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Rockhampton Regional Council
13-Oct-2017
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South Rockhampton Local Catchment Study

Baseline Flooding and Hazard Assessment - Volume 1

Rockhampton Regional Council

Queensland Government

South Rockhampton Local Catchment Study

Baseline Flooding and Hazard Assessment - Volume 1

The South Rockhampton Local Catchment Study was jointly funded with the Department of Local Government, Racing and Multicultural Affairs through the Natural Disaster Resilience Program. The joint project aimed to enhance understanding of localised flood behaviour, along with options for management of the local flood impacts for improved flood resilience in South Rockhampton.

Client: Rockhampton Regional Council

ABN: 59 923 523 766

Prepared by

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

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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

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 South Rockhampton Local Catchment Study, which is the subject of this report.

Flooding in South Rockhampton can occur as a result of two different flood mechanisms:

- Riverine flooding due to rainfall over the Fitzroy River catchment.
- Flash flooding due to rainfall over the local urban catchment.

This study focuses on flash flooding due to rainfall over the local urban catchment.

The key objectives of this study are:

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

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

Catchment Characteristics

The South Rockhampton urban catchment covers approximately 10.8 km^2 within the suburbs of The Range, Rockhampton City, Allenstown, Depot Hill and Port Curtis. The western catchment boundary follows the crest of the Range, which is roughly aligned to Agnes Street. Elevations along this ridgeline reach up to 65mAHD with moderate slopes (5% - 10%) directing stormwater runoff east through the City towards the primary drainage path, known locally as the 'Main Drain'. For the purposes of this report the Main Drain upstream of the North Coast Rail Line is referred to as Upper Main Drain, with the area downstream of the North Coast Rail Line referred to as Lower Main Drain.

The catchments within the Rockhampton City (adjacent to the Upper Main Drain) discharge towards the Fitzroy River, with runoff south of this catchment draining to both the Lower Main Drain (via overland flow paths) and the Fitzroy River (via an underground drainage system). These catchments have flat slopes in comparison to the upper reaches of the catchment.

The lower catchment south of the rail and main drain has little natural grade with the majority being below 6 mAHD. This wetland area is known as the Fiddes Street Lagoon area and commonly retains water during the wet season. Most of the lagoon area drains to the south-east via cross-drainage under Fiddes Street towards Gavial Creek, which outlets to the Fitzroy River.

Hydrologic / Hydraulic Analysis

The South Rockhampton Phase 1 Baseline Flood Study included the development of a TUFLOW model for the urban South Rockhampton catchment. This model utilises a direct rainfall approach to modelling to determine the overland flow paths and establish baseline flood extents and depths within the study area.

Anecdotal and recorded data for the catchment was used to calibrate and verify the TUFLOW model. The model was calibrated to a local flood event caused by TC Marcia in February 2015 and verified to two other local flood events, namely Ex-TC Debbie in March 2017 and Ex-TC Oswald in January 2013. The model calibrated very well to the 2015 event and was verified by the 2017 event. The verification of the 2013 event was not as successful due to some variances in rainfall data and blockage of some critical drainage structures.

On completion of the calibration, various design events and durations were run and results extracted. The critical duration for the catchment was determined to be the 120 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 any properties surrounding the Upper Main Drain area. The critical controls within the catchment are the cross drainage structures which move water from one side of the railway to the other.

The modelling has confirmed that there are a number of key hydraulic controls within the catchment – particularly the Main Drain, Rail Embankment and Lower Dawson Road.

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

Baseline Flood Hazard and Vulnerability Assessment

Following completion of baseline model development, design event modelling and sensitivity analyses; a flood hazard and vulnerability assessment was completed for the South Rockhampton urban catchment. This included:

- Flood hazard analysis.
- Vulnerability assessment of key infrastructure.
- Evacuation route analysis.
- Building inundation and impact assessment.
- Flood Damages Assessment (FDA).

Each of these aspects has been discussed in further detail below.

Flood Hazard

Flood hazard categorisation provides a better understanding of the variation of flood behaviour and hazard across the floodplain and between different events. The degree of hazard varies across a floodplain in response to the following factors:

- Flow depth.
- Flow velocity.
- Rate of flood level rise (including warning times).
- Duration of inundation.

Identifying hazards associated with flood water depth and velocity help focus management efforts on minimizing the risk to life and property. As such, a series of Flood Hazard Zones have been developed according to ARR 2016, in alignment with recommendations made in the ARR, Data Management and Policy Review (AECOM, 2017).

Figure E1 shows the ARR 2016 flood hazard classification limits, which are the adopted hazard categories for this project, along with a general description of the risk associated with each category.

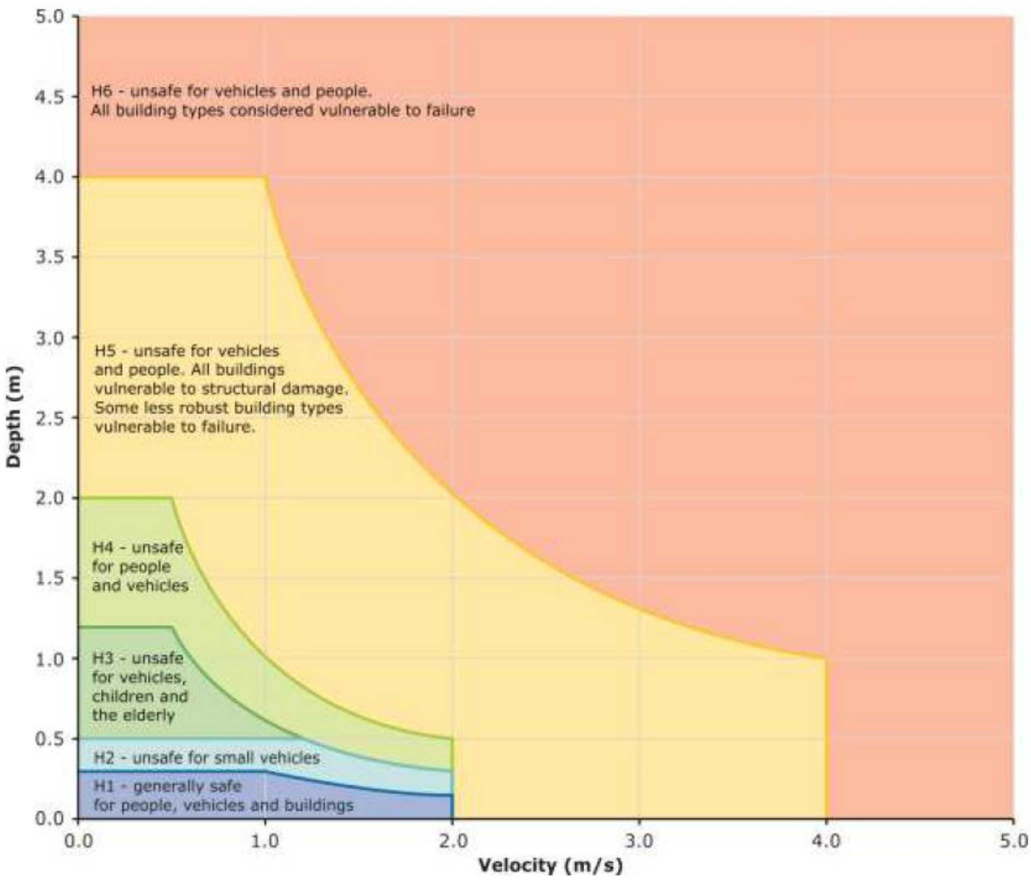

Figure E1 Hazard Vulnerability Classifications (Graphical)

Analysis of the 1% AEP baseline flood hazard within the South Rockhampton urban catchment generally shows:

- Low to medium hazard (H1 and H2) across the majority of urbanised areas west of Gladstone Road and within the CBD and urbanised Depot Hill areas.
- High hazard (H3 and H4) within the Upper Main Drain, Lower Main Drain, Fiddes Street wetland, Stanley Street / Talford Street west of Gladstone Road, Saleyards Park, Kettle Park and O'Shanesy Park areas.
- Extreme hazard (H5) within portions of the Upper Main Drain, Lower Main Drain, Kettle Park, O'Shanesy Park and the South Rockhampton Cemetery (main channel flow path only).

Vulnerability Assessment

A baseline vulnerability assessment has been undertaken to identify critical infrastructure and community assets which are at risk of flooding. The following categories have been included in this assessment:

- Water and sewerage infrastructure.
- Emergency services facilities including ambulance, police, fire and hospitals.
- Community infrastructure including schools, day-care centres, nursing homes, retirement villages and community facilities.
- Key road and rail assets.

The following provides a summary of key findings of the vulnerability assessment:

- The Fitzroy Street Sewage Pump Station (SPS, Ref: 463755), Arthur Street SPS (Ref: 463754), Lower Dawson Road SPS (Ref: Caravan Park) and Ferguson Street SPS (Ref: 463756) are predicted to have less than 0.2% AEP flood immunity. It is noted however that some of these pump stations are below ground and improvements to flood immunity would be very difficult to achieve. It is recommended this information be passed onto FRW as the asset owner.
- Low depth flooding is predicted at TAFE Rockhampton, Blue Care Homes and Allies Early Learning Centre in the 0.2% AEP event.
- Frequent flooding is predicted at Rockhampton Fire Station, Rockhampton Ambulance Centre, The Cathedral College and Allenstown State School.
- The North Coast Rail Line is predicted to experience frequent flooding to Top of Ballast level, within the city reaches, with some areas predicted to be inundated during the 1EY local catchment event.
- A number of road segments are predicted to experience inundation in the 1EY event and larger. Estimated Time of Submergence ranges from 2.0 hours to approximately 5.5 hours in the 1% AEP event.

Evacuation Routes

Generally local catchment flooding within the South Rockhampton catchment is due to short duration, high intensity rainfall events. The relatively steep upper catchment and urbanisation throughout much of the upper, middle and lower catchment can result in inundation of residential and commercial buildings. In addition, inadequate stormwater infrastructure in some locations results in nuisance flooding within the urbanised catchment due to overland runoff.

Due to the short critical duration of the South Rockhampton catchment, the warning time between the commencement of the rain event and subsequent flood inundation can be short. This limits the opportunity for evacuation, and generally the action taken by the community is to '*shelter in place*' until the flooding has passed.

An assessment of evacuation routes has therefore focussed on areas that become isolated during flooding, as well as high hazard areas that may require flood free evacuation access.

The following areas have been assessed as being isolated and/or lack adequate evacuation routes during the PMF event:

- Depot Hill Area à Bounded by Arthur Street to the north, West Street to the west, Lucius Street to the south and Denison Street to the east.
- Area bounded by Stanley Street, Bolsover Street, O'Connell Street and Quay Street.
- Area bounded by Cambridge Street, Murray Street, Denham Street and Denison Street.

Building Impact Assessment

Council provided a building database containing ~28,000 digitised buildings focussed on Creek flooding extents in North Rockhampton and Fitzroy River flood extents in South Rockhampton. Of these, ~5,900 buildings contained surveyed data.

In order to complete a Building Impact Assessment and FDA, a complete building database with floor levels, classifications and ground levels is needed within the modelled area. To achieve this, the following tasks were completed:

- Review of the digitised buildings, to remove erroneous data such as *footpaths*, *building demolished*, *no building* etc.
- Estimation of ~5,600 floor levels and ground levels within the South Rockhampton modelled area, for buildings outside Council's surveyed database.
- Classification of ~7,040 buildings within the South Rockhampton modelled area, in accordance with ANUFLOOD requirements.

The ground level at each building was estimated from aerial survey (LiDAR) provided for the project. Ground levels were assigned to the building footprints based on the average LiDAR elevation within the building extents.

Buildings lacking data regarding number of storeys were assumed to be one storey. Buildings on slabs were assumed to have a minimum habitable floor level of 100mm above ground level. Low set buildings were assumed to have a minimum habitable floor level of 600mm above ground level and high set buildings were assumed to have a minimum habitable floor level of 1,800mm above ground level. Buildings lacking data regarding what type of floor they have were assumed to be on slabs.

Table E2 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the South Rockhampton urban catchment. These results are also shown graphically in Figure E2. Existing buildings which experience flood levels above ground level are noted and buildings inundated above floor level are shown in brackets beside.

Note that the indicated number of buildings is for entire buildings. Residential multi-unit buildings may contain multiple dwellings per building. Also, large commercial/industrial buildings may include multiple businesses.

Table E2 № of Buildings Impacted

AEP (%)	№ Residential Buildings	№ Commercial Buildings
	Flood level above property ground level (building inundated above floor level)	Flood level above property ground level (building inundated above floor level)
1EY	40 (7)	13 (10)
39.4	100 (18)	26 (17)
18.1	250 (40)	59 (35)
10	328 (56)	82 (51)
5	354 (66)	95 (60)
2	485 (100)	145 (97)
1	576 (124)	172 (123)
0.2	944 (244)	266 (198)
0.05	1184 (335)	330 (273)
-	1991 (713)	681 (580)

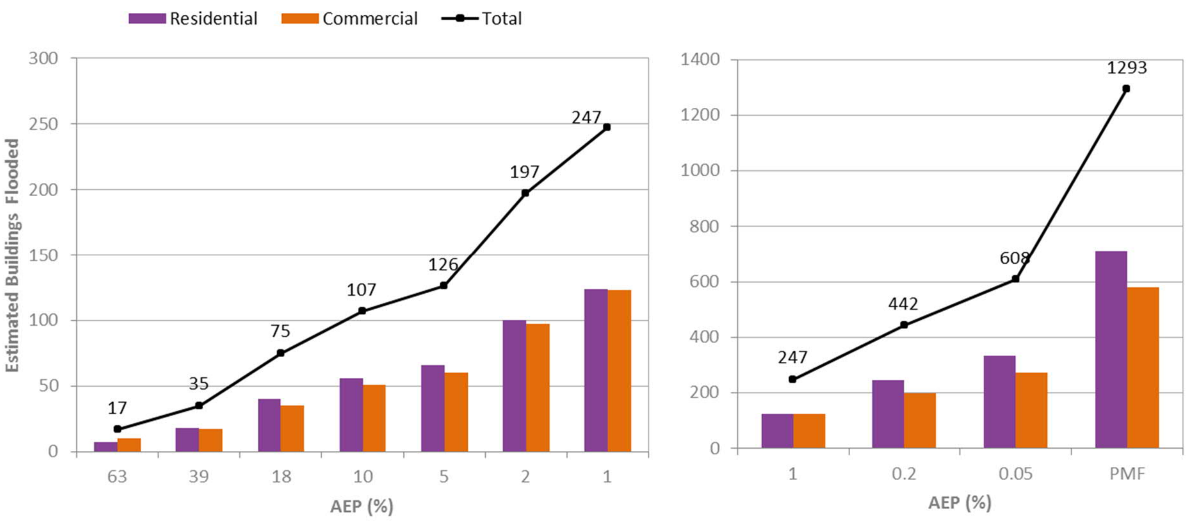

Figure E2 Estimated Buildings with Above Floor Flooding (Number of Buildings)

As shown in Figure E3, median flood depths are generally less than 0.2 metre for each flood event. This indicates that reductions in flood depths of 0.2 metre could significantly reduce overall damage. The figure also shows that a significant number of buildings experience flood depths of 0.2 metre or less during frequent events such as the 1EY flood event, generally corresponding to higher flood damages.

It is noted that where surveyed floor levels were not available, slab on ground buildings were assumed to have a floor level 0.1m above the existing ground level. This is consistent with other studies undertaken in the Rockhampton area, however may result in a higher estimate of inundated buildings and consequential flood damages due to the increased incidence of above floor flooding.

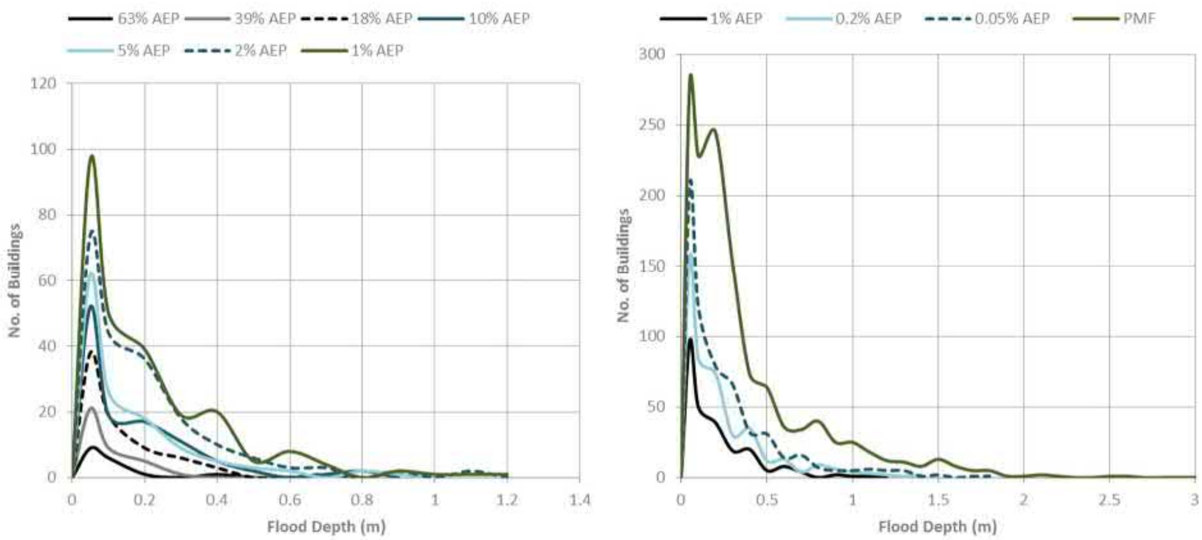

Figure E3 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

Flood Damages Assessment

Flood damages, or the anticipated cost to residents, businesses and infrastructure due to flooding, have been estimated using a standardised approach adopted throughout Australia. The approach estimates the tangible impacts flooding has on people, property, and infrastructure, such as flooding of a building and/or contents, the lost opportunity value associated with wages and revenue and flooding of transport and utility networks. These tangible impacts are estimated based on the depth, likelihood of flooding and type of building. Intangible impacts, such as emotional stress and inconvenience, were not quantified due to their non-tangible nature.

Figure E4 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from $805,000 (1EY flood event) to $128M (PMF event) using the O2 Environmental Damage Curves. Figure 34 shows that 17 buildings are expected to be inundated above floor in the 1EY event, whilst 1,293 buildings are anticipated to be inundated above floor in the PMF event.

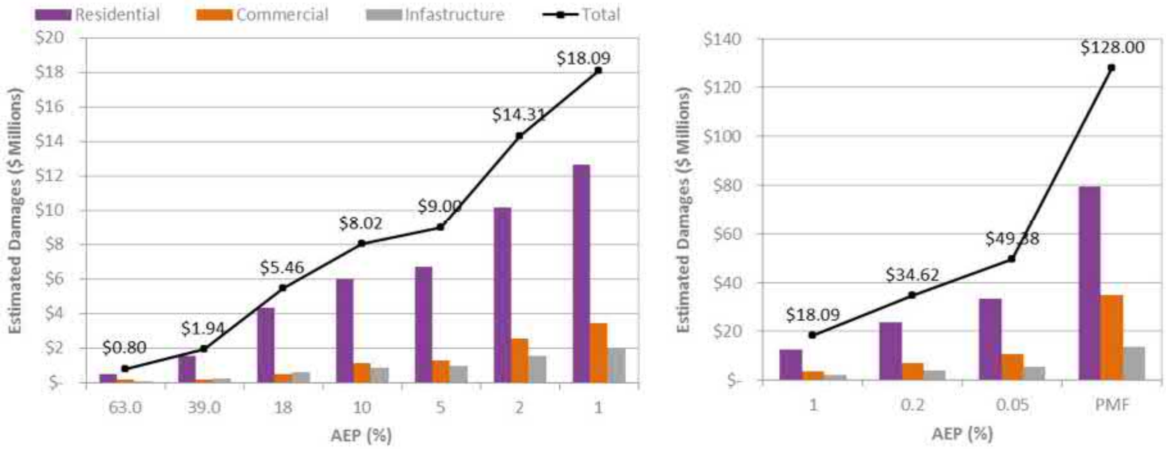

Figure E4 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

These figures also demonstrate that residential buildings make up the large majority of impacted buildings, and the estimated flood damages, within the South Rockhampton local catchment across the full range of design events assessed.

While the above provides an estimate of potential damages during specific flood events, understanding what damages may be expected on an annual basis is often an easier way to relate risk to residents and businesses. As such, the above damages were converted to Average Annual Damages (AAD) based on the likelihood of the flood event and the total estimated damage during that event.

The calculated AAD for the South Rockhampton urban catchment is estimated to range from approximately $2,847,000 to $2,916,000 per annum.

Figure E5 provides a breakdown of the AAD and building impact assessment. The area in blue corresponds to individual building AAD (residential and non-residential combined) in brackets of $100 per annum. The orange line corresponds to the cumulative AAD for residential and non-residential buildings combined. Note that this does not include infrastructure damages.

As shown, 79% of all buildings exhibit less than $500 damage per annum.

55% of damages are associated with less than 5% of all buildings. This demonstrates that a minority of buildings produce more than half of damages.

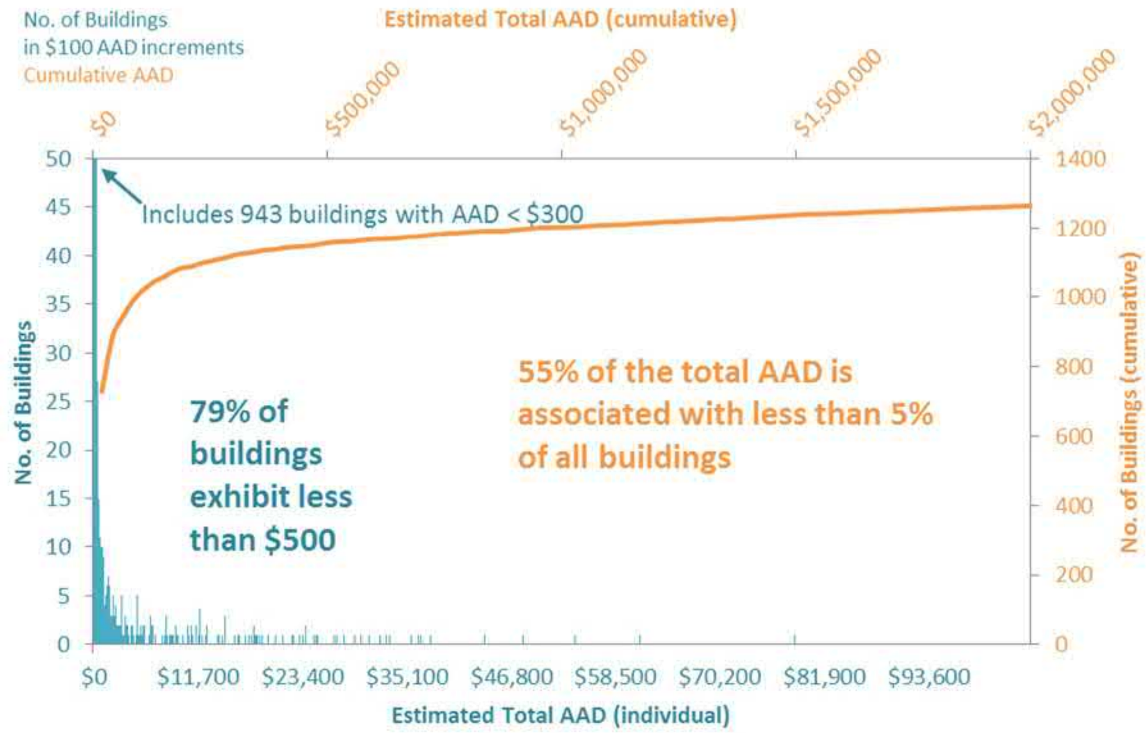

Figure E5 Individual Building vs. Cumulative Total Average Annual Damages

Rainfall Gauge, Maximum Flood Height Gauge and Flood Warning Network

Review of the existing rainfall gauge, maximum flood height gauge and flood warning network yielded the following recommendations/findings for the South Rockhampton catchment:

- Additional rain gauges should be installed at NRSTP and SRSTP.
- Additional maximum flood height gauges should be installed at:
  - Stanley Street / Talford Street corner, near Gladstone Road Seafoods;
  - West Street (north of Stanley Street), within the Upper Main Drain reserve; and
  - Elizabeth Street / Saleyards Street, adjacent the rail corridor.
- There is no current flood warning system within the South Rockhampton catchment.

Recommendations

A number of recommendations have been made in relation to this study:

- Baseline flood mapping (i.e. peak depths, velocities and water surface elevations) provided in this study should be used to update Council's current Planning Scheme layers, at the next available opportunity.
  - Final post-processing of the GIS flood layers is recommended in accordance with the procedures outlined in the ARR, Data Management and Policy Review (AECOM, 2017).
  - Appropriate freeboard provisions should be included, based on the findings of the sensitivity analyses outlined in this study. It is further recommended that Council apply additional freeboard (nominally 0.5 m) in the Lower Main Drain area (upstream of the rail line) for planning purposes.
- This report and associated outputs should be communicated to the community and relevant stakeholders when appropriate.

- Hydrologic and hydraulic modelling undertaken for this study has been based on methods and data outlined in Australian Rainfall and Runoff 1987. The 1987 revision has been adopted as per Council's request. It is recommended that future updates to this study incorporate the new 2016 updates.
- It is recommended that Council continue to undertake building floor level survey within the South Rockhampton catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained.
- It is recommended that Council continue to record rainfall and flood heights associated with future South Rockhampton catchment flood events. This data will support ongoing model calibration / validation works that should be undertaken in future updates to this study. The implementation of additional gauges identified in this study is also recommended.
- The assessment of flood behaviour within the South Rockhampton catchment has been the subject of previous technical investigations associated with the South Rockhampton Flood Levee project in 2014.
  - It is noted that the previous modelling used for the levee project has been updated and these results should be reviewed and adopted for the South Rockhampton Levee project moving forward. It may be necessary to make alterations to the current design to account for the latest modelling undertaken.
- The baseline vulnerability and flood hazard assessment outputs from this report should be used to support Phase 3 of the Study (Flood Mitigation Options Development and Assessment). Furthermore, the assessment of potential flood mitigation options should consider the implications to the South Rockhampton Flood Levee.

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 South Rockhampton Local Catchment Study, which is the subject of this report.

Flooding in South Rockhampton can occur as a result of two different flood mechanisms:

- Riverine flooding due to rainfall over the Fitzroy River catchment.
- Flash flooding due to rainfall over the local urban catchment.

This study focuses on flash flooding due to rainfall over the local urban catchment.

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

1.2 Phased Approach

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

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

This report covers the technical investigations and results from Phase 1 and 2 of the study. It is intended that this report informs and should be read in conjunction with the South Rockhampton Local Catchment Study – Mitigation Options Analysis report, which constitutes Phase 3 of this study.

1.3 Phase 1 and 2 Study Objectives

The key objectives of this study are:

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

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

1.4 Report Structure

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

· *Volume 1 à Study methodology, results, findings and recommendations (this report).*

· *Volume 2 à 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 hydraulic model.

· Section 6.0 presents the results of the calibration and verification events.

· 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 presents the flood hazard and risk assessment carried out within Phase 2.

· Section 10.0 and 11.0 summaries the conclusions and outlines recommendations.

· Section 11.0 presents the references used during the study.

1.5 Notes on Flood Frequency

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

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 duration.
- Aerial survey data (in the form of LiDAR) used to develop the topography for the hydraulic model has a vertical accuracy of $\pm$ 0.15 m on clear, hard surfaces and a horizontal accuracy of $\pm$ 0.45 m.
- Where information gaps existed in the underground drainage network, assumptions were made to fill these gaps using desktop assessment methods.
- Assessment of the probability of coincident local rainfall and Fitzroy River flood events has not been undertaken.
- The hydraulic model has been calibrated to a single historical event, being the local flood event which occurred as a result of TC Marcia in February 2015. The model has been validated to two other local flood events, namely Ex-TC Debbie in March 2017 and Ex-TC Oswald in January 2013.
- Hydrologic and hydraulic modelling is based on methods and data outlined in Australian Rainfall and Runoff (AR&R) 1987. The 1987 revision has been adopted as per Council's request. Refer to the ARR, Data Management and Policy Review (AECOM, 2017) for details surrounding changes recommended in the 2016 revision.
- Any use which a third party makes of this document, or any reliance on or decision to be made based on it, is the responsibility of such third parties. AECOM accepts no responsibility for damages, if any, suffered by any third party as a result of decisions or actions made based on this document.
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AR&R Revision Project 15 outlines several fundamental themes which are also particularly relevant:

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

2.0 Study Area Characteristics

2.1 General Description

The South Rockhampton urban catchment covers approximately 10.8 km^2 within the suburbs of The Range, Rockhampton City, Allenstown, Depot Hill and Port Curtis. The western catchment boundary follows the crest of the Range, which is roughly aligned to Agnes Street. Elevations along this ridgeline reach up to 65mAHD with moderate slopes (5% - 10%) directing stormwater runoff east through the City towards the primary drainage path, known locally as the 'Main Drain'. For the purposes of this report the Main Drain upstream of the North Coast Rail Line is referred to as Upper Main Drain, with the area downstream of the North Coast Rail Line referred to as Lower Main Drain.

The catchments within the Rockhampton City (adjacent to the Upper Main Drain) discharge towards the Fitzroy River, with runoff south of this catchment draining to both the Lower Main Drain (via overland flow paths) and the Fitzroy River (via an underground drainage system). These catchments have flat slopes in comparison to the upper reaches of the catchment.

The lower catchment south of the rail and main drain has little natural grade with the majority being below 6 mAHD. This wetland area is known as the Fiddes Street Lagoon area and commonly retains water during the wet season. Most of the lagoon area drains to the south-east via cross-drainage under Fiddes Street towards Gavial Creek, which outlets to the Fitzroy River.

Further discussion surrounding the existing flood behaviours during local catchment events are given in Sections 6.0 and 7.0. Figure 1 provides a visual representation of key flow patterns within the study area during local catchment events.

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0 200 400 600 800 1,000

Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Topography (mAHD)

- < 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 15
- 15 - 20
- 20 - 40
- > 40

Data Sources:

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

South Rockhampton Model

Sub-catchment Delineation and Natural Flow Paths

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	21/05/2018
VERSION:	A

Figure
1

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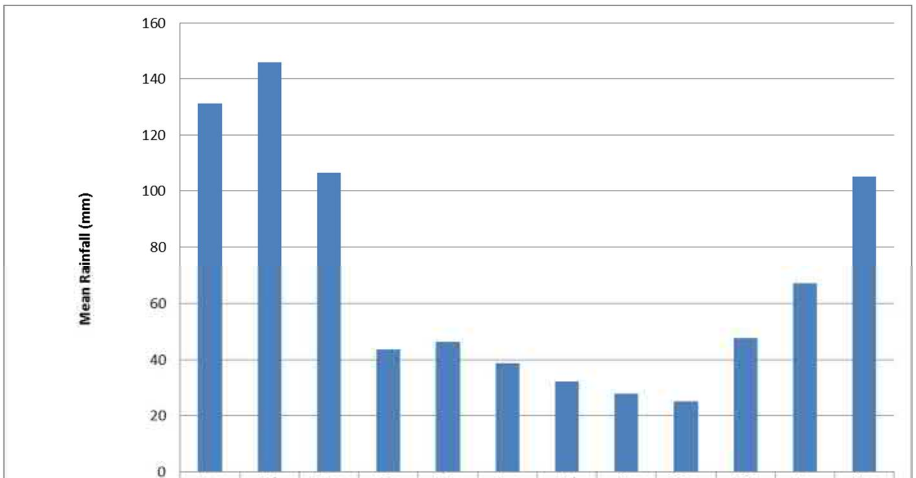
2.2 Climate Characteristics

The South Rockhampton local catchment is centred on latitude 23º 23’ 14.85” south, about 5.5km north of the Tropic of Capricorn. The catchment centroid is about 30km west 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.

2.3 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) respectively 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

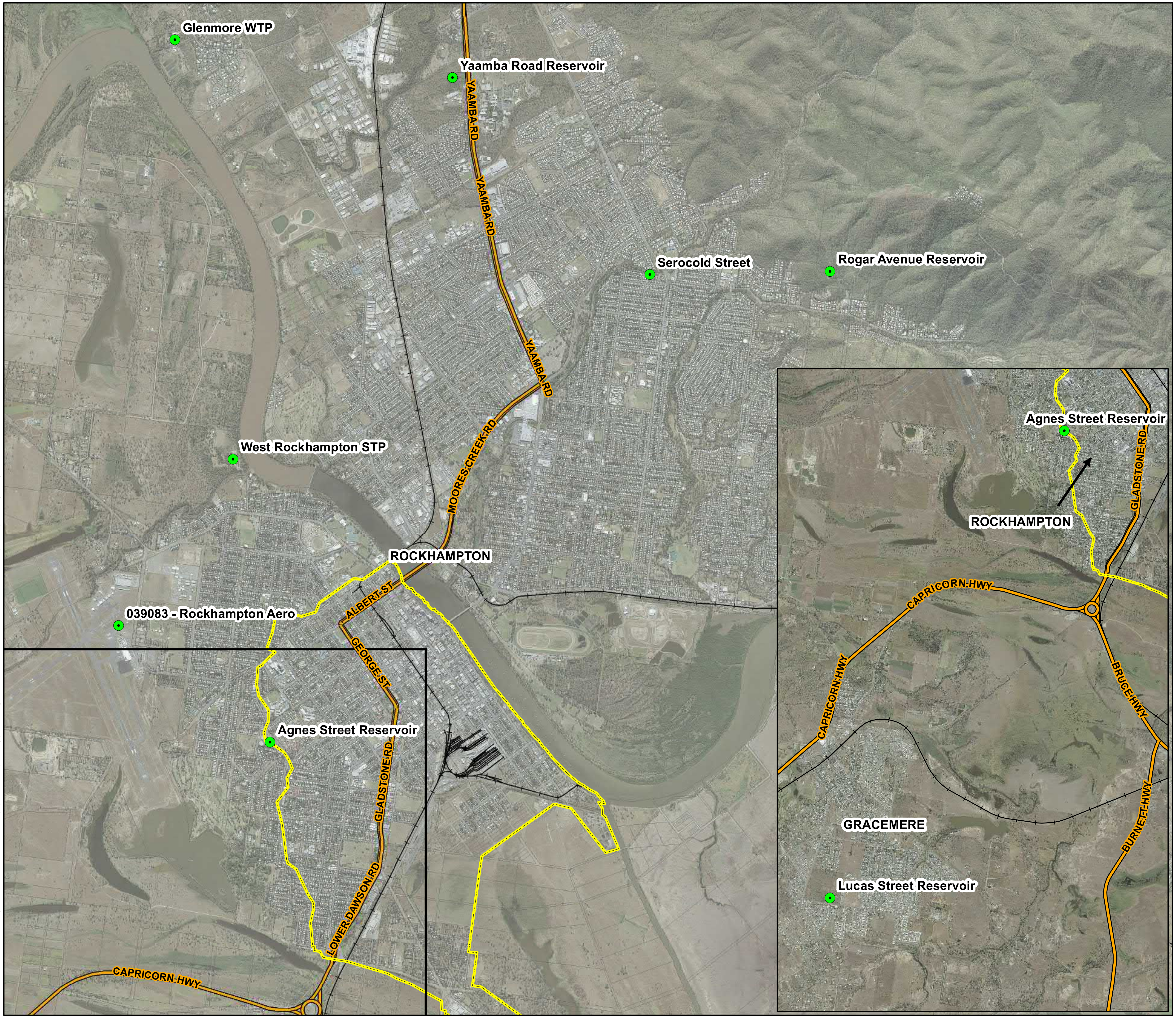
Figure 2 Mean Monthly Rainfall at the Rockhampton Airport Rainfall Station

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 was important in accurately verifying the validity of the hydrodynamic model.

It is noted that pluviographic data obtainable through the BoM website (www.bom.gov.au) is available for the Rockhampton Airport (Rockhampton Aero – Site Number 039083). RRC also maintains 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.



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Rockhampton Regional Council

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Metres

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LEGEND

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

Data Sources:

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

South Rockhampton Model

Rainfall Gauge Locations

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VERSION:	A

Figure 3

Of the abovementioned gauges, Agnes Street Reservoir bordering the western boundary of the study area, is likely to represent the best-estimate of historic rainfall events for the South Rockhampton Local Catchment model. As such, this gauge will be used to inform hydrologic inputs for historic events where available data permits.

Rainfall data comparison between the Agnes Street Reservoir and West Rockhampton STP (discussed in Section 4.2) provides a reasonable indication of the spatial variability of rainfall across the South Rockhampton urban catchment for historical calibration / verification events.

2.4 Historic Local Catchment Events

Significant local rainfall events leading to overland flooding of the South Rockhampton urban catchment often originate from tropical cyclonic activity and rapidly intensifying troughs. Notable incidents of such meteorological events occurring in recent times include the 2013, 2015 and 2017 events. Other significant events including the 1991 and 2008 events are noted to have caused flooding in South Rockhampton, although have not been assessed within this study. This is due to the lack of available data for the 1991 event and the 2008 event being previously simulated in the SRFL Interior Drainage project (AECOM, 2014).

This study included the simulation of 2013, 2015 and 2017 local catchment events, with the 2015 event serving as the calibration event. The 2017 and 2013 events have been used to verify the model performance.

2.5 Riverine Flooding Influence

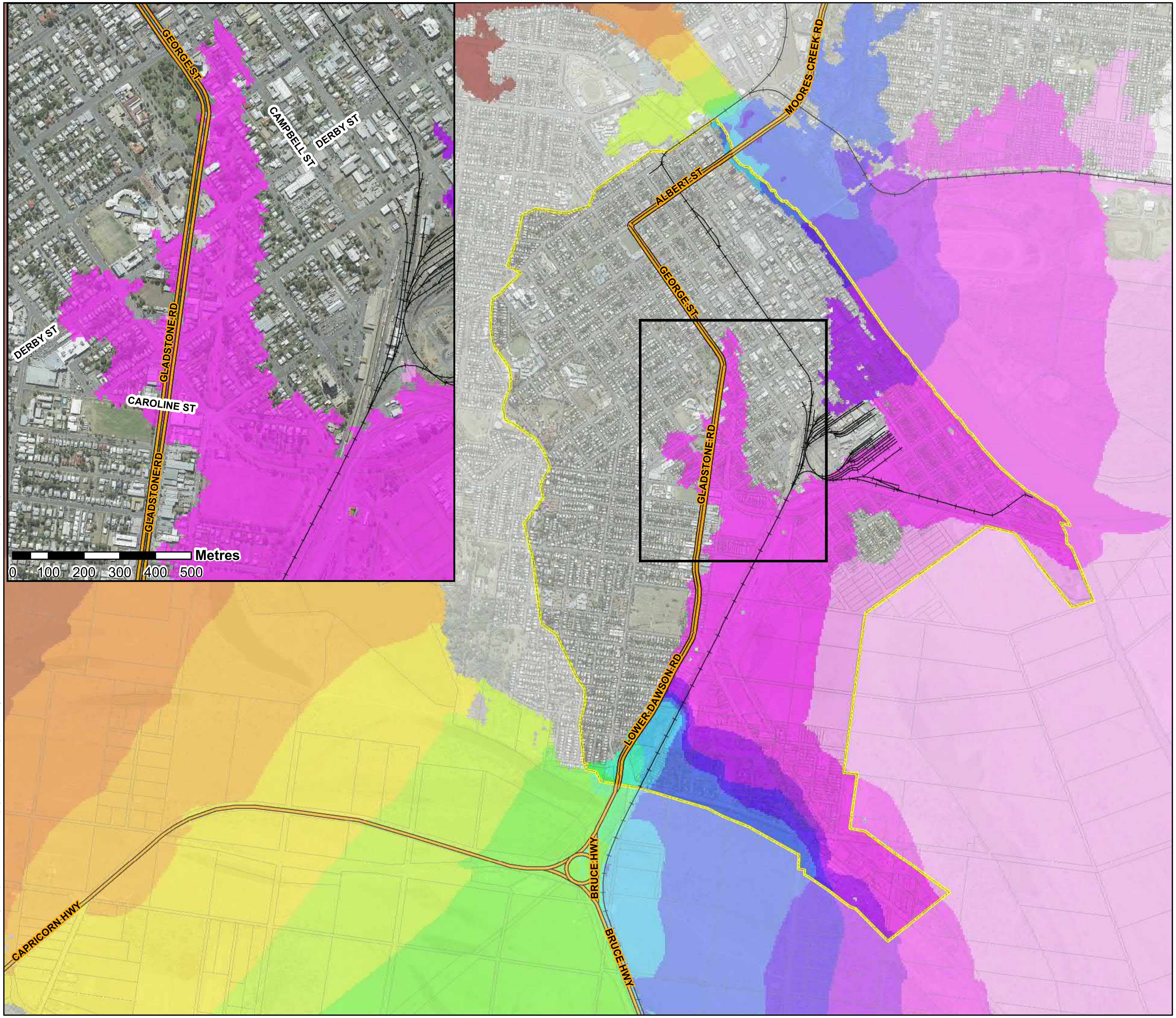
Riverine floods in Rockhampton can result from extended periods of rainfall within the 142,000km^2 Fitzroy River basin. As peak discharge increases along the Fitzroy River, a key breakout occurs upstream of Rockhampton at the Pink Lily meander. This can result in the inundation of large areas of Depot Hill, Port Curtis and Allenstown.

Figure 4 outlines the riverine flood heights for a 1% AEP flood event. It is evident that significant portions of the South Rockhampton catchment become inundated by riverine flood waters in a flood event of this magnitude. The lower portion of the Upper Main Drain becomes inundated with flood waters up to 8 mAHD.

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 a 18% AEP riverine event. The results form a component of the discussion made in Section 8.4.

2.6 Flood Warning System

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



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Rockhampton Regional Council

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0 200 400 600 800 1,000 1,200

Metres

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AECOM
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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Peak Riverine Flood Height (mAHD)

- < 7.7
- 7.71 - 7.85
- 7.86 - 8
- 8.01 - 8.15
- 8.16 - 8.3
- 8.31 - 8.45
- 8.46 - 8.6
- 8.61 - 8.75
- 8.76 - 8.9
- 8.91 - 9.05
- 9.06 - 9.2
- 9.21 - 9.35
- 9.36 - 9.5
- 9.51 - 9.65
- 9.66 - 9.8
- > 9.81

Flood results are based on riverine catchment events

Data Sources:

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

South Rockhampton Model Peak Fitzroy River Flood Heights

1% AEP Riverine Flood Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 4

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3.0 Available Data

3.1 General

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

- Previous studies (AECOM, 2017, AECOM, 2014a and AECOM, 2014b).
- Tidal data (MSQ, 2014).
- Topographical data in the form of LiDAR (AAM Pty Ltd, 2016).
- Aerial photography (RRC).
- Stormwater infrastructure network database (RRC).
- Details of hydraulic structures within the study area (RRC).
- Historical rainfall data for the 2013, 2015 and 2017 flood events (RRC).
- 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. It is Council's intent to finalise this implementation plan over the coming two years. 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 SRFL Interior Drainage Modelling Report (AECOM, 2014b)

An investigation was undertaken as part of the SRFL project to separately assess the performance of the internal drainage system, determine the impacts on properties within the levee area and to provide input into the design of the internal drainage infrastructure of the levee. The hydraulic model developed as part of this study has been used in the optimisation process for the levee alignment and drainage configuration however this report only presents the assessment of the final levee configuration and impacts.

This study involved assessment of existing flooding conditions of the South Rockhampton urban area and assessment of the changes to the flooding regime due to construction of the proposed levee and internal drainage infrastructure.

To carry out this assessment, a 1D/2D TUFLOW hydraulic model was developed which included representation of the trunk underground drainage infrastructure within the urban area and included major culverts and hydraulic controls that are part of the drainage system.

The infrastructure associated with the internal drainage of the levee was incorporated into the model and hydraulic analysis was undertaken for a range of design flood events including the 18%, 10%, 5%, 2%, 1% and 0.5% AEP events. Local catchment events and combined events (including the Fitzroy River) were assessed for a range of AEP's.

Outputs from the model were used to inform design of the internal drainage infrastructure for the levee system and determine flooding conditions with the levee in place.

3.2.3 SRFL Hydraulic Model Development (AECOM, 2014a)

The South Rockhampton Flood Levee (SRFL) planning and for tender design 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 and the Interior Drainage model has been adopted as the base model to be updated for use in this study. Reference should be made to the SRFL Hydraulic Model Development and Comparison report (AECOM, 2014) and SRFL Interior Drainage Report (AECOM, 2014) for further details.

This report details the updates to the SRFL Interior Drainage model and does not incorporate any changes made to the Fitzroy River model.

3.3 Tidal Data

Historic tidal data used in the January 2013 and February 2015 verification events was obtained from open data made available by Maritime Safety Queensland. Historical records are available for the inclusive period of 1996-2016 at Port Alma. Adjustments to the timing and levels were made in order to estimate corresponding levels in the Fitzroy River at Rockhampton.

It is noted that tidal data for the 2017 event was not yet available from Maritime Safety Queensland and hence a static Mean High Water Springs (MHWS) level of 2.66 mAHD was applied. Previous investigations undertaken during the SRFL project have shown that tidal levels within the Fitzroy River have a negligible effect on local catchment flood levels.

For design events and sensitivities with no Fitzroy River flooding, tailwater levels used during this investigation were based on the MHWS level at Rockhampton (2.66m AHD). The MHWS level was sourced from the 2014 QLD Tide Tables book (MSQ, 2014).

3.4 Topographic Data

The topographical information used for the South Rockhampton 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 1m. It is stated in the report provided by AAM Pty Ltd that the Horizontal Spatial Accuracy is estimated to be ±0.40m and the Vertical Spatial Accuracy is estimated to be ±0.15m, on clear open ground. Council undertook elevation checks and commented that the accuracy of the LiDAR is within the ±0.15m vertical tolerance on hard surfaces.

In addition to LiDAR, surveyed levels (AECOM, 2014b) of the following have been maintained from the previous model:

- Lower Dawson Road / Upper Dawson Road / Jellicoe Street Intersection.
- Yeppen North Bridge approach.
- Gladstone Road – George Street.
- William Street.
- Hastings Deering CAT site.

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 10cm 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

Given the lack of pit inlet dimensions, nominal dimensions of 900x600mm were assigned to all pits digitised within the hydraulic model. Sensitivity analysis involving increasing the dimensions of all pits to 2000x2000mm resulted in minimal change in flood levels or extents. This was expected as the existing pipe capacity is commonly the limiting component of the stormwater network.

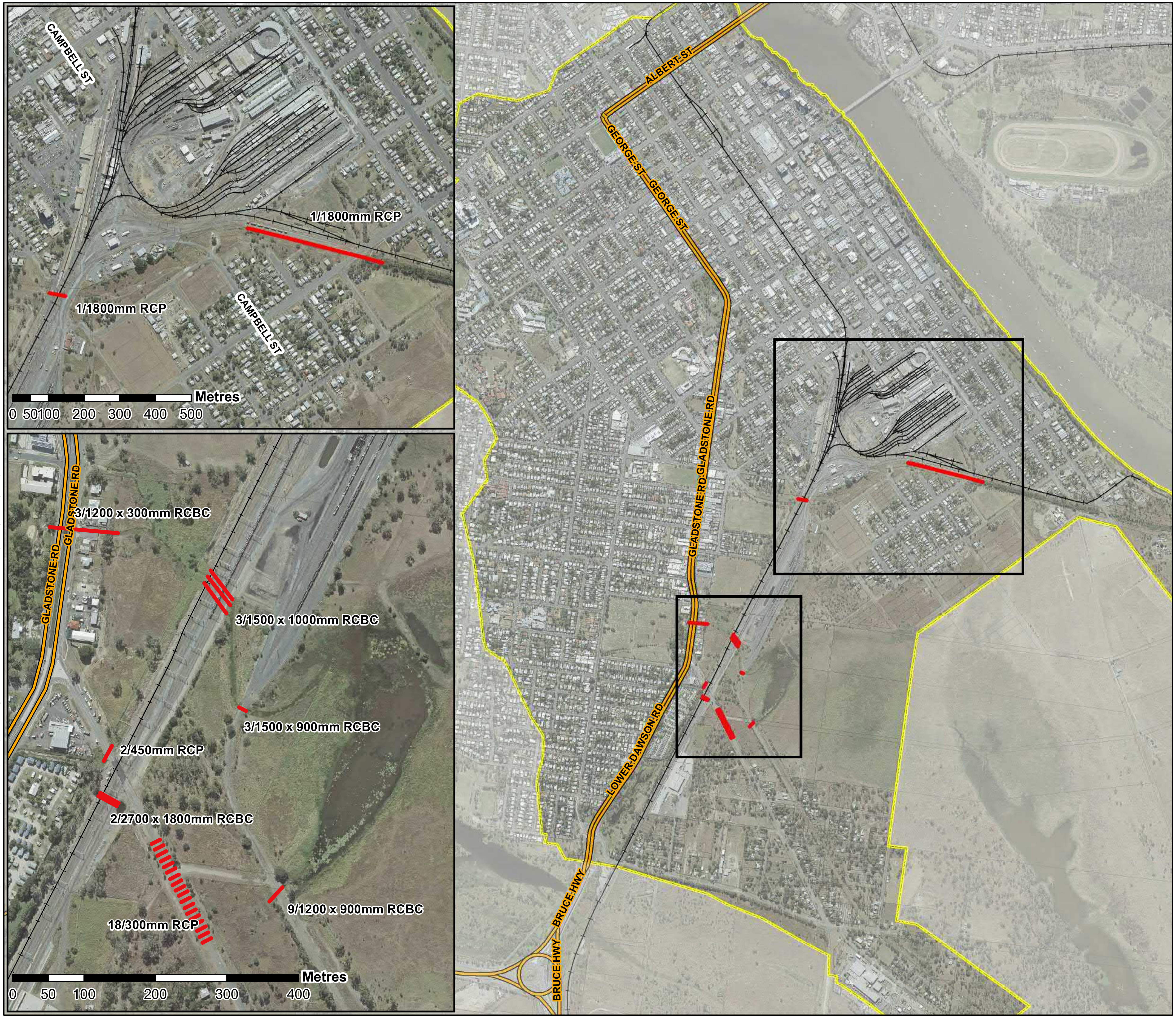
3.7 Hydraulic Structures

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

Approximately 75 culverts were identified within the hydraulic model extent, with three of these beneath Lower Dawson Road and 18 under the North Coast Rail Line. Minor structures which were not expected to convey significant flows or connect key flow paths were not incorporated in the hydraulic model. Table 1 presents a list of major structures within the study area which were incorporated into the hydraulic model. All structures are represented in a 1-dimensional scheme.

Table 1 Key Hydraulic Structures Incorporated to the Model

Drainage Structure	Configuration
Major Road	
Gladstone Road	3/1200 x 300mm RCBC
Local Roads	
Port Curtis Road (northwest of railway line)	2/450mm RCP
Port Curtis Road (southeast of railway line)	18/300mm RCP
Quay Street	1/1800mm RCP
Railway Lines	
Upper Main Drain	1/1800mm RCP
Cemetery Flow path (primary line)	3/1500 x 1000mm RCBC
Cemetery Flow path (secondary line)	3/1500 x 900mm RCBC
Port Curtis Road (upstream)	2/2700 x 1800mm RCBC
Port Curtis Road (downstream)	9/1200 x 900mm RCBC



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Metres

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LEGEND

- Key Hydraulic Structures
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

South Rockhampton Model

Key Hydraulic Structures

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 5

3.8 Historical Rainfall Data

Historical rainfall records for 2013, 2015 and 2017 events were acquired from BoM and provided by Council in the form of 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 2, where:

- ✓ à reliable data;
- ⃠ à unreliable data; and
- ✗ à no available data.

Table 2 Summary of Rainfall Data used in the Study

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

3.9 Historical Flood Records

3.9.1 Anecdotal Data

RRC undertook targeted consultation with individual property owners to collect anecdotal flood records from known local catchment flooding 'hotspots' within the study area. The outcome of which was provided by Council for hydraulic model calibration/verification purposes. Surveyed levels of peak flood heights were established using local resident advice, debris marks and water level marks / extents.

The anecdotal data locations are shown in Figure 6, with the collated data presented in Table 3 and Table 4. It is noted that some reported levels are inconsistent with others in the vicinity in these cases the suspected flood event was adopted. These instances are marked in the table below.

Table 3 Anecdotal Data

Point ID	Easting (m)	Northing (m)	Reported Flood Event	Adopted Flood Event	Peak Flood Level (mAHD)
2	245404.5	7412182	2013	2013	8.78
2a			2015	2015	8.65[1]
4	245362.3	7410512	2013	2015[2]	7.08
5			2015	2013[2]	7.30
11	245433.2	7410878	2015	2015	6.75
12	245451.2	7410874	2015	2013[2]	7.75

Point ID	Easting (m)	Northing (m)	Reported Flood Event	Adopted Flood Event	Peak Flood Level (mAHD)
13	245517.4	7410881	2013	2013	7.76
14	245263	7411025	2015	2013[2]	7.65
15	245229.5	7411161	2015	2013[2]	7.75
16	245271.2	7411125	2015	2015	7.24
17	245257	7411210	2013	2013	7.47
18	245249.9	7410963	2013	2013	7.75
19	245213.6	7411031	2013	2013	7.71

[1] *Level approximated from commentary*
[2] *Review of community consultation data suggested an incorrect flood event was provided.*

Table 4 Anecdotal Data Comments

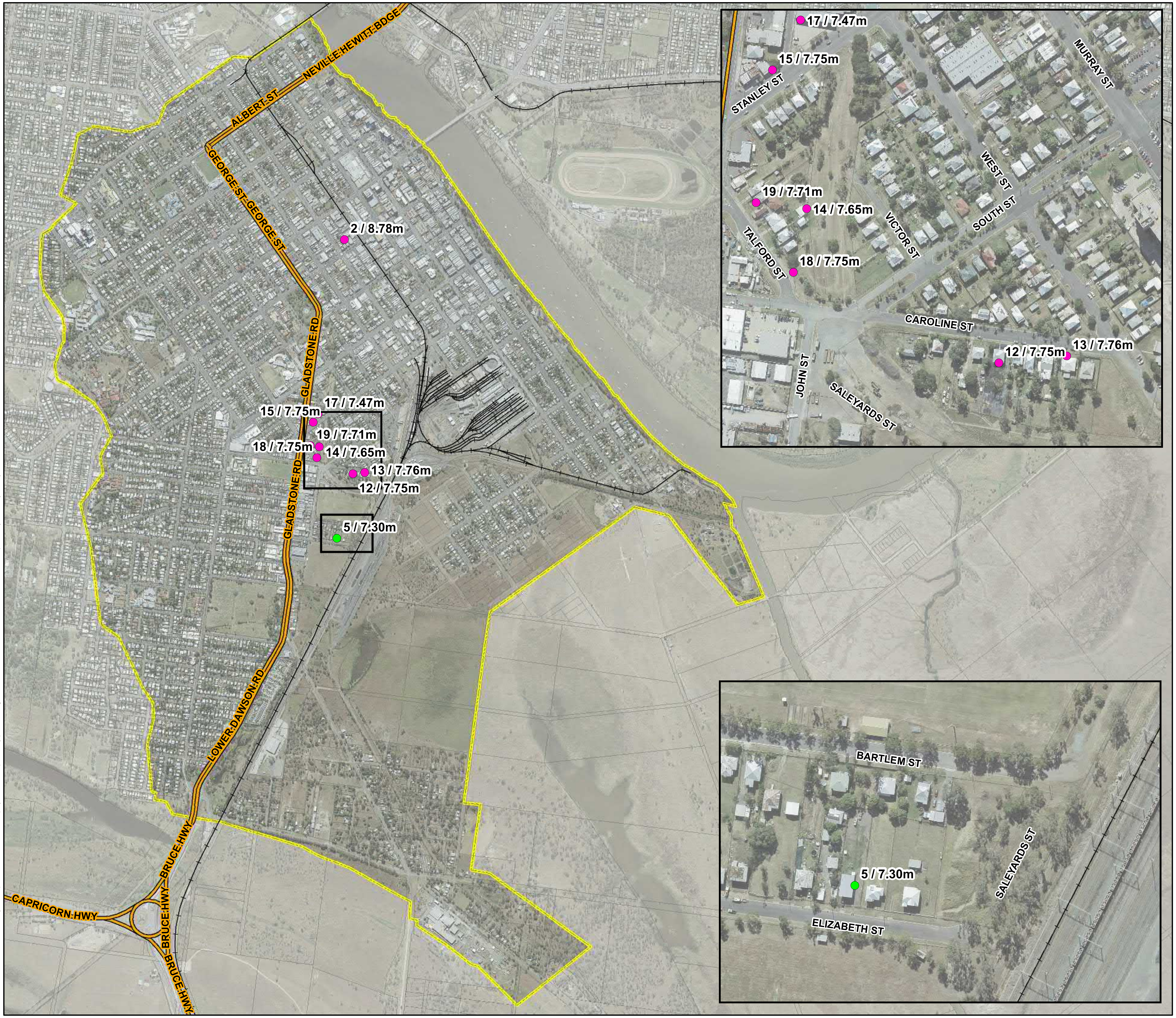
Point ID	Comment
2	8.7754 ankle high depth advised: 2013 event-picked; 2015 event just went up to the front yard.
2a	
4	7.0786 2013 event; flash flood duration generally 4 days
5	7.2986 2015 event
11	6.7509 Advised level picked ; 2015 event
12	7.749 2015 event; water entered into the property on Friday morning; stain on a building pole; duration of flooding-a day; not in agreement with 29 Caroline St observation; perhaps 2013 event
13	7.7583 II rung of the stair advised for 2013 event; Level picked
14	7.6549 2015 event; clear water line stain on the shed; duration of flooding- two days; 2013 event was a week-long flooding.
15	7.7455 2015 event; height to stained urn advised and picked
16	7.238 2015 event; marked with a pen
17	7.4695 2013 event; No marks visible; level was advised
18	7.7475 2013 event ; clear stain on a electricity pole; 187 Talford St ;advised
19	7.7096 2013 event; clear water stain on the wall.

Given the variations in reported levels, varying accuracy allowances were adopted for each recorded point. Inconsistencies in reported levels lower confidence in the data resulting in higher allowances. These are summarised in the table below.

Table 5 Adopted Allowances for Anecdotal Records

Point ID	Peak Flood Level (mAHD)	Adopted Flood Event	Allowance (m)	Comments
2	8.78	2013	±0.30	
2a	8.65	2015	±0.30	
4	7.08	2015	±0.30	
5	7.30	2013	±0.30	
11	6.75	2015	±0.50	Increased allowance due to reliance on memory and surrounding data points.
12	7.75	2013	±0.30	
13	7.76	2013	±0.30	

Point ID	Peak Flood Level (mAHD)	Adopted Flood Event	Allowance (m)	Comments
14	7.65	2013	±0.30	
15	7.75	2013	±0.30	
16	7.24	2015	±0.30	
17	7.47	2013	±0.50	Increased allowance due to reliance on memory and surrounding data points.
18	7.75	2013	±0.30	
19	7.71	2013	±0.30	



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Metres

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LEGEND

Anecdotal Records

- 2013 Event
- 2015 Event
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

South Rockhampton Model

Anecdotal Records Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 6

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3.9.2 Recorded Water Level Data

Water level data recorded at key locations in the Upper and Lower portions of the Main Drain and Fiddes Lagoon areas were provided by Council for the 2017 event. The data included the locations and maximum readings of gauges shown in Figure 7. Table 6 presents the spatial locations and peak heights of Council's gauges within the South Rockhampton Local Catchment model for the 2017 event. Adopted verification tolerances in the 2017 event were ±0.15m.

Table 6 Recorded Gauge Data for 2017 flood event

Gauge Label	Gauge ID	Easting (m)	Northing (m)	Zero Gauge Level (mAHD)	Peak Gauge Depth (m)
West St (Upper Main Drain)	RSM-061	245583.49	7410814.72	5.70	0.00*
Broadway (Lower Main Drain)	RSM-062	247036.76	7410746.18	3.72	0.45
Fiddes St / Lucius Street	RSM-063	246205.46	7410113.33	4.90	0.42

** Gauge was dry during event*

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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

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LEGEND

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

Data Sources:

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

South Rockhampton Model

2017 Recorded Gauge Data Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 7

4.0 Hydrologic Inputs

4.1 Direct Rainfall Approach

4.1.1 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.

4.1.2 Approach

Two dimensional rainfall excess time series for each AEP event and duration were created to represent the local net precipitation for the study area. This 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).

4.2 Historic Rainfall Data

Historic rainfall records for the 2013, 2015 and 2017 events were obtained for the Rockhampton Aero pluviograph station located approximately 3km northwest of the study area. Records at Council-managed gauges were available for the 2015 and 2017 events, although the incremental 2015 data was noted as erroneous due to a suspected power failure. Records from the privately-owned gauge at Serocold Street were obtained by Council for the 2013 and 2015 events. Data was not available from the Serocold Street gauge for the 2017 event. Rainfall plots of the abovementioned events are included in subsequent sections.

4.2.1 2013 Event – Ex-TC Oswald

Tropical Cyclone Oswald passed over parts of Queensland and New South Wales towards the end of January 2013, reducing in intensity to a tropical low system before reaching Rockhampton. Ex-TC Oswald resulted in significant precipitation over a number of days across Rockhampton, resulting in local catchment flooding followed by a Fitzroy River flood peak of 8.61m as a result of rainfall in the Fitzroy River catchment. The timeseries of rainfall data from the Rockhampton Aero rainfall gauge is shown in Figure 8.

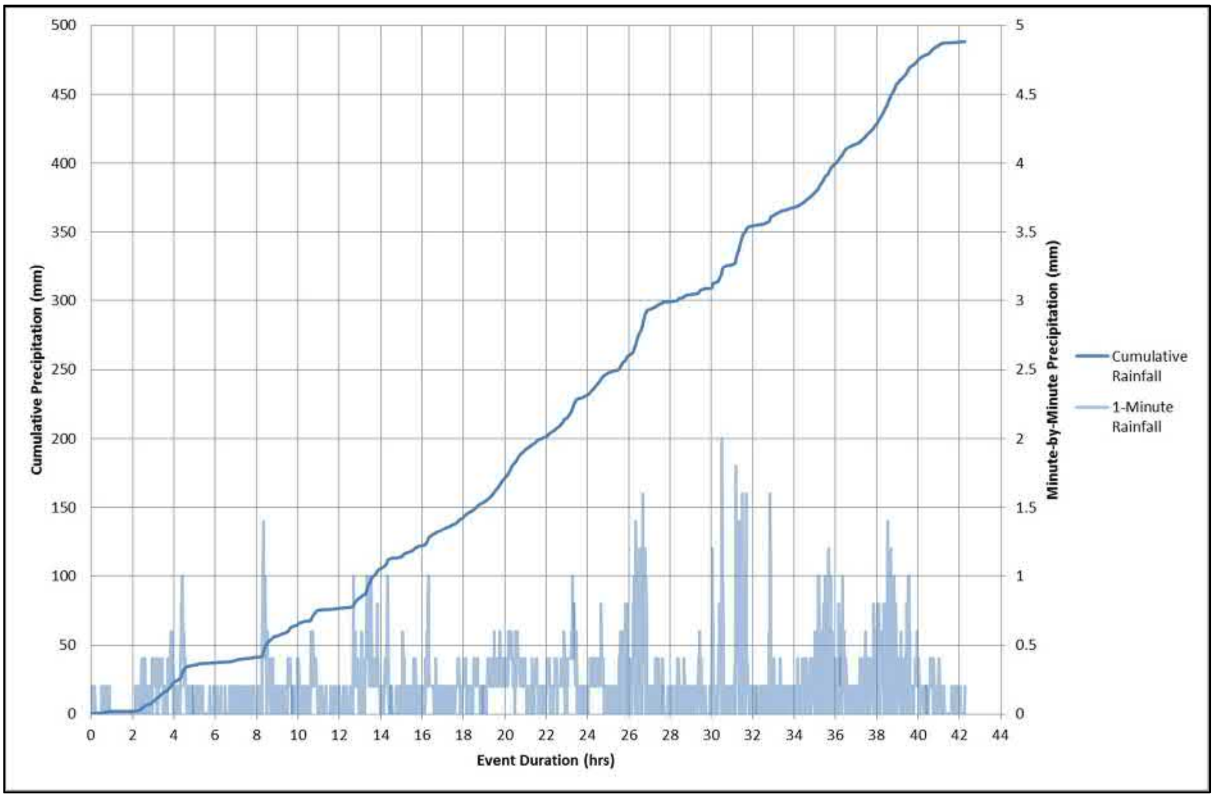


Figure 8 2013 Event Rainfall (Rockhampton Aero)

Records from Rockhampton Aero provided a total rainfall depth of 488.2mm in a 42 hour period, with the Serocold Street records totalling 700.5mm (43% increase); a clear indication of the high variability in the spatial distribution of rainfall during this event.

Given this high variance, the Rockhampton Aero data was scaled by 40% up to 683.5mm to resemble rainfall depths at the other gauges within the catchment more closely.

Table 7 Summary of 2013 Event Rainfall Data

Total Rainfall (mm)		Difference (mm)	Difference	Adopted Rainfall
Rockhampton Aero	Serocold Street			
488.2	700.5	212.3	43%	Rockhampton Aero +40%

4.2.2 2015 Event – TC Marcia

Tropical Cyclone Marcia crossed the east coast of Queensland as a category 5 system on the 20th of February, 2015. The system weakened to a category 3 cyclone before delivering a total rainfall depth of 206.2mm to Rockhampton with the peak 14 hour period rainfall depth totalling 177.6mm.

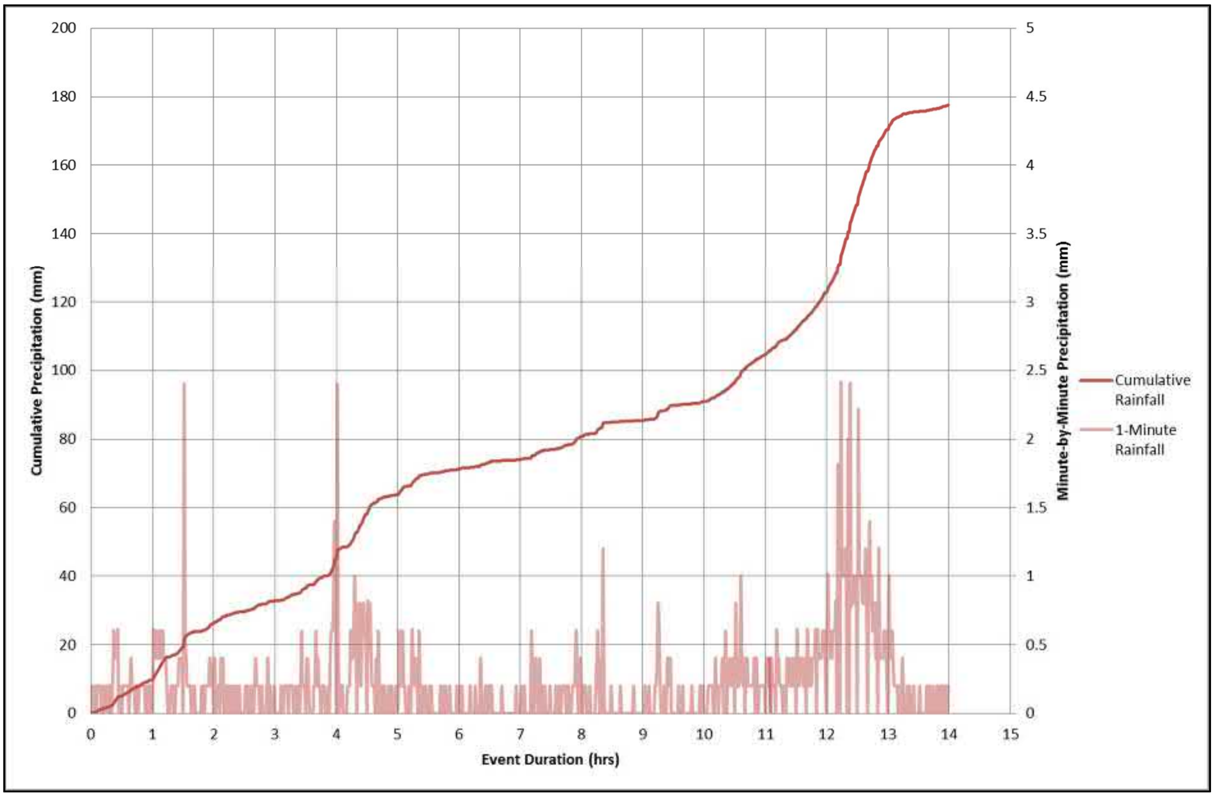


Figure 9 2015 Event Rainfall (Rockhampton Aero)

Rainfall depths recorded at Serocold Street totalled 245mm, approximately 19% more than that of the Rockhampton Aero. The timeseries of rainfall data at Rockhampton Aero for the 2015 event is shown in Figure 9. A summary of the available rainfall data is included below in Table 8.

Table 8 Summary of 2015 Event Rainfall Data

Rainfall Gauge	Total Rainfall (mm)	Difference to Rockhampton Aero (mm)	Difference to Rockhampton Aero (%)
Rockhampton Aero	206.2	-	-
Serocold Street	245.0	38.8	19%
West Rockhampton STP	329.0	122.8	60%
Agnes Street Reservoir	325.0	118.4	57%
Rogar Avenue Reservoir	309.0	102.4	50%
Glenmore WTP	167.7	-38.9	-19%
Yaamba Road Reservoir	245.0	38.8	19%

It was noted that West Rockhampton STP, Agnes Street Reservoir, Rogar Avenue Reservoir, Glenmore WTP and Yaamba Road Reservoir datasets were potentially erratic due to power failure. With this in mind, the Rockhampton Aero rainfall data was used for the 2015 calibration event.

4.2.3 2017 Event – Ex-TC Debbie

Ex-TC Debbie moved across the Fitzroy Catchment and Rockhampton in late March 2017. Significant rainfall triggered a major Fitzroy River flood peak of 8.90m at Rockhampton, preceded by a local catchment flood event as a result of the 204.5mm fell at the Agnes Street Reservoir and was adopted across the South Rockhampton catchment.

Although Rockhampton Aero records were obtained (totalling 186.6mm), detailed 1-minute interval records were available for Agnes St Reservoir gauges and as such was adopted. The timeseries of rainfall data at Agnes Street Reservoir for the 2017 event is shown in Figure 10.

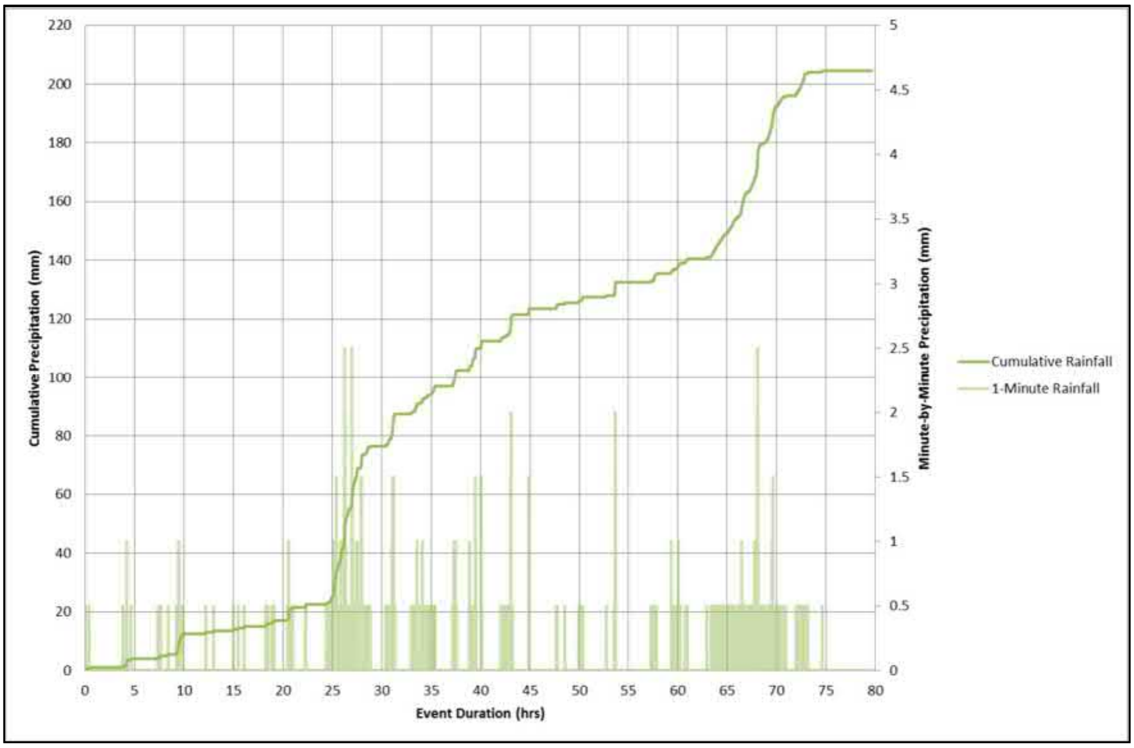


Figure 10 2017 Event Rainfall (Agnes St Reservoir)

Total rainfall depths between the gauges in South Rockhampton varied by less than 10%, indicating limited variability in rainfall between the upper and lower catchments of South Rockhampton.

Table 9 Summary of 2017 Event Rainfall Data

Rainfall Gauge	Total Rainfall (mm)	Difference to Rockhampton Aero (mm)	Difference to Rockhampton Aero (%)
Rockhampton Aero	186.6	-	-
West Rockhampton STP	203.0	16.4	9%
Agnes Street Reservoir	204.5	17.9	10%
Rogar Avenue Reservoir	308.0	121.4	65%
Glenmore WTP	199.7	13.1	7%
Yaamba Road Reservoir	211.0	24.4	13%
Lucas Street Reservoir	200.0	13.4	7%

With the exclusion of Rogar Street Reservoir, comparison between the rainfall stations revealed a peak discrepancy of less than 25mm, with the rainfall depth measured at Agnes Street Reservoir only

10% above that of Rockhampton Aero, confirming the suitability of the Agnes Street Reservoir data for the 2017 verification event.

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 (150.5117 E, 23.3750 S). The IFD input data set obtained is shown in Table 10.

Table 10 Adopted IFD Input Parameters

Parameter	Value
1 hour, 2 year intensity (mm/hr)	43.4
12 hour, 2 year intensity (mm/hr)	8.6
72 hour, 2 year intensity (mm/hr)	2.4
1 hour, 50 year intensity (mm/hr)	86.7
12 hour, 50 year intensity (mm/hr)	18.6
72 hour, 50 year intensity (mm/hr)	6.2
Average Regional Skewness	0.22
Geographic Factor, F2	4.22
Geographic Factor, F50	17.69

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 11.

Table 11 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	33.6	43.4	55.5	63.0	73.0	86.7	97.5
2	21.8	28.2	36.2	41.2	47.8	56.9	64.1
3	16.6	21.6	27.8	31.7	37	44.1	49.7
6	10.4	13.6	17.7	20.3	23.7	28.4	32.2
12	6.54	8.55	11.3	13.0	15.4	18.6	21.1

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 South Rockhampton Local Catchment Study which has a catchment area of approximately 10.8 km^2 and a critical duration of 2 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 12.

Table 12 Adopted PMP Parameters

Duration (hrs)	Rainfall Total (mm)	Rainfall Intensity (mm/hr)
1	410	410
2	620	310
3	750	250

The AEP of the PMP event was calculated as recommended in AR&R (Pilgrim, et al, 1987). For a catchment area of 10.8km^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 events. An initial loss of 15mm and continuing loss of 1.0mm were applied to pervious areas, for all design events. Sensitivity of the model to initial and continuing losses was undertaken for the 2013 and 2015 verification events which showed only minor discrepancies through varying initial loss from 0 to 25mm and continuing loss from 0.0 to 2.5mm. This is discussed in more detail in Section 6.0.

5.0 Hydraulic Model Development

5.1 Overview

This section of the report discusses the further development of the existing hydraulic model previously used to assess the interior drainage of the South Rockhampton Flood Levee System. 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 5m to 3m numerical Cartesian grid. A timestep of 1.5 second was adopted (2.0 second previously), giving an effective runtime of approximately 8 real-time hours to 1 simulation hour.

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

See Appendix A for more hydraulic model development details.

5.2 Hydraulic Model Parameters

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

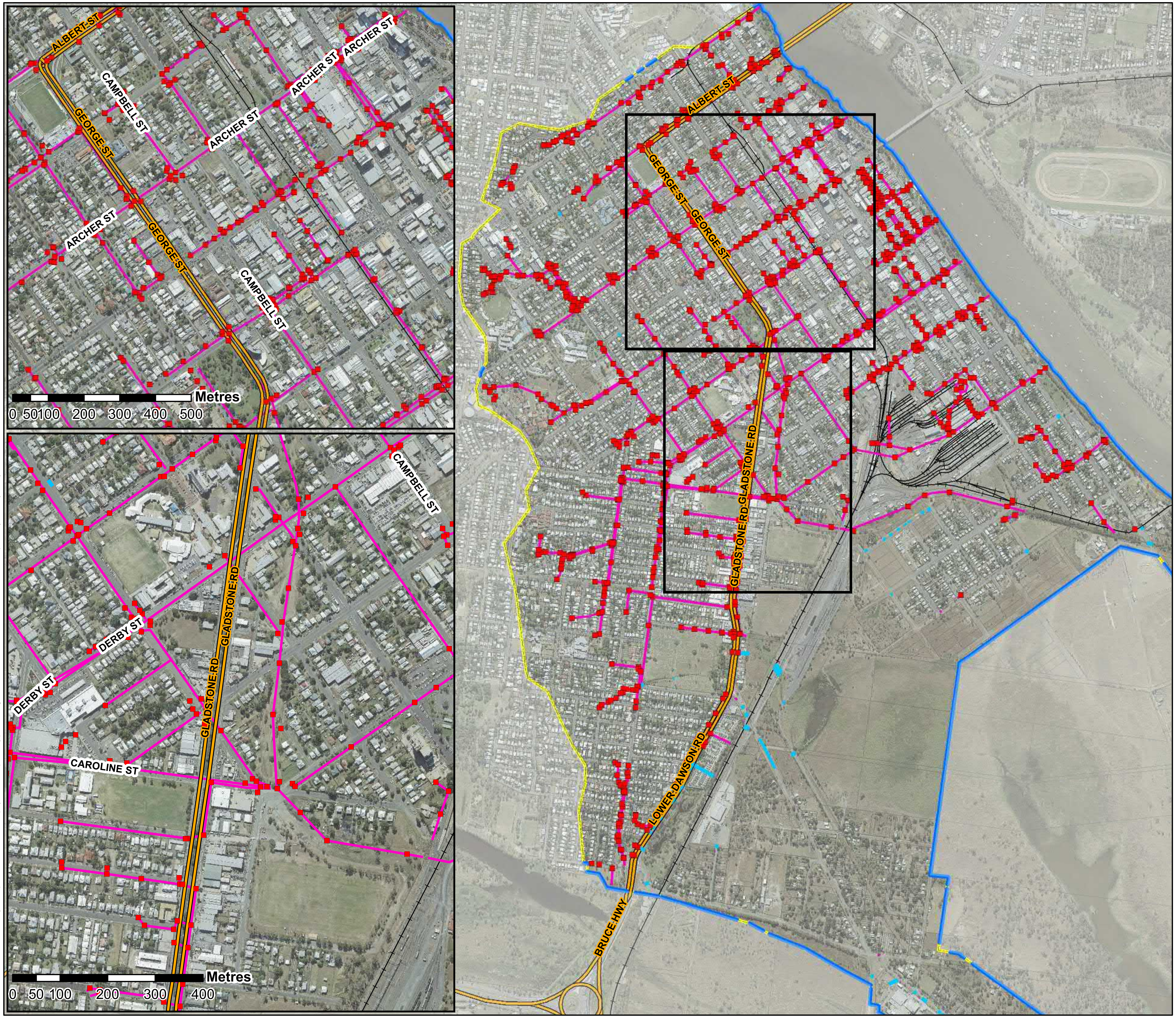
An overview of the model setup and key parameters for the model is provided in Table 13.

Table 13 Hydraulic Model Setup Overview

Parameter	South Rockhampton 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	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 North Rockhampton Creek Models.
Eddy Viscosity	Smagorinsky
Model Calibration	Calibrated to 2015 event, verified to 2013 and 2017 events.
Downstream Model Boundary	27 rating curve boundary conditions along the northern, western and southern boundaries for all events, 1 tidal boundary on the eastern 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% Roughness, Riverine and Local Catchment Coincident Event, Inlet Structure Dimensions and Climate Change

5.3 Model Setup

A visual representation of the model setup including the code, boundaries, 1D network and hydraulic roughness delineation are included as Figure 11, Figure 12 to supplement the detailed updates outlined in Appendix A.



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LEGEND

- Pit Intlet
- Boundary Conditions
- Culvert
- Pipes
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

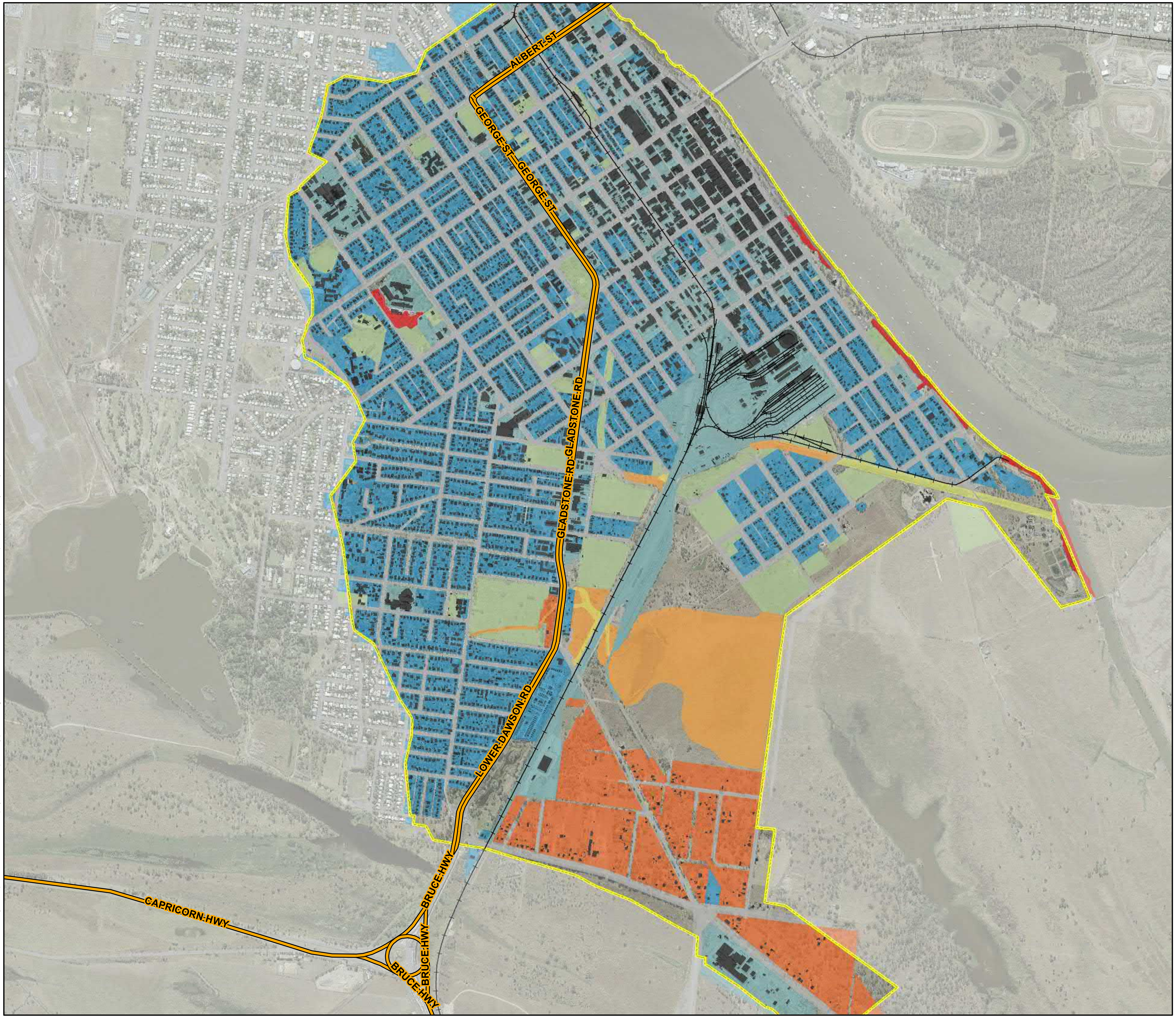
South Rockhampton Model

Model Setup and 1D Network Map

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 11

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 11 Model Setup.mxd



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Rockhampton Regional Council

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Metres

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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Building Footprints
- Road Corridor
- Urban block
- Commercial/Industrial block
- Open space
- Medium Vegetated Channel with mangroves, debris and tall grass
- Dense Vegetation / Densely Vegetated Channel
- Medium Vegetated Channel
- Light Vegetation
- Steep Slopes

Data Sources:

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

South Rockhampton Model

Hydraulic Roughness Delineation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 12

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6.0 Calibration and Verification

6.1 Adopted Methodology

Calibration and verification of the TUFLOW model was undertaken by simulating historical flood events and comparing the results to recorded / anecdotal data provided by Council.

The model was calibrated to the 2015 flood event, in which the model parameters were varied to better match anecdotal data by varying roughness, initial losses, continuing losses and stormwater infrastructure assumptions (connectivity, roughness and blockage).

The calibrated model was then verified to the 2017 and 2013 events with the only change being modification of the initial losses to 0.0mm to account for excluding the pre-burst rainfall in the model simulations. Exclusion of the pre-burst rainfall was undertaken to make model runtimes more manageable.

Varying tidal levels were applied to the 2013 and 2015 based on historic records, although these had negligible effects on the peak flood heights at recorded points. Synthetic varying tidal levels were applied for the 2017 event in the absence of available recorded data.

It should be noted that surveyed peak flood levels are generally based upon flood debris marks or reported flood marks and are of varying levels of accuracy; therefore they are less reliable than recorded gauge levels. Adopted calibration tolerances for anecdotal records are detailed in Table 5.

6.2 Calibration to the 2015 Event

The 2015 rainfall gauge data at the Rockhampton Aero station was applied to the TUFLOW model. The maximum water surface elevations were extracted from the hydraulic model and compared to recorded peak flood levels provided by RRC.

The following model iterations were simulated for the 2015 event:

Table 14 February 2015 Event Calibration Model Iterations Summary

Model Iteration No.	Initial Loss (mm)	Continuing Loss (mm)	Other Changes
E001	15	1.0	Blockage factors for the culverts under the railway updated - 70% blockage applied to 1/1800mm RCP in Upper Main Drain and 50% blockage applied to 3/1500x1000mm RCBC downstream of South Rockhampton Cemetery. This was based on site inspections undertaken by AECOM which revealed significant blockage and damage to these hydraulic structures. Inclusion of 225mm network downstream of calibration point 2a. Locations of these updates are show in Figure 13.
E002	25	2.5	-
E003	15	1.5	-
E004	15	1.0	-
E005	10	1.0	-
E006	5	1.0	-
E007	0	1.0	-
E008	0	0.0	-
E009	15	1.0	Additional 15% roughness

Peak flood levels were recorded at 4 locations within the South Rockhampton area. The simulated peak heights for each model iteration were compared to the heights at the recorded locations. Results from the various scenarios are presented in Table 15.

Table 15 February 2015 Calibration Event Results

Point ID	Recorded Level (mAHD)	Peak Flood Height (mAHD)								
		E001	E002	E003	E004	E005	E006	E007	E008	E009
2a	8.650	8.69	8.68	8.68	8.68	8.68	8.68	8.68	8.68	8.68
4	7.069	6.44	6.16	6.19	6.20	6.21	6.21	6.22	6.24	6.20
11	6.751	7.08	7.03	7.04	7.05	7.05	7.05	7.05	7.06	7.05
16	7.238	7.11	7.04	7.06	7.07	7.07	7.07	7.07	7.09	7.07

Analysis of the results reveals the following:

- Initial losses have an impact of 20mm or less (refer to scenarios E004 and E007) for a variance of 15mm to 0mm.
- The study area is predicted to be marginally more responsive with variance in continuing losses given differences of up to 30mm are evident between scenarios E007 (1.0mm continuing loss) and E008 (0.0 continuing loss).
- Increases to hydraulic roughness in the order of 15% is expected to attenuate the flood peak (albeit slight), generally resulting in the lower peak flood heights observed when comparing scenarios E004 and E009.
- When comparing E001 and E004 it was evident that additional roughness and blockage to cross-drainage structures within the rail corridor increases the predicted peak water surface elevation by more than 240mm south of Saleyards Street. Increased peak heights are also present within the Upper Main Drain which saw an increase of up to 40mm.

The map in Figure 14 presents the comparison of water levels at recorded height locations for scenario E001. The differences between the calculated and recorded flood levels are categorised into bands. Locations where the model predictions are within adopted tolerance ranges are shown as orange (high, but within tolerance), light blue (low, but within tolerance) and green (within tolerance). Locations where model predications are outside the tolerance ranges are shown as red and dark blue points.

Table 16 Calibration Results Analysis

Point ID	Recorded Level (mAHD)	Peak Height (mAHD)			Difference (m)	Tolerance
		E001	Lower Tolerance	Upper Tolerance		
2a	8.65	8.69	8.35	8.95	0.04	In tolerance, high
4	7.07	6.44	6.77	7.37	-0.63	Below tolerance
11	6.75	7.08	6.25	7.25	0.33	In tolerance, high
16	7.24	7.11	6.94	7.54	-0.13	In tolerance, low

Key outcomes from the calibration are:

- Of the four recorded points, three were within the corresponding tolerances with the average difference calculated to be -0.10 m.
- A large difference between modelled and recorded levels was noted in the storage area adjacent the rail, south of Saleyards Street. It is predicted that this discrepancy is a result of higher event blockage occurring at the 3/1500x1000 RCBCs during the cyclone. Additionally, review of the sub-surface network indicates some trunk mains which relieve runoff from the main drain are performing better than expected given their age and the potential blockage from debris transported by the cyclonic winds.

The adopted calibration settings are geographically presented in Figure 13 and relate to scenario E001 outlined and discussed above.

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DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800

Metres

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(when printed at A3)

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LEGEND

Hydraulic Roughness

- 0.017 (Aged Concrete)
- 0.024 (Brick Arch)
- 0.025 (Silt / Debris)
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

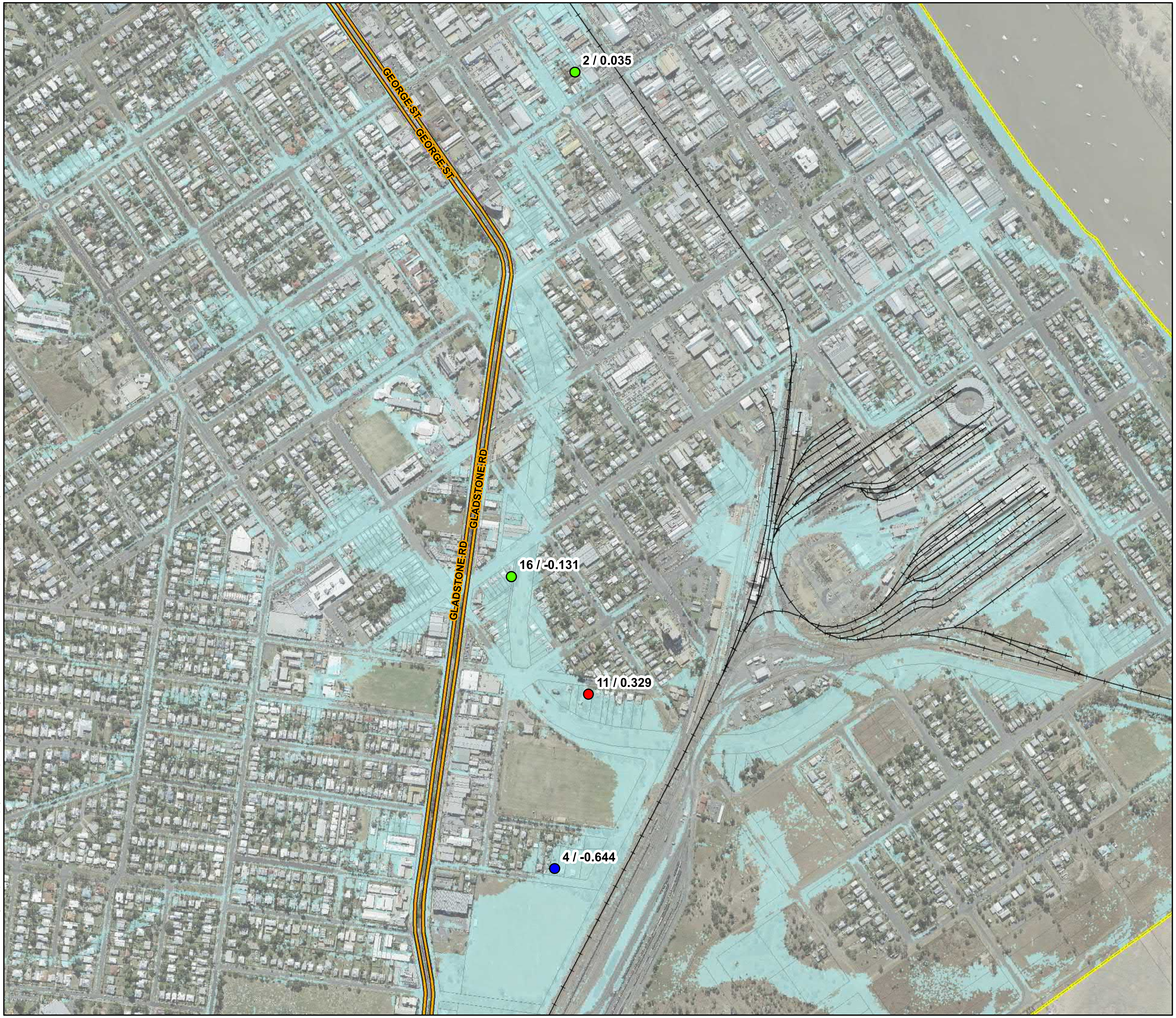
South Rockhampton Model

Infrastructure with Increased Roughness and Blockage Values

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 13

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 13 Increased Roughness.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

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(when printed at A3)

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LEGEND

Difference in PWSE (m)

- < -0.30 (Below tolerance)
- -0.30 - -0.16 (In tolerance, low)
- -0.15 - 0.15 (In tolerance)
- 0.16 - 0.30 (In tolerance, high)
- > 0.30 (Above tolerance)
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- February 2015 Modelled Extent

Data Sources:

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

South Rockhampton Model

Februrary 2015 Calibration Results

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 14

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 14 Feb 2015 Calibration.mxd

6.3 Verification to the 2017 Event

During calibration of the model to the 2015 event, Ex-TC Debbie occurred resulting in a moderate rainfall event in South Rockhampton during late March 2017. Council supplied recorded gauge data at three points within the model which have been compared to the peak flood heights predicted during the simulation. It is noted that one recorded gauge level within the study areas was below the adopted DEM level, although was dry during the event.

In order to undertake the verification, some adjustment had to be made to the E001 model. These are summarised below in Table 17.

Table 17 March 2017 Event Verification Event Model Iterations Summary

Model Iteration No.	Initial Loss (mm)	Continuing Loss (mm)	Other Changes
E001	15	1.0	As shown above in Table 14
E001b	0	1.0	As shown above in Table 14

During the 2017 event, there was significant rainfall leading up to the actual flood event. The adjustments to the initial and continuing losses in iteration E001b are due to the pre burst rainfall being removed from the hyetograph to reduce modelling times, the catchment is assumed to be saturated by the pre burst rainfall, therefore no initial losses need to be applied during the verification event.

Table 18 March 2017 Verification Results Analysis

Point ID	Anecdotal Level (mAHD)	Peak Height (mAHD)			Difference (m)	Tolerance
		E001b	Lower Tolerance	Upper Tolerance		
RSM - 061	Dry	Dry	-	-	N/A	
RSM - 062	3.72	3.66	3.57	3.87	-0.06	In tolerance, low
RSM - 063	4.90	5.07	4.75	5.05	0.17	In tolerance, high

Analysis of the verification results reveals the following:

- Point RSM – 061 was noted to be 'dry' in the event and this was simulated in the model.
- Point RSM - 062 closely matches the gauged level.
- RSM - 063 is within tolerance, although high. It is expected that the blockage to rail cross-drainage structures will attenuate storage upstream of the rail and reduce this level to within 0.15m of the recorded height.
- The average difference between simulated and recorded levels is 0.05m, with a standard deviation of 0.09m.

Figure 15 presents the comparison of water levels at recorded height locations for scenario E001b. Given the close match between simulated and recorded peak flood heights, the E001 model is considered to be an excellent verification to the 2017 event; although more recorded levels are desirable to develop holistic confidence in the model performance.

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0 100 200 300 400
Metres

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(when printed at A3)

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LEGEND

Difference in PWSE (m)

- -0.15 - 0.15 (In tolerance)
- 0.15 - 0.30 (In tolerance, high)
- Highways
- Railway Lines
- Cadastre
- March 2017 Modelled Extent

Data Sources:

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

South Rockhampton Model

March 2017 Verification Results

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 15

6.4 Verification to the 2013 Event

In order to verify the model to the rainfall data for Ex-TC Oswald in January 2013 was obtained from the Rockhampton Aero site. Council obtained anecdotal peak water elevations from residents in know hotspots, the limitations of this data have been discussed above in 3.9.1, and these heights have been compared to the peak flood heights predicted during the simulation. It is noted that some of the anecdotal heights are inconsistent with the surrounding data points.

In order to undertake the verification, some adjustment had to be made to the E001 model. These are summarised below in Table 19.

Table 19 January 2013 Event Verification Model Iterations Summary

Model Iteration No.	Initial Loss (mm)	Continuing Loss (mm)	Other Changes
E001	15	1.0	As shown above in Table 14
E001c	0	1.0	As per run E001b in Table 14, plus a 40% increase in rainfall, the table drain in the model reinstated to 2013 conditions and the council stockpiles adjusted to May 2013 conditions.

As the model was built using 2017 information and 2016 LiDAR some adjustments needed to be made to ensure the model represented 2013 conditions. The adjustments to the initial and continuing losses in iteration E001c are due to the pre burst rainfall being removed from the hyetograph to reduce modelling times, the catchment is assumed to be saturated by the pre burst rainfall, and therefore no initial losses need to be applied during the verification event. The additional rainfall was applied to the measured data to account for the spatial variability of the rainfall experienced across the Rockhampton region.

Table 20 January 2013 Verification Results Analysis

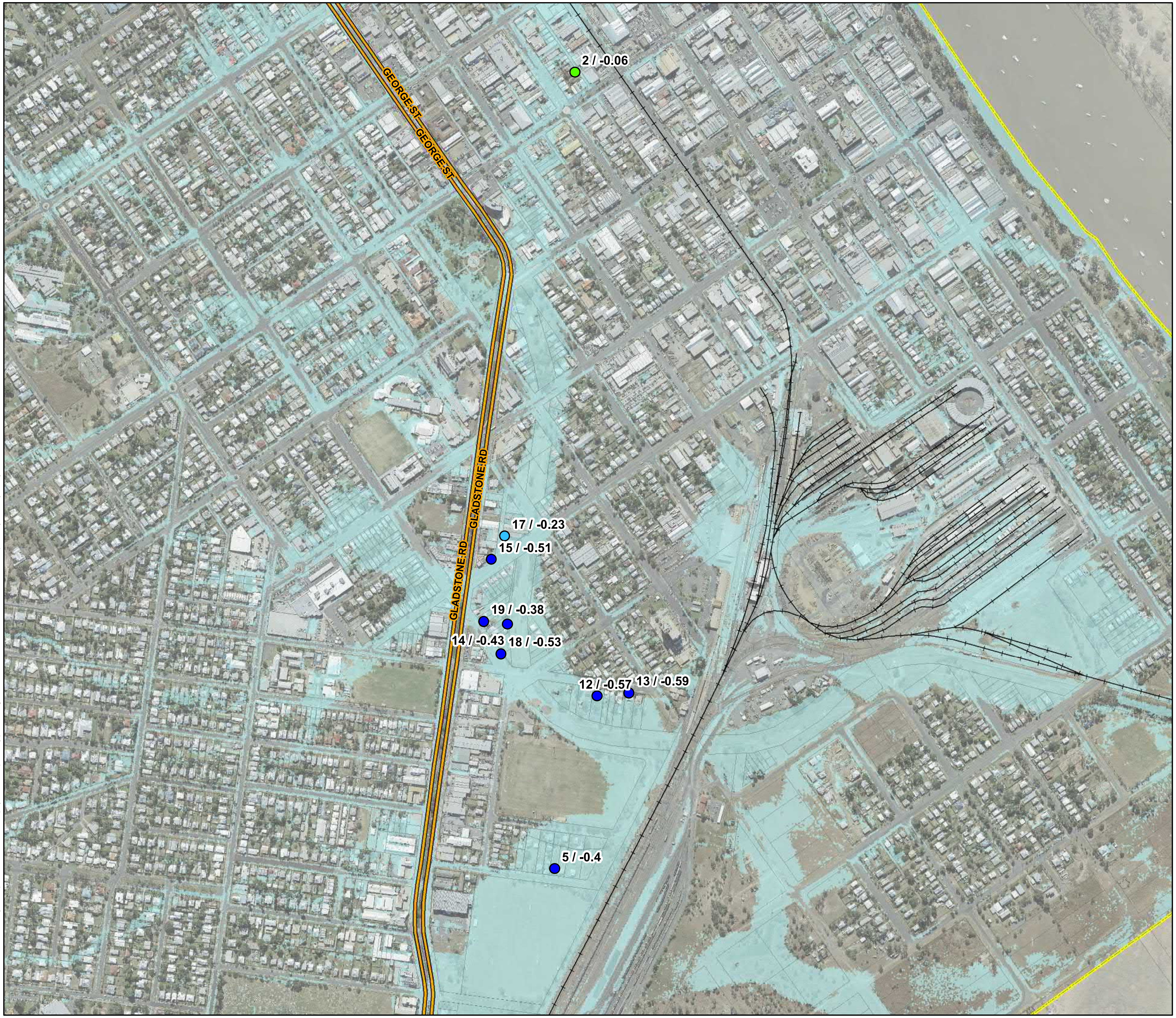
Point ID	Anecdotal Level (mAHD)	Peak Height (mAHD)			Difference (m)	Tolerance
		E001c	Lower Tolerance	Upper Tolerance		
2	8.78	8.72	8.63	8.93	-0.06	In tolerance, low
5	7.30	6.90	7.15	7.45	-0.40	Below tolerance
12	7.75	7.18	7.60	7.90	-0.57	Below tolerance
13	7.76	7.17	7.61	7.91	-0.59	Below tolerance
14	7.65	7.22	7.50	7.80	-0.43	Below tolerance
15	7.75	7.24	7.60	7.90	-0.51	Below tolerance
17	7.47	7.24	7.22	7.72	-0.23	In tolerance, low
18	7.75	7.22	7.60	7.90	-0.53	Below tolerance
19	7.71	7.33	7.56	7.86	-0.38	Below tolerance

Analysis of the results reveals the following:

- Across most verification points the model is consistently 0.4 – 0.6 m lower than the recorded peak flood heights.
- The average difference between simulated and recorded levels is -0.41 m with a standard deviation of 0.16 m.

Although the verification is consistently lower, the reason for this is suspected to be due to the lack of available rainfall data within the catchment and therefore the inability to accurately represent the volume of water entering the catchment. A majority of the anecdotal data points mentioned above are located with the main drain area, which is highly sensitive to the blockage of the culverts under the rail line and the trunk mains which remove overland flow from the main drain. The condition of these structures are difficult to determine during the event, therefore the ability to achieve an accurate verification is also affected.

Figure 16 presents the comparison of water levels at recorded height locations for scenario E001c. Given the reasons outlined above, along with the fact that the water levels were collected up to four years after the flood event, the model is representing the current catchment conditions adequately.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

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(when printed at A3)

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LEGEND

Difference in PWSE (m)

- < -0.30 (Below tolerance)
- -0.30 - -0.16 (In tolerance, low)
- -0.15 - 0.15 (In tolerance)
- 0.16 - 0.30 (In tolerance, high)
- > 0.30 (Above tolerance)
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- January 2013 Modelled Extent

Data Sources:

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

South Rockhampton Model

January 2013 VerificationResults

PROJECT ID	60534898
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VERSION:	A

Figure
16

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6.5 Key Findings

Summarised below are the key calibration / verification parameters for the South Rockhampton Local Catchment model.

6.5.1 Final Design Losses and Roughness

The final design losses adopted following the calibration and verification process is outlined in Table 35 in Appendix A. Most pervious areas were modelled with an initial loss of 15 mm and continuing loss of 1 mm.

The adopted roughness values for each of the different land uses are outlined in Table 34 in Appendix A. Following the calibration and verification process the adopted roughness for the cross drainage structures beneath the railway was increased by 67%.

6.5.2 Adopted Blockage

The adopted blockage for the final baseline design for the railway includes, 70% blockage applied to the 1800 mm diameter RCP in the Upper Main Drain and 50% blockage applied to the three 1500 by 1000 mm RCBC downstream of South Rockhampton Cemetery.

This was based on site inspections undertaken by AECOM which revealed significant blockage and damage to these hydraulic structures.

6.5.3 Critical Areas

Critical areas within this catchment are areas surrounding the Upper Main Drain, the cross drainage structures which convey runoff from the Upper Main Drain to the Fitzroy River and the rail culverts which provide connection from either side of the railway.

In undertaking the calibration / verification process, it was noted that there was a consistently large difference between modelled and recorded levels in the storage area adjacent the rail line, south of Saleyards Street. This is particularly evident in the 2013 and 2015 events.

It is suspected that a lack of available rainfall data within the catchment is a potential cause, as well as the highly sensitive nature of the rail culverts and main drain pipe network with respect to blockage. At this stage, it is recommended that additional verification events are assessed in the future to gain further confidence in the modelling outputs in this area. In the interim, it is further recommended that Council apply additional freeboard (nominally 0.5 m) in this area for planning purposes.

7.0 Baseline Hydraulic Modelling

7.1 Overview

The E001 South Rockhampton Local Catchment model was used to simulate the 1 EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF events.

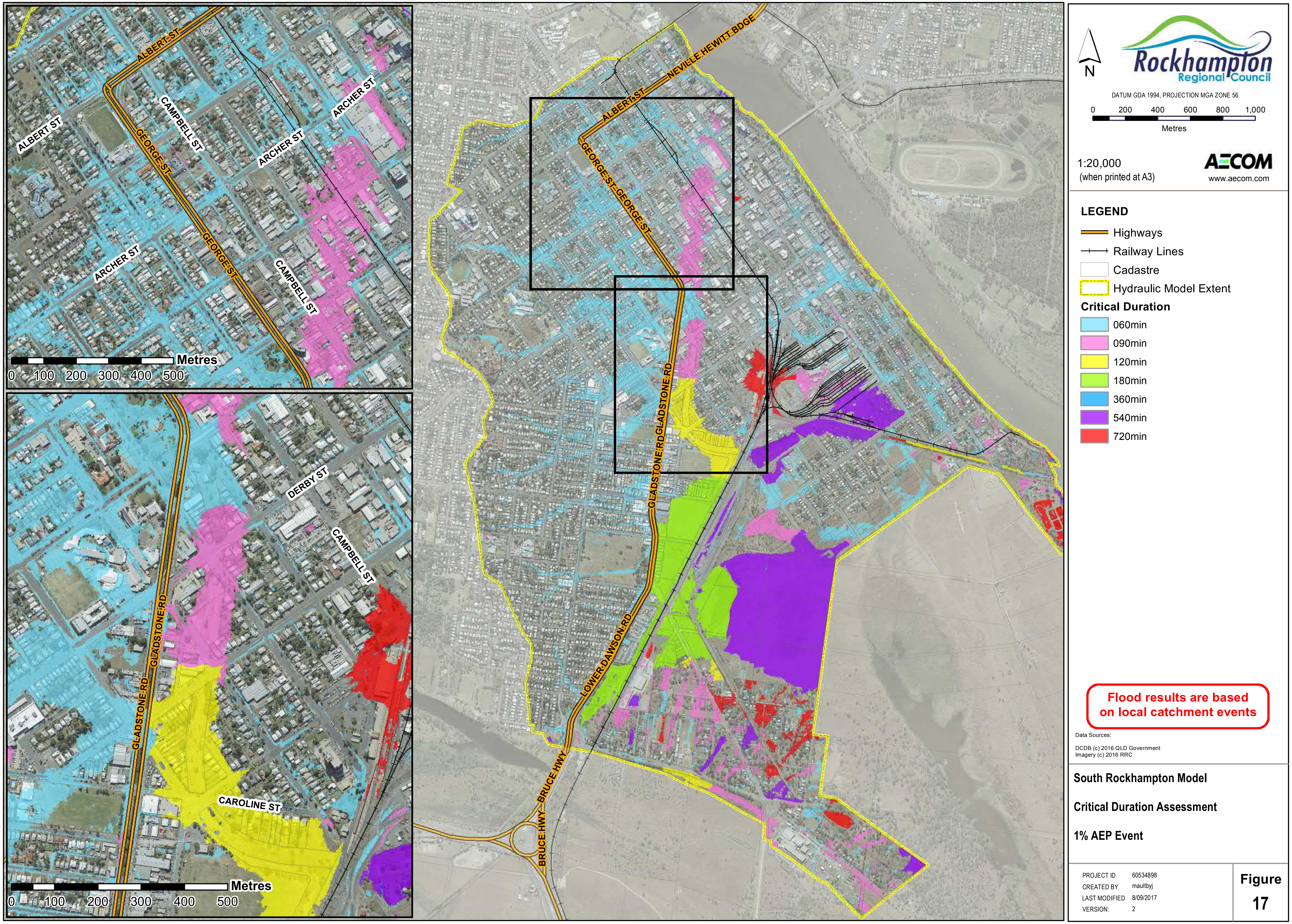
7.2 Critical Duration Assessment

The critical storm duration for the South Rockhampton Local Catchment area was assessed by simulating the 60m, 90m, 120m, 180m, 360m, 540m and 720m durations for the 1% AEP event. Figure 17 shows that for a 1% AEP event, the Upper Main Drainage Path shares critical durations of 60m, 90m and 120m, with the natural storage area between Lower Dawson Road and the railway line being critical in the 180m duration storm event.

Analysis of differences between the 60m, 90m and 120m storm events (refer Figure 18 and Figure 19) in the upper reaches of the main drain and catchment indicated peak water surface elevations generally varied by 50mm or less. Given the significance of the Upper Main Drainage Path flood behaviours, especially near Caroline Street, a critical duration of 120m was adopted for the catchment.

With the exception of the 1% AEP event, the 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 60m, 90m, 120m, 180m, 360m, 540m and 720m 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 independent of the critical storm duration variance across the model extent.


ALBERT ST
NEVILLE HEWITT BDGE
GEORGE ST
CAMPBELL ST
ARCHER ST
GLADSTONE RD
DERBY ST
CAROLINE ST
LOWER DAWSON RD
BRUCE HWY
Metres
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Rockhampton Regional Council
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Metres
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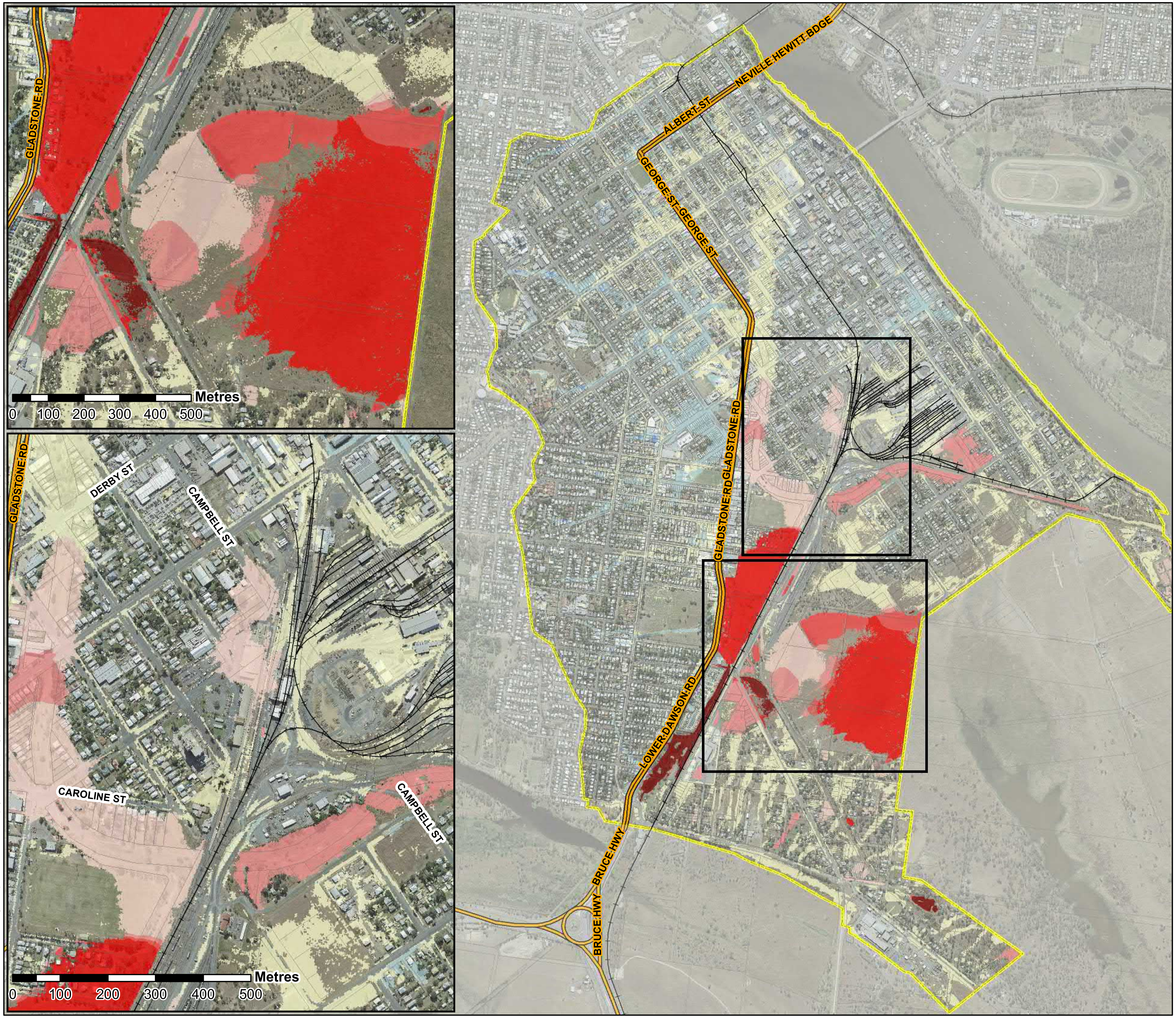
LEGEND
Highways
Railway Lines
Cadastre
Hydraulic Model Extent
Critical Duration
060min
090min
120min
180min
360min
540min
720min
Flood results are based on local catchment events
Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC
South Rockhampton Model
Critical Duration Assessment
1% AEP Event
PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 8/09/2017
VERSION: 2
Figure 17



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Metres

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(when printed at A3)

AECOM
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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

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

Flood results are based on local catchment events

Data Sources:

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

South Rockhampton Model

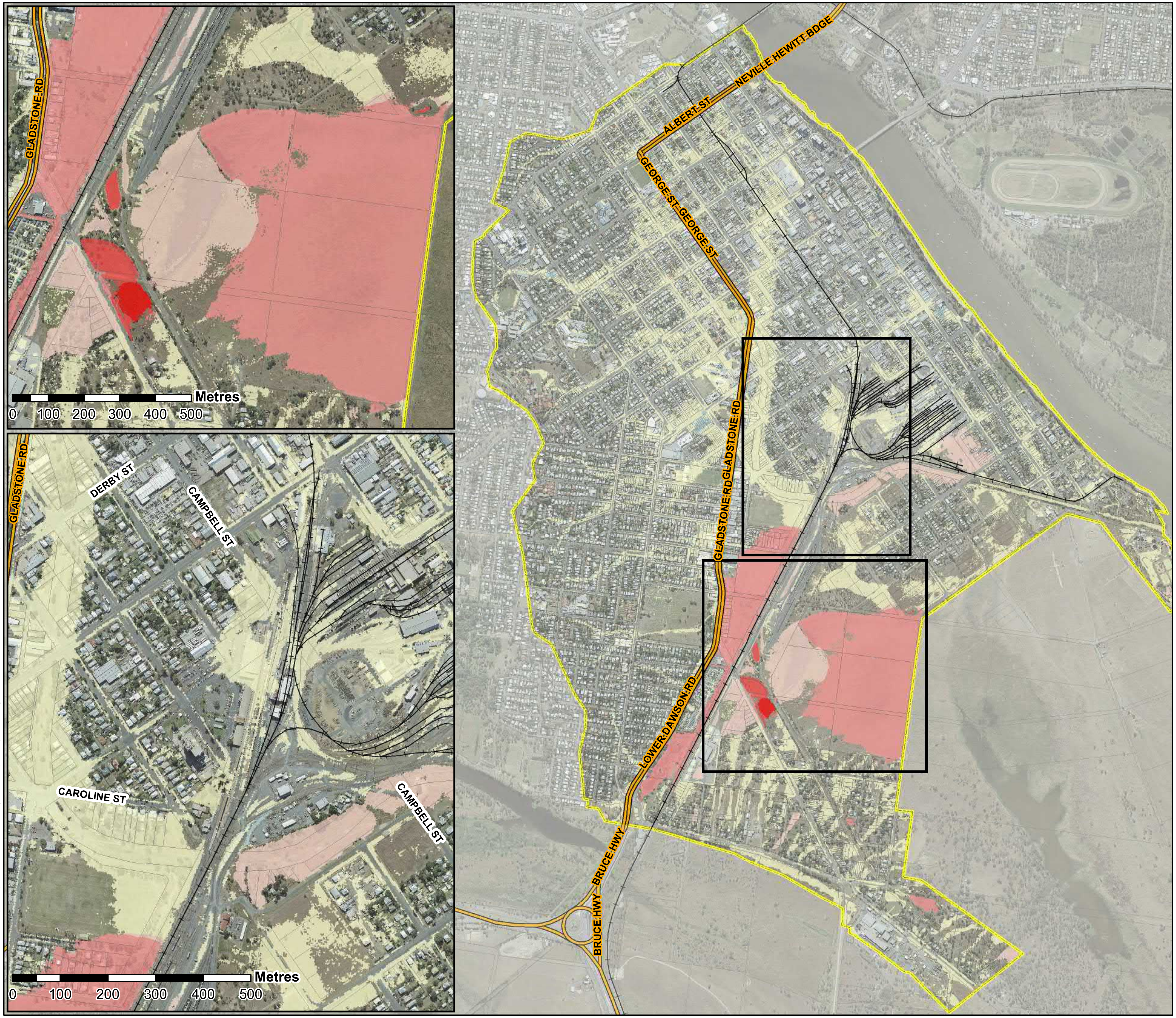
120min PWSE minus 60min PWSE

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 18

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 18_120m minus 60m.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000

Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in 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

Flood results are based on local catchment events

Data Sources:

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

South Rockhampton Model

120min PWSE minus 90min PWSE

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 19

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 19_120m minus 90m.mxd

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 flow depth is less than 75mm 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

Flood waters are largely contained within the road and drainage reserves with some ponding occurring across private properties along the Upper Main Drainage Path and along Derby Street and Stanley St west of Gladstone Road. Peak flood depths are generally less than 300 mm throughout urban flow paths due to the significant natural slopes, with depths in the Upper Main Drainage Path reaching 900 mm near Caroline Street.

Peak depth average flood velocities reach 1m/s in the upper reaches of the catchment with a lower peak of only 0.5 m/s in the Upper Main Drainage Path. Velocities through the South Rockhampton Cemetery flow path reach up to 1.5 m/s, lessening to 1 m/s where storage directly upstream of the railway line drains towards the Fiddes Street Lagoon area. Water surface elevations adjacent the rail peak under 6 mAHD.

- **Maps 4 to 6** – 39% AEP Baseline

The flood extent remains similar to the 1 EY Baseline, with the flood extent becoming wider in sections of the Upper Main Drain. Additional pooling occurs at the corner of Talford and Stanley Street, with the flood extent intercepting additional properties. Again depths in the Upper Main Drain reach up to 900 mm near Caroline Street. Additional inundation occurred over the council stockpile area.

Peak depth averaged velocities are again similar to the 1 EY Baseline event, velocities across the council stockpile area reach up to 1.5 m/s. Peak flows down Stanley Street and Derby Street reach 1.5 m/s. Water surface elevations adjacent to the rail peak under 7 mAHD.

- **Maps 7 to 9** – 18% AEP Baseline

Again the flood extent continues to become wider along the main flow paths especially within the Upper Main Drain. Notable flow begins to break out across Murray, West and Stanley Streets, in areas surrounding the Upper Main Drain. Depths in the main drain near Caroline Street reach up to 1.8 m. As the flow is now breaking out over the road the peak depth averaged velocities in these sections are predicted to peak at 2.0 m/s. Velocities within the Upper Main Drain average up to 0.5 m/s. Water surface elevations adjacent to the rail peak under 7 mAHD.

- **Maps 10 to 12** –10% AEP Baseline

Overland flows exceed the capacity of the road corridor and subsurface network along several natural flow paths from the western extent of the model, with runoff notably overtopping Canning Street, West Street and Murray Street which near Archer Street. Flood waters are also predicted to exceed the road corridor and inundate developed parcels surrounding Denham Street as runoff is directed to Central Park and ultimately the Main Drain.

Notable ponding of up to 1.2 m is expected at the corner of Talford Street and Stanley Street which extends northwest to parcels adjacent Derby Street. This results in overtopping of Gladstone Road and Stanley Street as overland runoff joins flows in the Upper Main Drain. Peak depths predicted in the Upper Main Drain upstream of the railway line are in the order of 1.2 to 1.5 m, with several properties upstream of Caroline Street experiencing depths of up to 0.9 m.

Peak depth averaged velocities are predicted to reach 2.0 m/s along steep sections of the road corridor, with small segments exceeding 2.0 m/s along the southwest portions of Archer Street and Denham Street as well as Brae Street. Predicted velocities in the Upper Main Drain are largely between 0.5 to 1.0 m/s, with peaks of up to 2.0 m/s across road surfaces and Council's material stockpile area directly of Caroline Street. Water surface elevations adjacent the rail peak under 7 mAHD.

· **Maps 13 to 15** – 5% AEP Baseline

The flood extent along the Upper Main Drain continues to widen, the extent of flooding on Kettle Park increases significantly as more water pools behind the railway line. Peak depths predicted in the Upper Main Drain upstream of the railway line are in the order of 1.8 to 2.1 m.

Peak Average Depth Velocities of flow across road ways continue to increase with flows greater than 2.0 m/s expected crossing Murray Street. Water surface elevations adjacent the rail peak under 8 mAHD.

· **Maps 16 to 18** – 2% AEP Baseline

Steep drainage lines from the eastern edge of the model are expected to be similar in depth and extent to those predicted in a 5% AEP event. Extensive increases to storage extents is noted upstream of the railway line, with the wetland area now overtopping into the table drain behind the caravan park. Peak flood depths within the channels of the Upper Main Drain and South Rockhampton Cemetery downstream of Gladstone Road are predicted to be up to 2.1 m deep. Noteworthy increases to extents are also observed within the Fiddes Street Lagoon area, with extents and depths approaching that of the 1% AEP event. Approximately two thirds of the main channel is now expected to see peak depth averaged velocities of at least 0.5 m/s.

· **Maps 19 to 21** – 1% AEP Baseline

Overland flow paths exceed the capacity of the road and subsurface drainage infrastructure along multiple natural flow paths within the extent of the model. Runoff continues to overtop Canning Street, Talford Street, West Street and Murray Street, while increasing in extents resulting in more affected properties. The natural flow paths connecting into the Upper Main Drain become evident and cross many local roads including Campbell Street, Denham Street, Kent Street and Fitzroy Street with depths ranging up to 0.6 m.

On the eastern extent of the model, which falls towards the Fitzroy River, at the intersection of Stanley and East Street overland flow depths of up to 0.9 m are predicted, causing inundation of some surrounding private properties. From the intersection the overland flow path continues through private land parcels before crossing Quay Street and discharging into the Fitzroy River. Peak depths predicted in the Upper Main Drain upstream of the railway line are in the order of 1.8 to 2.1 m, with some properties upstream of Caroline Street experiencing depths up to 1.2 m.

Peak averaged depth velocities are predicted to exceed 2.0 m/s along the steeper sections of North Street, Archer Street, Denham Street, Brea Street and Penlington Street. Predicted velocities in the Upper Main Drain are largely between 0.5 to 1.0 m/s, with peaks of up to 2.0 m/s across road surfaces and Council's material stockpile area directly of Caroline Street. Water surface elevations adjacent the rail peak under 7 mAHD.

· **Maps 22 to 24** – 0.2% AEP Baseline

Runoff along steep flow paths increases in extent from the 1% AEP. Significant increases to peak flood extents are noted in the upper portion of the Upper Main Drain and storage areas adjacent Port Curtis Road, with the leg south of the railway line now overtopped by up to 0.6 m. Storage areas adjacent to the railway line are seen to largely increase in depth, with the deeper segments reaching up to 3.0 m.

Comparison of peak flood depth maps indicates a significant amount of runoff is attenuated by the railway line, with the predicted flood height along the entirety of the rail being unanimously between 7 and 8 mAHD. Though extents have increased, peak flood heights within the Upper Main Drainage Path are expected to be similar to that of a 1% AEP event. The main channel within the Upper Main Drain is expected to see peak depth average velocities of 0.5 m/s or higher.

- **Maps 25 to 27** – 0.05% AEP Baseline

Overland flow paths greatly exceed the capacity of the road and subsurface drainage infrastructure along all natural flow paths. Of particular note, properties along Murray Street, West Street and the southwestern leg of Denham Street are expected to being inundated and cut off by runoff. Local roads throughout the Upper Main Drainage Path are predicted to be overtopped by up to 0.9 m towards the lower portion, with the lowest point in Caroline Street predicted to see up to 1.8 m over the road crest.

Localised ponding occurring within the eastern extent of the model is exacerbated, with several blocks adjacent East Street and Alma Street seeing depths of up to 0.6 m. Significant ponding along Stanley Street is evident, with evacuation routes from Depot Hill and the southern end of Rockhampton City being cut by up to 0.6 m of fast-flowing water across Quay St.

Peak averaged depth velocities within the Upper Main Drain are predicted to be largely 0.5m/s across developed land parcels and up to 2.0 m/s (though generally between 1.0 to 2.0 m/s) across inundated road corridors. Similar to the 0.2% AEP, flows overtopping Saleyards Street are expected to reach up to 2.0 m/s. Water surface elevations adjacent the rail peak under 8 mAHD.

- **Maps 28 to 30** – PMF Baseline

The PMF event predicts substantially higher inundation extents and depths, with private land inundation extending across a number of blocks up to a peak water surface elevation of 13 mAHD. Properties coinciding with steep natural flow paths are also predicted to be impacted with surrounding road corridors inundated, restricting available evacuation routes. Depths within the Upper Main Drain are predicted to exceed 3.0 m in the channelized sections and up to 3.0 m within private properties.

The railway line acts as a major hydraulic control, causing extensive ponding between 2.4 to 2.7 m deep upstream of the rail, resulting in a peak water surface elevation of more than 8.0 mAHD, which overtops the rail foundation. Higher peak depth averaged flood velocities are predicted across properties, with some instances expected to exceed 1.0 m/s. Overtopping velocities at Gladstone road are predicted to exceed 2.0 m/s, which may lead to significant erosion at and downstream of the highway. The Lower Main Drain breaks its banks downstream of Wood Street and falls towards the wetland storage areas near Gavial Creek.

- **Map 31** – Design Event Extent Comparison

Events up to a magnitude of 1% AEP show minor increases to flood extents at and upstream of the Upper Main Drain, with the 18% AEP event leading to both exceed sub-surface stormwater network capacity and broad overtopping of local road crests within the main drain. Storage areas upstream of the railway line are largely at capacity within a 10% AEP event, with 2% AEP events and larger causing impacts to several additional properties south of Saleyards Street. The 2% AEP event also exceeds the storage capacity of the detention basin southeast of Lower Dawson Road, with excess volumes filtering towards the Fiddes Street Lagoon Area.

The lagoon area provides adequate storage for 120 minute duration events up to the 0.05% AEP event, with the PMF causing substantial increases to peak flood extents both upstream and downstream of the railway line. The PMF event also increases the Upper Main Drainage Path extents by 70-80%.

7.4 Baseline Peak Discharges

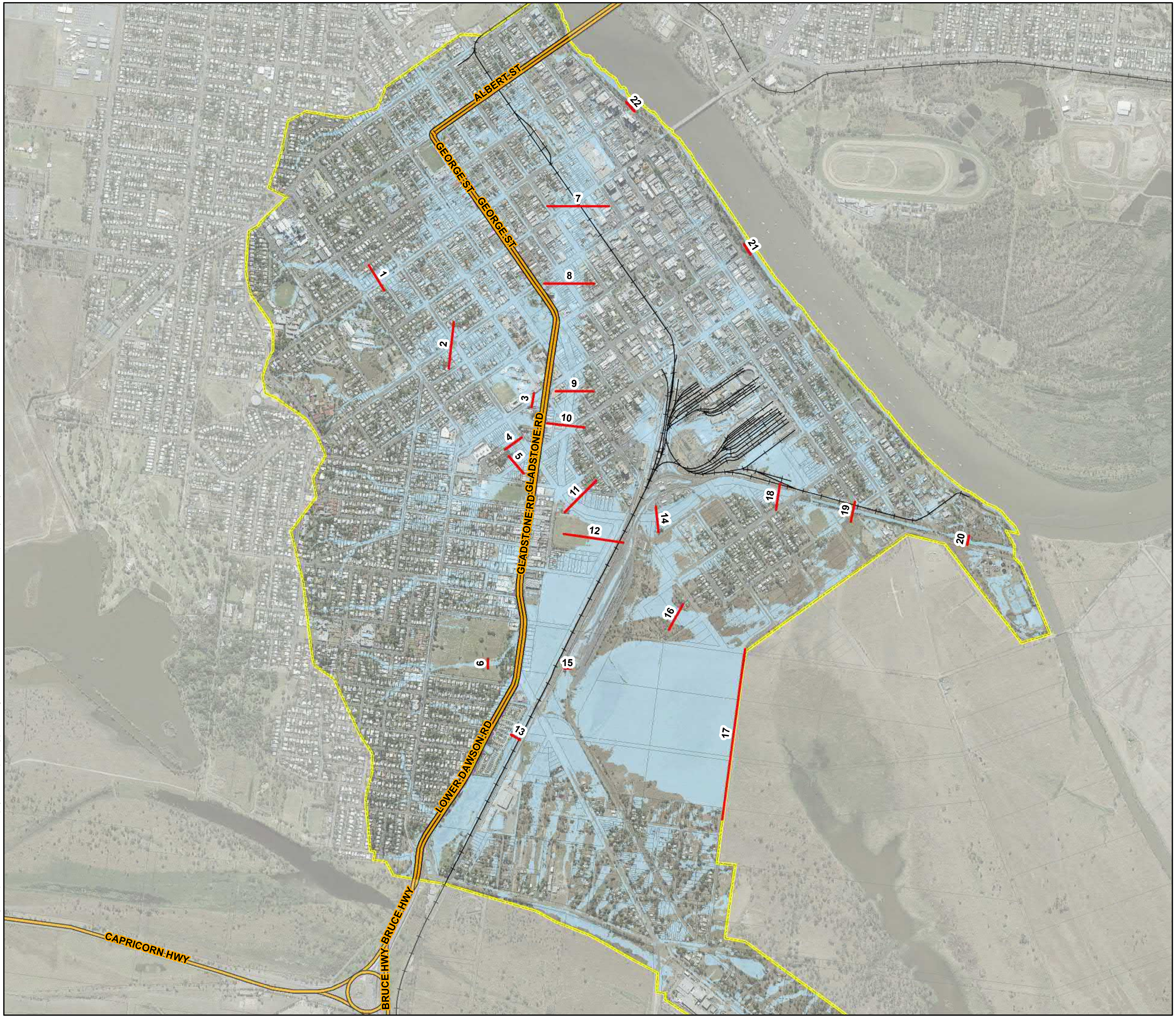
Peak discharges across the range of simulated design events were extracted at key locations, including but not limited to:

- Urban flow paths stretching from the western boundary towards the Upper Main Drain;
- South Rockhampton Cemetery flow path;
- Upper Main Drain and Lower Main Drain;
- Saleyards Street overflow;
- Downstream of rail;
- Fiddes Street Lagoon outlets; and

The cumulative flow from trunks mains conveying runoff perpendicular to the throat of the Fitzroy River have also been included in order to assess their conveyance against overland runoff through the Upper Main Drainage Path. Refer to Figure 20 for extraction cross-section locations. Table 21 below presents the results at corresponding locations.

Table 21 Summary of Baseline Peak Discharges

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (120 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Archer Street	1	3.0	4.6	7.1	8.3	8.8	10.8	12.3	18.1	23.0	40.4
Denham Street	2	1.4	2.6	5.7	7.2	7.9	10.5	12.3	18.9	23.4	40.9
Derby Street	3	0.0	0.2	0.8	1.4	1.8	3.8	5.0	9.3	12.9	22.0
Talford Street	4	0.1	0.9	3.9	5.3	5.9	9.2	11.1	17.8	23.2	61.3
Stanley Street	5	0.1	0.5	3.0	3.6	3.8	5.5	6.9	11.8	15.7	27.5
South Rockhampton Cemetery	6	1.8	2.9	4.4	5.1	5.4	6.5	7.5	11.3	14.1	25.3
Upper Main Drain	7	0.2	0.4	1.8	2.7	3.1	5.8	8.0	17.6	25.5	66.5
	8	0.1	0.1	1.9	3.2	3.9	8.0	10.8	23.8	34.3	82.8
	9	0.1	0.1	6.9	11.0	12.7	21.3	25.7	41.7	53.3	112.4
	10	0.2	0.3	6.5	11.1	13.2	24.2	29.2	50.5	67.5	135.6
	11	0.1	1.6	10.5	15.5	17.7	29.8	38.4	72.6	100.7	270.6
Saleyards Street	12	0.1	0.1	1.8	7.6	10.6	28.1	37.1	72.4	100.7	260.4
Caravan Park Table Drain	13	0.6	0.9	1.2	1.4	1.6	5.5	8.6	19.0	28.4	42.7
Downstream Rail	14	0.1	0.1	0.4	0.5	0.6	1.0	1.2	1.9	1.8	46.6
	15	1.1	1.5	2.0	3.0	3.2	4.2	4.6	5.9	13.6	55.7
West Street	16	0.3	0.7	1.7	2.2	2.4	3.8	4.6	7.8	10.7	58.6
Fiddes Lagoon Outflow	17	0.2	0.3	0.6	0.7	0.8	1.8	9.8	27.8	44.7	413.8
Lower Main Drain	18	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.6	1.6	24.5
	19	2.1	2.6	3.2	3.5	3.7	4.6	5.1	7.1	9.4	11.1
	20	2.1	2.9	3.9	4.4	4.7	5.9	6.5	8.8	11.1	16.5
Trunk Main Outlet (All)	21	7.5	7.9	9.1	9.4	9.5	10.1	10.3	10.9	11.3	14.3
	22	7.3	8.4	9.3	9.7	9.8	10.5	10.8	11.5	12.1	14.8



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Rockhampton Regional Council

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Metres

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AECOM
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LEGEND

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

Data Sources:

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

South Rockhampton Model

Key Flow Path Discharge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 20

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 20 Key Flow Paths Discharge Locations.mxd

7.5 Stormwater Network Capacity

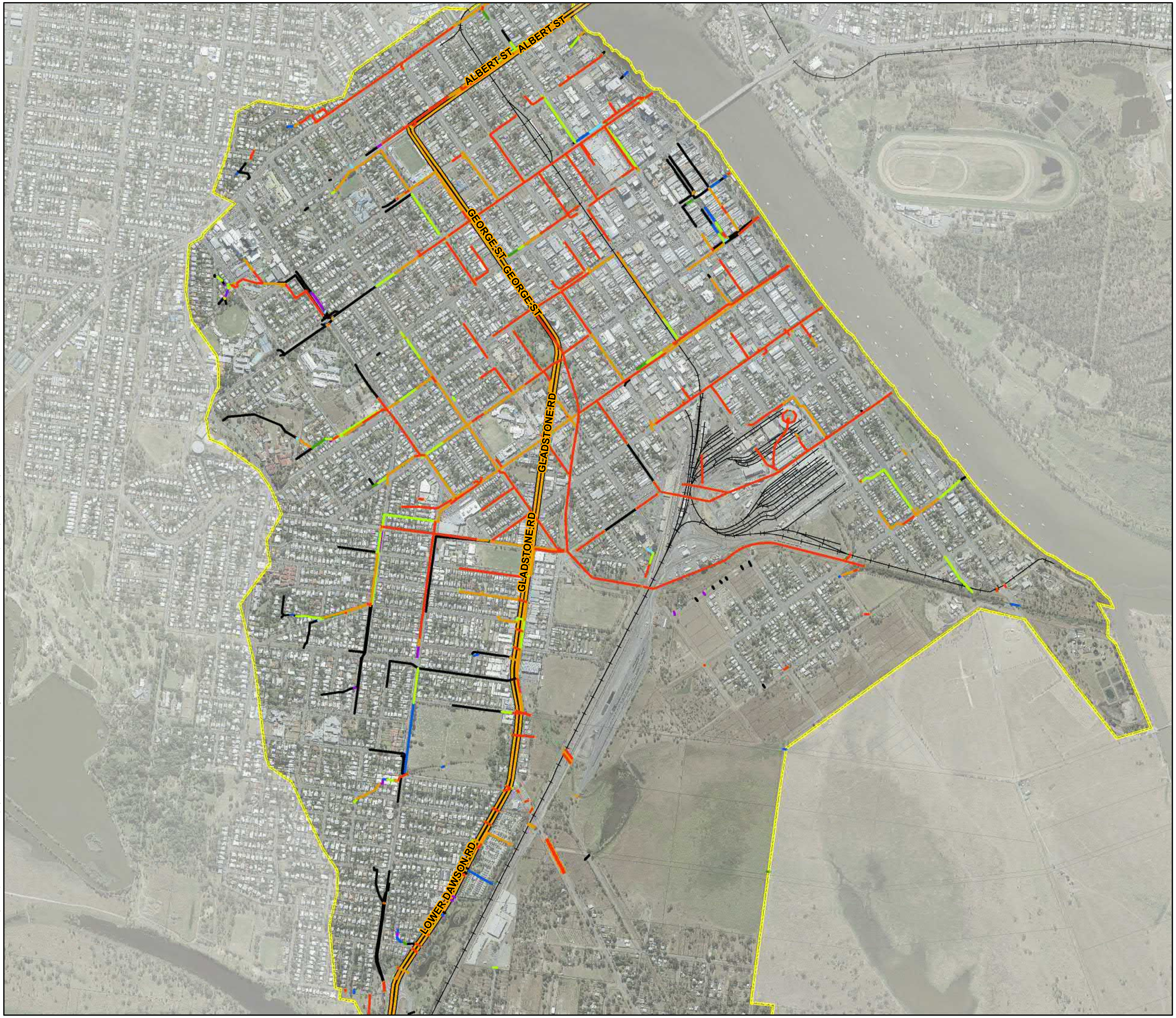
Figure 21 provides a spatial analysis of the existing underground network capacity, for the 120 minute storm duration. It can be seen that significant portions of the existing drainage network through the Main Drain and adjacent Gladstone Road have less than 1EY capacity. Approximately half the modelled network has less than 39% AEP capacity.

7.6 Implications for the South Rockhampton Flood Levee Project

As noted in Section 3.2, the assessment of flood behaviour within the South Rockhampton catchment has been the subject of previous technical investigations associated with the South Rockhampton Flood Levee project in 2014.

It is noted that the previous modelling used for the levee project has been updated and these results should be reviewed and adopted for the South Rockhampton Levee project moving forward. It may be necessary to make alterations to the current design to account for the latest modelling undertaken.

Furthermore, the assessment of potential flood mitigation options (which is the subject of Phase 3 of this study) should consider the implications to the South Rockhampton Flood Levee. This is particularly important for any future mitigation options which may alter the interior catchment management infrastructure proposed for the levee (i.e. interior catchment pump stations, etc).



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Rockhampton Regional Council

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Metres

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AECOM
www.aecom.com

LEGEND

Pipe Flowing Full in

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

Data Sources:

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

South Rockhampton Model

Basecase 1D Network Capacity Analysis

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/09/2017
VERSION:	A

Figure 21

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

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 à **Map SR-56**
- 15% Decrease in Roughness à **Map SR-57**

Map SR-56 indicates that with a uniformly increased roughness value across all material types, there is a corresponding increase in peak flood heights in the steeper areas of the catchment, resulting in a decrease in peak flood heights in storage areas adjacent the rail line. The majority of the urban areas within the catchment experience negligible increases in peak water surface elevations. Some residential areas adjacent to Derby Street, Gladstone Road and Archer Street are predicted to have minor increases in peak flood heights (up to 25 mm).

The result from the sensitivity analysis which applies a 15% decrease in manning's roughness values are shown in **Map SR-57**. The decrease in roughness indicates a corresponding decrease in peak flood heights across the steep overland flow paths and upper main drain, resulting in an increase in the peak flood heights in storage areas attenuated by the rail line. The reduction in peak flood heights is negligible throughout most of the catchment area however some residential areas adjacent to Derby Street, Gladstone Road and Archer Street are predicted to experience reductions in peak flood height of up to 25 mm.

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 South Rockhampton 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 SR-58 indicates that the 30% increase in applied rainfall significantly increases peak flood heights and extents throughout the urban catchment. The peak flood height for a 1% AEP event is predicted to increase by up to 255 mm within the upper main between Derby Street and Stanley Street. The peak flood height south of Saleyards Street (adjacent the rail) is predicted to increase by up to 350 mm which corresponds to a visibly increased flood extent across private parcels along Bartlem Street and John Street. The largest increase to peak flood height is predicted to be 500 mm within the retention basin at O'Shanesy Park. Despite the increased flood extent, the increase is not expected to inundate nearby houses on Jellicoe Street.

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 (5.55 mAHD) to coincide with a 1% AEP design storm event in the South Rockhampton catchment. The Fitzroy River flood height of 5.55 mAHD has been determined based upon results from RRC's Fitzroy River model (refer to Section 2.5).

As can be seen from **Map SR-59** the effect of this tailwater level extends to the upper main drain and storage area upstream of the rail corridor. The results indicate that the 18% AEP Fitzroy River event is dominant within the lower main drain and Fiddes Street Lagoon areas with increases in the order of 0.9 m within the storage area near Depot Hill and up to 2.9 m within the Lower Main Drain. An average increase of 40 mm is expected within the Upper Main Drain with a peak increase of 60 mm between Derby Street and Stanley Street. This is due to a tailwater effect imposed by the Fitzroy River levels which reduces the efficiency of trunk mains servicing the Upper Main Drain.

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.

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

- 20% Increase in Blockage à **Map SR-60**
- 50% Increase in Roughness à **Map SR-61**
- 100% Increase in Roughness à **Map SR-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 **SR-60** indicate that across the majority of the catchment, applying a 20% blockage to the stormwater network causes visible change in peak water surface elevation.

Steep flow paths and the Fiddes Street Lagoon areas are expected to be relatively unaffected with most areas being between ± 0.02 m of the baseline peak flood height results. The Upper Main Drain is expected to see an increase of up to 50 mm. A maximum increase in peak flood heights of up to 100 mm is expected within the Main Drain upstream of Wood Street.

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 higher peak flood heights in a number of areas. The majority of blocks east of West Street and south of William Street are predicted to experience up to 40 mm increases in peak flood height, with the intersections of Campbell Street and Alma Street with Archer Street expected to experience notable increases to peak flood extents. The Upper Main Drain is expected to see an increase of up to 240 mm across Stanley Street. A maximum increase in peak flood heights of up to 270 mm is expected within the storage area upstream of the rail corridor.

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 SR-62** indicate that several areas experience significant increases in peak flood heights. Key areas influenced by blockage of the stormwater infrastructure network include

- Upper Main Drain;
- Storage areas attenuated by the rail corridor;
- Lennox Street near Voss Park; and
- Intersections of:
  - Archer Street / Campbell Street
  - Stanley Street / East Street
  - Wood Street / East Street
  - Derby Street / Talford Street
  - Stanley Street / Talford Street
  - Stanley Street / Alma Street
  - William Street / East Street

Restriction of the trunk mains relieving the main drain results in significantly more runoff progressing overland towards the rail corridor. Portions of the Upper Main Drain are predicted to increase in peak flood extent, with the segment between Denham Street and William Street expected to double in width.

The peak flood heights across Caroline Street are particularly sensitive to blockage of the stormwater network, with predicted increases of up to 400 mm and a corresponding increase to flood extents. The attenuated area downstream of Saleyards Street is anticipated to increase in peak flood heights by up to 720 mm in an 18% AEP 120 minute storm events, resulting in additional properties impacted along Gladstone Road, Elizabeth Street and Bartlem Street. This increase also results in Port Curtis Road being overtopped in the 18% AEP event.

8.6 Inlet Structure Dimensions

As documented in Section 3.6, 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 **SR-63**, the difference in peak flood height is between ± 0.02 m across the majority of the catchment. 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 heights. The maximum change in peak flood height is expected to be 30mm within the Upper Main Drain.

8.7 Summary of Sensitivity Analysis Results

The results from the sensitivity analyses which were undertaken indicate that the most influential parameters are applied rainfall, riverine event tailwater levels and stormwater infrastructure blockage. As shown in Table 22, the 30% increase to rainfall resulted in an increase of more than 20 mm across almost 80% of the catchment with a peak increase of up to 0.5 m at O'Shanesy Park.

The 20%, 50% and 100% blockage analysis indicate that significant portions of the flooded area are impacted, especially intersections which are relieved by the subsurface drainage. Several hotspots which are sensitive to stormwater infrastructure blockage were identified, including the Upper Main Drain and intersections of Campbell Street / Archer Street and Alma Street / Archer Street. During a worst case scenario in which 100% of the subsurface network is blocked, 10% of the flood footprint is predicted to increase in peak flood height by more than 0.3 m.

The Fitzroy River sensitivity indicates that the lower portion of the catchment is predicted to experience significant increases in flood heights. The areas serviced by the trunk mains are also impacted due to the reduction in trunk main efficiency with the increased tailwater conditions.

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.

Table 22 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 has the most significant impact to predicted flood heights in the South Rockhampton catchment.

Table 22 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	Fitzroy River Tailwater Condition	20% Blockage of Stormwater Infrastructure	50% Blockage of Stormwater Infrastructure	100% Blockage of Stormwater Infrastructure	Increased Pit Dimensions
< -0.3	0%	0%	0%	0%	0%	0%	0%	0%
0.299 to -0.225	0%	0%	0%	0%	0%	0%	0%	0%
-0.225 to -0.150	0%	0%	0%	0%	0%	0%	0%	0%
-0.150 to -0.075	0%	0%	0%	0%	0%	0%	0%	0%
-0.075 to -0.02	3%	2%	0%	0%	2%	0%	0%	4%
-0.02 to 0.02	95%	95%	21%	54%	81%	56%	47%	90%
0.02 to 0.074	2%	3%	51%	10%	15%	29%	19%	6%
0.075 to 0.150	0%	0%	12%	8%	2%	4%	18%	0%
0.150 to 0.225	0%	0%	6%	5%	0%	6%	4%	0%
0.225 to 0.299	0%	0%	2%	2%	0%	5%	2%	0%
>0.3	0%	0%	8%	21%	0%	0%	10%	0%

9.0 Flood Hazard and Risk Assessment

9.1 Overview

Following completion of baseline model development, design event modelling and sensitivity analyses; a flood hazard and vulnerability assessment was completed for the South Rockhampton catchment. This included:

- Flood hazard analysis.
- Vulnerability assessment of key infrastructure.
- Evacuation route analysis.
- Building inundation and impact assessment.
- Flood Damages Assessment (FDA), including the calculation of Annual Average Damages (AAD).

Each of these aspects has been discussed in further detail below.

9.2 Baseline Flood Hazard Analysis

Flood hazard categorisation provides a better understanding of the variation of flood behaviour and hazard across the floodplain and between different events. The degree of hazard varies across a floodplain in response to the following factors:

- Flow depth.
- Flow velocity.
- Rate of flood level rise (including warning times).
- Duration of inundation.

Identifying hazards associated with flood water depth and velocity help focus management efforts on minimizing the risk to life and property. As such, a series of Flood Hazard Zones have been developed according to ARR 2016, in alignment with recommendations made in the ARR, Data Management and Policy Review (AECOM, 2017).

The hazard curves and classification names in ARR 2016 are identical to those of which shown in the Guide for Flood Studies and Mapping in Queensland document (DNRM, 2016). However, the ARR guidelines provide additional definition as to the classification levels for the hazard classes. This information is summarised in the Table 23 and Table 24.

Table 23 ARR 2016 Hazard Classification Descriptions

Hazard Vulnerability Classification	Description
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

Table 24 ARR 2016 Hazard Classification Limits

Hazard Vulnerability Classification	Classification Limit (D and V in combination) (m^2/s)	Limiting Still Water Depth (D) (m)	Limiting Velocity (V) (m/s)
H1	D*V ≤ 0.3	0.3	2.0
H2	D*V ≤ 0.6	0.5	2.0
H3	D*V ≤ 0.6	1.2	2.0
H4	D*V ≤ 1.0	2.0	2.0
H5	D*V ≤ 4.0	4.0	4.0
H6	D*V > 4.0	-	-

The ARR 2016 flood hazard classification limits are also shown graphically in Figure 22.

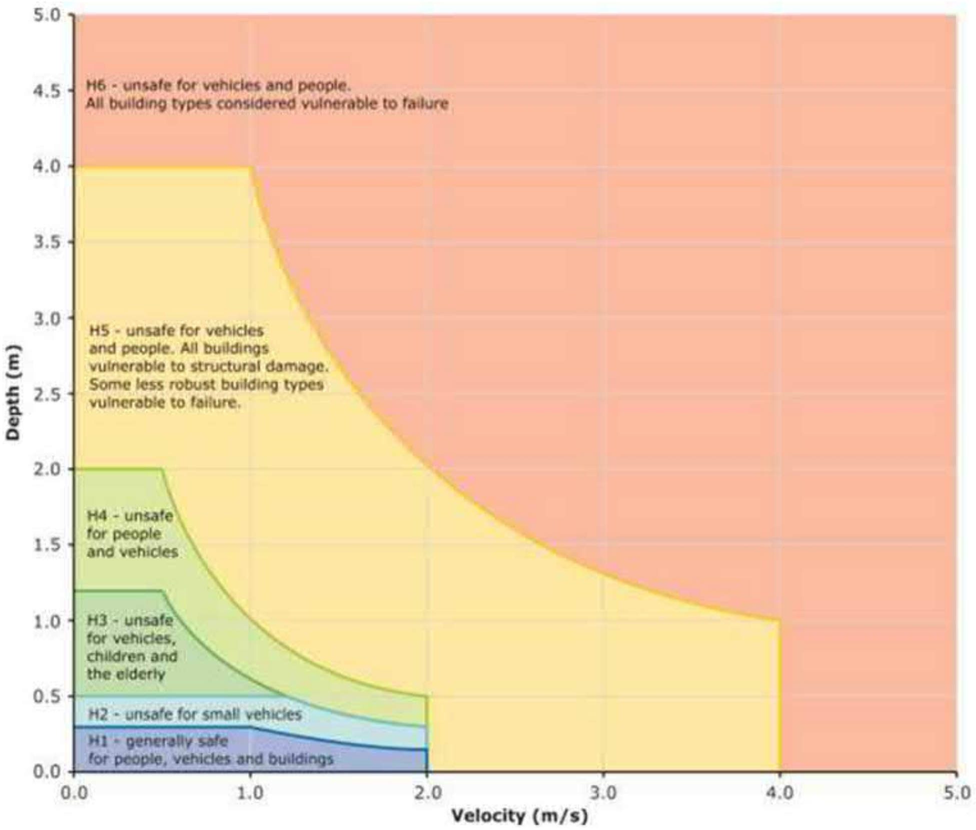


Figure 22 Hazard Vulnerability Classifications (Graphical)

Flood hazard mapping for the 18% and 1% AEP event has been included as maps **SR-64** to **SR-73** in the Volume 2 report. The hazard analysis for the 1% AEP event generally shows:

- Low to medium hazard (H1 and H2) across the majority of urbanised areas west of Gladstone Road and within the CBD and urbanised Depot Hill areas.
- High hazard (H3 and H4) within the Upper Main Drain, Lower Main Drain, Fiddes Street wetland, Stanley Street / Talford Street west of Gladstone Road, Saleyards Park, Kettle Park and O'Shanesy Park areas.
- Extreme hazard (H5) within portions of the Upper Main Drain, Lower Main Drain, Kettle Park, O'Shanesy Park and the South Rockhampton Cemetery (main channel flow path only).

9.3 Baseline Sewerage Infrastructure Flood Risk

Maps **SR-74** to **SR-78** show active sewerage infrastructure (gravity mains, rising mains, access chambers and pump stations) overlain on the 18% AEP and 1% AEP Baseline Flood Extents. The intent of these maps is to identify sewerage infrastructure at increased risk of flooding, and therefore potentially stormwater ingress (inflow).

It is recommended these maps are provided to Fitzroy River Water, to inform any future inflow/infiltration (I/I) identification and rectification works.

9.4 Baseline Vulnerability Assessment

A baseline vulnerability assessment has been undertaken to identify critical infrastructure and community assets which are at risk of flooding. The following categories have been included in this assessment:

- Water and sewerage infrastructure.
- Emergency services facilities including ambulance, police, fire and hospitals.
- Community infrastructure including schools, day-care centres, nursing homes, retirement villages and community facilities.
- Key road and rail assets.

Table 25 summarises the criterion used for each category, along with the corresponding reference to the specific table of results and locality figure.

Table 25 Vulnerability Assessment Criterion

Category	Criterion	Table	Figure
Water and Sewerage Infrastructure	Any electrified water or sewerage assets within the South Rockhampton catchment, experiencing flooding up to the baseline PMF event.	Table 26	Figure 23
Emergency Services	Any emergency services facilities within the South Rockhampton catchment, experiencing flooding up to the baseline PMF event.	Table 27	Figure 23
Community Infrastructure	Any community and critical infrastructure within the South Rockhampton catchment, experiencing flooding up to the baseline PMF event.	Table 27	Figure 23
Road Assets	Roads that have inundation depth greater than 0.3m in the 18% AEP event. *There are some exceptions included in the table which have less than 0.3m of inundation in the 18% AEP event, which represent critical roads within the South Rockhampton catchment.*	Table 28	Figure 24
Rail Assets	Rail segments that have inundation above top of ballast level (segments where rail ballast will be inundated)	Table 29	Figure 24

It is noted that depth values for road, rail and bridge assets were extracted from the centreline of the flooded road / rail / bridge segment.

Relevant information from the road asset vulnerability assessment has been collated and used in the evacuation assessment shown in Section 9.5.

Table 26 Water and sewage infrastructure - inundation depths for all events

Infrastructure Type (Asset ID)	Suburb	Location	Inundation Depths at Design AEP Events (m) – 120 minute storm										1% AEP Hazard Category *
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
South Rockhampton STP (639536) (entrance road)	Depot Hill	Quay Street Extended	-	-	-	-	-	-	-	-	-	0.11	-
Sewerage Pump Station (463755)	Rockhampton City	Fitzroy Street	-	-	0.24	0.28	0.30	0.36	0.40	0.54	0.64	1.17	H2
Sewerage Pump Station (463758)	Rockhampton City	East Lane	-	-	-	-	-	-	-	-	-	-	-
Sewerage Pump Station (463754)	Depot Hill	Arthur Street	-	-	-	-	-	0.13	0.19	0.38	0.48	0.92	H3
Sewerage Pump Station (QRX)	Port Curtis	Goss Street	-	-	-	-	-	-	-	-	-	-	-
Sewerage Pump Station (Caravan Park)	Allenstown	Lower Dawson Road	-	-	-	-	-	-	-	0.43	0.76	1.14	H2
Sewerage Pump Station (463756)	Allenstown	Ferguson Street	-	-	0.11	0.13	0.13	0.15	0.16	0.60	0.87	1.15	H1
Sewerage Pump Station (Littler Cum Ingham Park)	Depot Hill	Quay Street	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (463699)	The Range	Agnes Street	-	-	-	-	-	-	-	-	-	-	-

* Where there is no inundation predicted in the 1% AEP event, the 1% AEP Hazard Category is shown as a dash. There may however be some residual hazard in events greater than 1% AEP.

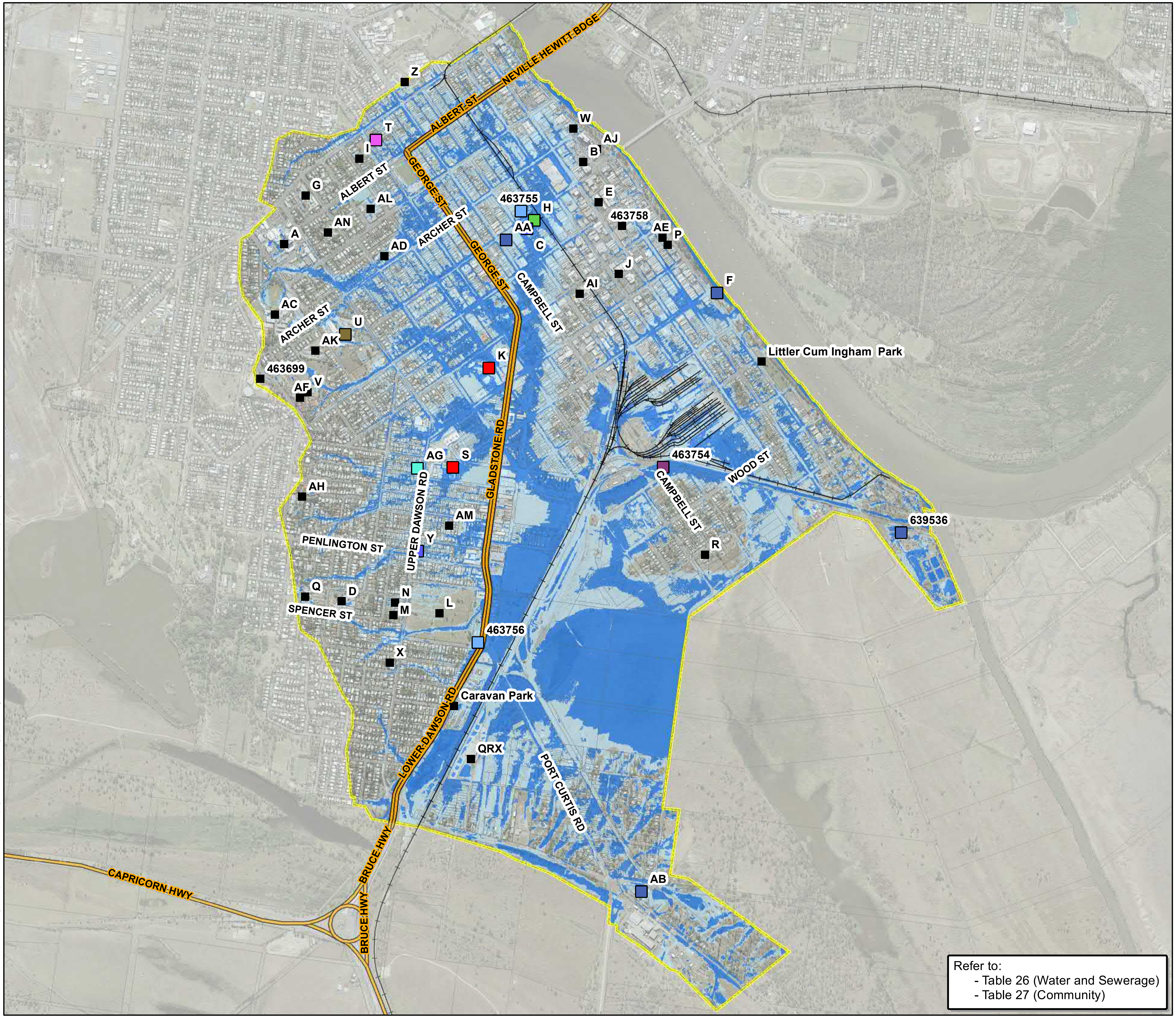
Table 27 Critical infrastructure, emergency facilities and possible evacuation shelters - Inundation depths for all events

ID	Infrastructure | Facility Name	Suburb	Location	Inundation Depths at Design AEP Events (m) – 120 minute storm										1% AEP Hazard Category *
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
A	Rockhampton Base Hospital	The Range	2-78 Canning Street	-	-	-	-	-	-	-	-	-	-	-
B	Rockhampton Rural Fire Office	Rockhampton City	3/34 East Street	-	-	-	-	-	-	-	-	-	-	-
C	Rockhampton Fire Station	Rockhampton City	59 Fitzroy Street	-	-	-	0.07	0.08	0.13	0.16	0.35	0.45	1.01	H1
D	Mater Hospital Rockhampton	The Range	31 Ward Street	-	-	-	-	-	-	-	-	-	-	-
E	Rockhampton Police Station	Rockhampton City	161 Bolsover Street	-	-	-	-	-	-	-	-	-	-	-
F	Rockhampton Coast Guard	Rockhampton City	299 Quay Street	-	-	-	-	-	-	-	-	-	0.36	-
G	Hillcrest Private Hospital	The Range	4 Talford Street	-	-	-	-	-	-	-	-	-	-	-
H	Rockhampton Ambulance Centre (driveway entrance)	Rockhampton City	57 Fitzroy Street	-	0.38	0.54	0.58	0.60	0.67	0.71	0.85	0.94	1.48	H3
I	C&K Leichhardt Community Kindergarten	The Range	19-21 West Street	-	-	-	-	-	-	-	-	-	-	-
J	City Occasional Childcare Centre	Rockhampton City	189 Alma Street	-	-	-	-	-	-	-	-	-	-	-
K	The Cathedral College	Allenstown	186 West Street	0.15	0.19	0.32	0.37	0.38	0.44	0.47	0.56	0.61	0.73	H3
L	Rockhampton Cemetery	Allenstown	113-171 Upper Dawson Road	-	-	-	-	-	-	-	-	-	-	-
M	St Peter's After School Care	The Range	170 Upper Dawson Road	-	-	-	-	-	-	-	-	-	-	-
N	St Peter's Primary School	The Range	158 Upper Dawson Road	-	-	-	-	-	-	-	-	-	-	-

ID	Infrastructure | Facility Name	Suburb	Location	Inundation Depths at Design AEP Events (m) – 120 minute storm										1% AEP Hazard Category *
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
P	Rockhampton TAFE	Rockhampton City	240 Quay Street	-	-	-	-	-	-	-	-	-	-	-
Q	Bethany Home	The Range	75 Ward Street	-	-	-	-	-	-	-	-	-	-	-
R	Depot Hill State School	Depot Hill	53-63 O'Connell Street	-	-	-	-	-	-	-	-	-	-	-
S	Allenstown State School (Margaret St Entrance)	Allenstown	13-33 Upper Dawson Road	0.22	0.29	0.36	0.39	0.40	0.45	0.47	0.58	0.66	0.84	H3
T	Capricorn Radio 4You	Rockhampton City	51 Murray Street	-	-	-	-	-	-	-	-	0.10	0.16	-
U	TAFE Rockhampton (Canning St Entrance)	The Range	114-190 Canning Street	-	-	-	-	0.07	0.07	0.08	0.11	0.13	0.21	H1
V	Rockhampton Girls Grammar School	The Range	155 Agnes Street	-	-	-	-	-	-	-	-	-	-	-
W	Rockhampton Media Centre	Rockhampton City	110 Victoria Parade	-	-	-	-	-	-	-	-	-	-	-
X	Munro Home	The Range	210 Upper Dawson Road	-	-	-	-	-	-	-	-	-	-	-
Y	Blue Care Homes	Allenstown	89 Upper Dawson Road	-	-	-	0.13	0.13	0.15	0.16	0.22	0.30	0.50	H1
Z	Eventide Home	Wandal	97 Campbell Street	-	-	-	-	-	-	-	-	-	-	-
AA	A.B.C. Developmental Learning Centre	Rockhampton City	245 Campbell Street	-	-	-	-	-	-	-	-	-	0.16	-
AB	Port Curtis Rd Primary School	Port Curtis	145 Port Curtis Road	-	-	-	-	-	-	-	-	-	0.14	-
AC	Rockhampton Grammar School	The Range	53-89 Agnes Street	-	-	-	-	-	-	-	-	-	-	-
AD	Archer Street Child Care Centre	The Range	148 Archer Street	-	-	-	-	-	-	-	-	-	-	-

ID	Infrastructure | Facility Name	Suburb	Location	Inundation Depths at Design AEP Events (m) – 120 minute storm										1% AEP Hazard Category *
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
AE	Australian Broadcast Corporation	Rockhampton City	236 Quay Street	-	-	-	-	-	-	-	-	-	-	-
AF	Rockhampton Girls Grammar Outside School Care	The Range	155 Agnes Street	-	-	-	-	-	-	-	-	-	-	-
AG	Allies Early Learning Centre	Allenstown	40 Upper Dawson Road	-	-	-	-	-	-	0.07	0.14	0.17	0.24	H1
AH	The Range Convent Blue Nursing Homes	The Range	263 Agnes Street	-	-	-	-	-	-	-	-	-	-	-
AI	Rockhampton Special School	Rockhampton City	91-115 William Street	-	-	-	-	-	-	-	-	-	-	-
AJ	Seven Queensland Rockhampton	Rockhampton City	130 Victoria Parade	-	-	-	-	-	-	-	-	-	-	-
AK	Rockhampton Grammar School Early Learning Centre	The Range	124 Quarry Street	-	-	-	-	-	-	-	-	-	-	-
AL	Benevolent Aged Care	The Range	60 West Street	-	-	-	-	-	-	-	-	-	-	-
AM	Allenstown Childcare	Allenstown	27 Ross Street	-	-	-	-	-	-	-	-	-	-	-
AN	Bethesda Aged Care Services	The Range	58 Talford Street	-	-	-	-	-	-	-	-	-	-	-

* Where there is no inundation predicted in the 1% AEP event, the 1% AEP Hazard Category is shown as a dash. There may however be some residual hazard in events greater than 1% AEP.



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LEGEND

Critical Infrastructure Inundation (Lowest Immunity)

- Outside PMF Event
- 1 EY
- 39%
- 18%
- 10%
- 5%
- 2%
- 1%
- 0.2%
- 0.05%
- PMF
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

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

South Rockhampton Model
Critical Infastructure Inundation

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VERSION:	2

Figure 23

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Table 28 Roads Assets - Inundation Lengths and TOS for 1% AEP event and Inundation depths for all events

ID	Road | Street Name	Suburb	1% AEP Inundation Length (m)^	1% AEP TOS (hrs)^	Inundation Depths at Design AEP Events (m) – 120 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
1	Denham Tce	Allenstown	95	3.0	0.28	0.30	0.36	0.38	0.39	0.43	0.45	0.52	0.56	0.69	H3
2	Gladstone Rd (Church St to Ross St)	Allenstown	265	2.5	0.44	0.50	0.57	0.59	0.60	0.62	0.64	0.68	0.70	0.78	H3
3	Gladstone Rd (Stanley St)	Allenstown	240	3.1	0.00	0.33	0.51	0.54	0.55	0.60	0.61	0.75	0.94	1.81	H3
4	Grant St (Caroline St to Talford St)	Allenstown	90	2.9	0.11	0.24	0.50	0.57	0.59	0.70	0.75	0.89	0.98	1.77	H3
5	Margaret St	Allenstown	70	3.2	0.37	0.43	0.50	0.53	0.55	0.59	0.61	0.72	0.79	0.97	H3
6	Patrick St	Allenstown	95	2.4	0.38	0.45	0.50	0.54	0.56	0.65	0.69	0.83	0.93	1.58	H3
7	South St (Caroline St to West St)	Allenstown	85	5.6	0.00	0.36	0.80	0.96	1.02	1.25	1.34	1.59	1.76	2.50	H4
8	Stanley St (Caroline St to Talford St)	Allenstown	215	4.1	0.27	0.71	0.93	0.97	0.99	1.05	1.08	1.19	1.33	2.19	H3
9	Stanley St (Gladstone Rd to West St)	Allenstown	215	4.8	0.15	0.17	0.50	0.67	0.74	0.99	1.09	1.37	1.56	2.37	H5
10	Talford St	Allenstown	70	3.8	0.14	0.58	0.79	0.83	0.85	0.92	0.95	1.06	1.20	2.06	H3
11	West St	Allenstown	120	3.6	0.00	0.19	0.61	0.72	0.76	0.94	1.05	1.39	1.61	2.42	H4
12	Caroline St (west of Gladstone Rd)	Depot Hill	260	5.7	0.00	0.30	0.74	0.90	0.96	1.19	1.28	1.53	1.70	2.44	H4
13	Murray Ln (Cambridge St to Archer St)	The Range	205	3.2	0.40	0.44	0.48	0.50	0.51	0.53	0.54	0.58	0.60	0.66	H3
14	Alma Ln (Archer St to Fitzroy St)	Rockhampton City	225	2.6	0.13	0.39	0.54	0.59	0.60	0.68	0.73	0.88	0.98	1.50	H3
15	Alma Ln (Cambridge St to Albert St)	Rockhampton City	215	2.7	0.00	0.32	0.43	0.46	0.47	0.51	0.53	0.58	0.62	0.74	H3
16	Archer St	Rockhampton City	70	2.2	0.26	0.32	0.40	0.43	0.44	0.47	0.49	0.54	0.57	0.66	H3

ID	Road | Street Name	Suburb	1% AEP Inundation Length (m)^	1% AEP TOS (hrs)^	Inundation Depths at Design AEP Events (m) – 120 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
17	Campbell Ln	Rockhampton City	210	4.8	0.46	0.53	0.75	0.81	0.84	0.98	1.04	1.25	1.41	2.12	H4
18	Campbell St	Rockhampton City	95	5.5	0.22	0.34	0.63	0.71	0.73	0.79	0.81	0.87	0.90	1.06	H3
19	Denison Ln	Rockhampton City	135	2.5	0.16	0.28	0.42	0.47	0.48	0.55	0.59	0.72	0.82	1.36	H3
20	Fitzroy St (Kent St to Alma St)	Rockhampton City	240	2.6	0.14	0.48	0.65	0.69	0.71	0.78	0.82	0.97	1.07	1.60	H3
21	George St	Rockhampton City	170	3.8	0.46	0.49	0.73	0.83	0.86	0.99	1.05	1.27	1.43	2.19	H4
22	Kent St	Rockhampton City	215	2.8	0.00	0.26	0.47	0.53	0.55	0.63	0.67	0.83	0.96	1.58	H3
23	Quay Ln	Rockhampton City	150	3.2	0.13	0.16	0.41	0.49	0.52	0.66	0.72	0.90	1.01	1.31	H3
24	William St (Campbell St to Gladstone Rd)	Rockhampton City	130	3.0	0.22	0.25	0.49	0.59	0.62	0.76	0.82	1.04	1.20	1.96	H3
25	Garden St	Port Curtis	65	5.6	0.26	0.43	0.70	0.75	0.78	0.89	0.93	1.00	1.04	1.19	H3

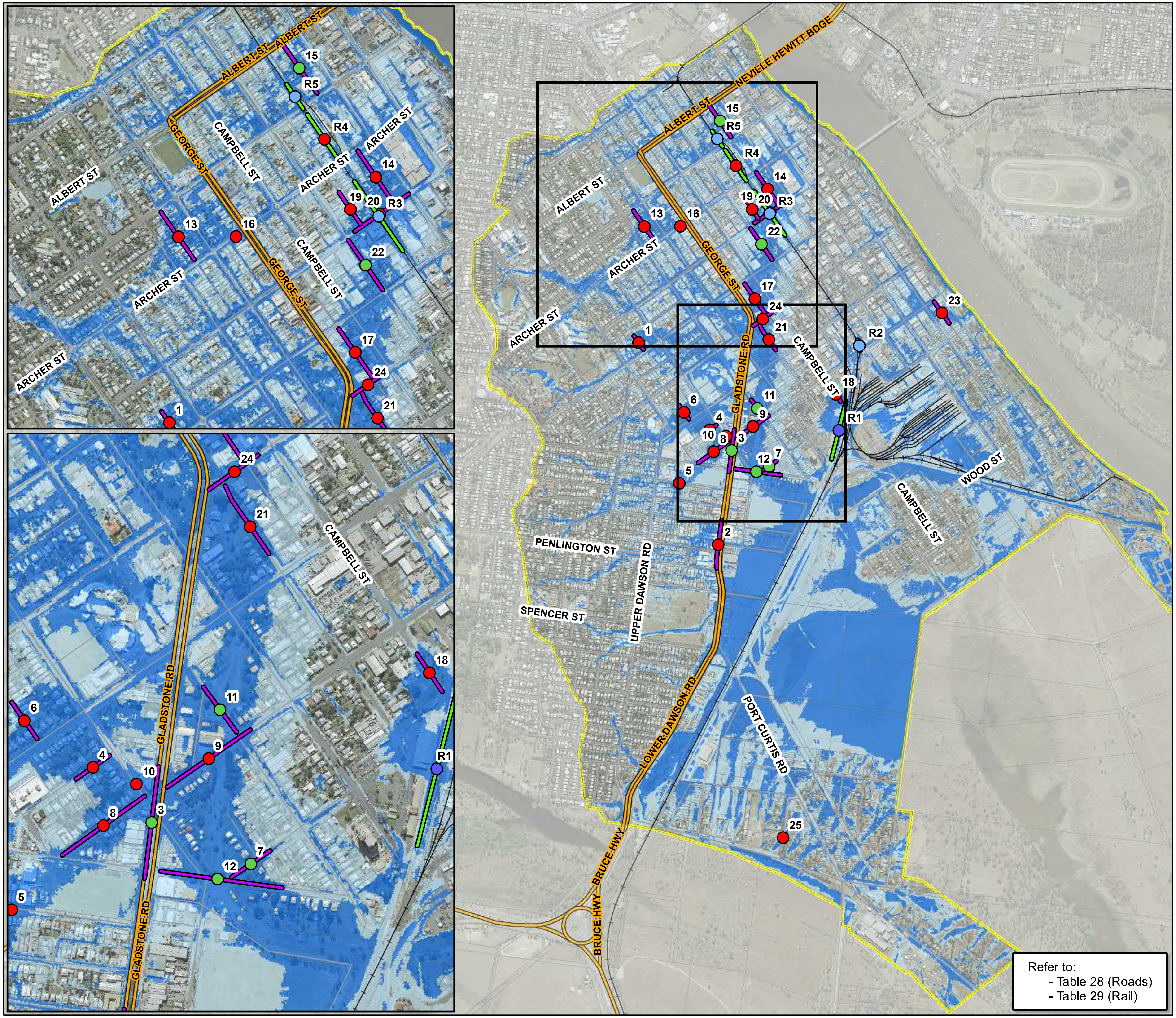
^Note: inundation lengths and TOS values are approximate only, and can vary depending on actual rainfall patterns and antecedent conditions.

* Maximum flood depth at road centreline extracted within the flooded road segment. Flood depths will vary at road shoulders and therefore results are approximate only.

Table 29 Rail Assets - Inundation lengths for 1% AEP event and inundation depths for all events

ID	Rail Line	Suburb	1%AEP Inundation Length (m)^	Inundation Depths at Design AEP Events (m) – 120 minute storm *										1% AEP Hazard Category **
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
R1	North Coast Rail Line (eastern end of South St)	Depot Hill	330	-	-	-	0.09	0.09	0.15	0.17	0.22	0.26	0.41	H1
R2	North Coast Rail Line (corner Stanley St and Denison St)	Deport Hill	60	-	-	0.10	0.11	0.12	0.14	0.15	0.17	0.19	0.23	H1
R3	North Coast Rail Line (corner Fitzroy St and Denison St)	Rockhampton City	300	-	-	0.21	0.25	0.27	0.34	0.38	0.52	0.62	1.15	H2
R4	North Coast Rail Line (Denison St – Archer St to Cambridge St)	Rockhampton City	210	0.09	0.10	0.13	0.14	0.15	0.19	0.22	0.30	0.34	0.51	H1
R5	North Coast Rail Line (Denison St – Cambridge St to Albert St)	Rockhampton City	105	-	-	0.08	0.10	0.11	0.15	0.17	0.23	0.26	0.40	H1

^Note: inundation lengths are approximate only.
* Maximum flood depth at rail centreline extracted within the flooded rail segment. Flood depths will vary across the formation and therefore results are approximate only.



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LEGEND

Road, Rail and Bridge Infrastructure (Lowest Immunity)

- Outside PMF Event
- 1 EY
- 39%
- 18%
- 10%
- 5%
- 2%
- 1%
- 0.2%
- 0.05%
- PMF
- 1% AEP Rail Inundation Extent (Lengths >75m shown)
- 1% AEP Road Inundation Extent (Lengths >75m shown)
- Highways
- Railway Lines
- Road Centrelines
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

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

South Rockhampton Model
Critical Infastructure Inundation

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VERSION:	2

Figure 24

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9.4.1 Vulnerability Assessment Summary

The following provides a summary of key findings of the vulnerability assessment:

- The Fitzroy Street SPS (Ref: 463755), Arthur Street SPS (Ref: 463754), Lower Dawson Road SPS (Ref: Caravan Park) and Ferguson Street SPS (Ref: 463756) are predicted to have less than 0.2% AEP flood immunity. It is noted however that some of these pump stations are below ground and improvements to flood immunity would be very difficult to achieve. It is recommended this information be passed onto FRW as the asset owner.
- Low depth flooding is predicted at TAFE Rockhampton, Blue Care Homes and Allies Early Learning Centre in the 0.2% AEP event.
- Frequent flooding is predicted at Rockhampton Fire Station, Rockhampton Ambulance Centre, The Cathedral College and Allenstown State School.
- The North Coast Rail Line is predicted to experience frequent flooding to Top of Ballast level, within the city reaches, with some areas predicted to be inundated during the 1EY local catchment event.
- A number of road segments are predicted to experience inundation in the 1EY event and larger. Estimated TOS ranges from 2.0 hours to approximately 5.5 hours.

9.5 Evacuation Routes

Generally local catchment flooding within the South Rockhampton catchment is due to short duration, high intensity rainfall events. The relatively steep upper catchment and urbanisation throughout much of the upper, middle and lower catchment can result in inundation of residential and commercial buildings. In addition, inadequate stormwater infrastructure in some locations results in nuisance flooding within the urbanised catchment due to overland runoff.

Due to the short critical duration of the South Rockhampton catchment, the warning time between the commencement of the rain event and subsequent flood inundation can be short (refer Figure 28 to Figure 32). This limits the opportunity for evacuation, and generally the action taken by the community is to '*shelter in place*' until the flooding has passed.

An assessment of evacuation routes has therefore focussed on areas that become isolated during flooding, as well as high hazard areas that may require flood free evacuation access. Table 30 provides a summary of the isolated areas and key evacuation routes, assessed up to the PMF event.

Table 30 Isolated Areas Summary

Isolated Area	Key Evacuation Route/s	Accessed Via	Warning Time Until Evac. Route Cut	Figure Ref.
Depot Hill (Bounded by Arthur St to the north, West St to the west, Lucius St to the south and Denison St to the east)	Bolsover St Fiddes St	Wood St Lucius St	Up to 1.0 hour Up to 1.5 hours	Figure 25
Area bounded by Stanley St, Bolsover St, OConnell St and Quay St	East St Bolsover St	Direct Access	Up to 0.5 hour	Figure 26
Area bounded by Cambridge St, Murray St, Denham St and Denison St	Gladstone Road	Direct Access	Up to 0.5 hour	Figure 27

Figure 25 Isolated Area – Depot Hill area (Note: PMF flood extents shown)

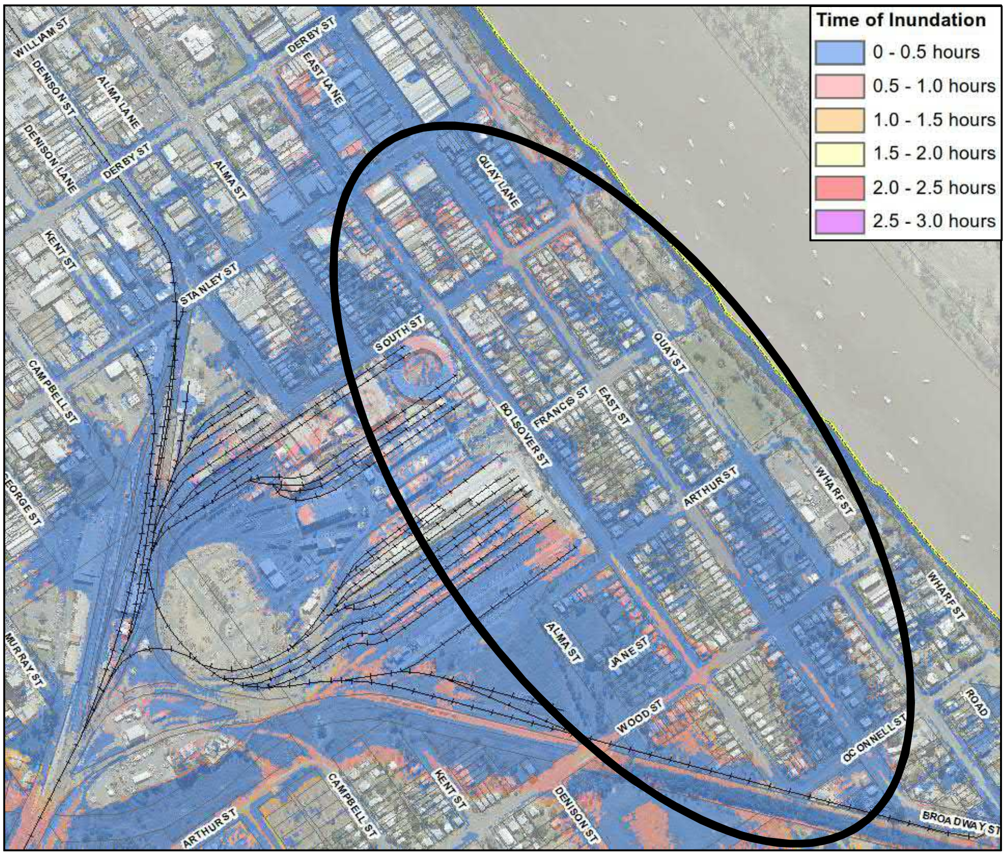


Figure 26 Isolated Area – Bounded by Stanley St, Bolsover St, OConnell St and Quay St (Note: PMF flood extents shown)

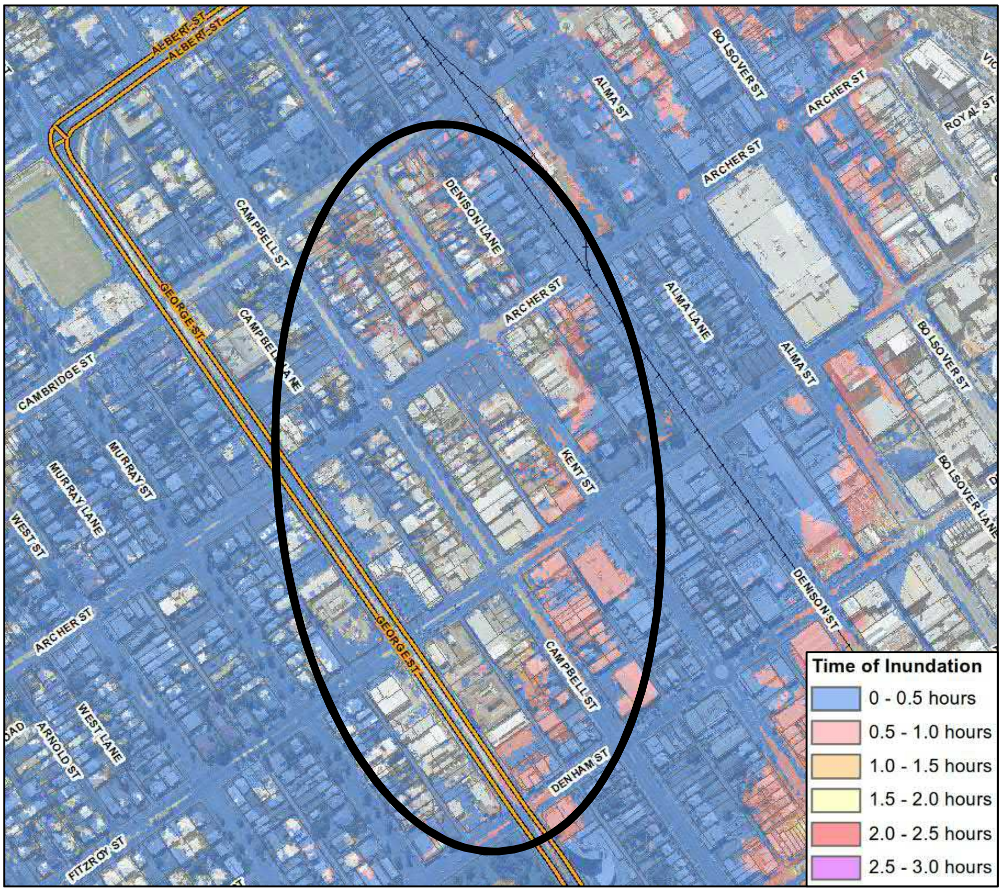
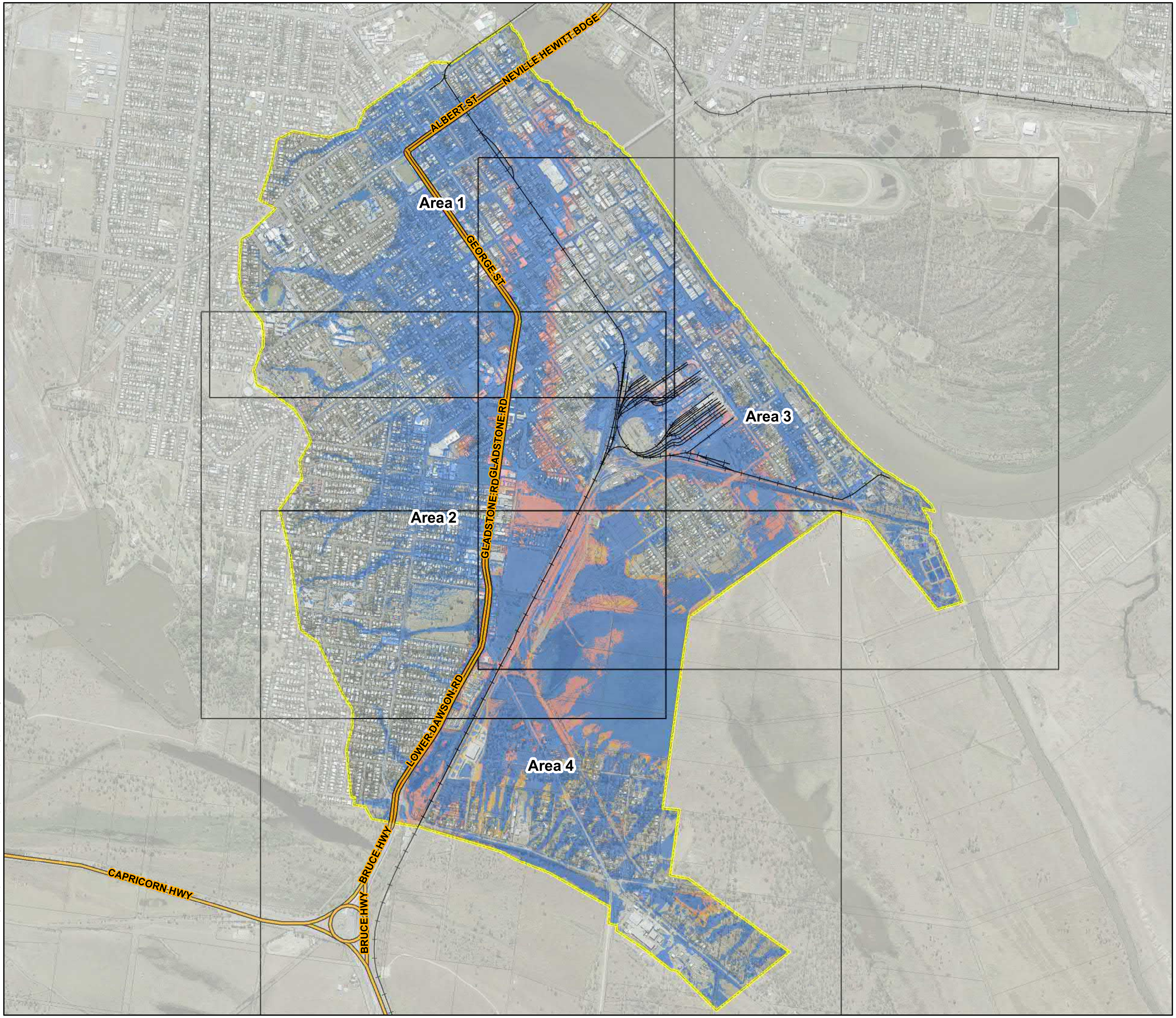


Figure 27 Isolated Area – Bounded by Cambridge St, Murray St, Denham St and Denison St (Note: PMF flood extents shown)



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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.5 hours
- 0.5 - 1.0 hours
- 1.0 - 1.5 hours
- 1.5 - 2.0 hours
- 2.0 - 2.5 hours
- 2.5 - 3.0 hours

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

South Rockhampton Model
Time of Inundation - Catchment Overview

PMF 120min Storm event

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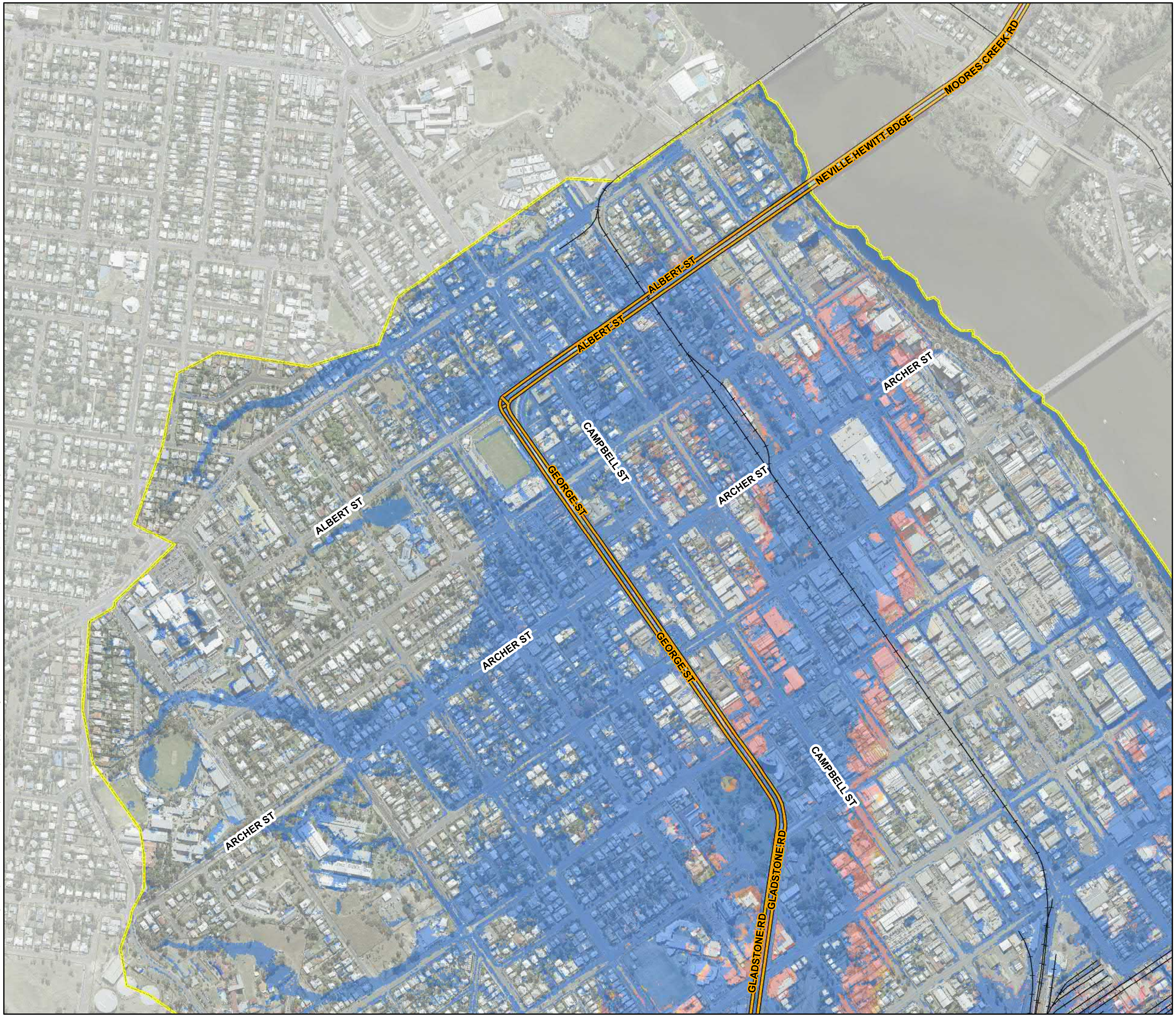
Figure 28



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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.5 hours
- 0.5 - 1.0 hours
- 1.0 - 1.5 hours
- 1.5 - 2.0 hours
- 2.0 - 2.5 hours
- 2.5 - 3.0 hours

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

South Rockhampton Model
Time of Inundation - Area 1

PMF 120min Storm event

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Figure 29

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Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.5 hours
- 0.5 - 1.0 hours
- 1.0 - 1.5 hours
- 1.5 - 2.0 hours
- 2.0 - 2.5 hours
- 2.5 - 3.0 hours

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

South Rockhampton Model
Time of Inundation - Area 2

PMF 120min Storm event

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VERSION:	2

Figure 30

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Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.5 hours
- 0.5 - 1.0 hours
- 1.0 - 1.5 hours
- 1.5 - 2.0 hours
- 2.0 - 2.5 hours
- 2.5 - 3.0 hours

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

South Rockhampton Model
Time of Inundation - Area 3

PMF 120min Storm event

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VERSION:	2

Figure 31

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Rockhampton Regional Council

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Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.5 hours
- 0.5 - 1.0 hours
- 1.0 - 1.5 hours
- 1.5 - 2.0 hours
- 2.0 - 2.5 hours
- 2.5 - 3.0 hours

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

South Rockhampton Model
Time of Inundation - Area 4

PMF 120min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/09/2017
VERSION:	2

Figure 32

9.6 Building Impact Assessment and Flood Damages Assessment

The predicted baseline flood levels were used to undertake a building impact assessment and FDA, including calculation of AAD for the catchment.

Flood damages, or the anticipated cost to residents, businesses and infrastructure due to flooding, have been estimated using a standardised approach adopted throughout Australia. The approach estimates the tangible impacts flooding has on people, property, and infrastructure, such as flooding of a building and/or contents, the lost opportunity value associated with wages and revenue and flooding of transport and utility networks. These tangible impacts are estimated based on the depth, likelihood of flooding and type of building. Intangible impacts, such as emotional stress and inconvenience, were not quantified due to their non-tangible nature.

A building's estimated depth of flooding and whether it is a residential single story, multi-story or raised building or a non-residential building, determines the total estimated flood damage for that building. The direct flood damage is determined based on depth-damage curves, which relate building type, building area and flood depth to the damage associated with the structure and content. Indirect damages associated with lost opportunity value, i.e. wages and revenue and the cost of temporary relocation, are then estimated as an additional percentage for residential and non-residential buildings. The combined direct and indirect damages then represent the total damage to the building. Infrastructure damages, i.e. water treatment plants and utility and transport networks, are then estimated as a percentage of the total residential and non-residential damage combined.

Full details of the methodology applied during this study, has been included in Appendix B.

9.6.1 Baseline Building Impact Assessment

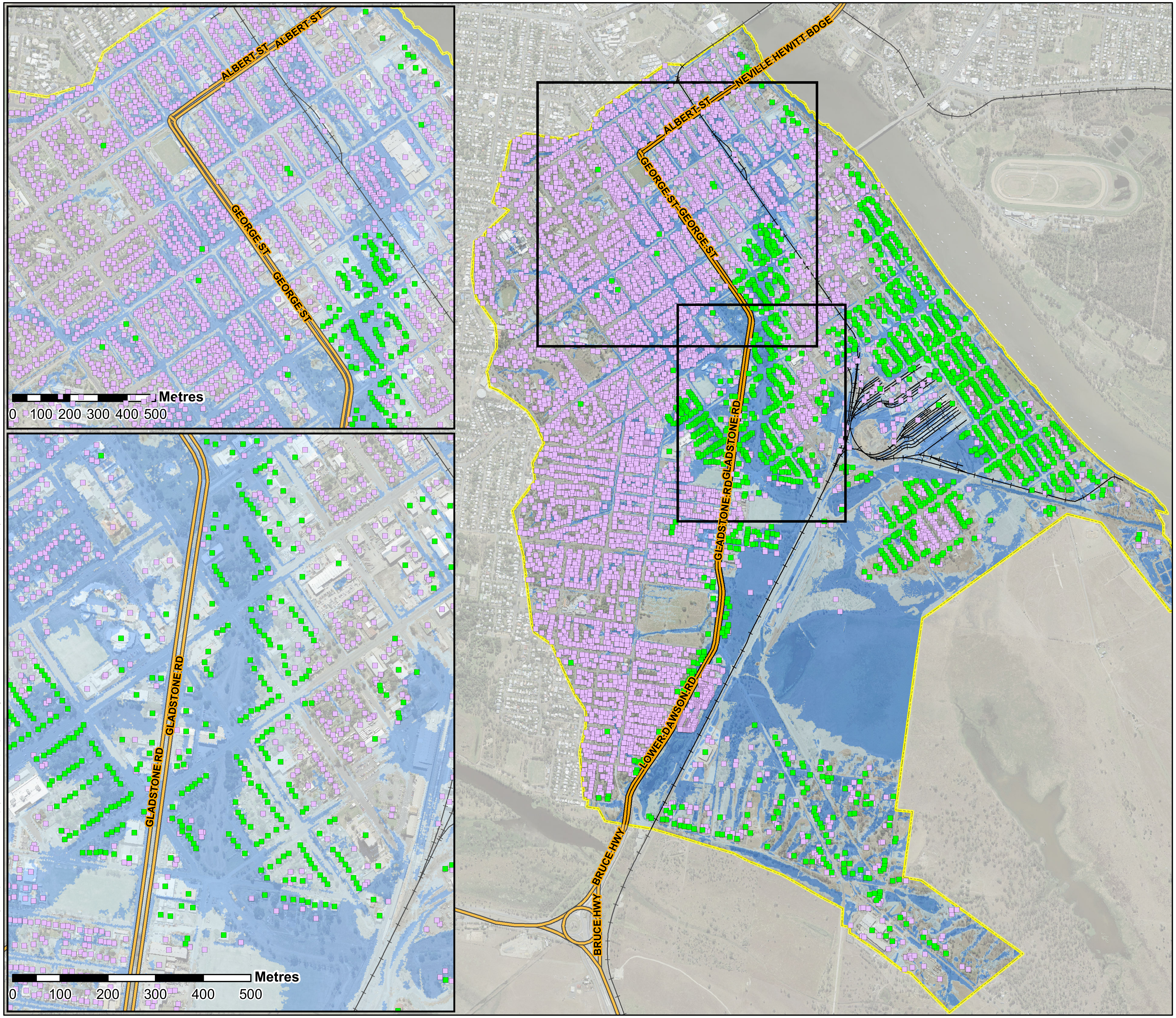
Council provided a building database, containing ~28,000 buildings digitised within the modelled area. Of these, ~5,900 buildings contained surveyed data, focussed on Creek flooding extents in North Rockhampton and Fitzroy River flood extents in South Rockhampton (refer Figure 33).

In order to complete a Building Impact Assessment and FDA, a complete building database with floor levels, classifications and ground levels is needed within the PMF direct rainfall flood extent. To achieve this, the following tasks were completed:

- Review of the digitised buildings, to remove erroneous data such as *footpaths*, *building demolished*, *no building* etc.
- Estimation of floor levels and ground levels for buildings outside Council's surveyed database (~22,100 buildings in total, with ~5,600 within South Rockhampton catchment).
  - The height above ground level was assumed based on information in the "*Floor_type*" field.
- Classification of buildings within the modelled area, in accordance with ANUFLOOD requirements (~28,000 buildings in total, with ~7,040 within South Rockhampton catchment):
  - Buildings were divided into residential and commercial based on a combination of fields, depending on what fields contained data for each building.
  - Residential buildings were assigned a class based on the "*Struc_type*" & "*Floor_type*" fields. Detached single storey buildings were also classified by floor area.
  - Commercial buildings were assigned a size class based on floor area – small/medium/large.
  - Commercial building classifications were assigned based on the "*Land_use_d*" field, with a value class of 3 (on a scale from 1 to 5) assigned to buildings lacking data.

The ground level at each building was estimated based on the 1m LiDAR DEM provided for the project. Ground levels were assigned to the building footprints based on the average elevation of the DEM within the building extents.

Buildings lacking data regarding number of storeys were assumed to be one storey. Buildings on slabs were assumed to have a minimum habitable floor level of 100mm above ground level. Low set buildings were assumed to have a minimum habitable floor level of 600mm above ground level and high set buildings were assumed to have a minimum habitable floor level of 1,800mm above ground level. Buildings lacking data regarding what type of floor they have were assumed to be on slabs.



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

- Surveyed Floor Levels
- GIS-Derived Floor Levels
- Highways
- Railway Lines
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

FLOOR LEVEL SUMMARY

Surveyed Floor Levels = 1,440
GIS-Derived Floor Levels = 5,602

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

South Rockhampton Model
Building Database Summary

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/09/2017
VERSION:	2

Map SR-33

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\SR_Figure35_SurveyedBuildings.mxd

Table 31 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the South Rockhampton catchment. These results are also shown graphically in Figure 34.

Existing buildings which experience flood levels above ground level are noted and buildings inundated above floor level are shown in brackets beside.

Note that the indicated number of buildings is for entire buildings. Residential multi-unit buildings may contain multiple dwellings per building. Also, large commercial/industrial buildings may include multiple businesses.

Table 31 № of Buildings Impacted

AEP (%)	№ Residential Buildings	№ Commercial Buildings
	Flood level above property ground level (building inundated above floor level)	Flood level above property ground level (building inundated above floor level)
1EY	40 (7)	13 (10)
39	100 (18)	26 (17)
18	250 (40)	59 (35)
10	328 (56)	82 (51)
5	354 (66)	95 (60)
2	485 (100)	145 (97)
1	576 (124)	172 (123)
0.2	944 (244)	266 (198)
0.05	1184 (335)	330 (273)
PMF	1991 (713)	681 (580)

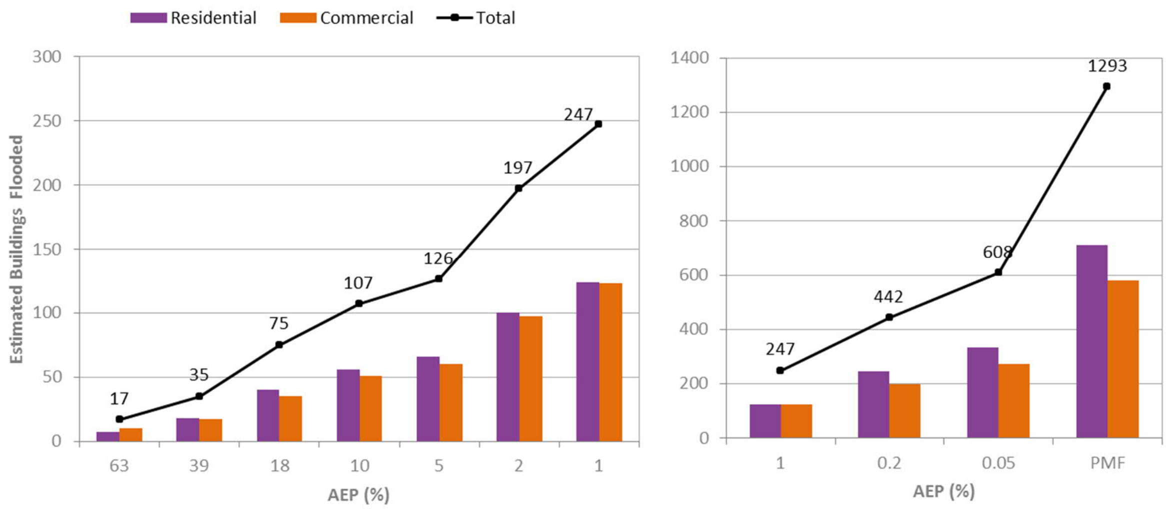


Figure 34 Estimated Buildings with Above Floor Flooding (Number of Buildings)

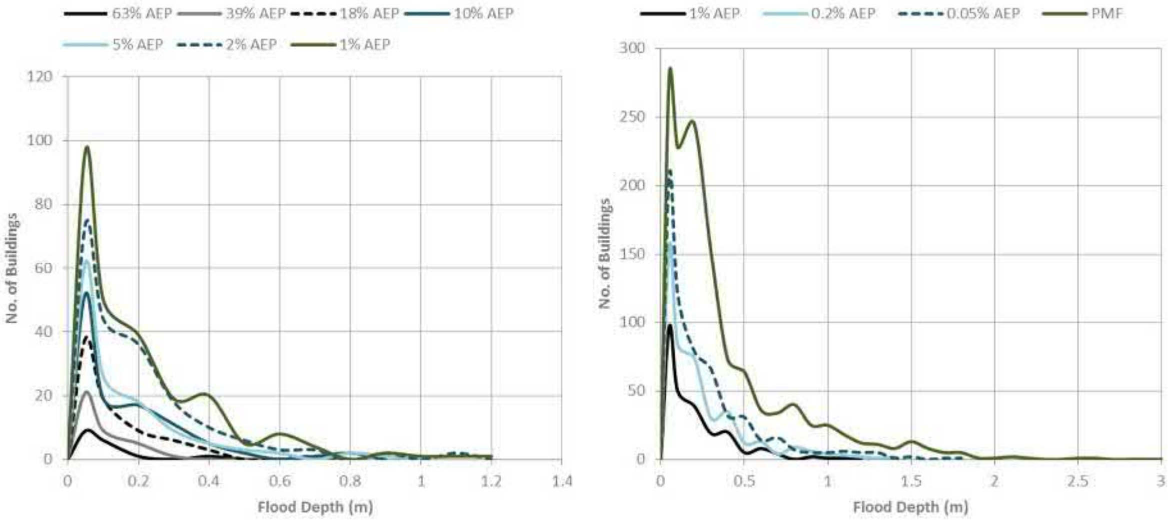
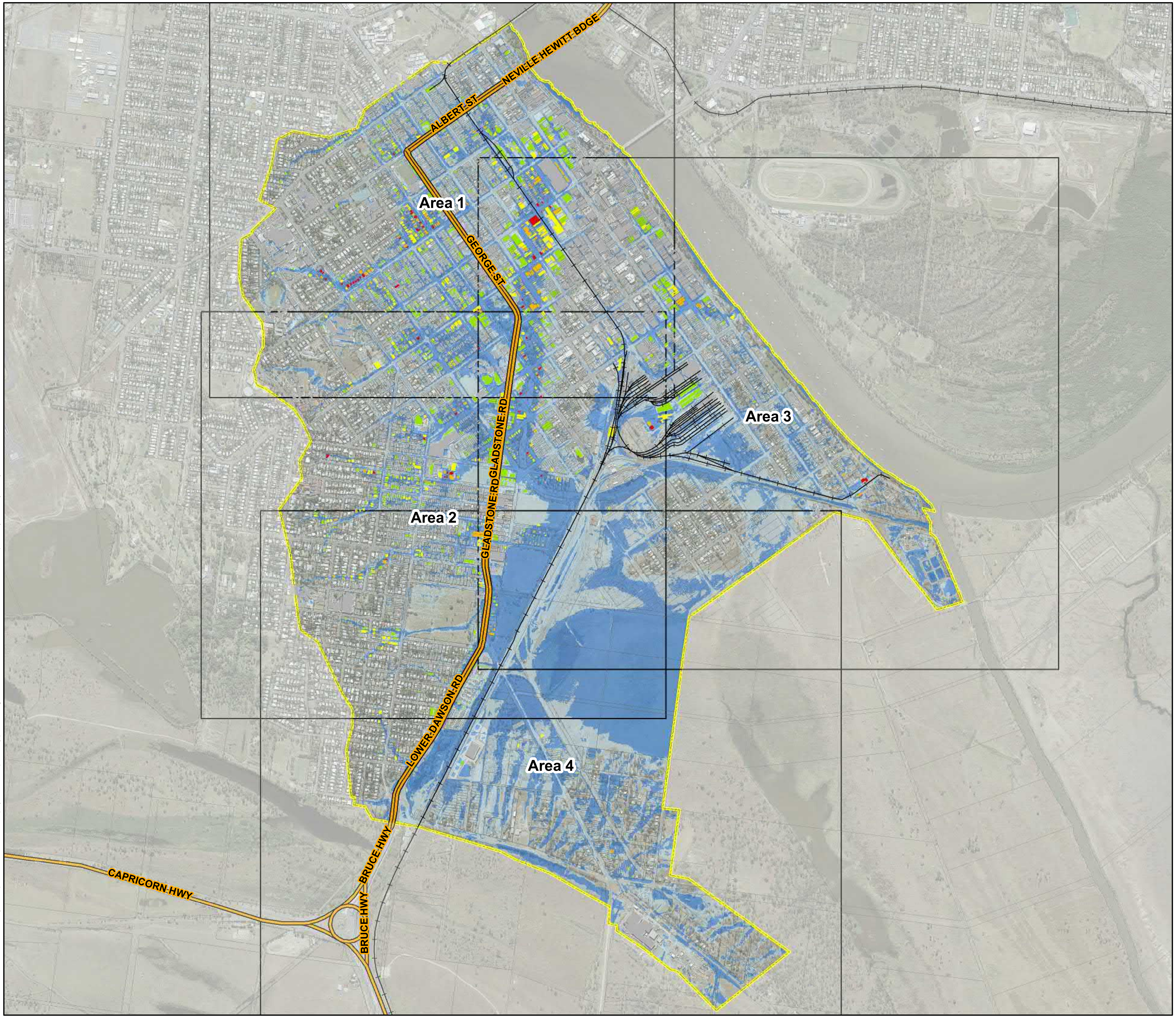


Figure 35 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

As shown in Figure 35, median flood depths are generally less than 0.2 metre for each flood event. This indicates that reductions in flood depths of 0.2 metre could significantly reduce overall damage.

It is noted that where surveyed floor levels were not available, slab on ground buildings were assumed to have a floor level 0.1m above the existing ground level. This is consistent with other studies undertaken in the Rockhampton area, however may result in a higher estimate of inundated buildings and consequential flood damages due to the increased incidence of above floor flooding.

Figure 36 to Figure 40 shows the location of buildings predicted to experience above floor flooding, grouped by the earliest AEP upon which they become inundated.



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

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside PMF Extent
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Flood results are based on local catchment events

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

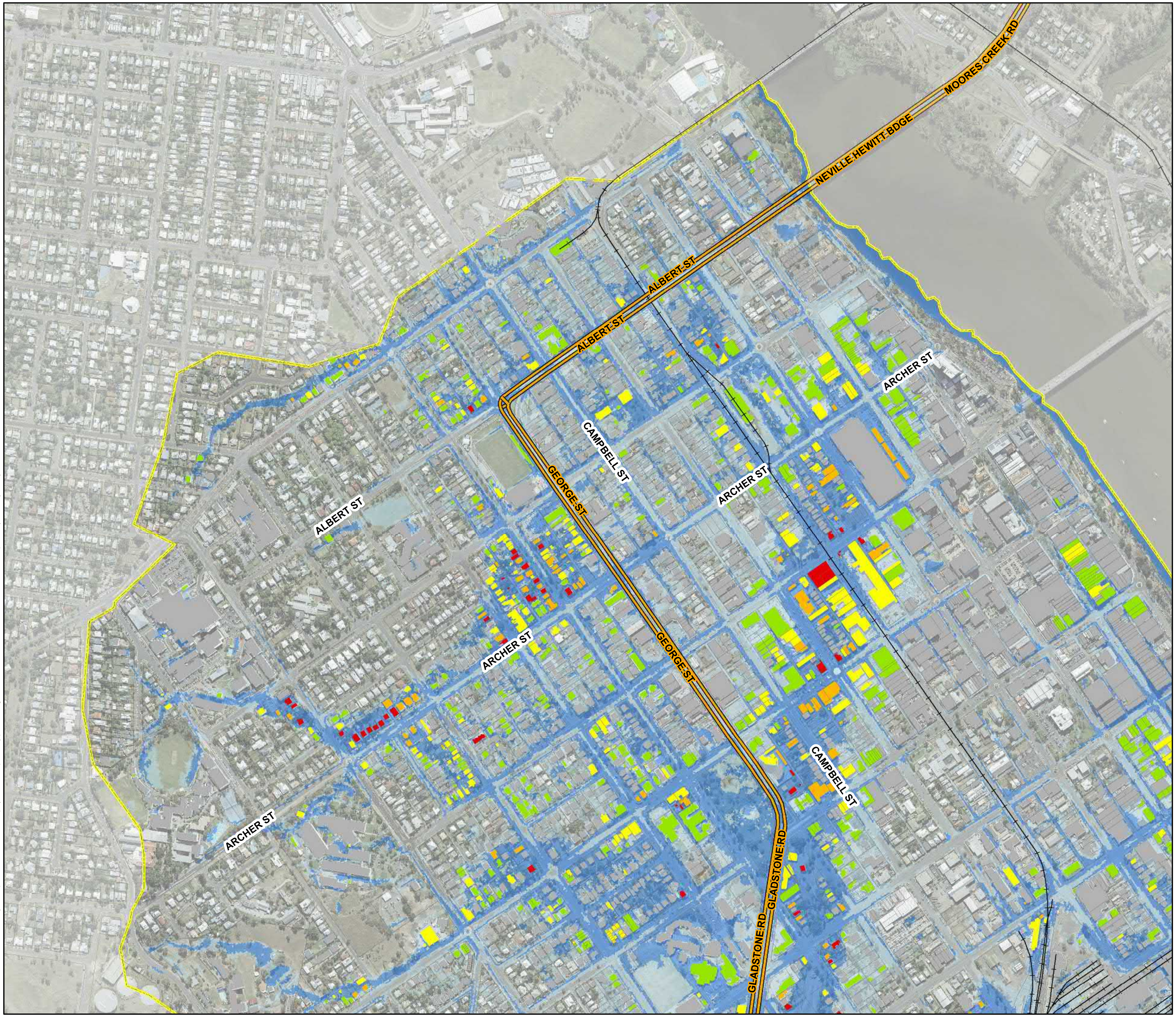
Results Filtering:
75mm Min. Depth
100m² Min. Area

South Rockhampton Model
Inundation of Buildings with Above Floor Level Flooding - Catchment Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/10/2017
VERSION:	2

Figure 36

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 36_Phase_2_Property_Inundation - Catchment Overview.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:8,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside PMF Extent
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Flood results are based on local catchment events

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

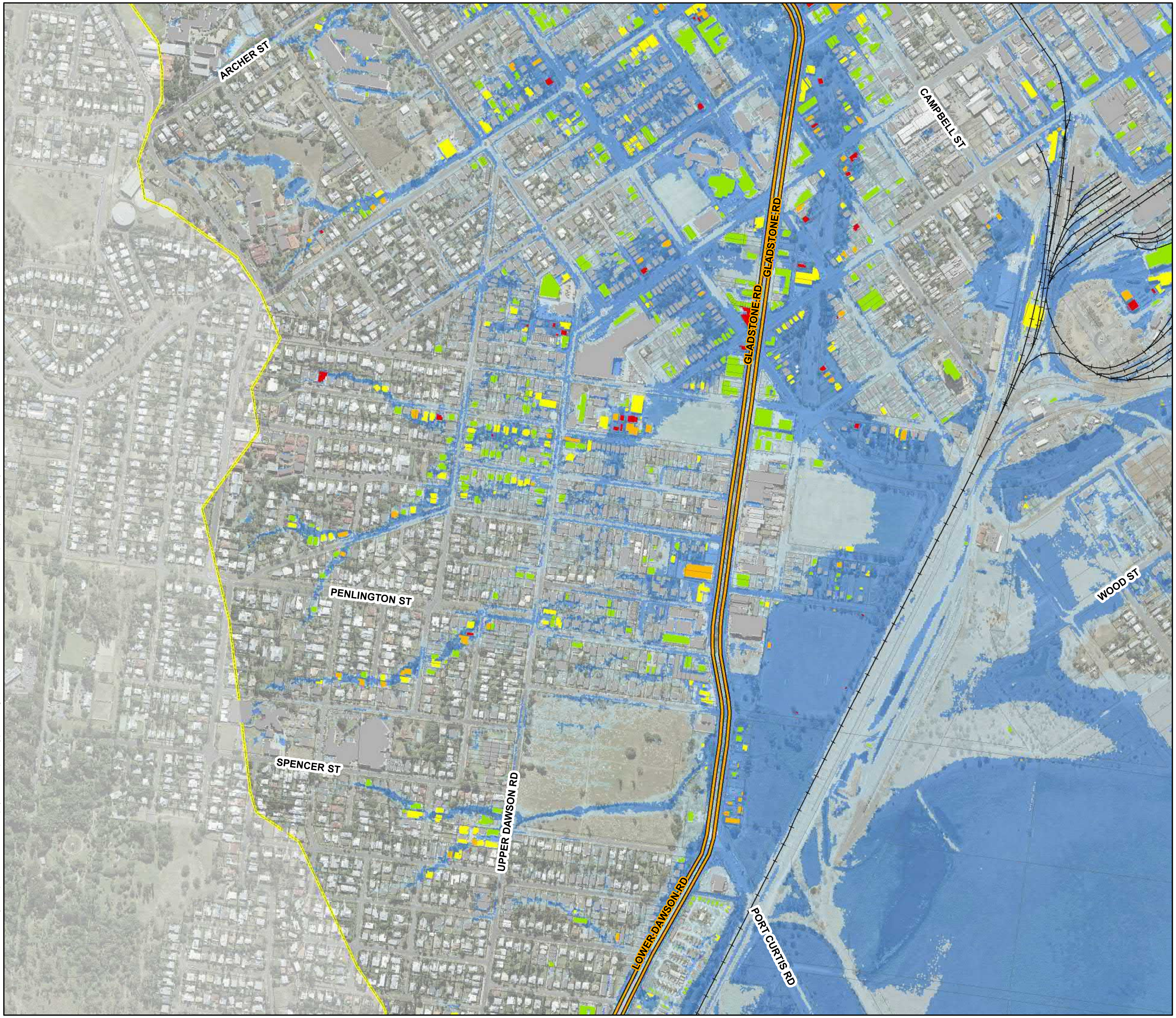
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

South Rockhampton Model
Inundation of Buildings with Above Floor Level Flooding - Area 1

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/10/2017
VERSION:	2

Figure 37

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 37_Phase_2_Property_Inundation - Area 1.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:8,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside PMF Extent
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

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

South Rockhampton Model
Inundation of Buildings with Above Floor Level Flooding - Area 2

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	11/10/2017
VERSION:	2

Figure 38

N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500

Metres

1:10,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside PMF Extent
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Flood results are based on local catchment events

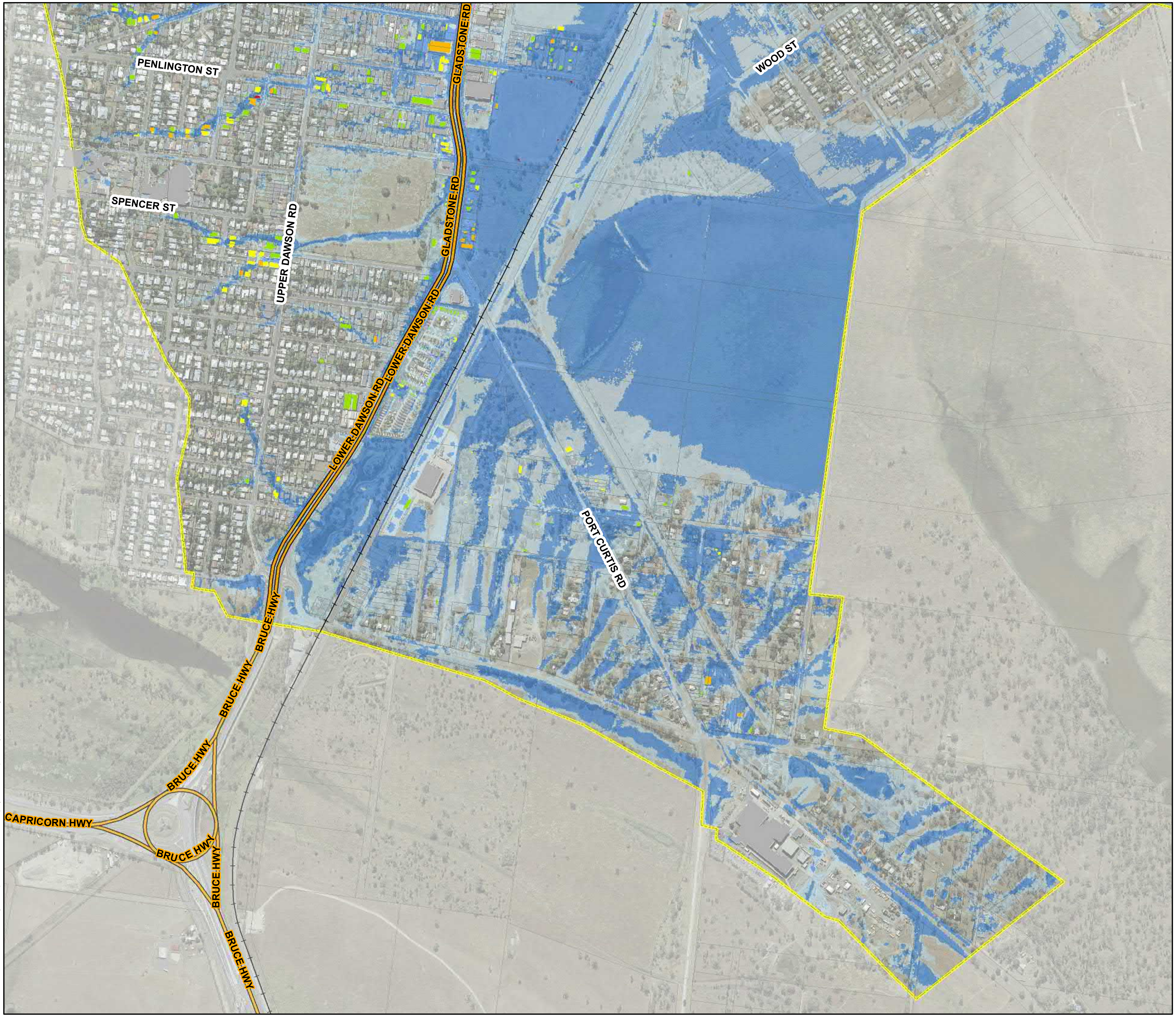
Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

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

South Rockhampton Model Inundation of Buildings with Above Floor Level Flooding - Area 3

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	11/10/2017
VERSION:	2

Figure 39



Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500

Metres

1:10,000
(when printed at A3)

AECOM
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LEGEND

- Highways
- Railway Lines

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside PMF Extent
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

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

South Rockhampton Model Inundation of Buildings with Above Floor Level Flooding - Area 4

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/10/2017
VERSION:	2

Figure 40

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\Figure 40_Phase_2_Property_Inundation - Area 4.mxd

9.6.2 Baseline Flood Damages Assessment

Table 32 presents a summary of the estimated tangible flood damages (in March 2017 $) for a range of design flood events, using the WRM (2006) residential stage damage curves and ANUFLOOD commercial stage damage curves. Table 33 presents a summary of the estimated tangible flood damages (in March 2017 $) for a range of design flood events, using the O2 Environmental (2012) residential stage damage curves and ANUFLOOD commercial stage damage curves (Department of Natural Resources and Mines, 2002).

It should be noted that the damage values in the residential and commercial columns of the tables represent the total of direct and indirect damage costs. As can be seen, the impact of changing the source of the damage curves is minimal for smaller events and increases with the magnitude of the flood event. These values should be considered the upper and lower bounds for damages.

Table 32 Summary of flood damages using WRM stage-damage curves

AEP (%)	Flood Damages (,000s of March 2017 $)			
	Residential	Commercial	Infrastructure	Total
63	$530	$198	$88	**$816**
39	$1,558	$159	$219	**$1,935**
18	$4,217	$521	$601	**$5,339**
10	$5,831	$1,130	$870	**$7,831**
5	$6,529	$1,285	$976	**$8,789**
2	$9,862	$2,527	$1,531	**$13,920**
1	$12,149	$3,438	$1,917	**$17,505**
0.2	$21,846	$7,030	$3,530	**$32,406**
0.05	$30,148	$10,572	$4,955	**$45,676**
PMF	$66,612	$34,785	$12,055	**$113,451**

Table 33 Summary of flood damages using O2 Environmental stage-damage curves

AEP (%)	Flood Damages (,000s of March 2017 $)			
	Residential	Commercial	Infrastructure	Total
63	$520	$198	$87	**$805**
39	$1,562	$159	$219	**$1,940**
18	$4,324	$521	$614	**$5,460**
10	$6,002	$1,130	$892	**$8,024**
5	$6,716	$1,285	$1,000	**$9,001**
2	$10,204	$2,527	$1,576	**$14,307**
1	$12,664	$3,438	$1,985	**$18,087**
0.2	$23,806	$7,030	$3,786	**$34,622**
0.05	$33,427	$10,572	$5,383	**$49,382**
PMF	$79,481	$34,785	$13,733	**$127,999**

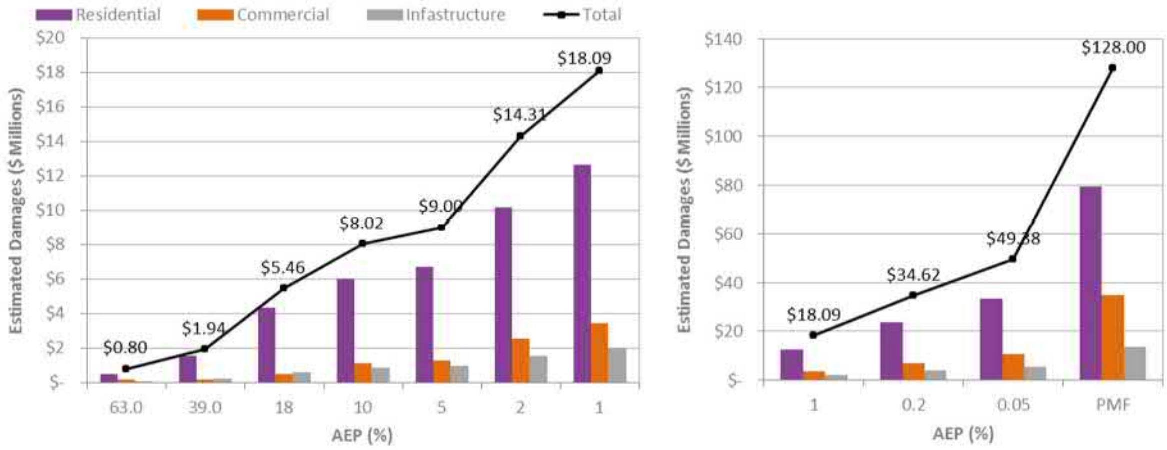


Figure 41 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

Figure 41 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from $805,000 (1EY flood event) to $128M (PMF flood event). Figure 34 shows that 17 buildings are expected to be inundated above floor in the 1EY event, whilst 1,293 buildings are anticipated to be inundated above floor in the PMF event

These figures also demonstrate that residential buildings make up the large majority of the estimated flood damages, within the South Rockhampton catchment across the full range of design events assessed.

9.6.3 Average Annual Damages

While the above provides an estimate of potential damages during specific flood events, understanding what damages may be expected on an annual basis is often an easier way to relate risk to residents and businesses. As such, the above damages were converted to Average Annual Damages (AAD) based on the likelihood of the flood event and the total estimated damage during that event. The AAD is determined by taking the estimated damage for each AEP event and multiplying it by the likelihood of the event. The process is repeated and AAD values are summed for the total AAD. For instance, the AAD for a 10% AEP event is based on the estimated $8.02M damages and 10% or 0.01 likelihood, corresponding to an AAD of $802,000. As a result, low-likelihood events such as the PMF have minor influence due to their low probability of occurrence.

AAD is a measure of the average tangible flood damages experienced each year, and is calculated as the area under the Probability Damages Curve. Therefore, accurate estimates of AAD require consideration of flood events ranging from the smallest flood that causes damage, up to the PMF. For this study, flood events ranging from the 1EY (exceedance per year) event up to the PMF have been considered.

The probability-damage curves used to calculate AAD are displayed in Appendix B. Using the WRM damage curves results in an AAD of approximately **$2,847,000** and using those from O2 Environmental gives an AAD of approximately **$2,916,000**. The difference of approximately 2.4% provides a relatively narrow range for the estimated AAD.

The following graphs and discussions present the O2 Environmental data for analysis.

Figure 42 shows the breakdown of residential, non-residential and infrastructure AAD over the entire catchment. As shown, a total AAD cost of $2.916M is estimated, with the majority (75%) being attributed to residential buildings. It is noted that 25% of AAD is attributed to non-residential (commercial) buildings.

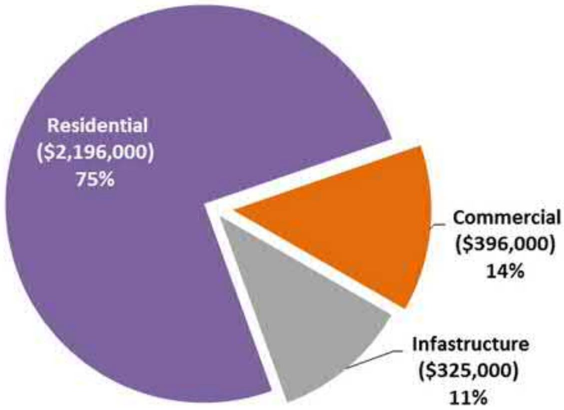


Figure 42 Total AAD by Building Type

Figure 43 and Figure 44 breakdown the AAD for residential and non-residential properties. It can be seen that 75% of residential and 86% of non-residential properties experience a damage cost of less than $500 per annum. As a result, 55% of the total AAD is associated with only 5% of all buildings, demonstrating that a minority of buildings produce the majority of damages within the catchment.

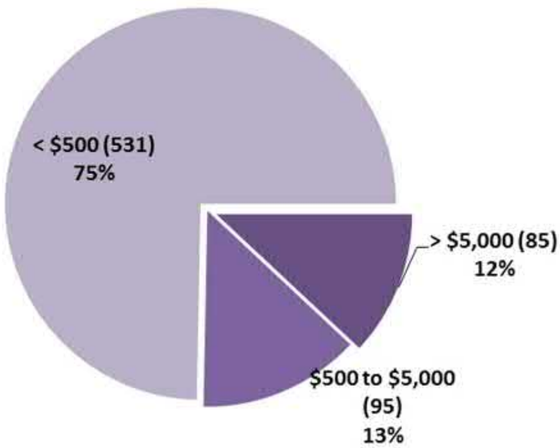


Figure 43 Residential AAD (Number of Buildings)

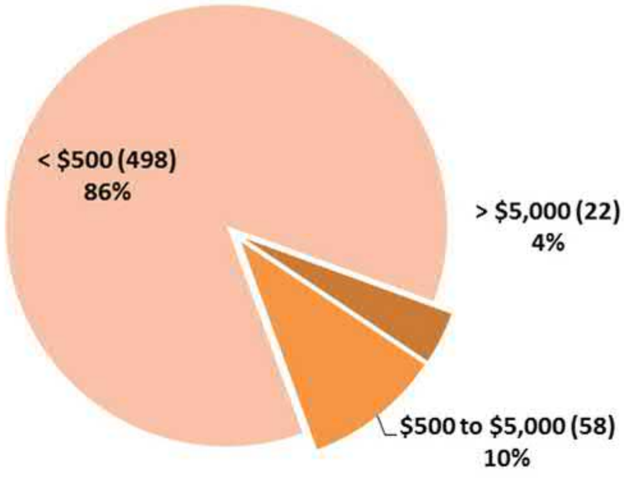


Figure 44 Non-Residential AAD (Number of Buildings)

9.6.4 AAD Summary

Figure 45 summarises the same information as above in a different manner. The area in blue corresponds to individual building AAD (residential and non-residential combined) in brackets of $100 per annum. The orange line corresponds to the cumulative AAD for residential and non-residential buildings combined. Note that this does not include infrastructure damages.

As shown, 79% of all buildings exhibit less than $500 damage per annum. In addition 55% of damages are associated with less than 5% of all buildings. Again, this demonstrates that a minority of buildings produce the majority of damages.

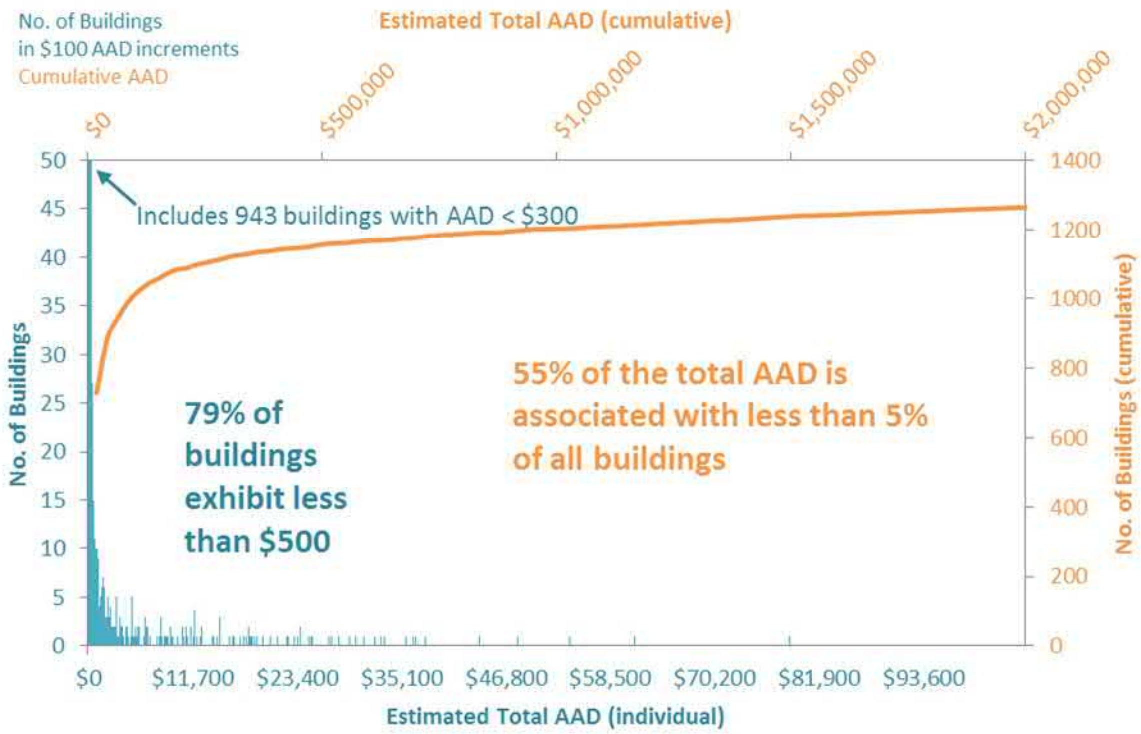


Figure 45 Individual Building vs. Cumulative Total Average Annual Damages

9.7 Rainfall Gauge and Maximum Flood Height Gauge Network Coverage

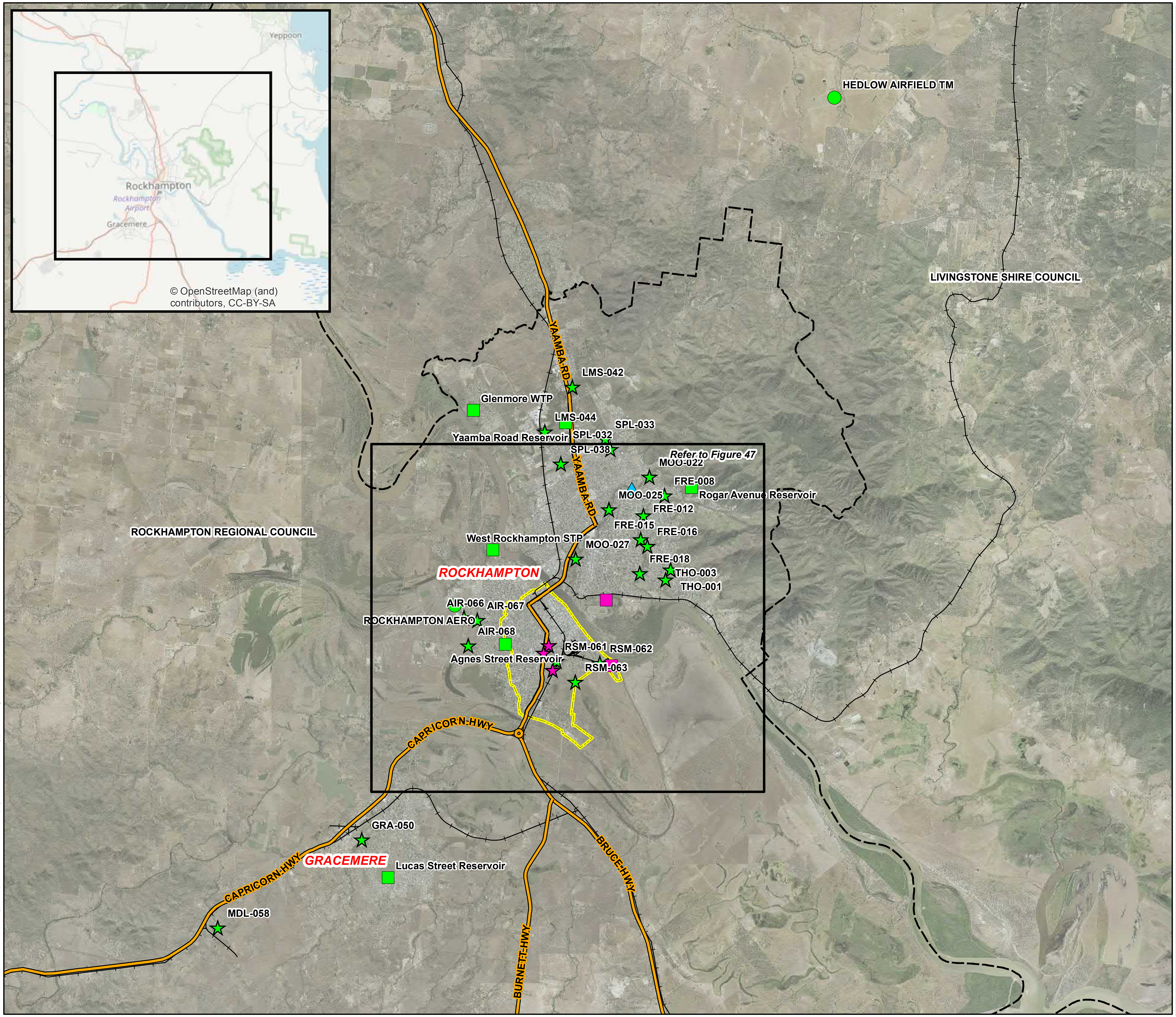
Figure 46 and Figure 47 show the location of existing rainfall gauges within the Rockhampton region, plus Council's maximum flood height gauges.

A high level desktop review of the coverage provided by the existing gauges has been undertaken, with the following recommendations provided for future upgrades to the system:

- Additional Council rain gauges could be installed at North Rockhampton Sewerage Treatment Plant (NRSTP) and South Rockhampton Sewerage Treatment Plant (SRSTP). These locations are ideal as they are already administered by Council (through Fitzroy River Water) and have access to telemetry.
- In addition to the three existing maximum flood height gauges within the South Rockhampton catchment, it is recommended that gauges be install in the following locations (as shown on Figure 47):
  - Stanley Street / Talford Street corner, near Gladstone Road Seafoods;
  - West Street (north of Stanley Street), within the Upper Main Drain reserve; and
  - Elizabeth Street / Saleyards Street, adjacent the rail corridor.

9.8 Flood Warning Network Coverage

As noted in Section 2.6, there is currently no flood warning network for the South Rockhampton catchment.



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 1 2 3 4 5 6

Kilometers

1:120,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

Active Flood Gauges
- RRC

Active Rainfall Gauges
- BOM
- RRC

Inactive Rainfall Gauges
- Private

Proposed Flood Gauges
- RRC

Proposed Rainfall Gauges
- RRC
- Highways
- Railway Lines
- Hydraulic Model Extent Local
- Government Boundaries

Data Sources:

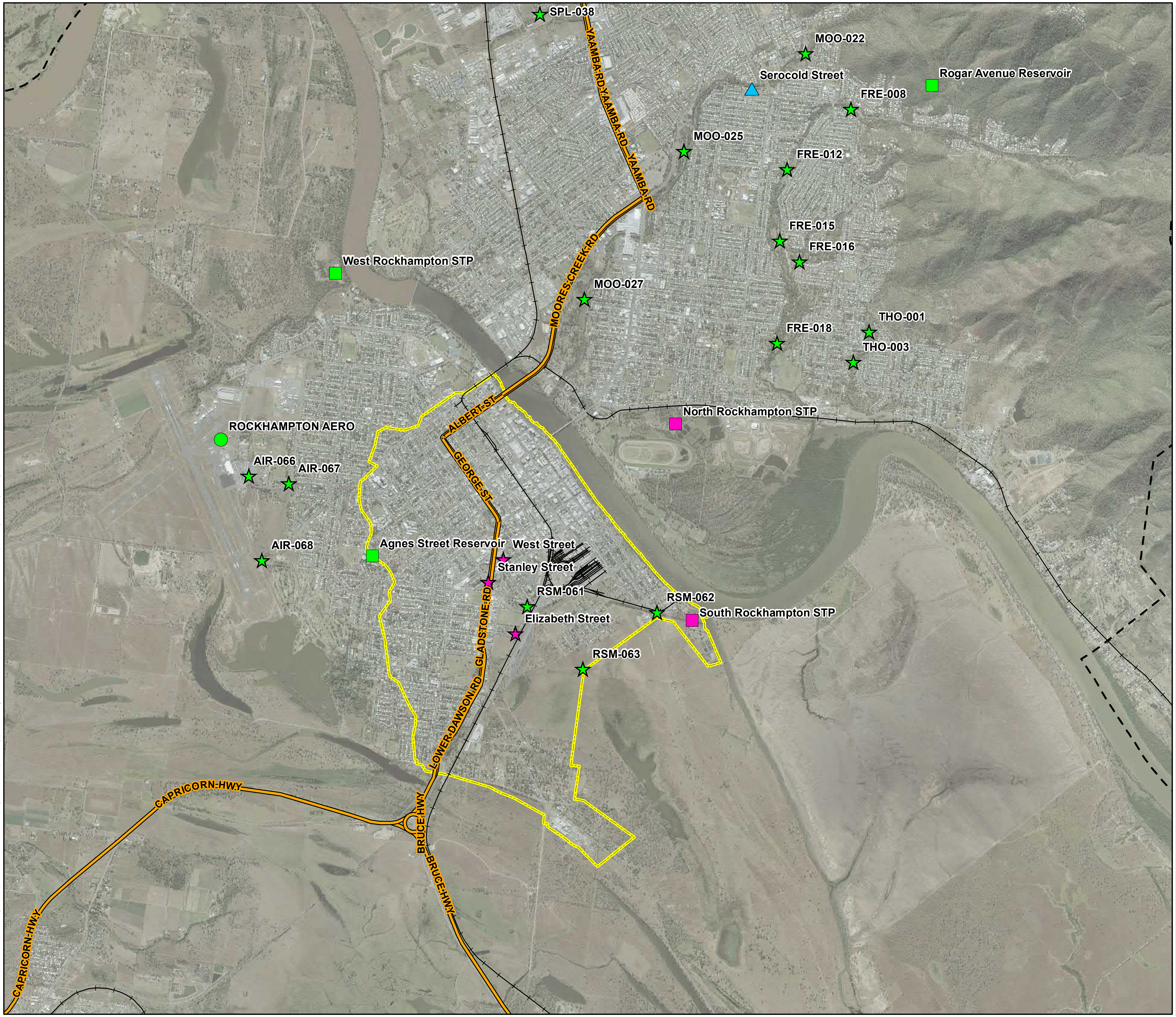
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

South Rockhampton Model
Rainfall Gauge and Flood Record Network

Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	7/09/2017
VERSION:	2

Figure 46



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 0.5 1 1.5 2
Kilometers

1:40,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

Active Flood Gauges
- RRC

Active Rainfall Gauges
- BOM
- RRC

Inactive Rainfall Gauges
- Private

Proposed Flood Gauges
- RRC

Proposed Rainfall Gauges
- RRC

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

Data Sources:

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

South Rockhampton Model
Rainfall Gauge and Flood Record Network

Figure 46 Inset - Rockhampton

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	7/09/2017
VERSION:	2

Figure 47

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\South Rockhampton Publishing\Report Figures\SR_Figure52_Phase_2_Gauges.mxd

10.0 Conclusion

10.1 Baseline Model Development

The South Rockhampton Phase 1 Baseline Flood Study included the development of a 1D/2D dynamically linked TUFLOW model for the urban catchment. This model utilises a direct rainfall approach to simulate key overland flow paths and establish baseline flood extents and depths within the study area.

10.1.1 Model Calibration

Anecdotal and recorded data was received and used to calibrate the model to a local flood event caused by TC Marcia in February 2015. Further model validations were undertaken for two other local flood events, namely Ex-TC Debbie in March 2017 and Ex-TC Oswald in January 2013. The model calibrated / validated well to the 2015 and 2017 events. The validation to the 2013 event was not as successful due to likely spatial variances in rainfall data (and limited historical gauge data), as well as potential blockage of critical drainage structures.

In undertaking the calibration / verification process, it was noted that there was a consistently large difference between modelled and recorded levels in the storage area adjacent the rail line, south of Saleyards Street. This is particularly evident in the 2013 and 2015 events. At this stage, it is recommended that additional verification events are assessed in the future to gain further confidence in the modelling outputs in this area. In the interim, it is further recommended that Council apply additional freeboard (nominally 0.5 m) in this area for planning purposes.

Despite this, the model calibrates and validates well with modelled behaviours anticipated to appropriately predict flood patterns at the time of this study.

10.1.2 Design Event Modelling

On completion of the calibration / validation process, various design flood events and durations were simulated and results extracted. The critical duration for the catchment was determined to be the 120 minute event. A comparison of the design events found that for events up to 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 and are predicted to impact public and privately owned infrastructure throughout the catchment.

The modelling has confirmed that there are a number of key hydraulic controls within the catchment – particularly the North Coast Rail Line and the upper Main Drain area. Results from this phase of the project will support the further identification and evaluation of flood mitigation options to reduce existing flood risk.

10.1.3 Sensitivity Analysis

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.

10.2 Baseline Flood Hazard and Vulnerability Assessment

The baseline flood hazard and vulnerability assessment undertaken for the South Rockhampton catchment has identified areas of increased flood risk. The following sections summarise the findings.

10.2.1 Flood Hazard

As can be seen on maps **SR-69** to **SR-73** the 1% AEP baseline flood hazard within the South Rockhampton catchment generally shows:

- Low to medium hazard (H1 and H2) across the majority of urbanised areas west of Gladstone Road and within the CBD and urbanised Depot Hill areas.
- High hazard (H3 and H4) within the Upper Main Drain, Lower Main Drain, Fiddes Street detention basin, Stanley Street / Talford Street west of Gladstone Road, Saleyards Park, Kettle Park and O'Shanesy Park areas.

- Extreme hazard (H5) within portions of the Upper Main Drain, Lower Main Drain, Kettle Park, O'Shanesy Park and the South Rockhampton Cemetery (main channel flow path only).

10.2.2 Vulnerability Assessment

The following provides a summary of key findings of the vulnerability assessment:

- The Fitzroy Street SPS (Ref: 463755), Arthur Street SPS (Ref: 463754), Lower Dawson Road SPS (Ref: Caravan Park) and Ferguson Street SPS (Ref: 463756) are predicted to have less than 0.2% AEP flood immunity. It is noted however that some of these pump stations are below ground and improvements to flood immunity would be very difficult to achieve. It is recommended this information be passed onto FRW as the asset owner.
- Low depth flooding is predicted at TAFE Rockhampton, Blue Care Homes and Allies Early Learning Centre in the 0.2% AEP event.
- Frequent flooding is predicted at Rockhampton Fire Station, Rockhampton Ambulance Centre, The Cathedral College and Allenstown State School.
- The North Coast Rail Line is predicted to experience frequent flooding to Top of Ballast level, within the city reaches, with some areas predicted to be inundated during the 1EY local catchment event.
- A number of road segments are predicted to experience inundation in the 1EY event and larger. Estimated TOS ranges from 2.0 hours to approximately 5.5 hours.

10.2.3 Evacuation Routes

The following areas have been assessed as being isolated and/or lack adequate evacuation routes during the PMF event:

- Depot Hill Area à Bounded by Arthur Street to the north, West Street to the west, Lucius Street to the south and Denison Street to the east.
- Area bounded by Stanley Street, Bolsover Street, O'Connell Street and Quay Street.
- Area bounded by Cambridge Street, Murray Street, Denham Street and Denison Street.

10.2.4 Building Impact Assessment

The building impact assessment shows the following:

- 53 buildings (17 with above floor flooding) predicted to be impacted in the 1EY event.
- 309 buildings (75 with above floor flooding) predicted to be impacted in the 18% AEP event.
- 748 buildings (247 with above floor flooding) predicted to be impacted in the 1% AEP event.
- 2,672 buildings (1,293 with above floor flooding) predicted to be impacted in the PMF event.
- Significant number of buildings with less than 0.2m flood depth in frequent events, such as 1EY.

10.2.5 Flood Damages Assessment

The following provides a summary of the Flood Damages Assessment findings:

- WRM and O2 curves used to establish upper and lower bounds for tangible flood damages:
  - $805,000 to $816,000 damages estimated in 1EY event.
  - $5,339,000 to $5,460,000 damages estimated in 18% AEP event.
  - $17,505,000 to $18,087,000 damages estimated in 1% AEP event.
  - $113,451,000 to $127,999,000 damages estimated in PMF event.
- AAD ranging from **$2,847,000 to $2,916,000** for WRM and O2 damage curves respectively.
- 65% of the total AAD is associated with residential buildings.

- 75% of residential buildings and 86% of commercial buildings exhibit less than $500 damage per annum.
- 55% of the total AAD is attributed to less than 5% of all buildings.

10.2.6 Rainfall Gauge, Maximum Flood Height Gauge and Flood Warning Network

Review of the existing rainfall gauge, maximum flood height gauge and flood warning network yielded the following recommendations/findings for the South Rockhampton catchment:

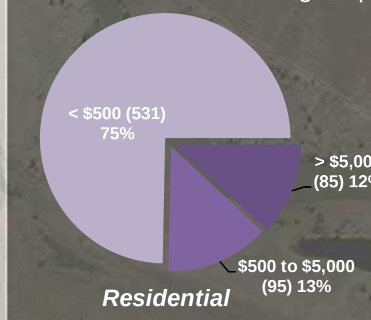
- Additional rain gauges should be installed at NRSTP and SRSTP.
- Additional maximum flood height gauges should be installed at:
  - Stanley Street / Talford Street corner, near Gladstone Road Seafoods;
  - West Street (north of Stanley Street), within the Upper Main Drain reserve; and
  - Elizabeth Street / Saleyards Street, adjacent the rail corridor.
- There is no current flood warning system within the South Rockhampton catchment.

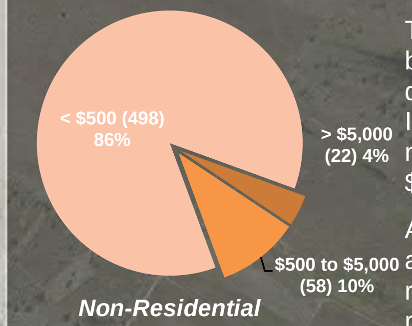
An overview of building impacts and flood damages is provided in Figure 48.

South Rockhampton Catchment Overview

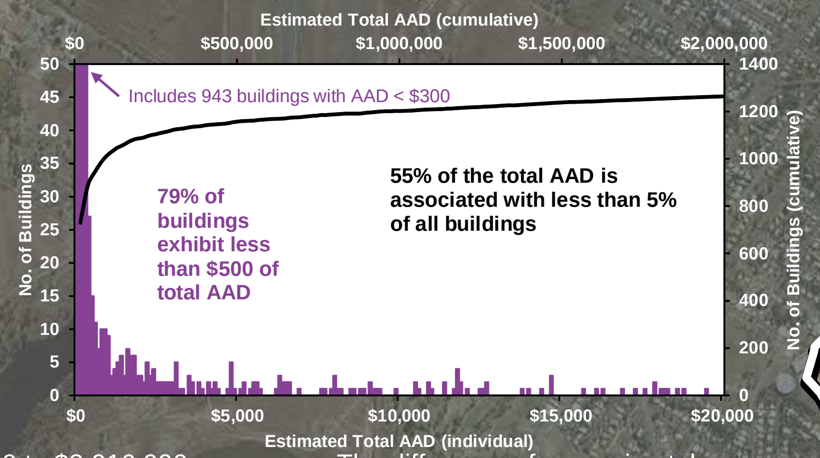
Average Annual Damages

Average Annual Damage (AAD) is a measure of the average tangible flood damages experienced each year, and is calculated as the area under the Probability Damages Curve. Therefore, accurate estimates of AAD require consideration of flood events ranging from the smallest flood that causes damage, up to the Probable Maximum Flood (PMF).





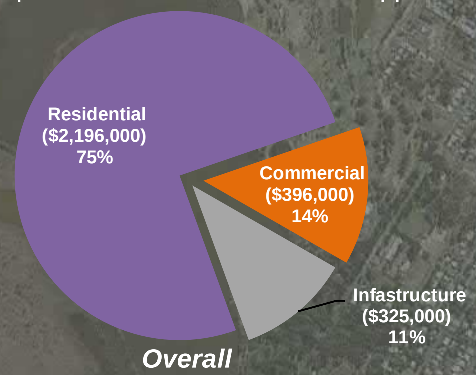
For this study, flood events ranging from the 1EY (exceedance per year) event up to the PMF have been considered.



The calculated AAD for the South Rockhampton catchment is estimated to range from approximately $2,847,000 to $2,916,000 per annum. The difference of approximately 2% provides a narrow range for the estimated AAD.

The majority (75%) of AAD is attributed to residential buildings. Commercial buildings make up 14% of the damages with the remaining 11% attributed to Infrastructure. 75% of residential and 86% of non-residential properties experience less than $500 of AAD.

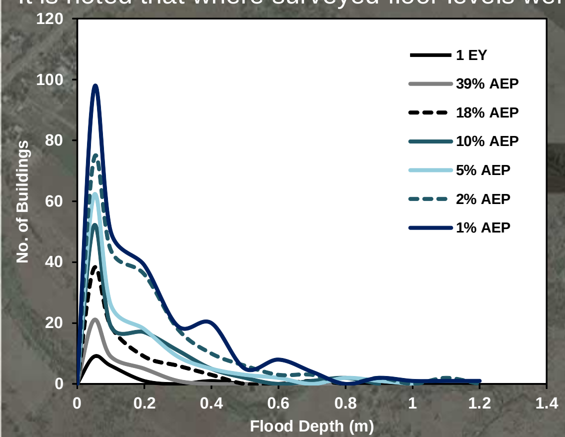
As a result, 55% of the total AAD is associated with only 5% of all buildings, revealing that a minority of buildings are responsible for the majority of damages.

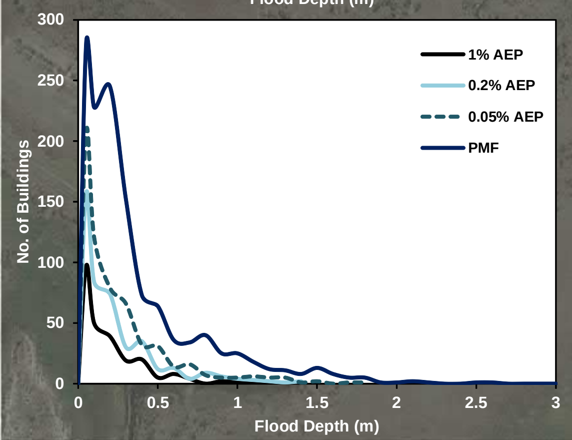


Depth of Inundation

Median flood depths are generally less than 0.1 metres for each flood event. This indicates that reductions in flood depths of 0.1 metres could significantly reduce overall damage. The figures also show that a significant number of buildings experience flood depths of 0.2 metre or less during frequent events such as the 1EY flood event, generally corresponding to higher flood damages.

It is noted that where surveyed floor levels were not available, slab on ground buildings were assumed to have a floor level of 0.1m above the existing ground level. This is consistent with other studies undertaken in the Rockhampton area, however may result in a higher estimate of inundated buildings and consequential flood damages due to the increased incidence of above floor flooding.



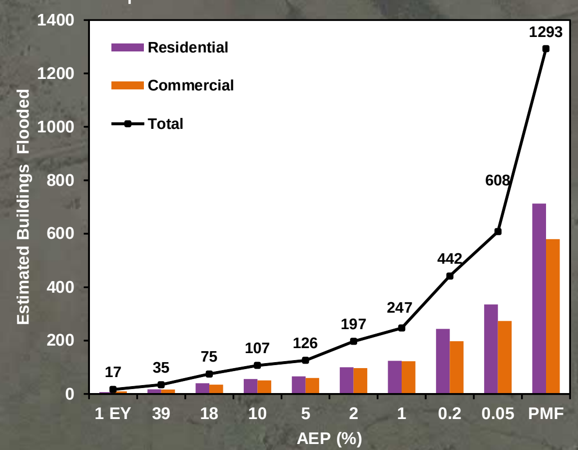


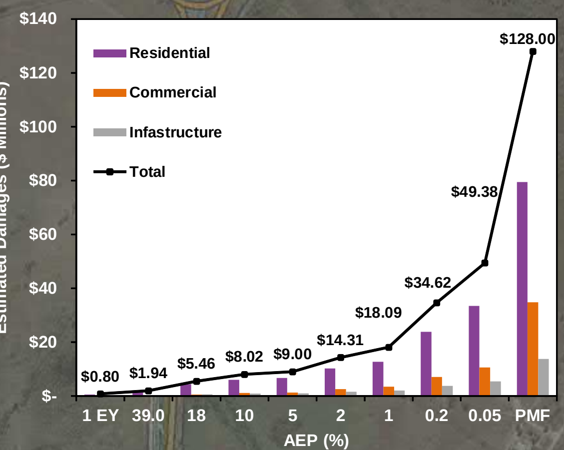
Flood Damages

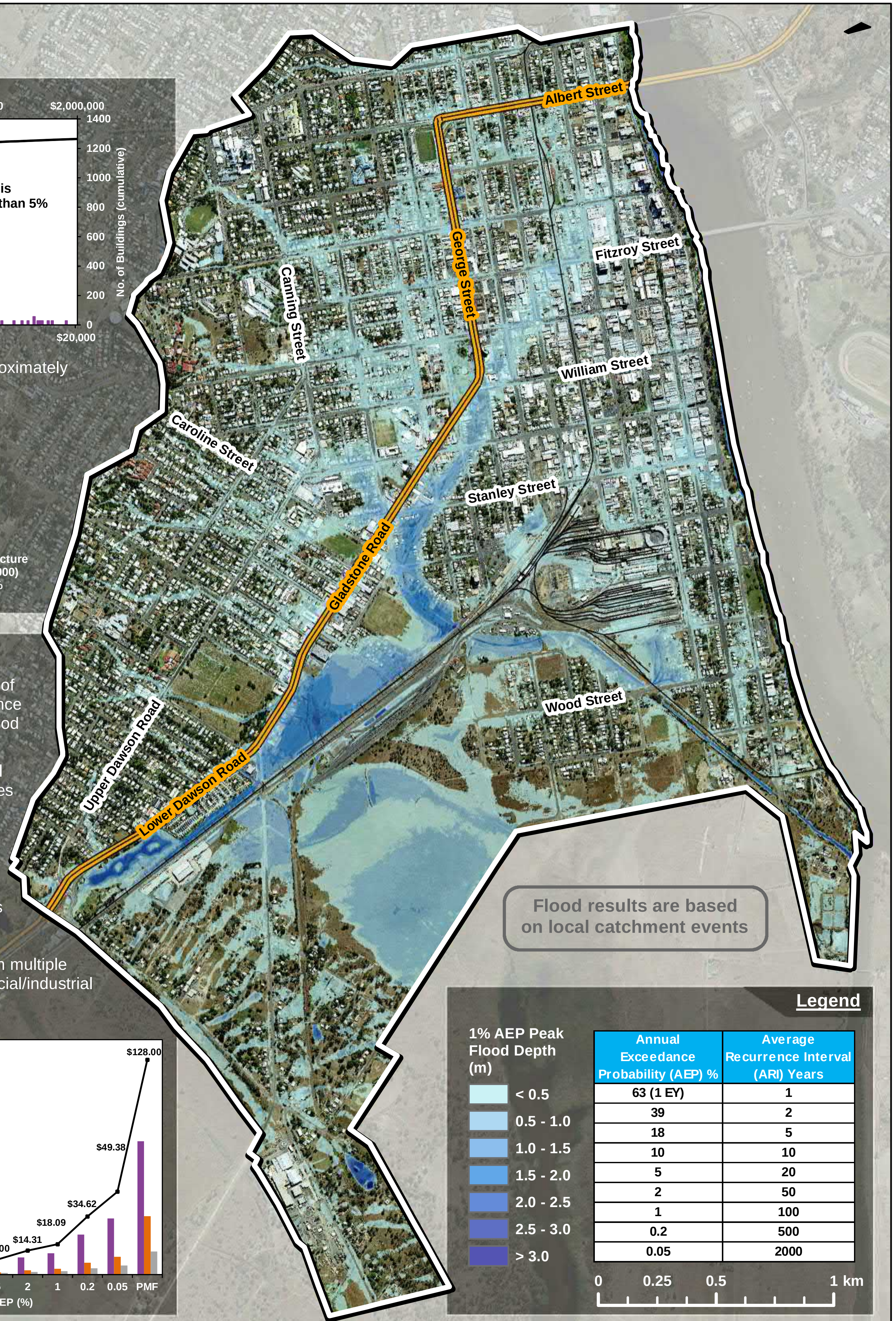
The figures below provide a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the South Rockhampton catchment.

Note that the indicated number of buildings is for entire buildings.

Residential multi-unit buildings may contain multiple dwellings per building. Also, large commercial/industrial buildings may include multiple businesses.







Legend

1% AEP Peak Flood Depth (m)

- < 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- > 3.0

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
0.2	500
0.05	2000

0 0.25 0.5 1 km

11.0 Recommendations

A number of recommendations have been made in relation to this study:

- Baseline flood mapping (i.e. peak depths, velocities and water surface elevations) provided in this study should be used to update Council's current Planning Scheme layers, at the next available opportunity.
  - Final post-processing of the GIS flood layers is recommended in accordance with the procedures outlined in the ARR, Data Management and Policy Review (AECOM, 2017).
  - Appropriate freeboard provisions should be included, based on the findings of the sensitivity analyses outlined in this study. It is further recommended that Council apply additional freeboard (nominally 0.5 m) in the Lower Main Drain area (upstream of the rail line) for planning purposes.
- This report and associated outputs should be communicated to the community and relevant stakeholders when appropriate.
- Hydrologic and hydraulic modelling undertaken for this study has been based on methods and data outlined in Australian Rainfall and Runoff 1987. The 1987 revision has been adopted as per Council's request. It is recommended that future updates to this study incorporate the new 2016 updates.
- It is recommended that Council continue to undertake building floor level survey within the South Rockhampton catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained.
- It is recommended that Council continue to record rainfall and flood heights associated with future South Rockhampton catchment flood events. This data will support ongoing model calibration / validation works that should be undertaken in future updates to this study. The implementation of additional gauges identified in this study is also recommended.
- The assessment of flood behaviour within the South Rockhampton catchment has been the subject of previous technical investigations associated with the South Rockhampton Flood Levee project in 2014.
  - It is noted that the previous modelling used for the levee project has been updated and these results should be reviewed and adopted for the South Rockhampton Levee project moving forward. It may be necessary to make alterations to the current design to account for the latest modelling undertaken.
- The baseline vulnerability and flood hazard assessment outputs from this report should be used to support Phase 3 of the Study (Flood Mitigation Options Development and Assessment). Furthermore, the assessment of potential flood mitigation options should consider the implications to the South Rockhampton Flood Levee.

12.0 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.

TUFLOW 2016 Manual

Maritime Safety Queensland (2014) QLD Tide Tables book.

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

Rockhampton Regional Council (2014b), South Rockhampton Flood Levee – Interior Drainage Report, prepared by AECOM, 2014b.

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 seconds. The corresponding 1D time step has been set at 0.75 seconds. These time steps represent the maximum feasible time step given the grid cell size.

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

One-Dimensional Network Development

As detailed in Section 3.6, RRC provided a large amount of data related to the existing stormwater drainage network within the study area. Underground pipes were incorporated into the model as 1D elements, which are dynamically linked to the 2D domain via pit and outlet structures. One sizeable trunk main outlet was linked to more than one 2D cell given that the combined width of the trunk main barrels exceeded the refined grid cell size of 3 m. All pits have been represented using assumed dimensions of 900 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 initially set as 0.015 for RCPs and RCBCs, with specifically-noted brick egg trunk mains adopting a roughness of 0.024. Structures noted to have significant blockage and sedimentation were increased in roughness to 0.025.

Site inspection of key hydraulic structures connecting flow paths intersecting with the railway line revealed significant organic debris building up at the structure inlets. The single 1800 mm diameter RCP within the Upper Main Drain was estimated to have 70% blockage, and the three 1500 by 1000 mm RCBCs to the south adopted a conservative estimate of 50% blockage, given the surrounding vegetation was dense enough to prohibit access to the structure location.

Final roughness and blockage values for design events were adopted in accordance with the conclusions reached in Section 6.0.

Model Topography

Base model topography was derived from LiDAR survey flown in 2016 and supplied by RRC. The data was supplied as a 1m resolution Digital Elevation Model (DEM). As noted in Section 3.4, a number of surveyed levels have been maintained from the previous model:

- Lower Dawson Road / Upper Dawson Road / Jellicoe Street Intersection.
- Yeppen North Bridge approach.
- Gladstone Road – George Street.
- William Street.
- Hastings Deering CAT site.

Crest levels of the railway lines and several key roads were also maintained from the previous model. Surveyed road crowns across major flow paths include:

- Lower Dawson Road / Gladstone Road / George Street.
- Port Curtis Road.
- Fiddes Street / Lucius Street.
- Old Bruce Highway (South).
- Wood Street.

Further topographical adjustments incorporated into the model from previous projects includes survey points along existing open channels. This survey was compared to the LiDAR elevations and Basecase DEM. The channel and crest inverts were enforced using of z-lines.

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 regarding 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 34.

Table 34 Adopted Roughness Values

Material Description	Manning's 'n'			
	Depth 1 (m)	Manning's 'n' 1	Depth 2 (m)	Manning's 'n' 2
Urban Block	0.1	0.060	0.3	0.120
Commercial/Industrial Block	0.1	0.020	0.3	0.040
Open Space	0.1	0.050	0.3	0.035
Medium vegetated channel with mangroves, debris and tall grass	0.1	0.070	0.5	0.050
Building	0.1	0.018	0.3	0.500
Dense vegetation / Densely vegetated channel	0.1	0.080	0.5	0.060
Medium vegetated channel	0.1	0.070	0.3	0.050
Base layer	0.1	0.050	0.3	0.040
Road reserve	0.025			
Light vegetation	0.1	0.060	0.3	0.045
Steep slopes	0.1	0.100	0.3	0.060

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. Any losses applied remove the loss depth from the rainfall amount **prior** to being applied as a boundary on 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 (January 2013 and March 2017) 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 were not adjusted. 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 35.

Table 35 Adopted Initial and Continuing Loss Values

Material Description	Initial Loss (mm)	Continuing Loss (mm/h)
Urban Block	15	1
Commercial/Industrial Block	7.5	0.5
Open Space	15	1
Medium vegetated channel with mangroves, debris and tall grass	15	1
Building	0	0
Dense vegetation / Densely vegetated channel	15	1
Medium vegetated channel	15	1
Base layer	15	1
Road reserve	0	0
Light vegetation	15	1
Steep slopes	0	0

Initial Conditions

Initial water levels were applied to the 1D pipe network and 2D domain. The MHWS water level of 2.66 mAHD was specified for the entire model area under design events. This ensured that model boundaries represented the water level of the Fitzroy River were represented at the first time step of the model simulation. During the calibration and verification events the applied initial water level was adjusted to the first height corresponding with the model start time from the tidal boundary hydrograph.

Boundary Conditions

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

- Direct rainfall.
- Height versus discharge (HQ) outflow boundaries.
- Height versus time (HT) boundaries for the Fitzroy River.

Direct rainfall has been applied to the 2D domain; background to this approach is described in Section 4.1. HQ type boundaries allow flood waters to discharge from the model relative to the water surface elevation. Using a downstream slope value established using the 1 m DEM, TUFLOW automatically generates a height versus discharge curve (rating curve) which is applied to the model boundary. A HT boundary applies a water level to the boundary cells based on a water level versus time curve. MHWS was adopted for design events and historic tidal data during the calibration and verification events (where data permitted) was adopted for the Fitzroy River channel.

A summary of the boundary conditions applied to the three models are summarised in Table 36.

Table 36 Summary of Boundary Conditions

Boundary Type	Details
Direct rainfall	Applied across entire 2D domain
HT	· Fitzroy River outflow boundary (north-eastern boundary)
HQ	· 2 outflow boundaries applied along the western model boundary · 3 outflow boundaries applied along the north-western model boundary · 1 outflow boundaries applied along the eastern model boundary · 21 outflow boundaries applied along the southern model boundary

Appendix B

Tangible Flood Damages Assessment Methodology

Appendix B Tangible Flood Damages Assessment Methodology

1.0 Introduction

As part of the South Rockhampton Local Catchment Study, a flood damages assessment has been conducted to help quantify the financial burden borne by the community due to the local catchment flood damages. The flood damages assessment will also assist in assessing the potential economic benefits of the proposed mitigation options, in providing flood mitigation for the study area during local catchment flood events.

This flood damages assessment considers the financial impacts of flooding, comprising the costs associated with direct damages to property and infrastructure, and indirect costs associated with the disruptive impacts of flooding. This document presents the methodology used to assess flood damages, and the resulting estimates.

2.0 Estimating Flood Damages

2.1 Overview

Flooding can result in significant financial and social impacts on a community. A breakdown of the various types of flood damages is displayed in Figure 49. As intangible flood damages are difficult to quantify as a monetary value, they have not been included in this flood damages assessment. Therefore, reference to flood damages within this report refers to tangible flood damages only.

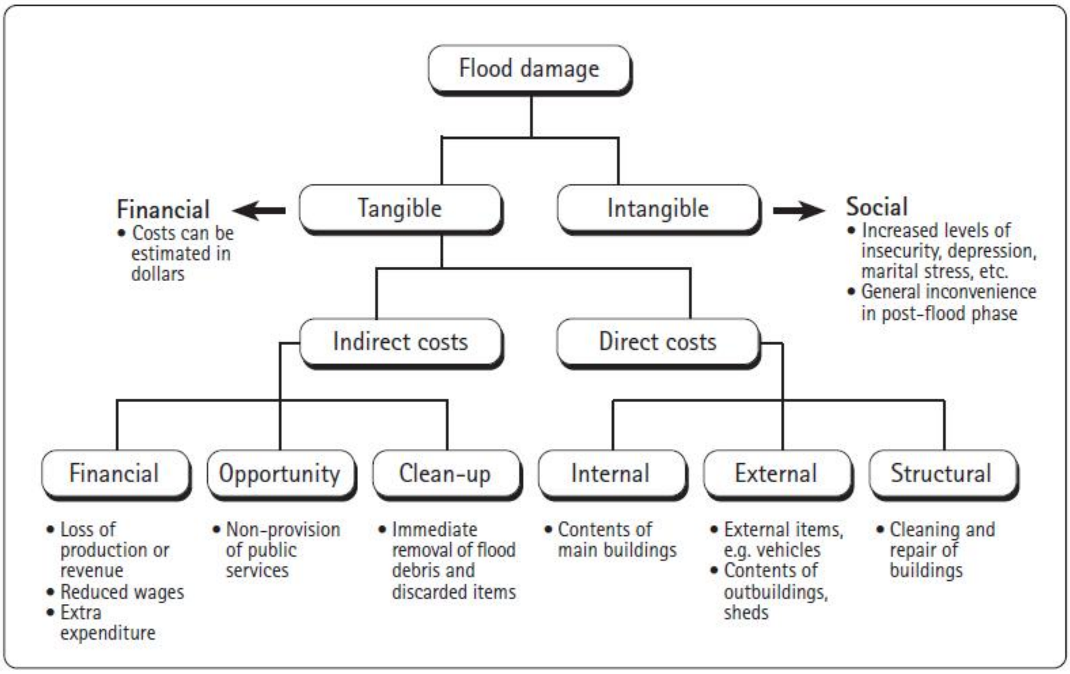


Figure 49 Breakdown of flood damage categories (source: DNRM, 2002)

2.2 General Methodology

Flood damages have been estimated through the application of stage-damage curves. These curves provide damage costs as a function of water depth, and are used to estimate direct flood damages for individual buildings based on the peak flood depth that the building experiences during a flood event. Indirect damages and infrastructure damage have been estimated as a percentage of the direct damage. The assessment has been undertaken using the results of the hydraulic modelling undertaken for the study area.

Alternative Approaches

Several approaches for estimating residential flood damages and stage-damage curves have been applied in Australia, including those by the Victorian Natural Resources and Environment, Risk Frontiers, WRM (for Sunshine Coast Regional Council) and O2 Environmental (for Ipswich City Council). While these approaches follow the same general approach, they use different estimates for stage-damage curves or consider damage types differently. A summary of literature relevant to these approaches is provided below. These provide detail on these alternative approaches.

Department of Infrastructure, Planning and Natural Resources (DIPNR) (2004) "Floodplain Management Guideline No 4 Residential Flood Damage Calculation", New South Wales Government, February 2004

Middelmann-Fernandes, M. H. (2010) "Flood Damage Estimation Beyond Stage-Damage Functions: an Australian Example", Geoscience Australia, Canberra, Australia, 2010, Journal of Flood Risk Management

Department of Natural Resources and Water (2002) "Guidance on the Assessment of Tangible Flood Damages", Queensland Government, 2002

O2 Environmental (2012) "Stage Damage Functions for Flood Damage Estimation – Interim Functions for 2012", Prepared for Ipswich City Council, April 2012

Sunshine Coast Regional Council (2010) "Estimation of Tangible Flood Damages (Maroochy River, Mountain Creek and Sippy Creek Catchments)", April 2010.

Smith, D. I. (1994) "Flood Damage Estimation – A Review of Urban Stage-Damage Curves and Loss Functions", Centre for Resource and Environmental Studies, Australian National University, Canberra, Australia, July 1994, Water SA

WRM Water & Environment (2006a) "Stage-Damage Relationships for Flood Damage Assessment in Maroochy Shire", WRM Water & Environment Pty Ltd, June 2006, prepared for Maroochy Shire Council

WRM Water & Environment (2006b) "Brisbane Valley Flood Damage Minimisation Study Brisbane City Flood Damage Assessment", WRM Water & Environment Pty Ltd, October 2006, prepared for Brisbane City Council City Design, submitted to the Queensland Floods Commission of Inquiry on 17 May 2011

The Queensland Department of Natural Resources and Mines (DNRM) recommends the use of the ANUFLOOD stage-damage curves for estimating potential flood damages; however there is a consensus that ANUFLOOD underestimates damage values for residential properties. For instance, DIPNR (2004) states:

"The Victorian Natural Resources and Environment, Rapid Assessment Method (RAM) for Floodplain Management, May 2000, indicates that ANUFLOOD estimates needed to be increased by 60% to be in the vicinity of Water Studies damages surveys. Even with this adjustment ANUFLOOD estimates are still well below those of Risk Frontiers."

A review of residential stage-damage curves was undertaken as part of the South Rockhampton Flood Levee project (AECOM, 2014). This review compares flood damages estimated using the ANUFLOOD stage-damage curves against two of the Australian methods mentioned above and one approach used in the USA, and demonstrates the variation in estimates of flood damages between different approaches. Based on this review, the WRM stage-damage curves and O2 Environmental stage-damage curves based on rebuilding costs have been adopted for estimating residential direct damages, to be presented as bounds of potential flood damages.

The ANUFLOOD stage-damage curves have been adopted for estimation of commercial direct damages due to the lack of alternatives.

Actual and Potential Damages

The stage-damage curves used during this study provide estimates of the potential flood damages which would occur during a flood event if no actions were taken to reduce the amount of damage.

During actual flood events, residents will usually take measures to reduce the amount of damage incurred, such as moving possessions to higher ground.

The reduction in flood damages resulting from such preventative measures is dependent on the warning time available during a flood, the experience of the community in preparing for flooding and whether or not it is possible to move possessions to safety.

Residents of the study area typically have very little notice prior to a local catchment flood event, as critical durations for the study area are short (in the order of 1 to 3 hours). Therefore the stage-damage curves were not adjusted using the ratios of actual to potential (A/P) flood damages recommended in DNRM (2002). An actual to potential damages ratio of 1 has been applied to all the damage curves.

2.3 Residential Damages

The following section describes the stage-damage curves that have been used to assess the value of residential flood damages for the assessment.

O2 Environmental Stage Damage Curves

Direct residential damages were estimated using the O2 Environmental (2012) stage-damage curves based on rebuilding costs, which are presented in Table 37 to Table 39. Individual curves are given for external, contents and structural damages. Figure 50 presents stage damage curves representing total flood damages (sum of external, contents and structural damages).The external and damage component is based on the WRM (2006a) curves adjusted to present day dollars (refer Section 2.6, Table 44), the contents damage component is based on the WRM (2006a) curves scaled to have a maximum value equal to the average household contents insurance value of $80,000, and the structural damage component is based on estimates of rebuilding costs (O2 Environmental, 2012) also adjusted to present day dollars.

Damage calculations were carried out separately for the external, contents and structural damage components and combined to give total damages. This allowed a range of raised building heights to be easily assessed, with external damages increasing with over ground depth, and contents and structural damages increasing with over floor depth. Raised floor levels were estimated as described in Section 3.4.

All damage values have been adjusted to March 2017 Dollars, which corresponds to the most recent Consumer Price Index (CPI) values available. Details of the adjustment are provided in Section 2.6. No adjustment of Stage-Damage curves to represent actual / potential flood damages was undertaken, as described in Section 2.2.

Table 37 O2 Environmental Stage-Damage curves for residential external damage (March 2017 $)

Depth Over Ground (m)	Fully Detached			Semi or Non Detached		
	Vehicle Damages	Other Damages	Total Damages	Vehicle Damages	Other Damages	Total Damages
0	$0	$0	$0	$0	$0	$0
0.025	$0	$2,276	$2,276	$0	$1,024	$1,024
0.5	$13,528	$5,918	$19,446	$12,264	$6,373	$18,637
1	$33,252	$9,332	$42,583	$25,160	$8,763	$33,923
2	$33,378	$10,925	$44,303	$25,160	$9,787	$34,947

Table 38 O2 Environmental Stage-Damages curves for residential contents damage (March 2017 $)

Depth Over Floor (m)	Detached Single Storey	Detached Double Storey	Detached High Set	Multi-unit Single Storey	Multi-unit Double Storey
0	$0	$0	$5,000	$0	$0
0.025	$15,000	$10,000	$15,000	$15,000	$10,000
0.5	$40,000	$25,000	$40,000	$30,000	$20,000
1	$64,000	$40,000	$64,000	$48,000	$32,000
2	$80,000	$50,000	$80,000	$60,000	$40,000
2.75	$80,000	$60,000	$80,000	$60,000	$50,000
3.7	$80,000	$65,000	$80,000	$60,000	$55,000
4.7	$80,000	$80,000	$80,000	$60,000	$60,000

Table 39 O2 Environmental Stage-Damage curves for residential structural damage (March 2017 $)

Depth Over Floor (m)	Detached Single Storey (200m^2)	Detached Single Storey (150m^2)	Detached Double Storey (2 x 150m^2)	High Set Queenslander (200m^2)	Multi-unit Single Storey	Multi-unit Double Storey
0	$0	$0	$0	$0	$0	$0
0.025	$10,796	$7,936	$10,796	$7,936	$7,337	$5,393
0.15	$19,694	$14,358	$20,429	$14,889	$13,397	$10,129
0.5	$85,060	$66,271	$87,480	$78,831	$57,838	$53,609
1	$141,259	$112,984	$112,860	$116,670	$96,060	$79,340
1.5	$141,259	$112,984	$117,540	$116,670	$96,060	$80,052
2	$141,259	$112,984	$122,232	$116,670	$96,060	$80,052
2.3	$141,259	$112,984	$122,232	$116,670	$96,060	$80,052
2.8	$154,927	$123,227	$135,889	$136,431	$105,353	$92,771
3	$176,701	$141,485	$157,900	$159,494	$120,152	$108,451
4	$176,701	$141,485	$157,900	$162,761	$120,152	$110,678
5	$176,701	$141,485	$157,900	$169,286	$120,152	$115,110
5.2	$176,701	$141,485	$157,900	$180,579	$120,152	$122,797
6	$176,701	$141,485	$157,900	$198,837	$120,152	$135,210

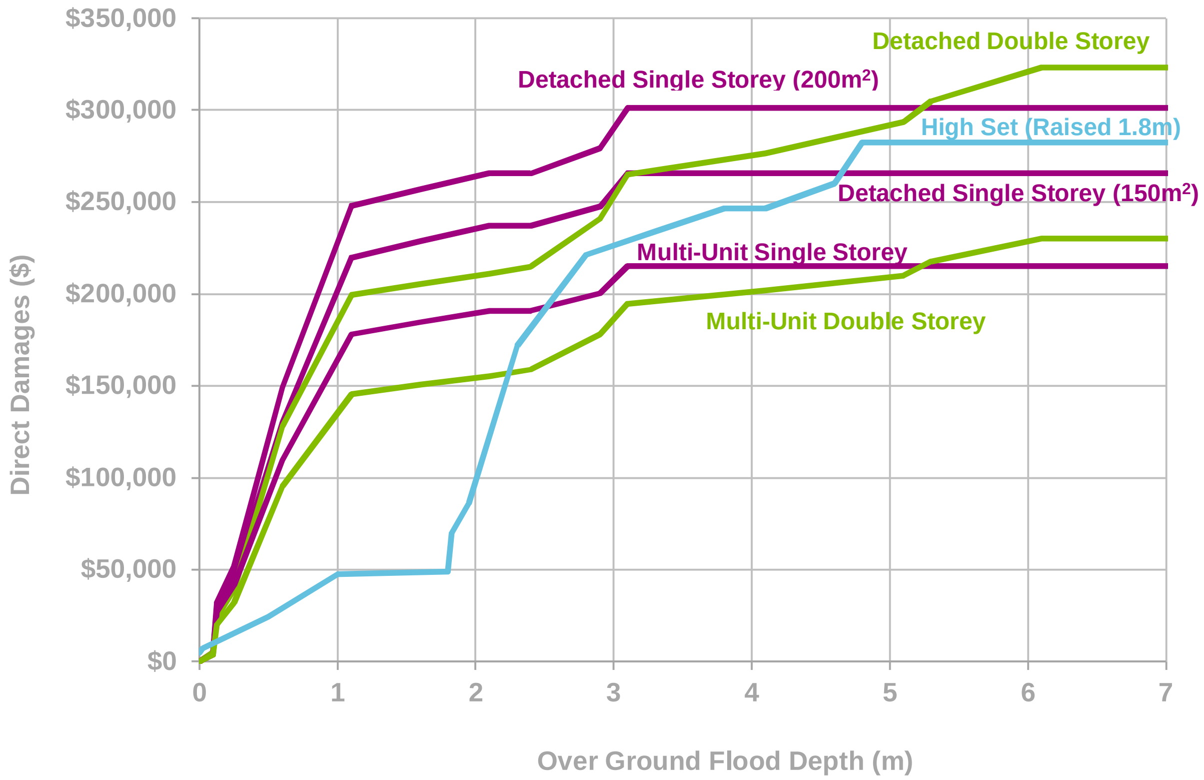


Figure 50 Total residential stage-damage curves based on O2 Environmental curves (March 2017 $)

WRM Stage Damage Curves

Direct residential damages were estimated using the WRM (2006a) stage-damage curves presented in Table 40 to Table 42. Individual curves are given for external, contents and structural damages, which were derived from stage-damage surveys conducted in Maroochy Shire on the Sunshine Coast. Figure 51 presents stage damage curves representing total flood damages (sum of external, contents and structural damages).

Damage calculations were carried out separately for the external, contents and structural damage components and combined to give total damages. This allowed a range of raised building heights to be easily assessed, with external damages increasing with over ground depth, and contents and structural damages increasing with over floor depth. Raised floor levels were estimated as described in Section 3.4.

All damage values have been adjusted to March 2017 Dollars, which corresponds to the most recent CPI values available. Details of the adjustment are provided in Section 2.6. No adjustment of Stage-Damage curves to represent actual / potential flood damages was undertaken, as described in Section 2.2.

Table 40 WRM Stage-Damage curves for residential external damage (March 2017 $)

Depth Over Ground (m)	Fully Detached			Semi or Non Detached		
	Vehicle Damages	Other Damages	Total Damages	Vehicle Damages	Other Damages	Total Damages
0	$0	$0	$0	$0	$0	$0
0.025	$0	$2,276	$2,276	$0	$1,024	$1,024
0.5	$13,528	$5,918	$19,446	$12,264	$6,373	$18,637
1	$33,252	$9,332	$42,583	$25,160	$8,763	$33,923
2	$33,378	$10,925	$44,303	$25,160	$9,787	$34,947

Table 41 WRM Stage-Damage curves for residential contents damage (March 2017 $)

Depth Over Floor (m)	Detached Single Storey	Detached Double Storey	Detached High Set	Multi-unit Single Storey	Multi-unit Double Storey
0	$0	$0	$0	$0	$0
0.025	$15,169	$11,900	$2,877	$6,669	$5,754
0.5	$36,746	$26,546	$7,192	$37,531	$14,515
1	$55,185	$41,454	$11,115	$47,731	$19,746
2	$66,300	$50,608	$13,338	$51,915	$22,362

Table 42 WRM Stage-Damage curves for residential structural damage (March 2017 $)

Depth Over Floor (m)	Detached Single Storey	Detached Double Storey	Detached High Set	Multi-unit Single Storey	Multi-unit Double Storey
0	$0	$0	$0	$0	$0
0.025	$13,648	$10,368	$4,200	$14,698	$7,743
0.5	$19,685	$15,092	$4,987	$19,817	$11,680
1	$24,803	$19,160	$6,955	$24,410	$13,517
2	$32,809	$25,066	$7,612	$24,803	$16,536

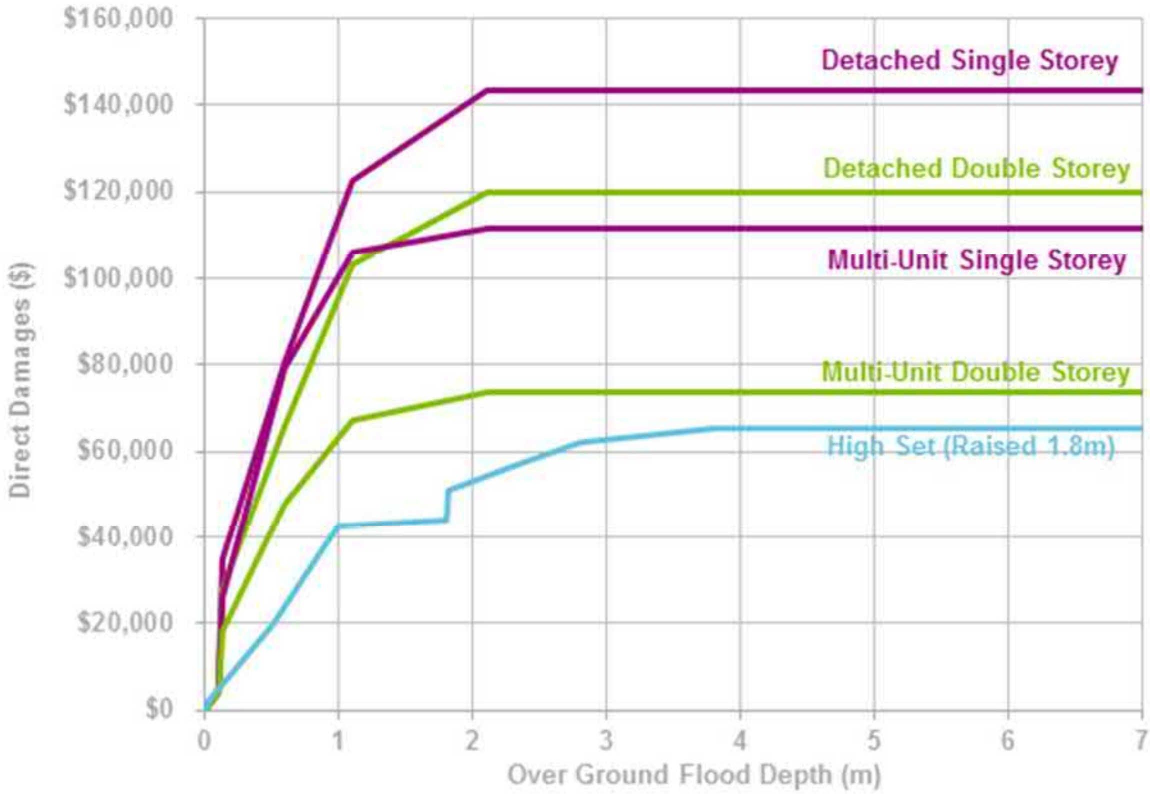


Figure 51 Total residential stage-damage curves based on WRM curves (March 2017 $)

Indirect Damages

Indirect residential damages were assumed to be 15% of the total direct residential damages (Department of Natural Resources and Mines, 2002).

2.4 Commercial Damages

The following section describes the stage-damage curves that have been used to assess the value of commercial flood damages for the assessment.

ANUFLOOD Stage-Damage Curves

Commercial, industrial and public building damages were estimated using the ANUFLOOD commercial stage-damage curves summarized in Table 43 and Figure 52. Commercial buildings were assigned a value class based on their use. Details on building classification are presented in Section 3.3. It should be noted that large-classed building damages were estimated using area directly (i.e. the large-class building damage curves are in units of $/m2 vs. $).

Raised floor levels were estimated as described in Section 3.4. Estimated damages were assumed to remain constant after a depth over floor of 2m, corresponding to the maximum damage value provided in the ANUFLOOD literature.

All damage values have been adjusted to March 2017 Dollars, which corresponds to the most recent CPI values available. Details of the adjustment are provided in Section 2.6. No adjustment of Stage-Damage curves to represent actual / potential flood damages was undertaken, as described in Section 2.2.

Table 43 ANUFLOOD Stage-Damage curves for commercial properties (March 2017 $)

Depth Over Floor (m)	Small – Damages in $ (< 186 m²)					Medium – Damages in $ (186 - 650 m²)					Large – Damages in $/m² (> 650 m²)				
	Value Class					Value Class					Value Class				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0.25	$3,197	$6,396	$12,791	$25,582	$51,165	$10,128	$20,253	$40,506	$81,011	$162,023	$10	$22	$46	$89	$177
0.75	$7,995	$15,988	$31,978	$63,956	$127,913	$24,516	$49,032	$98,066	$196,132	$392,263	$57	$113	$224	$447	$899
1.25	$11,991	$23,985	$47,967	$95,935	$191,868	$37,307	$74,616	$149,230	$298,501	$596,924	$118	$235	$473	$942	$1,883
1.75	$13,324	$26,648	$53,297	$106,594	$213,187	$41,303	$82,611	$165,220	$330,440	$660,880	$192	$388	$774	$1,546	$3,091
2	$14,123	$28,248	$56,494	$112,989	$225,978	$43,969	$87,941	$175,879	$351,759	$703,518	$231	$462	$923	$1,847	$3,695

* Note that damage costs for Large Commercial Properties are based on a 'dollars per m²' rate, whereas damage costs for Small and Medium Commercial Properties are based on a pure 'dollar' rate.

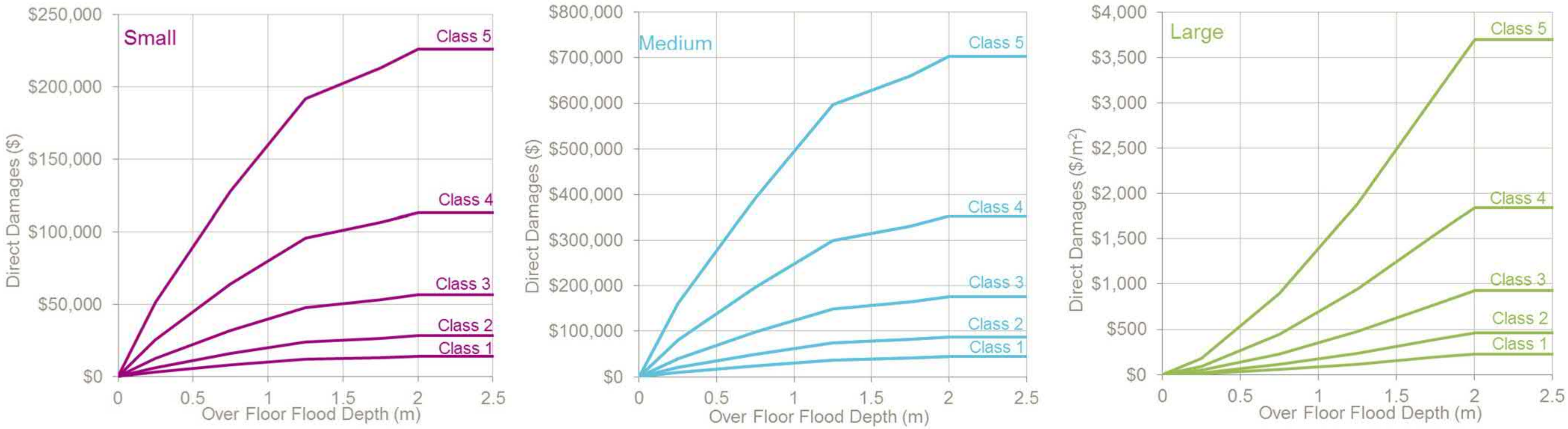


Figure 52 ANUFLOOD Stage-Damage curves for commercial properties (March 2017 $)

Indirect Damages

Indirect damages for commercial buildings were assumed to be 55% of the direct damages. This number is significantly higher than the indirect damage value for residential buildings due to the assumed loss of business revenue, as per DNRM (2002). It should be noted that this applies to all buildings classified as commercial, which includes community assets such as park facilities, schools, etc. which may not actually recognize business–related revenue.

2.5 Infrastructure Damages

Costs associated with damage to infrastructure such as roads, water and wastewater facilities, and utilities have been estimated as 15% of the total direct residential and commercial flood damages. This is consistent with the recommendations of the Office of Environment and Heritage (BMT WBM, 2011).

2.6 Consumer Price Index Adjustment

All stage-damage curves were adjusted to present day dollars based on CPI ratios. Current CPI values were taken from the most recent statistics available from the Australian Bureau of Statistics (ABS) dated March 2017.

The commercial ANUFLOOD damage curves were adjusted using the CPI for All Groups, as the allotment of ANUFLOOD damages to structure damages and contents damages is unknown. The external and structural components of O2 Environmental damages were adjusted separately using the relevant CPI's. The contents component of the O2 Environmental damages were not indexed, as the maximum value of $80,000 for residential contents damages is considered reasonable for the study area. Table 44 presents an overview of the CPI adjustments.

Table 44 CPI adjustment summary

Damage Curve	Relevant CPI Group	Reference	Reference CPI	Current CPI	CPI Increase
ANUFLOOD Commercial	All Groups	DNRW, 2002	76.1	110.5	45.2%
O2 Residential External *Motor Vehicle*	Maintenance and repair of motor vehicle	WRM, 2006	85.5	108.1	26.4%
O2 Residential External *Other Damage*	Tools and Equipment for house and garden	WRM, 2006	94.2	107.2	13.8%
O2 Residential Contents	N/A	O2 Environmental, 2012	---	---	---
O2 Residential Structural	Maintenance and repair of dwelling	O2 Environmental, 2012	99.6	112.6	13.1%
WRM External *Motor Vehicle*	Maintenance and repair of motor vehicle	WRM, 2006	85.5	108.1	26.4%
WRM External *Other Damage*	Tools and Equipment for house and garden	WRM, 2006	94.2	107.2	13.8%
WRM Contents	All Groups	WRM, 2006	84.5	110.5	30.8%
WRM Structural	Maintenance and repair of dwelling	WRM, 2006	85.8	112.6	31.2%

3.0 Building Classification

3.1 Introduction

Building data within the study area was supplied by RRC and classified using land use data provided. Information was generated at a planning level of detail considered adequate for the purpose of this study. Surveyed building flood levels were included where available. Other detailed building information such as entry location, structure and content values and actual businesses, was not included.

3.2 Footprints

Building footprints were supplied by Council. The area of the building footprint was used for classifying buildings into different size classes. For large commercial buildings, the stage-damage curves give damages in units of $\$/m^2$, therefore building areas were used directly in the damage calculations.

3.3 Class

Buildings were assigned a building class which determined the damage curve applied to each building. To assign classes to buildings, the attribute data for each building footprint was used. Based on a combination of the structure type and land use data fields, buildings were categorized as either residential or commercial, while recognizing that ANUFLOOD includes commercial, industrial and public buildings all within the *commercial* building type.

Residential Buildings

Residential buildings were further classified based on size and raised height to align with the building classes presented in Section 2.3. Building classification was based on the structure type and number of storeys where available, otherwise it was based on land use. Buildings in residential or rural zones without any other data were categorised as detached single storey slab-on-ground houses. Detached, single storey, slab-on-ground houses were finally categorised by the area of the digitised building footprints.

Commercial Buildings

Commercial buildings were further classified based on size and value of the building contents to align with the classes presented in Section 2.4. The ANUFLOOD damage value classes for commercial buildings are shown in Figure 53.

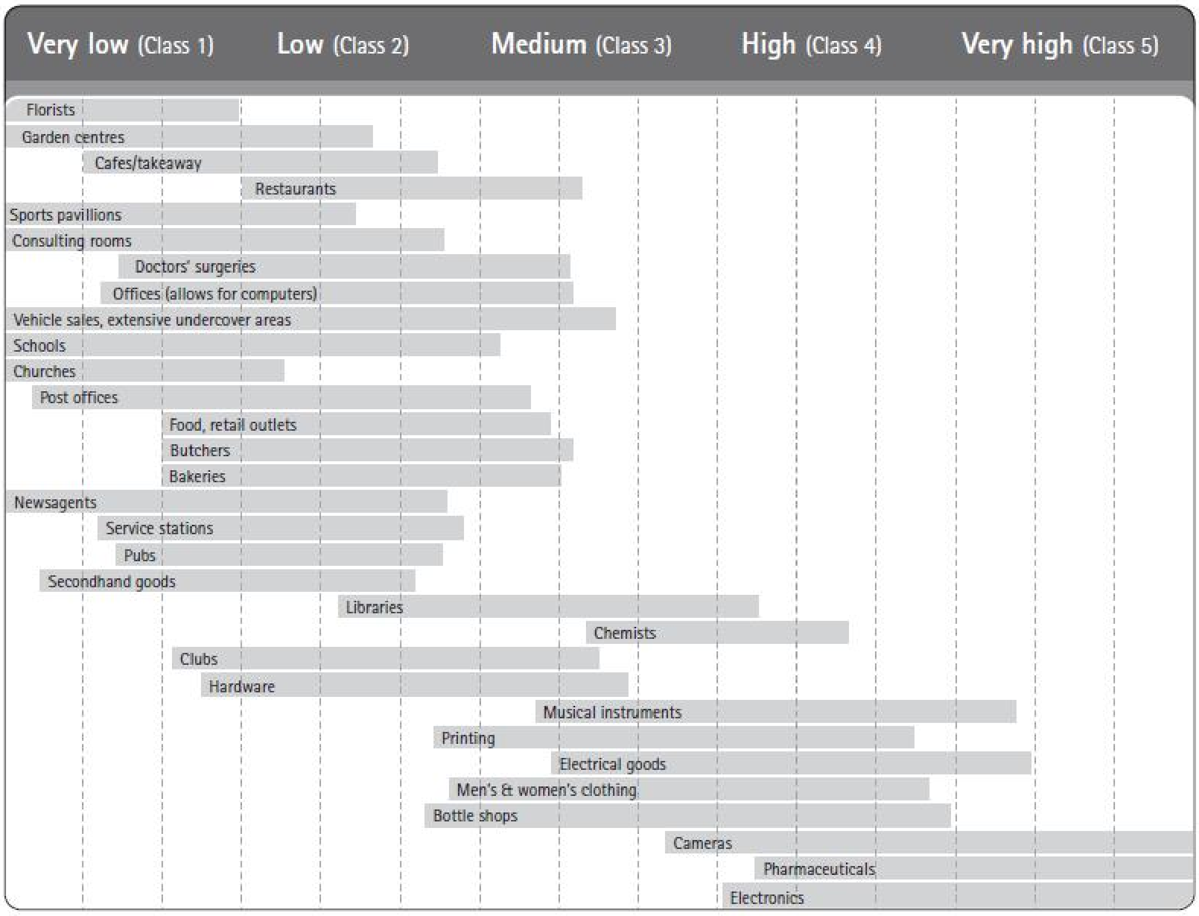


Figure 53 ANUFLOOD commercial damage value classes (source: DNRM, 2002)

As ANUFLOOD provides a range of property classes for each property type, a single value class has been assigned based on the land use field of the building footprints dataset. Where the land use did not correspond directly to an ANUFLOOD damage value class, a reasonable value class was assigned. Areas labelled as footpaths were assumed not to be buildings and were not classified. Sheds and Garages were given a classification based on land use data. Table 45 shows the value class assigned to each land use in the building footprints dataset. Where the land use of a commercial building was not known, the building was assigned class 3.

Table 45 Assignment of commercial damage class values based on Council land use dataset

Council Land Use	Class	Council Land Use	Class	Council Land Use	Class
Animals Special	3	Hospitals/Nursing Homes	2	Service Station	2
Builders Yards / Contractors Yard	3	Hotel/Tavern	2	Shop Single	3
Car Park	2	Iceworks	2	Shops 2 to 6	3
Car Yards etc	2	Heavy Industry	3	School	2
Caravan Parks	2	Horses	1	Service Station	2
Cattle Breeding/Fattening	2	Irrigation Small Corps	2	Shop Single	3
Cemeteries	1	Library	3	Shops Main Retail	3
Child Care Centre	1	Licenced Clubs	2	Shops over 6	3
Churches/Halls	1	Light Industry	3	Shops Secondary Retail	3
Clubs Non-Business	2	Motel	2	Showgrounds etc	2
Community Facilities	2	Noxious Industry	3	Sports Clubs	2
Council Owned	2	Nurseries	2	Theatre/Cinema	3
Defence Forces	4	Offices	2	Tourist Attraction	3
Drive Shopping Centre	3	Oil Depot	3	Transformers	3
Fire/Ambulance	3	Orchards	2	Transport Terminal	3
Flats with Shops	3	Parks & Gardens	1	Tropical Fruits	1
Funeral Parlours	1	Poultry	2	Uni/Schools etc	2
General Industry	3	Reservoirs etc	3	Vineyards	2
Guesthouse	2	Restaurant	2	Warehouses etc	3
Harbour Industries	3	Retail Warehouse	2	Welfare Homes	2

3.4 Levels

The ground level at each building was estimated based on the 1m LiDAR DEM provided for the project. Ground levels were assigned to the building footprints based on the average elevation of the DEM within the building extents.

Buildings were classified as one or two storey based on their attribute data. Buildings lacking data regarding number of storeys were assumed to be one storey. Buildings on slabs were assumed to have a minimum habitable floor level of 100mm above ground level. Low set buildings were assumed to have a minimum habitable floor level of 600mm above ground level and high set buildings were assumed to have a minimum habitable floor level of 1,800mm above ground level. Buildings lacking data regarding what type of floor they have were assumed to be on slabs.

4.0 Bibliography

AECOM. (2014). *South Rockhampton Flood Levee - Residential Depth-Damage Curve Review.* Rockhampton: AECOM Australia Pty Ltd.

Australian Bureau of Statistics. (2017, April 26). *6401.0 - Consumer Price Index, Australia, Mar 2017.* Retrieved June 9, 2017, from Australian Bureau of Statistics Web site: http://www.abs.gov.au/Ausstats/abs@.nsf/mf/6401.0

BMT WBM. (2011). *Belongil Creek Floodplain Risk Management Study and Plan - Discussion Paper 2: Flood Damages Assessment.* Brisbane: BMT WBM Pty Ltd.

Department of Infrastructure, Planning and Natural Resources. (2004). *Floodplain Management Guideline No 4 Residential Flood Damage Calculation.* Sydney: New South Wales Government.

Department of Natural Resources and Mines. (2002). *Guidance on the Assessment of Tangible Flood Damages.* Brisbane: The State of Queensland.

Middelmann-Fernandes, M. H. (2010, March). Flood Damage Estimation Beyond Stage-Damage Functions: an Australian Example. *Journal of Flood Risk Management, 3*(1), 88-96.

O2 Environmental. (2012). *Stage Damage Functions for Flood Damage Estimation – Interim Functions for 2012.* Fortitude Valley: O2 Environmental.

Smith, D. I. (1994, July). Flood Damage Estimation – A Review of Urban Stage-Damage Curves and Loss Functions. *Water SA, 20*(3), 231-238.

Sunshine Coast Regional Council. (2010). *Estimation of Tangible Flood Damages (Maroochy River, Mountain Creek and Sippy Creek Catchments).* Maroochydore: Sunshine Coast Regional Council.

WRM Water & Environment. (2006a). *Stage-Damage Relationships for Flood Damage Assessment in Maroochy Shire.* Spring Hill: WRM Water & Environment Pty Ltd.

WRM Water & Environment. (2006b). *Brisbane Valley Flood Damage Minimisation Study - Brisbane City Flood Damage Assessment.* Spring Hill: WRM Water & Environment Pty Ltd.