AECOM

Floodplain Management Services
Rockhampton Regional Council
14-Jul-2017
Doc No. 60534898-RE-NR-003

Ramsay Creek Local Catchment Study

Baseline Flooding Assessment - Volume 1

Ramsay Creek Local Catchment Study

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

14-Jul-2017

Job No.: 60534898

AECOM in Australia and New Zealand is certified to ISO9001, ISO14001 AS/NZS4801 and OHSAS18001.

Quality Information

Document Ramsay Creek Local Catchment Study

60534898

Ref p:\605x\60534898\8. issued docs\8.1 reports\north rockhampton\ramsay creek\revb_revised\ramsay creek local catchment_baseline flood study_volume 1_revb_revised.docx

Date 14-Jul-2017

Prepared by Jordan Maultby

Reviewed by Richard Corbett

Revision History

Rev	Revision Date	Details	Authorised	
			Name/Position	Signature
0	30-May-2017	Draft for Client Review	Ben McMaster Rockhampton Office Manager	Original Signed
A	12-Jun-2017	Phase 1 Final Issue	Ben McMaster Rockhampton Office Manager	Original Signed
B	14-Jul-2017	Revised to Include Sensitivity Analysis	Ben McMaster Rockhampton Office Manager	

Table of Contents

List of Plates

List of Tables

List of Figures

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
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 Ramsay 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, 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, awareness campaigns and planning scheme updates.
- Determination of key hydraulic controls within the study area to support the future assessment of potential flood mitigation options.

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 Ramsay Creek catchment covers an area of approximately 18.5 km^2 starting in the mountainous areas to the North of Rockhampton-Yeppoon Road and extending westwards to the Fitzroy River. The southern boundary of the Ramsay Creek catchment adjoins the northern boundary of the Limestone Creek catchment, and extends from Olive Street in Parkhurst to Belmont Road near the Glenmore Water Treatment Plant. The northern catchment boundary passes centrally through The Olive Estate and the southern section of Glenlee estate. The catchment then traverses open floodplain areas to the confluence with the Fitzroy River. The western boundary is the Fitzroy River.

The upper Ramsay Creek catchment varies in elevation from 229mAHD to 32mAHD, covering an area of approximately 7.0km^2. The land use in the upper catchment is predominantly dense bushland and open grazing land with very little urbanisation. Overland runoff from the catchment quickly accumulates within the upper reach of Ramsay Creek due to the steep natural topography and is conveyed by the natural creek channel towards The Olive Estate.

Ramsay Creek is an ephemeral meandering system consisting of low flow paths and riffle pools within the mid and lower portions of the catchment. The natural creek bed material is generally silty / sandy soils. Riparian vegetation along the creek can also vary from very dense grasses, shrubs and trees – to very limited vegetation in higher velocity sections of the reach.

Urban overland flow paths within the Ramsay Creek catchment generally follow defined natural or constructed channels and road corridors. The Ramsay Creek catchment runoff generally flows from east to west towards the Fitzroy River, with the Bruce Highway and North Coast Rail Line the main controls within the catchment. Individual sub-catchments flow towards Ramsay Creek from either the south or north, with the creek channel bisecting the overall catchment.

The Ramsay Creek Study included the development of a 1D/2D dynamically linked TUFLOW model for the lower urbanised portion of the Ramsay Creek catchment. This model utilises a combination of runoff-routing and direct rainfall approaches in order to simulate overland flow paths and creek flood behaviour in order to establish baseline flood extents and depths within the study area.

Input data for the catchment was sourced and utilised within this process, although the absence of anecdotal and recorded flood event data meant the model was unable to be calibrated and validated to historical flood events. In order to maintain consistency across the North Rockhampton local catchment models, loss and roughness parameters from other successfully calibrated models were adopted as the best estimate until recorded data within the catchment becomes available.

Various design flood events and storm durations were simulated and assessed to develop an understanding of key flood behaviour. The critical duration for the catchment was determined to be the 90 minute event. A comparison of the design events found that for events up until the 39% 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 properties north of Stirling Drive and commercial parcels fronting Yaamba Road. The critical controls within the catchment are the open channel drains between developed parcels and cross-drainage structures beneath major road and rail corridors.

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 flood event 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 Ramsay 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):

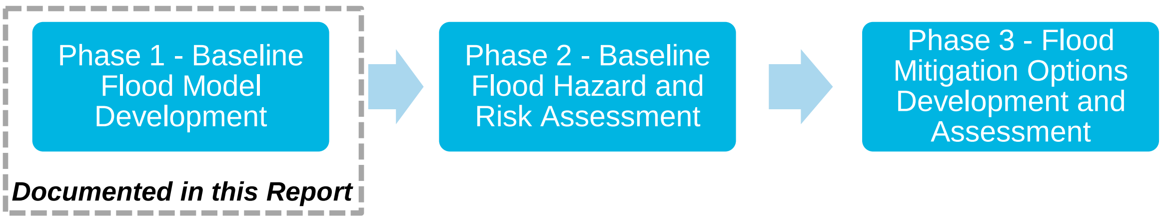
- Ramsay Creek;
- Limestone Creek;
- Splitters Creek;
- Moores Creek;
- Frenchmans Creek; and
- Thozets Creek.

This study focuses on flooding due to rainfall over the Ramsay 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 Ramsay Creek Local Catchment Study will be split into three distinct phases, as outlined below.



Phase 1 involved the development of a numerical model to simulate baseline flood behaviour associated with a range of local rainfall design events. Future Phases 2 and 3 will involve 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, awareness campaigns and updates to the planning scheme.
- 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 Ramsay 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 Baseline design flood depths, levels, velocities and extents for the study area.
- Section 8.0 presents results of the sensitivity analyses.
- Section 9.0 summaries the conclusions and outlines recommendations.
- Section 10.0 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 not been calibrated to historic events due to lack of anecdotal and recorded 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.
- Where information has been supplied by the Client or other external sources, the information has been assumed correct and accurate unless stated otherwise. No responsibility is accepted by AECOM for incorrect or inaccurate information supplied by others.

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 Ramsay Creek catchment covers an area of approximately 18.5 km^2 starting in the mountainous areas to the North of Rockhampton-Yeppoon Road and extending westwards to the Fitzroy River. The southern boundary of the Ramsay Creek catchment adjoins the northern boundary of the Limestone Creek catchment, and extends from Olive Street in Parkhurst to Belmont Road near the Glenmore Water Treatment Plant. The northern catchment boundary passes centrally through The Olive Estate and the southern section of Glenlee estate. The creek catchment then traverses open floodplain areas to the Fitzroy River. The western boundary is the Fitzroy River.

The upper Ramsay Creek catchment varies in elevation from 229 mAHD to 32 mAHD, covering an area of approximately 7.0 km^2. The land use in the upper catchment is predominantly dense bushland and open grazing land with very little urbanisation, as shown in Plate 1. Overland runoff from the catchment quickly accumulates within the upper reach of Ramsay Creek due to the steep natural topography and is conveyed by the natural creek channel towards The Olive Estate.

Plate 1 Ramsay Creek at Stirling Drive

The land use in the mid catchment is predominantly rural residential, with land parcels being larger than an acre in most cases. The remainder of the mid to lower catchment is open land and floodplain.

Table 1 Catchment Land Uses

Land Use	Proportion
Rural / Mountainous	89%
Urban	11%
• Industrial / Commercial	(6%)
• Residential	(94%)

Ramsay Creek is an ephemeral meandering stream consisting of low flow paths, pools and riffles, within the mid and lower portions of the catchment. The natural creek bed material is generally silty / sandy soils. Riparian vegetation along the creek can also vary from very dense grasses, shrubs and trees – to very limited vegetation in high velocity sections of the reach.

Plate 2 Ramsay Creek at Bruce Highway

Several segments of the reach contain ponding water in scoured areas as a result of the high velocity flood waters, one of these segments is highlighted in Plate 2. 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, as highlighted in Plate 3.

Plate 3 Ramsay Creek at Belmont Road

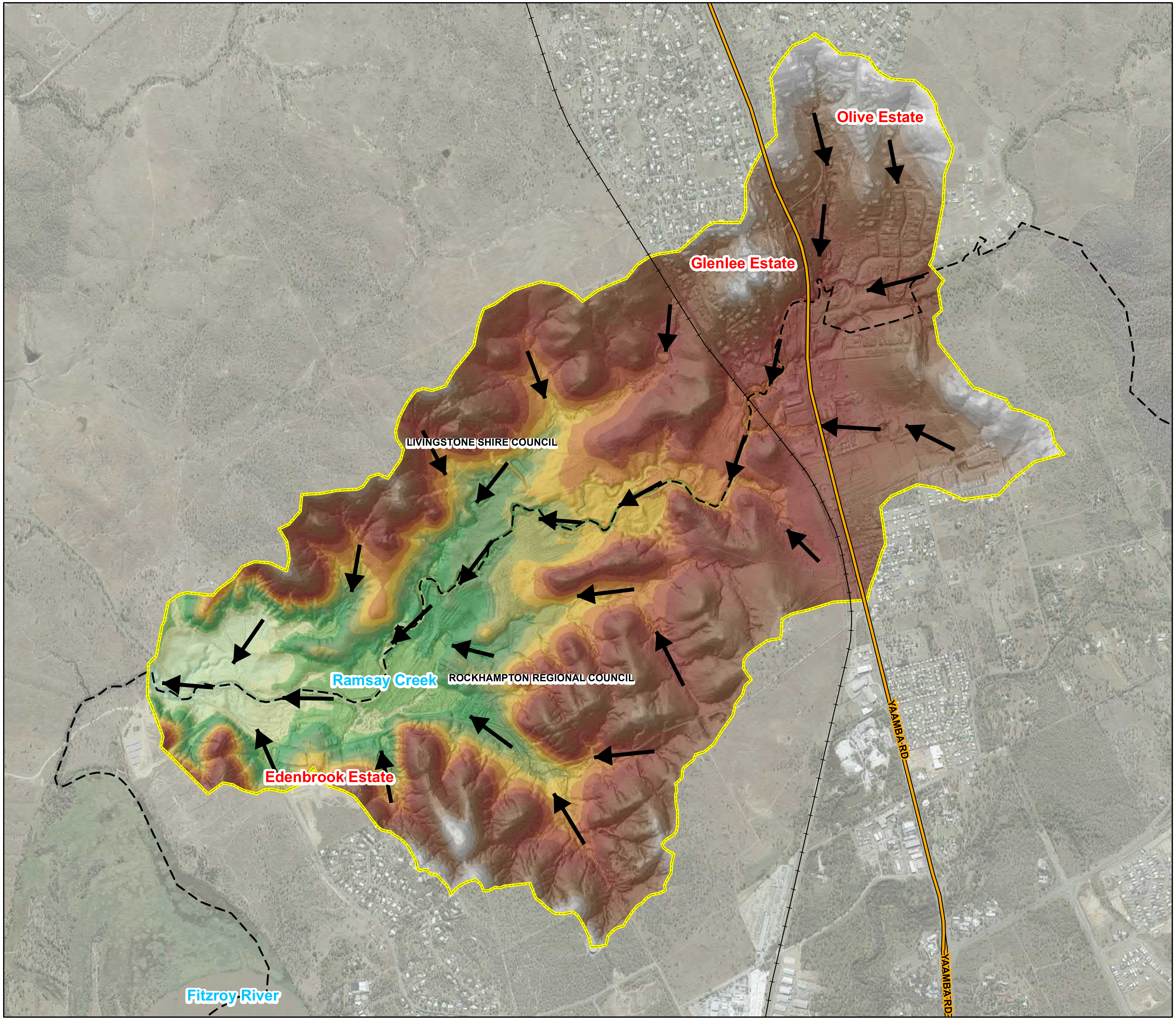
2.2 Urban Sub-Catchments

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

Key sub-catchment flow paths within the urban catchment are visible along the following reserves:

- Stirling Drive (Olive Estate);
- Sondra Lena Drive (Glenlee Estate); and
- Edenbrook Drive (Edenbrook Estate).

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



N

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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Local_Government_Boundary

Topography (mAHD)

- < 4.01
- 4.01 - 6.00
- 6.01 - 8.00
- 8.01 - 10.00
- 10.01 - 12.00
- 12.01 - 14.00
- 14.01 - 16.00
- 16.01 - 18.00
- 18.01 - 20.00
- 20.01 - 23.00
- 23.01 - 26.00
- 26.01 - 30.00
- 30.01 - 35.00
- 35.01 - 40.00
- 40.01 - 45.00
- 45.01 - 50.00
- 50.01 - 55.00
- 55.01 - 60.00
- 60.01 - 65.00
- > 65.00

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

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

Ramsay Creek Model

Sub-catchment Delineation and Natural Flow Paths

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 1

2.3 Climate Characteristics

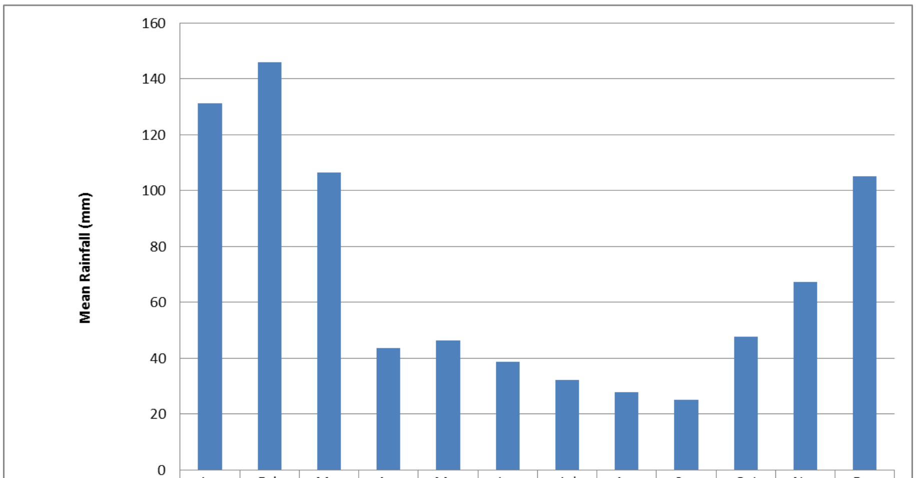
The Ramsay Creek local catchment is situated at latitude 23º 16' 48.92" south, about 17km north of the Tropic of Capricorn. The catchment centroid is about 39km northwest of the Pacific Ocean at Thompson Point. As a result, the catchment experiences a tropical maritime climate.

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.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Rainfall (mm)	131.1	145.8	106.4	43.5	46.3	38.6	32.0	27.7	25.0	47.7	67.2	105.0

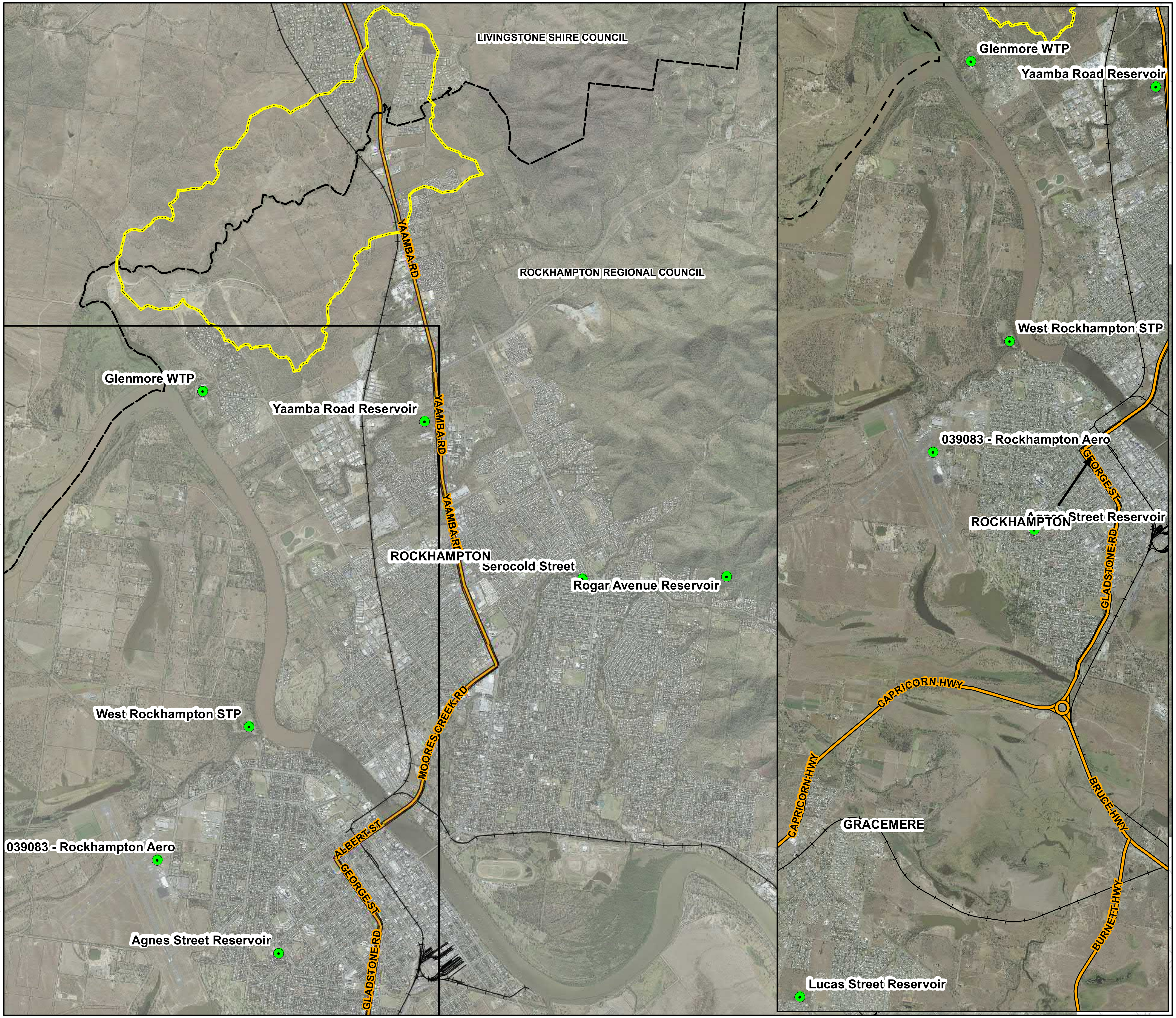
Figure 2 Mean Monthly Rainfall at the Rockhampton Airport Rainfall Station

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 will be key in accurately verifying the hydrodynamic model when recorded data becomes available.

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 SCADA (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 30 minute rainfall data from a private residence at Serocold Street, Frenchville. The rainfall stations are represented spatially in Figure 3.



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 630 1,260 1,890 2,520

Metres

1:50,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

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

Data Sources:

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

Ramsay Creek Model

Rainfall Gauge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 3

None of the gauges reside within the Ramsay Creek catchment. The closest rainfall gauge is Yaamba Road Reservoir which is situated approximately 4.5 km south of the Ramsay Creek Catchment. Given its proximity, the Yaamba Road Reservoir rain gauge is currently the best estimate of historic rainfall data within the Ramsay Creek catchment.

2.5 Historic Local Catchment Events

Significant local rainfall events leading to overland flooding of the Ramsay 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 does not include the simulation of historic events due to a lack of anecdotal and/or recorded data for the catchment to calibrate / verify the model performance. However, loss / roughness factors from other calibrated local creek catchment models were adopted.

2.6 Riverine Flooding Influence

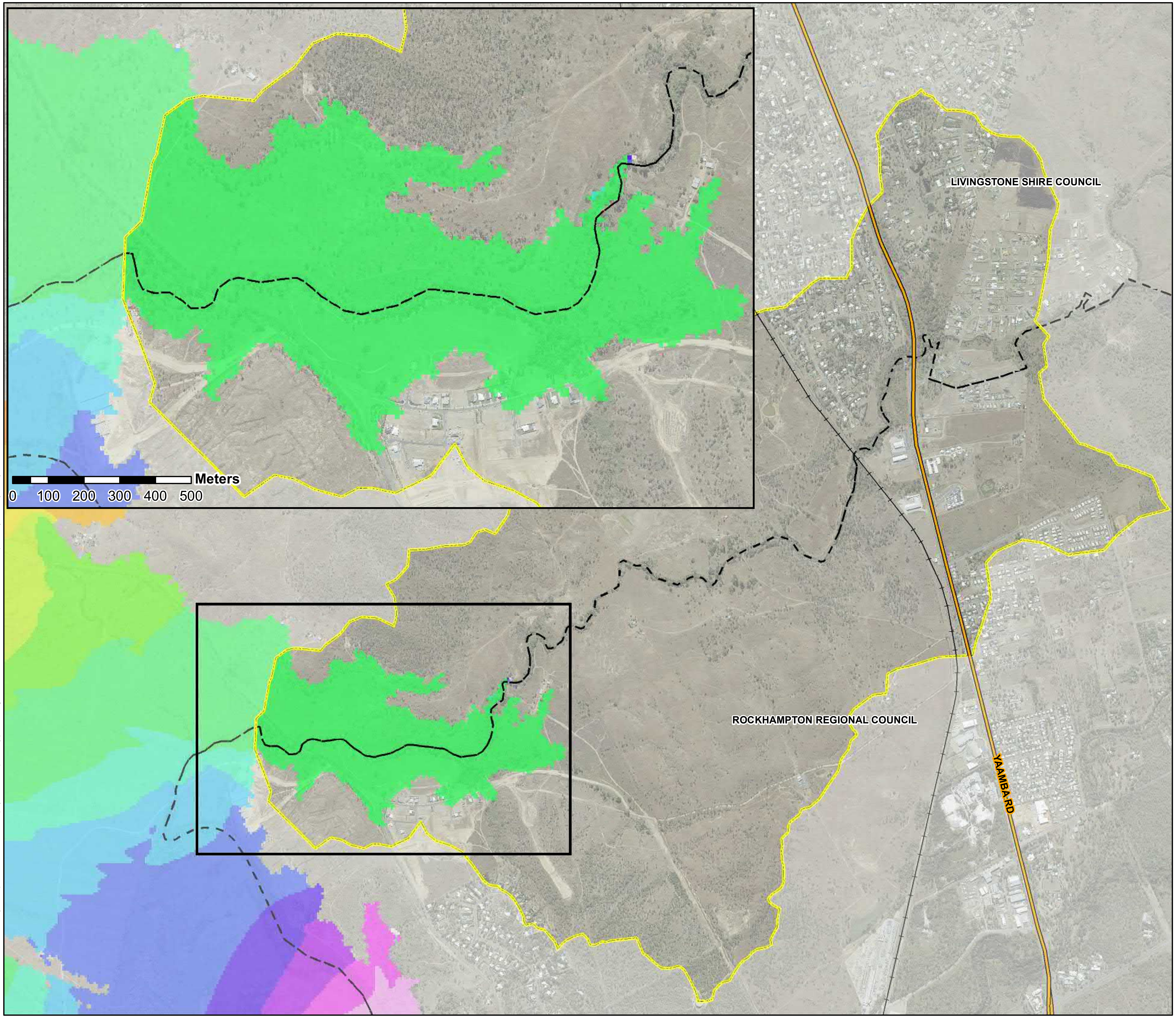
Riverine floods in Rockhampton can result from extended periods of rainfall within the 142,000 km^2 Fitzroy River basin. As peak discharge increases along the Fitzroy River, a key breakout occurs upstream of Rockhampton at the Pink Lily meander. This can result in the inundation of large areas of South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

Figure 4 outlines the riverine flood heights for a 1% AEP flood event. It is evident that portions of the lower Ramsay Creek catchment become inundated by riverine flood waters in a flood event of this magnitude. Fitzroy River 1% AEP floodwaters extend along Ramsay Creek, just short of McLaughlin Street. A few residential lots north of Edenbrook Drive as well as the Belmont Drive / Edenbrook Drive intersection are predicted to be inundated in a 1% AEP event.

The effect of riverine backwater levels on local catchment flood behaviour have been modelled as a part of the sensitivity analysis which simulates the coincidence of a 1% AEP local catchment event with an 18% AEP riverine event. The results form a component of the discussion made in Section 8.4.

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 Ramsay Creek catchment during local rainfall events.



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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Local Government Boundary

Peak Riverine Flood Extent (mAHD)

- < 11.700
- 11.700 - 11.725
- 11.725 - 11.750
- 11.750 - 11.775
- 11.775 - 11.800
- 11.800 - 11.825
- 11.825 - 11.850
- 11.850 - 11.875
- 11.875 - 11.900
- 11.900 - 11.925
- 11.925 - 11.950
- 11.950 - 11.975
- 11.975 - 12.000
- 12.000 - 12.025
- 12.025 - 12.050
- > 12.050

Flood results are based on riverine catchment events

Data Sources:

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

Ramsay Creek Model
Peak Fitzroy River Flood Heights

1% AEP Riverine Flood Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 4

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.
- Topographical data (AAM Pty Ltd).
- Aerial photography (RRC).
- Stormwater infrastructure network database (RRC).
- Details of hydraulic structures within the study area (RRC).
- Historical rainfall data for the 2013, 2015 and 2017 flood events. (BoM).
- Historical flood records for the 2013, 2015 and 2017 flood events (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 Ramsay Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014)

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

- Ramsay Creek (the focus of this report).
- Limestone 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 the 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.

No calibration was undertaken due to the lack of anecdotal or recorded levels.

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 5m grid resolution may not be representing the creek channel adequately, in areas where the channel is less than 10m 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 100mm to 200mm 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 200mm and 200mm for the 39% AEP event and between 200mm and 500mm 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

Ramsay Creek's outlet is located upstream of Fitzroy River Barrage and as such is not influenced by tidal levels. The weir on the southern side of the barrage has a crest level of 3.65mAHD 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 Ramsay 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.

Creek channel cross-section survey has also been provided by Rockhampton Regional Council, at locations where the LiDAR was not representing the terrain. Comparisons between creek dimensions using the 2009 and 2016 topographic datasets were undertaken to provide an indication of where the creek channel had changed. This comparison was used in conjunction with the latest imagery in order to pinpoint areas which showed both differences in bed level and dense vegetation. These areas were subsequently inspected by AECOM staff to confirm the need for survey.

Final areas were nominated for surveyed cross-sections which revealed more than 1 m vertical discrepancies (in comparison to the LiDAR) in some instances. Detailed comparison of the LiDAR and surveyed cross-sections are included in Appendix B.

Due to the dynamic geomorphic behaviours of Ramsay 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 current conditions.

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 600mm, where practicable.
- Upstream pipe diameter matched downstream pipe diameter

3.7 Hydraulic Structures

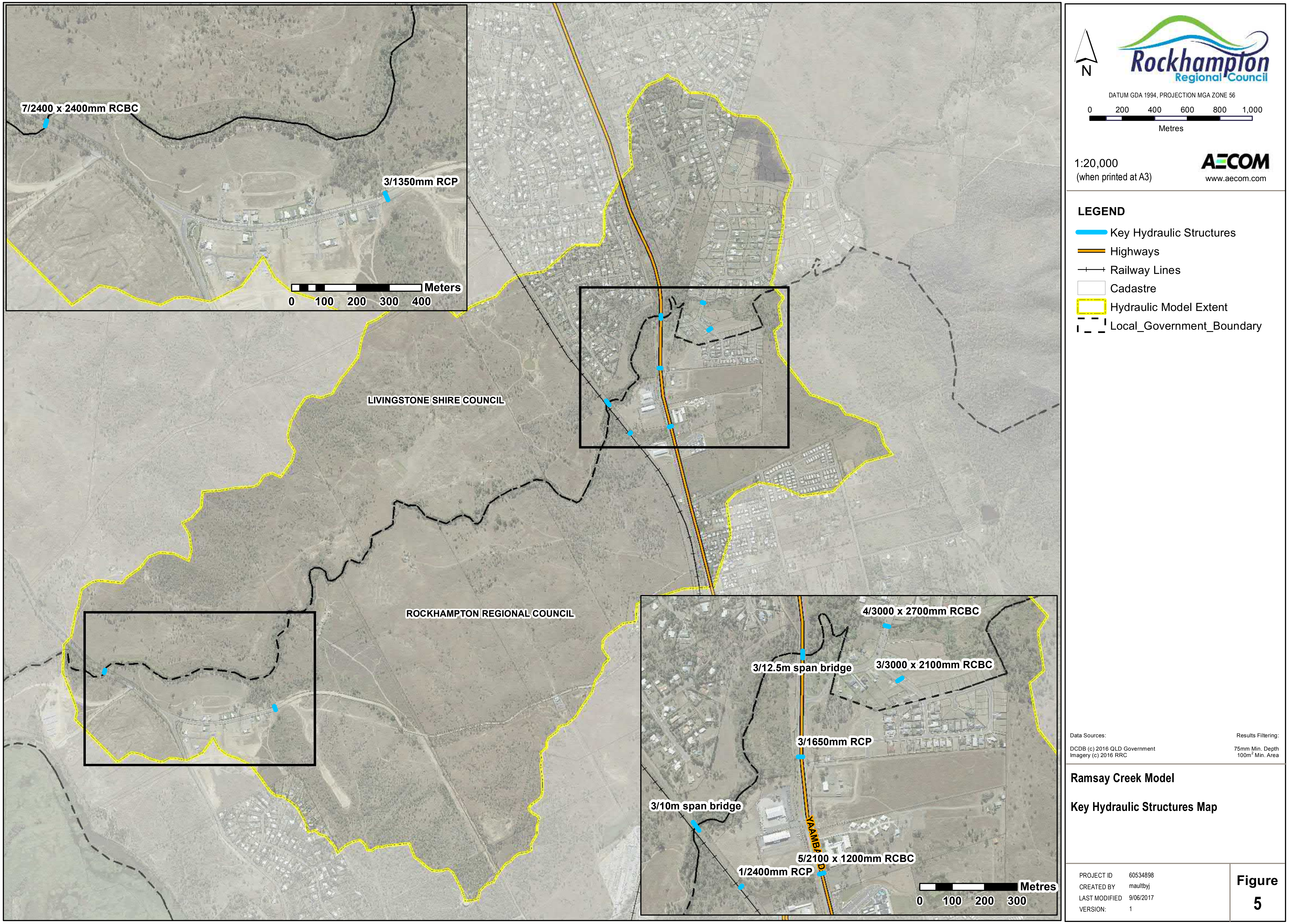
Identification of hydraulic structures associated with the major road / rail crossings within the study area was completed using a combination of council's stormwater infrastructure network database and site visits.

Approximately 52 culverts and 2 bridge structures were identified within the Ramsay Creek catchment. 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. The locations of these hydraulic structures are shown in Figure 5. Culvert structures were represented as 1-dimensional elements within the hydraulic model, with the exception of the Stirling Drive culverts 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	3/12.5m span bridge	2D
North Coast Rail Line	3/10m span bridge	2D
Major Culverts		
Stirling Drive	4/3000 x 2700mm RCBC	2D
Paramount Park	3/3000 x 2100mm RCBC	1D
Belmont Road	7/2400 x 2400mm RCBC	2D
North Coast Rail Line	1/2400mm RCP	1D
Yaamba Road	5/2100 x 1200mm RCBC	1D
	2/1650mm RCP	1D
William Palfrey Road	3/1350mm RCP	1D



7/2400 x 2400mm RCBC
3/1350mm RCP
Meters
0 100 200 300 400
LIVINGSTONE SHIRE COUNCIL
ROCKHAMPTON REGIONAL COUNCIL
4/3000 x 2700mm RCBC
3/12.5m span bridge
3/3000 x 2100mm RCBC
3/1650mm RCP
3/10m span bridge
YAAMBA RD
5/2100 x 1200mm RCBC
1/2400mm RCP
Metres
0 100 200 300
N
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)
AECOM
www.aecom.com
LEGEND
Key Hydraulic Structures
Highways
Railway Lines
Cadastre
Hydraulic Model Extent
Local_Government_Boundary
Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC
Results Filtering:
75mm Min. Depth
100m² Min. Area
Ramsay Creek Model
Key Hydraulic Structures Map
PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 9/06/2017
VERSION: 1
Figure
5

3.8 Site Inspection

A site inspection was carried out by AECOM staff in May 2017 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	✓	✓	✗

This data wasn't specifically utilised within the Ramsay Creek catchment due to the lack of flood height data for the various events. Therefore no calibration and verification of the model could be conducted.

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 Ramsay Creek catchment (Aurecon, 2014) and was provided by RRC. The model computes the design discharge hydrographs from this catchment 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.

An XP-RAFTS model was necessary as the hydraulic model did not cover the entire catchment and therefore the direct rainfall approach could not estimate runoff from the portion of the catchment that was outside the model extent.

4.1.2 Model Configuration

The upper Ramsay 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 8 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 (as specified by Aurecon, 2014) 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 Ramsay 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.

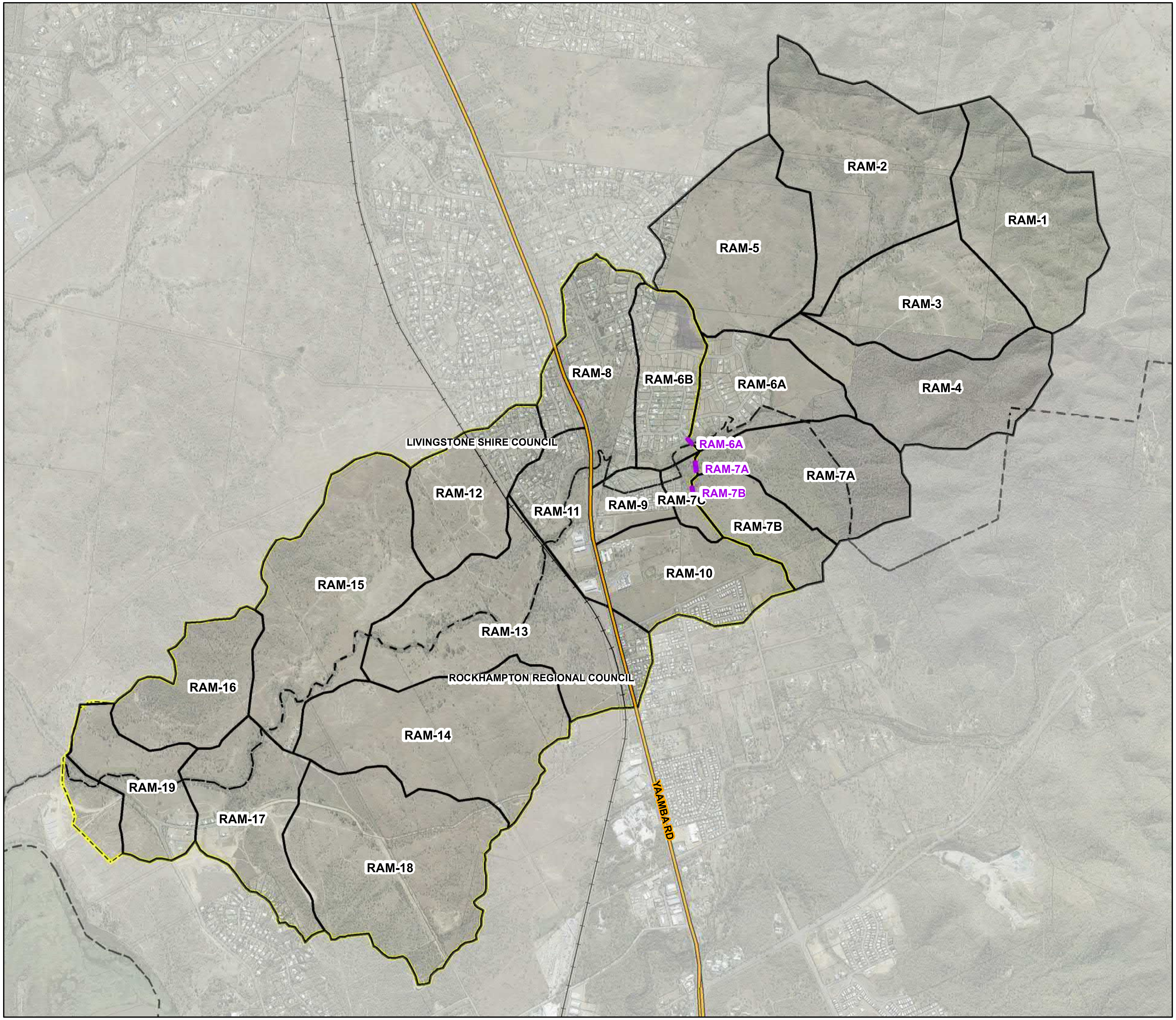
There are also several disadvantages associated with the use of the direct rainfall approach:

- 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 rainfall excess was calculated by applying initial and continuing losses to the design rainfall to represent infiltration and storage of runoff in surface depressions. Losses chosen for this project are discussed in Section 4.3.5.

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).



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250

Metres

1:25,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

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

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

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

Ramsay Creek Model

Hydrologic and Hydraulic Model Layout

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 6

Filename: R:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Ramsay Creek Publishing\Figure Hydrologic and Hydraulic Models.mxd

4.3 Design Rainfall Data

4.3.1 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 4.

Table 4 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 5.

Table 5 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

4.3.2 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 4.3.4).

4.3.3 Areal Reduction Factors

The IFD rainfall values derived in Section 4.3.1 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.

4.3.4 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 Ramsay Creek Local Catchment Study which has a catchment area of approximately 18.5 km^2 and a critical duration of 1.5 hours (refer Section 7.2).

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 6.

Table 6 Adopted PMP Parameters

Duration (hrs)	Rainfall Total (mm)	Rainfall Intensity (mm/hr)
1	400	400
1.5	510	340
2	600	300
3	720	240

The AEP of the PMP event was calculated as recommended in AR&R (Pilgrim, et al, 1987). For a catchment area of 18.5km^2, the PMP event is approximately a 1 in 10,000,000 AEP event.

4.3.5 Design Event Rainfall Loss Parameters

Design event losses were established based on the results of the calibration and verification simulations conducted on other local creek catchment models in the surrounding area, which were calibrated to recorded data. 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 22 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 Ramsay Creek hydraulic model.

The XP-RAFTS hydrologic 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 15mm and continuing loss of 1.0mm 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 Ramsay 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 7 Hydrologic Model Setup Overview

Event (AEP)	Previous Study Peak Inflows (m^3/s)	This Study Peak Inflows (m^3/s)			Difference
	Node RAM-6A*	Node RAM-6A*	Node RAM-7A*	Node RAM-7B*	
1EY	-	12	1	1	-
39%	19	19	2	2	0.0%
18%	-	31	4	3	-
10%	41	38	5	4	-7.3%
5%	55	49	6	5	-10.9%
2%	73	64	9	6	-12.3%
1%	86	76	10	7	-11.6%
0.2%	143	121	17	11	-15.4%
0.05%	-	160	22	15	-
PMF	524	514	72	43	-1.9%
January 2013	-	-	-	-	-
February 2015	-	-	-	-	-
March 2017	-	-	-	-	-

* Note: Sub-catchment node reference as per Figure 6.

As outlined in Section 4.3.5, variation in the adopted rainfall losses results in some differences in the hydrologic inflows between the previous and current studies.

In contrast, a higher total loss was applied to events larger than 18% AEP, resulting in lesser flows being applied to the model boundary, especially for events for 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 Ramsay 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 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 1.5 second was adopted (2.0 second previously), giving an effective runtime of approximately 4.1 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.

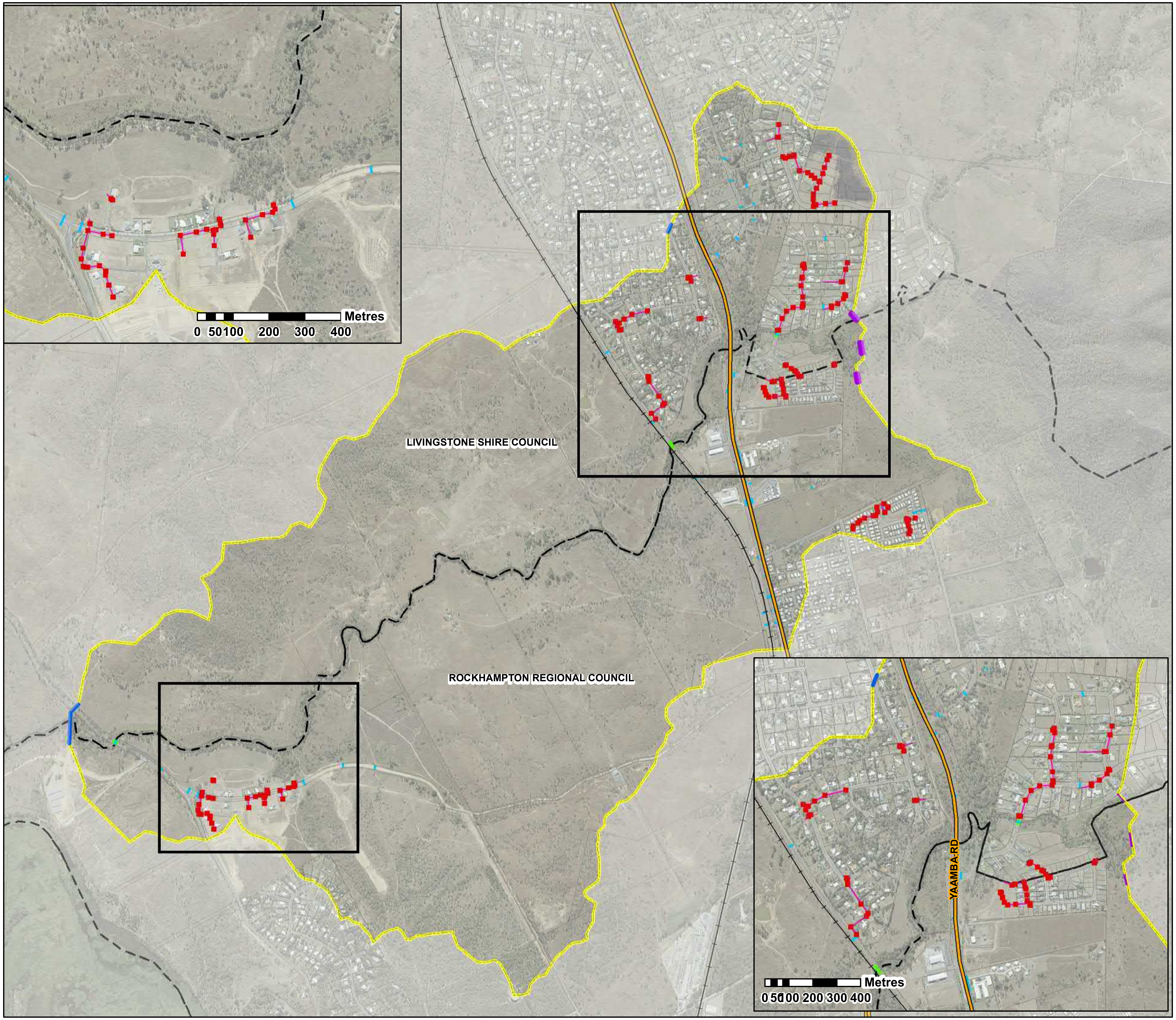
An overview of the model setup and key parameters for the model is provided in Table 8.

Table 8 Hydraulic Model Setup Overview

Parameter	Ramsay 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 4.3.1
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 Ramsay Creek Model and Ramsay Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014).
Eddy Viscosity	Smagorinsky
Model Calibration	Calibration data not available.
Downstream Model Boundary	3 inflow boundaries along the north-eastern boundary, 1 height-flow boundary on the south-western boundary.
Timesteps	1.5 second (3m 2D) and 0.75 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 7 and Figure 8 to supplement the detailed updates outlined in Appendix A.



N

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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Cadastre
- Pit Inlet
- Pipe
- Culverts
- Inflow Boundary Condition
- Outflow Boundary Condition
- Layered Flow Constriction
- Hydraulic Model Extent
- Local_Government_Boundary

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

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

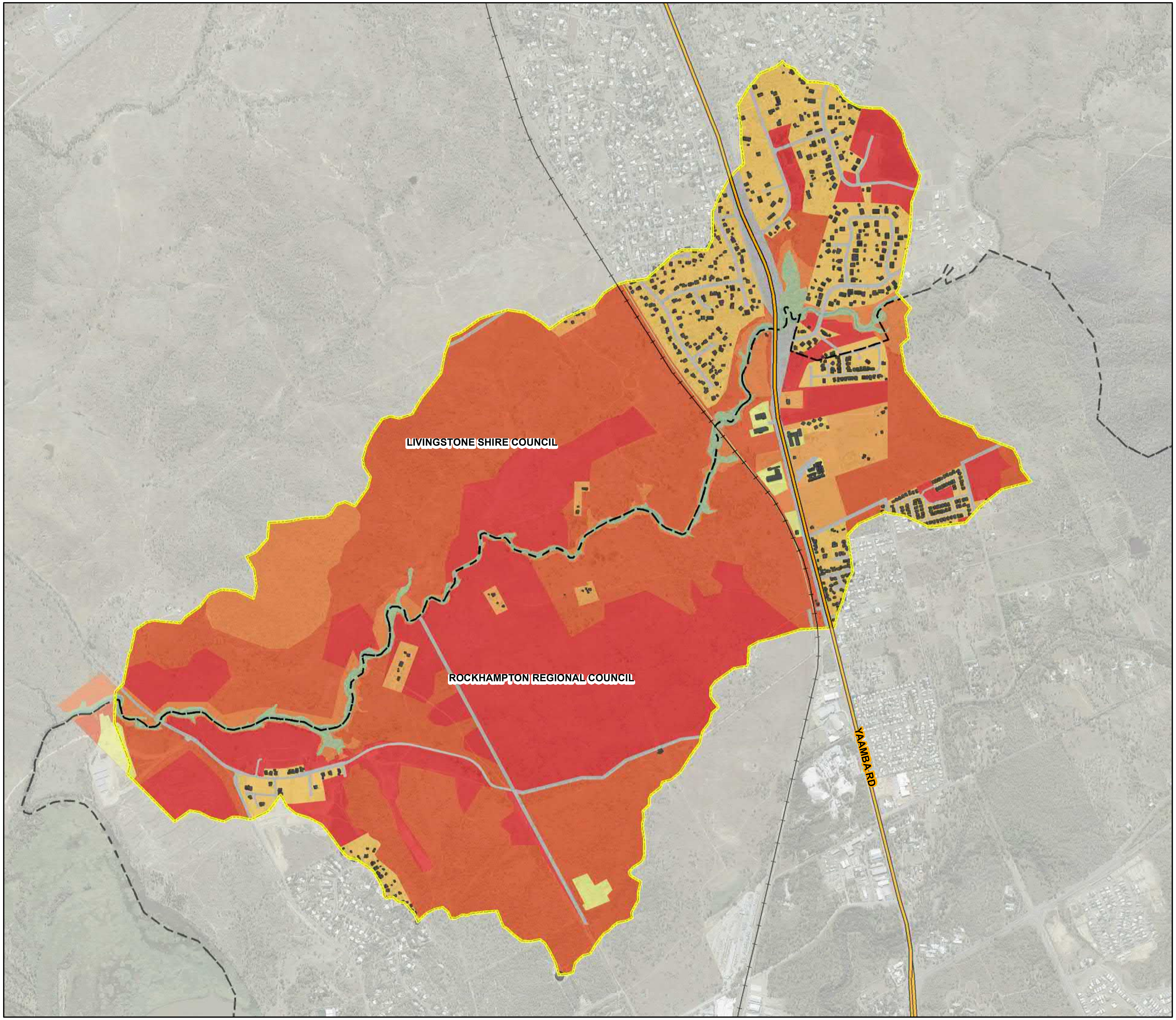
Ramsay Creek Model

Model Setup and 1D Network Map

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 7

Filename: R:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Ramsay Creek Publishing\Figure Model Setup and 1D Network Map.mxd



N

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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Local_Government_Boundary
- Building Footprints
- Road Corridor
- Creek Channel
- Riparian Corridor
- Railway
- Commercial Industrial Block
- High Density Residential
- Medium Density Residential
- Low Density Residential
- Medium Vegetation
- Low Vegetation
- Long Grass

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

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

Ramsay Creek Model

Hydraulic Roughness Delineation

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 9/06/2017
VERSION: 1

Figure 8

7.0 Baseline Hydraulic Modelling

7.1 Overview

The Ramsay 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.

7.2 Critical Duration Assessment

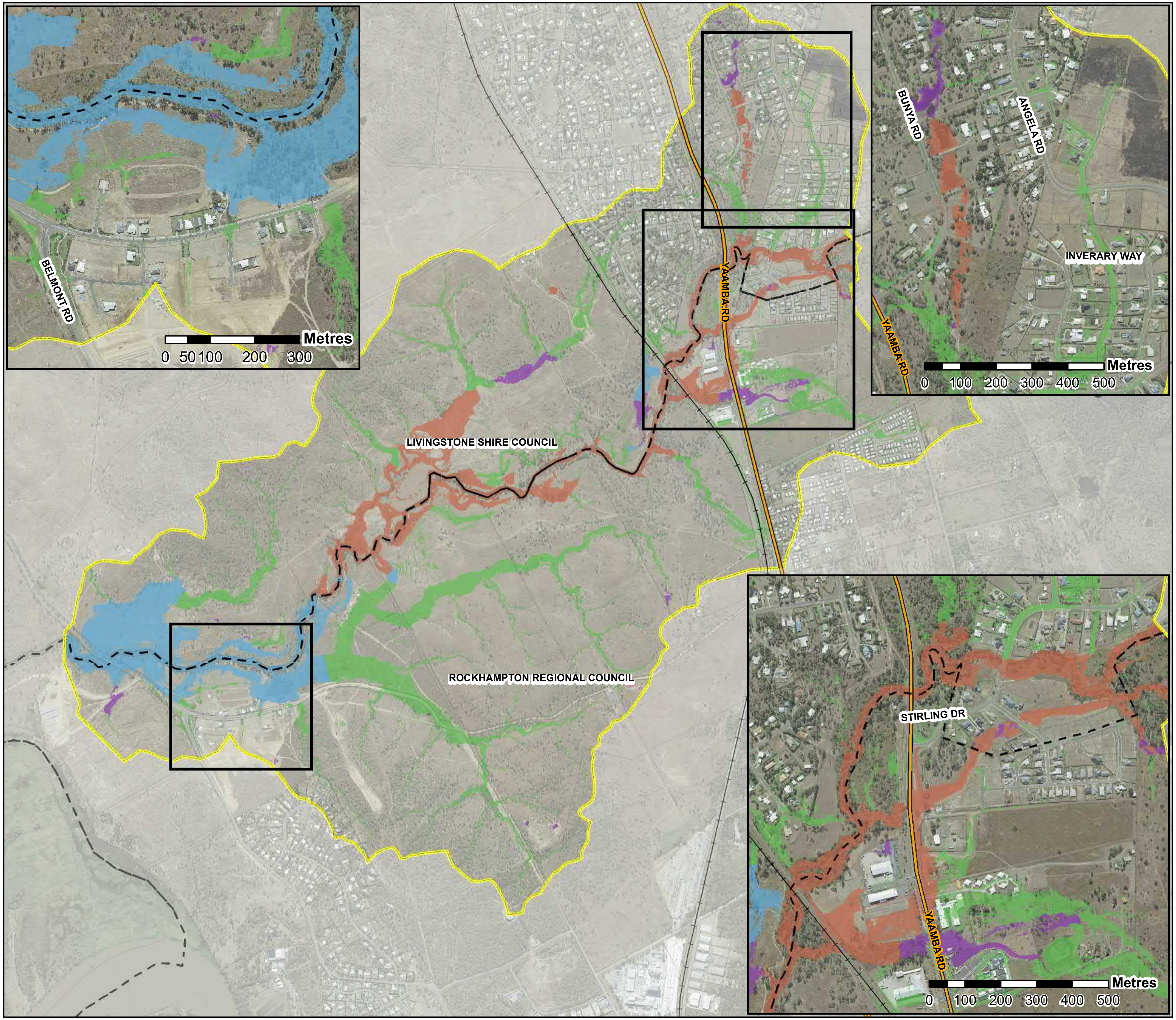
The critical storm duration for the Ramsay Creek Local Catchment area was assessed by simulating the 60min, 90min, 120min, 180min, 270min and 360min durations for the 1% AEP event.

Figure 9 shows that for a 1% AEP event, Ramsay Creek itself has a critical duration of 120 minute. However, the difference between the 90 minute and 120 minute within the creek upstream of Yaamba Road varies by less than 60 mm, with the 90 minute critical in the southern segment along Yaamba Road north of Olive Street. The 90 minute was a good balance between the 60 minute and 120 minute in the higher urban areas. As such and in order to reduce model runtime, the 90 minute event was selected as the critical duration.

Analysis of differences between the 90 minute and 120 minute storm events, as shown in Figure 10 revealed approximately 77% of the instances were within ±20 mm with the 120 minute event being higher across approximately 18% of the cells. Figure 11 highlights the palette histogram of the 90min PWSE minus the 120min design storm events.

With the exception of the 1% AEP event, the 90 minute critical duration was applied to all design flood events mentioned in Section 7.1. For the 1% AEP a ‘Max:Max’ analysis was undertaken, whereby results from the 60min, 90min, 120min, 180min, 270min and 360min 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.



N

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)

AECOM
www.aecom.com

LEGEND

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

Event Duration

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

Flood results are based on local catchment events

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

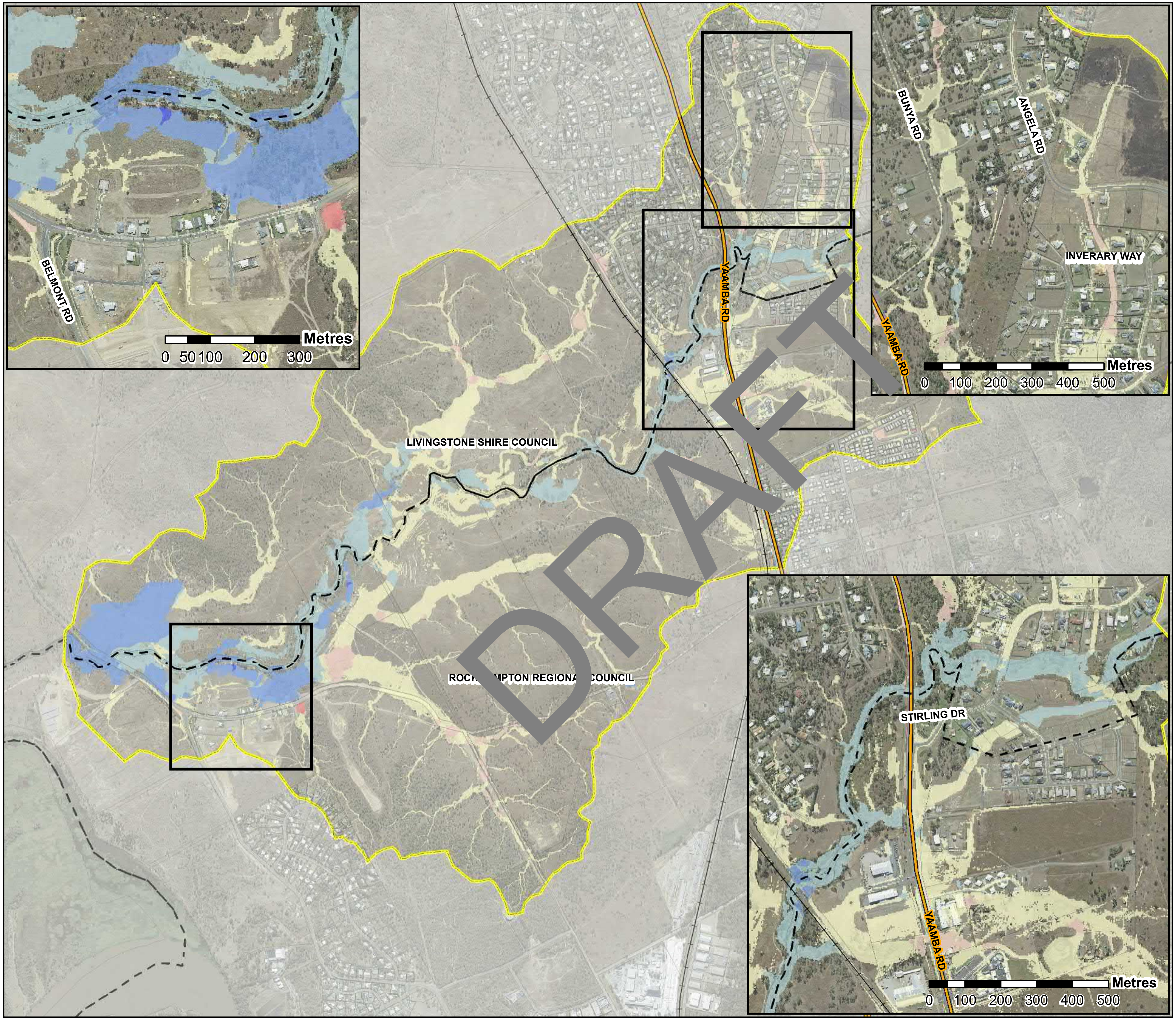
Results Filtering:
75mm Min. Depth
100m² Min. Area

Ramsay Creek Model
Critical Duration Assessment

1% AEP Event

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 9/06/2017
VERSION: 1

Figure 9



N

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)

AECOM
www.aecom.com

LEGEND

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

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

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

Ramsay Creek Model

90min PWSE minus 120min PWSE

1% AEP Event

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 9/06/2017
VERSION: 1

Figure 10

Filename: R:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Ramsay Creek Publishing\Figure 1%AEP 90min minus 120m.mxd

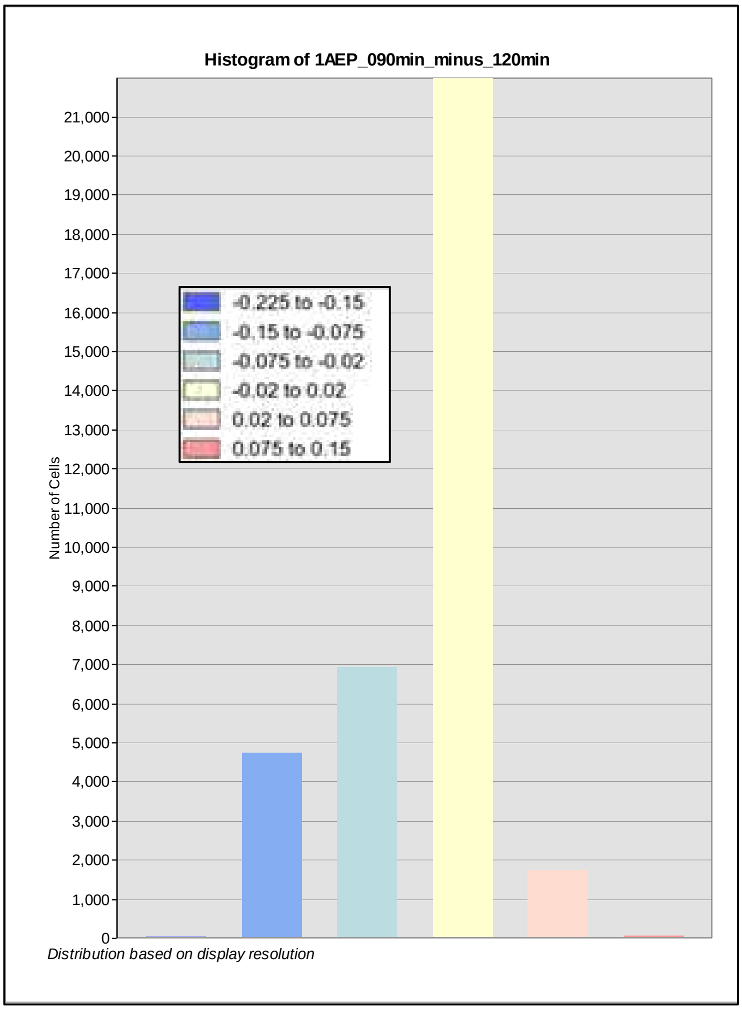


Figure 11 Palette Histogram of 1% AEP 90min PWSE minus 120min PWSE (m)

7.3 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 not excluded 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.

The baseline modelling shows:

- **Maps 1 to 3** – 1 EY Baseline

It can be noted that within the Ramsay Creek catchment, various privately owned water storage dams exist, which can be seen on the mapping. During the 1 EY event, the runoff is maintained within the creek channel with depths ranging from 1.5 m to 3 m. The wider catchment has various overland flow paths, one of which crosses Edenbrook Drive with depths of less than 0.3 m. Flows within the upper portions of the catchment above Yaamba Road are mainly contained within the capacity of the road and drainage network. It is noted that some private properties experience flow depths of less than 0.3m near the intersection of Inverary Way and Stirling Drive.

The peak flood height at Yaamba Road and the North Coast Rail Line is up to 28 mAHD and 24 mAHD respectively. Peak depth averaged velocities within Inverary Way drainage corridor reach up to 1.5 m/s. Velocities within Ramsay Creek exceed 2 m/s in localised areas.

- **Maps 4 to 6** – 39% AEP Baseline

In comparison to the 1 EY scenario, the flood extents expand slightly within the Ramsay Creek corridor. There is some additional ponding adjacent to Yaamba Road and the North Coast Rail Line but there is minimal impact on surrounding properties. Depths within the lower sections of Ramsay Creek are greater than 3 m. The peak flood height at Yaamba Road and the North Coast Rail Line is up to 28 mAHD and 26 mAHD respectively. Peak depth averaged velocities of up to 2 m/s is expected within Ramsay Creek.

- **Maps 7 to 21** – 18% AEP Baseline

The 18% AEP event results in some inundation of private properties situated adjacent to Yaamba Road. Greater inundation also occurs in the properties near the corner of Inverary Way and Stirling Drive. The overland flow paths in the lower Ramsay Creek catchment are significantly wider. The depth of water within Ramsay Creek exceeds 3 m for the modelled reach. Peak depth averaged velocities within the Stirling Drive are up to 1.5 m/s.

- **Maps 22 to 24** –10% AEP Baseline

The properties backing onto the Inverary Way open channel are expected to be impacted to a greater extent. The properties on Yaamba Road also become affected by wider overland flow paths. The peak flood height at Yaamba Road and the North Coast Rail Line is up to 28 mAHD and 26 mAHD respectively. The flow path through the properties on Argyle Avenue, has a peak depth averaged velocity of 1.5 m/s.

- **Maps 25 to 27** – 5% AEP Baseline

In the 5% AEP event a significant flow path develops across Belmont Road with a depth of up to 0.6 m. Apart from the very lowest sections of Ramsay Creek, the flow is contained to the main creek channel. In the lower catchment, the flow breaks out of the creek and begins to spread over the natural floodplain. The peak water surface height at the Yaamba Road crossing is between 28 mAHD and 30 mAHD. Peak depth averaged velocities within Ramsay Creek are greater than 2.0 m/s.

- **Maps 28 to 30** – 2% AEP Baseline

The flood extents continue to expand in the 2% AEP event, with up to 1.8 m in water depth on the upstream side of Yaamba Road. Peak depths up to 2.4 m are expected upstream of the railway line. The industrial developments to the east of Yaamba road continue to experience inundation by an overland flow path. The velocities through these properties range from 0.25 m/s to 1 m/s.

- **Maps 31 to 45** – 1% AEP Baseline

In the 1 % AEP event, runoff continues build-up at Yaamba Road with depths of up to 1.8 m at some of the culverts. From the mapping it can be noted that breakout flows occur more frequently along the creek reach. A small flow path starts to cross Edenbrook Drive to a depth of less than 0.3 m. Inundation continues for the properties in Inverary Way. The peak depth averaged velocities of flows going though Argyle Avenue open channel are greater than 2 m/s.

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

Connectivity between Ramsay Creek and the adjacent floodplains is expected along the majority of the modelled reach. Flow through the industrial area adjacent to Yaamba Road continues to increase with depths of up to 2.1 m expected. The peak flood height at Yaamba Road and the North Coast Rail Line is up to 30 mAHD and 28 mAHD respectively. Velocities within the Argyle Avenue drain are greater than 2 m/s and within the industrial area the peak depth averaged velocity is up to 1 m/s.

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

The flood extents continue to expand significantly in the 0.05% AEP event. Flows through the industrial area increase and affect larger areas of private property, with depths of up to 1.5 m. The peak water surface elevation upstream of Yaamba Road is up to 30 mAHD. Peak depth averaged velocities along most of the major flow paths are greater than 2 m/s.

- **Maps 52 to 54** – PMF Baseline

Within the Argyle Avenue collection of houses some properties become inundated with flood waters. Most of the industrial area adjacent to Yaamba Road experiences inundation with depths of up to 1.2 m in some places. Edenbrook drive becomes overtopped near its intersection with Belmont Road in the PMF event. During the PMF event both the railway and Yaamba Road are significantly overtopped. Velocities throughout a large portion of the catchment are greater than 2 m/s.

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

Events up to the 1% AEP show minor increases in flood extents for the length of Ramsay Creek, with the largest increases in the 0.2% AEP (and greater). Between the 1% AEP baseline case and the PMF event, the width of flooding within Ramsay Creek increases to four times the size.

7.4 Baseline Peak Discharges

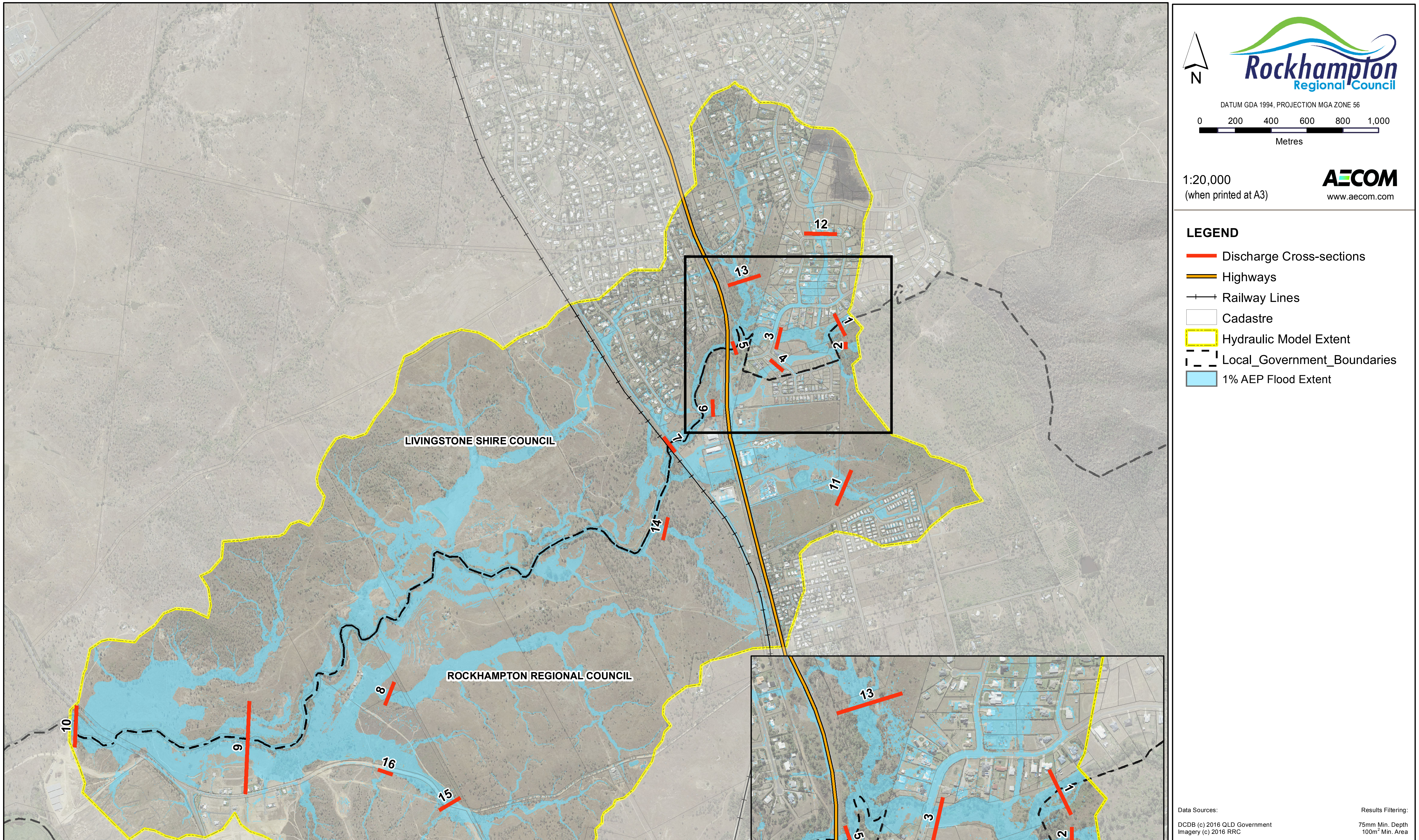
Peak discharges across the range of simulated design events for the 90m critical duration, were extracted at key locations, including but not limited to:

- Ramsay Creek major crossings;
- Ramsay Creek tributaries;
- Olive Street;
- Inverary Way; and
- Belmont Drive.

Refer to Figure 12 for extraction cross-section locations. Table 9 below presents the results at corresponding locations.

Table 9 Summary of Baseline Peak Discharges

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (90 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Ramsay Creek	1	11.5	19.4	30.4	38.1	48.5	63.5	75.8	120.4	159.6	511.5
	2	1.4	2.4	3.8	4.9	6.3	8.6	10.2	16.6	22.4	69.9
	3	13.1	21.5	33.5	40.7	51.4	61.5	70.5	108.8	146.6	429.7
Argyle Avenue	4	2.5	4.1	6.6	9	12.7	19.8	25.9	43.5	54.3	176.2
Ramsay Creek	5	15.7	25.1	37.6	45.2	55.4	68.8	81	125.8	168.4	364.3
	6	3.0	4.9	7.1	9.1	11.8	13.3	14.7	23.4	32	123.5
	7	19.1	30.4	45.2	54.6	67.5	83.3	96.2	145.6	175.4	322
McLaughlin Street	8	13.7	18.9	25.4	29.6	35.2	39.7	45.5	65	81.7	157.4
Ramsay Creek	9	35.5	55.2	79.9	94.6	114.8	142.6	164.3	268.4	368.8	1287.8
Belmont Drive	10	34.8	54.8	80.3	93.3	112.3	139.4	161.3	257.4	356.7	1297.4
Olive Street	11	3.4	4.5	6	7.1	8.7	9.8	11.2	18.3	23.3	41.7
Inverary Way	12	3.8	5.1	7	8.2	9.7	10.6	12.2	17.1	21.5	34.4
Bunya Road	13	3.4	4.5	6.2	7.6	9.5	10.9	12.6	17.6	27.2	71.6
Tributary to Ramsay Creek	14	4.5	6.6	9.4	11	13.2	14.9	16.9	25.4	30.9	58.8
McLaughlin Street	15	11.5	19.7	28.3	32.8	38.8	42.9	49.4	70.9	90.3	156.5
William Palfrey Road	16	1.7	2.3	3.1	3.6	4.3	4.7	5.3	7.4	9.2	14.3



Data Sources:

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

Results Filtering:

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

Ramsay Creek Model

Key Flow Path Discharge Locations

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 18/07/2017
VERSION: 1

Figure 12

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Ramsay Creek Publishing\Figure Plot Outputs.mxd

7.5 Stormwater Network Capacity

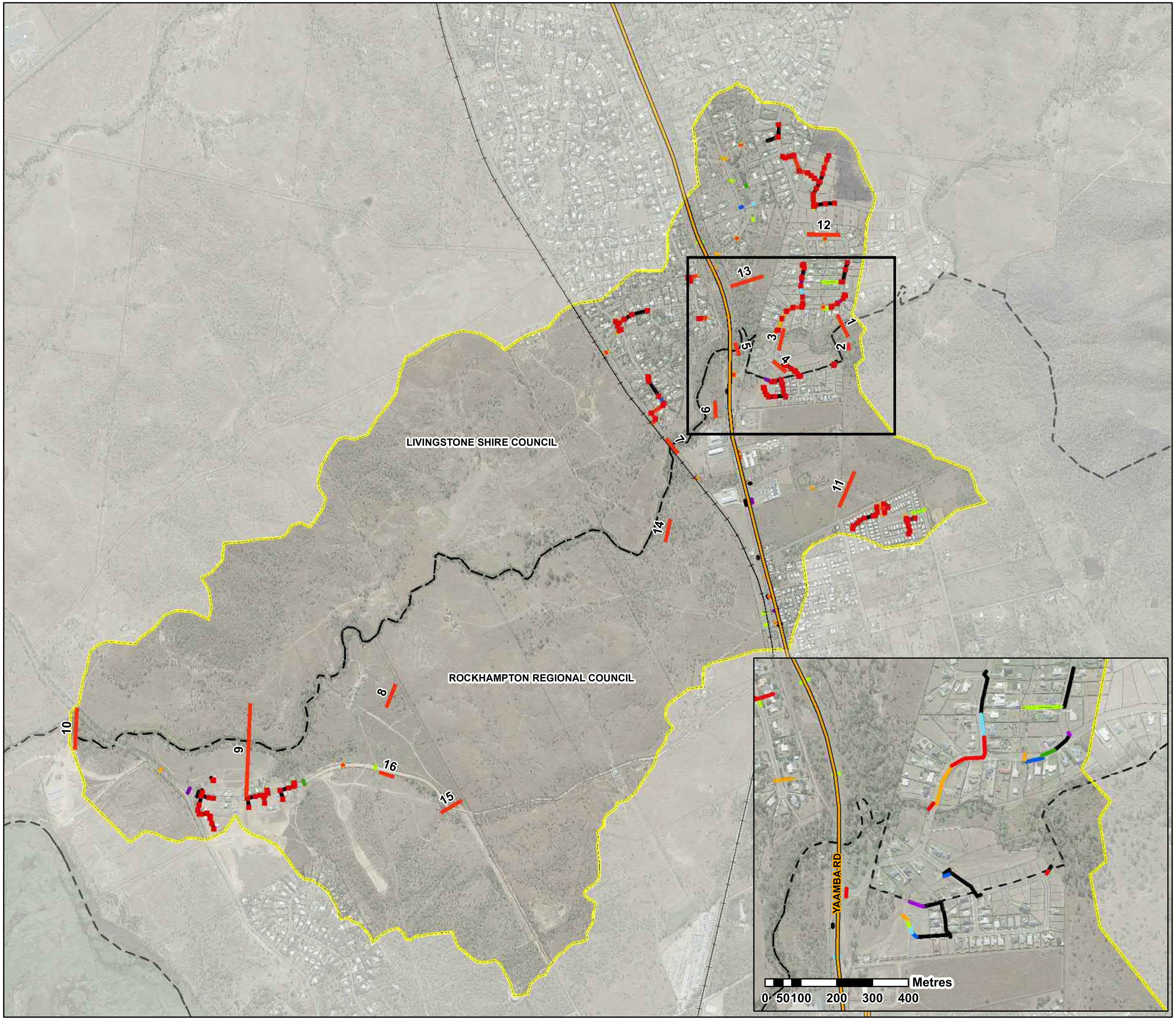
Figure 13 provides a spatial analysis of the existing underground network capacity during the 90 min storm duration. It shows the event at which the capacity of the pipe/culvert is reached. It is noted that culverts were considered to have reached capacity once they exceeded 80% of their full flow capacity.

It can be seen that several segments of the network have less than 1 EY immunity (an estimated 28% of the modelled network). Approximately 44% of the network has less than 10% AEP immunity, including the majority of the network within the residential areas north of Ramsay Creek. In a 1% AEP event, approximately 53% of the network is considered as flowing at full capacity.

7.6 Implications of the Rockhampton Northern Access Upgrade Project

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

It is noted that the RNAU project proposes new cross-drainage configurations, including duplication of the Ramsay Creek Bridge. It is recommended that the baseline models and mapping be updated by Council upon the completion of the RNAU construction phase (planned for 2018).



N

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)

AECOM
www.aecom.com

LEGEND

- Discharge Cross-sections
- Pit Inlet

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
- Local_Government_Boundary

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

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

Ramsay Creek Model

Basecase 1D Network Capacity Analysis

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

Figure 13

7.7 Comparison with Previous Study Results

7.7.1 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.

7.7.2 Changes Implemented in this Study

The updated model has been upgraded to a rain-on-grid model with upper catchment XP-Rafts inflows, 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 200 pipes and 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 10.

Table 10 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

7.7.3 Results Comparison between Previous and Current Study

Figure 14 to Figure 17 show the differences in predicted peak flood heights and depths as a result of the changes listed above. The comparison shows:

- **Figure 14** – 18% AEP Height Difference Map

Various overland flow paths that were previously modelled as inflows directly into Ramsay Creek are now represented due to the direct rainfall approach. The overland flow paths coincide with the gullies and lower sections of the topography, as the runoff moves towards Ramsay Creek.

Floodwater attenuation in the industrial estate upstream of Yaamba Road has reduced, with significant areas that were wet now modelled as dry during the 18% AEP event. This difference can be attributed to an increase in development in the area resulting in flow paths becoming more defined and some land areas filled.

Conveyance from the overland flow path that intersects Argyle Avenue results in changes in flood heights compared to the previous model. These changes can be attributed to development occurring in the area and the introduction of the culvert and 1d network within the residential area, which was constructed after the original model was developed.

The introduction of bridge structures being modelled as a layered flow construction has resulted in levels upstream of the Stirling Drive bridge over Ramsay Creek increasing as the losses across the bridge stricture are more accurately represented.

As the previous model applied overland flow directly to the creek reach, the change to direct rainfall modelling has resulted in the retarding basins situated alongside Bunya Road having a greater effect. The attenuation of flows within the basins explains the reduction in waters levels in the flow path upstream of Ramsay Creek.

Overall the Ramsay Creek reach below Yaamba Road is modelled as have higher peak flood heights than the previous study, this difference can be attributed to the changes made to the losses and the 2016 LiDAR being higher across the majority of the model extent.

Other localised differences between the models can be attributed to slight changes in topography and a more refined model grid size.

- **Figure 15** – 18% AEP Depth Difference Map

The areas of 'was wet now dry' and reductions in depths in the industrial and new residential area are the result of new development occurring after the previous model was developed, and the inclusion of the retarding basins. The overall increases in depth from the previous model can be attributed to the reduced continuing loss that has been applied to the 18% AEP event resulting in increased inflows into the creek system.

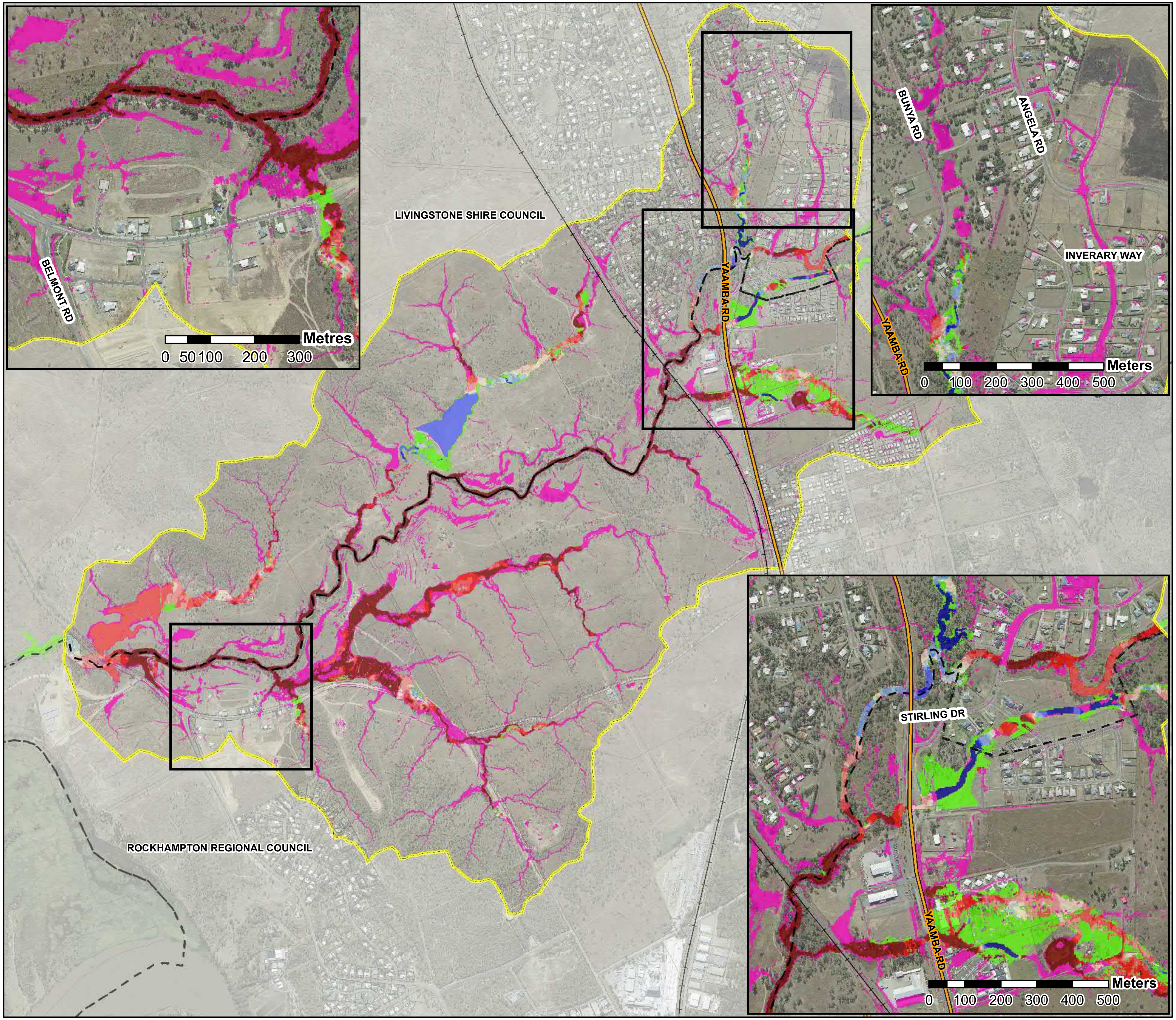
- **Figure 16** – 1% AEP Height Difference Map

The reduction in flood heights around the intersection of Yaamba Road and Ramsay Creek is the result of including the retention basins in the sub-catchment upstream. The storage allowed by these basins reduces the peak flows and flood elevations.

Again the inclusion of the developed areas surrounding Yaamba road explains the changes in flood height across the area. Throughout the remainder of the model the changes in water elevation are as expected due to the elevation change in LiDAR and reductions in losses.

- **Figure 17** – 1% AEP Depth Difference Map

The impact of the retention basins on the current study can be seen in Figure 17, with the depth of flow reducing downstream. The inflows adopted for the 1% AEP event were lower than the previous model, which also explains the changes in depths at the start of Ramsay Creek. Various other changes slight differences can be explained by the differences in LiDAR and losses adopted throughout the model.



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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- Local Government Boundary

Difference in Height (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
100m² Min. Area

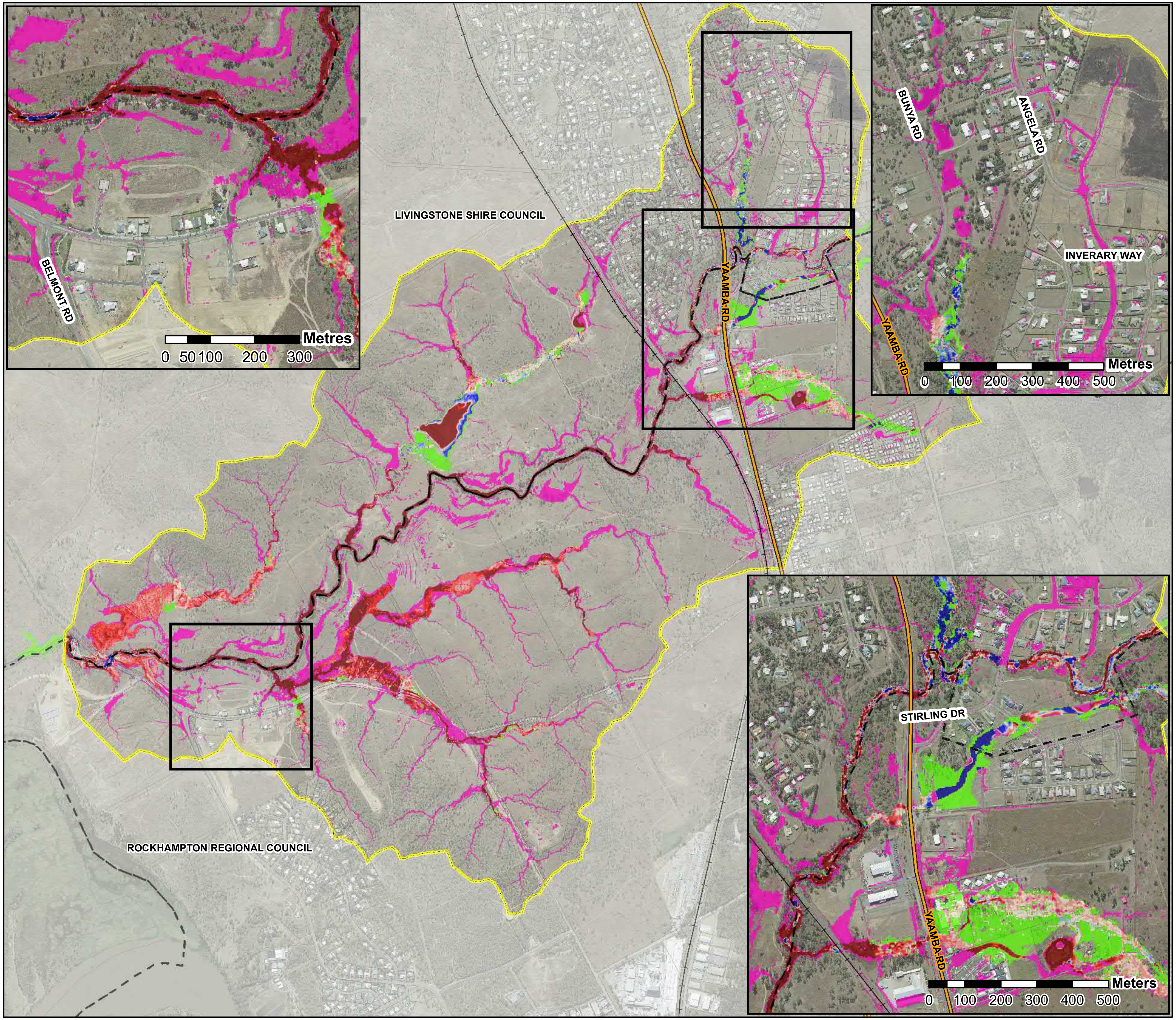
Ramsay Creek Model
Difference in Peak Flood Heights
Current Study minus Previous Study

18% AEP 090min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 14

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



N

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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- Local Government Boundary

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

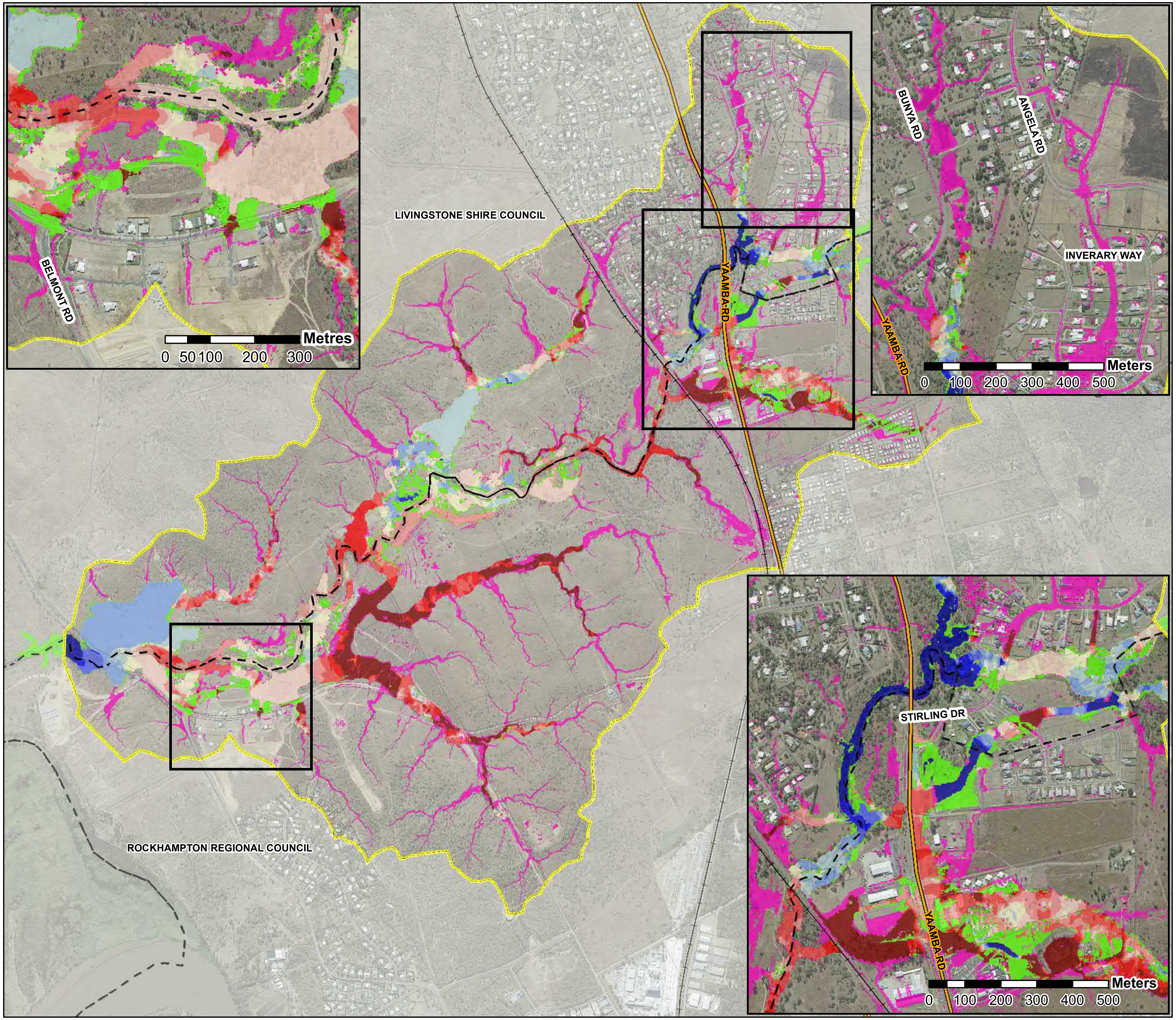
Ramsay Creek Model
Difference in Peak Flood Depths
Current Study minus Previous Study

18% AEP 090min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 15

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



N

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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- Local Government Boundary

Difference in Height (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

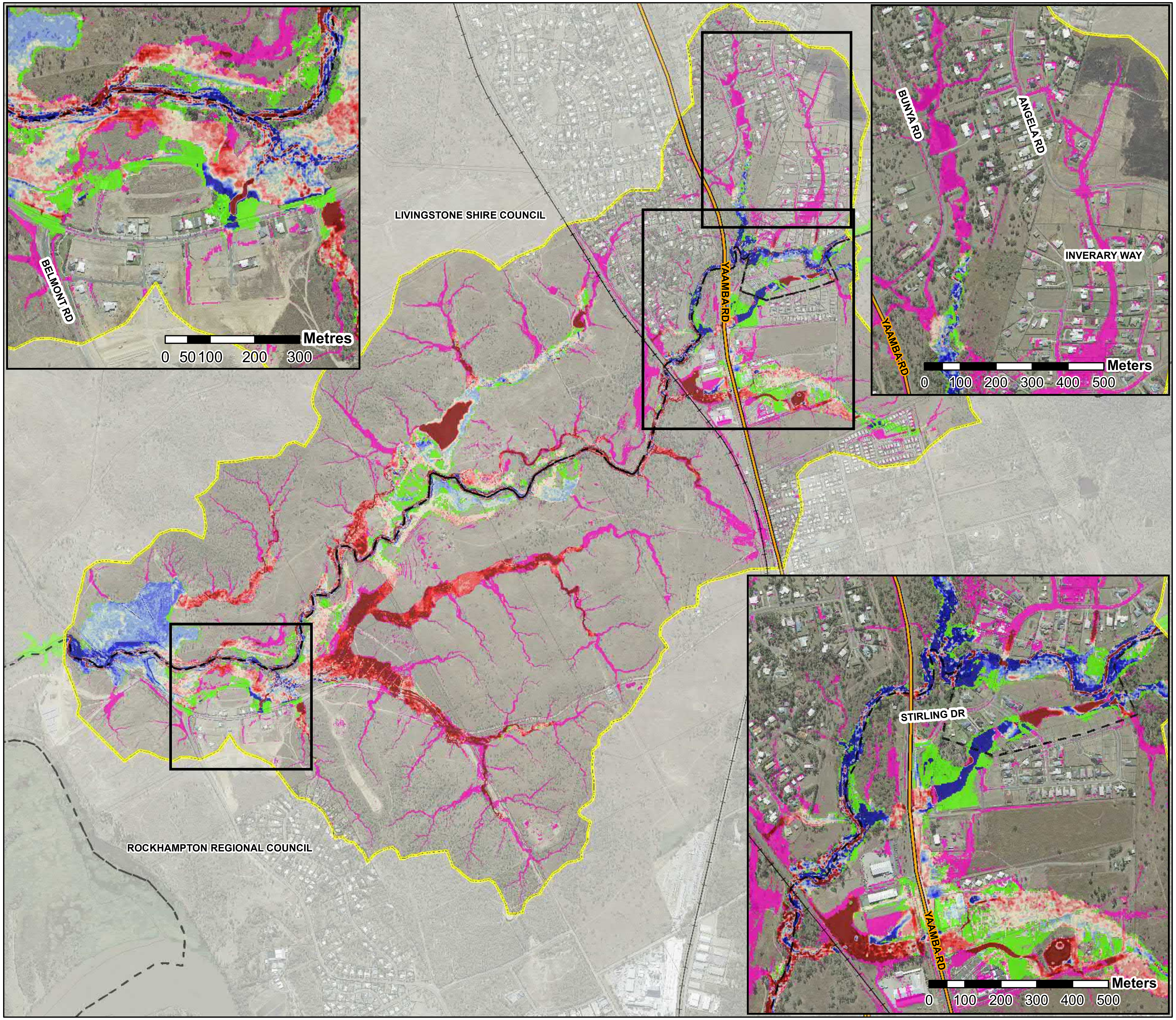
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

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

1% AEP 090min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 16



N

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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- Local Government Boundary

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

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

1% AEP 090min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 17

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

8.0 Sensitivity Analysis

8.1 Overview

A number of sensitivity analyses have been completed as part of the study which included:

- 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.

8.2 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 RC-56**
- 15% Decrease in Roughness → **Map RC-57**

Map RC-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. In the steep areas of the Ramsay creek catchment, the roughness parameters have minimal influence, as is to be expected due to the slope controlling the flow behaviours. The most significantly impacted areas are that of the creek channel and neighbouring floodplain areas, with increases of peak flood heights by up to 0.2m.

The result from the sensitivity analysis which applies a 15% decrease in manning's roughness values are shown in **Map RC-57**. The decrease in roughness indicates a combination of increases and decreases in peak flood elevations. In the areas where storages or very flat land exists the decreased roughness increased the peak flood elevations by up to 0.075 m. In contrast the steeper and deeper sections of the Creek and overland flow paths the peak flood heights reduced by up to 0.15 m.

8.3 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 Ramsay 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 RC-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 0.3m and 0.75m. Results indicate that for smaller tributaries of the creek system, peak flood heights will increase between 0.15m and 0.225m.

8.4 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 (8.4 mAHD) to coincide with a 1% AEP design storm event in the Ramsay Creek catchment. The Fitzroy River flood height of 8.4 mAHD has been determined based upon results from RRC's Fitzroy River model (refer to 3.2.4).

As can be seen from **Map RC-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 1.2m. The variation in peak water surface elevation across the rest of the catchment is negligible.

8.5 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 8.7).

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 RC-60**
- 50% Increase in Roughness → **Map RC-61**
- 100% Increase in Roughness → **Map RC-62**

8.5.1 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 **RC-60** indicate that across the entirety 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.

8.5.2 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 the corner of Condra Lena Drive and Price Drive with the downstream areas predicted to experience reduced flood levels as a consequence of the upstream culvert capacity being reduced.

8.5.3 100% 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 RC-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 Edenbrook Drive, Florida Crescent, Emmerson Drive as well as the corner of Condra Lena Drive and Price Drive.

8.6 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 **RC-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.

8.7 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.

8.7.1 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.

8.7.2 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).

8.7.2.1 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.

8.7.2.2 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.

8.7.2.3 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.

8.7.3 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.

8.7.3.1 Debris Availability

Table 11 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 Ramsay Creek has been selected as source areas generally falling between the High and Low categories.

8.7.3.2 Debris Mobility

Table 12 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 Ramsay Creek has been selected as source areas generally falling between the High and Low categories.

8.7.3.3 Debris Transportability

Table 13 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 Ramsay 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.

8.7.3.4 Debris Potential

Table 14 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 Ramsay Creek has been selected as the combination of individual factors is MMH.

8.7.3.5 AEP Adjusted Debris Potential

Table 15 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 Ramsay Creek has been selected as the Event AEP assessed is 18%.

8.7.3.6 Design Blockage Level

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

Table 16 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 19.

8.7.3.7 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 17 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 19.

Table 18 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 19.

Table 19 Ramsay 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
3/3000x2100mm RCBC	$L_{10} < W < 3*L_{10}$	Low	0%	2.0	M	15%	15%
3/1350mm RCP	$W < L_{10}$	Low	25%	2.1	M	15%	25%
2/1650mm RCP	$L_{10} < W < 3*L_{10}$	Low	0%	2.1	M	15%	15%
5/2100x1500mm RCBC	$L_{10} < W < 3*L_{10}$	Low	0%	2.7	M	15%	15%
2/900x900mm RCBC	$W < L_{10}$	Low	25%	1.8	M	15%	25%
2/900x900mm RCBC	$W < L_{10}$	Low	25%	4.8	L	0%	25%
4/3000x2700mm RCBC	$L_{10} < W < 3*L_{10}$	Low	0%	2.1	M	15%	15%

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 Ramsay Creek is 25%.**

8.7.4 Results of Sensitivity Analysis

The results which are presented on **Map RC-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 South of Stirling Drive under Yaamba Road – up to 90 mm increase in peak flood height.
- Culvert under Argyle Avenue – up to 110mm increase in peak flood height.
- Culvert under Stirling Drive between Inverary Way intersections – up to 270mm increase in peak flood height.
- Culvert under Inverary Way – up to 40mm increase in peak flood height.
- Culvert under Edenbrook Drive – up to 90mm increase in peak flood height.
- Culvert under Stirling Drive – up to 60mm increase in peak flood height.

8.8 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 20, 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 0.3m and 0.75m as previously discussed in section 8.3.

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, although this is not expected to impact existing buildings.

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 Ramsay 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 20 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 Ramsay Creek catchment.

Table 20 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%	0.2%
-0.02 to 0.02	45.0%	59.4%	2.7%	99.9%	99.7%	98.5%	88.1%	99.6%	99.3%
0.02 to 0.074	33.5%	13.9%	16.1%	0.1%	0.0%	0.5%	0.5%	0.0%	0.4%
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%

9.0 Conclusion

9.1 Key Findings

The Ramsay Creek Phase 1 Baseline Flood Study included the development of a TUFLOW model for the lower portion of the Ramsay 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.

Data for the catchment was sourced and utilised during this process, although the absence of anecdotal and recorded data meant the model was unable to be calibrated and validated to historical flood events. In order to maintain consistency across North Rockhampton local catchment models, rainfall losses and roughness parameters from other calibrated models were adopted until 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 90 minute event. A comparison of the design events found that for events up until the 39% 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 properties north of Stirling Drive and commercial parcels fronting Yaamba Road. The critical controls within the catchment are the open channel drains between developed parcels and cross-drainage structures beneath major road and rail corridors.

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 flood event data becomes available. Updates to the model should also be undertaken once the RNAU project is completed by the Department of Transport and Main Roads (currently planned for 2018).

10.0 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.

Institution of Engineers Australia (1998), Australian Rainfall and Runoff – A Guide to Flood Estimation, Volumes 1 and 2.

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

Maritime Safety Queensland (2014) QLD Tide Tables book.

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

Rockhampton Regional Council (2014), Ramsay Creek Hydrologic and Hydraulic Modelling Report, prepared by Aurecon, 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 1.5 second. The corresponding 1D time step has been set at 0.75 seconds. These time steps represent an appropriate time step 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 0.0002 m 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. All pits have been represented using assumed dimensions of 900 mm by 600 mm. Pit inlet elevations have been adopted using surveyed levels where possible and corresponding LiDAR levels where data gaps exist.

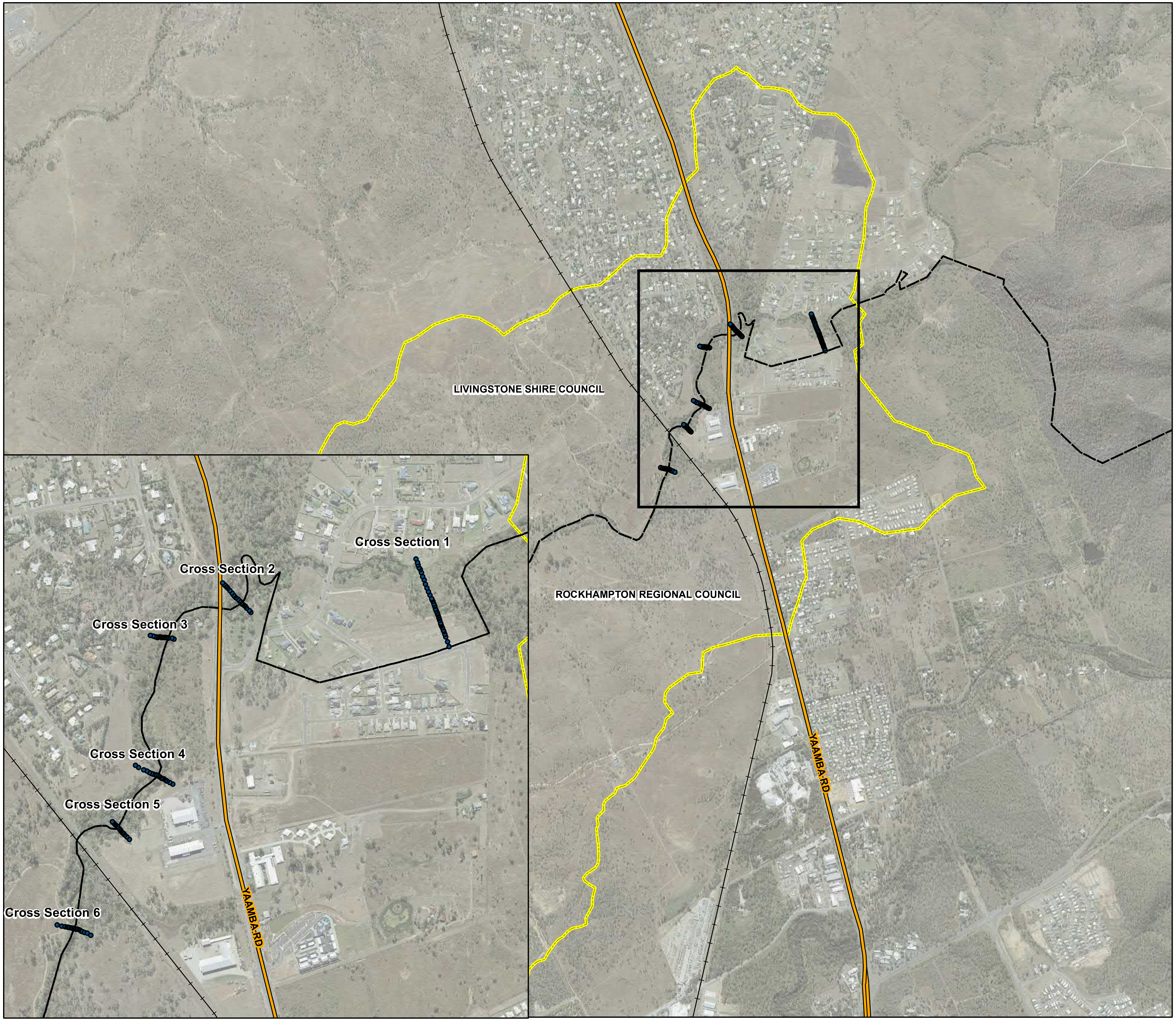
All culverts were represented as dynamically linked 1D elements, with major sets of closely situated culverts being digitized using multi-cell links (CN-SX lines). Culvert roughness was set as 0.015 for RCPs and RCBCs.

Bridge Structure Losses

Bridges were digitised as 2D layered flow constrictions. Standard form loss coefficients were calibrated using HEC-RAS models. Losses in the TUFLOW model were increased based on the velocity head 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 1 m resolution Digital Elevation Model (DEM). Within reference to Figure 18, a number of surveyed cross sections have been obtained and incorporated into the model.



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)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Local_Government_Boundary
- Cross Section Survey Points

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

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

Ramsay Creek Model

Cross Section Survey Point Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/06/2017
VERSION:	1

Figure 18

Surveyed cross-sections through areas of dense vegetation compared to the LiDAR elevations and incorporated into the model using 2d_zsh layers to lower the vegetated areas (visible in the imagery) by the calculated discrepancies. Cross-sections across areas of combined scour and dense vegetation were digitized within the model through tinning the surveyed cross-section back to LiDAR elevations upstream and downstream of the surveyed cross-section. Examples instances of the ‘before and after’ creek channels are presented below in Figure 19.

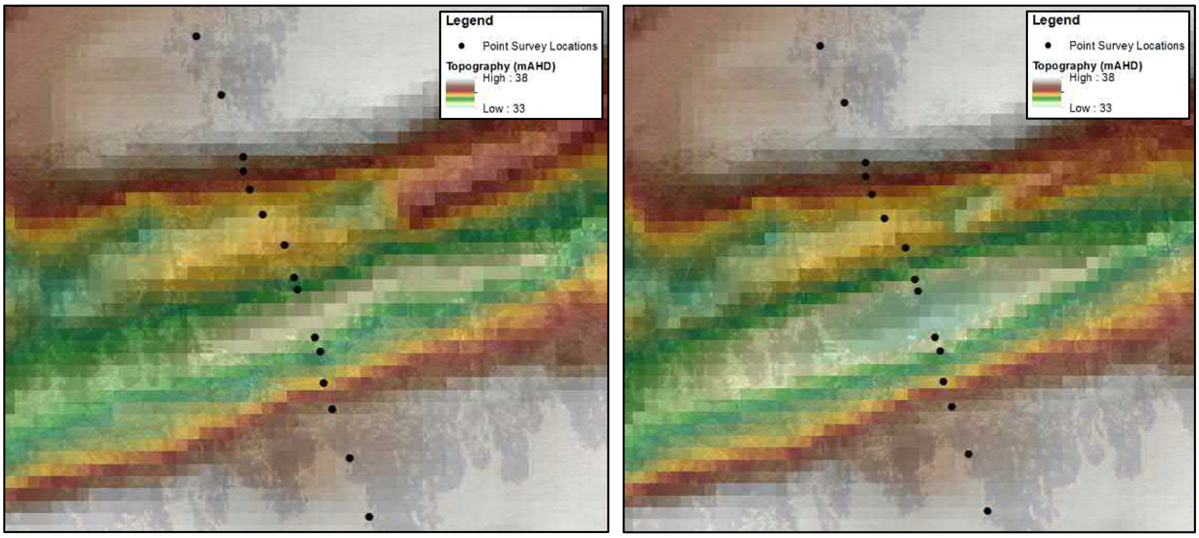


Figure 19 Model Topography using LiDAR (left) versus Model Topography using LiDAR + Survey (right)

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 21.

Table 21 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
Commercial/Industrial	0.1	0.03	0.3	0.06
Dense Vegetation	0.1	0.1	0.3	0.06
Medium Vegetation	0.1	0.075	0.3	0.05

Material Description	Manning's 'n'			
	Depth 1 (m)	Manning's 'n' 1	Depth 2 (m)	Manning's 'n' 2
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	0.1	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

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 22.

Table 22 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
Commercial/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

Material Description	Initial Loss (mm)	Continuing Loss (mm/h)
Rail Reserve	15	1
Fitzroy River Bed (at DS boundary)	0	0
Long Grass	0	0
Buildings	0	0

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 Ramsay Creek Local Catchment model. The types of boundaries are as follows:

- Direct rainfall.
- Time-varying discharge (QT) inflow boundaries for external catchments.
- Height versus flow (HQ) 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 23.

Table 23 Summary of Boundary Conditions

Boundary Type	Details
Direct rainfall	Applied across entire 2D domain
QT	Inflows for the external catchments (northeast boundary)
HT	Fitzroy River outflow boundary (western boundary)

Appendix B

Surveyed Cross-section Comparison

Appendix B Surveyed Cross-section Comparison

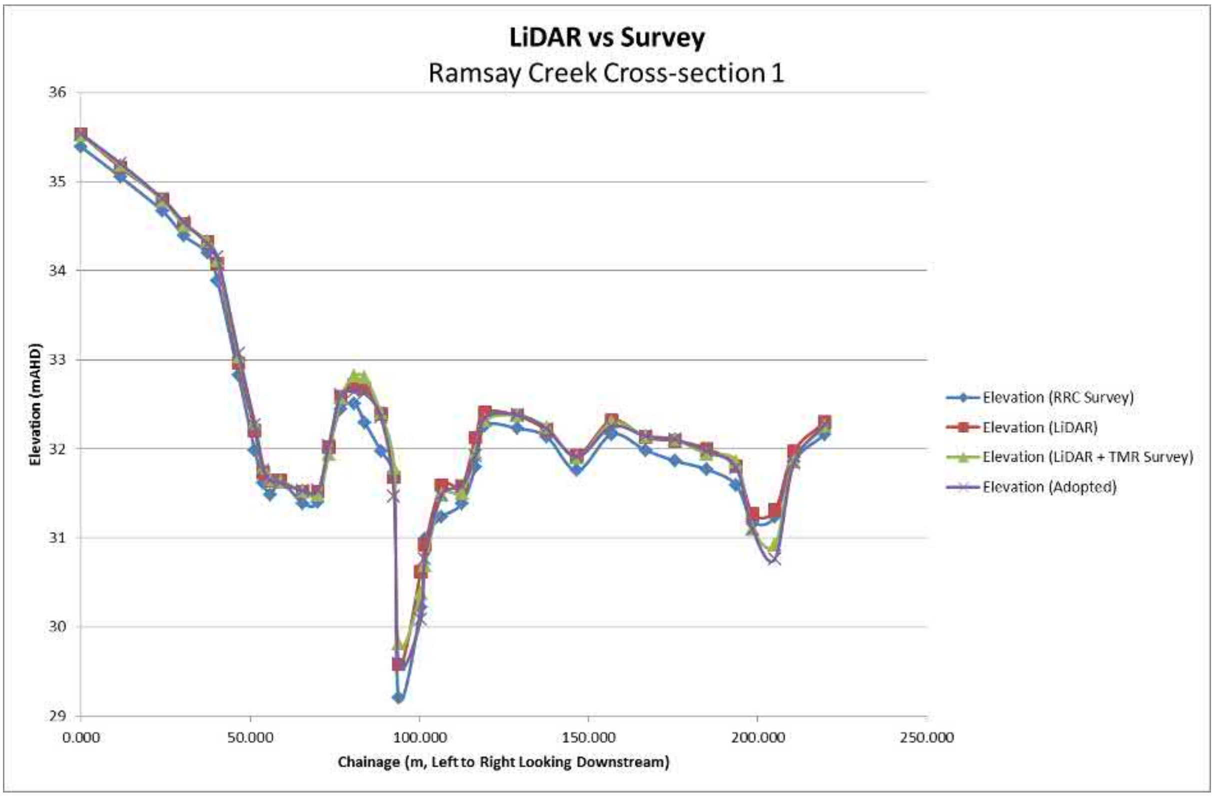


Figure 20 LiDAR verses Survey comparison at Cross-section 1

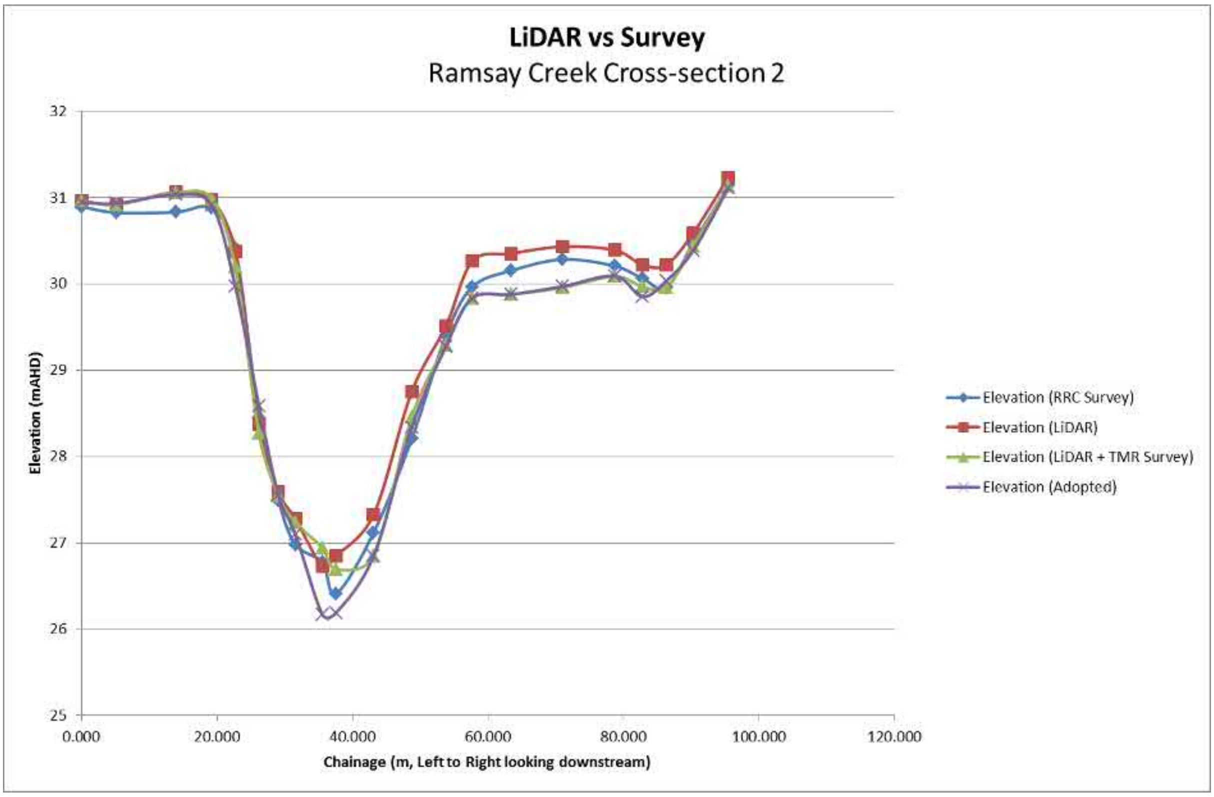


Figure 21 LiDAR verses Survey comparison at Cross-section 2

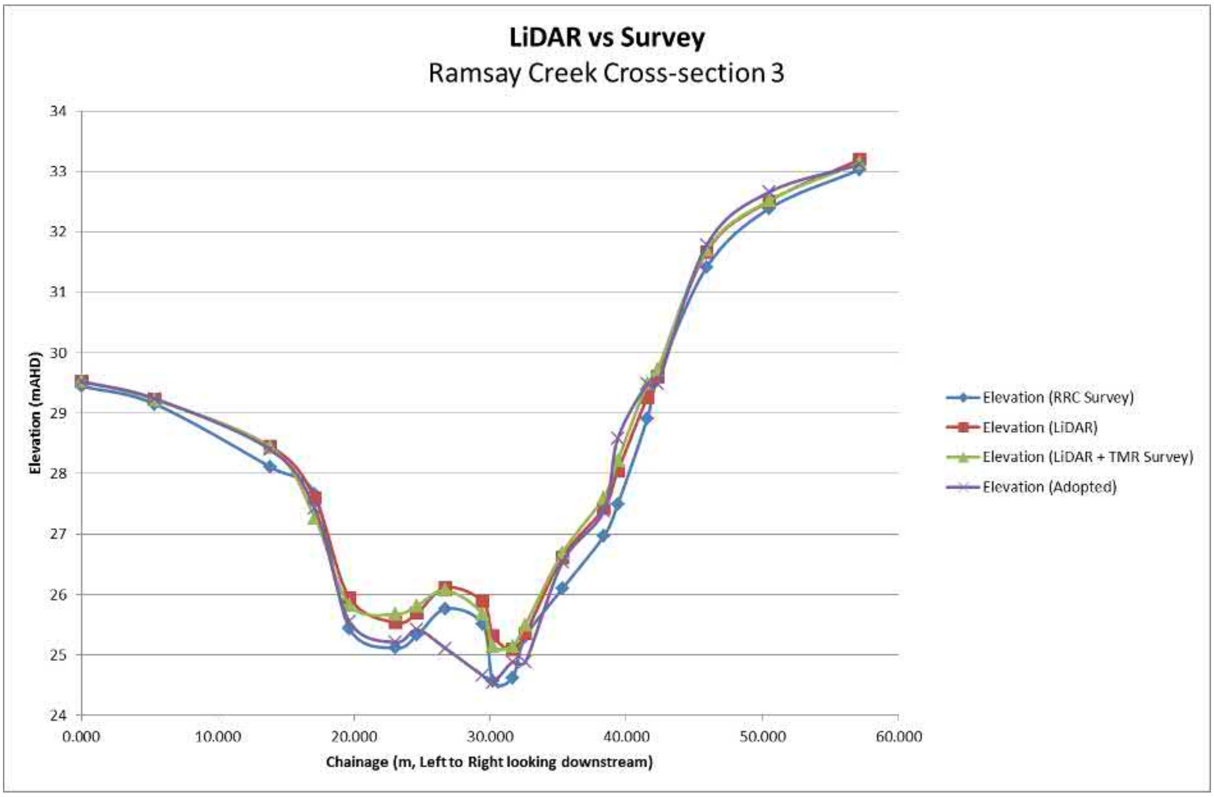


Figure 22 LiDAR verses Survey comparison at Cross-section 3

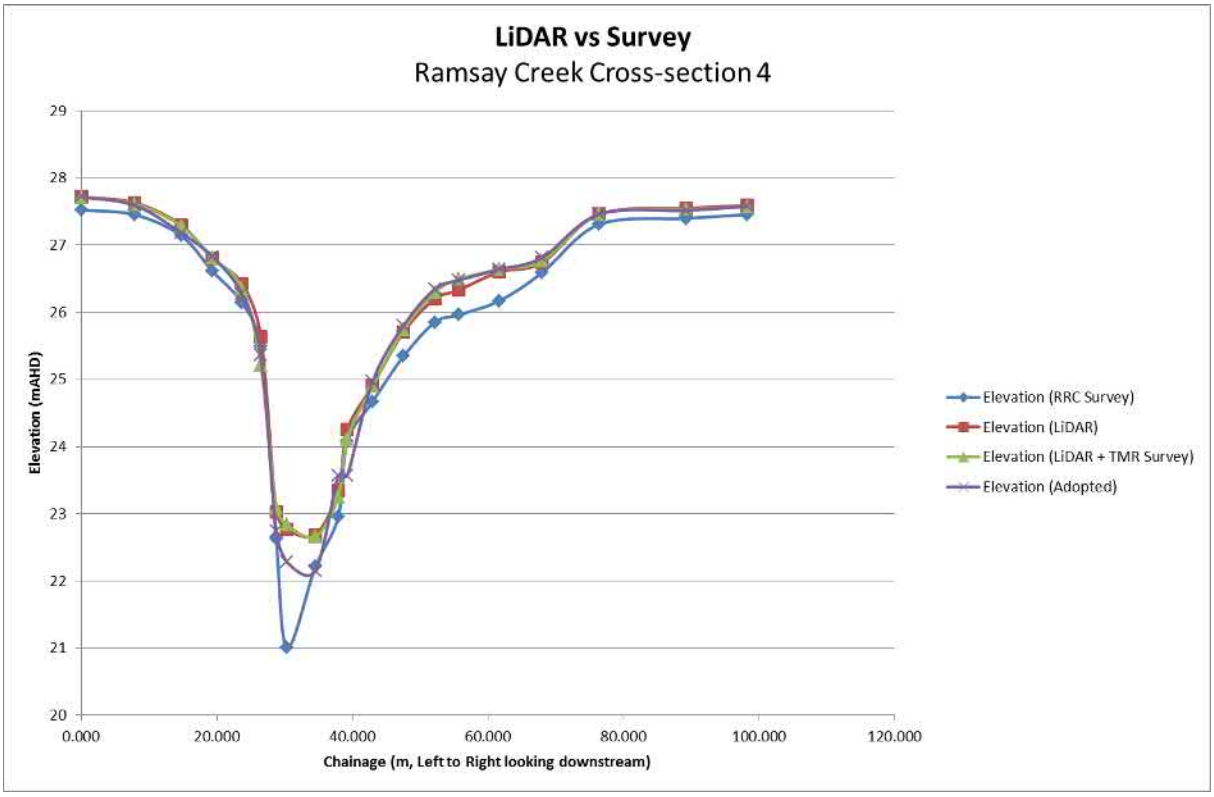


Figure 23 LiDAR verses Survey comparison at Cross-section 4

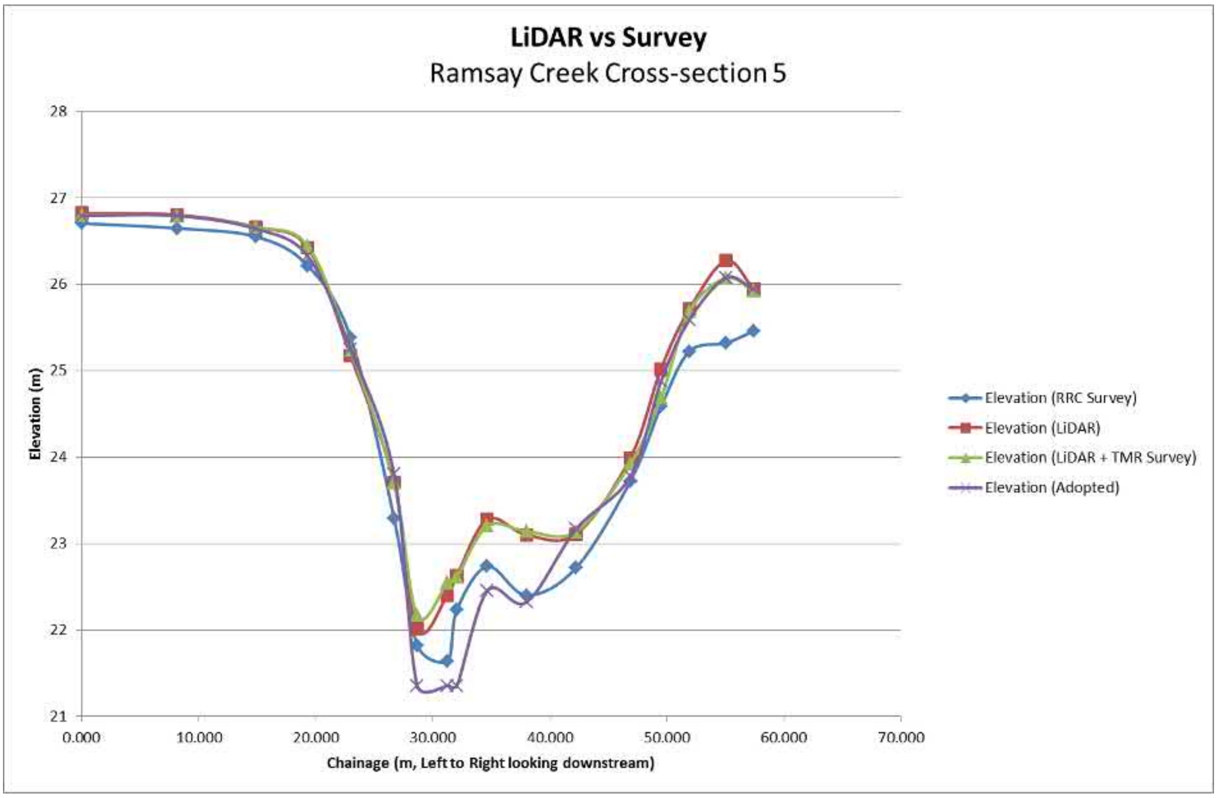


Figure 24 LiDAR verses Survey comparison at Cross-section 5

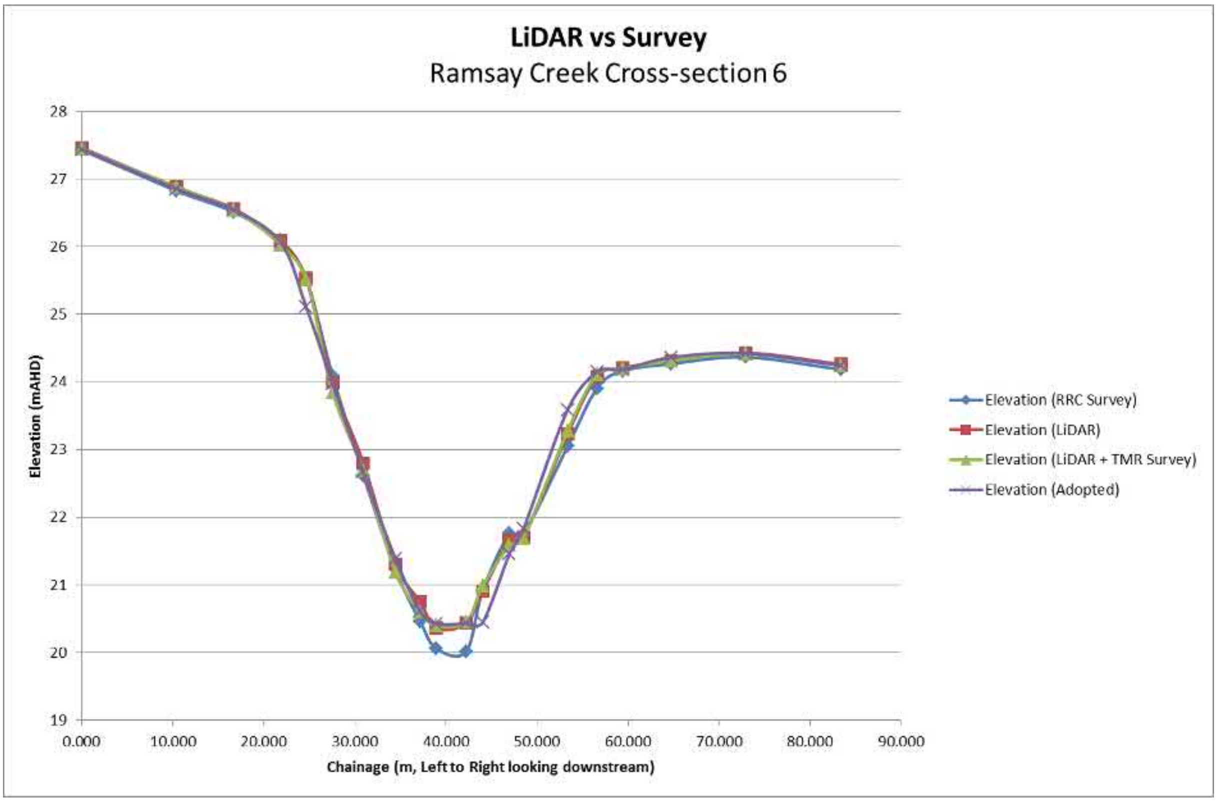


Figure 25 LiDAR verses Survey comparison at Cross-section 6