Floodplain Management Services
Rockhampton Regional Council
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Limestone Creek Local Catchment Study

Baseline Flooding Assessment - Volume 1

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Baseline Flooding Assessment - Volume 1

Client: Rockhampton Regional Council

ABN: 59 923 523 766

Prepared by

AECOM Australia Pty Ltd
Level 1, 130 Victoria Parade, PO Box 1049, Rockhampton QLD 4700, Australia
T +61 7 4927 5541 F +61 7 4927 1333 www.aecom.com
ABN 20 093 846 925

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Ref 60534898

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Date 14-Jul-2017

Prepared by Jordan Maultby

Reviewed by Richard Corbett

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Rev	Revision Date	Details	Authorised	
			Name/Position	Signature
0	26-May-2017	Draft for Client Review	Ben McMaster Rockhampton Office Manager	Original Signed
A	14-Jul-2017	Phase 1 Final Issue	Ben McMaster Rockhampton Office Manager	

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Glossary / Abbreviations

1D	One-Dimensional
2D	Two-Dimensional
AECOM	AECOM Australia Pty Ltd
AEP	Annual Exceedance Probability (refer to Notes on Flood Frequency in Section 1.5)
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
DEM	Digital Elevation Model
DFE	Defined Flood Event
DNRM	Queensland Department of Natural Resources and Mines
ESTRY	1D component of TUFLOW
EY	Exceedances per Year
GIS	Geographical Information Systems
GSDM	Generalised Short Duration Method
IFD	Intensity Frequency Duration
LiDAR	Light Detecting and Ranging
Max:Max	Maximum flood levels across a range of storm durations within the model extent
MHWS	Mean High Water Springs
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PWSE	Peak Water Surface Elevation
RCP	Reinforced Concrete Pipe
RCBC	Reinforced Concrete Box Culvert
RNAU	Rockhampton Northern Access Upgrade
RRC	Rockhampton Regional Council
TUFLOW	1D / 2D hydraulic modelling software

Executive Summary

In December 2016, Rockhampton Regional Council (RRC) engaged AECOM Australia Pty Ltd (AECOM) to undertake the Floodplain Management Services (FMS) program for the 2017 calendar year. The FMS program entails the completion of a number of individual floodplain management projects including the Limestone Creek Local Catchment Study, which is the subject of this report.

Flooding in North Rockhampton can occur as a result of three different flood mechanisms:

- Riverine flooding due to rainfall over the Fitzroy River catchment.
- Overland flooding due to rainfall over the local urban catchment.
- Creek flooding due to rainfall over the local creek catchment.

This study focuses on overland and creek flooding due to rainfall over the local catchment.

The key objectives of this study are:

- The development of a detailed hydraulic model based on current best practice procedures, capable of adequately simulating the flood characteristics and behaviour of the local catchment using the latest available data.
- The development of clear and easy to understand flood mapping products for use in future community education and awareness campaigns.
- Determination of key hydraulic controls within the study area which will later be used to inform mitigation options analysis.

The minimisation of flood damages through more informed and reliable planning, appropriate mitigation, education, and disaster response is the key to developing more resilient communities which will ultimately result in future growth and prosperity. The overall objective of this study is to minimise loss, disruption and social anxiety; for both existing and future floodplain occupants.

The Limestone Creek catchment covers an area of approximately 42.4 km^2 starting within the northwestern reaches of Mount Archer National Park, north of Rockhampton-Yeppoon Road, and extending westwards through the Parkhurst industrial estate towards the Fitzroy River. The southern boundary passes through CQ University and residential subdivisions south of the Rockhampton Soundshell. The northern boundary extends from Olive Street in Parkhurst to Belmont Road near the Glenmore Water Treatment Plant. The Fitzroy River forms the western boundary of the catchment.

The Limestone Creek catchment runoff generally flows from east to west towards the Fitzroy River, with the Bruce Highway and North Coast Rail Line the main hydraulic controls within the catchment. Individual sub-catchments flow towards Limestone Creek generally from either the south or north, with the creek channel bisecting the overall catchment.

The Limestone Creek Phase 1 Baseline Flood Study included the development of a TUFLOW model for the lower portion of the Limestone Creek local catchment. This model utilises a combination of runoff-routing and direct rainfall approaches in order to determine the overland flow paths and establish baseline flood extents and depths within the study area.

Recorded data was received and used to compare the model to a local flood event caused by Ex-TC Debbie in March 2017. Holistic calibration and verification was unable to be undertaken due to the lack of historical data. Comparisons revealed that, whilst the model is expected to perform well at the upper end of the middle catchment segment (near Boundary Road) in a large event, smaller events do not meet the set tolerances further downstream of Yaamba Road. It is expected that the model performance (especially during smaller events) will benefit from rainfall data collected within the catchment, creek channel bathymetric survey and additional anecdotal / gauge data.

In order to maintain consistency across North Rockhampton local catchment models, loss and roughness parameters from other successfully calibrated models were adopted as the best estimate until additional recorded data within the catchment becomes available.

Various design events and durations were simulated and assessed to develop an understanding of the key flood behaviours. The critical duration for the catchment was determined to be the 180 minute event. A comparison of the design events found that for events up until the 18% AEP event the road and subsurface drainage infrastructure was able to prevent runoff from entering private property. For larger flood events, the overland flow paths continue to develop. The critical areas of this catchment are industrial properties alongside Limestone Creek and those within the Rachel Drive area. The critical controls within the catchment are the open drain alongside McLaughlin Street, the culverts and bridge crossings of Yamba Road and the railway line.

Sensitivity analyses have been undertaken to highlight the uncertainties in the model results and support the selection and application of an appropriate freeboard provision when using the model outputs for planning purposes.

It is recommended that the model be reviewed when additional flood event and topographic data becomes available. Updates to the model should also be undertaken once the Rockhampton Northern Access Upgrade Project is completed by the Department of Transport and Main Roads (currently planned for 2018).

1.0 Introduction

1.1 Project Background

In December 2016, Rockhampton Regional Council (RRC) engaged AECOM Australia Pty Ltd (AECOM) to undertake the Floodplain Management Services (FMS) program for the 2017 calendar year. The FMS program entails the completion of a number of individual floodplain management projects including the Limestone Creek Local Catchment Study, which is the subject of this report.

Flooding in North Rockhampton can occur as a result of three different flood mechanisms:

- Riverine flooding due to rainfall over the Fitzroy River catchment.
- Overland flooding due to rainfall over the local urban catchment.
- Creek flooding due to rainfall over the local creek catchment.

There are six creek catchments located within North Rockhampton which discharge to the Fitzroy River. These are (northernmost first):

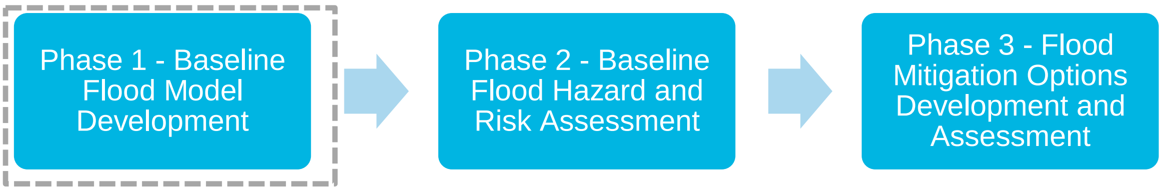
- Ramsay Creek;
- Limestone Creek;
- Splitters Creek;
- Moores Creek;
- Frenchmans Creek; and
- Thozets Creek.

This study focuses on flooding due to rainfall over the Limestone Creek and contributing urban catchments.

Despite the inclusion of a coincident local catchment and riverine flood in the sensitivity analysis, flood hazard and associated risks posed by riverine flooding have been investigated and reported separately in previous studies and does not form a component of this report.

1.2 Phased Approach

The Limestone Creek Local Catchment Study has been split into three distinct phases, as outlined below.



Documented in this Report

Phase 1 involved the development of calibrated numerical models to simulate baseline flood behaviour associated with a range of local rainfall design events and relevant sensitivities. Future Phase 2 will involve the assessment of a range of design events hazards and risks. Future Phase 3 involves the assessment of a range of structural and non-structural flood mitigation options to reduce the hazard and risk posed by future local catchment flood events.

This report covers the technical investigations and results from Phase 1 of the study. Should Phases 2 and 3 be investigated at a later date, they should be read in conjunction with this report.

1.3 Phase 1 Study Objectives

The key objectives of this study are:

- The development of a detailed hydraulic model based on current best practice procedures, capable of adequately simulating the flood characteristics and behaviour of the local catchment using the latest available data.
- The assessment of existing flood risk within the study area. It is expected that these results will be used to inform long term infrastructure planning, future emergency planning and floodplain management.
- The development of clear and easy to understand flood mapping products for use in future community education and awareness campaigns.
- Determination of key hydraulic controls within the study area which will later be used to inform mitigation options analysis.

The minimisation of flood damages through more informed and reliable planning, appropriate mitigation, education, and disaster response is the key to developing more resilient communities which will ultimately result in future growth and prosperity. The overall objective of this study is to minimise loss, disruption and social anxiety; for both existing and future floodplain occupants.

1.4 Report Structure

The Limestone Creek Local Catchment Study – Baseline Flooding and Hazard Assessment Report has been separated into 2 volumes:

- *Volume 1 → Study methodology, results, findings and recommendations (this report).*
- *Volume 2 → A3 GIS mapping associated with the Volume 1 report.*

The structure of this Volume 1 report is as follows:

- Section 2.0 describes the characteristics of the local catchment, including rainfall distributions, historic events and impacts associated with riverine flood events.
- Section 3.0 outlines the data available for the development and calibration of the hydraulic model.
- Section 4.0 outlines the hydrologic inputs.
- Section 5.0 details the development of the Baseline hydrologic model.
- Section 6.0 details the development of the Baseline hydraulic model.
- Section 7.0 presents the results of the calibration event.
- Section 8.0 presents the Baseline design flood depths, levels, velocities and extents for the study area.
- Section 9.0 presents results of the sensitivity analyses.
- Section 10.0 summaries the conclusions and outlines recommendations.
- Section 11.0 presents the references used during the study.

1.5 Notes on Flood Frequency

The frequency of flood events is generally referred to in terms of their Annual Exceedance Probability (AEP) or Average Recurrence Interval (ARI). For example, for a flood magnitude having 5% AEP, there is a 5% probability that there will be floods of equal or greater magnitude each year. As another example, for a flood having 5 year ARI, there will be floods of equal or greater magnitude once in 5 years on average. Events more frequent than 50% AEP should be expressed as X Exceedances per Year (EY). The correspondence between the two systems is presented in the ensuing table.

Annual Exceedance Probability (AEP) %	Average Recurrence Interval (ARI) Years
63 (1 EY)	1
39	2
18	5
10	10
5	20
2	50
1	100
0.5	200
0.2	500

In this report, the AEP terminology has been adopted to describe the frequency of flooding.

1.6 Limitations and Exclusions

The following limitations apply to this study:

- With the exception of the 1% AEP design flood event, all design flood events were assessed for a single critical duration, based on an analysis of multiple storm durations for the 1% AEP event.
    - GIS mapping for the 1% AEP design flood event was prepared using a 'Max:Max' analysis of multiple storm durations, whereas all other design flood events were mapped for only the critical storm.
- Aerial survey data (in the form of LiDAR) used to develop the topography for the hydraulic model has a vertical accuracy of ± 0.15 m on clear, hard surfaces and a horizontal accuracy of ± 0.45 m.
- Where information gaps existed in the underground drainage network, assumptions were made to fill these gaps using desktop assessment methods.
- Assessment of the probability of coincident local rainfall and Fitzroy River flood events has not been undertaken.
- The hydraulic model has been calibrated to a single historical event, being the local flood event which occurred as a result of Ex-TC Debbie in March 2017. No verification to other historical events has been undertaken, due to the lack of available data.
- The approach adopted assumes each catchment is independent of the adjacent catchments. It does not allow for jointly occurring design events. The cross connections between catchments occur in the less frequent events, given this low likelihood of an event actually occurring, this approach was deemed acceptable for this study.
- Hydrologic and hydraulic modelling is based on methods and data outlined in Australian Rainfall and Runoff (AR&R) 1987. The 1987 revision has been adopted as per Council's request. Refer to the ARR, Data Management and Policy Review (AECOM, 2017) for details surrounding changes recommended in the 2016 revision.
- Any use which a third party makes of this document, or any reliance on or decision to be made based on it, is the responsibility of such third parties. AECOM accepts no responsibility for damages, if any, suffered by any third party as a result of decisions or actions made based on this document.
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AR&R Revision Project 15 outlines several fundamental themes which are also particularly relevant:

- All models are coarse simplifications of very complex processes. No model can therefore be perfect, and no model can represent all of the important processes accurately.
- Model accuracy and reliability will always be limited by the accuracy of the terrain and other input data.
- Model accuracy and reliability will always be limited by the reliability / uncertainty of the inflow data.
- A poorly constructed model can usually be calibrated to the observed data but will perform poorly in events both larger and smaller than the calibration data set.
- No model is ‘correct’ therefore the results require interpretation.
- A model developed for a specific purpose is probably unsuitable for another purpose without modification, adjustment, and recalibration. The responsibility must always remain with the modeller to determine whether the model is suitable for a given problem.

2.0 Study Area Characteristics

2.1 General Description

The Limestone Creek catchment covers an area of approximately 42.4 km^2 starting within the north-western reaches of Mount Archer National Park, north of Rockhampton-Yeppoon Road, and extending westwards through the Parkhurst industrial estate towards the Fitzroy River. The southern boundary passes through CQ University and residential subdivisions south of the Rockhampton Soundshell. The northern boundary extends from Olive Street in Parkhurst to Belmont Road near the Glenmore Water Treatment Plant. The Fitzroy River forms the western boundary of the catchment.

The upper Limestone Creek catchment varies in elevation from 435 mAHD to 32 mAHD, covering an area of approximately 30.4 km^2. The land use in the upper catchment is predominantly dense bushland with very little urbanisation. Overland runoff from the catchment quickly accumulates within the upper reach of Limestone Creek due to the steep natural topography and is conveyed by the natural creek channel towards the Fitzroy River. Plate 1 highlights a typical cross section of Limestone Creek at Alexandra Street.

The land use in the mid and lower catchment is split between residential and commercial uses, with a large percentage of undeveloped land (refer to Table 1). Major industry within the catchment includes CQ University, Sibelco, Dreamtime Cultural Centre and Department of Primary Industries amongst many others. The lower catchment is predominantly undeveloped with some rural residential lots and floodplain areas.

Table 1 Catchment Land Uses

Land Use	Proportion
Rural / Mountainous	91%
Urban	9%
• Industrial / Commercial	(46%)
• Residential	(54%)

Plate 1 Limestone Creek at Alexandra Street Extended after the 2017 Fitzroy River Flood Event

Limestone Creek is an ephemeral meandering system consisting of low flow pools and riffles within the mid and lower portions of the catchment. The natural creek bed material varies from exposed medium-sized cobbles / rocks to silty / sandy soils. Riparian vegetation along the creek can also vary from very dense grasses, shrubs and mature trees – to very limited vegetation in high velocity sections of the reach. An example of a section of the creek with high velocity is provided in Plate 2.

Plate 2 Limestone Creek at McMillan Avenue

Several segments of the reach contain ponding water in deeper section of the creek that have been scoured as a result of the high velocity flood waters. In some sections, the natural channel material is mobile, resulting in ongoing geomorphic processes in response to high flow events. The dynamic nature of the creek results in a continual process of scour and sediment deposition (particularly small to medium-sized rocks) with some evidence of scour exceeding a metre in depth. An example is provided in Plate 3.

Plate 3 Limestone Creek Scour Hole at Boundary Road

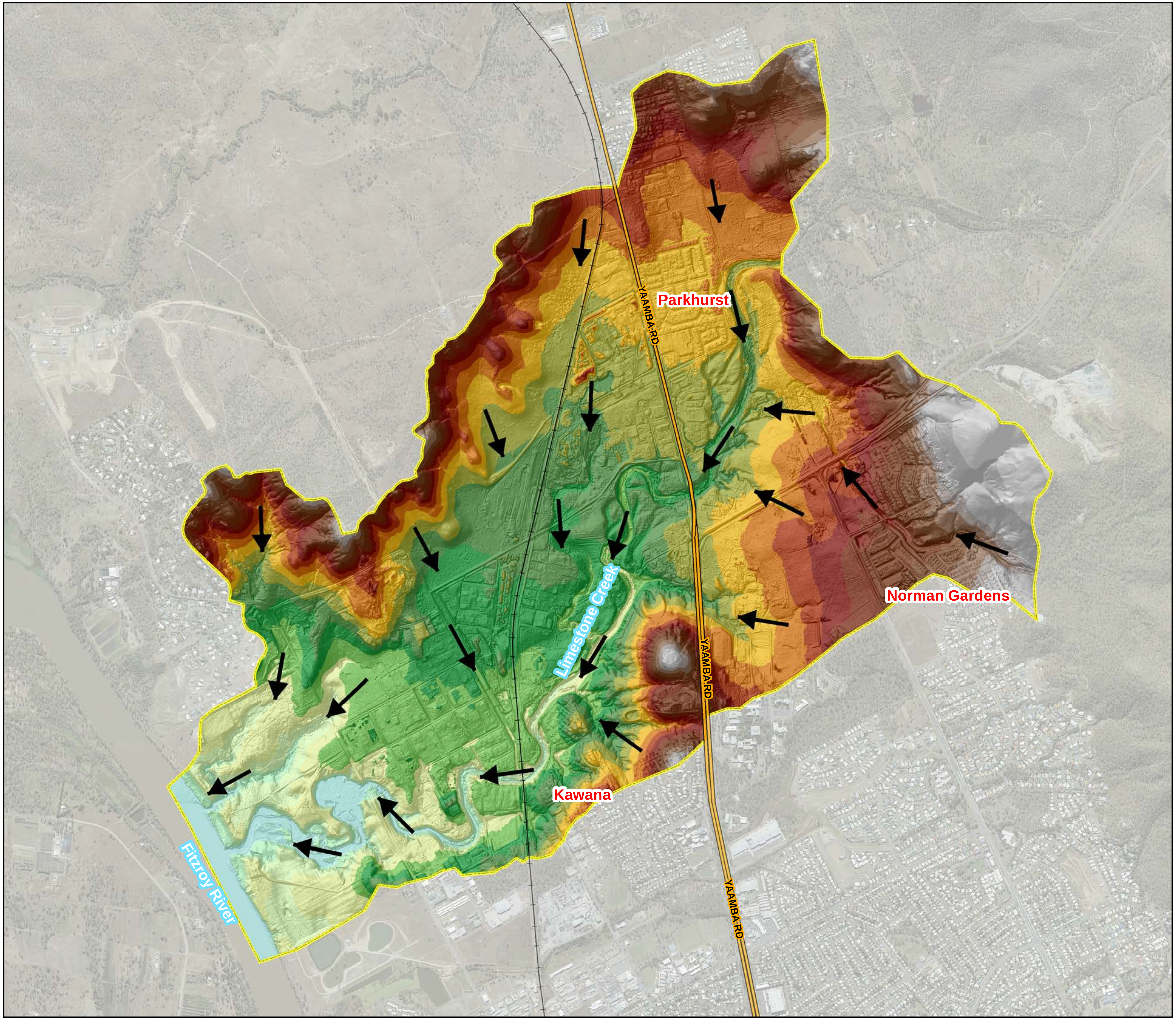
2.2 Urban Sub-Catchments

Urbanisation has increased the proportion of impervious areas such as roads, concrete and building structures. Urban overland flow paths within the Limestone Creek catchment generally follow defined natural or constructed channels and road corridors.

Key sub-catchment flow paths within the Limestone Creek catchment include:

- Foulkes Street, off Norman Road;
- Rachel Drive, off Yaamba Road in Parkhurst;
- Mason Avenue, off Yaamba Road in Parkhurst; and
- Peppermint Drive, west of the Yaamba Road Water Reservoir.

The Limestone Creek catchment runoff generally flows from east to west towards the Fitzroy River, with the Bruce Highway and North Coast Rail Line the main hydraulic controls within the catchment. Individual sub-catchments flow towards Limestone Creek generally from either the south or north, with the creek channel bisecting the overall catchment.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000

Metres

1:20,000
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent

Topography (mAHD)

- < 3
- 3.01 - 5
- 5.01 - 7
- 7.01 - 9
- 9.01 - 11
- 11.01 - 13
- 13.01 - 15
- 15.01 - 17
- 17.01 - 19
- 19.01 - 21
- 21.01 - 23
- 23.01 - 25
- 25.01 - 28
- 28.01 - 30
- 30.01 - 35
- 35.01 - 40
- 40.01 - 45
- 45.01 - 60
- 60.01 - 75
- > 75

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model

Sub-catchment Delineation and Natural Flow Paths

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CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure 1

2.3 Climate Characteristics

The Limestone Creek local catchment is situated at latitude 23º 18' 3.14" south, about 15km north of the Tropic of Capricorn. The catchment centroid is about 36km northwest of the Pacific Ocean at Thompson Point. As a result, the catchment experiences a tropical maritime climate.

The climate is dominated by summer rainfalls with heavy falls likely from severe thunderstorms and occasionally from tropical cyclones. Heavy rainfall is most likely to occur between the months of December to March.

2.4 Rainfall Characteristics

Rockhampton has a mean annual rainfall of approximately 800mm. The highest mean monthly rainfall of 145mm generally occurs in February. The highest and lowest annual rainfall recorded at the Rockhampton Airport is 1631mm (in 1973) and 360mm (in 2002) which shows a significant variation in annual rainfall, year on year.

The highest monthly rainfall of 660mm was recorded in January 1974. The highest daily rainfall of 348mm was recorded on the 25th of January 2013. The following graph shows the distribution of the mean monthly rainfall depth throughout the year at the Rockhampton Airport.

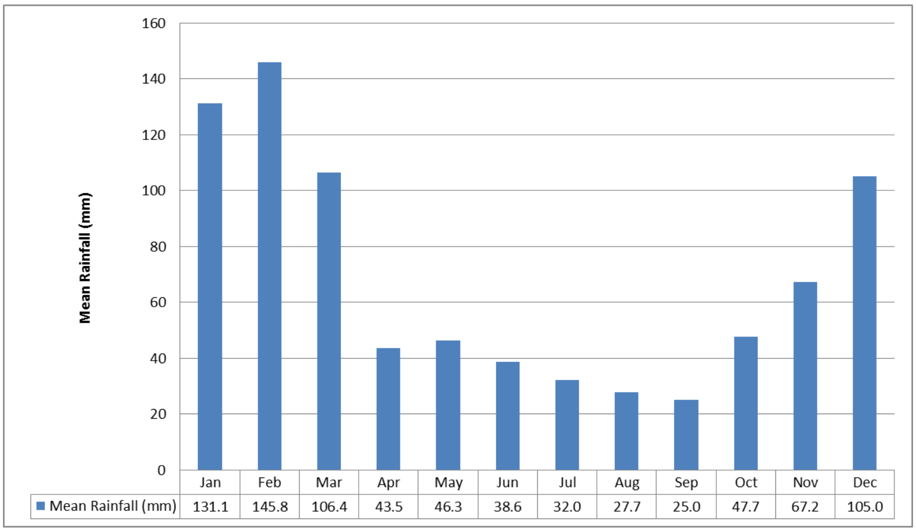


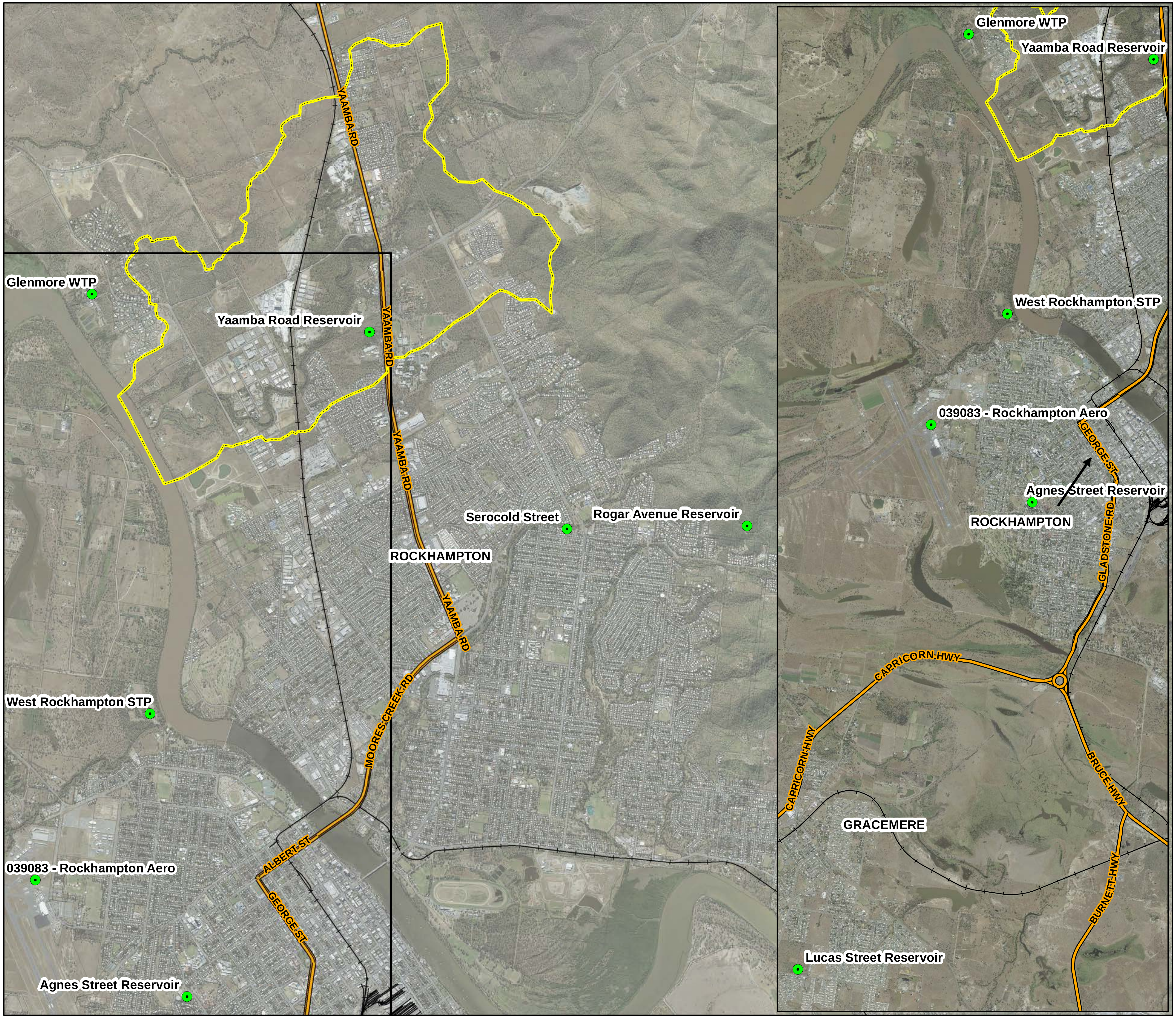
Figure 2 Mean Monthly Rainfall at the Rockhampton Airport Rainfall Station

Analysis of historical rainfall records at key gauges across the City confirmed that the spatial variability of rainfall can significantly vary between North Rockhampton and South Rockhampton. With this in mind, the compilation of historical rainfall records within the catchment was important to accurately verifying the validity of the hydrodynamic model.

It is noted that pluviographic data obtainable through the BoM website (www.bom.gov.au) is available for the Rockhampton Airport (Rockhampton Aero – Site Number 039083). RRC also maintains minute-by-minute rainfall gauges at the following locations:

- Agnes Street Reservoir.
- Glenmore Water Treatment Plant (WTP).
- Rogar Avenue Reservoir.
- West Rockhampton Sewage Treatment Plant (STP).
- Yaamba Road Reservoir.
- Lucas Street Reservoir.

In addition to the above, Council have in the past also obtained rainfall data from a private residence at Serocold Street, Frenchville. The rainfall stations are represented spatially in Figure 3.



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Metres

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(when printed at A3)

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LEGEND

- Rainfall Gauge Locations
- Highways
- Hydraulic Model Extent
- Railway Lines
- Cadastre

Data Sources:

DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Limestone Creek Model

Rainfall Gauge Locations

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LAST MODIFIED 29/06/2017
VERSION: 1

Figure
3

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 3 Rainfall Gauge Station Locations.mxd

Of the gauges, Yaamba Road Reservoir is located within the urban segment of the Limestone Creek catchment and is therefore likely to represent the best-estimate of historic rainfall events for the Limestone Creek Local Catchment model. It is noted that the given the historic variance between the Rogar Avenue Reservoir gauge and nearby urban gauges, rainfall in the mountainous area of the catchment may differ significantly from recorded totals along Yaamba Road.

2.5 Historic Local Catchment Events

Significant local rainfall events leading to overland flooding of the Limestone Creek catchment often originate from tropical cyclonic activity, rapidly intensifying troughs and depressions. Notable incidents of such meteorological events occurring in recent times include the 2013, 2015 and 2017 events.

This study included the simulation of the 2017 local catchment event, which served as the calibration event to verify the model performance.

2.6 Riverine Flooding Influence

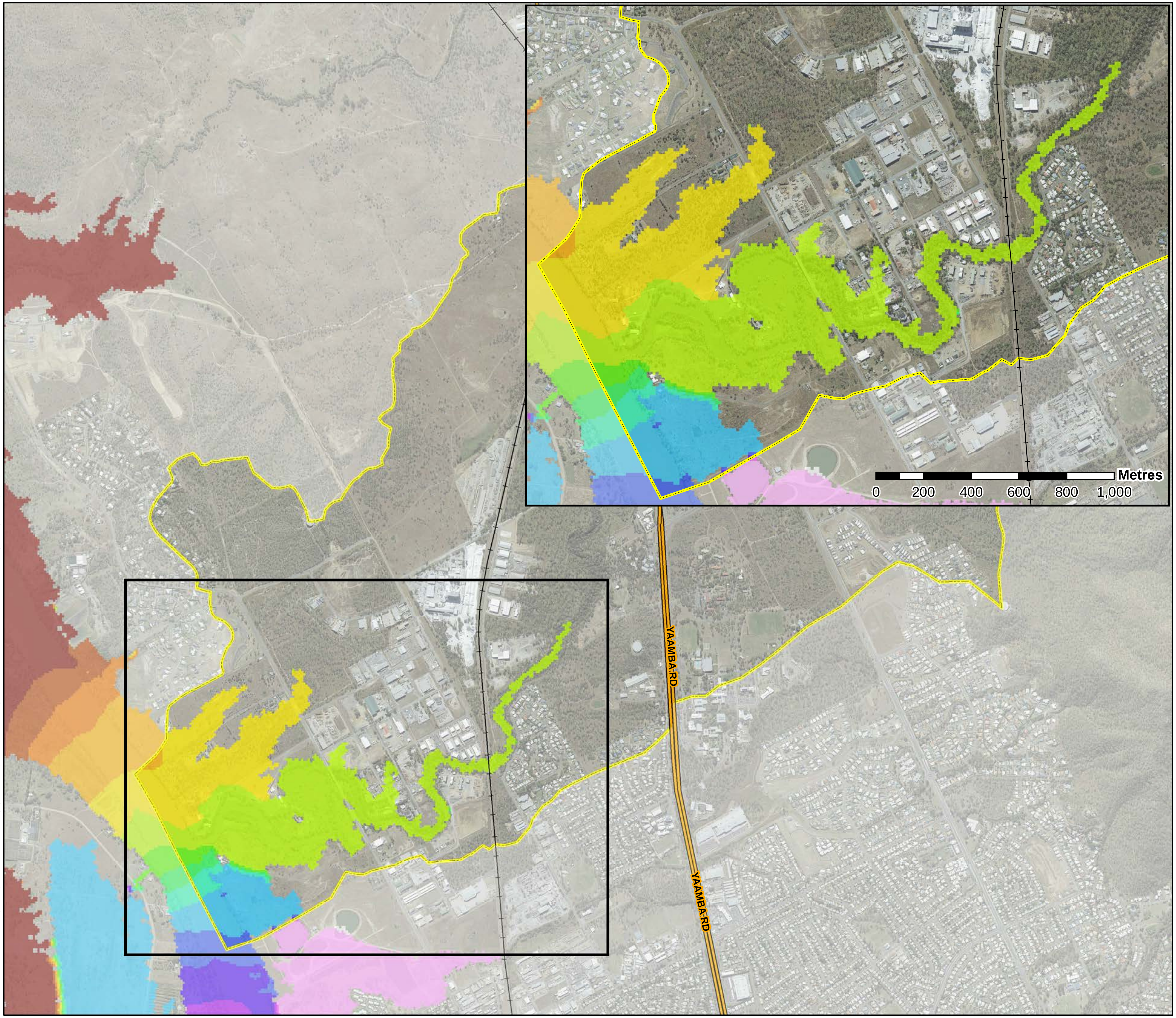
Riverine floods in Rockhampton can result from extended periods of rainfall within the 142,000 km^2 Fitzroy River basin. As peak discharge increases along the Fitzroy River, a key breakout occurs upstream of Rockhampton at the Pink Lily meander, which can result in the inundation of large areas of South Rockhampton. In addition, backwater effects impact low-lying areas adjacent to creeks on the Northside and Southside of Rockhampton, including Limestone Creek which is the subject of this report.

Figure 4 outlines the riverine flood heights for a 1% AEP flood event. Portions of the lower Limestone Creek catchment become inundated by riverine flood waters in a flood event of this magnitude. Fitzroy River floodwaters extend along Limestone Creek north of the North Coast Rail Line, overtopping a small segment of Alexandra Street south of the bridge. Low-lying parcels are also inundated along Leichhardt Street.

The effect of riverine backwater levels on local catchment flood behaviour have been modelled as part of the sensitivity analysis which simulates the coincidence of a 1% AEP local catchment event with a 18% AEP riverine event. The results form a component of the discussion made in Section 8.3.

2.7 Flood Warning System

It is noted that a flood warning and classification system is not presently operated by BoM or RRC for the Limestone Creek catchment during local rainfall events.



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Metres

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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent

Peak Riverine Flood Height (mAHD)

- < 10.650
- 10.651 - 10.700
- 10.701 - 10.750
- 10.751 - 10.800
- 10.801 - 10.850
- 10.851 - 10.900
- 10.901 - 10.950
- 10.951 - 11.000
- 11.001 - 11.050
- 11.051 - 11.100
- 11.101 - 11.150
- 11.151 - 11.200
- 11.201 - 11.250
- 11.251 - 11.300
- 11.301 - 11.350
- > 11.350

Flood results are based on riverine catchment events

Data Sources:

DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Limestone Creek Model
Peak Fitzroy River Flood Heights

1% AEP Riverine Flood Event

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VERSION:	1

Figure 4

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3.0 Available Data

3.1 General

Available data for the development of baseline flood modelling for the catchment consisted of:

- Previous studies (AECOM, 2017, Aurecon, 2014, BMT WBM, 2014, AECOM, 2014).
- Tidal data (MSQ, 2014)
- Topographical data in the form of LiDAR (AAM Pty Ltd, 2016)
- Aerial photography (RRC).
- Stormwater infrastructure network database (RRC).
- Details of hydraulic structures within the study area (RRC).
- Historical rainfall data for the 2017 flood event (RRC).
- Historical flood records for the 2017 flood event (RRC).

Each of these is described in more detail in the subsequent sections.

3.2 Previous Studies

3.2.1 ARR, Data Management and Policy Review (AECOM, 2017)

Completed by AECOM in March 2017 as part of the 2017 FMS project, the ARR, Data Management and Policy Review report sought to identify the implications of applying the latest hydrological methodology presented in AR&R 2016, review Council's existing floodplain management policies and propose appropriate flood mapping guidance based on current industry mapping styles.

The recommendations of the report were to move to the AR&R 2016 hydrologic methodology. Council have consequently resolved to maintain the use of AR&R 1987 hydrologic methodologies whilst developing an implementation plan for the adoption of the AR&R 2016 methodology. AR&R implementation needs to be finalised over a two year period. A further recommendation of the review was to adopt current industry mapping standards as per DNRM 2016 Guidelines, which Council have agreed to adopt where applicable within the Floodplain Management Services Program.

3.2.2 Limestone Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014)

In May 2014 Aurecon delivered Revision 2 of the *Rockhampton Local Catchments Flood Study - Limestone Creek Hydrologic and Hydraulic Modelling Report* (Aurecon, May 2014). The Limestone Creek report formed part of a wider local catchments study whereby the following creeks were assessed:

- Limestone Creek (the focus of this report).
- Ramsay Creek.
- Splitters Creek.
- Moores Creek.
- Frenchmans Creek.
- Thozets Creek.
- Creeks in the Gracemere area including Washpool Creek, Middle Creek, Gracemere Creek and a Local Catchment.

The study applied XP-Rafts hydrologic model hydrographs as lumped catchment inflows to TUFLOW hydraulic models. The XP-Rafts hydrographs were applied directly within the creek channel, to represent the runoff from upstream sub-catchments. The modelling undertaken did not simulate overland flows within the upstream urban catchments, as no direct rainfall was applied within the TUFLOW model.

The TUFLOW two-dimensional hydraulic model was calibrated to a single recorded level from the January 2013 local catchment rain event. It was reported that the modelled flood level had an absolute average difference of -0.68 m when compared to the recorded level.

Design events were modelled for the 39% AEP, 18% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF local catchment flood events. Climate change scenarios were modelled for 20% and 30% increases in rainfall intensity, for the 1% AEP, 0.5% AEP and 0.2% AEP events.

3.2.3 Independent Review of Rockhampton Local Catchments Flood Study - Numerical Models (BMT WBM, 2014)

In June 2013 BMT WBM Pty Ltd (BMT WBM) were commissioned by RRC to carry out an independent review of the Rockhampton Local Catchments Flood Study, prepared by Aurecon (refer Section 3.2.2). At that time the reports were in Draft format, to allow for updates and finalisation following completion of the peer review.

BMT WBM presented their initial Hydrological Review on 23 July 2013, concluding that:

- The Frenchmans Creek XP-Rafts model appeared to be overestimating design flows, by up to double in the 1% AEP event, in comparison to a rational method and Watershed Bounded Network Model (WBNM).
- The Limestone Creek XP-Rafts model was representing peak flows reasonably well in comparison to the rational method and WBNM checks completed.

BMT WBM presented their interim Hydraulic Model Review on 31 July 2013, concluding that:

- The 5 m grid resolution may not be representing the creek channel adequately, in areas where the channel is less than 10 m wide. This is more prevalent in more frequent events, where flow widths are reduced.
- The location of some local inflows may need to be reviewed, to ensure the reporting of flood extents is ‘not ambiguous’.
- Downstream model boundaries are based on 18% AEP Fitzroy River flood levels. Consideration of Mean High Water Springs (MHWS) and Highest Astronomical Tide (HAT) may be more appropriate. Sensitivity analysis for the 39% AEP Frenchmans Creek event showed reduced flood levels of 100 mm to 200 mm across the lower floodplain area.
- Generally hydraulic structures were represented adequately, however there were some key structures not included in the TUFLOW model.
- Hydraulic roughness was represented through a spatially varying roughness layer. Generally Manning’s roughness values were within accepted industry ranges, however the riparian corridor (floodplain extent) and creek channel roughness values were found to be unusually high. Sensitivity analysis for the Frenchmans Creek model showed reductions in flood levels of between 200 mm and 200 mm for the 39% AEP event and between 200 mm and 500 mm for the 1% AEP event.
- Model stability in both the one-dimensional and two-dimensional domains was found to be acceptable.

RRC, Aurecon and BMT WBM undertook two technical workshops as follows:

- August 2013 → Discussion and review of model recalibration and design event modelling, following initial peer review findings provided by BMT WBM.
- December 2013 → Final meeting to discuss final recalibration results.

Following the workshops and consequence model updates completed by Aurecon, BMT WBM presented their final Hydrological Review on 4 February 2014. This concluded that the XP-Rafts hydrologic models were now considered acceptable by BMT WBM and therefore appropriate for use in the Local Catchments study.

3.2.4 SRFL Hydraulic Model Development (AECOM, 2014)

The South Rockhampton Flood Levee (SRFL) planning and detailed design for tender project was completed by AECOM throughout 2014, and included assessment of Fitzroy River and interior drainage flooding impacts as a result of the proposed SRFL scheme. The hydraulic component of the project involved development of two separate hydraulic models; the first being in relation to riverine flooding and the second to local catchment events.

The Fitzroy River model results have been used to inform tailwater levels during coincident events. Reference should be made to the SRFL Hydraulic Model Development and Comparison report (AECOM, 2014) for further details.

3.3 Tidal Data

Limestone Creek's outlet is located upstream of Fitzroy River Barrage and as such is not influenced by tidal fluctuations. The weir on the southern side of the barrage has a crest level of 3.65 mAHD which discharges to the fish ladder, acting as the control for water levels upstream of the barrage.

A negligible water level gradient between the creek outlet and Barrage was assumed during nominal river flows and hence tailwater levels were set to the barrage weir crest level for the suite of simulations.

3.4 Topographic Data

The topographical information used for the Limestone Creek Local Catchment model was provided by RRC in the form of LiDAR survey, which was undertaken between 30 September 2015 and 23 January 2016 by AAM Pty Ltd. The LiDAR points were used to generate a base Digital Elevation Model (DEM) with a grid spacing of 1 m.

It is stated in the report provided by AAM Pty Ltd that the Horizontal Spatial Accuracy is estimated to be ±0.40 m and the Vertical Spatial Accuracy is estimated to be ±0.15 m, on clear open ground. Council undertook elevation checks and commented that the accuracy of the LiDAR is within the ±0.15 m vertical tolerance on hard surfaces.

Due to the dynamic geomorphic behaviours of Limestone Creek, differences in channel elevations are evident between datasets of different time periods. As such, ideal circumstances would call for topographic data to be obtained before significant flood events in an attempt to best represent the creek conveyance at the time of the event.

With this in mind, the 2016 LiDAR 1 m DEM (with inclusion of ground survey) is expected to provide good representation of the creek channel for the March 2017 event.

3.5 Aerial Photography

Aerial photography of Rockhampton City and surrounding region was supplied by RRC. The dataset was supplied as a single mosaic image which covers the extents of the study area. The imagery was captured in September 2016 at a resolution of 10 cm intervals.

3.6 Stormwater Infrastructure Network Database

Drainage asset information was supplied by RRC in the form of GIS layers containing location, size and invert data for culvert, pit and pipe assets. A gap analysis of the database revealed significant proportions of pipe inverts and pit inlet dimensions were missing. RRC undertook an extensive desktop and field investigation to further improve the quality of the stormwater database, however some data gaps remained. Where stormwater infrastructure data was absent, details were estimated using the following assumptions:

- All upstream invert levels are at a higher elevation than downstream invert levels.
- Congruent pipe slopes between known inverts.
- No fall across pit structures.

- Minimum depth of cover of 600 mm, where practicable.
- Upstream pipe diameter matched downstream pipe diameter

Given the lack of pit inlet dimensions, nominal dimensions of 900 mm by 600 mm were assigned to all pits digitised within the hydraulic model. Sensitivity analysis involving increasing the dimensions of all pits to 2000 mm by 2000 mm resulted in minimal change in flood levels or extents. This was expected as the existing pipe capacity is commonly the limiting component of the stormwater network.

3.7 Hydraulic Structures

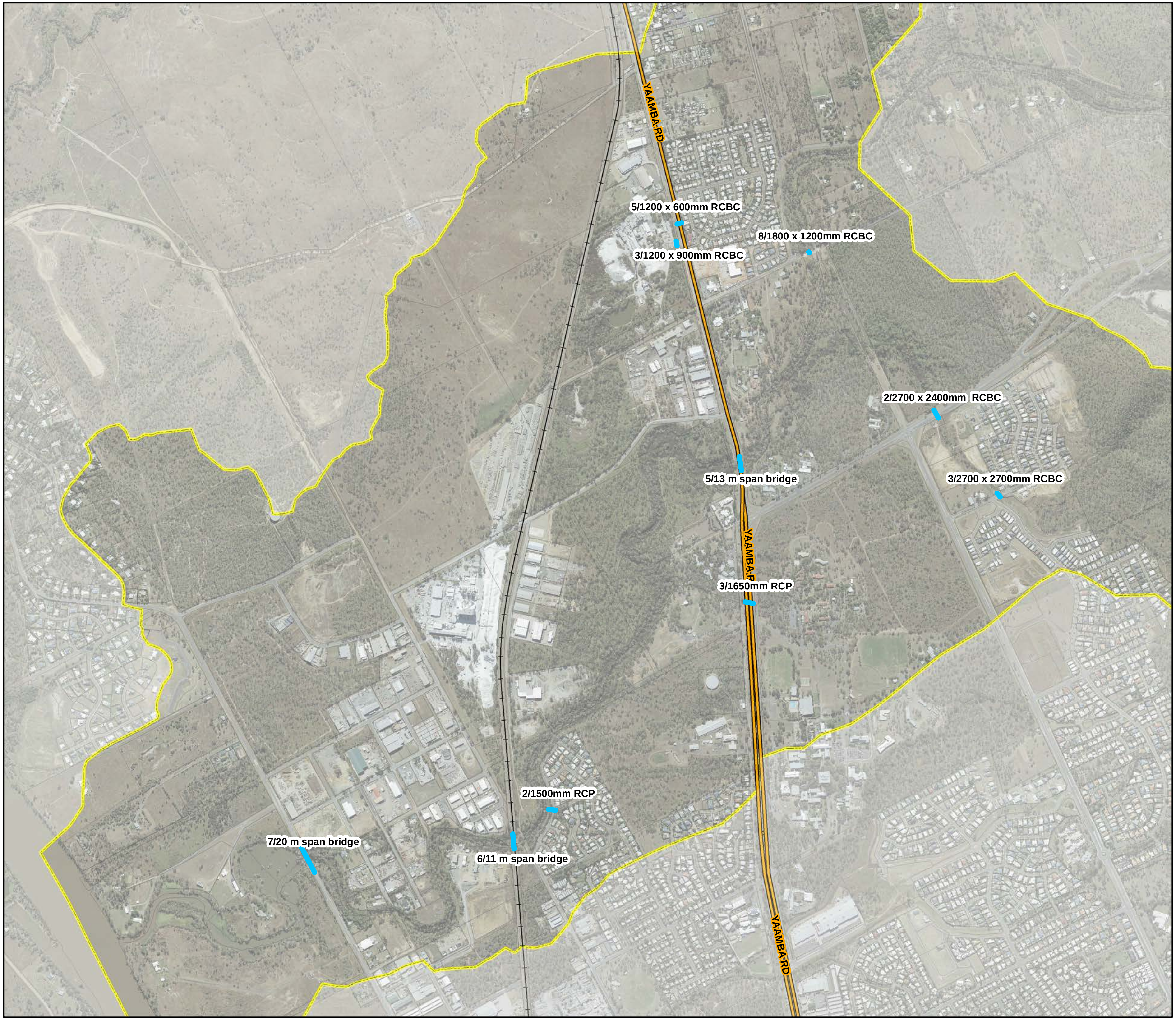
Identification of hydraulic structures associated with the major road / rail crossings within the study area was completed using a combination of council's stormwater infrastructure network database and site visits.

Approximately 61 culverts and 3 bridge structures were identified along Limestone Creek. Minor structures which were not expected to convey significant flows or connect key flow paths were not incorporated in the hydraulic model.

Table 2 presents a list of major structures within the study area which were incorporated into the hydraulic model; these are shown spatially in Figure 5. Culvert structures were represented as 1-dimensional elements within the hydraulic model and bridges which were represented within the 2-dimensional domain as layered flow constrictions.

Table 2 Key Hydraulic Structures Incorporated to the Model

Drainage Structure	Configuration	Model Representation
Bridges		
Yaamba Road	5/13 m span bridge	2D
North Coast Rail Line	6/11 m span bridge	2D
Alexandra Street	7/20 m span bridge	2D
Major Culverts		
Boundary Road	8/1800 x 1200mm RCBC	1D
Foulkes Street	3/2700 x 2700mm RCBC	1D
Yeppoon Road	2/2700 x 2400mm RCBC	1D
Yaamba Road	5/1200 x 600mm RCBC	1D
	3/1650mm RCP	1D
Sibelco Access Road	3/1200 x 900mm RCBC	1D
Peppermint Drive	2/1500mm RCP	1D



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LEGEND

- KeyStructures
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:

75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model

Location of Key Hydraulic Structures

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure
5

3.8 Site Inspection

A site inspection was carried out by AECOM staff and was used to capture and check structure details, hydraulic roughness parameters and catchment details for input to the modelling.

3.9 Historical Rainfall Data

Historical rainfall records for 2013, 2015 and 2017 events were acquired from BoM and provided by Council in the form of SCADA (1-minute intervals) for the range of rainfall stations shown in Figure 3. A list of rainfall gauging stations, their locations, type of data and applicable events is provided in Table 3, where:

- ✓ → reliable data;
- ⊘ → unreliable data; and
- ✗ → no available data.

Table 3 Summary of Rainfall Data used in the Study

Station Number	Site Name	Data Type	Operating Authority	2013 Flood Event	2015 Flood Event	2017 Flood Event
039083	Rockhampton Aero	1-Minute Intervals	BoM	✓	✓	✓
79	Agnes Street Reservoir	1-Minute Intervals	RRC	✗	⊘	✓
02	Glenmore WTP	1-Minute Intervals	RRC	✗	⊘	✓
25	Rogar Avenue Reservoir	1-Minute Intervals	RRC	✗	⊘	✓
42	West Rockhampton STP	1-Minute Intervals	RRC	✗	⊘	✓
14	Yaamba Road Reservoir	1-Minute Intervals	RRC	✗	⊘	✓
-	Lucas Street Reservoir	1-Minute Intervals	RRC	✗	✗	✓
-	Serocold Street	30-Minute Intervals	Private	✓	✓	✗

3.10 Historical Flood Records

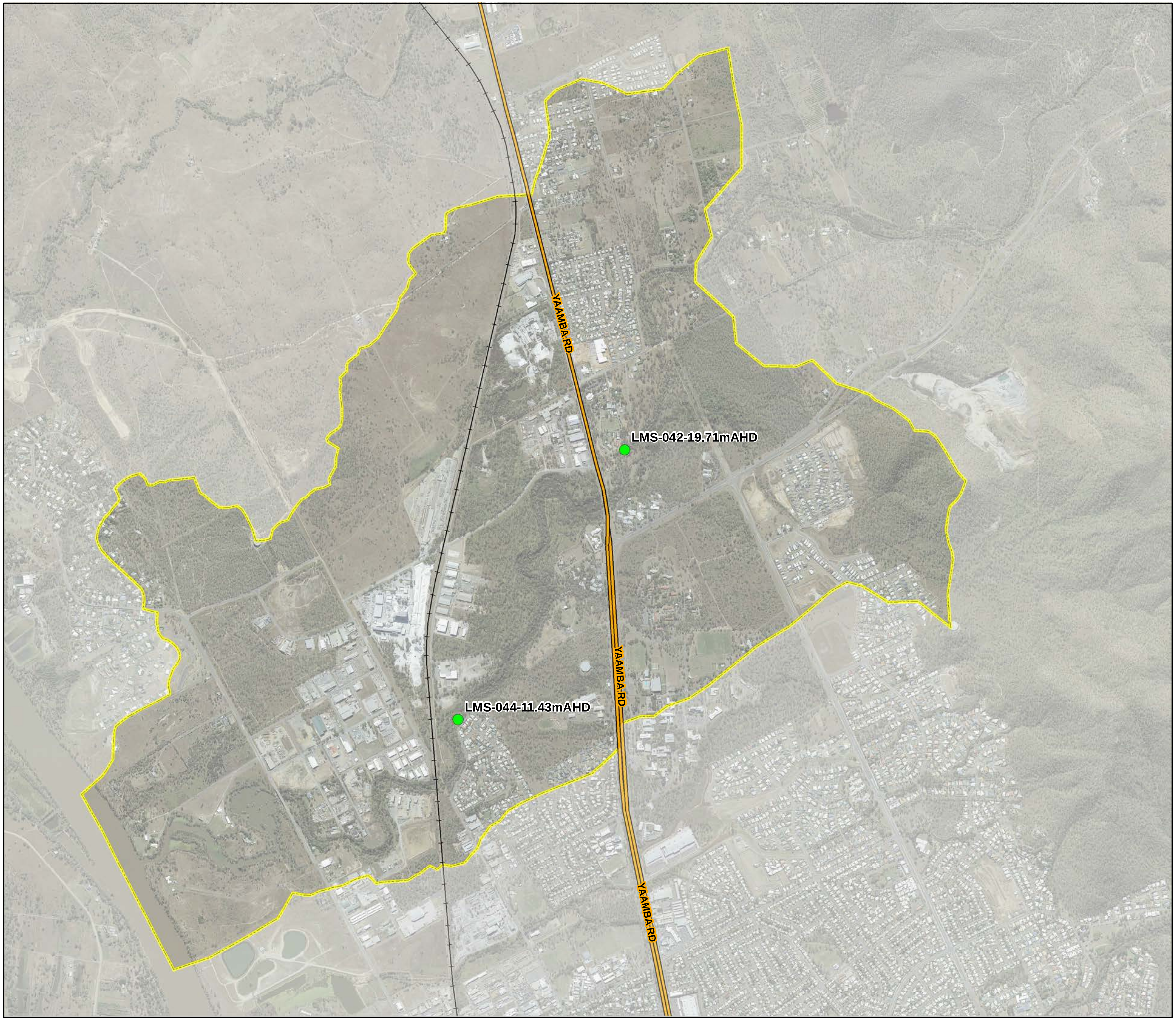
3.10.1 Recorded Water Level Data

The previous study involved calibrating the model to the January 2013 event, although this involved only a single anecdotal point. The recent March 2017 event occurred after the installation of two peak height gauges which were provided by Council. The data included the locations and maximum gauge heights shown in Figure 6.

Table 4 presents the spatial locations and peak heights of Council's gauges within the Limestone Creek Local Catchment for the 2017 event. Adopted vertical height tolerances were ±0.15 m.

Table 4 Recorded Gauge Data

Gauge Label	Point ID	Easting (m)	Northing (m)	Zero Gauge Level (mAHD)	Peak Gauge Depth (m)
Woods Road	42	246112.95	7420019.90	19.71	1.92
Peppermint Dr	44	245182.75	7418513.20	11.43	0.53



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- Gauge Record Points
- Highways
- Railway Lines
- Hydraulic Model Extent

Data Sources:

DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:

75mm Min. Depth
100m² Min. Area

Limestone Creek Model

2017 Recorded Data Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure
6

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4.0 Hydrologic Inputs

4.1 Runoff-Routing Approach

4.1.1 Overview

An XP-RAFTS runoff-routing hydrologic model has previously been developed for a northern portion of the Limestone Creek catchment (Aurecon, 2014) and was provided by RRC. The model computes the design discharge hydrographs by modelling catchment flows using Laurenson's non-linear routing methods. XP-RAFTS has been widely used throughout Queensland and is an accepted model to quantify flood flows. The model predicts flows for urban and rural catchments and is well suited to modelling this catchment.

Use of the existing XP-RAFTS model was necessary as the hydraulic model did not cover the entire catchment, as can be seen by Figure 7 and therefore the direct rainfall approach could not estimate runoff from the portion of the catchment that was outside the hydraulic model extent.

4.1.2 Model Configuration

The upper Limestone Creek catchment was delineated using a GIS interface based on the available topographic data. The portion of the catchment that was external to the hydraulic model extents was subdivided into 15 sub-catchments according to tributary network, catchment topography, land use and location where the hydrograph would be applied as a boundary condition to the hydraulic model.

Each sub-catchment was described in the XP-RAFTS model by specifying:

- Sub-catchment areas (in hectares).
- Average equal area sub-catchment slope (in %).
- Sub-catchment roughness.
- Fraction Impervious.

The roughness and fraction impervious factors were reviewed and no changes were made to those adopted from the existing Limestone Creek Hydrologic Model (Aurecon, 2014).

4.2 Direct Rainfall Approach

4.2.1 Overview

In traditional flood modelling, separate hydrological and hydraulic models are constructed. The hydrological model converts the rainfall within a sub-catchment into a peak flow hydrograph. This flow hydrograph is then applied to the hydraulic model, which estimates flood behaviour across the study area.

In the direct rainfall approach, the hydrological model is either partially or completely removed from the process. The hydrological routing is undertaken in the two dimensional hydraulic model domain, rather than in a lumped hydrological package.

The direct rainfall method involves the application of rainfall directly to the two dimensional model domain. The rainfall depth in a particular timestep is applied to each individual hydraulic model grid cell, and the two dimensional model calculates the runoff from this particular cell.

AR&R Revision Project 15 notes the following advantages of direct rainfall modelling:

- Use of the direct rainfall approach can negate the need to develop and calibrate a separate hydrological model, thus reducing overall model setup time.
- Assumptions on catchment outlet locations are not required. When a traditional hydrological model is utilised, an assumption is required on where the application of catchment outflows are made to the hydraulic model.
- Assumptions on catchment delineation are not required. Flow movement is determined by 2D model topography and hydraulic principles, rather than on the sub catchment discretisation, which is sometimes based on best judgement and can be difficult to define in flat terrains.

- Cross catchment flow is facilitated in the model. In flat catchments, flow can cross a catchment boundary during higher rainfall events. This can be difficult to represent in a traditional hydrological model.
- Overland flow is incorporated directly. Overland flow models in traditional hydrological packages require a significant number of small sub-catchments, to provide sufficient flow information to be applied to a hydraulic model.

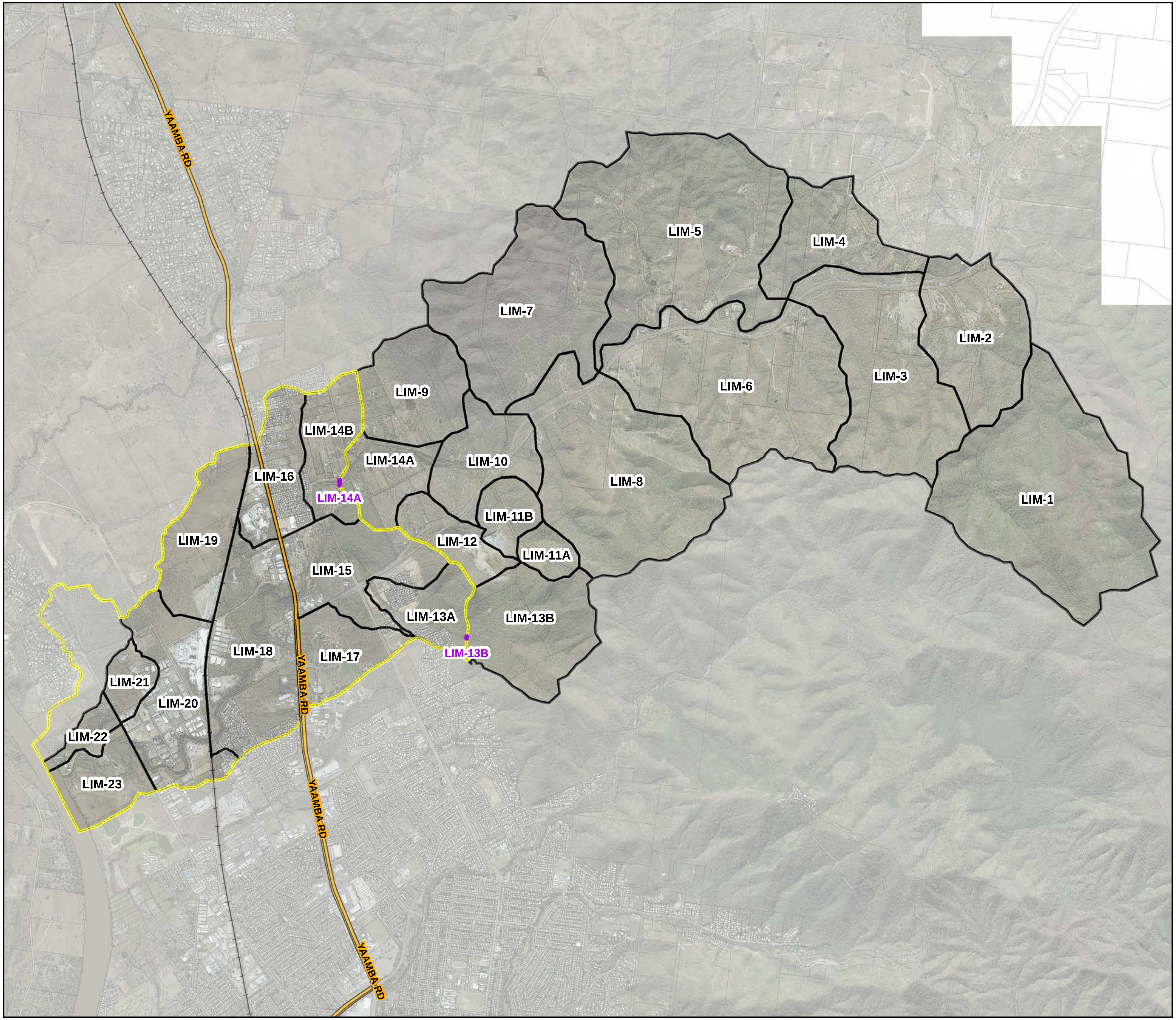
There are also several disadvantages associated with the use of the direct rainfall approach:

- Direct rainfall is a new technique, with limited calibration or verification to gauged data.
- The rain-on-grid approach can potentially increase hydraulic model run times.
- Requires digital terrain information. Depending on the accuracy of the results required, there may be a need for extensive survey data, such as aerial survey data.
- Insufficient resolution of smaller flow paths may impact upon timing. Routing of the rainfall applied over the 2D model domain occurs according to the representation of the flow paths by the 2D model.
- The shallow flows generated in the direct rainfall approach may be outside the typical range where Manning's 'n' roughness parameters are utilised.

4.2.2 Approach

Two dimensional rainfall time series for each design storm event were created to represent the local precipitation for the study area. The initial and continuing losses remove the loss depth from the design rainfall hydrograph prior to the remaining rainfall being applied to the 2D cells, to represent infiltration and storage of runoff in surface depressions. Losses chosen for this project are discussed in Section 4.4.5.

The time series of rainfall were developed for a range of design events by applying a temporal pattern in accordance with AR&R 1987 for magnitudes of 1 EY up to the PMP event (total of ten events).



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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydrologic Model Subcatchments
- Inflow Boundary
- Hydraulic Model Extent
- Hydrologic Model Subcatchments

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model

Hydrologic and Hydraulic Model Layout

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure 7

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4.3 Historic Rainfall Data

Historic rainfall records for the 2017 event was obtained for the Rockhampton Aero pluviograph station located approximately 11km southwest of the study area. Records at Council-managed gauges were also available for the 2017 event. Records from the privately-owned gauge at Serocold Street were not available from the Serocold Street gauge for the 2017 event. The simulated rainfall profile of the 2017 event is presented in the following sections.

4.3.1 2017 Event – Ex-TC Debbie

Ex-TC Debbie moved across the Fitzroy Catchment and Rockhampton in late March, 2017. Significant rainfall triggered a major Fitzroy River flood peak of 8.90 m at Rockhampton, preceded by a local catchment flood event as a result of the 211.0 mm of rain across the Limestone Creek urban catchment.

Detailed 1-minute interval records were available for the Yaamba Road Reservoir gauge. The gauge is located within the Limestone Creek catchment. As such, the Yaamba Road Reservoir rainfall data was adopted for calibration of the model. The timeseries of rainfall data at Yaamba Road Reservoir for the 2017 event is shown in Figure 8.

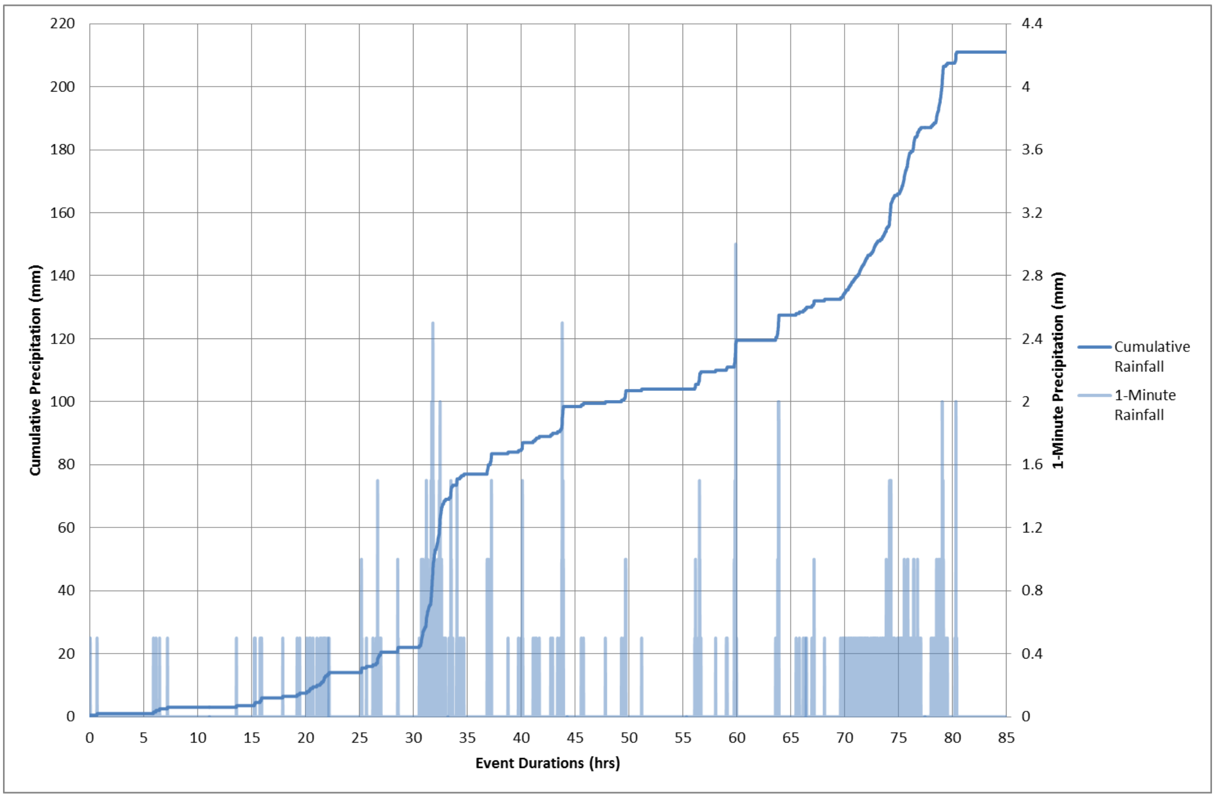


Figure 8 **2017 Event Rainfall (Yaamba Rd Reservoir)**

Total rainfall depths between the gauges in North Rockhampton showed recorded rainfall depths at Rogar Avenue were significantly higher than those situated further north and west of the catchment.

Rainfall Gauge	Total Rainfall (mm)	Difference to Rockhampton Aero (mm)	Difference to Rockhampton Aero (%)
Rockhampton Aero	186.6	-	-
West Rockhampton STP	203.0	16.4	9%
Agnes Street Reservoir	204.5	17.9	10%
Rogar Avenue Reservoir	308.0	121.4	65%

Rainfall Gauge	Total Rainfall (mm)	Difference to Rockhampton Aero (mm)	Difference to Rockhampton Aero (%)
Glenmore WTP	199.7	13.1	7%
Yaamba Road Reservoir	211.0	24.4	13%
Lucas Street Reservoir	200.0	13.4	7%

With the exclusion of Rogar Street Reservoir, comparison between the rainfall stations revealed a peak discrepancy of less than 25mm, with the rainfall depth measured at Yaamba Road Reservoir only 13% above that of Rockhampton Aero, confirming the suitability of the Yaamba Road Reservoir data for the urban catchment during the 2017 comparison event. However, given the mountainous proportion of the Limestone Creek catchment and the potential for spatial variability of rainfall, the Rogar Avenue Reservoir rainfall was applied to the model.

4.4 Design Rainfall Data

4.4.1 IFD Parameters

Design rainfall data was sourced from the Bureau of Meteorology (BoM) online IFD tool (bom.gov.au/water/designRainfalls/ifd-arr87/index.shtml). IFD parameters required to determine rainfalls for events not previously modelled were sourced using a single set of parameters, derived at the location (150.500 E, 23.300 S). The IFD input data set obtained is shown in Table 5.

Table 5 Adopted IFD Input Parameters

Parameter	Value
1 hour, 2 year intensity (mm/hr)	44.3
12 hour, 2 year intensity (mm/hr)	9.1
72 hour, 2 year intensity (mm/hr)	2.7
1 hour, 50 year intensity (mm/hr)	90.9
12 hour, 50 year intensity (mm/hr)	19.6
72 hour, 50 year intensity (mm/hr)	6.9
Average Regional Skewness	0.21
Geographic Factor, F2	4.22
Geographic Factor, F50	17.72

Standard techniques from AR&R 87 were used to determine rainfall intensities up to the 12 hour duration for the 1EY (exceedance per year), and 39%, 18%, 10%, 5%, 2% and 1% AEP events. The calculated IFD data is shown in Table 6.

Table 6 Intensity Frequency Duration Data for Rockhampton

Duration (hr)	Intensity (mm/hr)						
	1 EY	39% AEP	18% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1	34.2	44.3	57.3	65.4	76.2	90.9	103.0
2	22.4	29.1	37.6	43.0	50.1	59.8	67.5
3	17.3	22.4	29.1	33.2	38.8	46.4	52.3
6	11.0	14.3	18.6	21.3	25.0	29.9	33.8
12	7.0	9.1	12.0	13.9	16.3	19.6	22.3

4.4.2 Temporal Pattern

Temporal patterns for Zone 3 were adopted for events up to the 0.2% AEP using the standard methodology outlined in AR&R (1987).

Temporal pattern for the Probable Maximum Precipitation (PMP) event were sourced from data provided with the Generalised Short Duration Method (GSDM) guidebook (refer Section 4.4.4).

4.4.3 Areal Reduction Factors

The IFD rainfall values derived in Section 4.4.1 are applicable strictly only to one point; however AR&R state that they may be taken to represent IFD values over a small area (up to 4 km^2). No reduction of the IFD rainfall was undertaken due to the relatively small catchment areas associated with this investigation.

4.4.4 Probable Maximum Precipitation Event

The PMP has been defined by the World Meteorological Organisation (2009) as '*the greatest depth of precipitation for a given duration, meteorologically possible for a given size storm area at a particular location at a particular time of year*'.

The PMP event results in a Probable Maximum Flood (PMF) event. This is a theoretical event which is very unlikely to ever occur within any given catchment. The PMF event is typically used in design of hydraulic structures, such as dams. Its most common use is in design of dam spillways to minimise the risk of overtopping of a dam and minimise the likelihood of dam failure. Other than this practical use, it is used to provide an indication of the largest flood extents expected within any given catchment and also forms the upper bound within flood damages assessments. PMF behaviours can be used by emergency management agencies in their understanding of and planning for flood events.

The Generalised Short-Duration Method (GSDM), as revised in 2003, was applied to derive estimates of PMP for short duration storms. The GSDM applies to catchments up to 1,000 km^2 in area and durations up to 6 hours, which makes the method applicable to the Limestone Creek Local Catchment Study which has a catchment area of approximately 30.2 km^2 and a critical duration of 3 hours (refer Section 8.2).

Using the methodology set out in the GSDM Guidebook (BoM, 2003), the following data for the PMP was determined:

- The coastal GSDM Method is applicable as the catchment lies on the Queensland coast.
- The Roughness (R), Elevation Adjustment Factor (EAF) and Moisture Adjustment Factor (MAF) were calculated as 1.0, 1.0 and 0.90 respectively.
- PMP parameters were calculated as shown in Table 7.

Table 7 Adopted PMP Parameters

Duration (hrs)	Rainfall Total (mm)	Rainfall Intensity (mm/hr)
1	370	370
2	560	280
3	670	223

The AEP of the PMP event was calculated as recommended in AR&R (Pilgrim, et al, 1987). For a catchment area of 42.4 km^2, the PMP event is approximately a 1 in 10,000,000 AEP event.

4.4.5 Design Event Rainfall Loss Parameters

Design event losses were established based on the results of the calibration and verification events. The adopted losses vary from a maximum of 15 mm initial loss and 1.0 mm continuing loss for very pervious surfaces to a minimum of 0 mm for both the initial and continuing losses on impermeable materials, depending upon the material. They are presented in Table 26 in Appendix A.

Aurecon's previous study (2014) adopted variable losses depending on the event, whereas in this study the design losses adopted have been maintained across all events, excluding the PMF.

During the PMF design event it was assumed the catchment had been saturated by the pre-burst rainfall, in order to simulate this, the initial loss applied was reduced to 0 mm. This is a conservative approach, the continuing loss remained for the current study.

5.0 Hydrologic Inflows

5.1 Overview

As discussed in Section 4.1, the existing XP-RAFTS hydrologic model has been used to estimate inflows at the upstream boundary of the Limestone Creek hydraulic model.

The XP-RAFTS model was revised and updated during this investigation to ensure consistent rainfall and loss parameters were applied between the hydrologic and hydraulic models. An initial loss of 15 mm and continuing loss of 1.0 mm were applied, with rainfall being introduced using timeseries .csv files.

XP-RAFTS build version 2013 was used for this assessment. An overview of the hydrologic model development can be reviewed in the Limestone Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014).

5.2 Hydrologic Inflow Comparison

An overview of the inflows applied to the previous (Aurecon, 2014) and updated model (AECOM, 2017) is provided in Table 8.

Table 8 Model Inflows Comparison Overview

Event (AEP)	Previous Study Peak Inflows (m^3/s)	Current Study Peak Inflows (m^3/s)		Difference
	Node LIM-14*	Node LIM-13B*	Node LIM-14A*	
1EY	-	10	55	-
39%	80	15	85	6.3%
18%	124	22	129	4.0%
10%	162	26	157	-3.1%
5%	212	33	196	-7.5%
2%	276	39	249	-9.8%
1%	322	45	293	-9.0%
0.2%	531	73	476	-10.4%
0.05%	-	96	624	-
PMF	1,829	197	1,818	-0.6%
January 2013	256	-	-	-
February 2015	-	-	-	-
March 2017	-	19	136	-

* Note: Sub-catchment node reference as per Figure 7.

As outlined in Section 4.4.5, variation in the adopted rainfall losses results in some differences in the hydrologic inflows between the previous and current studies.

As can be seen from the loss comparison in Table 14, for the 18% AEP and smaller events the losses applied in the previous study were larger than the current study resulting in the larger inflow for the 18% AEP and 39% AEP design events. As the same losses were applied for all design events excluding the PMF in the current study, whereas in the previous study the losses were reduced for the larger events. This resulted in lesser inflows being applied to the current model boundary especially for events of 5% AEP and larger.

6.0 Hydraulic Model Development

6.1 Overview

This section of the report discusses the further development of the existing hydraulic model previously used to assess creek flooding in the Limestone Creek Local Catchment. The updated model has been used to assess key local catchment flood behaviours and deficiencies in the existing stormwater network leading to increased flood risk. These assessments will assist in the development of mitigation options in Future Phase 3.

In order to improve the representation of key hydraulic features, the model resolution was improved from a 5 m to 3 m grid. A timestep of 1 second was adopted (2.0 second previously), giving an effective runtime of approximately 4.6 real-time hours to 1 simulation hour.

TUFLOW build version 2016-03-AE was used for this assessment.

6.2 Hydraulic Model Parameters

Detailed updates made to the existing TUFLOW model are located within Appendix A.

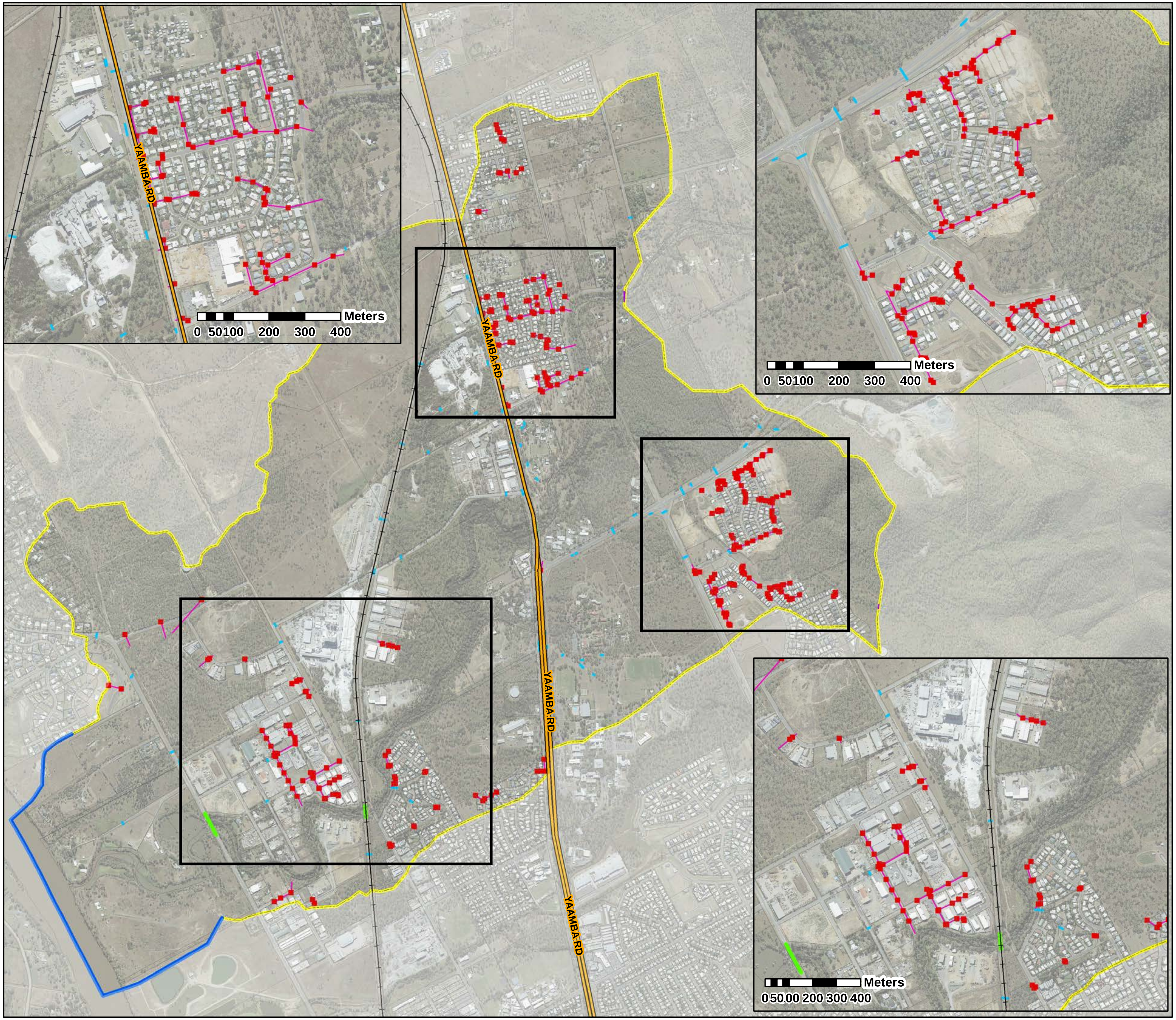
An overview of the model setup and key parameters for the model is provided in Table 9.

Table 9 Hydraulic Model Setup Overview

Parameter	Limestone Creek Local Catchment Model
Completion Date	May 2017
AEP's Assessed	1 EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF
Hydrologic Modelling	XP-RAFTS Inflow and Direct Rainfall Approach
IFD Input Parameters	Refer to Section 4.4.1
Hydraulic Model Software	TUFLOW version 2016-03-AE-w64-iDP
Grid Size	3m
DEM (year flown)	2016
Roughness	Spatially varying and depth varying standard values – consistent with Limestone Creek Model and Limestone Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014).
Eddy Viscosity	Smagorinsky
Model Calibration	Limited calibration to the 2017 event.
Downstream Model Boundary	3 inflow boundaries along the north-eastern boundary, 1 height-time boundary on the south-western boundary.
Timesteps	1 second (3m 2D) and 0.5 second (1D)
Wetting and Drying Depths	Cell centre 0.0002 m
Sensitivity Testing	Stormwater Infrastructure Blockage, ±15% Hydraulic Roughness, Riverine and Local Catchment Coincident Event, Inlet Structure Dimensions and Climate Change

6.3 Model Setup

A visual representation of the model setup including the code, boundaries, 1D network and hydraulic roughness delineation are included as Figure 9 and Figure 10 to supplement the detailed updates outlined in Appendix A.



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- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- Pit Inlet
- Pipe
- Culverts
- Inflow Boundary Conditions
- Outflow Boundary Condition
- Layer Flow Constrictions

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
100m² Min. Area

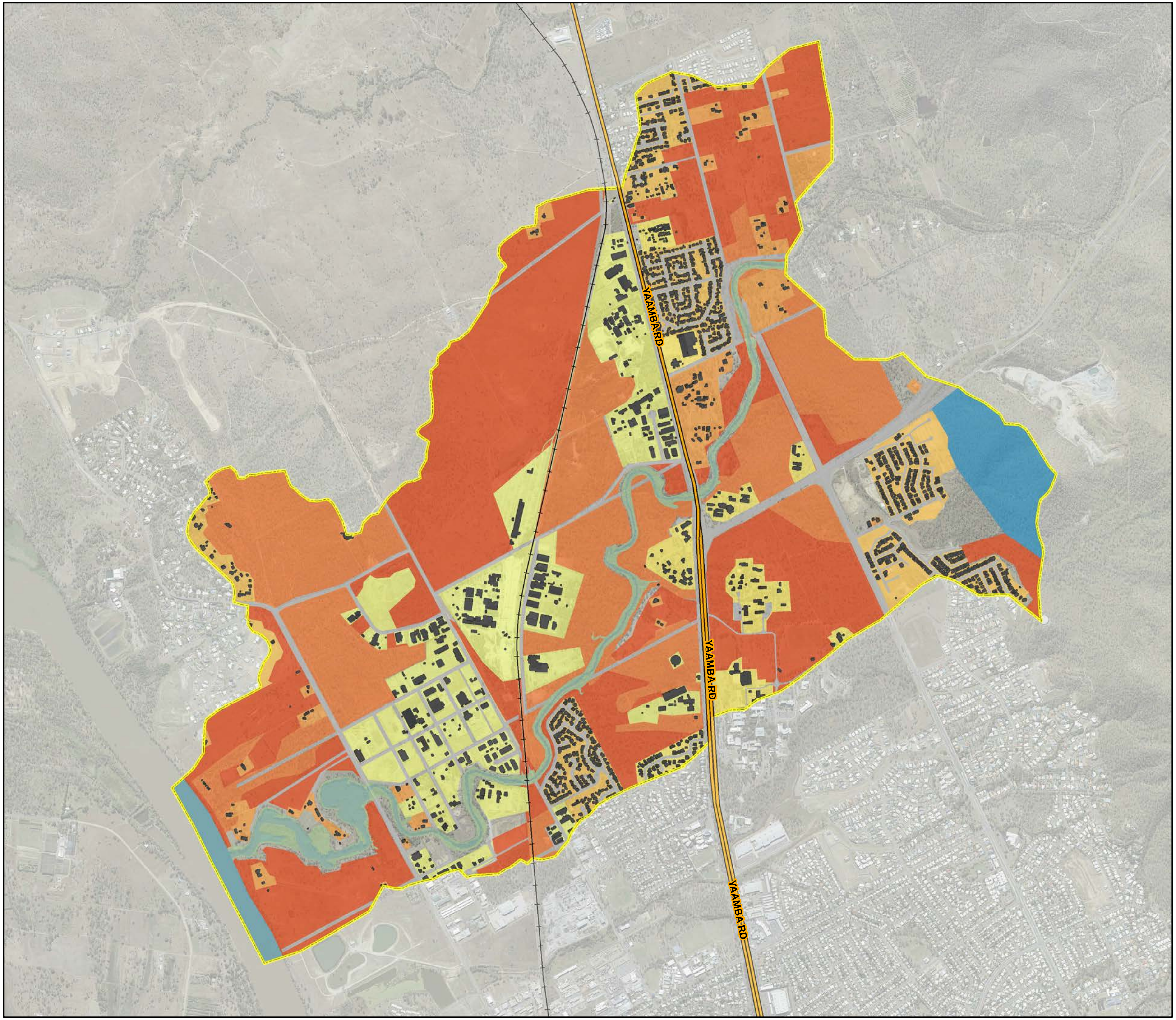
Limestone Creek Model

Model Setup and 1D Network Map

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure 9

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 9 Model Setup and 1D Network Map.mxd



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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Building Footprints
- Road Corridor
- Steep Slopes
- Fitzroy River Bed
- Creek Channel
- Riparian Corridor
- Railway
- Commercial Industrial Block
- High Density Residential
- Medium Density Residential
- Low Density Residential
- Medium Vegetation
- Low Vegetation

Data Sources:

DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:

75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model

Hydraulic Roughness Delineation

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 29/06/2017
VERSION: 1

Figure 10

7.0 Historic Event Comparison

7.1 Adopted Methodology

Assessment of the TUFLOW model performance against recorded gauge data was undertaken by simulating a historical flood event and comparing the results to recorded data provided by Council. The model was assessed using the 2017 flood event. The model parameters have been adopted based on roughness, initial losses, rainfall losses and stormwater infrastructure assumptions from neighbouring calibrated local catchment models. Exclusion of the pre-burst rainfall was adopted in order to make model runtimes more manageable.

The Barrage weir crest level of 3.65 mAHD was applied to the initial water level for the 2017 event. Recorded gauge data levels were based on peak flood debris and depth levels within the gauges managed by Council and as such tolerances have been adopted as ±0.15 m.

7.2 Comparison to the 2017 Event

The 2017 rainfall gauge data at the Rogar Avenue Reservoir gauge was applied to the TUFLOW model. The maximum water surface elevations were extracted from the hydraulic model and compared to recorded peak flood levels provided by RRC.

The following model iterations were simulated for the 2017 event.

Table 10 March 2017 Event Calibration Model Parameter Summary

Model Iteration No.	Initial Loss (mm)	Continuing Loss (mm)
E001	15	1.0

Peak flood levels were recorded at 2 locations within the Limestone Creek area. The simulated peak heights were compared to the heights at the recorded locations. Results from the various scenarios are presented in Table 11 below.

Table 11 March 2017 Calibration Event Results

Point ID	Recorded Level (mAHD)	Peak Flood Height (mAHD)
		E001
42	21.63	20.94
44	11.96	12.30

Analysis of the results reveals the following:

- The model may be underestimating flow upstream of Yaamba Road due to the spatial variability of rainfall across orographic features in the upper catchment and lack of rainfall data within the upper Limestone Creek catchment.
- Tributary flow paths may benefit from feature survey to ensure accurate overtopping of weir points in smaller events.
- The model may be overestimating peak flood levels downstream of Yaamba Road through sections of dense vegetation and sitting water. LiDAR is unable to penetrate such topographic features and as such, requires bathymetric survey in order to accurately represent the channel conveyance.

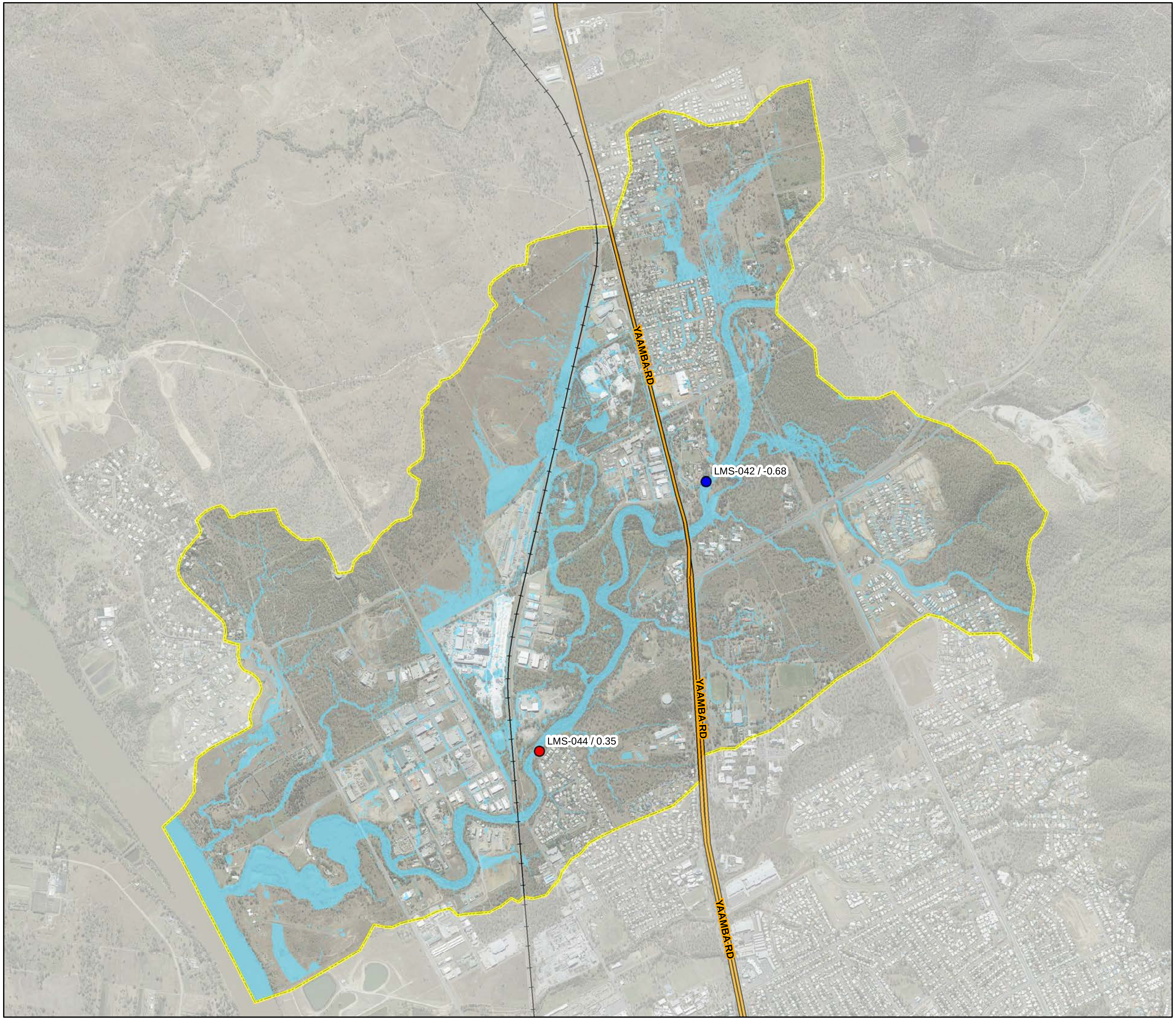
The map in Figure 11 presents the comparison of water levels at recorded height locations for the scenario E001, the analysis of the calibration results are in Table 12. The difference between the calculated and recorded flood levels are categorised into bands. Locations where the model predictions are within adopted tolerance ranges are shown as orange (high, but within tolerance), light blue (low, but within tolerance) and green (within tolerance). Locations where model predictions are outside the tolerances ranges are shown as red (above tolerance) and dark blue (below tolerance) points.

Table 12 March 2017 Calibration Results Analysis

Point ID	Recorded Level (mAHD)	Peak Height (mAHD)			Difference (m)	Tolerance
		E001	Lower Tolerance	Upper Tolerance		
42	21.63	20.94	21.48	21.78	-0.69	Below tolerance
44	11.96	12.30	11.81	12.11	0.34	Above tolerance

Key outcomes from the comparison are:

- Of the two recorded points, nether were within the corresponding tolerances with the average difference calculated to be -0.18 m and a standard deviation of 0.52 m.
- Rainfall data within the catchment is pertinent to obtaining confidence that appropriate inflows are being applied to the hydrologic and hydrodynamic models.
- Bathymetric survey of the creek channel at key locations is expected to better-represent actual channel conveyance which is expected to improve the model's comparison to historic events.
- Additional anecdotal and/or gauge data across the middle segment of the Limestone Creek catchment would assist in developing holistic confidence in the model performance.



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Calibration Results

Difference (m)

- < -0.30 (Below tolerance)
- -0.30 - -0.15 (In tolerance, low)
- -0.15 - 0.15 (In tolerance)
- 0.15 - 0.30 (In tolerance, high)
- > 0.30 (Above tolerance)
- Highways
- Railway Lines
- Hydraulic Model Extent

Simulated Peak Flood Extent

- Mar 2017 Event

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model
Calibration Results

March 2017 Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure
11

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 11 2017 Results.mxd

8.0 Baseline Hydraulic Modelling

8.1 Overview

The Limestone Creek Local Catchment model was used to simulate the 1 EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF events.

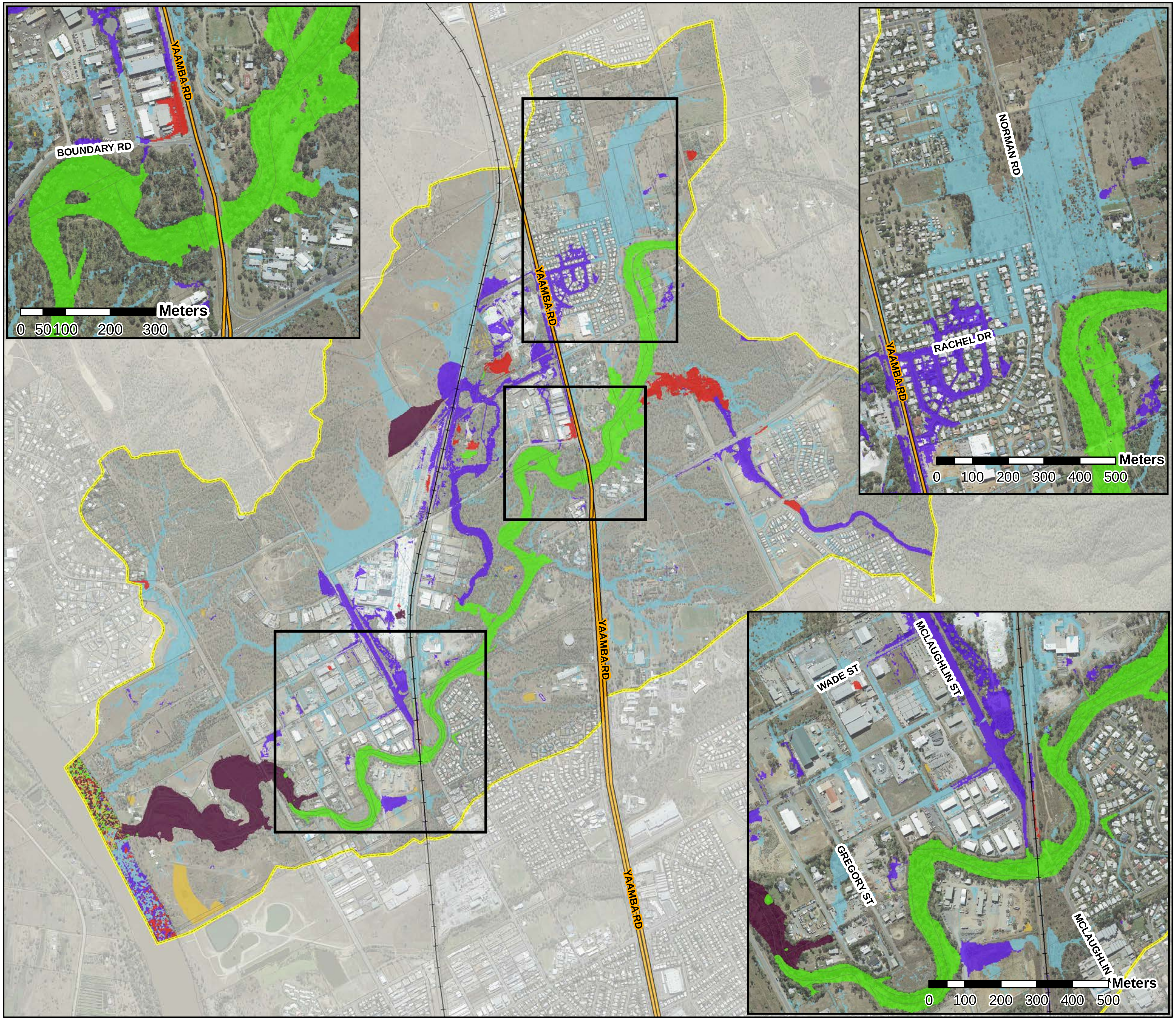
8.2 Critical Duration Assessment

The critical storm duration for the Limestone Creek Local Catchment area was assessed by simulating the 60 min, 90 min, 120 min, 180 min, 270 min and 360 min durations for the 1% AEP event. Figure 12 shows that for a 1% AEP event Limestone Creek is dominated by a critical duration of 180m until Alexandra Street where a reduced hydraulic grade sees the 270 min as the critical duration. Urban flow paths are generally highest within 60 min and 90 min events.

Analysis of the 60 min and 180 min durations reveals the peak flood height difference between the storm durations across the catchment, as shown in Figure 13. Differences of more than 300mm were evident immediately upstream of Yaamba Road south of Yeppoon Road. Other developed sections were shown to be up to 75 mm higher in a 60 min event than a 180 min event. The raster histogram shown in Figure 14 provided additional insight into the difference class proportions, showing approximately 91% of the instances where the 60 min was higher were less than 75 mm difference. With this in mind and given the significance of the creek influence on flooding in larger events, a critical duration of 180 min was selected.

With the exception of the 1% AEP event, the 180 minute critical duration was applied to all design flood events mentioned in Section 8.1. For the 1% AEP a ‘Max:Max’ analysis was undertaken, whereby results from the 60 min, 90 min, 120 min, 180 min, 270 min and 360 min storm durations were compared and the maximum flood levels extracted at each cell within the model domain.

This ensures that the maximum flood level for the 1% AEP design flood event which is used for Planning Purposes for the Rockhampton Region is shown to be independent of the critical storm duration variance across the model extent.



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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Critical Storm Duration

- 060m
- 090m
- 120m
- 180m
- 270m
- 360m

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
100m² Min. Area

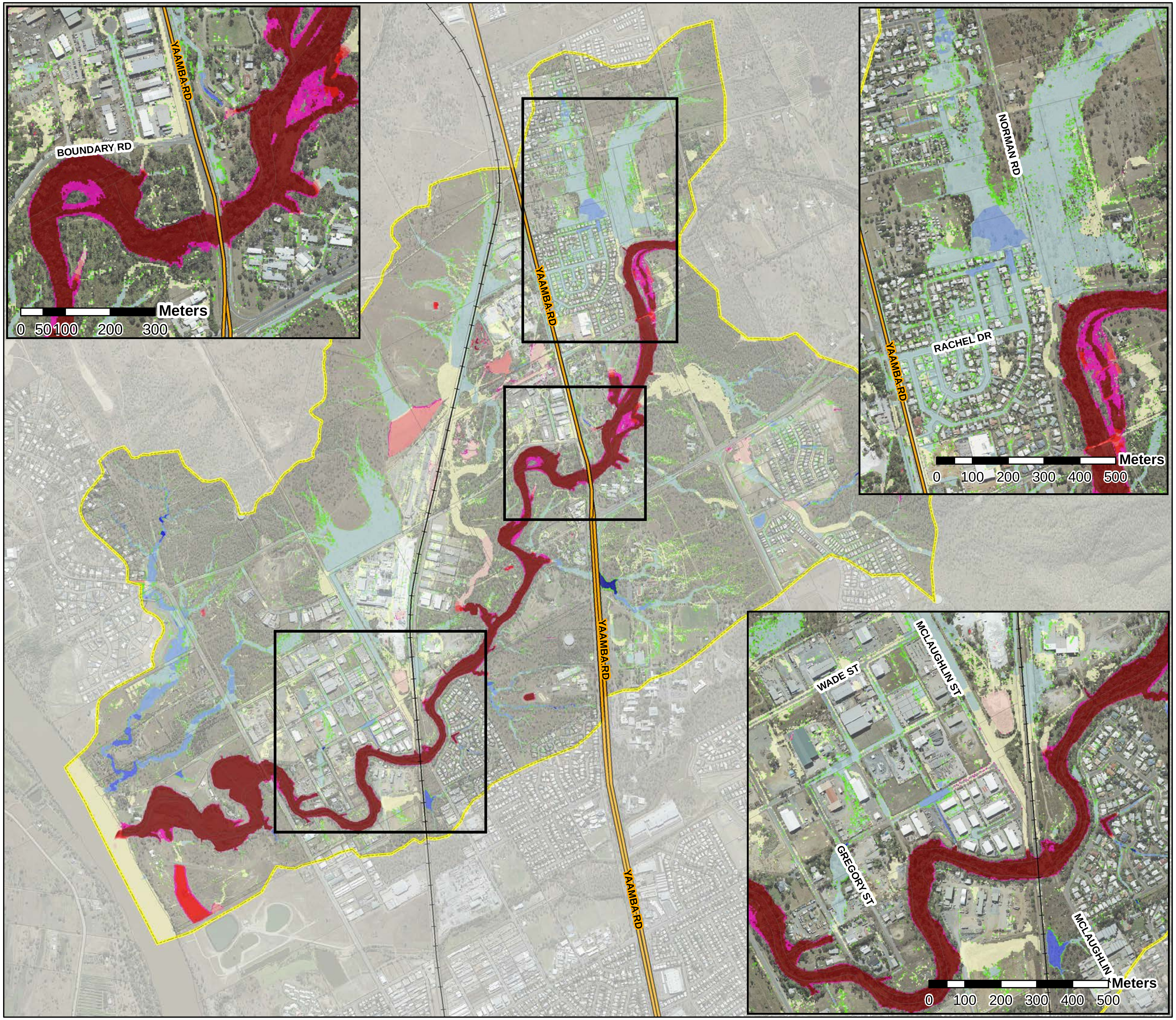
Limestone Creek Model
Critical Duration Assessment

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure
12

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 12 Critical Duration.mxd



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Metres

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(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in PWSE (m)

- < -0.3
- -0.3 to -0.225
- -0.225 to -0.15
- -0.15 to -0.075
- -0.075 to -0.02
- -0.02 to 0.02
- 0.02 to 0.075
- 0.075 to 0.15
- 0.15 to 0.225
- 0.225 to 0.3
- > 0.3
- Was Dry Now Wet*
- Was Wet Now Dry

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model
Difference in Peak Flood Heights
180min Storm minus 60min Storm

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure 13

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 13 1pAEP180minus60.mxd

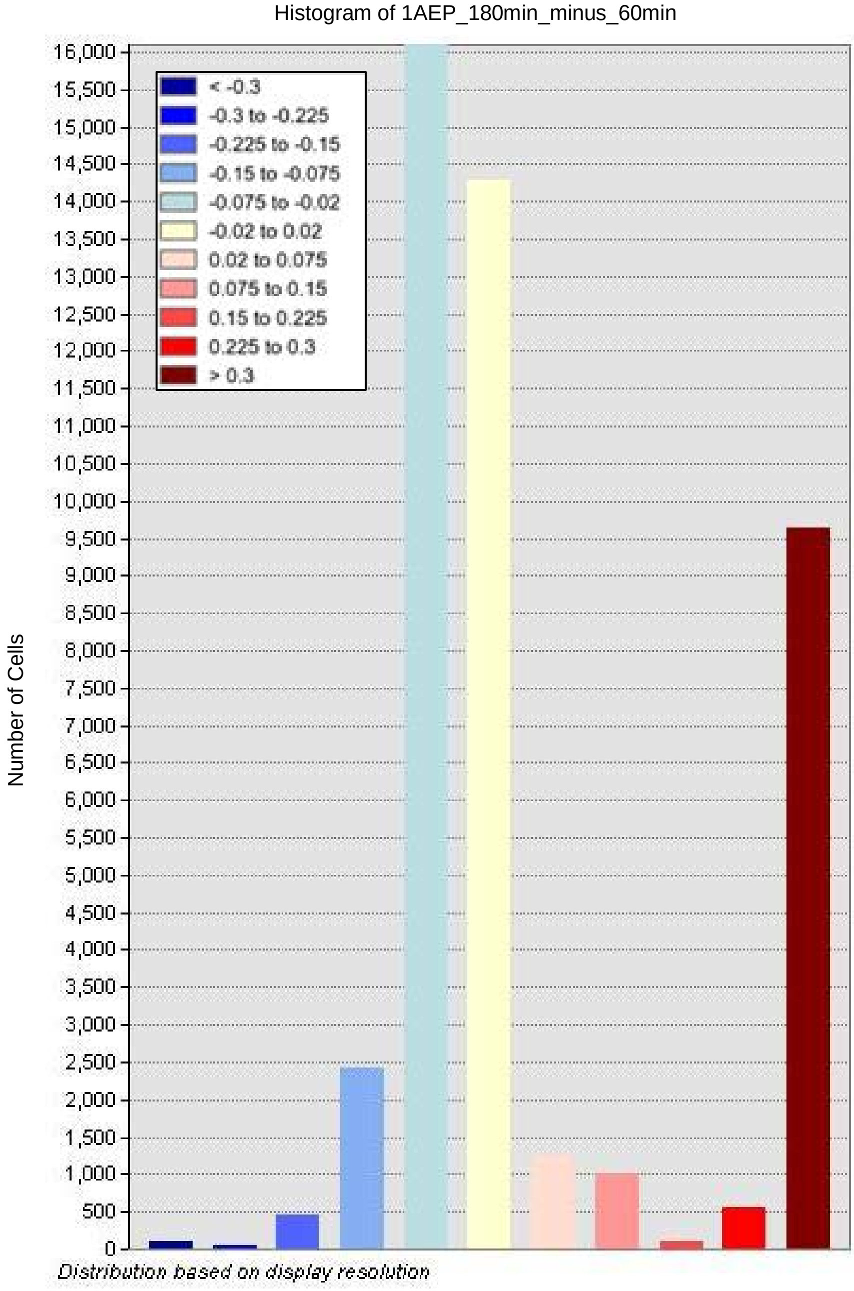


Figure 14 Palette Histogram of 1% AEP 180min PWSE minus 60min PWSE (m)

8.3 Baseline Flood Depths, Extents and Velocities

Rain-on-grid modelling uses a process whereby rainfall is applied to every model cell. Mapping of these results in their raw form would show that the entire model extent was flooded. For this reason, areas where the water depth is less than 75mm were removed from the mapping. In addition, a filtering process was completed whereby flooded areas of less than 100 m^2 were removed from the mapping. Note that these depths are still included in the computational scheme. This process is aligned to guidance from AR&R Project 15 (Engineers Australia, 2012).

Maps 1 to 30 of the Volume 2 report show the baseline design flood depth, heights and velocities for the 1 EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF events.

It is noted that significant inter-catchments flows occur during the 0.05% AEP and PMF events. To account for these flows, a number of changes were made to the model setup:

- The model boundary was extended into the neighbouring catchment to allow inter-catchment flows to be modelled (refer to Figure 9).
- Boundary conditions were included to allow these inter-catchment flows to exit the model, thereby maximising the accuracy of the flood level predictions (refer to Figure 9).

This approach assumes PMF flooding within each catchment is independent of the adjacent catchments. It does not allow for jointly occurring PMF events. Given the low likelihood of a PMF event actually occurring, this approach was deemed acceptable for this study.

The baseline modelling shows:

- **Maps 1 to 3** – 1 EY Baseline

In the 1EY event the depth of flow in Limestone Creek fluctuates between 1.5 m and 3 m. Flow paths over the remaining catchment remains largely within the capacity of the existing road and drainage infrastructure. Peak depth averaged velocities in Limestone Creek vary between 1 m/s and 2 m/s.

- **Maps 4 to 6** – 39% AEP Baseline

Flood extents in the 39% AEP event are mostly contained within drainage reserves and the creek system. Notably, flow paths overtop Boundary Road with depths of less than 0.3 m. Alexandra Street is also overtopped with depths less than 0.3 m. The overland flow path between Gregory Street and Leichhardt Street results in inundation depths of up to 0.9 m within industrial properties. Overland flows also cross over Norman Road near Newton Street, depth of flow of up to 0.9 m and velocities perpendicular to the road of up to 0.5 m/s are expected. The peak water surface elevation at the Yaamba Road intersection and the rail crossing is up to 20 mAHD and 10 mAHD respectively. The peak depth averaged velocity flowing down Rachel Drive is up to 1 m/s. Velocities within the upper extents of the Limestone Creek are greater than 2 m/s.

- **Maps 7 to 21** – 18% AEP Baseline

Similar to the 39% AEP event, the flow paths are mainly contained to open areas and drainage reserves. Some industrial properties experience localised inundation within their property, specifically those properties situated adjacent to Limestone Creek.

The peak water surface elevation at the Yaamba Road intersection is up to 20 mAHD, and at the rail crossing the elevation is up to 10 mAHD. Peak depth averaged velocities for the full length of Limestone Creek are greater than 2 m/s.

- **Maps 22 to 24** –10% AEP Baseline

The table drain running beside McLaughlin Street has a depth of less than 0.6 m, while at the downstream end; peak depths of up to 1.5 m are expected. The peak water surface elevation at the Yaamba Road intersection is up to 20 mAHD, and at the rail crossing the elevation is up to 12 mAHD. Peak depth averaged velocities within Limestone Creek are greater than 2 m/s.

- **Maps 25 to 27** – 5% AEP Baseline

Notable differences between the 5% AEP event and the 10% AEP event is that private properties begin to experience inundation within the Rachel Drive area. The peak water surface elevation at the Yaamba Road intersection is up to 22 mAHD, and at the rail crossing the elevation is up to 12 mAHD. The depth of flow paths crossing various local roads remains below 0.3 m, with the exception of Norman Road which has depths of up to 0.9 m at its lowest point.

- **Maps 28 to 30** – 2% AEP Baseline

Overland flow paths within the Limestone Creek catchment are predominantly within the capacity of the roads and drainage infrastructure. Natural flow paths within the system are evident, with significant attenuation of surface water occurring within the catchment, particularly adjacent to the North Coast rail line, with some depths of up to 1.2 m. There is expected to be several breakout flow paths from the main creek channel to the natural floodplain, although most of this area is still within open areas.

Additional properties on Rachel Drive will experience inundation, when compared to the 5% AEP event. Peak water surface elevations at the Yaamba Road crossing is up to 22 mAHD and at the rail crossing it is up to 12 mAHD. Peak depth averaged velocities in the table drain adjacent to McLaughlin Street are up to 1.5 m/s.

- **Maps 31 to 45** – 1% AEP Baseline

In the 1% AEP event the depth of the flow crossing Boundary Road reaches up to 0.6 m. Inundation of the shoulders along Yaamba Road is expected. The peak water surface elevation at Yaamba Road is up to 22 mAHD and up to 12 mAHD at the railway crossing. Flows within the upper creek reach have a velocity greater than 2 m/s.

- **Maps 46 to 48** – 0.2% AEP Baseline

Flood extents continue to expand when compared to the 1% AEP event. Peak depths in the table drain running alongside McLaughlin Street are up to 1.8 m at the downstream end. Properties within the industrial area at the lower section of Limestone Creek experience flood waters entering their properties in this event. Properties adjacent to the creek at the end of Coolibah Close, are also expected to experience inundation of their properties during this event. Within the industrial estate, velocities reach up to 1.5 m/s along some of the flow paths down existing roads. Steeper sections of the catchment and creek area experience peak depth averaged velocities greater than 2 m/s.

- **Maps 49 to 51** – 0.05% AEP Baseline

The overall peak flood extent in the 0.05% AEP baseline model is significantly larger than other events and follows the natural creek / floodplain topography. Multiple sections of Yaamba Road in both directions become overtopped by overland flow paths. Flows are not contained within the creek system, with breakouts occurring along most of the reach. A significant number of properties in the area surrounding Rachel Drive are inundated due to overland flow. Flood elevations at Yaamba Road reach 22 mAHD and 12 mAHD at the railway crossing. Velocities within the creek channel exceed 2 m/s.

- **Maps 52 to 54** – PMF Baseline

In the PMF event the peak flood extent impacts the majority of the catchment. Flows are not contained within the creek system and breakouts occur along most of the reach resulting in flooding of a number of residential and commercial areas. A large portion of properties in the area surrounding Rachel Drive are inundated due to overland flow. Flood depths throughout Rachel Drive and surrounding residential areas range up to 1.2m and the industrial area near McLaughlin street experience significant flooding with depths of between 1.5m to over 3m. Velocities within the creek channel exceed 2 m/s.

- **Map 55** – Design Event Extent Comparison

Flood extents on vary slightly for events up to 1% AEP magnitude. It can be seen that during the 0.2% AEP and 0.05% AEP events, the flood extents within the catchment expands with the natural floodplain conveying high flows. This is expected to result in the inundation of some residential properties.

The residential properties surrounding Rachel Drive experience significant inundation during the 0.2% AEP and 0.05% AEP events, largely due to the overland runoff from the undeveloped catchment to the north east.

8.4 Baseline Peak Discharges

Peak discharges across the range of simulated design events for the 180m critical duration, were extracted at key locations, including but not limited to:

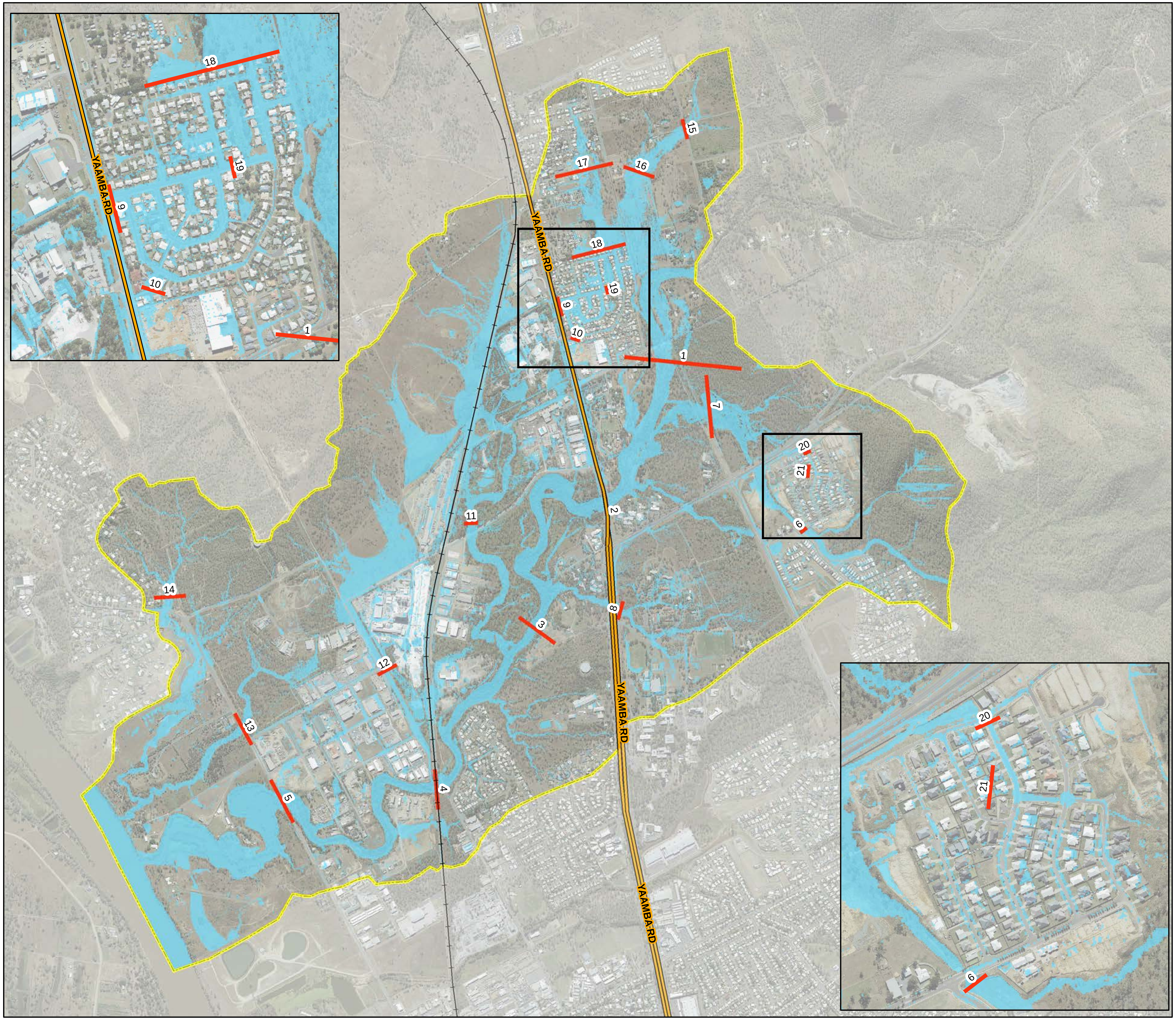
- Limestone Creek major crossings;
- Yaamba Road;
- Boundary Road;
- Rachel Drive;
- Nellie Close; and
- Alexandra Street.

Refer to Figure 15 for extraction cross-section locations. Table 13 below presents the results at corresponding locations.

Figure 15 for extraction cross-section locations. Table 13 below presents the results at corresponding locations.

Table 13 Summary of Baseline Peak Discharges

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (180 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Limestone Creek	1	57.6	89.4	133.7	162.5	202.9	259.8	306.2	491.3	640.8	1575.1
	2	69.3	105.1	154.1	185.8	229.2	289.0	338.5	542.7	703.7	1347.4
	3	71.4	108.5	158.3	190.9	235.1	295.5	345.7	546.2	652.1	1182.9
	4	75.0	114.6	166.4	200.7	246.9	312.5	367.3	586.0	751.8	1048.4
	5	76.6	117.3	171.6	207.1	255.3	322.1	378.7	603.5	775.3	1607.2
Foulkes Street	6	10.9	17.0	25.1	30.4	37.7	45.0	52.4	83.1	105.6	210.6
Norman Road	7	13.7	21.5	31.2	37.9	46.0	54.4	61.8	79.5	94.0	201.8
Yaamba Road	8	3.9	6.4	9.6	11.6	14.3	15.7	17.6	22.7	28.3	53.7
Rachel Drive	9	0.1	0.1	0.2	0.2	0.9	1.9	3.6	11.8	16.9	95.7
Nellie Close	10	0.3	0.5	0.8	1.4	2.4	3.2	4.5	9.0	11.3	50.3
Boundary Road	11	2.5	4.7	8.0	10.4	13.8	16.9	20.3	39.5	54.1	146.1
McLaughlin Street	12	3.4	5.7	7.8	10.0	12.9	15.8	18.6	28.1	34.9	66.1
Alexandra Street	13	1.9	3.6	5.8	7.2	8.8	9.8	11.4	17.5	22.5	34.2
Belmont Road	14	4.4	6.6	8.3	9.7	11.4	12.2	13.9	20.5	25.6	36.5
McMillan Avenue	15	2.1	2.9	4.2	4.8	5.6	6.0	6.6	9.6	11.8	16.7
Rural near Norman Road	16	3.2	5.0	6.6	8.0	9.5	10.5	12.0	17.9	22.8	32.9
Mason Avenue	17	2.4	4.2	4.5	5.2	6.0	7.4	8.4	10.4	12.7	17.6
Norman Road flow from North	18	2.9	4.7	7.4	9.2	12.0	15.3	16.8	26.8	35.1	89.6
Rachel Drive	19	0.4	0.9	1.5	2.4	3.3	3.8	4.8	9.5	12.7	59.6
Geoff Wilson Drive	20	0.2	0.2	0.5	0.9	1.1	1.2	1.5	1.9	2.2	2.5
	21	0.0	0.1	0.1	0.2	0.4	0.5	0.8	1.8	2.4	4.7



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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Discharge Cross-sections
- 1% AEP Flood Extent

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
100m² Min. Area

Limestone Creek Model

Key Flow Path Discharge Locations

PROJECT ID	60534898
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LAST MODIFIED	29/06/2017
VERSION:	1

Figure 15

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8.5 Stormwater Network Capacity

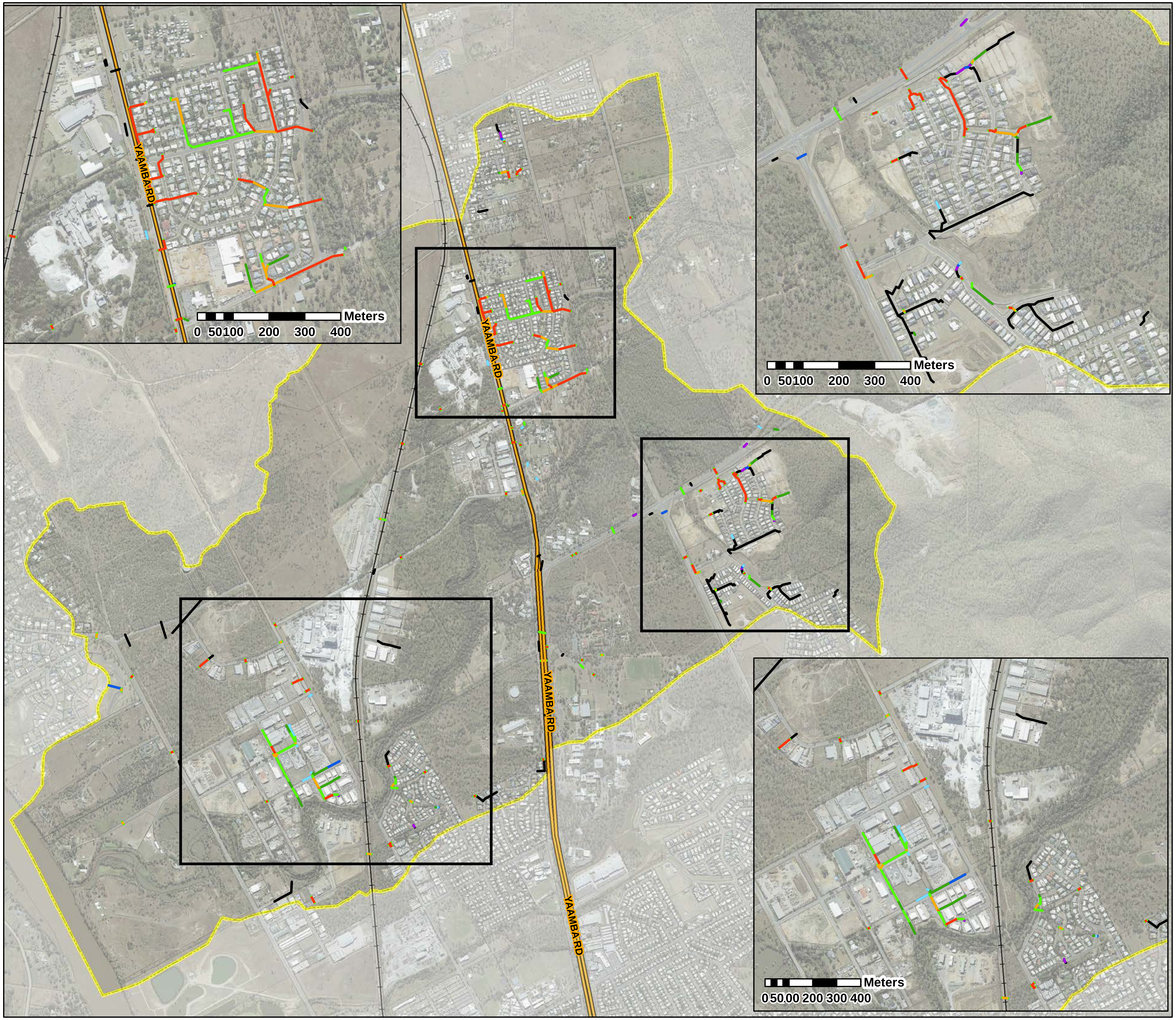
Figure 16 provides a spatial analysis of the existing underground network capacity during the 180 minute critical storm duration. It shows the event at which the capacity of the pipe/culvert is reached. It is noted that culverts were considered to have reached capacity once they exceeded 80% of their full flow capacity.

It can be seen that several segments of the network have less than 1EY immunity – an estimated 28% of the modelled network. Approximately 60% of the network has less than 10% AEP immunity, including the majority of the network within the residential areas north of Boundary Road and Grevillea Drive. In a 1% AEP event, approximately 67% of the network is considered as flowing at full capacity.

8.6 Implications of the Rockhampton Northern Access Upgrade Project

The assessment of flood behaviour within the Limestone Creek catchment has been the subject of current technical investigations associated with the Rockhampton Northern Access Upgrade (RNAU) project currently being undertaken by Department of Transport and Main Roads. The project represents the duplication of the Bruce Highway from Rockhampton – Yeppoon intersection to Terranova Drive.

It is noted that the RNAU project proposes new cross-drainage configurations. It is recommended that the baseline models and mapping be upgrades by Council upon the completion of the RNAU construction phase.



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LEGEND

Pipe Flowing Full in

- 1EY
- 39% AEP
- 18% AEP
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- > 1% AEP
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:

75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model

Basecase 1D network Capacity Analysis

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	17/07/2017
VERSION:	1

Figure
16

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 16 1D Network Capacity.mxd

8.7 Comparison with Previous Study Results

8.7.1 Recommended Changes from Previous Study Peer Review

Within BMT WBM's Independent Review of Rockhampton Local Catchments Flood Study - Numerical Models (2014), several recommendations were made to improve the flood behaviours predicted by the TUFLOW model. These include:

- Refined grid cell size;
- Depth-varying roughness and more detailed delineation;
- Industry-standard hydrologic losses and MHWS tidal boundary;
- Improved representation of hydraulic structures; and
- Additional verification of the model to recorded events.

8.7.2 Changes Implemented in this Study

The updated model has been upgraded to a combined XP-RAFTS inflow and direct rainfall model with a reduced grid size of 3m. The combination of a reduced grid size and rain applied across the urban catchment provides significantly more detail on local catchment flow paths and better informs future planning. Bridge structures have been digitized as layered flow constrictions in the 2D domain and applied a head loss to a single row of cells. This approach ensures a constant head loss is applied across the width of the structure.

The 1D network was updated to match Council's current GIS database. More than 300 pipes and several key culverts were added to the TUFLOW model within the 1D domain.

Channel roughness was inspected onsite and delineated in greater detail using the latest imagery. Hydraulic roughness was also applied with depth-varying roughness to better represent frictional losses of the water profile as depth increases.

The rainfall losses applied to both the urban catchment and XP-RAFTS hydrologic model were revised and updated to consistent values across the suite of design events as per standard industry practice. A comparison between the maximum losses applied is shown in Table 14.

Table 14 Adopted Maximum Losses Comparison

Event (AEP)	Previous Study		This Study	
	Maximum Initial Loss (mm)	Maximum Continuing Loss (mm/h)	Maximum Initial Loss (mm)	Maximum Continuing Loss (mm/h)
18% and smaller	15.0	2.5	15.0	1.0
10%	10.0	2.5	15.0	1.0
5%	5.0	2.5	15.0	1.0
2% and larger	0.0	2.5	15.0	1.0
PMF	0.0	0.0	0.0	1.0

The February 2017 calibration event was adopted as the calibration event in order to confirm the performance of the hydraulic model.

8.7.3 Results Comparison between Previous and Current Study

Figure 17 to Figure 20 show the differences in predicted peak flood heights and depths as a result of the changes listed above. The comparison shows:

- **Figure 17** – 18% AEP Height Difference Map

Several key overland flow paths previously modelled as inflows within the creek channel are identifiable. Flow paths generally follow drainage channels and rail / road corridors as runoff progresses towards Limestone Creek.

Comparison shows the predicted peak flood heights upstream of Yaamba Road Bridge are up to 300 mm higher in the updated modelling. The major flow path stretching upstream of Foulkes Road is predicted to be more confined to the man-made and natural channels with increases in height of more than 300 mm due to the changes in the latest topographic data.

The major flow path extending north of Boundary Road is expected to reduce in peak flood height by more than 300 mm due to the significant upstream attenuation of flows at the railway line and local roads. The attenuation results in a reduced peak height estimate within the channel between the rail and highway corridors.

Peak water surface elevations are predicted to decrease in the updated model south of the railway corridor due to the altered downstream boundary conditions and improved representation of the creek channel in the updated model.

- **Figure 18** – 18% AEP Depth Difference Map

Inspection of the depth comparison shows significant changes to the depth and an indication of change in conveyance of the creek channel. The conveyance of the channel is seen to have increased throughout the channel between the hydraulic model inflow boundary and Boundary Road.

Notable differences are also observed at the Yaamba Road Bridge with deeper flow along the outer bend of the creek meander simulated in the updated model. Given the significant local events of 2013 and 2015 occurring between topographic datasets, it is expected that this is a result of creek channel changes.

Reductions in the peak flood extent and confinement of floodwaters to the main channel is particularly prominent south of the railway line.

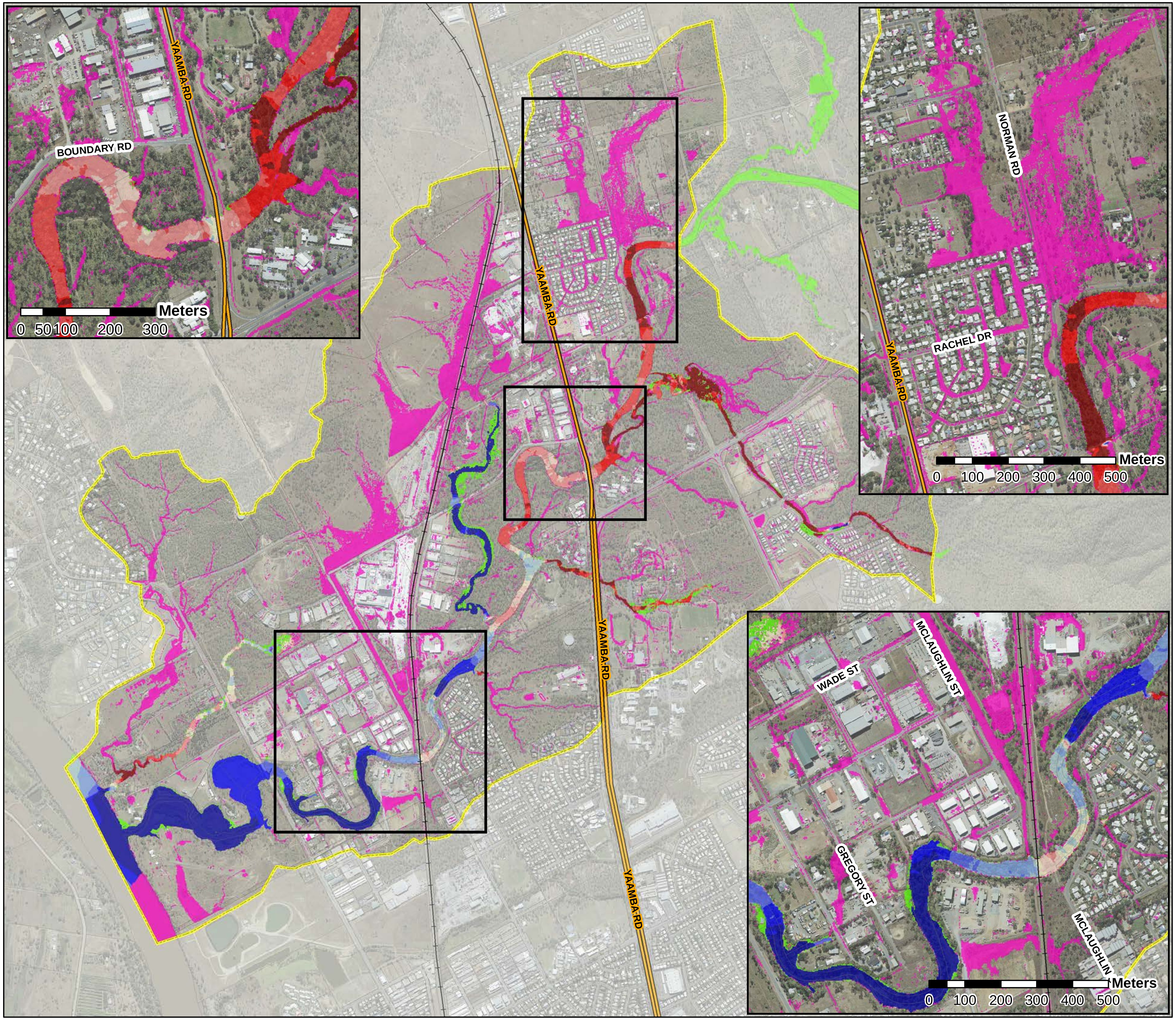
- **Figure 19** – 1% AEP Height Difference Map

Results of the comparison between peak flood heights during a 1% AEP event are largely similar to the discussion for the 18% event, but with a larger proportion of the creek channel expected to reach a lower peak height. A reduction in peak flood heights of more the 300 mm is predicted for most of the reach downstream of Yaamba Road. It is expected that this is a result of different topographic datasets, increased losses applied to the 1% AEP event and significant attenuation of overland flows, especially for tributaries north of Limestone Creek.

- **Figure 20** – 1% AEP Depth Difference Map

Peak flood depths are predicted to increase for most of the channel between the hydraulic model inflow and Boundary Road. A significant increase in flood depths is noted downstream of the eight 1800 mm by 1200 mm RCBCs under Boundary Road east of Yaamba Road, indicating changes between the 2009 and 2016 LiDAR.

The peak flood depths are predicted to mostly decrease between Yaamba Road and the rail corridor. Localised increases to depths are expected under the North Coast Rail Line Bridge along the low-flow portion of the channel cross-section. As in the 18% AEP event, the depths within the main channel section upstream and downstream of Alexandra Street Bridge are predicted to increase with a corresponding decrease to depths and peak flood extents on the adjacent flood plain.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

1:20,000
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in PWSE (m)

- < -0.3
- -0.3 to -0.225
- -0.225 to -0.15
- -0.15 to -0.075
- -0.075 to -0.02
- -0.02 to 0.02
- 0.02 to 0.075
- 0.075 to 0.15
- 0.15 to 0.225
- 0.225 to 0.3
- > 0.3
- Was Dry Now Wet*
- Was Wet Now Dry

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

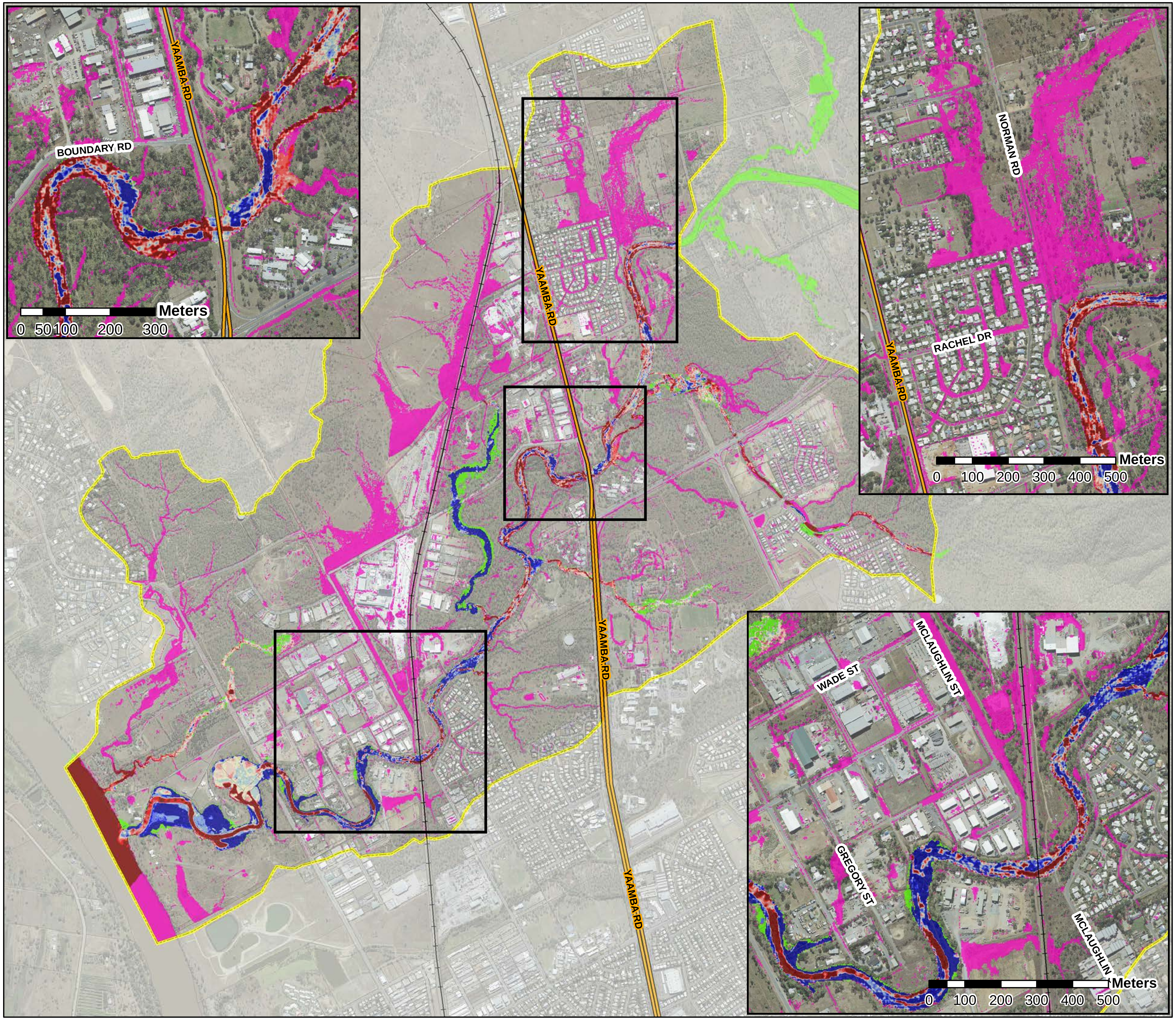
Limestone Creek Model
Difference in Peak Flood Heights
Current Study minus Previous Study

18% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure 17

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 17 Results Comparison 18% AEP.mxd



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DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

1:20,000
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in Depth (m)

- < -0.3
- -0.3 to -0.225
- -0.225 to -0.15
- -0.15 to -0.075
- -0.075 to -0.02
- -0.02 to 0.02
- 0.02 to 0.075
- 0.075 to 0.15
- 0.15 to 0.225
- 0.225 to 0.3
- > 0.3
- Was Dry Now Wet*
- Was Wet Now Dry

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

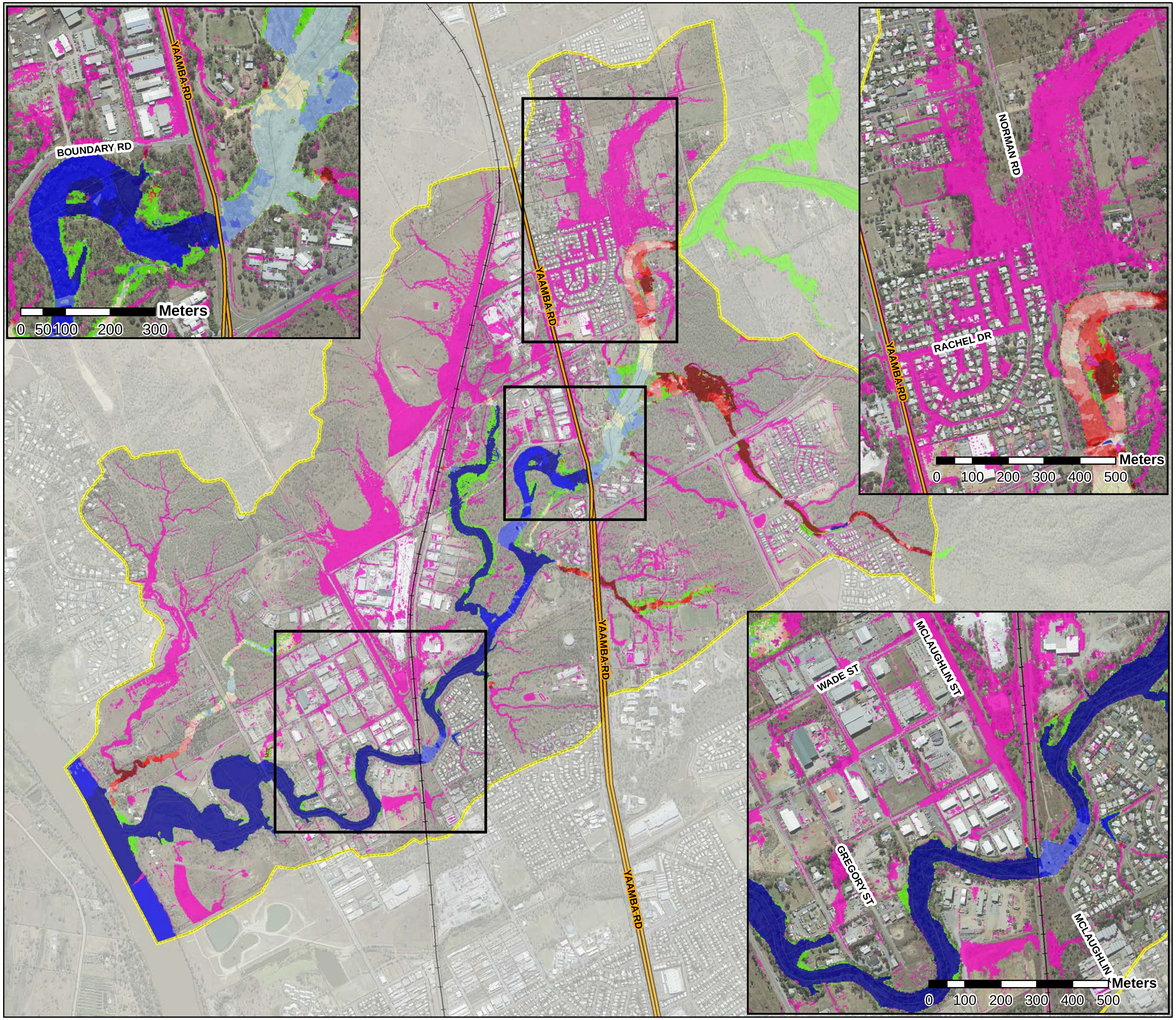
Limestone Creek Model
Difference in Peak Flood Depths
Current Study minus Previous Study

18% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure 18

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 18 Results Comparison 18% AEP (Depth).mxd



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DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000

Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in PWSE (m)

- < -0.3
- -0.3 to -0.225
- -0.225 to -0.15
- -0.15 to -0.075
- -0.075 to -0.02
- -0.02 to 0.02
- 0.02 to 0.075
- 0.075 to 0.15
- 0.15 to 0.225
- 0.225 to 0.3
- > 0.3
- Was Dry Now Wet*
- Was Wet Now Dry

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

Data Sources:

DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:

75mm Min. Depth
$100m^2$ Min. Area

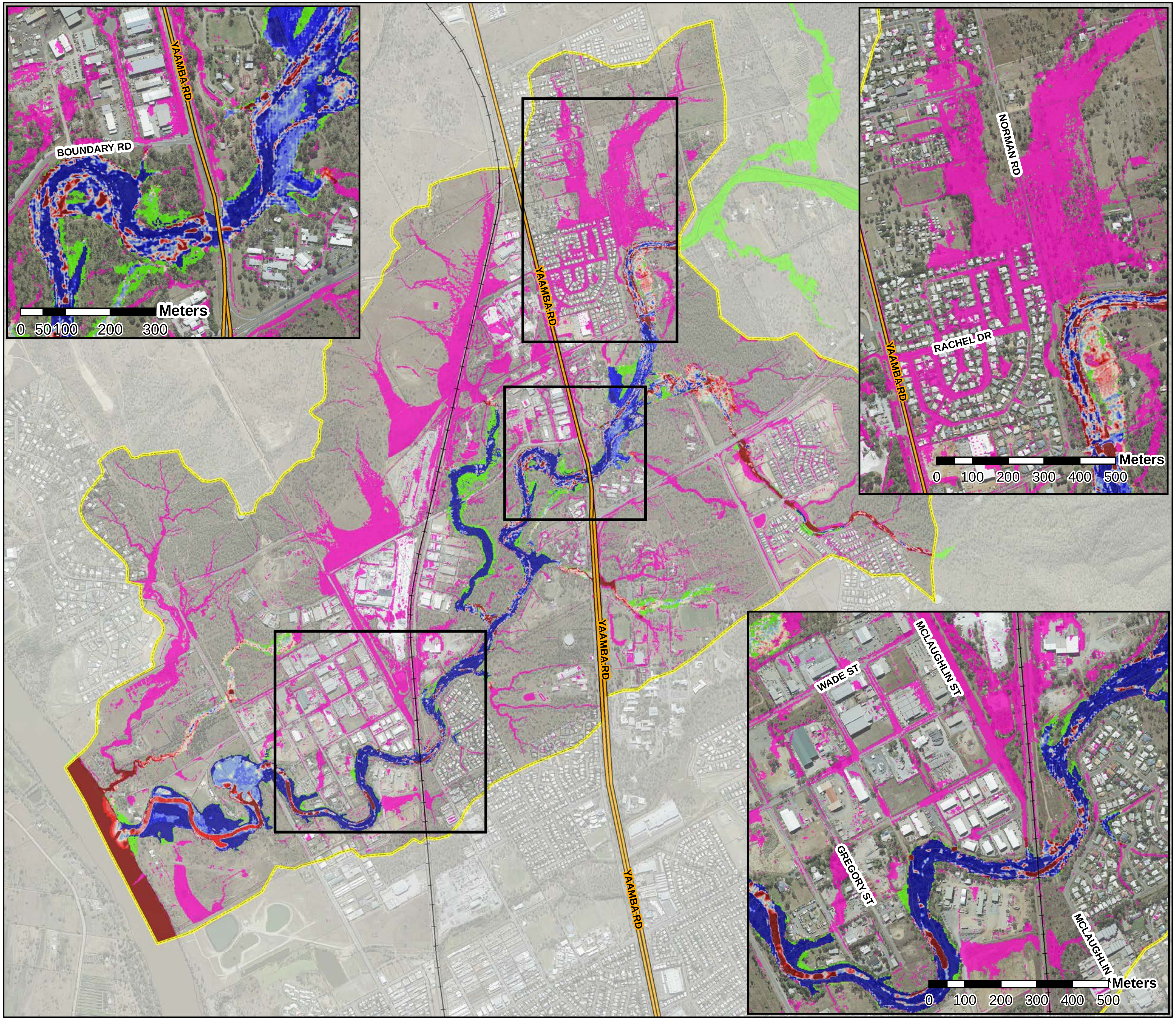
Limestone Creek Model
Difference in Peak Flood Heights
Current Study minus Previous Study

1% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure
19

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 19 Results Comparison 1% AEP.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

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(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in Depth (m)

- < -0.3
- -0.3 to -0.225
- -0.225 to -0.15
- -0.15 to -0.075
- -0.075 to -0.02
- -0.02 to 0.02
- 0.02 to 0.075
- 0.075 to 0.15
- 0.15 to 0.225
- 0.225 to 0.3
- > 0.3
- Was Dry Now Wet*
- Was Wet Now Dry

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Limestone Creek Model
Difference in Peak Flood Depths
Current Study minus Previous Study

1% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/06/2017
VERSION:	1

Figure 20

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Limestone Creek Publishing\Final Figure Mapping\Figure 20 Results Comparison 1% AEP (Depth).mxd

9.0 Sensitivity Analysis

- Sensitivity 1 – Increase in manning's roughness values (15%)
- Sensitivity 2 – Decrease in manning's roughness values (15%)
- Sensitivity 3 – Increase in rainfall intensities to replicate potential climate change impacts (30% increase in rainfall intensity).
- Sensitivity 4 – Coincident 18% AEP Fitzroy River Tailwater Level
- Sensitivity 5 – 20% Underground Stormwater Infrastructure Blockage
- Sensitivity 6 – 50% Underground Stormwater Infrastructure Blockage
- Sensitivity 7 – 100% Underground Stormwater Infrastructure Blockage
- Sensitivity 8 – Increased Inlet Structure Dimensions
- Sensitivity 9 – Key Cross Drainage Culvert Blockage

Further discussion on each sensitivity analysis is provided below.

9.1 Hydraulic Roughness

Testing of the model sensitivity to seasonal changes in roughness was undertaken for the 1% AEP event using both an increase and decrease in the Manning Roughness Coefficient by 15% across all material types. The sensitivity was implemented by increasing and decreasing all manning's roughness values listed in the TUFLOW materials file.

The following maps represent the results of the sensitivity testing.

- 15% Increase in Roughness → **Map LC-56**
- 15% Decrease in Roughness → **Map LC-57**

Map LC-56 indicates that with a uniformly increased roughness value across all material types, there is a corresponding overall increase in peak flood heights and overland flood extents. The majority of the urban areas within the catchment experience negligible increases in peak water surface elevations. Small areas north of Bondeson drive and Weatherall Street are predicted to have minor increases in peak flood heights in the realm of 20mm.The most significantly impacted areas within the Limestone Creek catchment are that of the creek channel and neighbouring floodplain areas, with increases of peak flood heights by up to 0.3m.

The result from the sensitivity analysis which applies a 15% decrease in manning's roughness values are shown in **Map LC-57**. The decrease in roughness indicates a corresponding decrease in peak flood heights. The reduction in peak flood heights is negligible throughout most of the catchment area however throughout the creek channel and the upper tributaries, the peak flood height has reduced by up to 0.35m.

9.2 Climate Change

A suite of climate change literature is available, covering global, national and more localised state based climate change discussion and analysis. Whilst much of the literature states that, for Queensland, total annual rainfall is decreasing and rainfall intensity during rainfall events is increasing, there is comparatively little literature recommending actual values to adopt for these changes.

The DERM, DIP and LGAQ Inland Flooding Study (2010) was specifically aimed at providing a benchmark for climate change impacts on inland flood risk. The study recommends a 'climate change factor' be included into flood studies in the form of a 5% increase in rainfall intensity per degree of global warming.

For the purposes of applying the climate change factor, the study outlines the following temperature increases and planning horizons:

- 2°Celsius by 2050;

- 3°Celsius by 2070; and
- 4°Celsius by 2100.

Other literature such as the Guidelines for Preparing a Climate Change Impact Statement (CCIS) published by the Queensland Office of Climate Change predict that by 2050 there will be a 20-30% increase in cyclonic rainfall intensity.

As a conservative approach, the overall rainfall in the Limestone Creek TUFLOW model was increased by 30% to represent the predicted rainfall patterns in 2100. The rainfall in the XP-RAFTS simulation for the inflows was also increased by 30%, for the 1% AEP design event.

Map LC-58 indicates that the 30% increase in applied rainfall significantly increases peak flood heights and extents throughout the catchment. The peak flood height throughout the majority of the creek channel increased between 0.5m and 1.2m. Results indicate that for smaller tributaries of the creek system, peak flood heights will increase between 0.15m and 0.6m. The climate change sensitivity also predicts that the peak flood extent will spread and impact residential areas including Bean Avenue north to Bondeson Drive, with depths of up to 0.2m. The peak flood extents and peak flood heights are also shown to increase in the commercial areas neighbouring McLaughlin street.

9.3 Riverine and Local Catchment Coincident Event

In the baseline design events, it was assumed that riverine and local catchment flooding would not coincide. In this sensitivity analysis, the downstream water level in the TUFLOW model was set at the peak flood height corresponding to the 18% AEP Fitzroy River flood event (7.85 mAHD) to coincide with a 1% AEP design storm event in the Limestone Creek catchment. The Fitzroy River flood height of 7.85 mAHD has been determined based upon results from RRC's Fitzroy River model (refer to section 3.2.4).

As can be seen from **Map LC-59** the effect of this Tailwater level is confined to the lower catchment area, with no additional buildings affected. The results indicate that in the lower catchment area, the peak flood height increases by between 0.3m and 1.5m. The variation in peak water surface elevation across the rest of the catchment is negligible.

9.4 Stormwater Infrastructure Blockage

Testing of the model sensitivity to the underground stormwater infrastructure being blocked by debris, was undertaken for the 18% AEP event using an increasing percentage blockage on the underground stormwater network. This excluded cross drainage structures which was the subject of a specific sensitivity analysis (refer to Section 9.6).

Sensitivities were undertaken using 20%, 50% and 100% blockage factors. The following maps represent the results of the sensitivity testing.

- 20% Increase in Blockage → **Map LC-60**
- 50% Increase in Roughness → **Map LC-61**
- 100% Increase in Roughness → **Map LC-62**

9.4.1 20% Blockage of Stormwater Infrastructure

A 20% blockage factor was adopted which can be considered as a reasonable representation of standard operating conditions throughout the working life of the stormwater infrastructure.

The results presented in map L**C-60** indicate that across the majority of the catchment, applying a 20% blockage to the stormwater network causes negligible change in peak water surface elevation with most areas being between ± 0.02 m of the baseline peak flood height results. However, specific areas in the vicinity of Rachel Drive and Newton Street have increases in peak flood heights by approximately 0.2m when the stormwater network is 20% blocked.

9.4.2 50% Blockage of Stormwater Infrastructure

A 50% blockage factor is more representative of stormwater infrastructure during extreme events where there is a more significant presence of flood borne debris.

Blockage of the stormwater infrastructure by 50% results in some higher peak flood heights in the area surrounding Col Crescent, Bean Avenue and Rachel Drive. Increases in peak flood heights in this area range from between 0.05m and 0.17m.

9.4.3 100% Blockage of Stormwater Infrastructure

As a worst case analysis, the model has also been tested with the stormwater network being 100% blocked.

The results shown in **Map LC-62** indicate that several areas experience increases in peak flood heights, but most of the flood extent remains within ± 0.02 m of the baseline 18% AEP design event. Areas which are predicted to experience the largest increases are Rachel Drive to Bean Avenue where the peak flood extents propagate further throughout the residential area and peak flood heights increase from between 0.15 to 0.3m.

9.5 Inlet Structure Dimensions

As documented in Appendix A, one of the assumptions made during the development of the 1D component of the TUFLOW model was that all inlet pits were a standard size of 900mm by 600mm. This assumption was made in the absence of survey inlet types and sizes.

A sensitivity analysis was undertaken in order to test the potential impact of this assumption. In order to test this sensitivity all pit sizes were increased from 900mm by 600mm to 2000mm by 2000mm.

As indicated in map **LC-63**, the difference in peak flood height is between ± 0.02 m. These results indicate that enabling larger portions of flow to enter the 1D system via the pit structures results in negligible differences to the peak flood height. Hence, it can be concluded that the model is not sensitive to inlet structure dimensions.

9.6 Key Cross-drainage Culvert Blockage

The following has been sourced from ‘Australian Rainfall & Runoff – Blockage guidelines for culverts and small bridges (Feb, 2015)’ and ‘Australian Rainfall & Runoff: A Guide to Flood Estimation (2016)’.

Blockage can have a severe impact on the capacity of drainage systems and peak flood extents. Determination of likely blockage levels and mechanisms, when simulating design flows, is therefore an important consideration in quantifying the potential impact of blockage of a particular structure on design flood behaviour.

This procedure has been developed to quantify the most likely blockage level and mechanism for a small bridge or culvert when impacted by sediment or debris laden floodwater. This procedure includes consideration of the impact of both floating and non-floating debris as well as non-floating sedimentation blockage within a structure. It is restricted to constant (i.e. not time-varying) structure blockage during throughout design event.

9.6.1 Factors influencing blockage

The factors that most influence the likely blockage of a bridge or culvert structure are;

- Debris Type and Dimensions - whether floating, non-floating or urban debris present in the source area and its size.
- Debris Availability – the volume of debris available in the source area.
- Debris Mobility – the ease with which available debris can be moved into the stream.
- Debris Transportability – the ease with which the mobilised debris is transported once it enters the stream.
- Structure Interaction – the resulting interaction between the transported debris and the bridge or culvert structure.

- Random Chance – an unquantifiable but significant factor.

9.6.2 Common Blockages

All blockages that do occur arise from the arrival and build-up of debris at a structure. There are three different types of debris typically present in debris accumulated upstream of or within a blocked structure. This debris may be classified as floating (e.g. trees), non-floating or depositional (e.g. sediment) and urban (e.g. cars and other urban debris).

9.6.2.1 Floating Debris

Floating debris in rural or forested streams is generally vegetation of various types. Small floating debris, less than 150mm long, can include small tree branches, sticks, leaves and refuse from yards such as litter and lawn clippings and all types of rural vegetation. Medium floating debris, typically between 150mm and 3m long, mainly consists of tree branches of various sizes. Large floating debris, more than 3m long, consists of logs or trees, typically from the same sources as for medium floating debris. Small items of vegetation will usually pass through drainage structures during floods, while larger items may be caught in the structure. Once larger items are caught, this then allows smaller debris to collect on the structure.

9.6.2.2 Non-Floating Debris

Non-floating debris in rural or forested streams is usually sediment of all types. Fine sediments (silt and sand) typically consist of particles ranging from 0.004 to 2mm. The deposition of finer clay-sized particles is normally a concern in tidal areas, with lower flood surface gradients and velocities. Gravels and cobbles consist of rock typically ranging in size from 2 to 63mm and 63 to 200mm respectively. The source of this material may be from gully formation, channel erosion, landslips or land mass failure although landslips and/or land mass failures of any size will likely create hyper concentrated or even debris flows which are not covered by this guideline. Boulders comprise rocks greater than 200mm. The source of boulders is mostly from gully and channel erosion, landslips and the displacement of rocks from channel stabilisation works.

9.6.2.3 Urban Debris

Urbanisation of catchments introduces many different man-made materials that are less common in rural or forested catchments and which can cause structure blockage. These include fence palings, building materials, and mattresses, garbage bins, shopping trolleys, fridges, large industrial containers and vehicles.

9.6.3 Design Blockage Level

The following tables and methodology has been used in the assessment of blockage. Assessment of Inlet Blockage (Floating or Non-Floating) and Barrel Blockage (Non-Floating) has been undertaken for each culvert selected for the sensitivity analyses. A “worst case” result is then adopted for the blockage across all structures assessed. This enables a comparative analysis of the model sensitivity to culvert blockage (as blockage is consistent) and a reasonable prediction of flood behaviours under the assessed event with logically-derived blockage.

9.6.3.1 Debris Availability

Table 15 Debris Availability - in Source Area of a Particular Type/Size of Debris (Table 6.6.1 ARR, 2016)

Classification	Typical Source Area Characteristics (1% AEP Event)
High	• Natural forested areas with thick vegetation and extensive canopy cover, difficult to walk through with considerable fallen limbs, leaves and high levels of floor litter. • Streams with boulder/cobble beds and steep bed slopes and steep banks showing signs of substantial past bed/bank movements. • Arid areas, where loose vegetation and exposed loose soils occur and vegetation is sparse. • Urban areas that are not well maintained and/or where old paling fences, sheds, cars and/or stored loose material etc., are present on the floodplain close to the water course.
Medium	• State forest areas with clear understory, grazing land with stands of trees. • Source areas generally falling between the High and Low categories.
Low	• Well maintained rural lands and paddocks with minimal outbuildings or stored materials in the source area. • Streams with moderate to flat slopes and stable bed and banks. • Arid areas where vegetation is deep rooted and soils are resistant to scour. • Urban areas that are well maintained with limited debris present in the source area.

A **Medium** classification of debris availability for Limestone Creek has been selected as source areas generally falling between the High and Low categories.

9.6.3.2 Debris Mobility

Table 16 Debris Mobility - Ability of a Particular Type/Size of Debris to be Moved into Streams (Table 6.6.2 ARR, 2016)

Classification	Typical Source Area Characteristics (1% AEP Event)
High	• Steep source areas with fast response times and high annual rainfall and/or storm intensities and/or source areas subject to high rainfall intensities with sparse vegetation cover. • Receiving streams that frequently overtop their banks. • Main debris source areas close to streams.
Medium	• Source areas generally falling between the High and Low mobility categories.
Low	• Low rainfall intensities and large, flat source areas. • Receiving streams infrequently overtops their banks. • Main debris source areas well away from streams.

A **Medium** classification of debris mobility for Limestone Creek has been selected as source areas generally falling between the High and Low categories.

9.6.3.3 Debris Transportability

Table 17 Debris Transportability - Ability to Transport Debris to the Structure (Table 6.6.3 ARR, 2016)

Classification	Typical Transporting Stream Characteristics (1% AEP Event)
High	• Steep bed slopes (> 3%) and/or high stream velocity (V > 2.5 m/s) • Deep stream relative to vertical debris dimension ($D > 0.5L_{10}$) • Wide stream relative to horizontal debris dimension.($W > L_{10}$) • Stream relatively straight and free of major constrictions or snag points. • High temporal variability in maximum stream flows.
Medium	• Stream generally falling between High and Low categories.
Low	• Flat bed slopes (< 1%) and/or low stream velocity (V < 1m/s). • Shallow depth relative to vertical debris dimension ($D < 0.5 L_{10}$). • Narrow stream relative to horizontal debris dimension ($W < L_{10}$). • Stream meanders with frequent constrictions/snag points. • Low temporal variability in maximum stream flows.

In the absence of historical data, the following is recommended:

> *In an urban area the variety of available debris can be considerable with an equal variability in L_{10}. In the absence of a record of past debris accumulated at the structure, an L_{10} of at least 1.5 m should be considered as many urban debris sources produce material of at least this length such as palings, stored timber, sulo bins and shopping trolleys. (Clause 6.4.4.1 ARR, 2016)*

As such, 1.5m has been adopted as the average length of possible debris in the upper 10% quantile (L_{10}).

A **High** classification of debris transportability for Limestone Creek has been selected as:

- Steep bed slopes (> 3%) and/or high stream velocity (V > 2.5 m/s)
- Deep stream relative to vertical debris dimension ($D > 0.5L_{10}$)
- Wide stream relative to horizontal debris dimension.($W > L_{10}$)
- High temporal variability in maximum stream flows.

9.6.3.4 Debris Potential

Table 18 1% AEP Debris Potential (Table 6.6.4 ARR, 2016)

Classification	Combinations of the Above (any order)
High	• HHH • HHM
Medium	• MMM • HML • HMM • HLL
Low	• LLL • MML • MLL

A **Medium** classification of debris potential for Limestone Creek has been selected as the combination of individual factors is MMH.

9.6.3.5 AEP Adjusted Debris Potential

Table 19 AEP Adjusted Debris Potential (Table 6.6.5 ARR, 2016)

Event AEP	(1% AEP) Debris Potential at Structure		
	High	Medium	Low
AEP > 5%	Medium	Low	Low
AEP 5% - AEP 0.5%	High	Medium	Low
AEP < 0.5%	High	High	Medium

A **Low** classification of AEP Adjusted Debris Potential for Limestone Creek has been selected as the Event AEP assessed is 18%.

9.6.3.6 Design Blockage Level

Subsequent components of the methodology were applied to each culvert individually.

Table 20 Most Likely Inlet Blockage Levels - B_{DES}% (Table 6.6.6 ARR, 2016)

Control Dimension Inlet Clear Width (W) (m)	AEP Adjusted Debris Potential At Structure		
	High	Medium	Low
$W < L_{10}$	100%	50%	25%
$L_{10} \leq W \leq 3*L_{10}$	20%	10%	0%
$W > 3*L_{10}$	10%	0%	0%

Inlet Blockage Levels based on the structure clear width was assessed for each culvert individually which can be reviewed in more detail within Table 23.

9.6.3.7 Sediment Deposition

A mean sediment size present of 63 to 200mm has been adopted based on site visits conducted after an event sized similarly to an 18% AEP event.

Table 21 Likelihood of Sediment Being Deposited in Barrel/Waterway (Table 6.6.7 ARR, 2016)

Peak Velocity Through Structure (m/s)	Mean Sediment Size Present				
	Clay/Silt 0.001 to 0.04 mm	Sand 0.04 to 2 mm	Gravel 2 to 63 mm	Cobbles 63 to 200 mm	Boulders >200 mm
>= 3.0	L	L	L	L	M
1.0 to < 3.0	L	L	L	M	M
0.5 to < 1.0	L	L	L	M	H
0.1 to < 0.5	L	L	M	H	H
< 0.1	L	M	H	H	H

This was assessed for each culvert individually which can be reviewed in more detail within Table 23.

Table 22 Most Likely Depositional Blockage Levels – B_{DES}% (Table 6.6.8 ARR, 2016)

Likelihood that Deposition will Occur	AEP Adjusted Non Floating Debris Potential (Sediment) at Structure		
	High	Medium	Low
>= 3.0	100%	60%	25%
1.0 to < 3.0	60%	40%	15%
0.5 to < 1.0	25%	15%	0%

As above, this was assessed for each culvert individually which can be reviewed in Table 23.

Table 23 Limestone Creek Culvert Blockage Assessment

Culvert Specification	Control Dimension	AEP Adjusted Debris Potential	Most Likely Inlet Blockage Levels	Peak Velocity (m/s)	Sediment Likelihood	Most Likely Depositional Blockage Levels	Highest Blockage Factor
5/1200x450mm RCBC	W < L10	Low	25%	1.7	M	15%	25%
3/900mm RCP	W < L10	Low	25%	2.0	M	15%	25%
3/600mm RCP	W < L10	Low	25%	0.9	M	15%	25%
8/1800x1200mm RCBC	L10 < W < 3*L10	Low	0%	5.3	L	0%	0%
2/1500mm RCP	L10 < W < 3*L10	Low	0%	1.6	M	15%	15%
3/1050mm RCP	W < L10	Low	25%	2.6	M	15%	25%
2/2700x2400mm RCBC	L10 < W < 3*L10	Low	0%	2.4	M	15%	15%
3/2700x2700mm RCBC	L10 < W < 3*L10	Low	0%	2.4	M	15%	15%
3/1650mm RCP	L10 < W < 3*L10	Low	0%	2.3	M	15%	15%
5/1200x600mm RCBC	W < L10	Low	25%	1.1	M	15%	25%

The highest blockage factor between both blockage scenarios is taken forward as the blockage adopted for the key cross-drainage structure sensitivity. The adopted blockage factor for Limestone Creek is 25%.

9.6.4 Results of Sensitivity Analysis

The results which are presented on **Map LC-64** show that there is negligible change to the flood extent and the change in peak flood height is minimal throughout most of catchment. However, there are a few specific areas where flood heights have increased due to the blockage of downstream culverts. The specific areas and the corresponding increase in peak flood heights are:

- Culvert under Foulkes Street – up to 0.8m increase in peak flood height
- Culvert under Rockhampton Yeppoon Road – up to 1.4m increase in peak flood height
- Culvert under Boundary Road – up to 0.2m increase in peak flood height
- Culvert under Belmont road – up to 0.12m increase in peak flood height

9.7 Summary of Sensitivity Analysis Results

The results from the sensitivity analyses which were undertaken indicate that the most influential parameters are the manning's roughness values and the applied rainfall. As shown in Table 24, the 15% increase roughness caused an increase of peak flood heights throughout a large portion of the catchment. Similarly, the climate change sensitivity can be seen to have increased the peak flood heights throughout almost the entire catchment, with levels rising between 0.15m and 1.2m as previously discussed in section 9.2.

The 20%, 50% and 100% blockage analysis indicate that only small portions of the flooded area are impacted. However, the localised areas are located within residential areas and may worsen property impacts and damages. The sensitivity runs have highlighted the critical structures which should be maintained regularly in order to minimise the impacts of long term debris build-up.

The Fitzroy River sensitivity indicates that the lower portion of the catchment is predicted to experience significant increases in flood heights. The areas influenced by the increased Tailwater conditions are primarily non developed and would not cause damage to properties, however between Alexandra street and Mclaughlin street, the Tailwater conditions cause the level throughout this section of limestone creek to increase and potential impact neighbouring properties.

It is expected that Council will apply an appropriate freeboard allowance to the PWSE's provided from this study, noting that this freeboard allowance should account for modelling uncertainty and the implications of the sensitivity analyses undertaken and discussed above. It should be noted that the Limestone Creek model is uncalibrated (due to an absence in recorded data) and therefore there is additional modelling uncertainty which should be accounted for in the freeboard provision.

Table 24 provides a summary of the percentage of the peak flood extent which is increased or decreased as a result of each sensitivity analysis. The results indicate that, apart from the climate change scenario and the Fitzroy river Tailwater scenario, the resulting peak flood heights are generally within ±0.3m of the baseline flood results. It is clear that climate induced changes to rainfall intensities would have the most significant impact to predicted flood heights in the Limestone Creek catchment.

Table 24 Summary of Sensitivity Analysis Results

Change in Peak Water Surface Elevation (m)	Percentage Area of Peak Flood Extent								
	15% Increased Roughness	15% Decreased Roughness	Climate Change to 2100	20% Blockage of Stormwater Infrastructure	50% Blockage of Stormwater Infrastructure	100% Blockage of Stormwater Infrastructure	Fitzroy River Tailwater Condition	Increased Pit Dimensions	Blockage of Key Cross Drainage Structures
-0.225 to -0.150	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
-0.150 to -0.075	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
-0.075 to -0.02	0.4%	24.1%	0.0%	0.0%	0.1%	0.8%	0.0%	0.4%	0.0%
-0.02 to 0.02	45.0%	59.4%	2.7%	99.9%	99.7%	98.5%	88.1%	99.6%	99.5%
0.02 to 0.074	33.5%	13.9%	16.1%	0.1%	0.0%	0.5%	0.5%	0.0%	0.2%
0.075 to 0.150	20.7%	0.1%	16.2%	0.0%	0.1%	0.1%	0.2%	0.0%	0.3%
0.150 to 0.225	0.3%	0.0%	17.2%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%
0.225 to 0.299	0.0%	0.0%	12.3%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
>0.3	0.0%	0.0%	35.6%	0.0%	0.0%	0.0%	10.9%	0.0%	0.0%

10.0 Conclusion

10.1 Key Findings

The Limestone Creek Phase 1 Baseline Flood Study included the development of a TUFLOW model for the lower portion of the Limestone Creek local catchment. This model utilises a combination of runoff-routing and direct rainfall approaches in order to determine the overland flow paths and establish baseline flood extents and depths within the study area.

Recorded data was received and used to compare the model to a local flood event caused by Ex-TC Debbie in March 2017. Verification was unable to be undertaken due to the lack of historical data, although the model results were compared to the discrepancies noted in the previous study. Whilst the current model showed improved comparisons to the 2013 event, improved model performance and confidence in the model could be realised through within-catchment rainfall data, creek channel bathymetric survey and additional anecdotal and gauge data.

Data for the catchment was sourced and utilised within this process, although the limited amount of anecdotal and recorded data meant the model was only calibrated and not validated to historical flood events. In order to maintain consistency across North Rockhampton local catchment models, loss and roughness parameters from other successfully calibrated models were adopted as the best estimate until additional recorded data within the catchment becomes available.

Various design events and durations were simulated and assessed to develop an understanding of the key flood behaviours. The critical duration for the catchment was determined to be the 180 minute event. A comparison of the design events found that for events up until the 18% AEP event the road and subsurface drainage infrastructure was able to prevent runoff from entering private property. For larger flood events, the overland flow paths continue to develop. The critical areas of this catchment are industrial properties alongside Limestone Creek and those within the Rachel Drive area. The critical controls within the catchment are the open drain alongside McLaughlin Street, the culverts and bridge crossings of Yamba Road and the railway line.

Sensitivity analyses have been undertaken to highlight the uncertainties in the model results and support the selection and application of an appropriate freeboard provision when using the model outputs for planning purposes.

It is recommended that the model be reviewed when additional flood event and topographic data becomes available. Updates to the model should also be undertaken once the Rockhampton Northern Access Upgrade Project is completed by the Department of Transport and Main Roads (currently planned for 2018).

11.0 References

Australian Rainfall and Runoff (2012). *Project 15 – Two Dimensional Modelling in Urban and Rural floodplains - Stage 1& 2 Report*. Available at: http://arr.ga.gov.au/, accessed 13 March 2017.

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BMT WBM (2016), TUFLOW User manual – Build 2016-03-AE.

Maritime Safety Queensland (2014) QLD Tide Tables book.

Rockhampton Regional Council (2014), Limestone Creek Hydrologic and Hydraulic Modelling Report, prepared by Aurecon Australia Pty Ltd, 2014.

Rockhampton Regional Council (2014), South Rockhampton Flood Levee – Hydraulic Model Development and Comparison Report, prepared by AECOM, 2014.

Appendix A

Hydraulic Model Development

Appendix A Hydraulic Model Development

Model Setup Parameters

The time step for the 2D model domain has been set to 1 second The corresponding 1D time step has been set to 0.5 seconds. These time steps are deemed to be appropriate given the grid cell size of 3 m.

The wetting and drying depth represents the depth of water on a cell which is the criteria for whether the cell is “wet” or “dry”. Direct rainfall modelling applies rainfall to each cell in small increments, so the wetting and drying values must also be very small or the intermediate calculations will not take place satisfactorily. The wetting and drying depth has been set to the default of 0.0002m for the centre of a cell.

One-Dimensional Network Development

As detailed in Section 3.6, RRC provided a large amount of data related to the existing stormwater drainage network within the study area. Underground pipes were incorporated into the model as 1D elements, which are dynamically linked to the 2D domain via pit and outlet structures. Pits have been represented using assumed dimensions of 900 mm by 600 mm where survey data did not exist. Pit inlet elevations have been adopted using surveyed levels where possible and corresponding LiDAR levels where data gaps exist.

All culverts were represented as dynamically linked 1D elements, with major sets of closely situated culverts being digitized using multi-cell links (CN-SX lines). Culvert roughness was set as 0.015 for RCPs and RCBCs.

Bridge Structure Losses

Bridges were digitised as 2D layered flow constrictions. Standard form loss coefficients were compared to head losses estimated from 1D HEC-RAS models. Form losses in the TUFLOW model were increased in order to better match the head loss predicted across the bridge structure in the HEC-RAS model.

Model Topography

Base model topography was derived from LiDAR survey flown in 2016 and supplied by RRC. The data was supplied as a 1m resolution Digital Elevation Model (DEM). TMR road corridor survey undertaken as a component of the Rockhampton Northern Access Upgrade Project has also been incorporated into the LiDAR.

Due to limitations surrounding large-scale hydraulic modelling, the adopted grid cell size (3 m) may not always adopt the peak crest level of roads. Given the hydraulic significance of road crests within urban catchment flow paths, heights were extracted from the 1 m LiDAR DEM at 1.5 m intervals (half the grid cell size) using centreline alignments provided by RRC. These point elevations were read into the model after the 1 m DEM in order to enforce the road crowns along all surfaces not previously surveyed.

Hydraulic Roughness and Losses

The specified hydraulic roughness reflects the different types of development and ground cover that exists within the hydraulic model extent. The roughness categories adopted for this study were developed based on aerial imagery, site visits and land use zoning information. Variable Manning’s ‘n’ values based on depth can be utilised within TUFLOW. Manning’s ‘n’ 1 is applied for all flow depths up to depth 1, between depths 1 and 2 the Manning’s ‘n’ utilised by TUFLOW is interpolated between Manning’s ‘n’ 1 and 2 and for all depths greater than depth 2 Manning’s ‘n’ 2 is applied. In the instance of road reserve a single roughness has been applied.

Specific roughness values for each category as applied in the model are outlined in Table 25.

Table 25 Adopted Roughness Values

Material Description	Manning's 'n'			
	Depth 1 (m)	Manning's 'n' 1	Depth 2 (m)	Manning's 'n' 2
High Density Residential	0.1	0.07	0.3	0.15
Medium Density Residential	0.1	0.06	0.3	0.12
Low Density Residential	0.1	0.05	0.3	0.09
Commerical/Industrial	0.1	0.03	0.3	0.06
Dense Vegetation	0.1	0.10	0.3	0.06
Medium Vegetation	0.1	0.075	0.3	0.05
Light Vegetation	0.1	0.06	0.3	0.045
Channel	0.1	0.06	0.3	0.05
Riparian Corridor (sluggish areas)	0.1	0.10	0.3	0.07
Maintained grass	0.035			
Road Reserve	0.025			
Rail Reserve	0.03			
Fitzroy River Bed (at DS boundary)	0.022			
Long Grass	0.1	0.045	0.3	0.035
Buildings	0.1	0.018	0.3	0.5
Steep Slopes	0.1	0.09	0.5	0.075

Rainfall losses allow TUFLOW to model situations in which water is prevented from reaching the ground or is infiltrated into the soil system before surface ponding and/or runoff occurs. When using a direct rainfall approach initial losses and continuing losses are specified for each material type; this takes into account the pervious nature of the material. The losses applied remove the loss depth from the rainfall hydrograph **prior** to the remaining rainfall being applied to the 2D cells. Once the initial losses have been satisfied the material is considered saturated and any additional rainfall will become surface water.

During the calibration process if events contained a pre-burst rainfall that was excluded from the simulation the initial losses applied were reduced to 0 mm. This simulates the catchment being saturated by the pre-burst rainfall. Continuing losses remained. This initial loss of 0mm was also applied to the PMF event, as it is conservative to consider the catchment saturated.

The initial losses and continuing losses applied to this model are indicated below in Table 26.

Table 26 Adopted Initial and Continuing Loss Values

Material Description	Initial Loss (mm)	Continuing Loss (mm/h)
High Density Residential	7.5	0.5
Medium Density Residential	7.5	0.5
Low Density Residential	7.5	0.5

Material Description	Initial Loss (mm)	Continuing Loss (mm/h)
Commerical/Industrial	7.5	0.5
Dense Vegetation	15	1
Medium Vegetation	15	1
Light Vegetation	15	1
Channel	0	0
Riparian Corridor (sluggish areas)	0	0
Maintained grass	15	1
Road Reserve	0	0
Rail Reserve	15	1
Fitzroy River Bed (at DS boundary)	0	0
Long Grass	0	0
Buildings	0	0
Steep Slopes	15	1

Initial Conditions

Initial water levels were applied to the 1D pipe network and 2D domain. The Barrage weir level of 3.65m was specified for the entire model area under the calibration and design events. This ensured that model boundaries represented the water level of the Fitzroy River at the first time step of the model simulation.

Boundary Conditions

A range of different boundary conditions have been applied within the Limestone Creek Local Catchment model. The types of boundaries are as follows:

- Direct rainfall.
- Time-varying discharge (QT) inflow boundaries for external catchments.
- Height versus time (HT) boundaries for the Fitzroy River.

Direct rainfall has been applied to the 2D domain; background to this approach is described in Section 4.2. The QT inflow boundaries apply the predicted inflow over time as generated by the XP-RAFTS hydrologic model for the catchment area external to the 2D domain. A HT boundary applies a water level to the boundary cells based on a water level versus time curve.

A summary of the boundary conditions applied to the model are summarised in Table 27.

Table 27 Summary of Boundary Conditions

Boundary Type	Details
Direct rainfall	Applied across entire 2D domain
QT	Inflows for the external catchments upstream of the hydraulic model extent.
HT	Fitzroy River outflow boundary (south-western boundary)