0.02 m	Inundation in street and inundation into lot up to 0.15 m depth	Consistent
18	Yard inundated up to 0.08 m	Inundation in street and inundation into lot up to 0.25 m depth	Consistent
19	Flood water present for more than 5 hours	Water in street and into lot for more than 5 hours	Consistent
21	Yard inundated up to 0.4 m	Lot inundated up to 0.45 m depth	Consistent
22	Yard inundated up to 0.4 m	Parts of lot inundated up to 0.20 m depth	Consistent
23	Yard inundated up to 0.05 m	Parts of lot inundated up to 0.05 m depth	Consistent
25	Inundation up to 1.0 m	Lot inundated up to 0.75 m depth	Consistent
26	Inundation up to 1.0 m	Lot inundated up to 1.00 m depth	Consistent
27	Inundation up to 0.5 m	Inundation of lot averages around 0.5 m	Consistent
28	Flood water present for more than 5 hours	Lot inundated for more than 5 hours	Consistent
29	Inundated up to 0.6 m	Parts of lot inundated up to 0.55 m depth	Consistent
30	Inundated up to 2.0 m	Lot inundated up to 2.65 m depth	Consistent
32	Inundation in street and surrounds	Inundation in street, lot frontage and surrounds	Consistent
33	Inundation up to 0.1 m	Parts of lot inundated up to 0.20 m depth	Consistent
34	Inundation up to 0.5 m	Lot inundated up to 0.30 m depth	Consistent

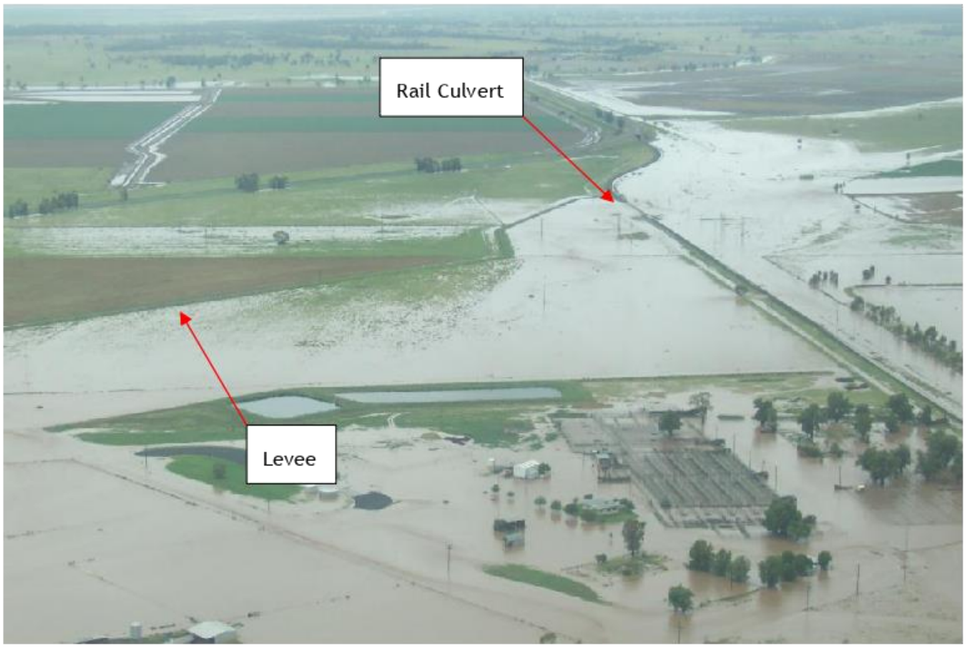


Figure 4.2 - Mulgate Creek flooding, looking north along the Saleyards and rail line, December 2004

Figure 4.3 - Mulgate Creek flooding, looking east at Francis Street Industrial Estate, December 2004

4.3.2 February 2012 event

Figure A.7 and Figure A.8 in Appendix A show the predicted February 2012 flood extents for Mulgate Creek and Long Gully derived by the MIKE-FLOOD model. The XP-RAFTS model inflows were used to represent the local catchment flows and the recorded Narrabri Creek at Narrabri (GS419003) discharge hydrograph was factored and input into the upstream end of the model to represent the Namoi River/Narrabri Creek flow that occurred during the event. The recorded peak Namoi River discharge during the February 2012 event was approximately 1,070 m^3/s, which has an AEP of approximately 20%.

Figure 4.4 shows the recorded and predicted water levels at the Narrabri Creek at Narrabri stream gauge as well as the predicted water levels in Mulgate Creek upstream of the Newell Highway (Newell reporting location - see Figure A.7) and Long Gully upstream of the Narrabri West Walgett Rail (Burt St reporting location - see Figure A.8).

The comparison of Narrabri Creek water levels shows that the MIKE-FLOOD model adequately represents the Narrabri Creek flows at the location of the gauge for this event.

The figure also shows that the Namoi River peaked some 15 hours after the Mulgate Creek peak for this event. A review of the recorded water level data from upstream gauges for this event showed that the Namoi River peak was generated by the catchment downstream of Boggabri. The Namoi River at Boggabri peaked about 48 hours after the peak at Narrabri.

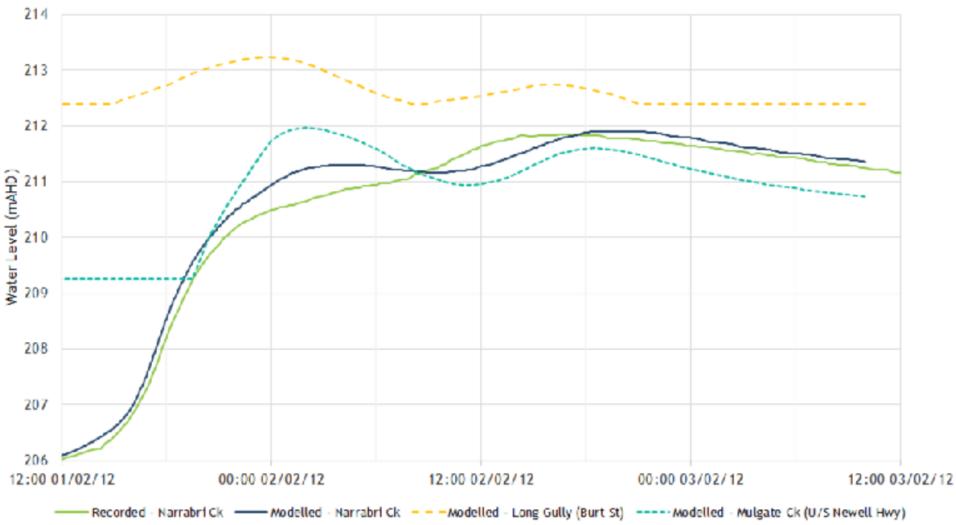


Figure 4.4 - Recorded and predicted water level hydrographs, February 2012 event

Table 4.2 compares the model results to the anecdotal flooding information provided during the community consultation process. The locations of the anecdotal information are shown in Figure A.7 and Figure A.8 in Appendix A. Overall, the model provides a reasonably good representation of the 2012 flood along Mulgate Creek and Long Gully. Predicted peak flood levels are on average marginally lower than the anecdotal data. Given that the rainfall temporal pattern adopted for this event was taken from a site 67 km away and therefore may not be reflective of the rainfall intensities in the catchment, the predicted flood extent appears reasonable.

Table 4.2 - Comparison of anecdotal flood information and modelling results, February 2012 event

ID	Anecdotal information	Modelling results	Comment
1	Not inundated	Lot not inundated	Consistent
2	Office inundated 0.1 m above floor level	Parts of lot inundated up to 0.25 m depth	Inconsistent
3	Inundation up to 0.25 m	Inundation of building to approximately 0.1 m depth	Consistent
4	Inundation up to 0.6 m around shed	Most of lot inundated to around 0.85 m depth	Consistent
6	Paddocks flooded up to many metres depth. Flooding less than 2004	Many paddocks inundated, some to great depth. Flooding to similar level than 2004	Consistent
7	Yard inundated up to 0.3 m depth	Parts of lot inundated to shallow depth	Consistent
8	Water up to 1.0 m above road	Goldman Street inundated up to around 0.5 m depth but depth upstream and downstream exceeds 1.0 m depth	Consistent
9	Surveyed peak level - 214.22 mAHD	Predicted peak level - 214.25 mAHD	Consistent
11	Flood water present for more than 5 hours	Duration of surrounding inundation greater than 5 hours, no inundation of property	Consistent
12	Flood water present for more than 5 hours	Duration of surrounding inundation greater than 5 hours, no inundation of property	Consistent
13	Inundation up to 0.5 m	Parts of lot inundated up to 0.15 m depth	Inconsistent
14	Inundation up to 0.5 m	Parts of lot inundated up to 0.35 m depth	Consistent
15	Inundation to floor level	Inundation within 0.05 m of floor level	Consistent
17	Inundation up to 0.3 m	Lot inundated up to 0.25 m depth	Consistent
18	Inundation up to 0.3 m	Parts of lot inundated up to 0.40 m depth	Consistent
19	Flood water present for more than 5 hours	Water in street and into lot for more than 5 hours	Consistent
20	Inundation up to 0.3 m	Lot inundated up to 0.25 m depth	Consistent
21	Inundation up to 0.3 m	Lot inundated up to 0.55 m depth	Consistent
22	Inundation up to 0.3 m	Lot inundated up to 0.25 m depth	Consistent
23	No property inundation	Parts of lot inundated to shallow depth	Inconsistent
24	Inundation up to 0.3 m	Parts of lot inundated up to 0.20 m depth	Consistent
25	Inundation up to 1.0 m	Lot inundated up to 0.95 m depth	Consistent
26	Inundation up to 1.5 m	Lot inundated up to 1.35 m depth	Consistent
27	Inundation up to 0.5 m	Inundation of lot averages around 0.6 m	Consistent
28	Flood water present for more than 5 hours	Duration of inundation greater than 5 hours	Consistent
29	Inundation up to 0.6 m	Parts of lot inundated up to 0.70 m depth	Consistent
30	Inundation up to 1.5 m	Lot inundated up to 2.85 m depth	Consistent
31	Inundation up to 2.0 m	Parts of lot inundated up to 0.35 m depth	Inconsistent
32	Inundation in street and surrounds	Inundation in street, lot frontage and surrounds	Consistent
33	Inundation up to 0.2 m	Lot inundated up to 0.25 m depth	Consistent
34	Inundation up to 0.3 m	Lot inundated up to 0.40 m depth	Consistent

35	Widespread inundation across site	Almost entire lot inundated	Consistent

4.3.3 Discussion of results

Overall, the model appears to predict peak flood levels moderately lower than the anecdotal data for the December 2004 and February 2012 events. Sensitivity testing of modelling parameters given in Section 6.3.2.1 would suggest that significant increases to Manning's roughness values are required to increase peak levels, therefore other factors may be contributing. It should be noted that all Manning's roughness and other hydraulic model parameters used in the local flooding calibration remained consistent with those values adopted from the regional flooding analysis. That is, the adopted hydraulic parameters are consistent for both regional and local flooding events.

It would appear that the greatest uncertainty surrounding the historical events is the limited information on rainfall depth and intensity, particularly short duration rainfall data. To overcome these potential shortcomings, the design discharges were validated against estimates made using the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2019) (see Section 5.3.2).

5 Estimation of design discharges

5.1 CHANGES FROM THE 2016 FLOOD STUDY

The 2016 flood study estimated regional and local design discharges and flood levels for events up to the 1% AEP and an extreme flood event. For the FRMP, design flood estimates were extended to include the 0.5% and 0.2% AEP events for both regional and local flooding.

The regional flooding design discharge estimates used the flood frequency analysis (FFA) from the 2016 flood study. Since the completion of the 2016 study no flow events of significance have been recorded at Narrabri so the FFA has not been updated.

The estimation of local flooding design discharges used the hydrologic model and the updated design rainfall associated with AR&R (Ball et al., 2019).

5.2 REGIONAL FLOODING

5.2.1 General

Design flood discharges for the Namoi River at Narrabri for events up to the 0.2% AEP event were estimated by annual series flood frequency analysis (FFA). All available flood information for Narrabri dating back to 1890 (126 years from 1890 to 2015) was included in the analysis. Kinhill (1991) also provided anecdotal evidence of flooding dating back to 1865 that was used to extend the data set. The FFA was undertaken to fit a Log-Pearson Type III distribution to an annual series of recorded (and inferred) peak flood discharges at Narrabri using the Bayesian inference methodology recommended in Australian Rainfall and Runoff (Ball et al., 2019) using the TUFLOW FLIKE software.

5.2.2 Extreme event

It is not possible to estimate the Probable Maximum Flood (PMF) using the FFA methodology because the PMF is beyond the credible limit of extrapolation from the 151 years of data used in the FFA. For this catchment, the PMF has a notional AEP of about 1 in 40,000 using the methodology given in AR&R (Ball et al., 2019). Therefore an estimate of a peak discharge for an 'extreme' flood has been made by using three times the 1% AEP discharge estimate.

5.2.3 Comparison with previous estimates

Table 5.1 shows a comparison of the 2016 flood study FFA design discharge estimates and estimates made by Kinhill (1991) and URS (2014). The results show that the WRM FFA is in reasonable agreement with the Kinhill (1991) study, with the 1% AEP event some 3% lower but the smaller events marginally higher. The differences are expected to be due to the additional 26 years of data and the different modifications made to the high flow rating. There are significant differences between the WRM FFA results and the URS (2014) estimates. It is noted that URS (2014) also identified the discrepancy in the Namoi River at Narrabri gauge and therefore adopted the Kinhill (1991) estimates for their design event modelling.

Table 5.1 - Comparison of regional design discharges with previous estimates

	Peak Discharge (m^3/s)		
Design Event	WRM FFA[b] (1865-2015)	Kinhill FFA (1991)	URS FFA (2014)
20% AEP	1,070	-	1,130
10% AEP	1,980	1,470	1,740
5% AEP	2,920	2,260	2,320
2% AEP	4,090	3,680	2,890
1% AEP	4,860	5,090	3,240
0.5% AEP	5,500	-	-
0.2% AEP	6,180	-	-
Extreme event	14,580 [a]	-	-

[a] - Extreme event given by 3 x 1% AEP
[b] - expected parameter quantiles adopted given minimal difference from AEP quantiles

5.3 LOCAL FLOODING

5.3.1 General

The calibrated hydrologic and hydraulic models were used to derive design discharges, flood levels, depths and velocities throughout the study area for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events and the PMF for existing conditions. All model parameters derived via the model calibration remained unchanged for the design event modelling.

5.3.2 Design discharges up to the 0.2% AEP event

5.3.2.1 Methodology

Design discharges for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP events were derived using the methodology given in AR&R (Ball et al., 2019) and then verified against estimates made using the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2019).

5.3.2.2 Design rainfall

Rainfall depths for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP design events were taken from the Bureau of Meteorology's (BoM) 2016 Intensity-Frequency-Duration (IFD) database. An IFD located approximately in the centre of Narrabri was adopted. All previous flood studies for Narrabri used IFDs from the BoM 1987 IFD database or earlier simpler methods. As a result of the updated IFDs, the design rainfall depths used in this supplementary flood study are in general slightly lower than the design rainfall depths adopted in the 2016 flood study. Decreases in rainfall depths of up to 16% are present (6 hour and 12 hour 1% AEP rainfalls).

5.3.2.3 Areal variability

Areal reduction factors (ARFs) based on the Mulgate Creek catchment area were applied for design rainfalls up to 0.2% AEP as per the recommendation in AR&R (Ball et al., 2019). No ARF was adopted for PMP rainfalls due to catchment area already being incorporated into the PMP rainfall estimation.

5.3.2.4 Temporal patterns

The Central Slopes temporal patterns from AR&R Data Hub (Geoscience Australia, 2017) were used for all events up to and including the 0.2% AEP event. Areal temporal patterns were used where appropriate.

5.3.2.5 Design losses

The recommended regional loss values for Narrabri from the AR&R Data Hub (Geoscience Australia, 2019) were an initial loss of 34.0 mm (prior to adjustment for preburst rainfall) and a continuing loss of 1.1 mm/h. The recommended regional loss values were adjusted during verification of the design discharges to the RFFE peak discharge estimates. The adopted design losses were as follows:

- An initial rainfall loss of:
    - 55 mm was applied to the 20% AEP event;
    - 45 mm was applied to the 10% AEP event;
    - 35 mm was applied to the 5% AEP event;
    - 10 mm was applied to the 2% AEP event; and
    - 5 mm was applied to the 1%, 0.5% and 0.2% AEP events.
- A continuing loss of 1.1 mm/h was applied to all design events up to and including the 0.2% AEP event.

5.3.2.6 XP-RAFTS results

The ensemble of ten temporal patterns was run for all design events for durations between 2 and 48 hours. The critical duration for Long Gully and Mulgate Creek catchments was consistent across the design events. The adopted ensemble for each design event is shown in Table 5.2. Figure 5.1 and Figure 5.2 show boxplots of the ensemble results for the 1% AEP event.

Table 5.2 - Adopted ensemble for each design event

AEP (%)	Adopted Ensemble
20	36 hour TP10
10	48 hour TP1
5	48 hour TP2
2	12 hour TP10
1	12 hour TP10
0.5	12 hour TP10
0.2	12 hour TP10

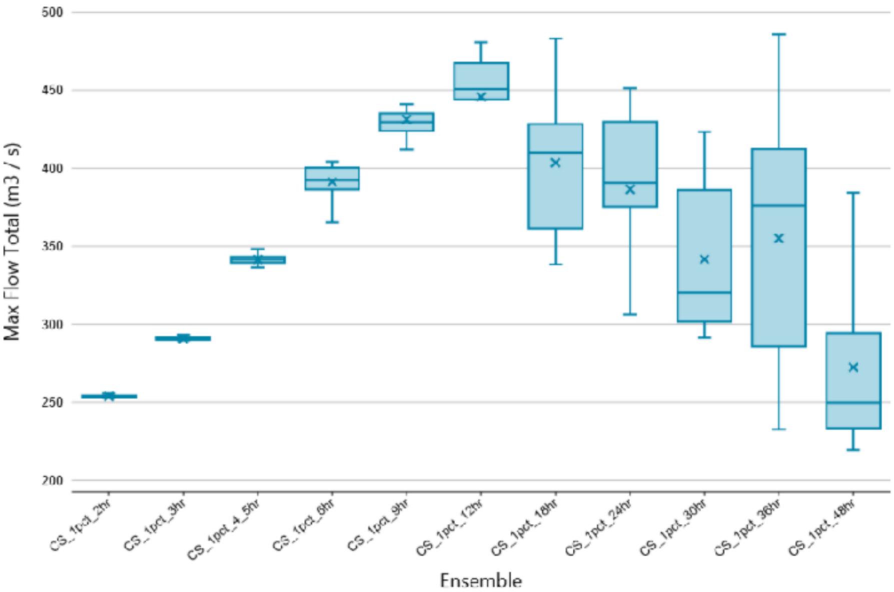


Figure 5.1 - Boxplot of 1% AEP design discharge ensembles, Mulgate Creek

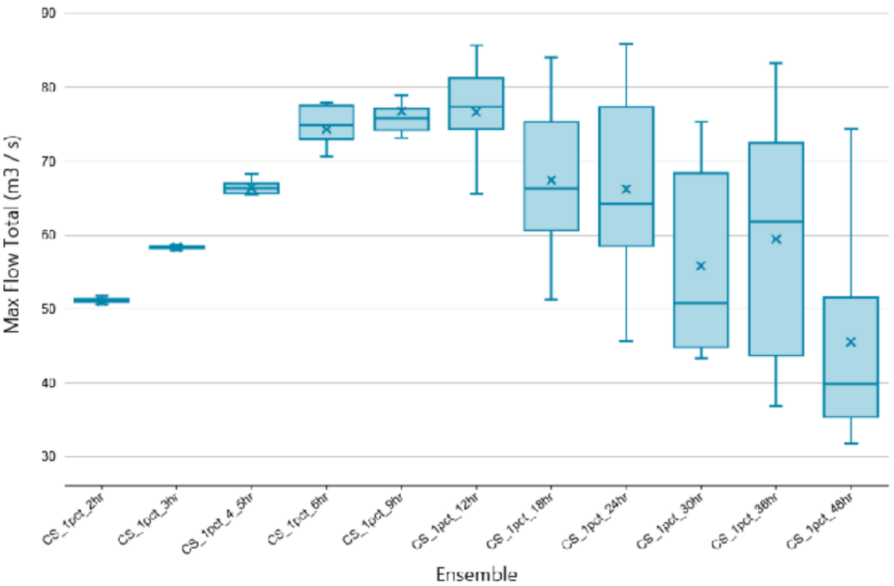


Figure 5.2 - Boxplot of 1% AEP design discharge ensembles, Long Gully

5.3.2.7 Regional Flood Frequency Estimation (RFFE) verification

Table 5.3 and Table 5.4 show the Mulgate Creek (to the Newell Highway) and Long Gully (to the Narrabri West Walgett Railway) design flood discharges estimated using the MIKE-FLOOD model (with XP-RAFTS inflows). The MIKE-FLOOD discharges take into account the flood storage and routing characteristics of the catchment that are not fully represented by the XP-RAFTS model. Given the flat nature of the floodplain, this method of deriving design discharges is more appropriate than using the XP-RAFTS model alone.

Given the limited data available for model calibration, the design discharges were validated against estimates made using the Regional Flood Frequency Estimation (RFFE) approach given in Ball et al. (2019). The RFFE approach is recommended for use when a peak discharge estimate is required on a small to medium sized ungauged catchment (Ball et al., 2019). The RFFE technique was developed by Dr Ataur Rahman and Dr Khaled Haddad from the University of Western Sydney with the assistance of Professor George Kuczera from the University of Newcastle and Mr Erwin Weinmann and is based on data from 853 gauged catchments across Australia. The RFFE method is calculated using a web based application.

The RFFE discharge estimates and the 5% and 95% confidence limits of the estimate for Mulgate Creek are given in Table 5.3. The RFFE used the following parameters:

- 201 km² catchment area;
- catchment outlet coordinates (149.777°E, -30.315°S); and
- catchment centroid coordinates (149.907°E, -30.291°S).

The RFFE discharge estimates and the 5% and 95% confidence limits of the estimate for Long Gully are given in Table 5.4. The RFFE used the following parameters:

- 28 km² catchment area;
- catchment outlet coordinates (149.747°E, -30.329°S) ; and
- catchment centroid coordinates (149.732°E -30.385°S).

Note that the web based RFFE program suggests that RFFE estimates for Long Gully may have a lower accuracy because of the 'unusual' shape of the catchment. The RFFE method also only produces peak design discharge estimates for design events up to and including the 1% AEP event.

Table 5.3 - XP-RAFTS/MIKE-FLOOD and RFFE design discharge estimates, Mulgate Creek

AEP (%)	XP-RAFTS/MIKE-FLOOD Discharge (m³/s)	RFFE Discharge (m³/s)		
		RFFE	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)
20	112	96	40	230
10	207	155	64	375
5	235	232	94	575
2	408	367	143	948
1	486	501	189	1,340
0.5	548	-	-	-
0.2	616	-	-	-

Table 5.4 - XP RAFTS/MIKE-FLOOD and RFFE design discharge estimates, Long Gully

AEP (%)	XP-RAFTS/MIKE-FLOOD Discharge (m^3/s)	RFFE Discharge (m^3/s)		
		RFFE	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)
20	23	16	7	38
10	39	26	11	62
5	48	38	15	95
2	73	61	24	157
1	88	83	31	222
0.5	102	-	-	-
0.2	118	-	-	

Table 5.3 shows that the XP-RAFTS/MIKE-FLOOD peak discharges in Mulgate Creek for the 20%, 10%, 5% and 2% AEP events are higher than the RFFE estimates but is lower for the 1% AEP event. For all design events the XP-RAFTS/MIKE-FLOOD peak design discharge is within the confidence limits of the RFFE estimate.

Table 5.4 shows that all XP-RAFTS/MIKE-FLOOD discharges in Long Gully for all design events are larger than the RFFE peak discharge estimate but always within the confidence limits of the RFFE estimate. On this basis, the XP-RAFTS/MIKE-FLOOD discharges have been adopted for the assessment.

5.3.3 Design discharges for the Probable Maximum Flood (PMF)

Table 5.5 shows PMF discharge estimates for Mulgate Creek (at the Newell Highway) and Long Gully (at the Narrabri West Walgett Railway). Design rainfalls for the PMF were determined in accordance with the Generalised Tropical Storm Method (Revised) (GTSMR) (BoM, 2005) and the Generalised Short Duration Method (GSDM) (BoM, 2003). As per recommendations in AR&R (Ball et al., 2019) rainfall losses of 0 mm initial and 1 mm/h continuing were adopted. As per recommendations in AR&R (Ball et al., 2019) ensemble temporal patterns from Jordan et al. (2005) were adopted for use with GSDM rainfall depths while GTSMR areal ensemble temporal patterns were adopted for use with GTSMR rainfall depths.

The critical duration storm for both catchments was found to be the 6 hour event. The discharges shown in Table 5.5 were derived using the XP-RAFTS model, because MIKE-FLOOD modelling shows significant inter-basin flow both in and out of these catchments for the PMF event.

Table 5.5 - XP-RAFTS PMF discharge estimates, Mulgate Creek and Long Gully

Catchment	XP-RAFTS Mean Peak Discharge (m^3/s)	Adopted Ensemble
Mulgate Creek	3,010	GSDM 6 hour TP5
Long Gully	610	GSDM 6 hour TP5

5.3.4 Coincident Namoi River flooding

The modelling of the December 2004 (see Figure 4.1) and February 2012 events (see Figure 4.4) showed that these two local catchment events coincided with moderate flow events in the Namoi River. Although the purpose of this section of the study is to investigate the flooding of the local Mulgate Creek and Long Gully catchments, it is necessary to define a Namoi River flow that would likely occur concurrently with the local catchment events.

A detailed joint probability analysis between the Namoi River and the local catchment flood events is required to provide a fully informed relationship between the two flood scenarios. However, in this case the peak flood levels at the confluence of the two systems will be wholly dominated by Namoi River flooding. In fact, Namoi River flooding produces higher design flood levels across most of the study area except for the upper reaches of the local creeks. The differences in sizes between the local and Namoi River catchments would also mean that large Namoi River floods would be unlikely to coincide with a local catchment event.

For this study, the coincident Namoi River flows have been determined from a review of the recorded stream gauge water level data along the Namoi River for the December 2004 and February 2012 events.

- For the December 2004 event, the Namoi River peak at the Narrabri gauge (GS419003) that corresponded to the local event was associated with runoff generated by the catchment downstream of the Turrawan gauge (GS419023), that is from the adjacent Bullawa Creek and Jacks Creek catchments (see Figure 1.1). Flood flows generated upstream of Turrawan (from Maules Creek) arrived at Narrabri well after the Mulgate Creek peak occurred and at a lower level. There were little to no flows from the Namoi River catchment upstream of Boggabri.
- For the February 2012 event, which was a longer duration event with more flow volume, the Namoi River flood peak corresponding to the local event was due to flows from the whole catchment downstream of Boggabri (the combined flows from Bullawa, Jacks and Maules creeks and others) and this peak occurred much later than the Mulgate Creek peak. The Namoi River peak from the catchment upstream of Boggabri occurred much later again. On further analysis, the Namoi River water level at the time of the Mulgate Creek peak would appear to have occurred due to runoff downstream of the Turrawan gauge, in a similar manner to 2004.

Given this, a design event generated from the catchment downstream of the Turrawan Gauge (Bullawa and Jacks creeks) has been used as the basis for determining the Namoi River discharge that would coincide with the local catchment event. The RFFE web based method (described in Section 5.3.2.7) has been used to determine the peak discharges from this catchment. To avoid the larger Namoi River events from impacting on local catchment flows, an AEP slightly higher has been used for each design event, as shown in Table 5.6.

Table 5.6 - Coincident Namoi River discharge adopted for each local design event

Mulgate Creek/Long Gully design event	Coincident Downstream Turrawan event	RFFE Derived Namoi River Discharge (m^3/s)
20% AEP	50% AEP	122
10% AEP	20% AEP	301
5% AEP	10% AEP	487
2% AEP	5% AEP	729
1% AEP	2% AEP	1,150
0.5% AEP		
0.2% AEP	1% AEP	1,570
PMF		

6 Design flood events

6.1 OVERVIEW

The calibrated MIKE-FLOOD model described in Section 3 was used to estimate peak depths, levels and extent of flooding for the 20% (5 year ARI), 10% (10 year ARI), 5% (20 year ARI), 2% AEP (50 year ARI), 1% AEP (100 year ARI), 0.5% AEP (200 year ARI) and 0.2% AEP (500 year ARI) design events and an extreme flood event for both local and regional flooding. As discussed in Section 5 the regional extreme event was based on the factoring the 1% AEP event by three, while the local extreme event was a PMF event, derived from probable maximum precipitation in the Mulgate Creek catchment hydrologic model. All model parameters derived via the model calibration remained unchanged for the design event modelling.

6.2 REGIONAL FLOODING

6.2.1 Design flood depth, levels and extents

Predicted flood extent, depths and flood contours for the regional 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.2% AEP and the extreme (3x1% AEP) event are shown in Appendix B. Figure 6.1, Figure 6.2 and Figure 6.3, show longitudinal profiles of peak flood levels for the historical events and design events along Narrabri Creek, Namoi River, and the Eastern Flood Runner of Doctors Creek and Horsearm Creek respectively. The Narrabri Creek and Namoi River longitudinal sections start and finish at their respective upstream and downstream confluences. The Eastern Flood Runner commences at the Doctors Creek and Narrabri Creek confluence and finishes at Old Gunnedah Road.

6.2.2 Peak flood level comparison to previous estimate

Table 6.1 shows the peak flood level estimates from the hydraulic model at the Namoi River at Narrabri (GS419002) and Narrabri Creek at Narrabri (GS419003) stream gauges and compares them to the 2016 flood study estimates. The results are similar to those found in the 2016 flood study with design levels varying minimally at the Namoi River and Narrabri Creek gauges. The inclusion of 0.5% and 0.2% AEP events shows that the nominated regional extreme flood event (3 x 1% AEP event) gives design flood levels over 2.2 m higher than the 1% AEP event and over 1.7 m higher than 0.2% AEP event.

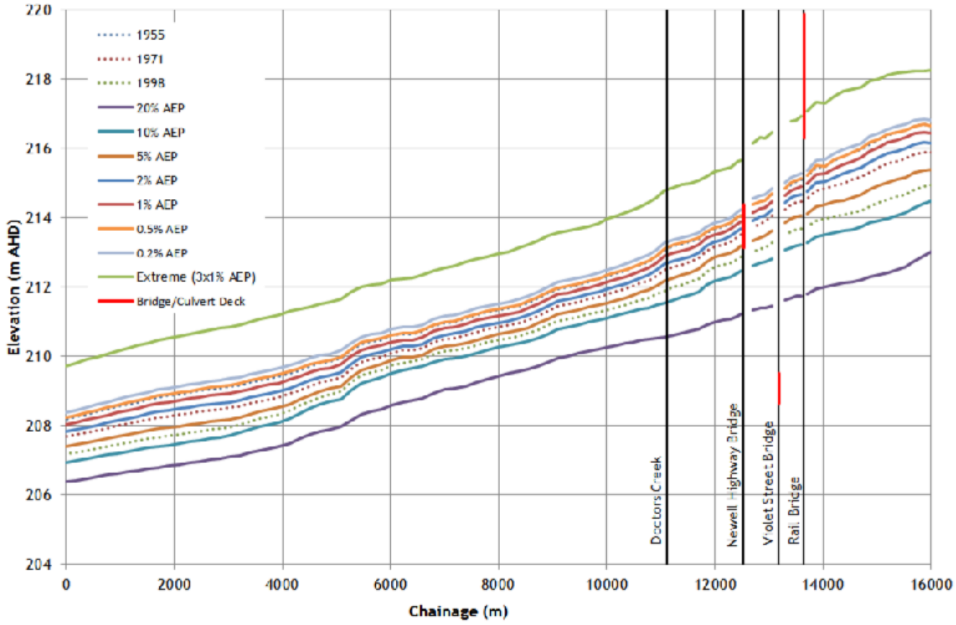


Figure 6.1 - Regional design and historical event longitudinal flood profiles, Narrabri Creek

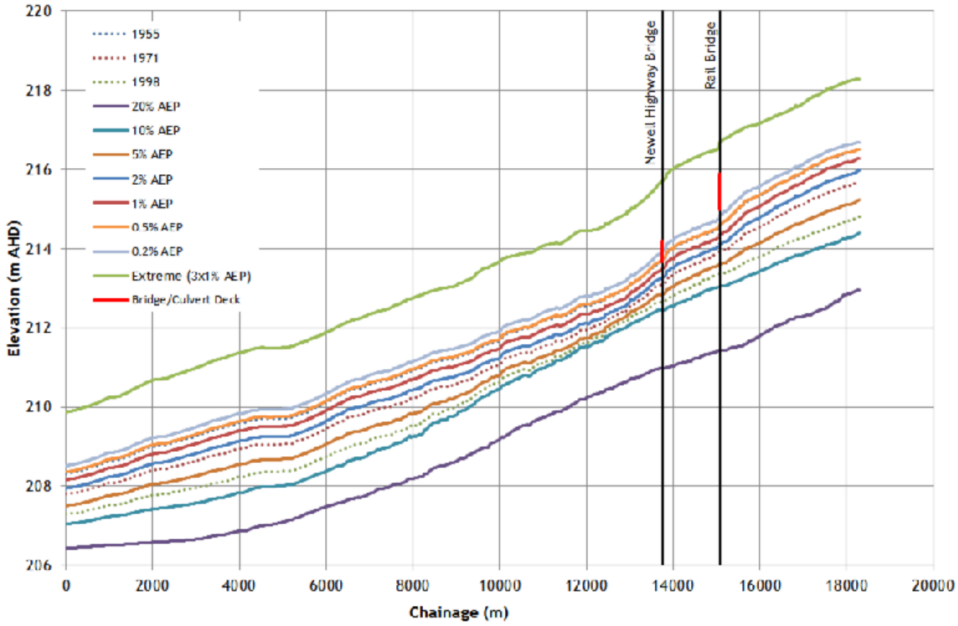


Figure 6.2 - Regional design and historical event longitudinal flood profiles, Namoi River

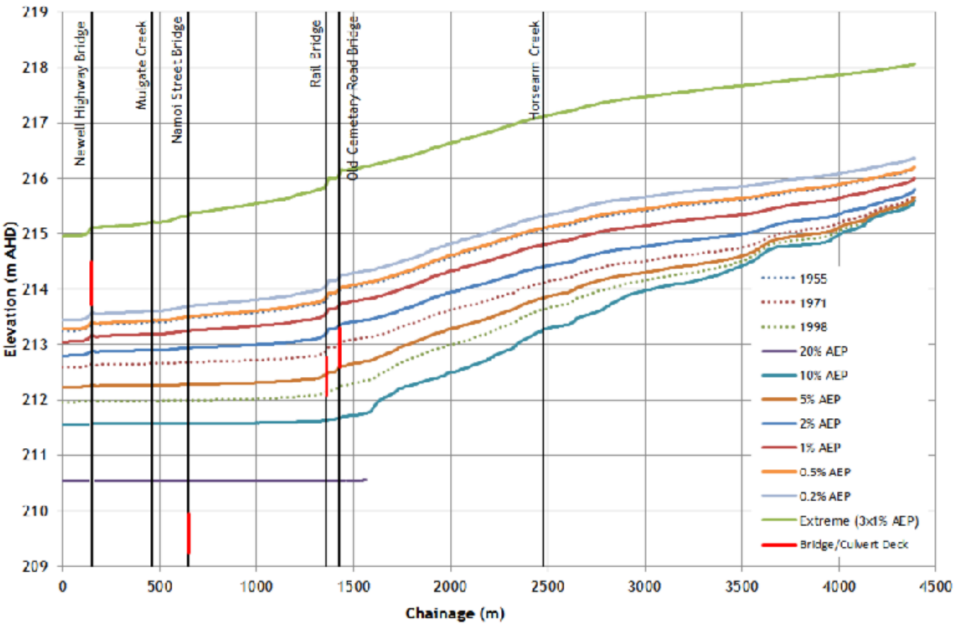


Figure 6.3 - Regional design and historical event longitudinal flood profiles, Eastern Flood Runner / Horsearm Creek / Doctors Creek

Table 6.1 - Comparison of peak regional design flood levels at the Namoi River and Narrabri Creek stream gauges

Design event	WRM (2016)		WRM (2019)	
	Namoi	Narrabri	Namoi	Narrabri
Extreme	10.91	11.51	10.79	11.57
0.2% AEP	-	-	9.02	9.77
0.5% AEP	-	-	8.81	9.58
1% AEP	8.62	9.34	8.56	9.36
2% AEP	8.37	9.08	8.34	9.11
5% AEP	7.97	8.55	7.91	8.53
10% AEP	7.51	7.74	7.51	7.80
20% AEP	6.04	6.56	6.03	6.56

6.3 LOCAL FLOODING

6.3.1 Design flood depth, levels and extents

Predicted flood extents, depths and flood contours for the local 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.2% AEP and the PMF events are shown in Appendix B. Table 6.2 shows the predicted distribution of flow at key reporting locations given in these figures for the various design events. Design event mapping shows that the 2004 event had an AEP of between 5% and 2% in Mulgate Creek and Long Gully and the 2012 event had an

AEP of between 5% and 1% in Mulgate Creek and about 5% AEP in Long Gully. Note that these flow distributions assume that the levees and bunds do not fail during flooding. The flow distributions and flood levels could potentially change if the levees and bunds fail. A description of flooding for the various events in the Mulgate Creek and Long Gully catchments are given below.

Table 6.2 - Floodplain flow distribution

Section ID	Peak discharge (m^3/s)						
	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Horsearm Creek							
H1	47.6	89.8	96.4	138.6	159.1	181.6	214.4
H2	67.5	109.7	116.8	148.9	160.7	171.7	186.2
H3	1.2	14.4	19.6	41.0	45.4	50.0	56.3
H4	57.9	101.9	111.4	191.7	219.2	242.0	268.2
Mulgate Creek							
M1	70.4	118.1	123.5	145.2	153.4	159.8	166.2
M2	62.0	103.9	113.4	210.8	257.6	301.1	350.5
K1	4.4	10.4	19.3	82.5	112.4	143.4	183.0
Doctors Creek							
D1	112.0	206.6	234.8	408.1	486.4	547.8	616.0
Long Gully							
L1	18.0	33.4	39.1	59.3	70.3	80.6	93.6
L2	23.0	39.2	48.4	73.4	87.7	101.8	118.3
N1	0.9	1.2	1.1	1.2	1.1	1.2	1.3

6.3.1.1 Mulgate Creek

Figure 6.4 shows the longitudinal profiles of peak flood levels for the historical events and design events along Mulgate Creek. The Mulgate Creek longitudinal section starts at the Horsearm Creek confluence and finishes just upstream of the rail culverts. The 1% AEP peak flood level from the regional flood modelling is also shown.

Figure 6.5 shows the longitudinal profiles of peak flood levels for the historical events and design events along Doctors Creek / Horsearm Creek. The Doctors Creek / Horsearm Creek longitudinal section starts at the Narrabri Creek confluence and finishes at Old Gunnedah Road. The 1% AEP peak flood level from the regional flood modelling is also shown.

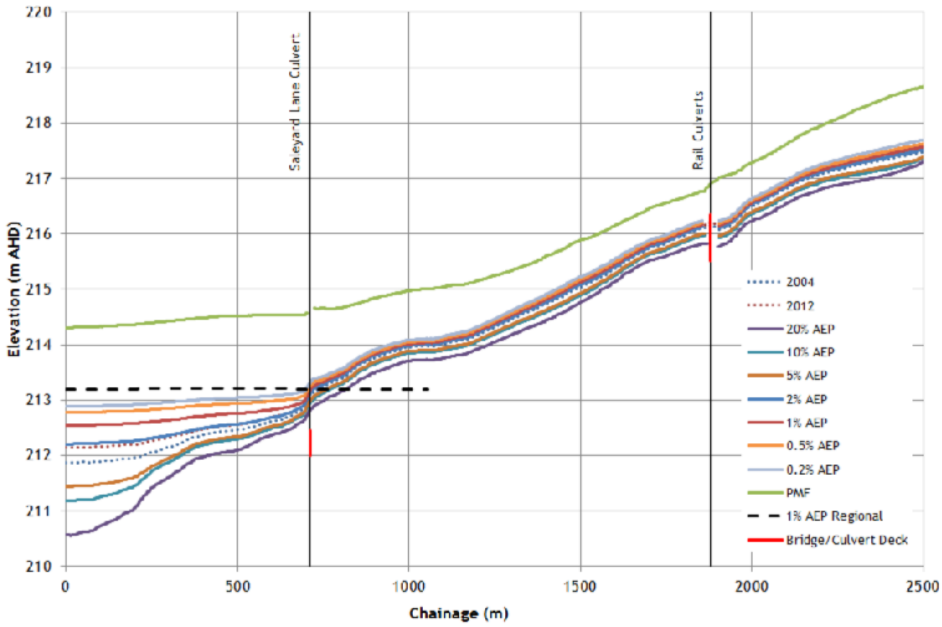


Figure 6.4 - Local design and historical event longitudinal flood profiles, Mulgate Creek

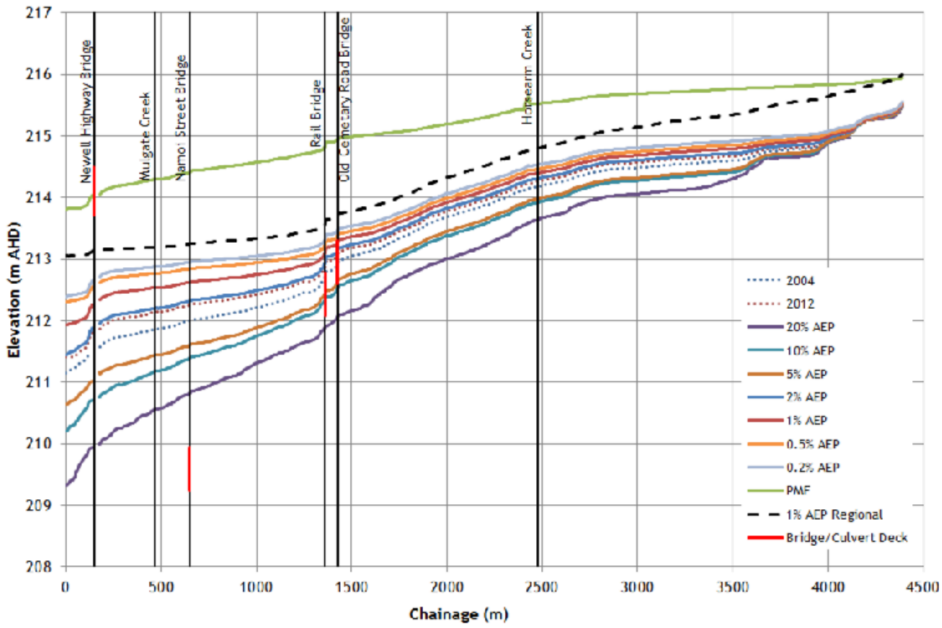


Figure 6.5 - Local design and historical event longitudinal flood profiles, Eastern Flood Runner / Horsearm Creek / Doctors Creek

The following is of note:

- The longitudinal sections show that Namoi River flooding dominates peak flood levels along the lower reaches of Horsearm Creek, Doctors Creek and Mulgate Creek adjacent to the urban areas of Narrabri;
- For the 20% AEP event, flows along Killarney Gap Road (K1) and to the west of the Newell Highway are generated from local catchment runoff (do not include Mulgate Creek overflows);
- Mulgate Creek overflows to Killarney Gap Road for events rarer than or equal to the 10% AEP event. The proportion of flow being conveyed along Killarney Gap Road increases as the magnitude of flow event increases with around 40% (or greater) of the total Mulgate Creek flow being conveyed along Killarney Gap Road for events equal to or greater than 2% AEP. It is likely that all of the Killarney Gap Road flows (K1) would bypass Narrabri if Killarney Gap Road and possibly the Newell Highway and the rail were not there. This could reduce 1% AEP flows in Doctors Creek (which includes flows from both Mulgate Creek and Horsearm Creek) by around 25%;
- Mulgate Creek overflows into Horsearm Creek upstream of the study area along Mulgate Creek Road (about 3.1 km southeast of Killarney Gap Road). The model predicts that less than 10% of the 1% AEP flow in Mulgate Creek overflows to Horsearm Creek at this location;
- Flooding is primarily contained to streets and undeveloped land between the Francis and Newell reporting locations (Francis St industrial area) for the 20% AEP event multiple developed lots inundated for the 10% AEP event;
- Mulgate Creek overflows the rail upstream of the Francis St industrial area for events rarer than or equal to the 5% AEP event;
- Horsearm Creek overflows into the urban areas of Narrabri for the 2% AEP event;
- The Old Cemetery Road and adjacent rail bridge do not appear to be significant constrictions to flow. However even a small afflux could potentially direct floodwater into the urban areas of Narrabri; and
- The 2% AEP event overtops the Newell Highway.

6.3.1.2 Long Gully

Figure 6.6 shows longitudinal profiles of peak flood levels for the historical events and design events along Long Gully. The Long Gully longitudinal section starts at the Namoi River confluence and finishes at end of the urban areas of Narrabri (Kelvin Vickery Avenue). The 1% AEP peak flood level from the regional flood modelling is also shown.

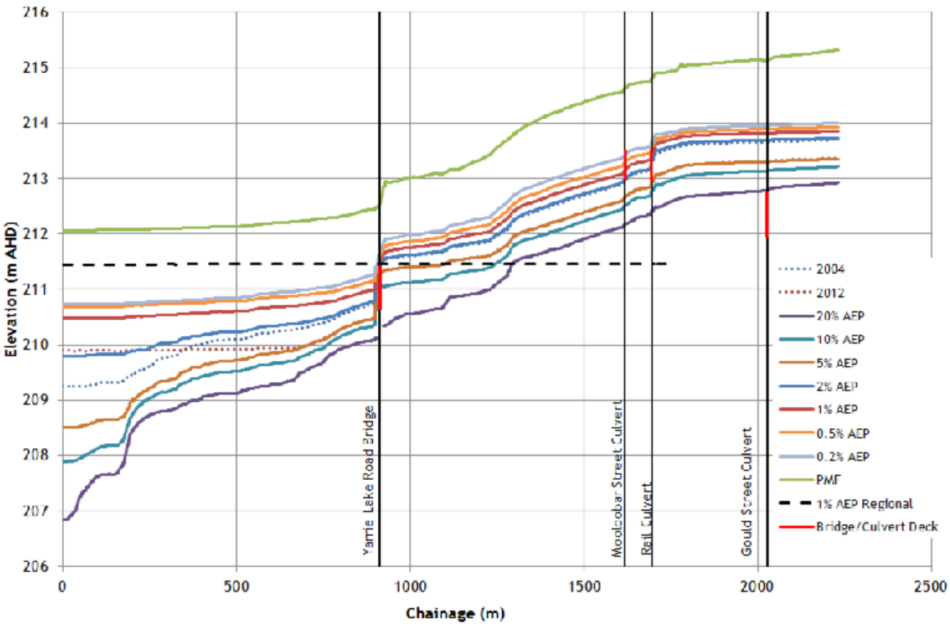


Figure 6.6 - Local design and historical event longitudinal flood profiles, Long Gully

The following is of note:

- The longitudinal sections show that Namoi River flooding dominates the lower sections of Long Gully below Yarrie Lake Road and Long Gully flows dominate flood levels for the remainder of Long Gully;
- The Newell Highway diverts Long Gully flows towards the Kamilaroi Highway for all design events but the diverted flows are small in comparison to the total catchment flows; and

6.3.2 Sensitivity analysis

6.3.2.1 Changes in floodplain roughness

The hydraulic model was used to assess the sensitivity of peak flood levels to changes in floodplain roughness for the 1% AEP event. For the purposes of the assessment the adopted floodplain Manning's 'n' of 0.08 was increased to 0.12 and decreased to 0.04 to test sensitivity. The floodplain roughness covers the majority of the inundated areas and therefore will have the greatest impact on model results. The results of the sensitivity analysis at the six reporting locations (shown in Figure B.10 in Appendix B) are shown in Table 6.3.

The results show that changes in Manning's 'n' values may significantly impact on flood levels at the Long Gully reporting locations, particularly when the roughness is decreased. In Mulgate Creek, the increased roughnesses increase peak flood levels at all reporting locations with the exception of the Newell Highway, where peak flood levels reduce. The higher roughness values appear to increase the available flood storage and change the timing of the flood peaks from the tributaries to reduce flood levels at this reporting location. The lower roughnesses produce significantly lower peak flood levels (except at the Newell Highway).

Table 6.3 - Sensitivity analysis of hydraulic model results to changes in floodplain roughness, 1% AEP event

Reporting Location	1% AEP Peak Level (mAHD)			Peak Level Change (m)	
	Calibrated	Increased Roughness	Decreased Roughness	Increased Roughness	Decreased Roughness
Burt	214.60	214.70	214.47	+0.10	-0.13
Kamilaroi	213.72	213.77	213.62	+0.05	-0.10
Newell	212.41	212.40	212.34	-0.01	-0.07
Francis	213.16	213.25	212.90	+0.09	-0.26
Reid	213.58	213.66	213.32	+0.08	-0.26
Shannon	214.65	214.75	214.43	+0.10	-0.22

6.3.2.2 Climate change

The Floodplain Development Manual (NSW Government, 2005) recognises the need for analysis of the consequences of climate change on flood levels and flood behaviour. For this assessment, sensitivity to climate change was tested by increasing peak rainfall and storm volume by 30% (NSW Government, 2007b) for the 1% AEP flood. This represents the 'worst case' of the three climate change sensitivity analyses recommended by the NSW Government (2007b). The results of this sensitivity analysis at the six reporting locations (shown in Figure B.10 in Appendix B) are shown in Table 6.4. The results show that climate change could increase peak 1% AEP flood levels significantly across the study area with an increase of 0.35 m at the Newell Highway in the Mulgate Creek catchment. The increased rainfall intensities would significantly increase the flood extent and flood levels through the urban areas of Narrabri.

Table 6.4 - Sensitivity analysis of hydraulic model results to climate change, 1% AEP event

Reporting Location	1% AEP Peak Level (mAHD)		Peak Level Change (m)
	Calibrated	Climate Change	
Burt	214.60	214.73	+0.13
Kamilaroi	213.72	213.86	+0.14
Newell	212.41	212.76	+0.35
Francis	213.16	213.31	+0.15
Reid	213.58	213.74	+0.16
Shannon	214.65	214.77	+0.12

7 Provisional hydraulic hazard mapping

7.1 OVERVIEW

The flood modelling results show that regional flooding poses the greatest threat to the developed areas of Narrabri. Significant areas of Narrabri are liable to flooding to varying levels of risk. Any development within floodprone areas would therefore be considered to be in a flood hazard zone as they are prone to damage if mitigation measures are not implemented. Provisional hydraulic hazard mapping has been prepared by combining the hazards from both local and regional flooding.

7.2 PROVISIONAL HYDRAULIC HAZARD

Figure C.1 to Figure C.8 in Appendix C show the provisional hydraulic hazard categories in the study area from a combination of local and regional catchment flooding. Provisional hydraulic hazards have been defined using the depth and velocity of the floodwaters calculated using the flood model and determined in accordance with Figure 7.1 as given in Appendix L of the NSW Floodplain Development (NSW Government, 2005).

The provisional hydraulic hazard mapping presented herein will be revised to represent true hazard categories during the next phase of the FRMP.

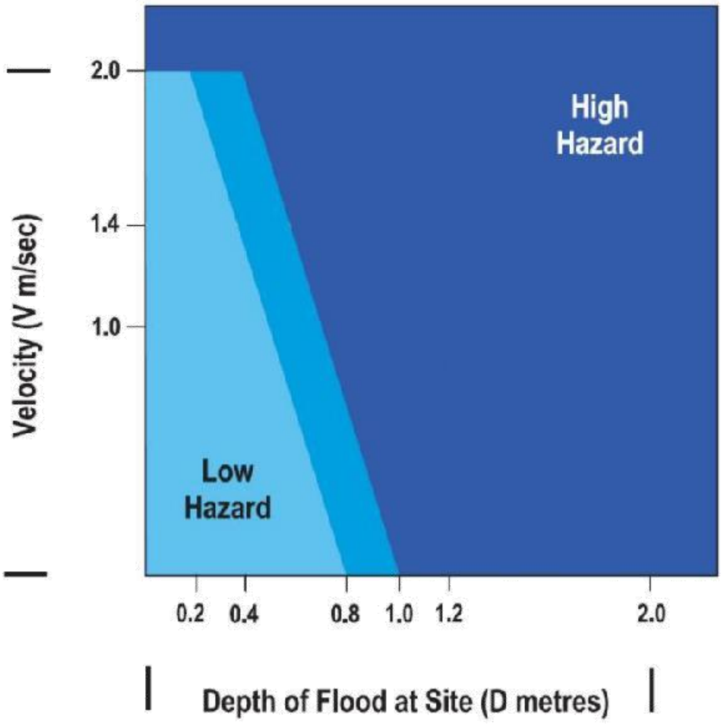


Figure 7.1 - Provisional hydraulic hazard categories (Source: NSW Government, 2005)

8 Conclusions

Narrabri Shire Council engaged WRM Water & Environment Pty Ltd (WRM) to prepare a Floodplain Risk Management Study and Plan (FRMP).This report details updates to the Narrabri Flood Study (WRM, 2016) conducted as part of the FRMP process to bring modelling up to date with the latest revision of AR&R (Ball et al., 2019).

The regional design discharges at Narrabri have been estimated from an annual series flood frequency analysis of the recorded flows at the two stream gauges at Narrabri using the methodology recommended in AR&R (Ball et al, 2019). The 1% AEP discharge at Narrabri was estimated to be 4,860 m^3/s, which is 3% lower than the previously adopted estimate (Kinhill, 1991) and slightly lower than the historical 1955 flood of the Namoi River. The estimated AEP of the 1955 flood is between 1% and 0.5% (i.e. between 100 and 200 year ARI).

The local design discharges were derived using an XP-RAFTS model developed for this study. XP-RAFTS design discharge estimates for the local catchments were validated against estimates from the Regional Flood Frequency Estimate (RFFE) program (Ball et al., 2019).

Hydraulic modelling of the study area has been undertaken to derive design flood levels, depths and extents for the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP flood events and an extreme flood. Preliminary hydraulic hazard mapping has also been prepared.

Following approval of this Flood Study, the following actions are recommended:

- Update Flood Planning Levels based on the results of this Flood Study, as well as Local Environmental Plans and Development Control Plans as appropriate;
- Update Council's GIS systems with the flood mapping outputs from this Flood Study;
- Update S149 certificates for properties affected by flooding; and
- Proceed to the preparation of the Floodplain Risk Management Study, to determine options to manage and/or reduce the flood risk taking into consideration social, ecological and economic factors.

On completion of the Floodplain Risk Management Study, preferred options recommended by Council will be presented in a Floodplain Risk Management Plan publicly exhibited for subsequent implementation by Council.

9 References

Ball et al. (2019)	*'Australian Rainfall and Runoff: A Guide to Flood Estimation'*, Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Commonwealth of Australia (Geoscience Australia), 2019.
BoM (2003)	*'The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method'*, Hydrometeorological Advisory Service, Commonwealth Bureau of Meteorology, June 2003.
BoM (2005)	*'Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method'*, Hydrometeorological Advisory Service, Commonwealth Bureau of Meteorology, September 2005.
DHI (2017)	*'MIKE FLOOD - 1D-2D Modelling: User Manual'*, Danish Hydraulic Institute, Denmark, 2017.
Geoscience Australia (2019)	AR&R Data Hub (software), Geoscience Australia, Version 2019_v1, 2019, <http://data.arr-software.org/>.
Innovyze (2018)	XP-RAFTS 2018.1.2 (software), Innovyze, Portland, USA, 2019.
Jordan et al. (2005)	*'Growth Curves and Temporal Patterns for Application to Short Duration Extreme Events'*, Jordan, P., Nathan, R., Mittiga, L. and Taylor, B., Australian Journal of Water Resources, Volume 9 No. 1, pages 69-80, 2005.
Kinhill (1991)	*'Narrabri Flood Study: Final Report'*, Kinhill Engineers Pty Ltd, NSW, May 1991.
Max Winders & Associates (2002)	*'Narrabri Supplementary Floodplain Management Study'*, Max Winders & Associates, QLD, February 2002.
NSW Government (2005)	*'Floodplain Development Manual - the management of flood liable land'*, New South Wales Government, Department of Infrastructure, Planning and Natural Resources, April 2005.
NSW Government (2007a)	*'Floodplain Risk Management Guideline - Flood Emergency Response Planning Classification Of Communities'*, New South Wales Government, Department of Environment and Climate Change, October 2007.
NSW Government (2007b)	*'Floodplain Risk Management Guideline - Practical Consideration of Climate Change'*, New South Wales Government, Department of Environment and Climate Change, October 2007.
URS (2011)	*'Narrabri Flood Study Review - Additional Assessment'*, Report Prepared for Narrabri Shire Council by URS Australia Pty Ltd, NSW, April 2011.
URS (2014)	*'Narrabri Flood Study Review'*, URS Australia Pty Ltd, NSW, February 2014.
WRM (2016)	*'Narrabri Flood Study: Namoi River, Mulgate Creek and Long Gully'*, Report prepared for Narrabri Shire Council by WRM Water & Environment Pty Ltd, QLD, December 2016.

10 Glossary

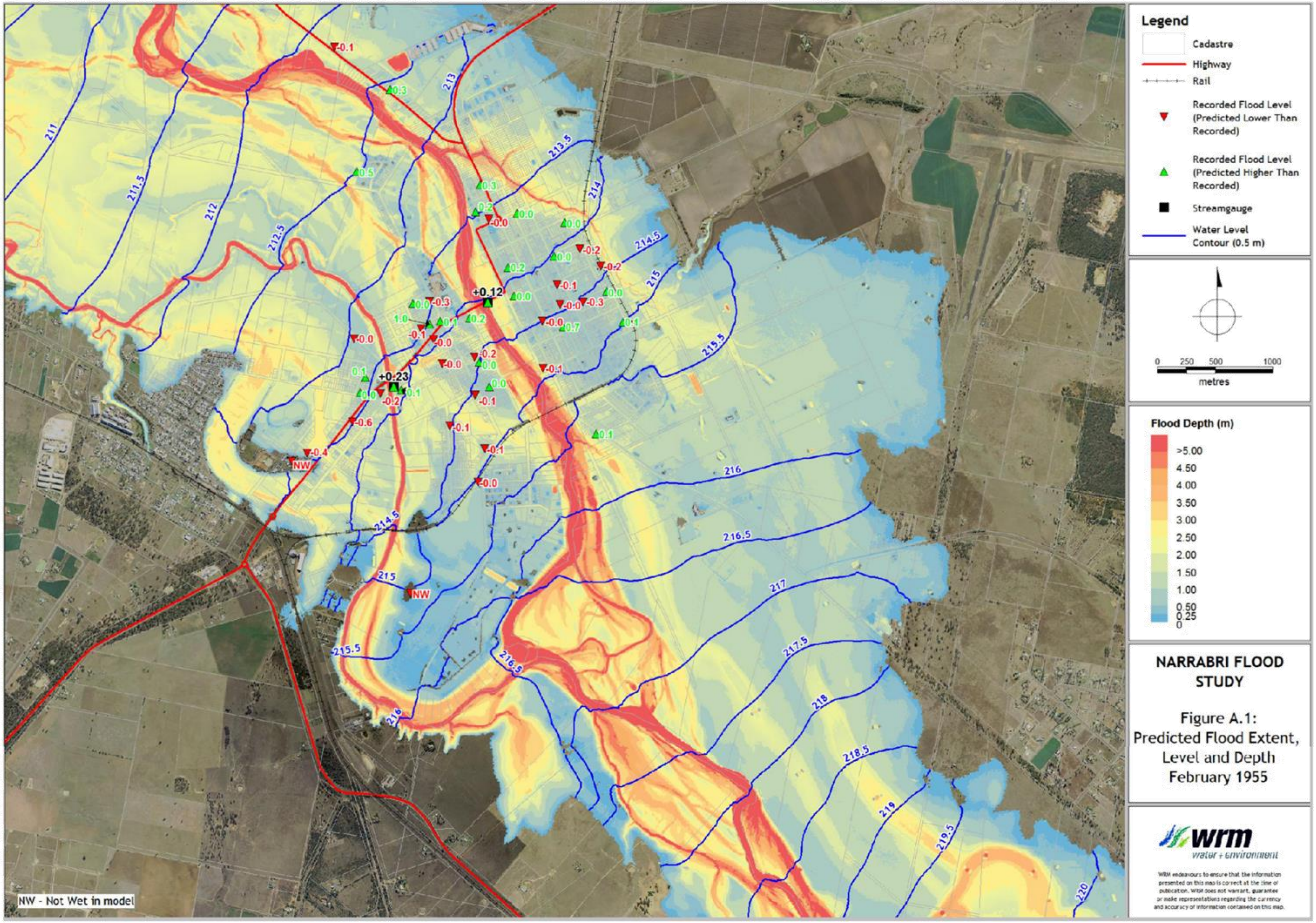
annual exceedance probability (AEP)	the chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. (see ARI)
Australian Height Datum (AHD)	a common national surface level datum approximately corresponding to mean sea level.
average recurrence interval (ARI)	the long-term average number of years between the occurrence of a flood as big as or larger than the selected event.
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.
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).
effective warning time	the time available after receiving advice of an impending flood and before 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	an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
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 PMF event. Note that the term flood liable land covers the whole floodplain, not just that part below the FPL (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.

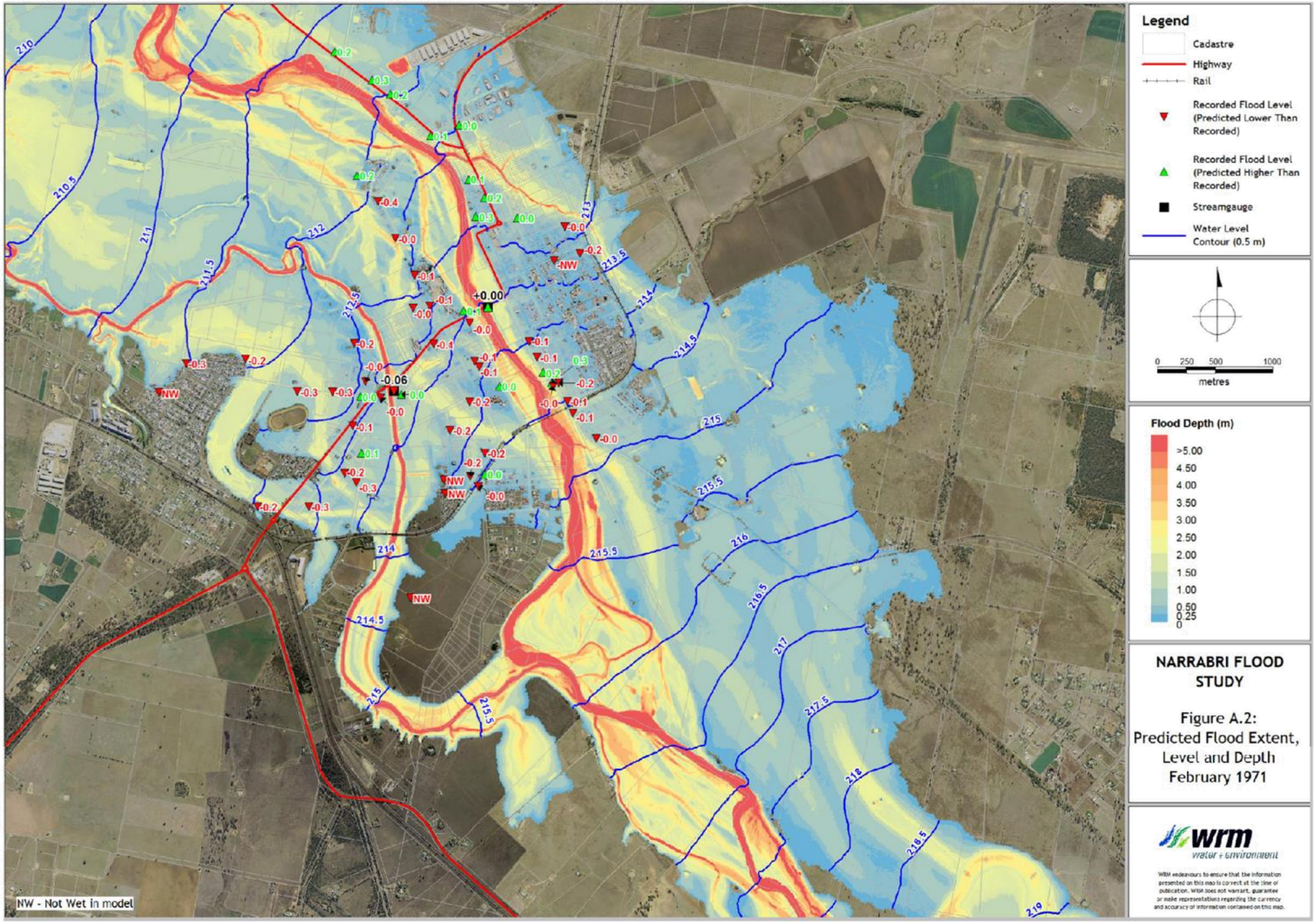
floodplain	area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	the measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain 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 diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	a sub-plan of a disaster plan that deals specifically with flooding. They can exist at state, division and local levels. Local flood plans are prepared under the leadership of the SES.
flood planning area	the area of land below the FPL and thus subject to flood related development controls.
flood planning levels (FPLs)	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.
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	land susceptible to flooding by the PMF event. Flood prone land is synonymous with flood liable land.
flood readiness	readiness is an ability to react within the effective warning time.
flood risk	potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk**: the risk a community is exposed to as a result of its location on the floodplain. **future flood risk**: the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk**: the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.

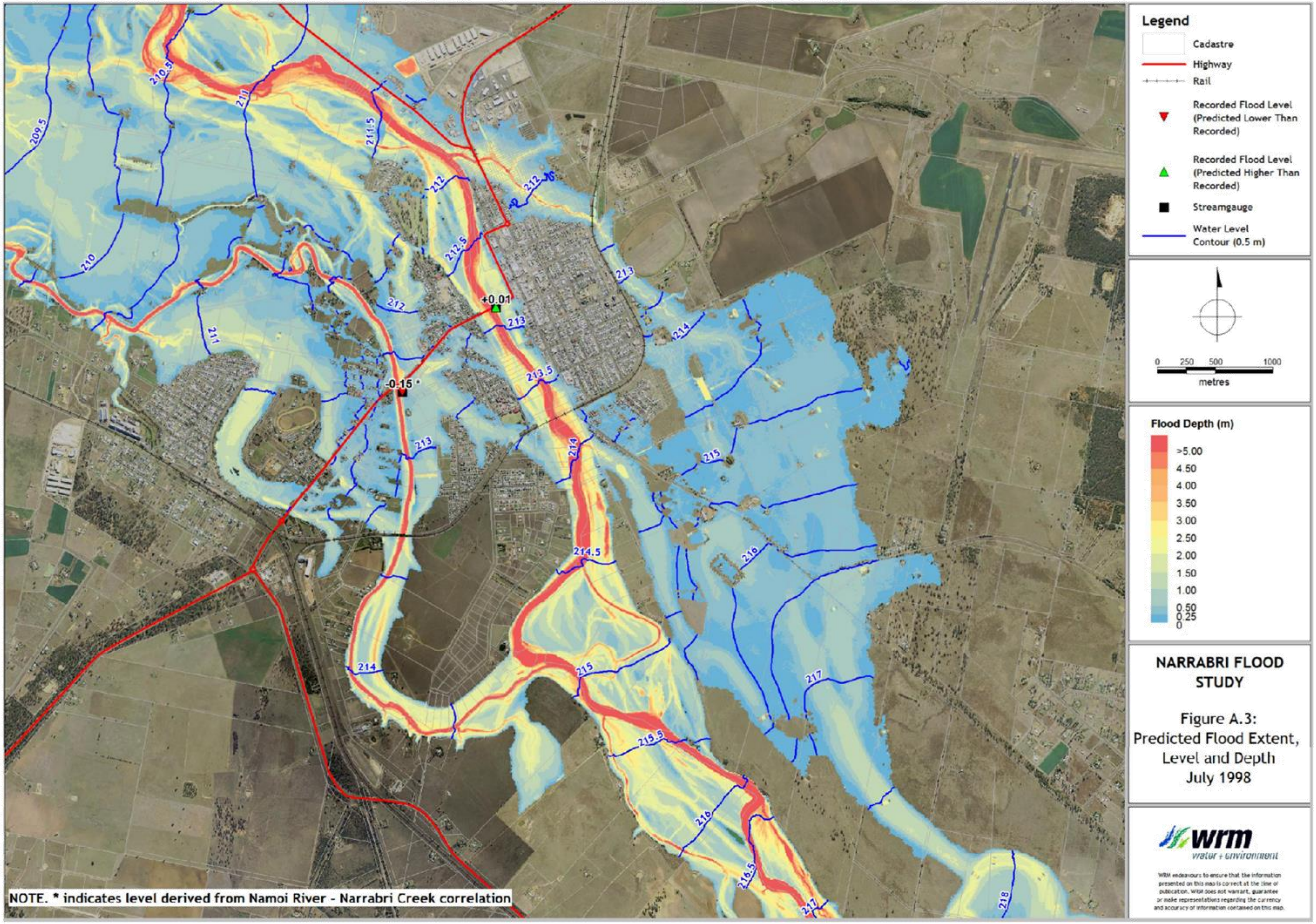
flood storage areas	those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
freeboard	provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
hazard	a source of potential harm or a situation with a potential to cause loss. In relation to this study the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in Appendix L of the Floodplain Development Manual (2005).
historical flood	a flood which has actually occurred.
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.
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.
peak discharge	the maximum discharge occurring during a flood event.
probable maximum flood (PMF)	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.
probable maximum precipitation (PMP)	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 annual exceedance probability).
risk	chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of 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 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.
MIKE-FLOOD	a one-dimensional and two-dimensional flood simulation software. It simulates the complex movement of floodwaters across a particular area of interest using mathematical approximations to derive information on floodwater depths, velocities and levels.
velocity	the speed or rate of motion (distance per unit of time, e.g., metres per second) in a specific direction at which the flood waters are moving.
water surface profile	a graph showing the flood stage at any given location along a watercourse at a particular time.

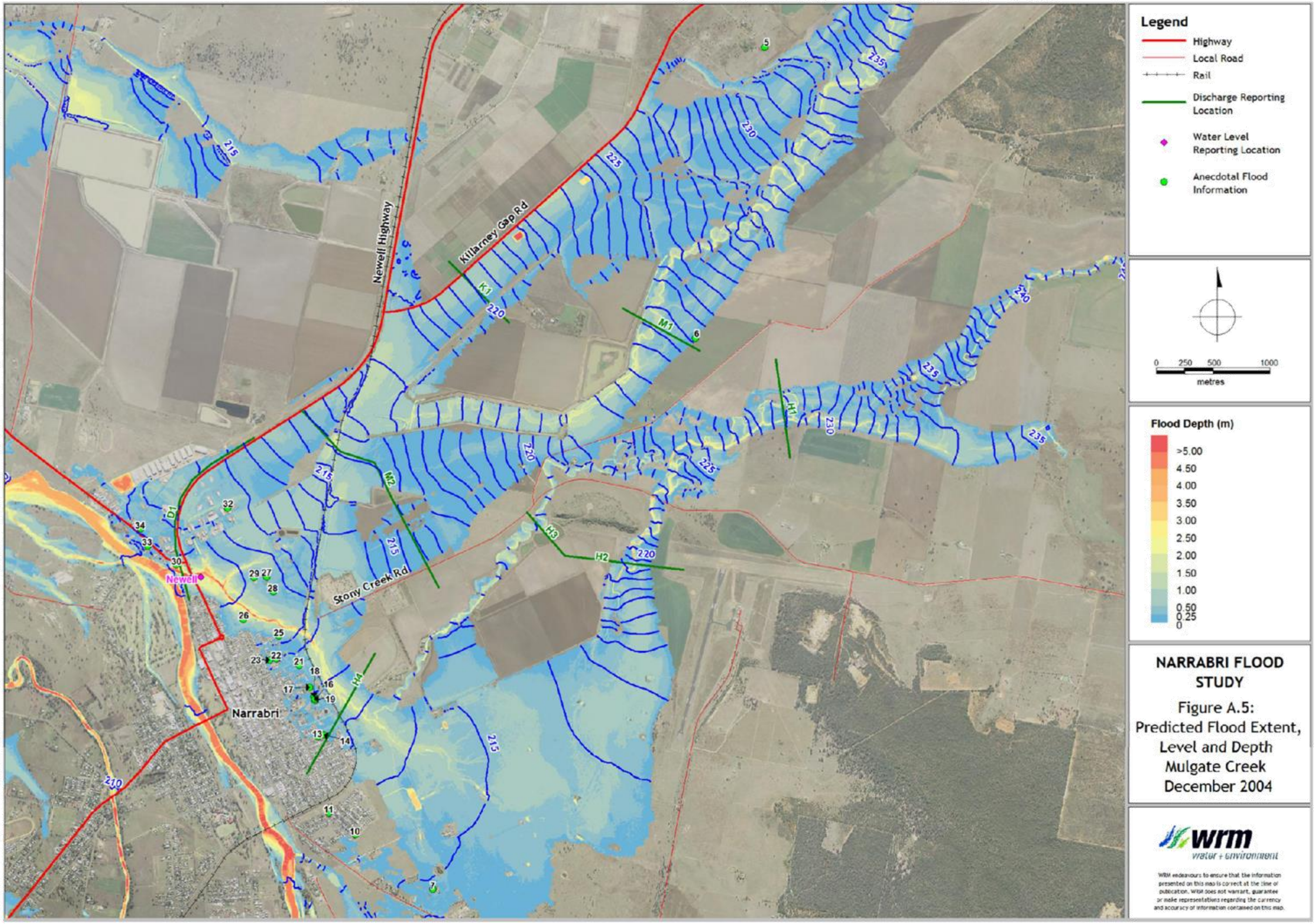
Appendix A - Historical event flood mapping

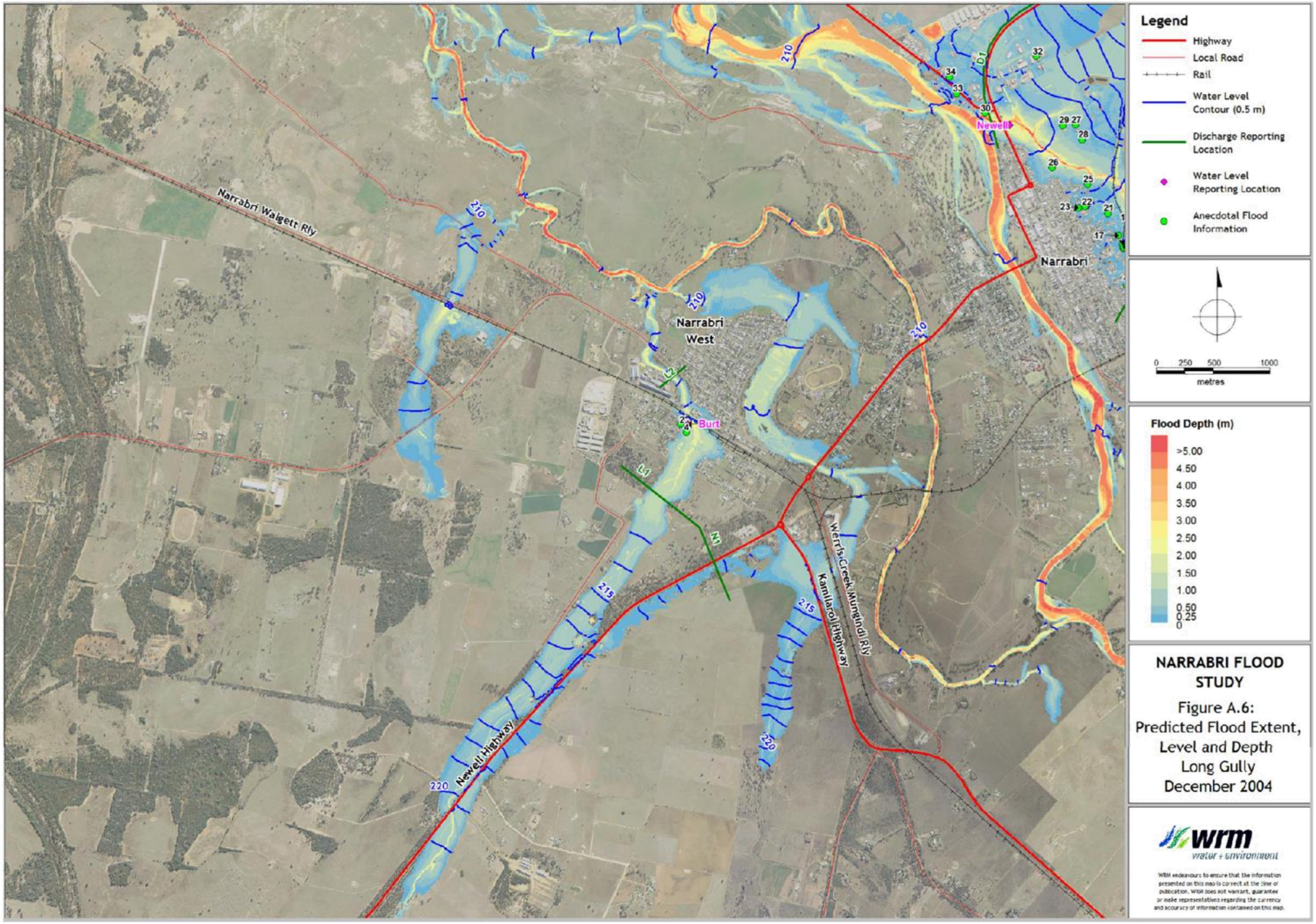

Legend
Cadastre
Highway
Rail
Recorded Flood Level (Predicted Lower Than Recorded)
Recorded Flood Level (Predicted Higher Than Recorded)
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure A.1: Predicted Flood Extent, Level and Depth February 1955
wrm
water + environment
NW - Not Wet in model


Legend
Cadastre
Highway
Rail
Recorded Flood Level (Predicted Lower Than Recorded)
Recorded Flood Level (Predicted Higher Than Recorded)
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure A.2: Predicted Flood Extent, Level and Depth February 1971
wrm
water + environment
WRM endeavours to ensure that the information presented on this map is correct at the time of publication. WRM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained on this map.
NW - Not Wet in model


Legend
Cadastre
Highway
Rail
Recorded Flood Level (Predicted Lower Than Recorded)
Recorded Flood Level (Predicted Higher Than Recorded)
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure A.3: Predicted Flood Extent, Level and Depth July 1998
wrm
water + environment
NOTE. * indicates level derived from Namoi River - Narrabri Creek correlation
+0.01
-0.15 *
209.5
210
210.5
211
211.5
212
212.5
213
213.5
214
214.5
215
215.5
216
216.5
217
218

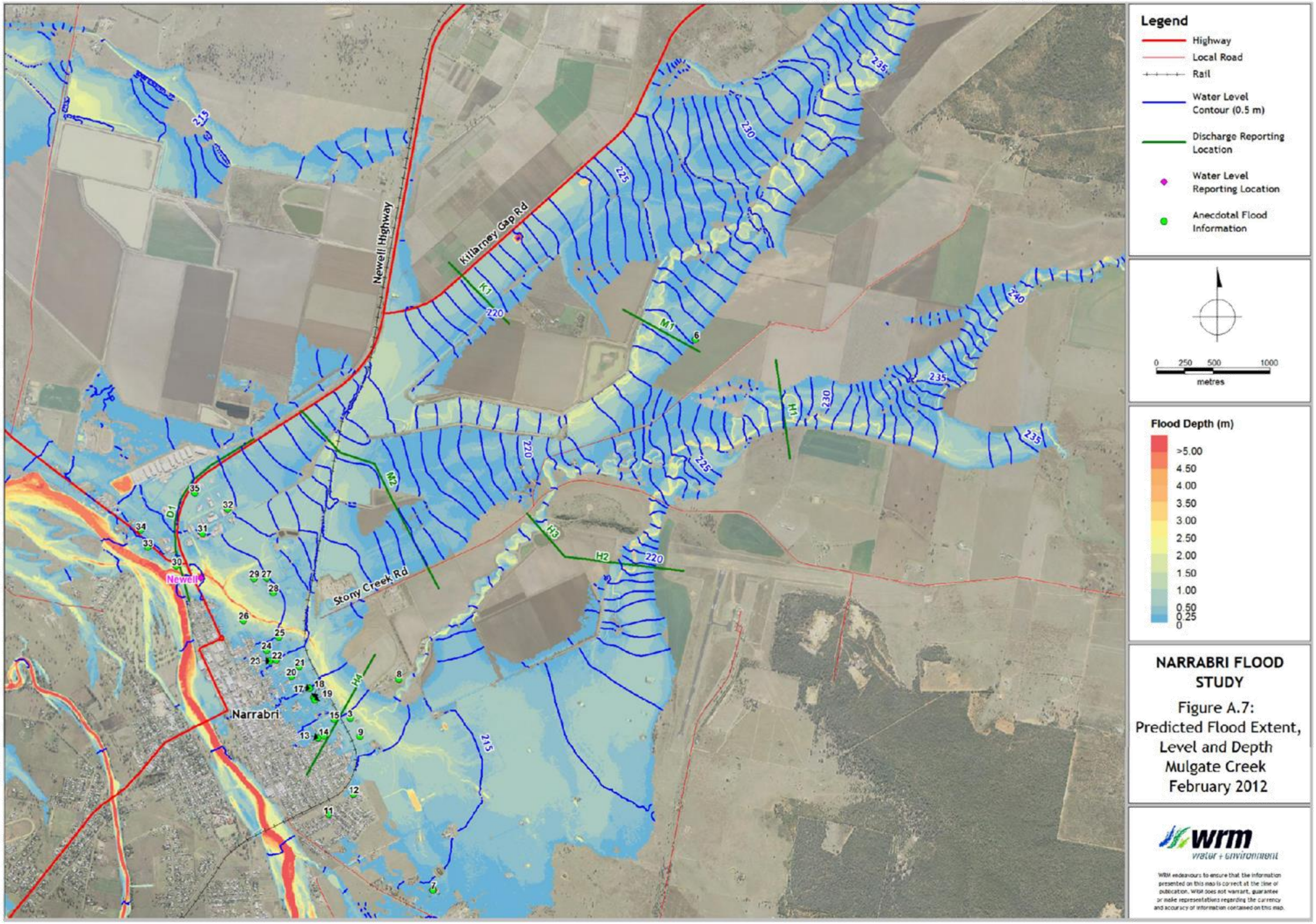
Legend
Cadastre
Highway
Rail
Streamgauge
419003
419002
0 250 500 1000
metres
Predicted Flood Extent
NARRABRI FLOOD STUDY
Figure A.4: Predicted and Observed Flood Extents July 1998
wrm
water + environment
WRM endeavours to ensure that the information presented on this map is correct at the time of publication. WRM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained on this map.

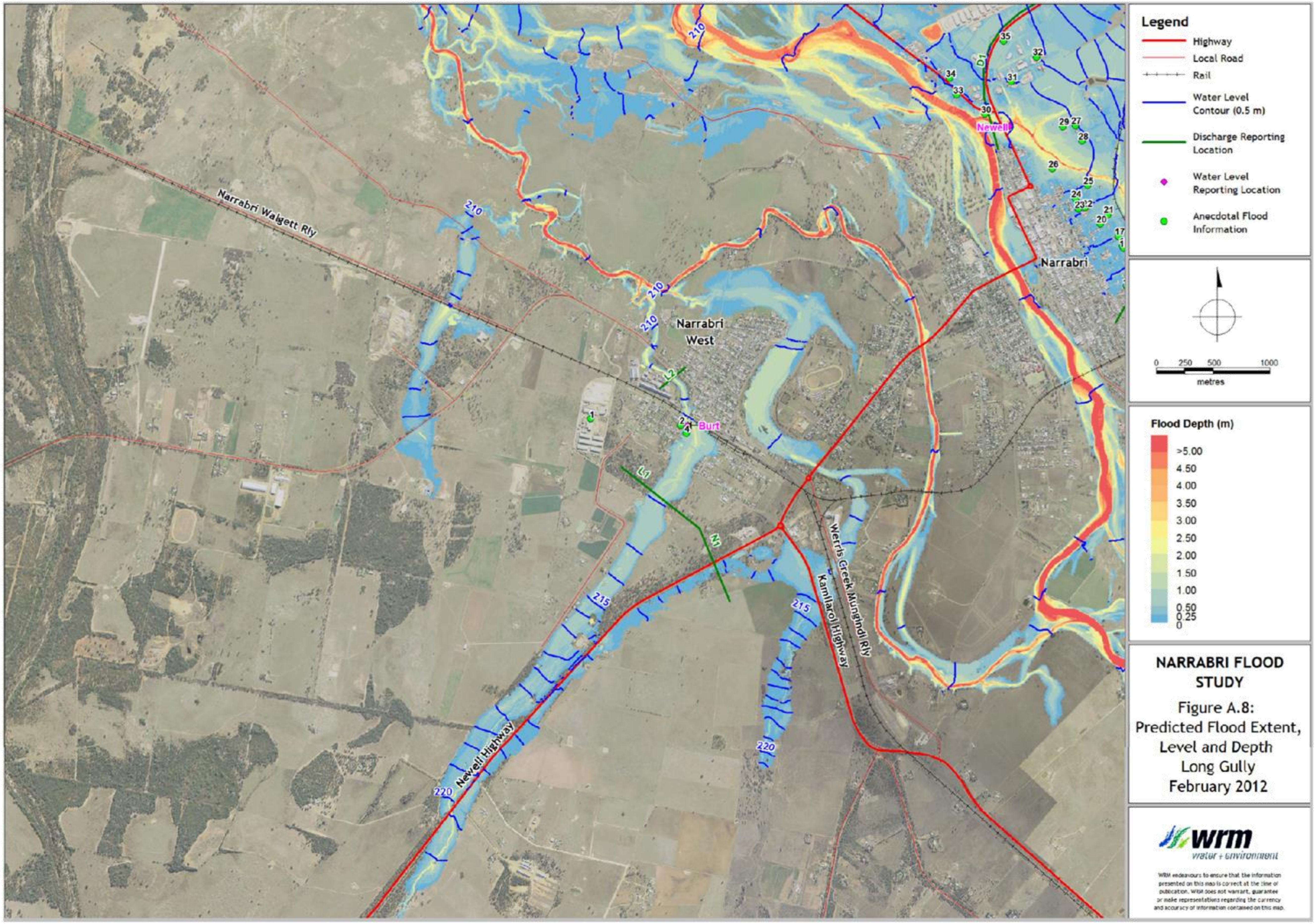

Legend
Highway
Local Road
Rail
Discharge Reporting Location
Water Level Reporting Location
Anecdotal Flood Information
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure A.5:
Predicted Flood Extent, Level and Depth
Mulgate Creek
December 2004
wrm
water + environment
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri
Newell



NARRABRI FLOOD STUDY

Figure A.6: Predicted Flood Extent, Level and Depth Long Gully December 2004

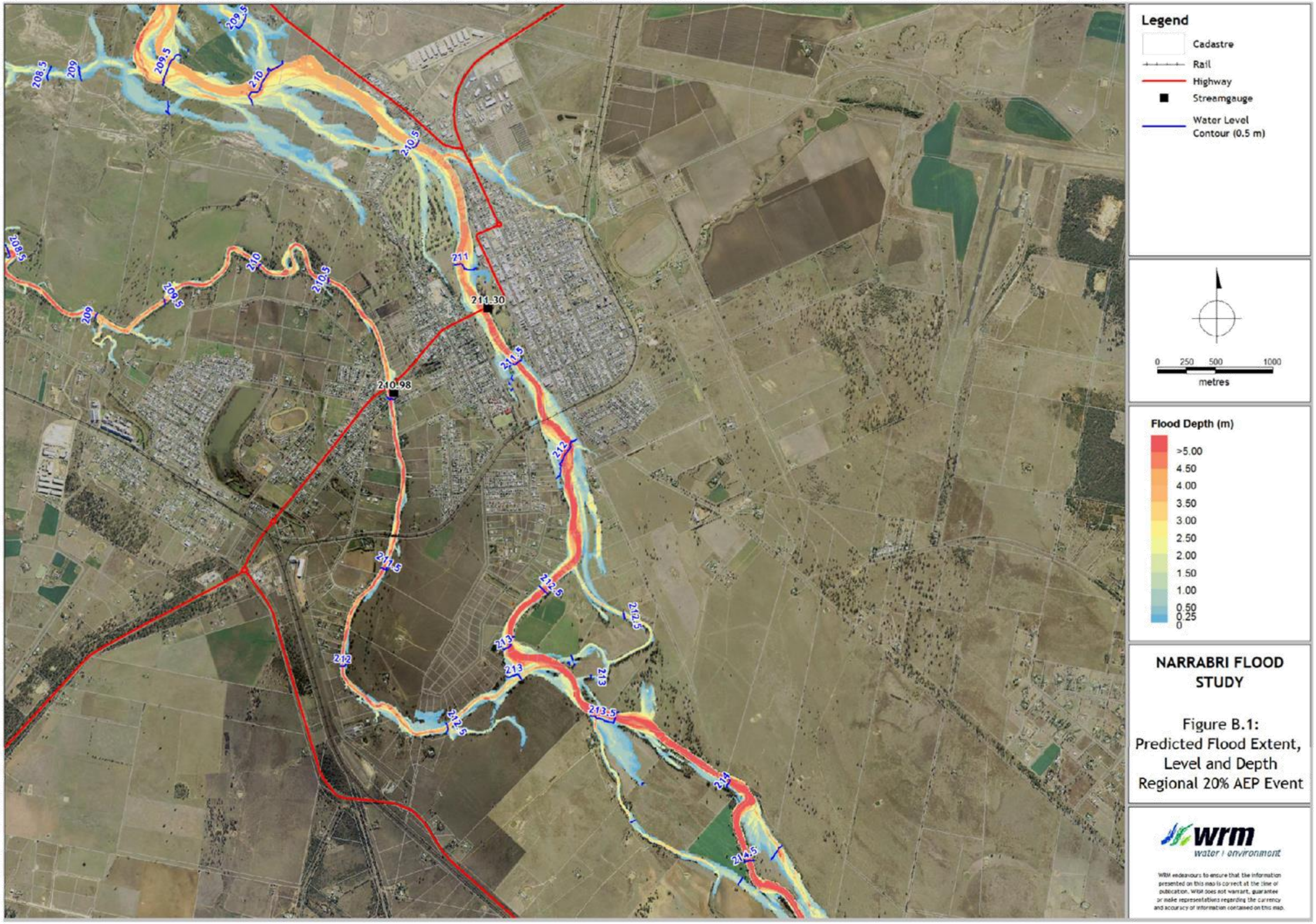

Legend
Highway
Local Road
Rail
Water Level Contour (0.5 m)
Discharge Reporting Location
Water Level Reporting Location
Anecdotal Flood Information
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure A.7: Predicted Flood Extent, Level and Depth Mulgate Creek February 2012
wrm water + environment
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri
Newell

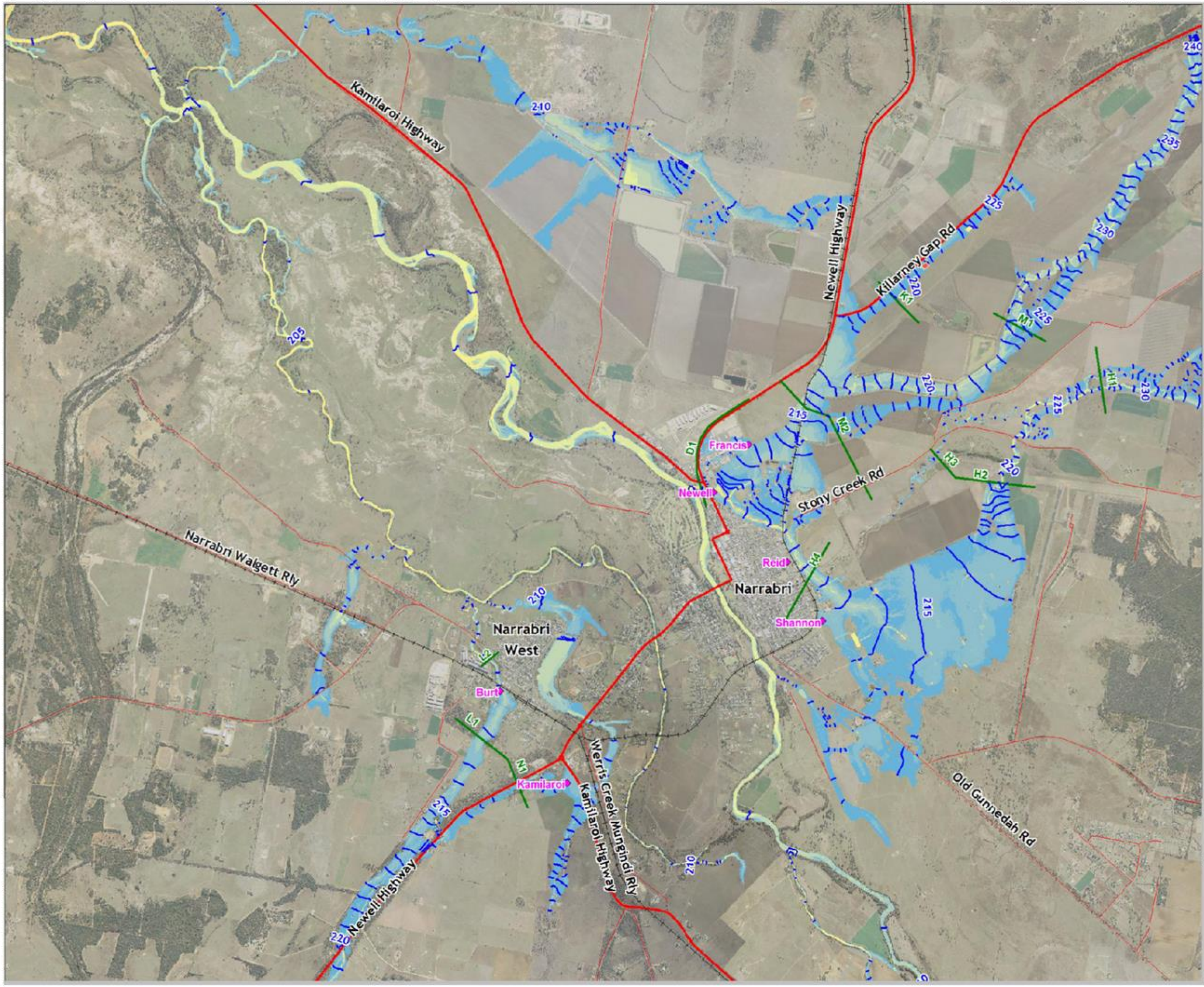


NARRABRI FLOOD STUDY

Figure A.8:
Predicted Flood Extent, Level and Depth
Long Gully
February 2012

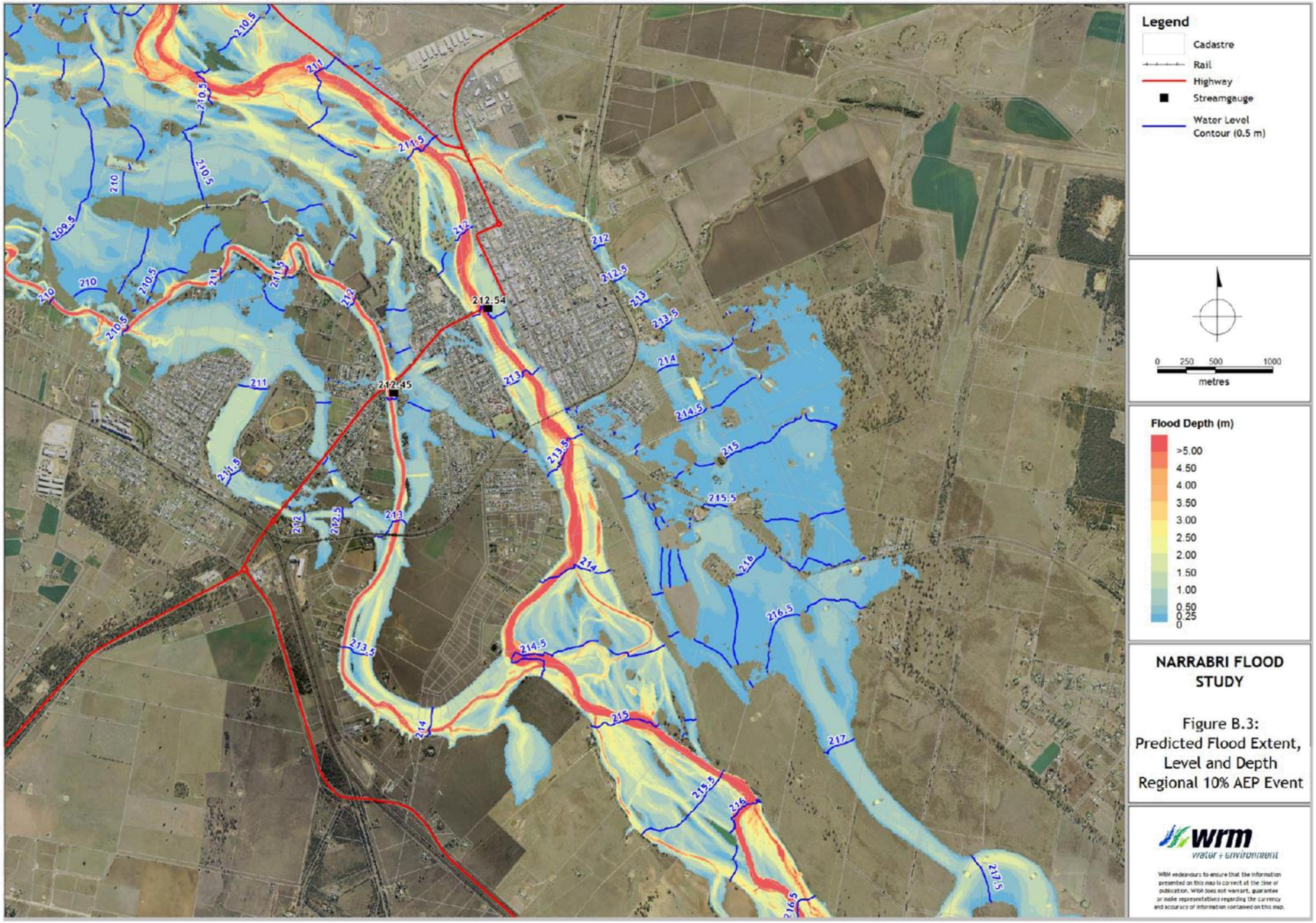
Appendix B - Design flood mapping

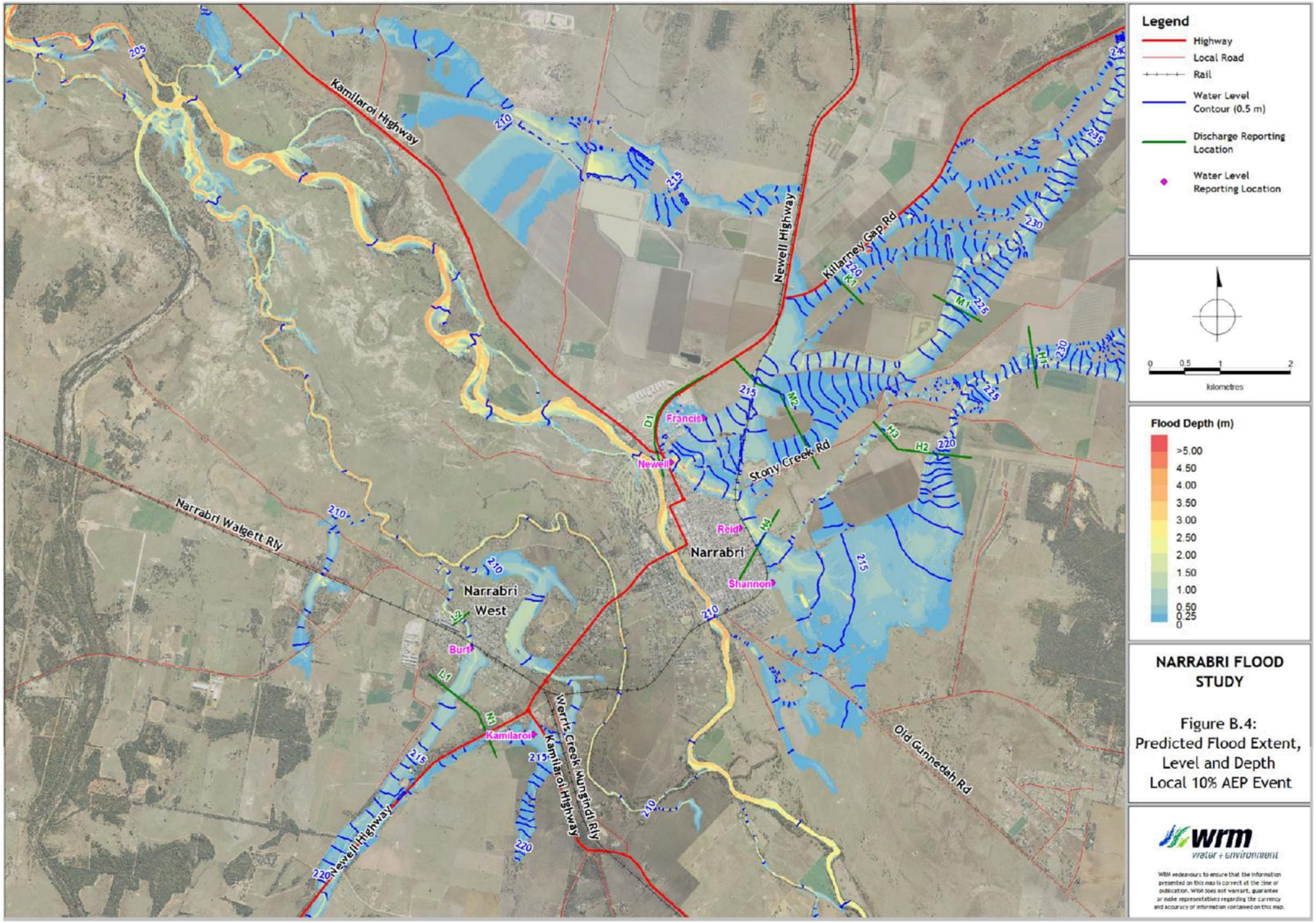

Legend
Cadastre
Rail
Highway
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.1:
Predicted Flood Extent, Level and Depth
Regional 20% AEP Event
wrm
water / environment
211.30
210.98

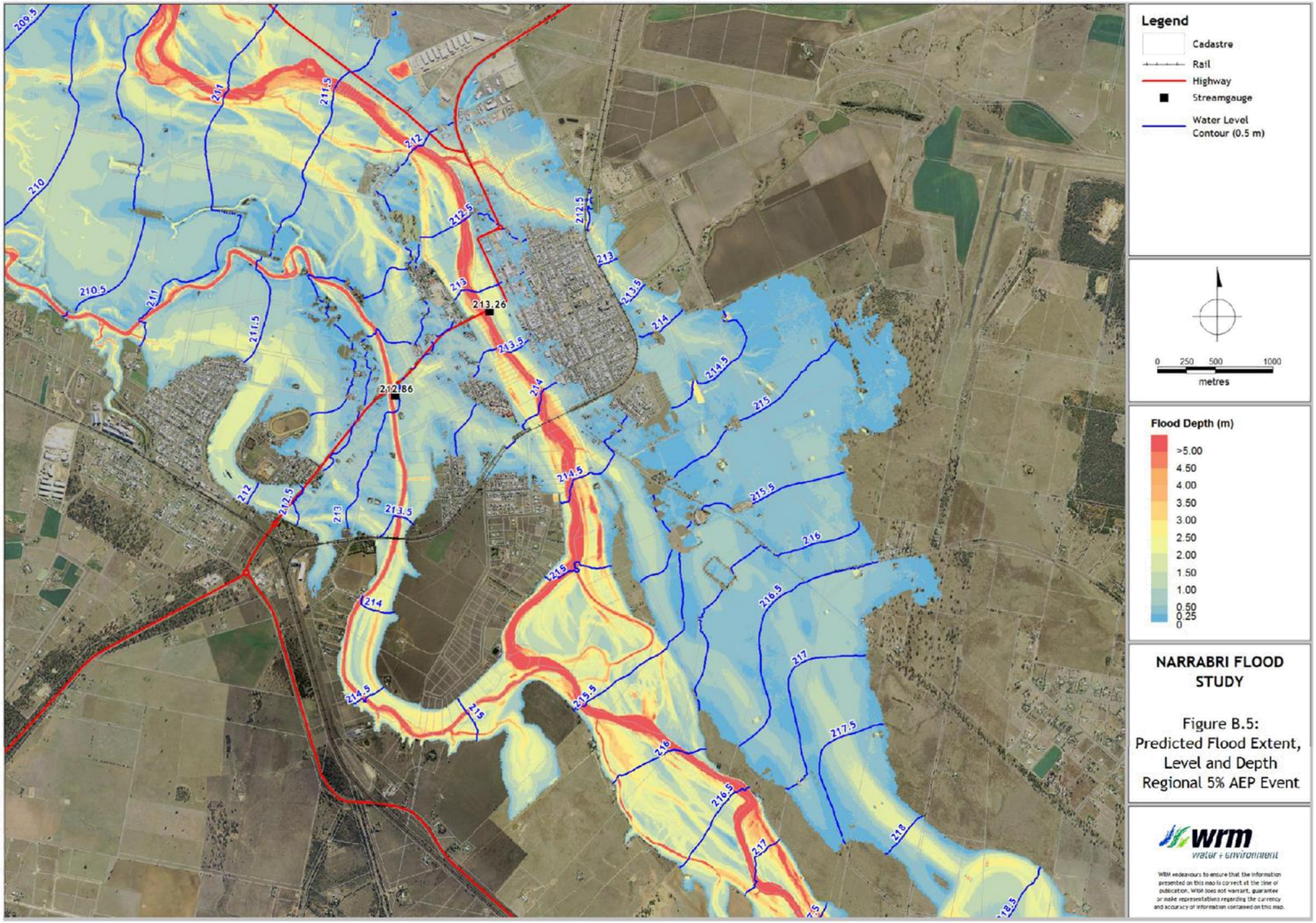


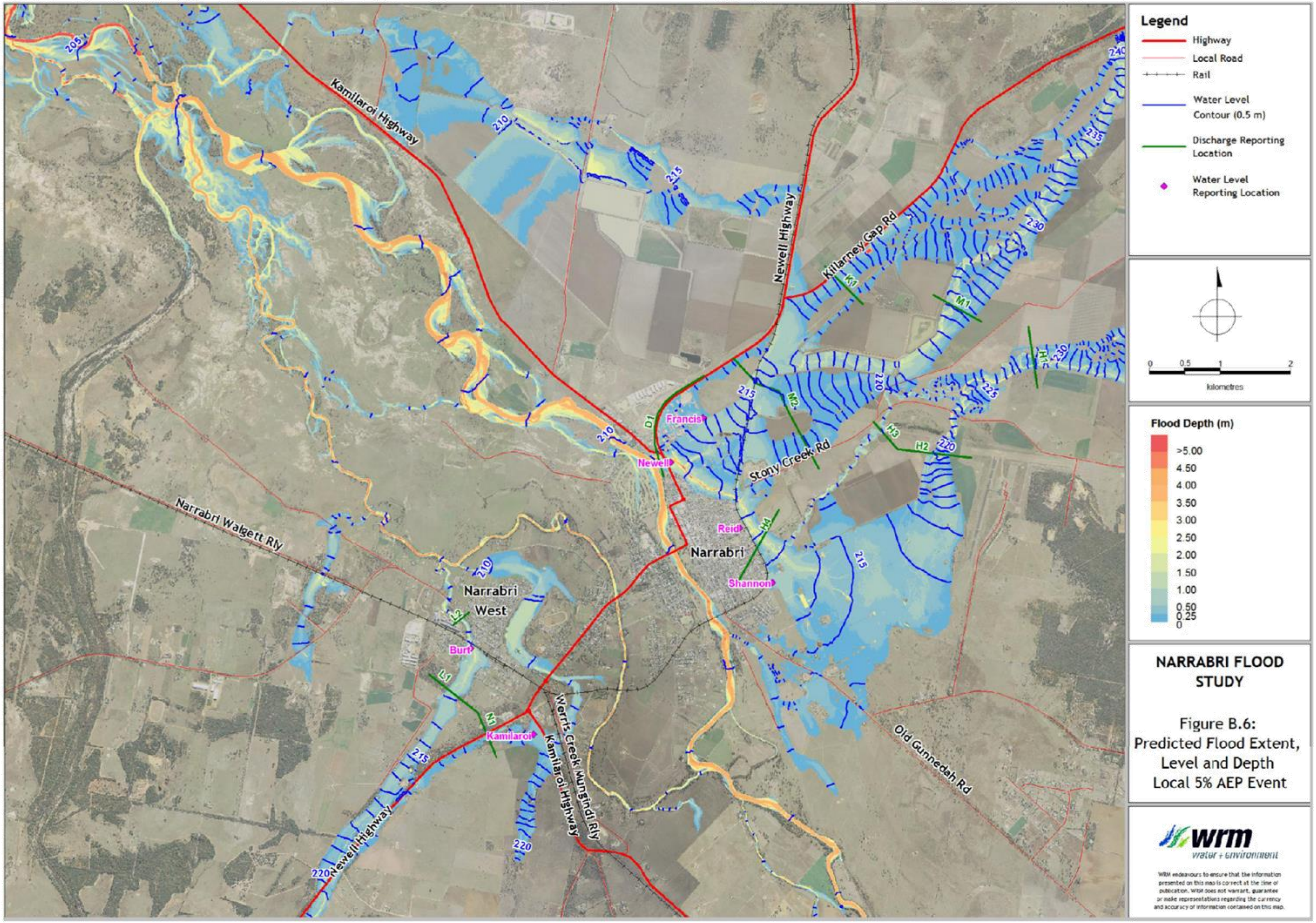
NARRABRI FLOOD STUDY

Figure B.2: Predicted Flood Extent, Level and Depth Local 20% AEP Event


Legend
Cadastre
Rail
Highway
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.3:
Predicted Flood Extent,
Level and Depth
Regional 10% AEP Event
wrm
water + environment
WRM endeavours to ensure that the information presented on this map is correct at the time of publication. WRM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained on this map.
212.54
212.45

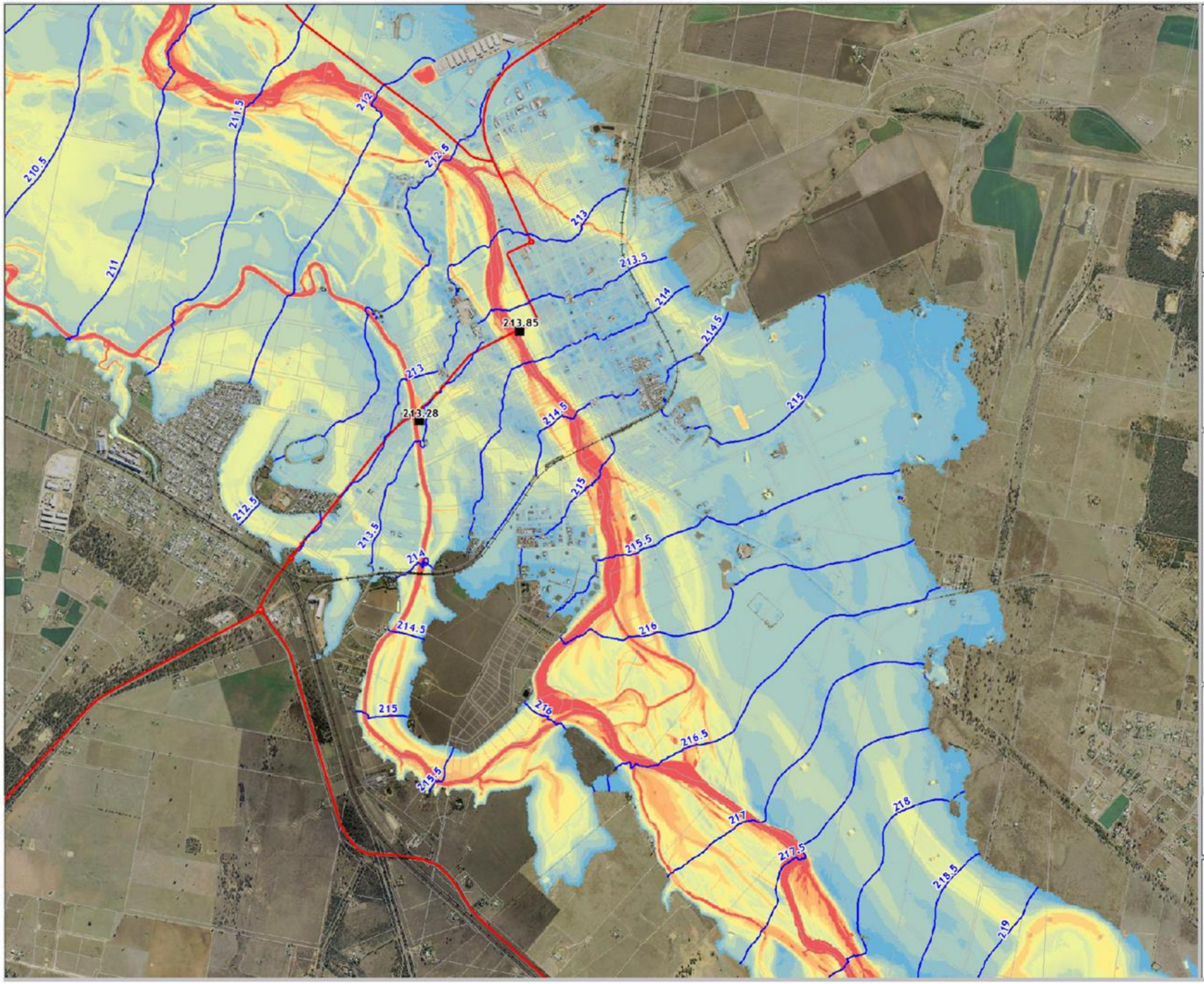

Legend
Highway
Local Road
Rail
Water Level Contour (0.5 m)
Discharge Reporting Location
Water Level Reporting Location
kilometres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
Kamilaroi Highway
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri Walgett Rly
Narrabri
Narrabri West
Werris Creek Mungindi Rly
Old Gunnedah Rd
Francis
Newell
Reid
Shannon
Burt
Kamilaroi
NARRABRI FLOOD STUDY
Figure B.4:
Predicted Flood Extent, Level and Depth
Local 10% AEP Event
wrm water + environment
WRM endeavours to ensure that the information presented on this map is correct at the time of publication. WRM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained on this map.


Legend
Cadastre
Rail
Highway
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.5: Predicted Flood Extent, Level and Depth Regional 5% AEP Event
wrm
water + environment
213.26
212.86



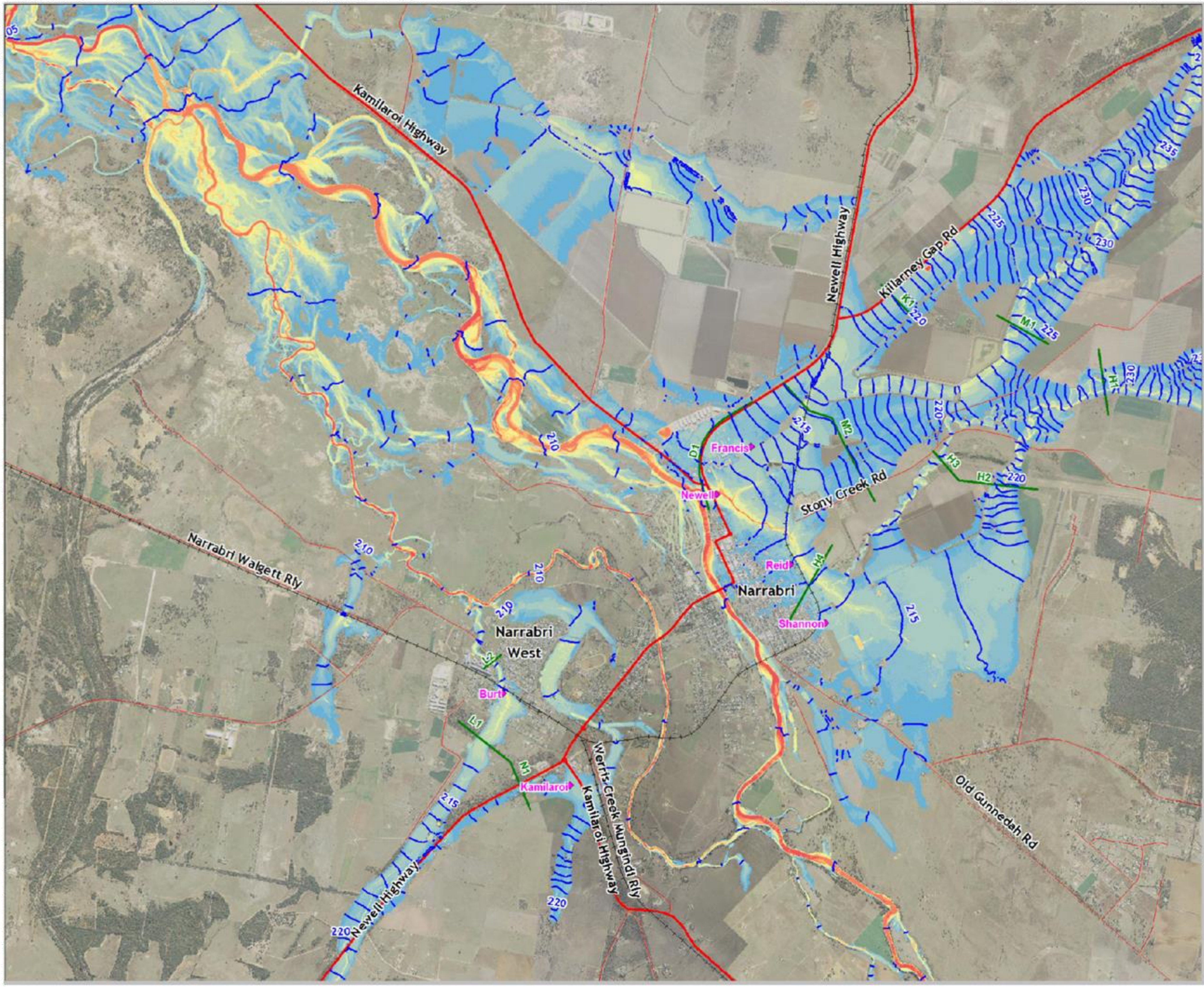
NARRABRI FLOOD STUDY

Figure B.6: Predicted Flood Extent, Level and Depth Local 5% AEP Event



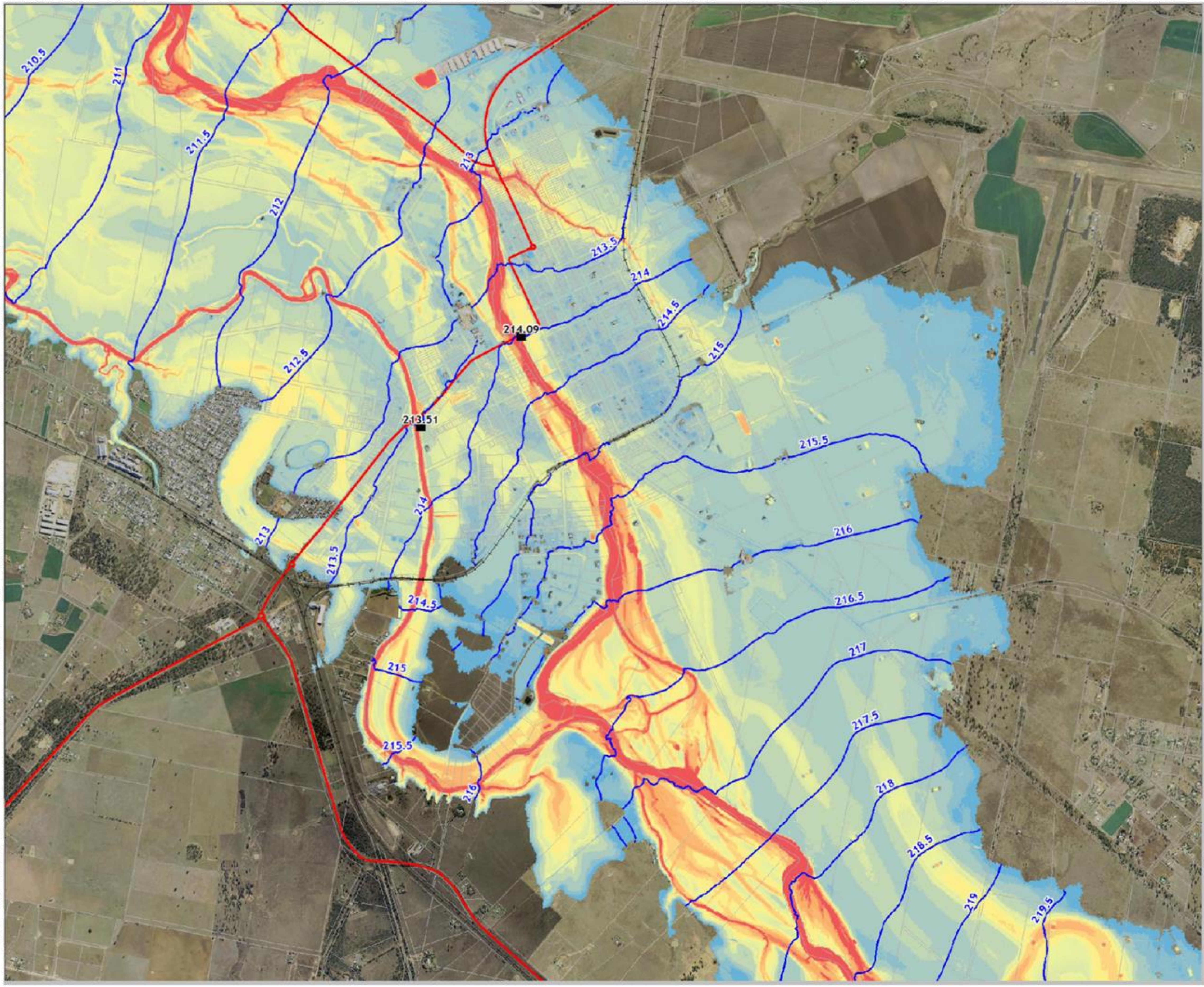
NARRABRI FLOOD STUDY

Figure B.7: Predicted Flood Extent, Level and Depth Regional 2% AEP Event



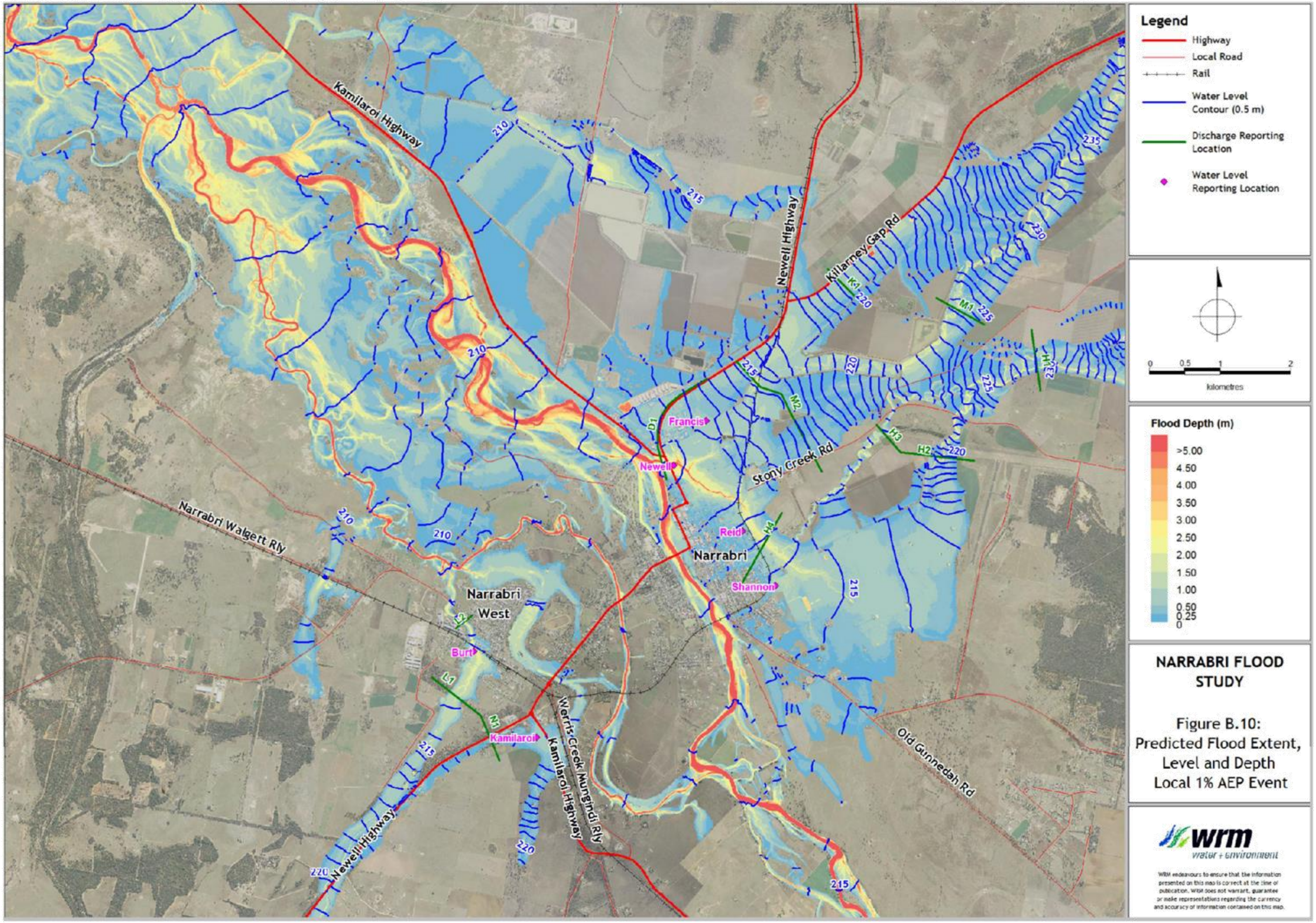
NARRABRI FLOOD STUDY

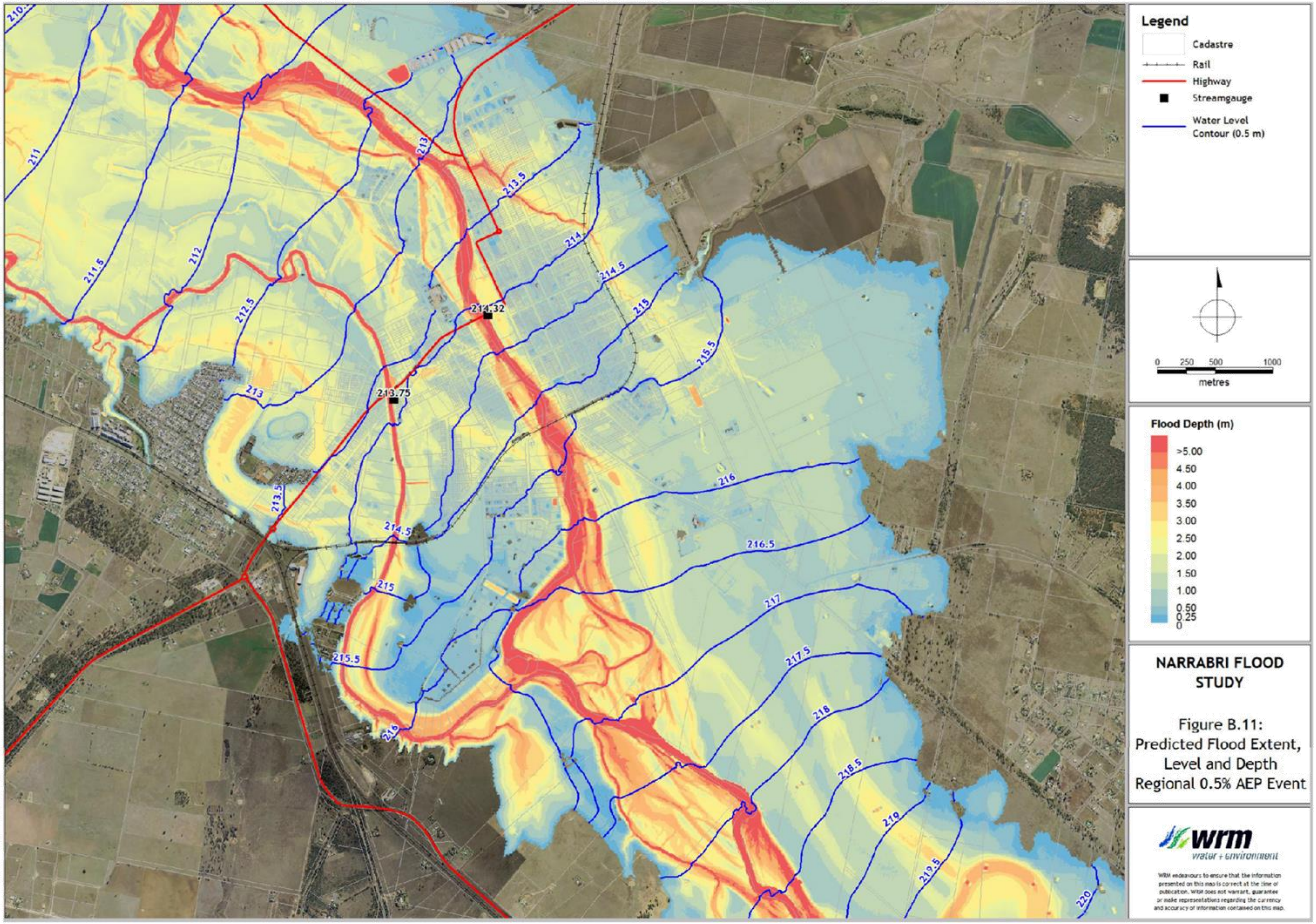
Figure B.8: Predicted Flood Extent, Level and Depth Local 2% AEP Event



NARRABRI FLOOD STUDY

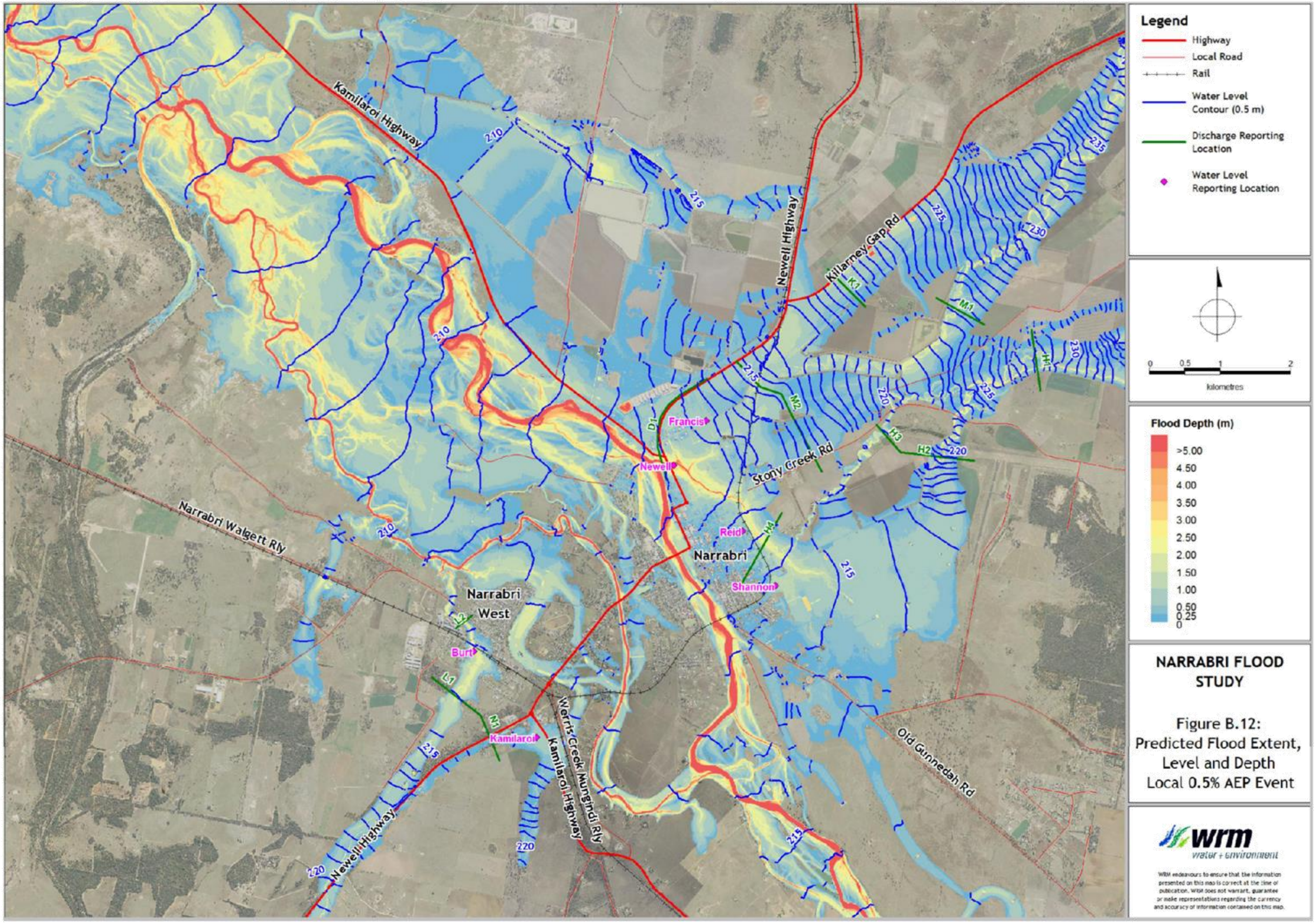
Figure B.9: Predicted Flood Extent, Level and Depth Regional 1% AEP Event

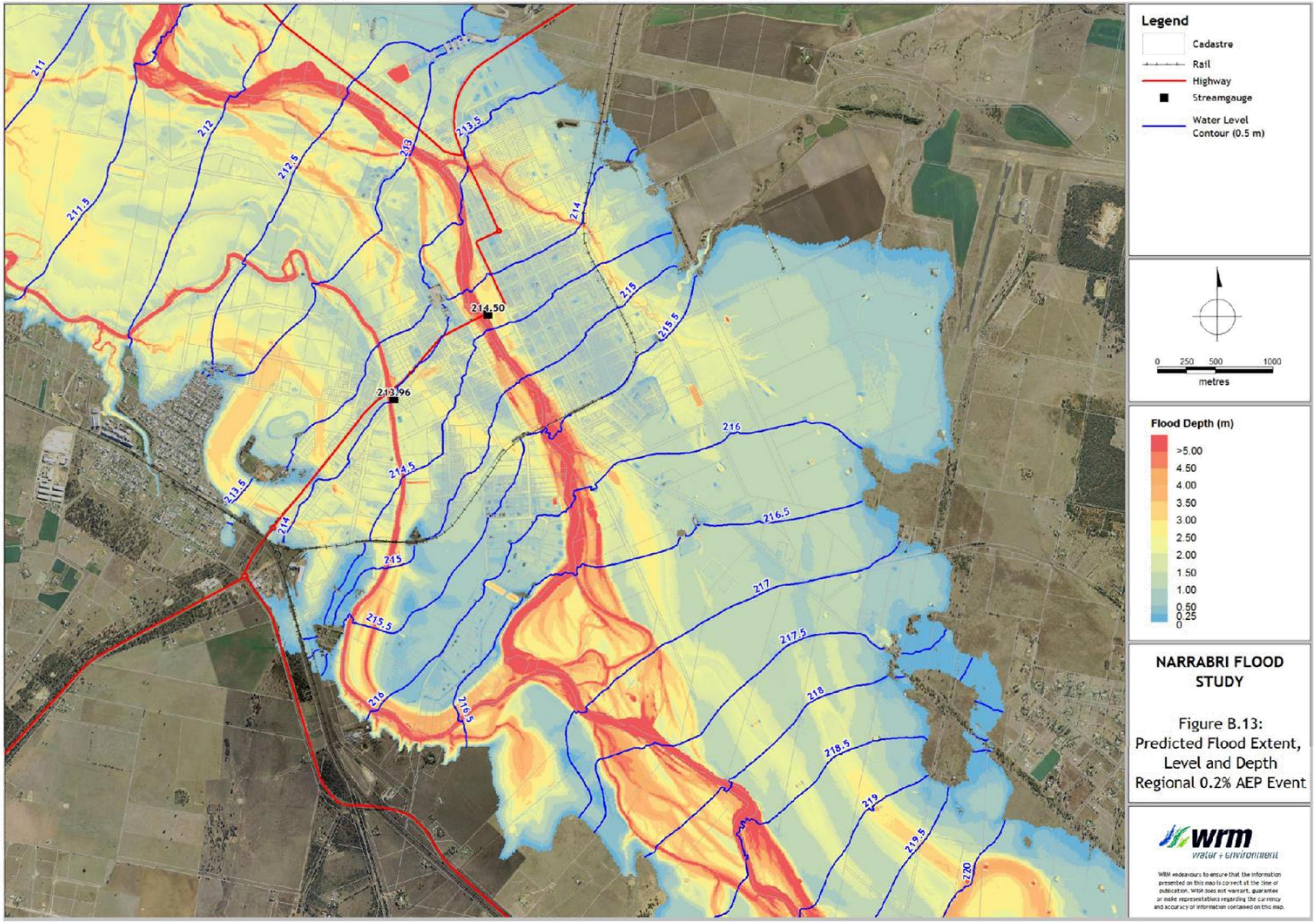

Legend
Highway
Local Road
Rail
Water Level Contour (0.5 m)
Discharge Reporting Location
Water Level Reporting Location
0 0.5 1 2
kilometres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.10: Predicted Flood Extent, Level and Depth Local 1% AEP Event
wrm
water + environment
Kamilaroi Highway
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri Walgett Rly
Old Gunnedah Rd
Narrabri
Narrabri West
Wee Waa Creek Mungindi Rly
Francis
Newell
Reid
Shannon
Burt
Kamilaroi

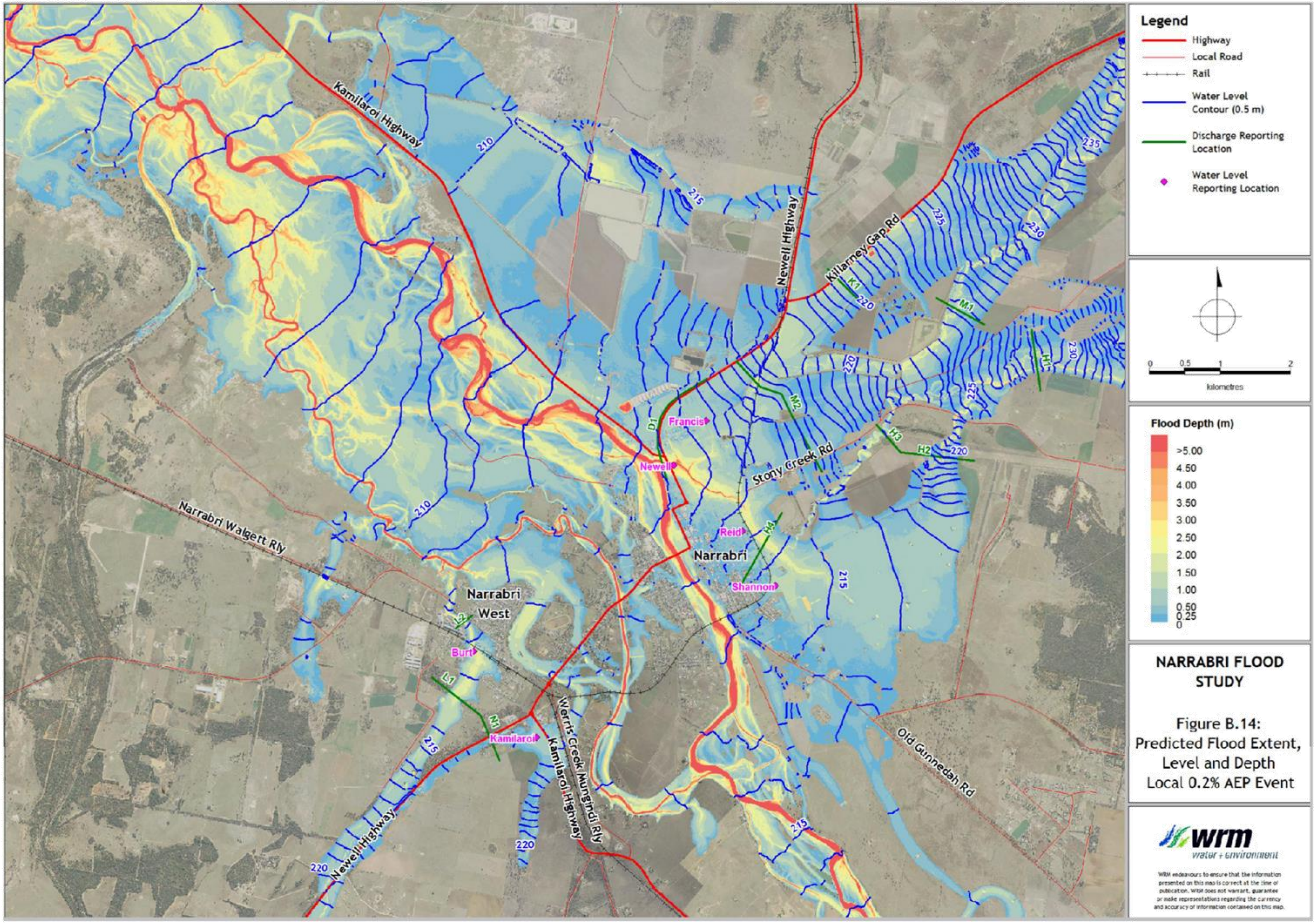


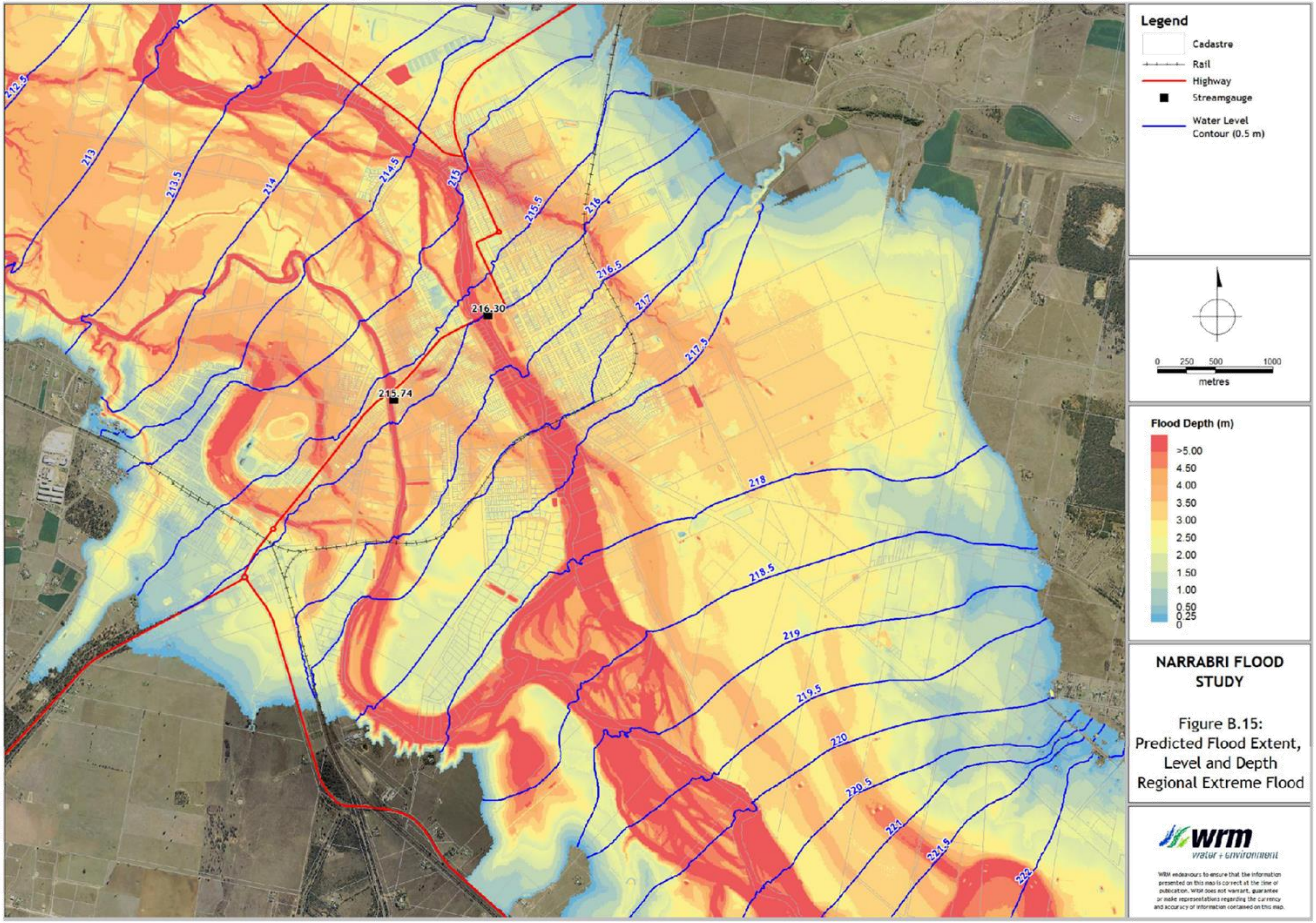
NARRABRI FLOOD STUDY

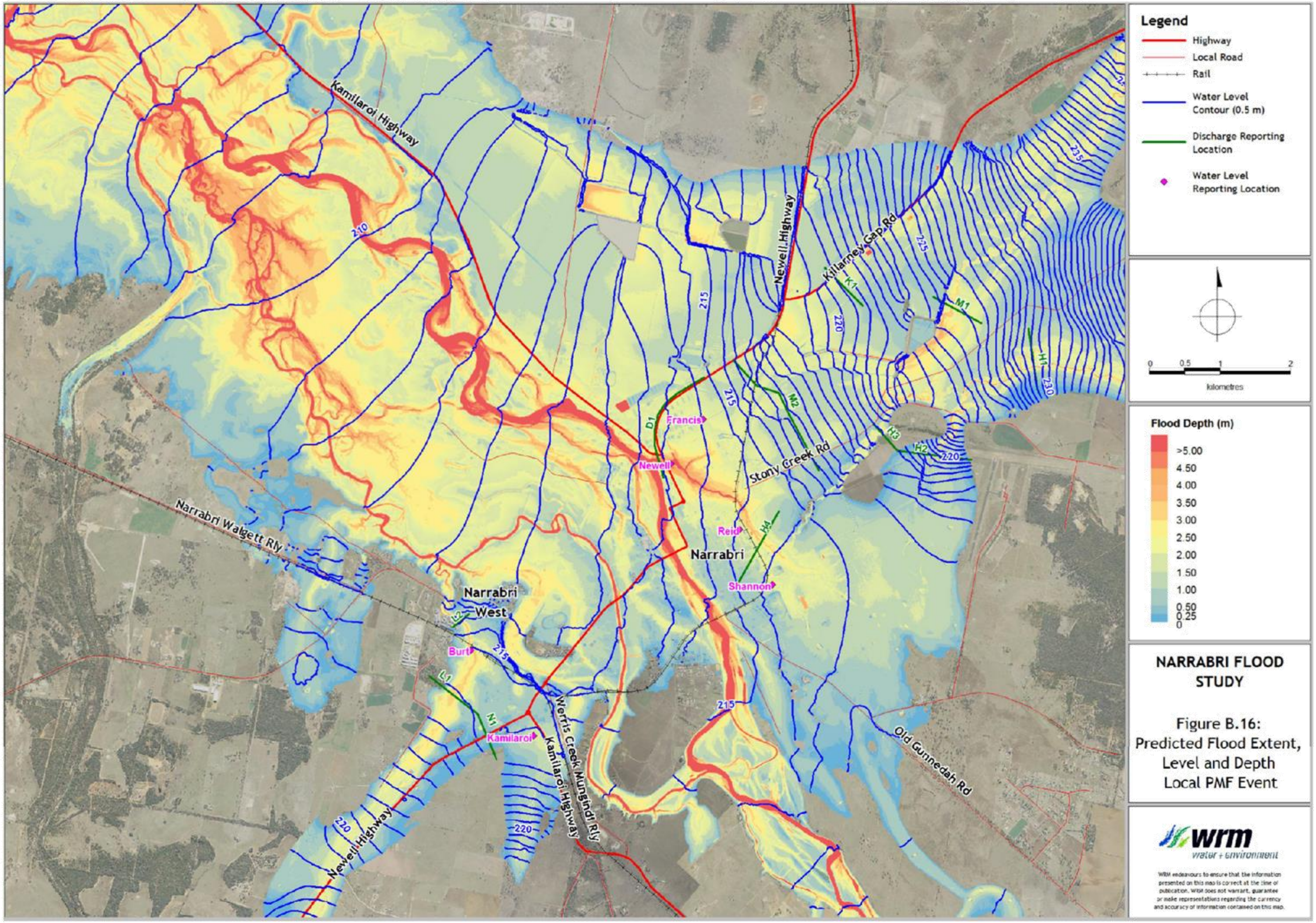
Figure B.11: Predicted Flood Extent, Level and Depth Regional 0.5% AEP Event


Legend
Highway
Local Road
Rail
Water Level Contour (0.5 m)
Discharge Reporting Location
Water Level Reporting Location
0 0.5 1 2
kilometres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.12: Predicted Flood Extent, Level and Depth Local 0.5% AEP Event
wrm
water + environment
Kamilaroi Highway
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri Walgett Rly
Narrabri
Narrabri West
Werris Creek Mungindi Rly
Old Gunnedah Rd
Francis
Newell
Reid
Shannon
Burt
Kamilaroi

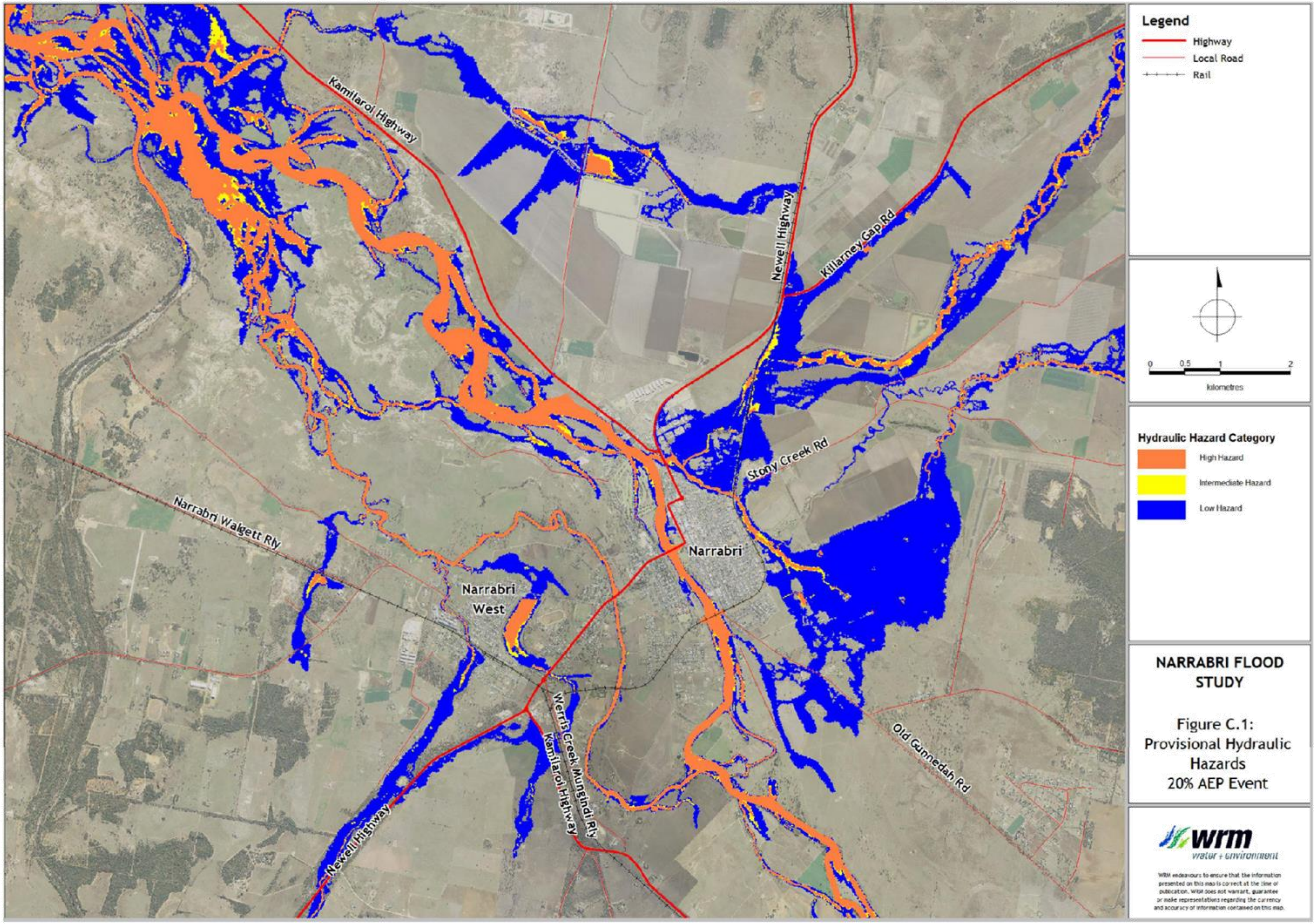

Legend
Cadastre
Rail
Highway
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.13:
Predicted Flood Extent, Level and Depth
Regional 0.2% AEP Event
wrm
water + environment
WRM endeavours to ensure that the information presented on this map is correct at the time of publication. WRM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained on this map.
214.50
213.96
211
211.5
212
212.5
213
213.5
214
214.5
215
215.5
216
216.5
217
217.5
218
218.5
219
219.5
220


Legend
Highway
Local Road
Rail
Water Level Contour (0.5 m)
Discharge Reporting Location
Water Level Reporting Location
0 0.5 1 2
kilometres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.14:
Predicted Flood Extent, Level and Depth
Local 0.2% AEP Event
wrm
water + environment
Kamilaroi Highway
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri Walgett Rly
Narrabri
Narrabri West
Wee Waa Creek Mungindi Rly
Kamilaroi Highway
Newell Highway
Old Gunnedah Rd
Francis
Newell
Reid
Shannon
Burt
Kamilaroi
K1
M1
H1
M2
H3
H2
H4
D1
L1
L2
N1
210
215
220
225
230
235


Legend
Cadastre
Rail
Highway
Streamgauge
Water Level Contour (0.5 m)
0 250 500 1000
metres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.15: Predicted Flood Extent, Level and Depth Regional Extreme Flood
wrm
water + environment
WRM endeavours to ensure that the information presented on this map is correct at the time of publication. WRM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained on this map.
216.30
215.74
212.5
213
213.5
214
214.5
215
215.5
216
216.5
217
217.5
218
218.5
219
219.5
220
220.5
221
221.5
222


Legend
Highway
Local Road
Rail
Water Level Contour (0.5 m)
Discharge Reporting Location
Water Level Reporting Location
0 0.5 1 2
kilometres
Flood Depth (m)
>5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.25
0
NARRABRI FLOOD STUDY
Figure B.16:
Predicted Flood Extent, Level and Depth
Local PMF Event
wrm
water + environment
Kamilaroi Highway
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri Walgett Rly
Narrabri
Narrabri West
Werris Creek Mungindi Rly
Old Gunnedah Rd
Francis
Newell
Reid
Shannon
Burt
Kamilaroi

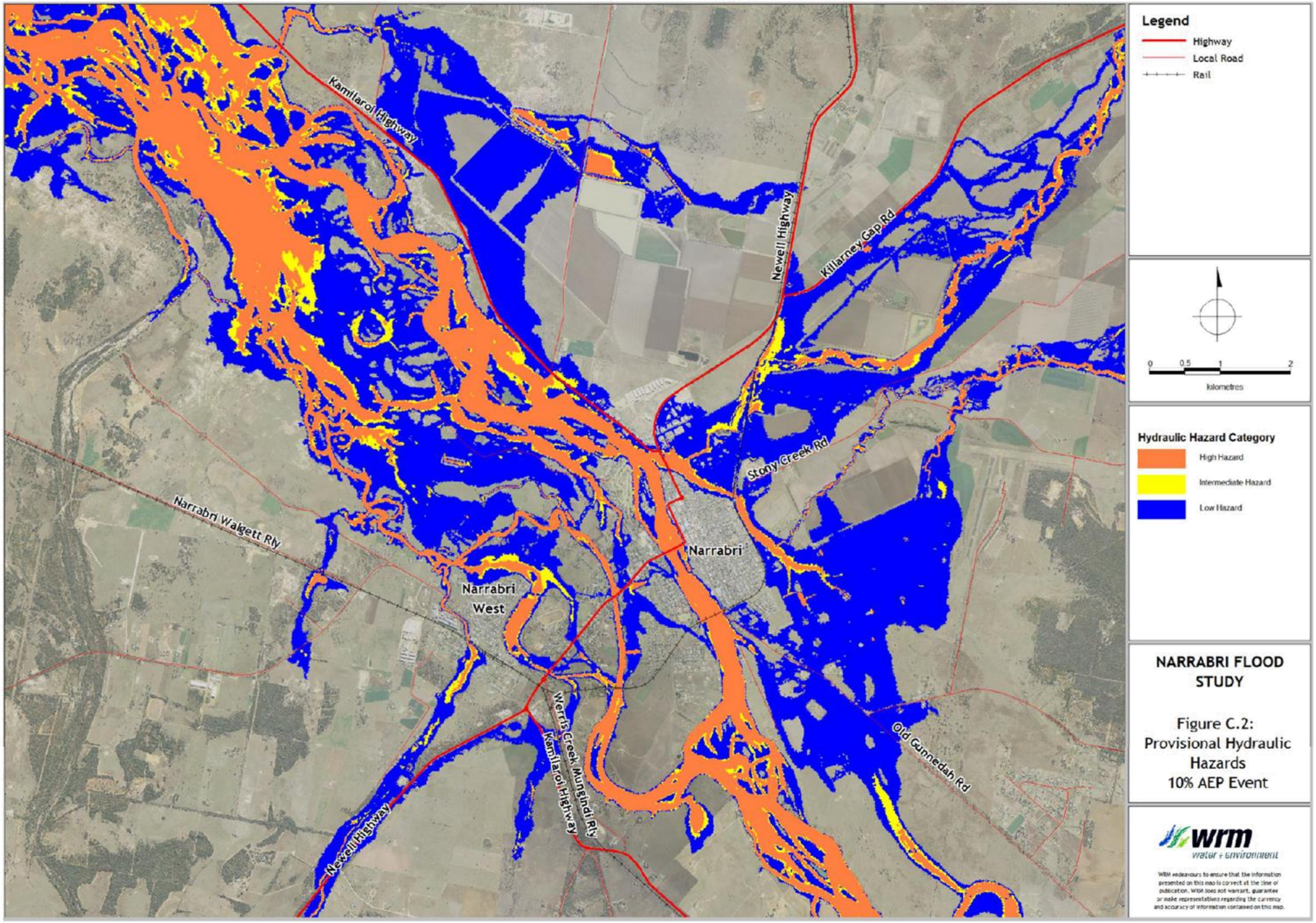
Appendix C - Provisional hydraulic hazard mapping

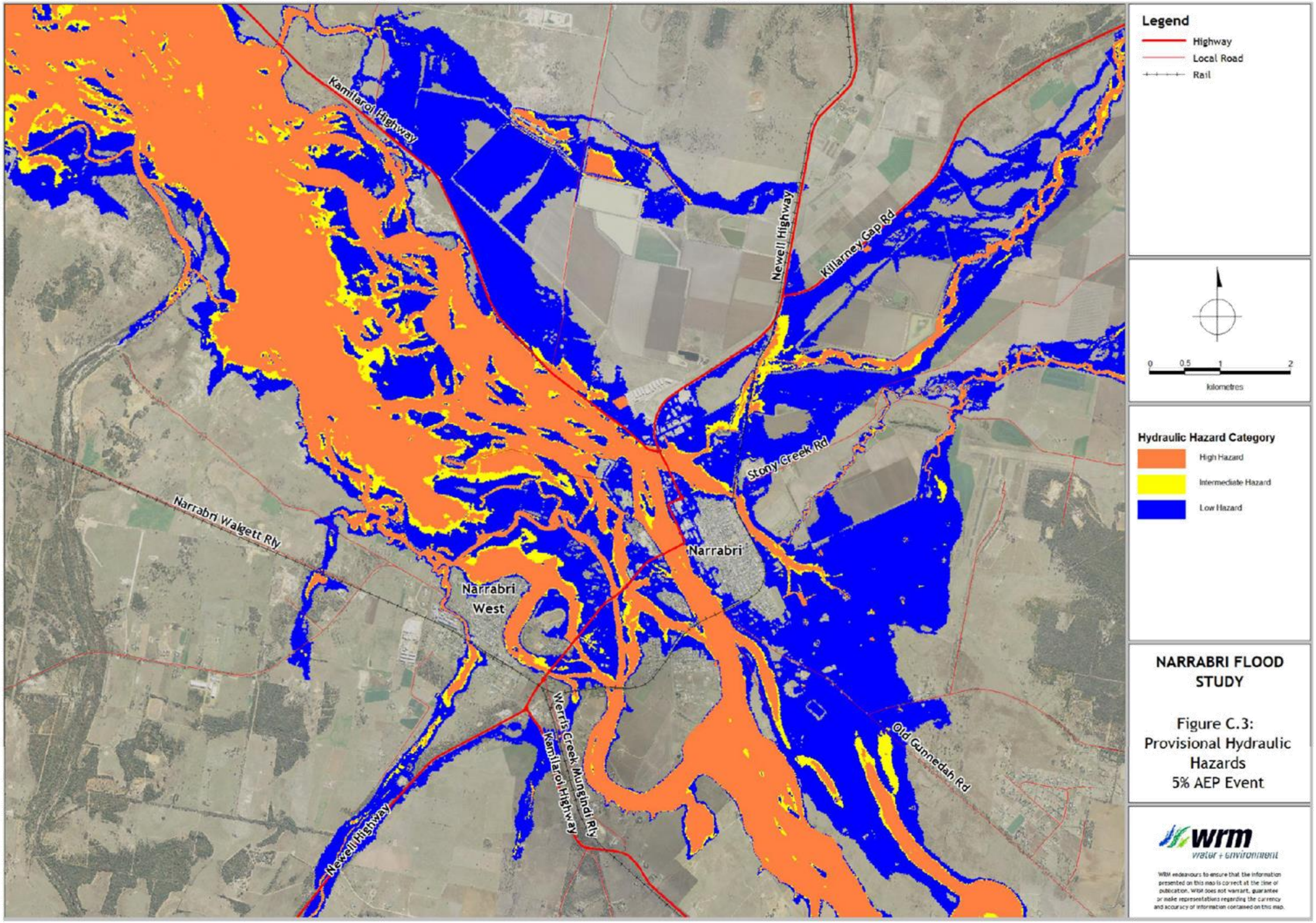


NARRABRI FLOOD STUDY

Figure C.1: Provisional Hydraulic Hazards 20% AEP Event

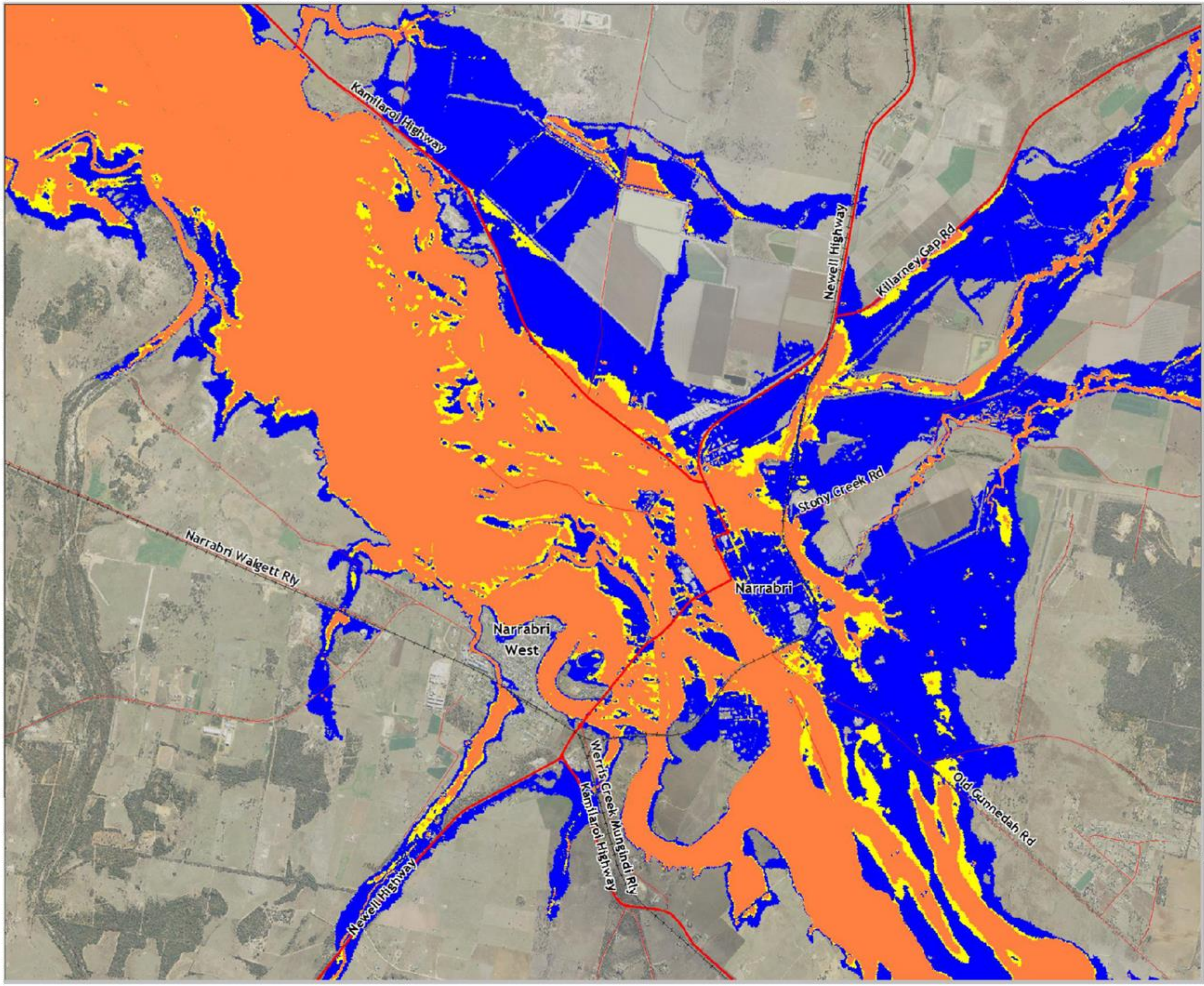
WRM endeavours to ensure that the information presented on this map is correct at the time of publication. WRM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained on this map.


Legend
Highway
Local Road
Rail
0 0.5 1 2
kilometres
Hydraulic Hazard Category
High Hazard
Intermediate Hazard
Low Hazard
NARRABRI FLOOD STUDY
Figure C.2:
Provisional Hydraulic Hazards
10% AEP Event
wrm
water + environment
Kamilaroi Highway
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri Walgett Rly
Narrabri
Narrabri West
Werris Creek Mungindi Rly
Kamilaroi Highway
Old Gunnedah Rd
Newell Highway



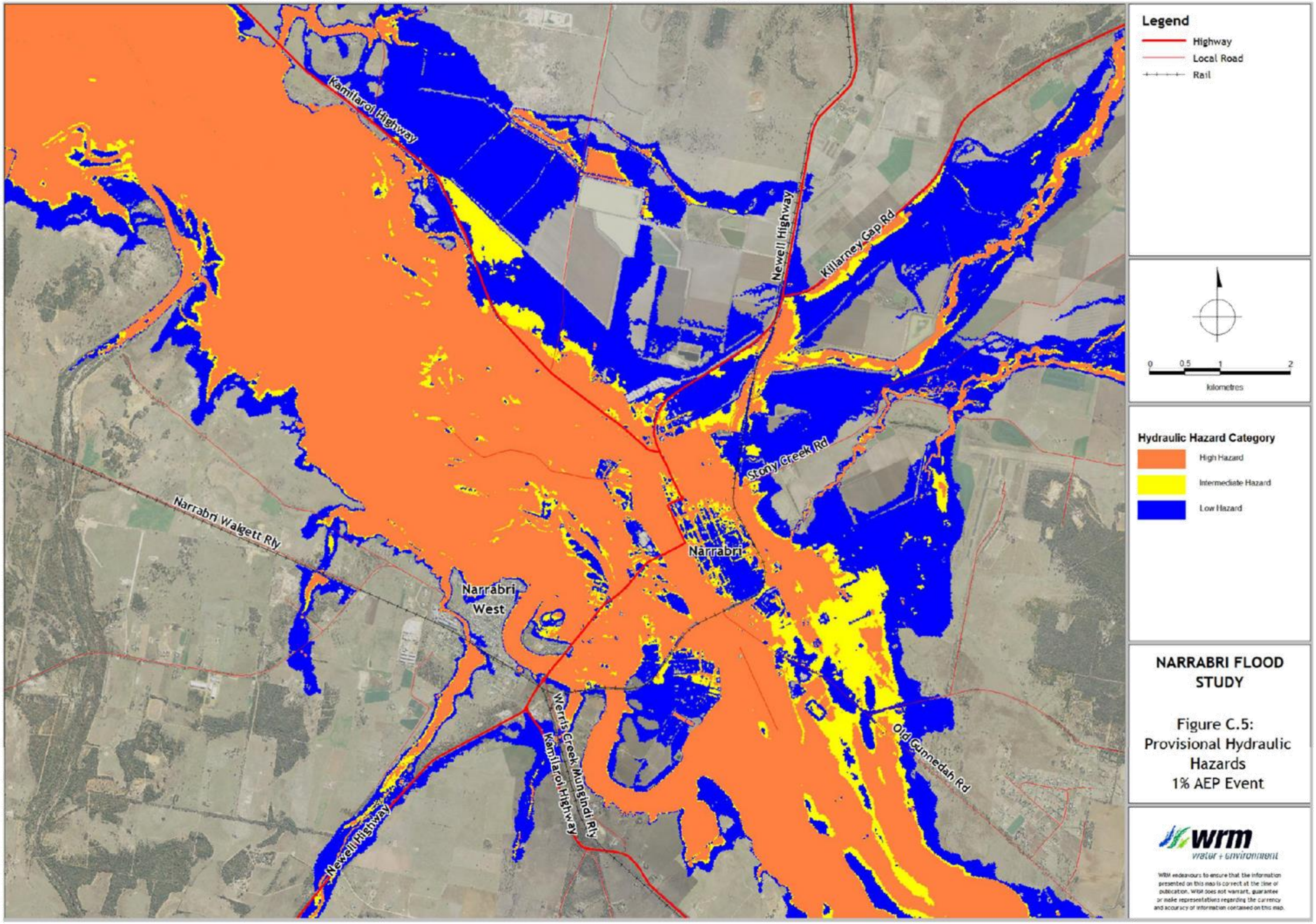
NARRABRI FLOOD STUDY

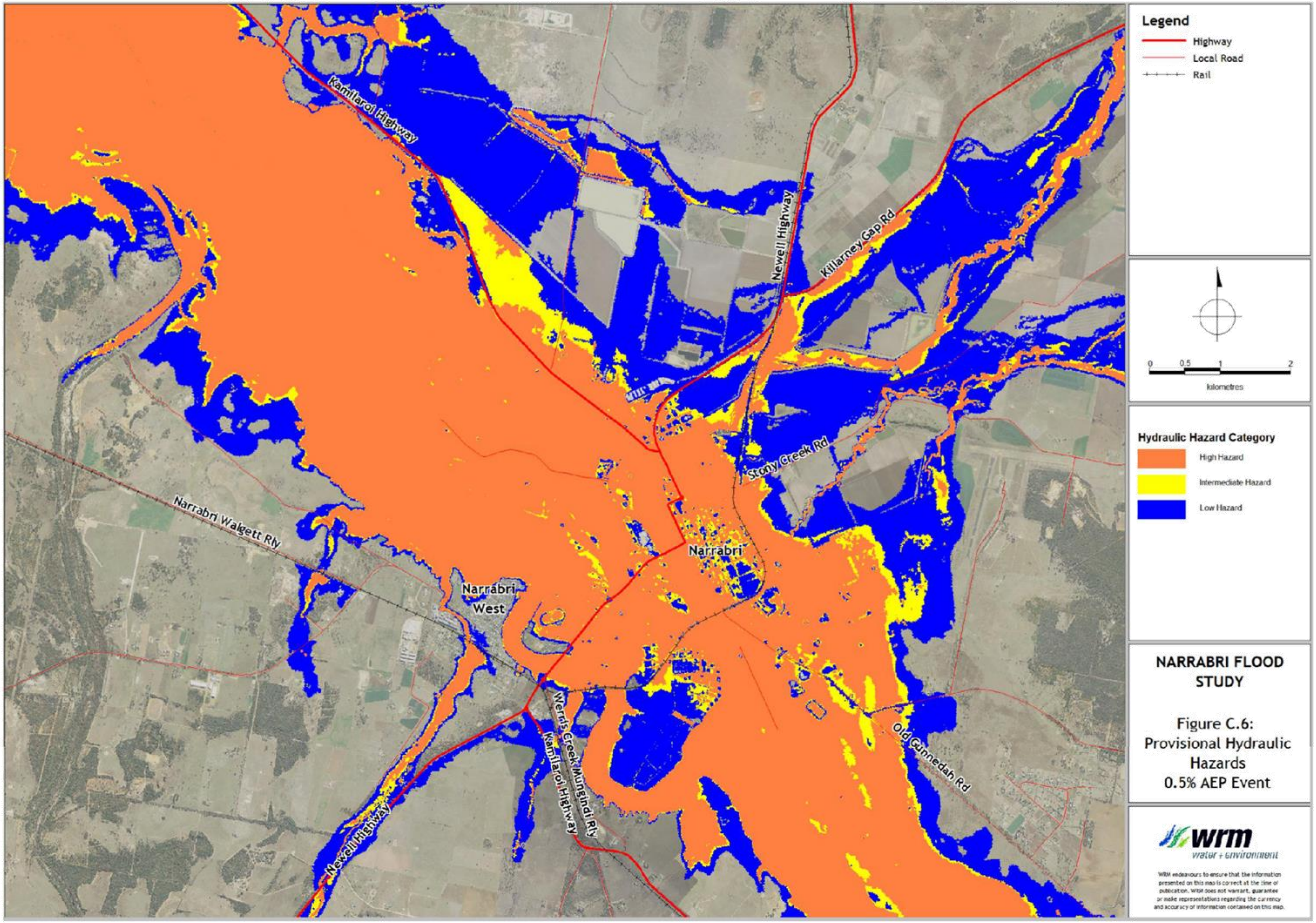
Figure C.3: Provisional Hydraulic Hazards 5% AEP Event



NARRABRI FLOOD STUDY

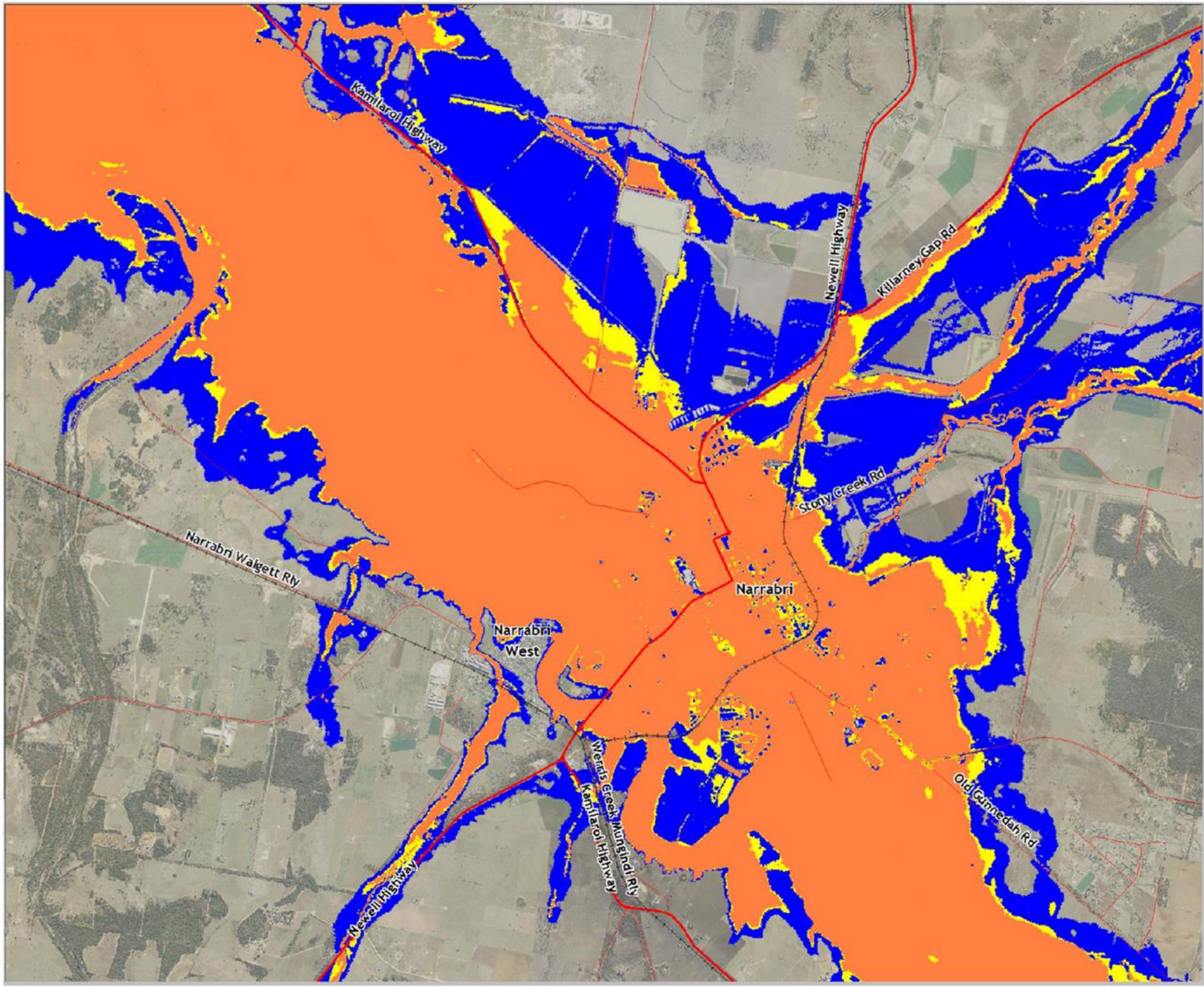
Figure C.4: Provisional Hydraulic Hazards 2% AEP Event


Legend
Highway
Local Road
Rail
kilometres
0
0.5
1
2
Hydraulic Hazard Category
High Hazard
Intermediate Hazard
Low Hazard
NARRABRI FLOOD STUDY
Figure C.5: Provisional Hydraulic Hazards 1% AEP Event
wrm water + environment
Kamilaroi Highway
Newell Highway
Killarney Gap Rd
Stony Creek Rd
Narrabri Walgett Rly
Narrabri
Narrabri West
Werris Creek Mungindi Rly
Kamilaroi Highway
Old Gunnedah Rd
Newell Highway



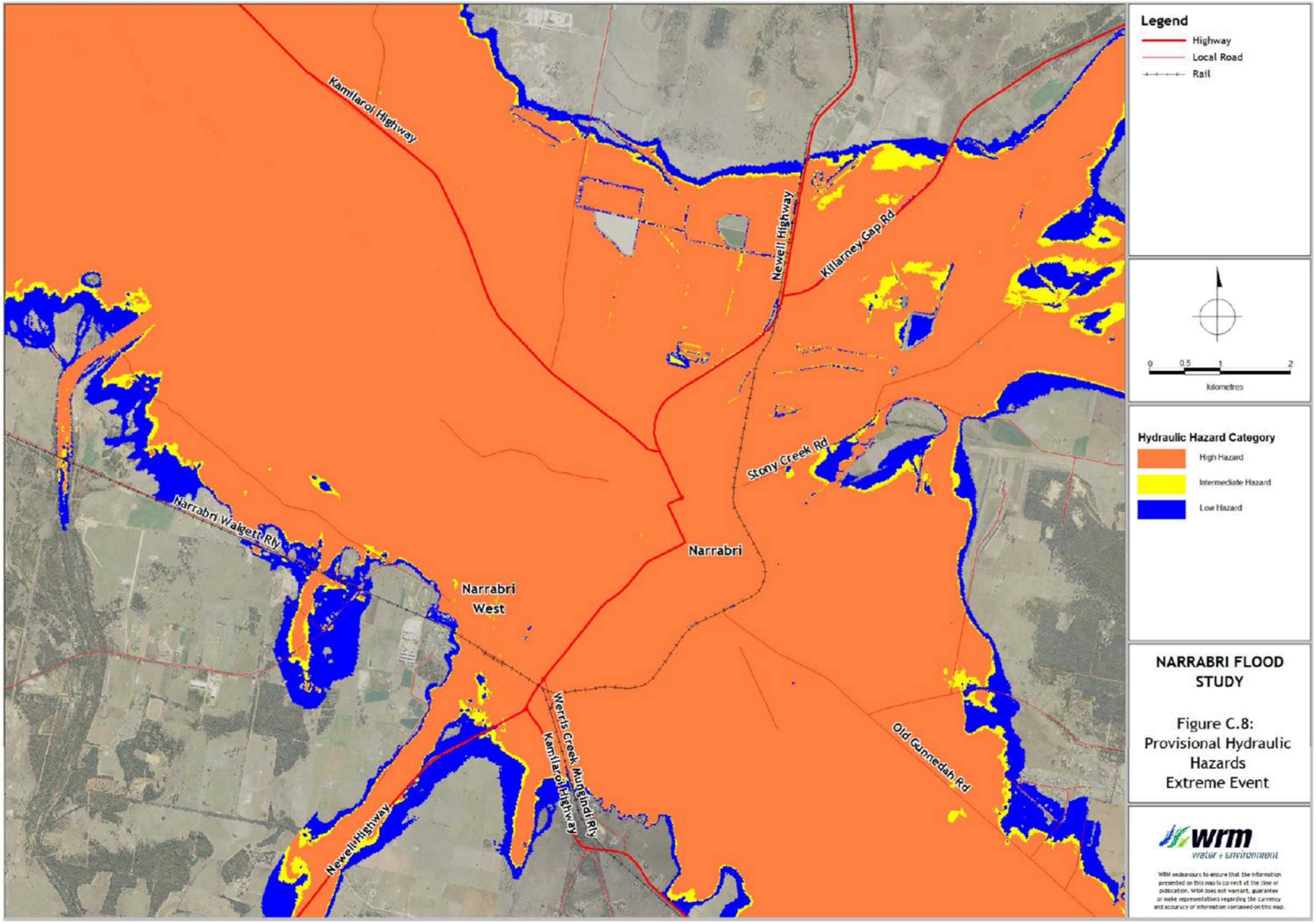
NARRABRI FLOOD STUDY

Figure C.6: Provisional Hydraulic Hazards 0.5% AEP Event



NARRABRI FLOOD STUDY

Figure C.7:
Provisional Hydraulic Hazards
0.2% AEP Event



NARRABRI FLOOD STUDY

Figure C.8: Provisional Hydraulic Hazards Extreme Event