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Splitters Creek Local Catchment Study

Baseline Flooding and Hazard Assessment - Volume 1

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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 Splitters Creek Catchment Study, which is the subject of this report.

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

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

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

The key objectives of this study are:

- To update Council's existing Splitters Creek TUFLOW model, to refine the grid size, incorporate latest LiDAR and aerial imagery information. It is noted that the current model configuration utilised an XP-Rafts hydrologic model to apply lumped flows directly to Splitters Creek.
- The assessment of existing flood risk within the study area, related to flooding within and directly adjacent to Splitters Creek. 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 Splitters Creek catchment covers an area of approximately 13.1 km^2 starting within the western extent of Mount Archer National Park and stretching to the eastern bank of the Fitzroy River. Splitters Creek is positioned between the larger catchments of Limestone Creek (north) and Moores Creek (southwest).

The upper half of Splitters Creek is a combination of confined ephemeral channels which join to form the wider Splitters Creek channel near Yaamba Road. Further downstream, the system graduates into a broader floodplain. The natural creek bed material varies from exposed medium-sized cobbles / rocks and maintained grass within the urbanised segments, to silty / sandy soils in lower-lying areas. Riparian vegetation along the creek can also vary from very dense grasses to shrubs and trees.

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

Previous Study

In May 2014 Aurecon delivered Revision 2 of the *Rockhampton Local Catchments Flood Study - Splitters Creek Hydrologic and Hydraulic Modelling Report* (Aurecon, May 2014). The study applied XP-Rafts hydrologic model hydrographs as lumped catchment inflows to the two dimensional TUFLOW hydraulic model. The XP-Rafts hydrographs were applied directly within the creek channel, to represent the runoff from upstream sub-catchments.

It should be noted that the modelling undertaken did not simulate overland flows within the upstream sub-catchments, as no direct rainfall was applied within the TUFLOW model.

The TUFLOW two-dimensional hydraulic model was calibrated to recorded levels from the January 2013 local catchment rain event. It was reported that the modelled flood levels had an absolute average difference of 0.42 m when compared to the recorded levels.

Design events were modelled by Aurecon for the 39%, 18%, 10%, 5%, 2%, 1%, 0.5%, 0.2% Annual Exceedance Probability (AEP) and Probable Maximum Flood (PMF) local catchment flood events. Climate change scenarios were modelled for 20% and 30% increases in rainfall intensity, for the 1%, 0.5% and 0.2% AEP events.

On 14 June 2016 Aurecon delivered to Council a memorandum detailing Splitters Creek Model Upgrade works, undertaken at Council's request. The model upgrade works centred around Council's development of a new Digital Elevation Model (DEM), with the intent of better representing flooding within the Splitters Creek catchment. The Aurecon Memorandum detailed a number of topographic, 1D network, XP-Rafts inflow, boundary condition and materials layer updates, as well as a summary of design events modelled, results and comparison to previously reported flooding characteristics.

Council's June 2016 Splitters Creek TUFLOW hydraulic model and XP-Rafts hydrologic model were used as the basis for this current study.

Updated Modelling

Prior to utilising Council's Splitters Creek TUFLOW hydraulic model in this current study to assess baseline flood hazard, a number of model updates were completed as part of this current study.

These included topographic updated to incorporate latest LiDAR and aerial imagery, plus more refined representation of the model grid, road crowns and channel invert levels. In addition, 1D network configuration and setup changes resulted in a more stable model.

Various design flood events and durations were simulated and results extracted. The critical duration for the catchment was determined to be the 60 minute event. A comparison of the design events found that for events up to the 18% AEP event, the road and subsurface drainage infrastructure was able to prevent runoff from entering private property. For larger flood events, the overland flow paths continue to develop and are predicted to impact public and privately owned infrastructure throughout the catchment.

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 Splitters Creek 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 adopted hazard categories along with a general description of the risk associated with each category.

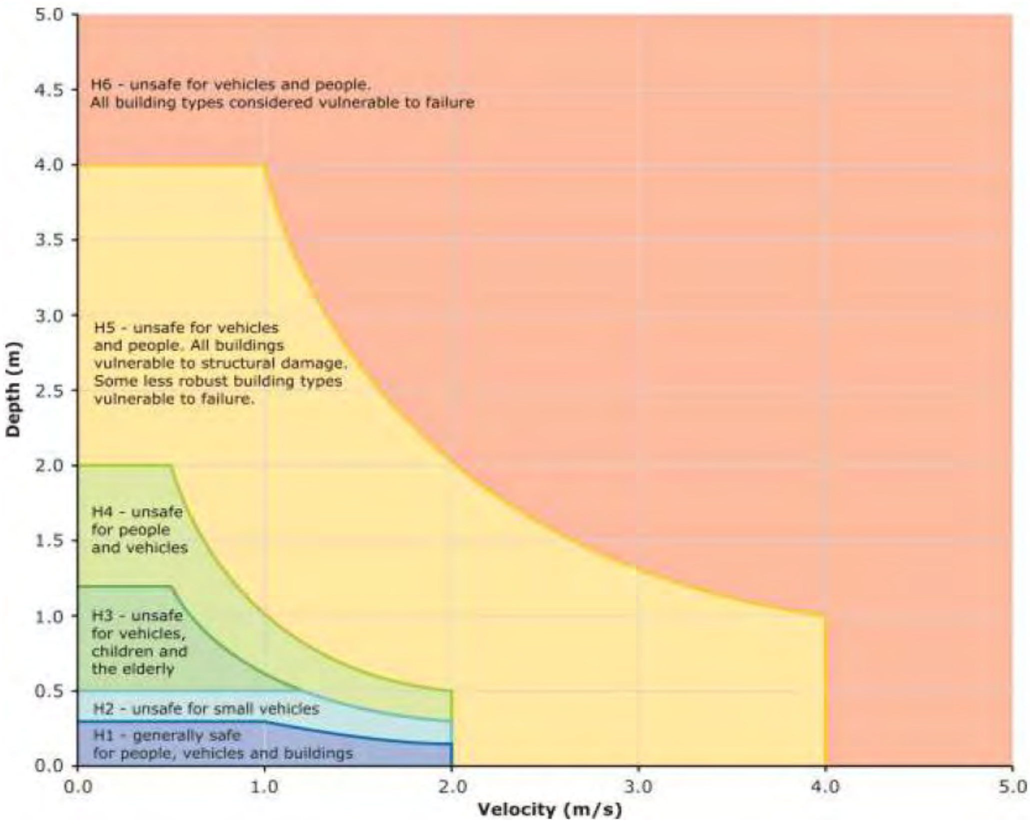

Figure E1 Hazard Vulnerability Classifications (Graphical)

Analysis of the 1% AEP baseline flood hazard within the Splitters Creek catchment generally shows:

- Low to medium hazard (H1 and H2) in some urbanised areas.
- High hazard (H3 and H4) within the floodplain area to the west of Alexandra Street Extended.
- High to extreme hazard (H4 and H5) within some natural and man-made open channels.
- Extreme hazard (H5 or H6) within the Splitters Creek channel and adjacent overbank areas.

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 Hadgraft Street Sewerage Pump Station (SPS, Ref: 463733) and Stringybark Avenue - Forest Park SPS (Ref: 463751) are predicted to have less than 0.2% flood immunity. It is noted however that the predicted flood levels and hazard are low in the 0.2% AEP event. It is recommended this information be passed onto FRW as the asset owner.
- Low depth flooding is predicted at the Norman Road Hospital in the 0.2% AEP.
- The North Coast Rail Line is predicted to be inundated over ballast level in the 10% AEP event and larger.
- A number of road segments are predicted to experience inundation in the 1EY event and larger. Approximate TOS values ranges from 0.5 hours to approximately 3.5 hours.

Evacuation Routes

Generally local catchment flooding within the Splitters Creek catchment is due to short duration, high intensity rainfall events. The relatively steep upper catchment and urbanisation throughout much of the 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 Splitters Creek 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:

- Bulman Street and Smithwick Street → loses evacuation via Wormald Street to Farm Street.
- Foxglove Avenue, Bushpea Court, Snow Gum Street and Plumb Drive → loses evacuation via Bramble Street to Farm Street.
- Primrose Avenue, Frangipani Court, Red Penda Court, Saintwood Avenue, Lace Flower Court and Silky Oak Court → loses evacuation via Bramble Street to Farm Street.
- Bramble Street, Mistletoe Avenue, Stringybark Avenue, Waratah Court, Messmate Court and Aspen Court → loses evacuation via River Rose Drive to Norman Road.
- Larcombe Street and Sandys Place → loses evacuation vis Macalister Street to Glenmore Road and/or via York Street to Haynes Street

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.

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 ~8,540 floor levels and ground levels within the Splitters Creek modelled area, for buildings outside Council's surveyed database.
- Classification of ~10,000 buildings within the Splitters Creek 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 Splitters Creek 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	3 (0)	0 (0)
39.4	9 (0)	0 (0)
18.1	18 (2)	8 (4)
10	33 (7)	13 (7)
5	72 (24)	18 (12)
2	107 (34)	23 (19)
1	132 (42)	24 (21)
0.2	324 (154)	51 (37)
0.05	457 (222)	68 (51)
-	864 (470)	164 (143)

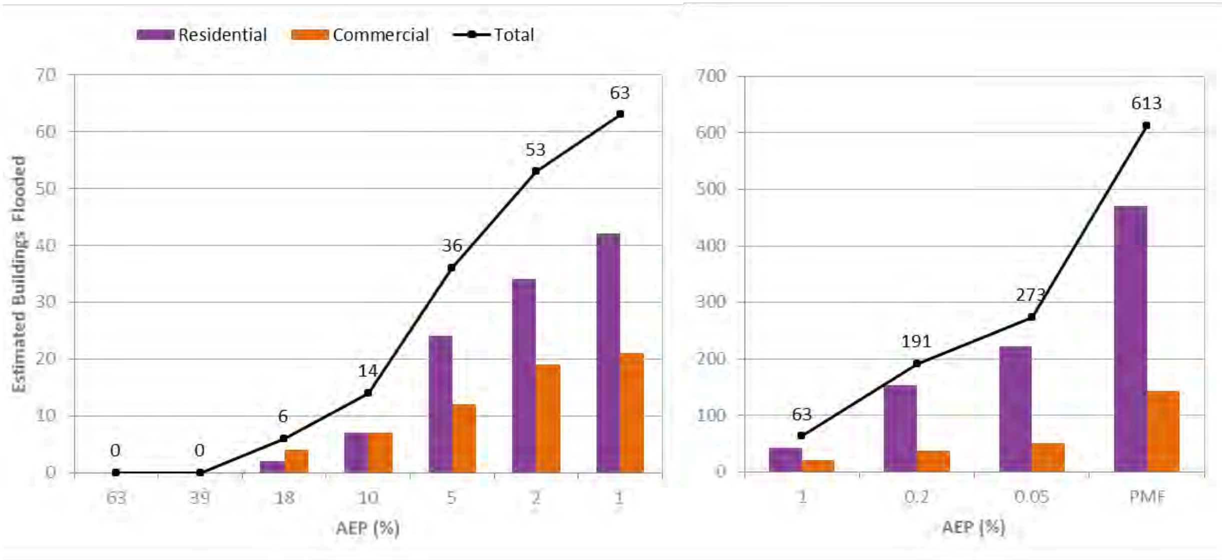

Figure E2 Estimated Buildings with Above Floor Flooding (Number of Buildings)

As shown in Figure E3, median flood depths are generally less than 0.5 metre for each flood event. This indicates that reductions in flood depths of 0.5 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.

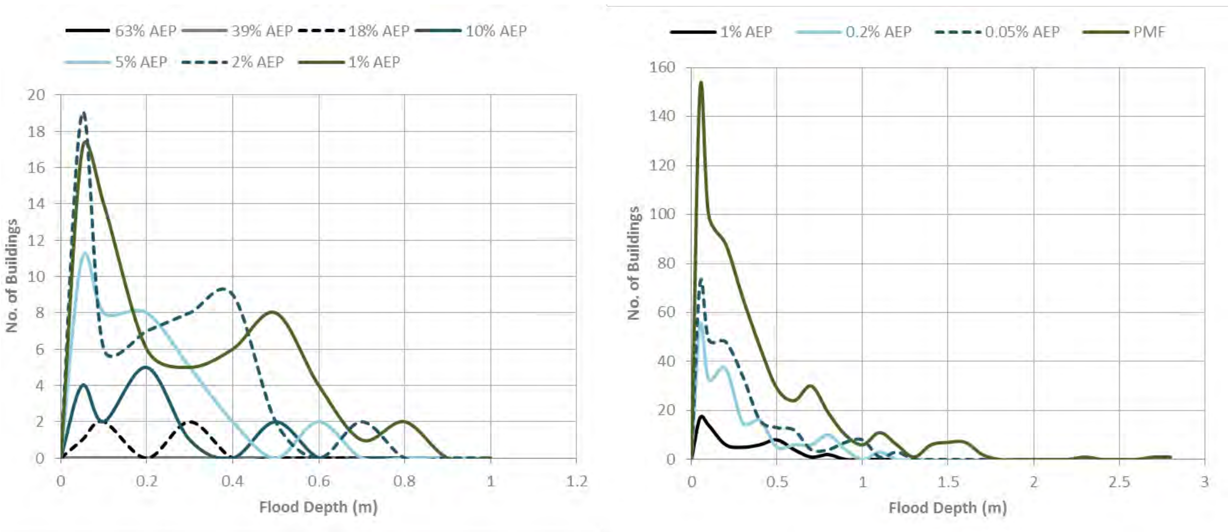

Figure E3 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings). Note: curves for the 63% AEP and 39% AEP events are not shown as there is not predicted to be above floor flooding in these events.

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 $42,000 (1EY flood event) to $92.7M (PMF event) using the O2 Environmental Damage Curves. Figure E2 shows that zero buildings are expected to be inundated above floor in the 1EY event, whilst 613 buildings are anticipated to be inundated above floor in the PMF event.

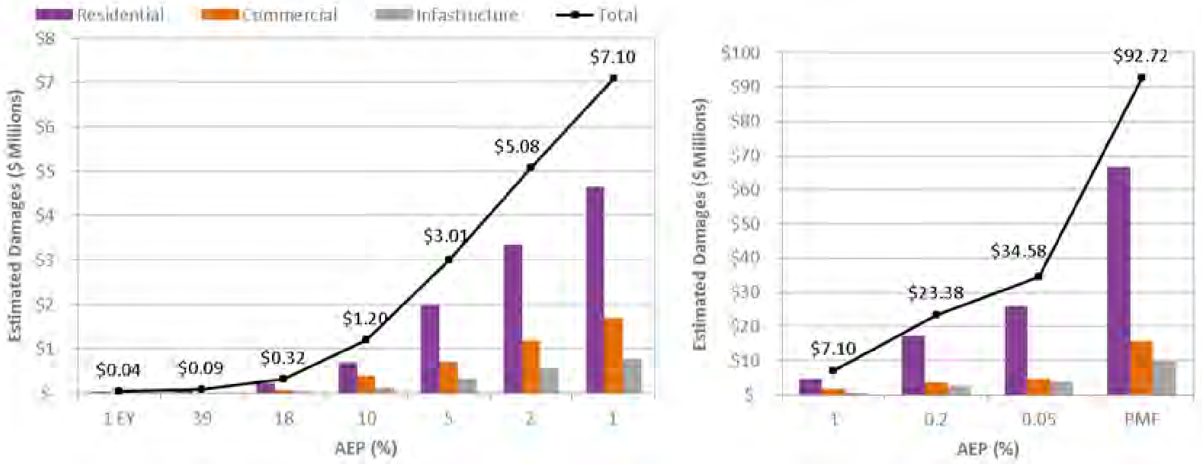

Figure E4 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

These figures also demonstrate that residential buildings make up the large majority of impacted buildings, and the estimated flood damages, within the Splitters Creek 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 Splitters Creek catchment is estimated to range from approximately $552,000 to $606,000 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.

72% of damages are associated with less than 5% of all buildings. This demonstrates that a minority of buildings produce the majority of damages.

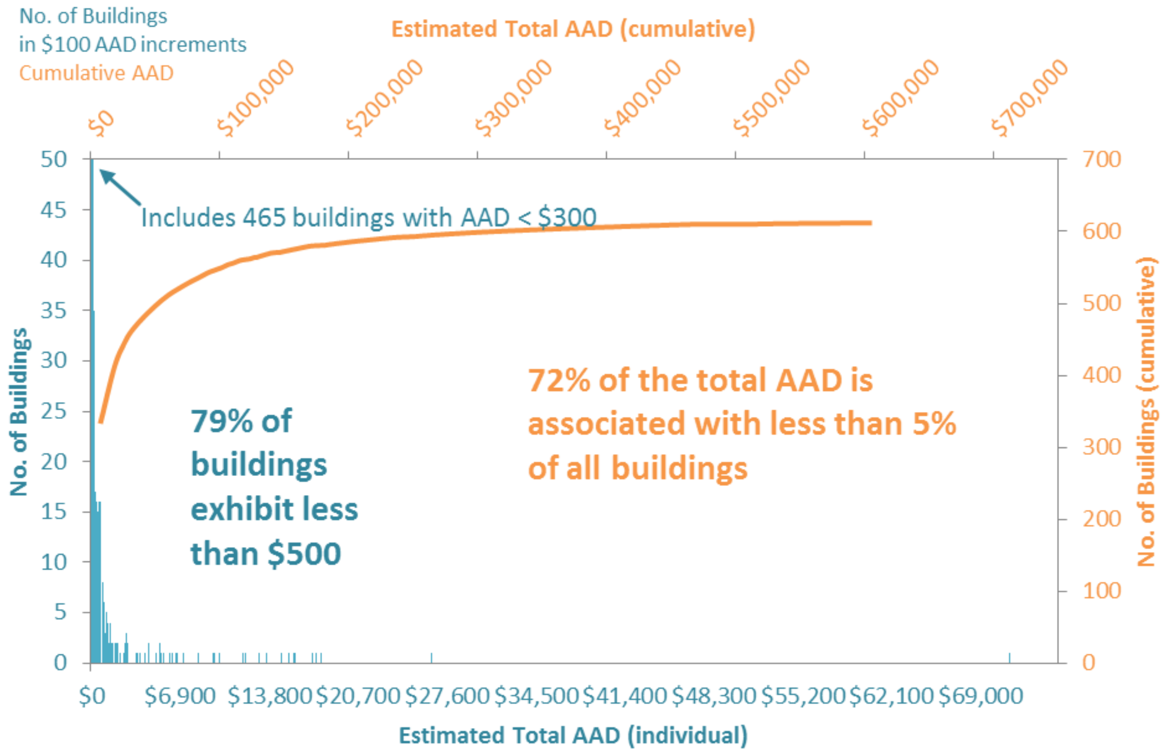

Figure E5 Individual Building vs. Cumulative Total Average Annual Damages

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 Splitters Creek catchment:

- Additional rain gauges should be installed at NRSTP and SRSTP.
- Additional maximum flood height gauges should be installed at Stringybark Avenue (Mistletoe Avenue intersection), Richardson Road and Thompson Street intersection, Kluver Street and Hadgraft Street (in the vicinity of the Hadgraft Street SPS).
- There is no current flood warning system within the Splitters Creek catchment.

Recommendations

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

- It is highly recommended that the TUFLOW model be upgraded to a direct rainfall hydrologic methodology in the future, to align with the outcomes of other studies undertaken for Council as part of the FMS project. Within this scope of works, updated calibration and validation of the model should be undertaken to historical local catchment events.
- 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.
- 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 Splitters Creek catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained and the TUFLOW model has been upgraded to the direct rainfall methodology.
- It is recommended that Council continue to record rainfall and flood heights associated with future Splitters Creek 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 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). Potential mitigation options should be focussed on both creek and overland flooding.

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 Splitters Creek Local Catchment Study, which is the subject of this report.

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

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

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

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

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

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

1.2 Phased Approach

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

Phase 1 and 2 involved the development of a numerical model to simulate baseline flood behaviour associated with a range of local catchment design events. Phase 2 assesses the 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 be read in conjunction with the:

- Rockhampton Local Catchments Flood Study - Splitters Creek Hydrologic and Hydraulic Modelling Report (Aurecon, May 2014), which constitutes the Phase 1 works; and
- Splitters Creek Local Catchment Study – Mitigation Options Analysis (AECOM, 2017), which constitutes Phase 3 of this study.

1.3 Phase 1 and 2 Study Objectives

The key objectives of this study are:

- Undertake updates to Council's existing Splitters Creek TUFLOW model (previously developed by others), to refine the grid size, incorporate latest topographic and aerial imagery information. It is noted that the current model configuration utilises an XP-Rafts hydrologic model to apply lumped flows directly to Splitters Creek. Rain on grid modelling has not been undertaken at Council's request.
- The assessment of existing flood risk within the study area, related to flooding within and directly adjacent to Splitters Creek. 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 Splitters Creek Local Catchment Study – Baseline Flooding and Hazard Assessment Report has been separated into 2 volumes:

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

The structure of this Volume 1 report is as follows:

- Section 2.0 summarises 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 of the hydraulic model.
- Section 4.0 outlines the hydrologic inputs and model outputs.
- Section 5.0 details the development of the Baseline hydraulic model.
- Section 6.0 presents the Baseline flood results, as well as a comparison to the previous study.
- Section 7.0 presents results of the sensitivity analyses.
- Section 8.0 presents the flood hazard and risk assessment.
- Sections 9.0 and 10.0 summarise the conclusions and outline recommendations.
- Section 11.0 presents the references used during the study.

1.5 Notes on Flood Frequency

The frequency of flood events is generally referred to in terms of their Annual Exceedance Probability (AEP) or Average Recurrence Interval (ARI). For example, for a flood magnitude having 5% AEP, there is a 5% probability that there will be floods of equal or greater magnitude each year. As another example, for a flood having 5 year ARI, there will be floods of equal or greater magnitude once in 5 years on average. Events more frequent than 50% AEP should be expressed as X Exceedances per Year (EY). The correspondence between the two systems is presented in Table 1.

Table 1 AEP and ARI Comparison

Annual Exceedance Probability (AEP) %	Average Recurrence Interval (ARI) Years
63 (1EY)	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:

- Baseline modelling and mapping is based in Council's existing TUFLOW model, which incorporates an XP-Rafts hydrologic model to apply lumped flows directly to Splitters Creek. **Modelling and mapping of overland flow paths has not been undertaken.**
- With the exception of the 1% AEP design flood event, all design flood events were assessed for a single critical duration, based on an analysis of multiple storm durations for the 1% AEP event.
    - GIS mapping for the 1% AEP design flood event was prepared using a 'Max:Max' analysis of multiple storm durations, whereas all other design flood events were mapped for only the critical storm.
- Aerial survey data (in the form of LiDAR) used to develop the topography for the hydraulic model has a vertical accuracy of ± 0.15 m on clear, hard surfaces and a horizontal accuracy of ± 0.45 m.
- Where information gaps existed in the underground drainage network, assumptions were made to fill these gaps using desktop assessment methods.
- Assessment of the probability of coincident local rainfall and Fitzroy River flood events has not been undertaken.
- The hydraulic model has previously been calibrated (by others) to a single historical event, being the local flood event which occurred in January 2013. The model has not been validated to any other historic events.
- The approach adopted assumes each catchment is independent of the adjacent catchments. It does not allow for jointly occurring design events. The cross connections between catchments occur in the less frequent events, given this low likelihood of an event actually occurring, this approach was deemed acceptable for this study.
- Hydrologic and hydraulic modelling is based on methods and data outlined in Australian Rainfall and Runoff (AR&R) 1987. The 1987 revision has been adopted as per Council's request. Refer to the ARR, Data Management and Policy Review (AECOM, 2017) for details surrounding changes recommended in the 2016 revision.
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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 Splitters Creek catchment covers an area of approximately 13.1 km^2 starting within the western extent of Mount Archer National Park and stretching to the eastern bank of the Fitzroy River. Splitters Creek is positioned between the larger catchments of Limestone Creek (north) and Moores Creek (southwest). In comparison to other local systems, Splitters Creek is less well-defined due to the small upper catchment (northeast of Norman Road) comprising of splayed tributary channels.

The upper Splitters Creek catchment varies in elevation from 300 mAHD to 70 mAHD, covering an area of just 1.8 km^2. The land within the upper and central portions of the catchment is predominantly urbanised with a combination of residential, commercial and industrial parcels. The lower segment downstream of the North Coast Rail Line (NCRL) is less developed with the flood extent widening rapidly across the floodplain towards the outlet on the southern boundary of the catchment. The Splitters Creek channel in the lower segment of the reach is shown in Plate 1.

Plate 1 Splitters Creek Channel at York Street

The land use in the upper catchment is predominantly medium density urban residential, with the majority of industrial and commercial areas situated within the central portion.

Table 2 Splitters Creek Catchment Land Uses

Land Use	Proportion
Rural / Mountainous	37%
Urban	63%
• Industrial / Commercial	(20%)
• Residential	(80%)

The upper half of Splitters Creek is a combination of confined ephemeral channels (natural and constructed) which join to form the wider Splitters Creek channel near Yaamba Road. Further downstream, the system graduates into a broader floodplain area. The natural creek bed material varies from exposed medium-sized cobbles / rocks and maintained grass within the urbanised segments, to silty / sandy soils in lower-lying areas. Riparian vegetation along the creek can also vary from very dense grasses to shrubs and trees. Examples of the various upper tributaries are provided in Plate 2.

Plate 2 Splitters Creek Tributaries – Vegetated Rock (top) / Maintained Grass (bottom)

The moderate to steep longitudinal slopes and open channels can result in high velocities, flood hazard and limited response times for crossings prone to flash flooding.

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

The following key urban flow paths within the urban catchment have been included:

- River Rose Drive
- Satinwood Avenue;
- Bulman Street; and
- Wackford Street.

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

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Metres

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LEGEND

- Natural_Flow_Lines
- Highways
- Railway Lines
- Hydraulic Model Extent

Topography (mAHD)

- < 4
- 4 - 7
- 7 - 10
- 10 - 13
- 13 - 16
- 16 - 19
- 19 - 22
- 22 - 25
- 25 - 28
- 28 - 31
- 31 - 34
- 34 - 37
- 37 - 40
- 40 - 45
- 45 - 50
- 50 - 55
- 55 - 60
- 60 - 100
- 100 - 200
- > 200

Data Sources:

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

Splitters Creek Model

Sub-catchment Delineation and Natural Flow Paths

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	1

Figure 1

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 1 Sub Catchment Delineation.mxd

2.2 Climate Characteristics

The Splitters Creek local catchment is situated at latitude 23º 19' 51.52" south, about 11 km north of the Tropic of Capricorn. The catchment centroid is about 27 km 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 800 mm. The highest mean monthly rainfall of 145 mm generally occurs in February. The highest and lowest annual rainfall recorded at the Rockhampton Airport is 1631 mm (in 1973) and 360 mm (in 2002) which shows a significant variation in annual rainfall, year on year.

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

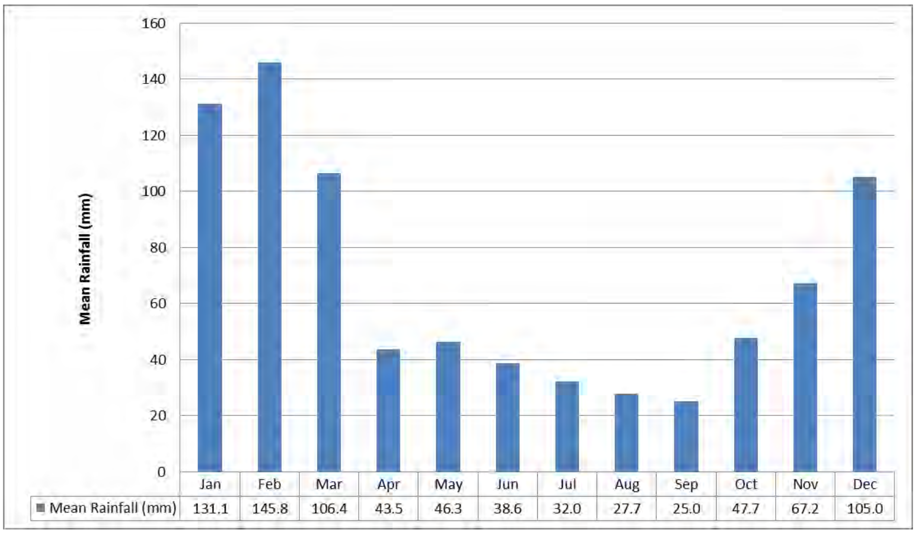


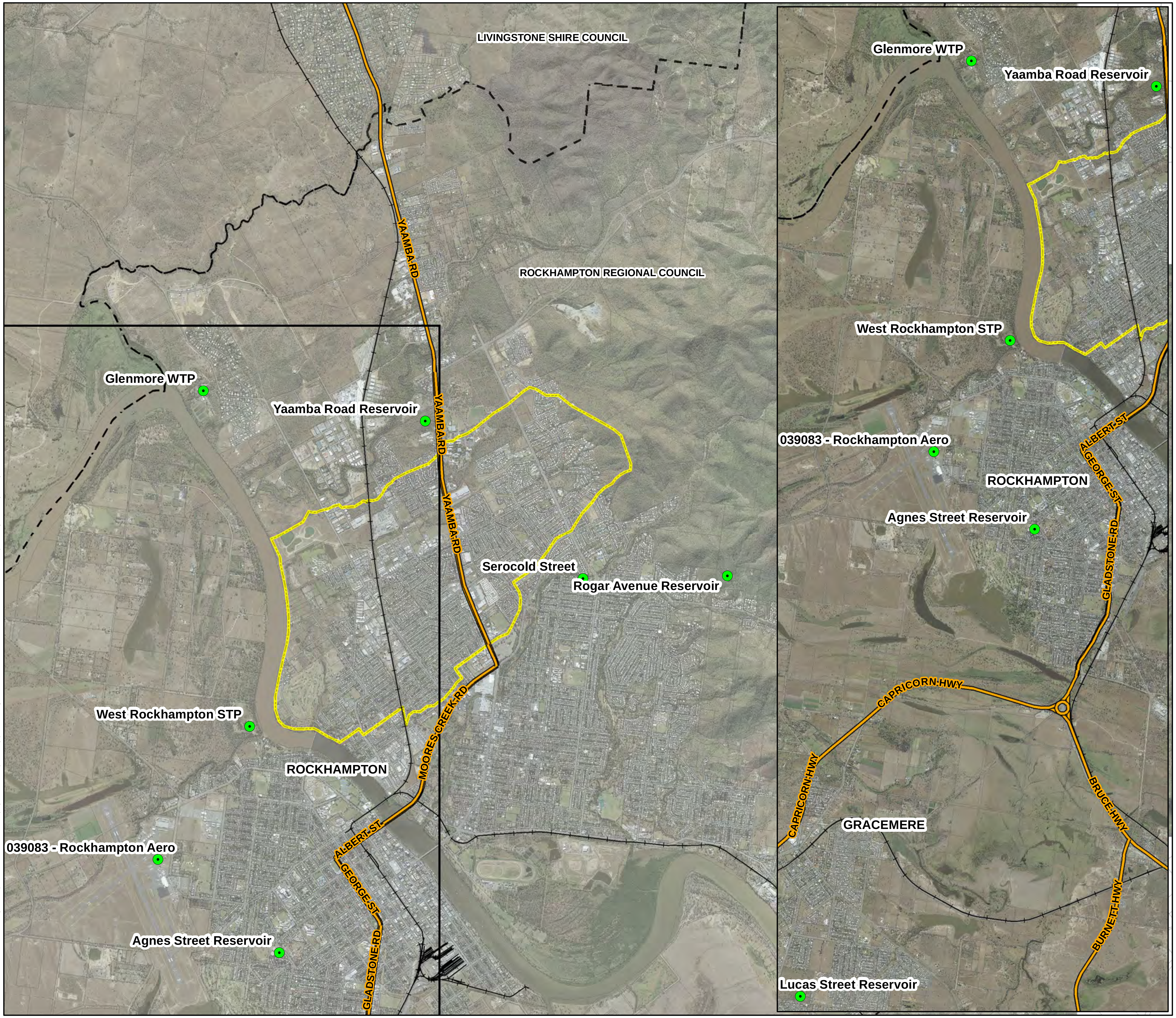
Figure 2 Mean Monthly Rainfall at the Rockhampton Airport Rainfall Station

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

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

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

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



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Rockhampton Regional Council

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0 500 1,000 1,500 2,000 2,500

Metres

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AECOM
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LEGEND

- Rainfall Gauge Locations
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent Local
- Government Boundaries

Data Sources:

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

Splitters Creek Model

Rainfall Gauge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	2

Figure
3

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

None of the abovementioned gauges are located within the Splitters Creek catchment. The Serocold Street and Yaamba Road Reservoir gauges lie within the urbanised portions of the adjacent catchment and are therefore likely to represent the best-estimate of historic rainfall events for the Splitters Creek Local Creek model.

2.4 Historic Local Catchment Events

Significant local rainfall events leading to overland flooding of the Splitters Creek urban catchment often originate from tropical cyclonic activity, rapidly intensifying troughs and depressions. Notable incidents of such meteorological events occurring in recent times include the 2013, 2015 and 2017 events. Other significant events include the 1991 and 2008 events.

This study did not include the simulation of any historical events, although the previous model (developed by others) was calibrated to the 2013 local catchment events to verify the model performance.

It is strongly recommended that the model is calibrated and validated to recent local catchment events when undertaking future upgrade of the model to the rain-on-grid approach with the inclusion of the full pit and pipe network.

2.5 Riverine Flooding Influence

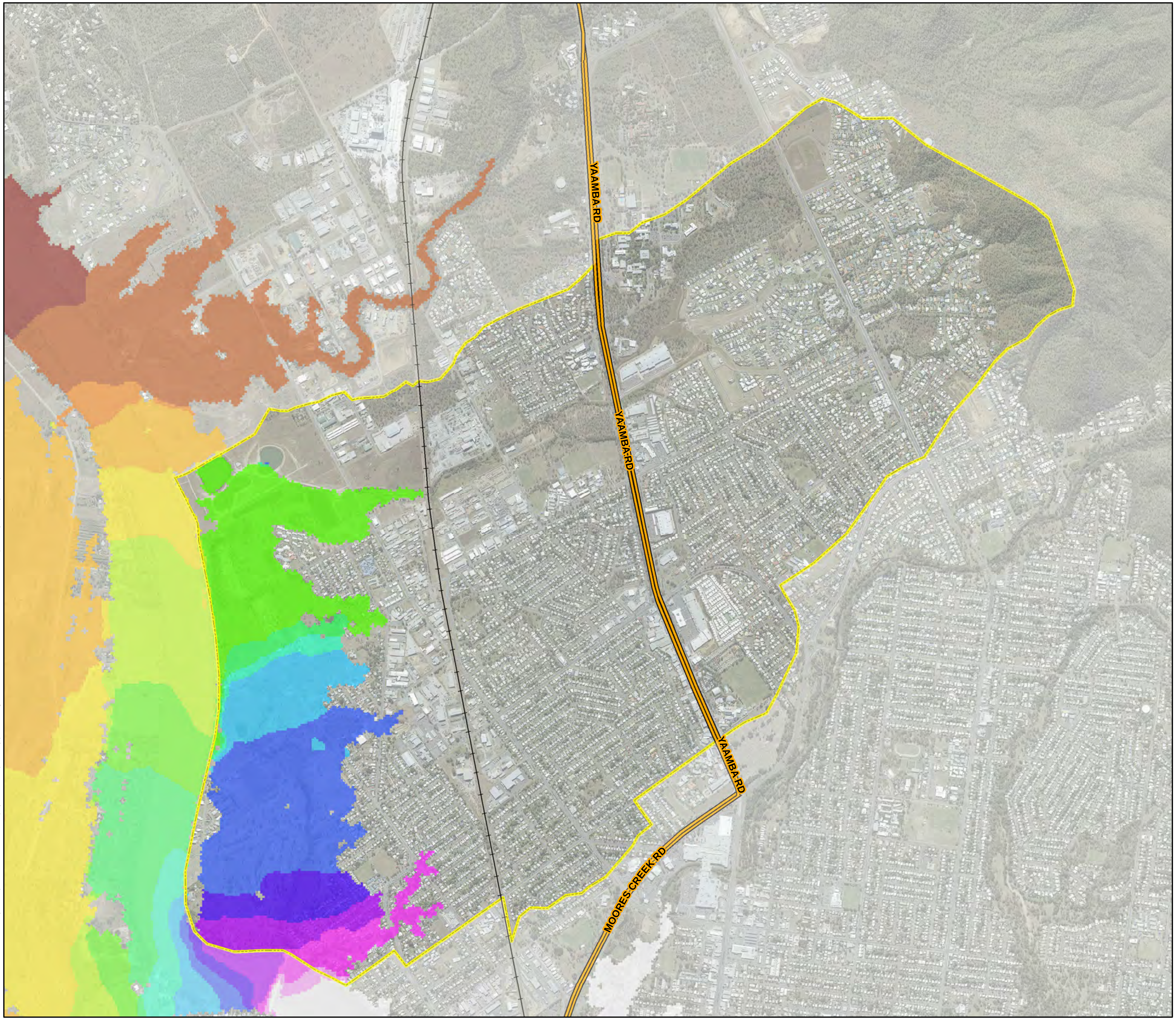
Riverine floods in Rockhampton can result from extended periods of rainfall within the 142,000 km^2 Fitzroy River basin. As peak discharge increases along the Fitzroy River, a key breakout occurs upstream of Rockhampton at the Pink Lily meander, which can result in the inundation of large areas of South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

Figure 4 outlines the riverine flood heights for a 1% AEP flood event. A review of the topography shows that portions of the lower Splitters Creek catchment become inundated by riverine flood waters in a flood event of this magnitude. Fitzroy River floodwaters extend along Splitters Creek with the fringe of the extent reaching the NCRL corridor. Further downstream, the western ends of Maloney Street and Farm Street are impacted by the Fitzroy River with Cramb Street, York Street and Haynes Street severely inundated. A significant number of low-lying properties west of Glenmore Road (near the Splitters Creek outlet) are also inundated with the peak flood extent reaching Wackford Street.

The effect of riverine backwater levels on local catchment flood behaviour have been modelled as part of the sensitivity analysis which simulates the coincidence of a 1% AEP local catchment event with a 18% AEP riverine event. The results form a component of the discussion made in Section 7.4.

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 Splitters Creek catchment during local rainfall events.



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Rockhampton Regional Council

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Metres

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AECOM
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LEGEND

- Existing Levee Systems
- Highways
- Railway Lines
- Hydraulic Model Extent

Peak Riverine Flood Height (mAHD)

- < 9.8
- 9.8 - 9.9
- 9.9 - 10
- 10.0 - 10.1
- 10.1 - 10.2
- 10.2 - 10.3
- 10.3 - 10.4
- 10.4 - 10.5
- 10.5 - 10.6
- 10.6 - 10.7
- 10.7 - 10.8
- 10.8 - 10.9
- 10.9 - 11
- 11.0 - 11.1
- 11.1 - 11.2
- > 11.2

Flood results are based on riverine catchment events

Data Sources:

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

Splitters Creek Model
Peak Fitzroy River Flood Heights

1% AEP Riverine Flood Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	2

Figure 4

3.0 Available Data

3.1 General

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

- Previous studies (Aurecon 2014 & 2016, BMT WBM 2014, AECOM 2014, 2015 & 2016).
- 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).

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

3.2 Previous Studies

3.2.1 Rockhampton Local Catchments Flood Study (Aurecon, May 2014)

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

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

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

The TUFLOW two-dimensional hydraulic model was calibrated to recorded levels from the January 2013 local catchment rain event. It was reported that the modelled flood levels had an absolute average difference of 0.42 m when compared to the recorded levels.

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

3.2.2 Wackford Street Drainage Investigation (AECOM, July 2016)

On 7 October 2015 AECOM delivered the final revision of the *Wackford Street Preliminary Drainage Investigation*. The investigation was intended to identity the current capacity of the stormwater drainage network, confirm the current drainage issues and identify short term and long term upgrades and/or augmentation, including associated indicative cost estimates. The outcomes of the study were used to inform the subsequent phase delivered to RRC on 6 July 2016.

The study involved site inspections and detailed discussions with local landowners used to support the development of a hydrodynamic model (TUFLOW) for the study area. The model was used to simulate a range of design flood events in order to:

- Establish an understanding of the existing flood risk in the area; and
- Assess the performance of proposed mitigation options.

Four options were taken forward into the preliminary design, including:

1. Re-grading of Wackford Street Carriageway.
2. Detention Basin Upstream of Wackford Street.
3. Drainage Diversion from Harriette Street.
4. Additional Underground Pipe Network in Wackford Street.

These options were combined into scenarios to assess the combined benefits. Consequently, it was recommended that the overall strategy be adopted as per the stages listed below:

- Stage 1A – Wackford Street Regrading (Option 1) – **$1.88M.**
- Stage 1B (Optional) – Wackford Street Underground Network (Option 4) - **$1.26M.**
- Stage 1C – Harriette Street Diversion (Option 3) – **$0.63M**.
- Stage 2A – Upstream Detention Basin (Option 2) – **$1.32M**

The outcomes of this study have been used to inform the detailed design of the Wackford Street Drainage Scheme which is currently being finalised by AECOM.

3.2.3 Webber Park Drainage Investigation (AECOM, 2017)

On 2 March 2016 AECOM delivered the final revision of the *Webber Park Preliminary Drainage Investigation*. The investigation was aimed at undertaking a preliminary stormwater drainage investigation of the catchment reporting to Webber Park, Norman Gardens in order to understand and quantify the existing flood risk and to scope and cost opportunities for possible mitigation works. The outcomes of this study were used to inform the preliminary design of options taken forward into the *Webber Park Drainage Investigation – Preliminary Design Report*.

The study involved site inspections and detailed discussions with local landowners used to support the development of a new hydrodynamic model (TUFLOW) for the study area. The hydrodynamic model was used to simulate a range of design flood events in order to establish an understanding of the existing flood risk in the area. The model was further utilised to assess the performance of proposed mitigation options to establish a way forward.

Outcomes from the preliminary assessment completed in 2016 led to the adoption of Scenario 3, whose stages were developed further in the recent preliminary design phase. Scenario 3 comprised of the following stages:

- Stage 1A – Construction of Overland Flow Paths.
- Stage 1B – Webber Park Detention Basin.
- Stage 2 – Duplication of Downstream Stormwater Drainage Network.

During preliminary design works, it was concluded that Stage 2 was not feasible due to constructability issues, impacts to private properties, conflicts with existing PUP assets, high cost and comparatively limited hydraulic benefit.

Consequently, it was recommended that the overall strategy be adopted as per the stages listed below:

- Stage 1A – Construction of Overland Flow Paths.
- Stage 1B – Webber Park Detention Basin.

3.2.4 Hydraulic Model Updates (Aurecon, June 2016)

On 14 June 2016 Aurecon delivered to Council a memorandum detailing Splitters Creek Model Upgrade works, undertaken at Council's request. The model upgrade works centred around Council's development of a new Digital Elevation Model (DEM), with the intent of better representing flooding within the Splitters Creek catchment.

The Aurecon Memorandum detailed a number of topographic, 1d network, XP-Rafts inflow, boundary condition and materials layer updates, as well as a summary of design events modelled, results and comparison to previously reported flooding characteristics.

Council's June 2016 Splitters Creek TUFLOW hydraulic model and XP-Rafts hydrologic model were used as the basis for this current study.

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

In June 2013 BMT WBM Pty Ltd (BMT WBM) were commissioned by RRC to carry out an independent review of the Rockhampton Local Catchments Flood Study, prepared by Aurecon (refer to Section 3.2.1). At that time the reports were in Draft format, to allow for updates and finalisation following completion of the peer review.

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

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

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

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

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

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

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

3.2.6 SRFL Hydraulic Model Development (AECOM, 2014)

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

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

3.3 Tidal Data

The Splitters Creek catchment has outlets located both upstream and downstream of the Fitzroy River Barrage. For the Splitters Creek's outlet located upstream of Fitzroy River Barrage, the weir on the southern side of the barrage was used to set tailwater levels. The weir has a crest level of 3.65 mAHD which discharges to the fish ladder, acting as the control for water levels upstream of the barrage.

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

For the tidal boundary downstream of the barrage, tailwater levels were based on the MHWS level at Rockhampton (2.66 mAHD). The MHWS level was sourced from the 2014 QLD Tide Tables book (MSQ, 2014).

3.4 Topographic Data

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

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

3.5 Aerial Photography

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

3.6 Stormwater Infrastructure Network Database

Drainage asset information was supplied by RRC in the form of GIS layers containing location, size and invert data for culvert, pit and pipe assets. This information was used to confirm the existing cross-drainage structures in the Splitters Creek model. RRC previously 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.
- Minimum depth of cover of 600 mm, where practicable.
- Upstream pipe diameter matched downstream pipe diameter.

3.7 Site Inspection

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

3.8 Hydraulic Structures

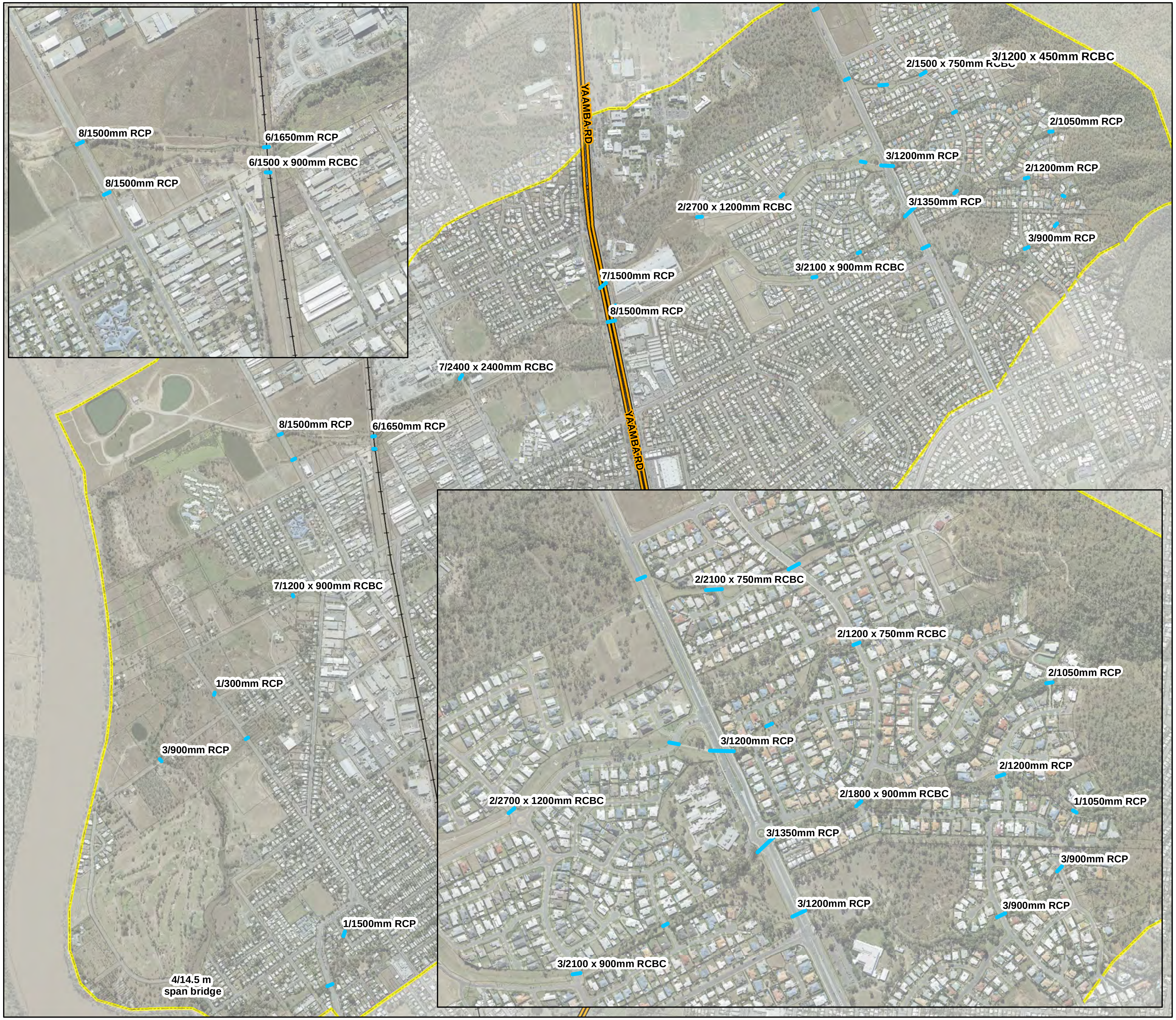
Identification of hydraulic structures associated with the major road / rail crossings within the study area was completed using a combination of council's stormwater infrastructure network database and site visits.

Approximately 34 major culverts and 1 bridge structure were identified across Splitters Creek and its various tributaries.

Table 3 presents a list of major structures within the study area which were incorporated into the hydraulic model; these are shown spatially in Figure 5. Culvert structures were represented as 1-dimensional elements within the hydraulic model and bridges were represented within the 2-dimensional domain as layered flow constrictions.

Table 3 Key Hydraulic Structures Incorporated to the Model

Drainage Structure	Configuration	Model Representation
Bridges		
Larcombe Street	4/14.5 m span bridge	2D
Major Culverts		
Norman Road	3/1200mm RCP	1D
	3/1350mm RCP	1D
River Rose Drive	2/2100mm x 1200mm RCBC	1D
Lilydale Close	2/1500mm x 600mm RCBC	1D
Norman Road	3/1200mm RCP	1D
	2/900mm RCP	1D
Walnut Avenue	2/2100mm x 750mm RCBC	1D
Norman Road	2/1050mm x 600mm RCBC	1D
Springfield Drive	2/1200mm x 750mm RCBC	1D
Rosewood Drive	2/1800mm x 900mm RCBC	1D
	3/900mm RCP	1D
Africander Avenue	3/900mm RCP	1D
Woodford Way	2/1200mm RCP	1D
Bramble Street	2/2700mm x 1200mm RCBC	1D
Stringybark Avenue	2/2700mm x 1200mm RCBC	1D
Bramble Street	3/2100mm x 900mm RCBC	1D
Satinwood Avenue	3/2100mm x 900mm RCBC	1D
Glenmore Road	1/4200mm x 2400mm RCBC	1D
York Street	3/900mm RCP	1D
Haynes Street	1/1800mm x 1200mm RCBC	1D
Yaamba Road	8/1500mm RCP	1D
	7/1500mm RCP	1D
Alexandra Street	8/1500mm RCP	1D
	8/1500mm RCP	1D
Woodford Way (Private Access)	2/1050mm RCP	1D
North Coast Rail Line	6/1650mm RCP	1D
Bulman Street	4/3000mm x 1500mm RCBC	1D
Kluver Street	1/1500mm RCP	1D
River Rose Drive	3/1800mm x 1200mm RCBC	1D
North Coast Rail Line	6/1500mm x 900mm RCBC	1D
Farm Street	7/1200mm x 900mm RCBC	1D
McLaughlin Street	7/2400mm x 2400mm RCBC	1D
Springfield Drive	2/1500mm x 750mm RCBC	1D



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LEGEND

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

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

Splitters Creek Model

Location of Key Hydraulic Structures

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	1

Figure 5

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 5 Key Structures.mxd

4.0 Hydrologic Modelling

4.1 Overview

This section of the report discusses the use of the existing XP-Rafts hydrologic model previously used to inform the Splitters Creek inflows, as a part of the Splitters Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014). The hydrologic model has been used to estimate sub-catchment inflows throughout the Splitters Creek hydraulic model.

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

4.2 Runoff-Routing Approach

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

The existing XP-Rafts model covers the major open flow paths within the catchment as can be seen by Figure 6.

4.2.1 Model Configuration

The Splitters Creek catchment was delineated using a GIS interface based on the available topographic data. The portion of the catchment that was external to the hydraulic model extents was subdivided into 25 sub-catchments according to tributary network, catchment topography, land use and location where the hydrograph would be applied as a boundary condition to the hydraulic model.

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

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

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

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 are shown in Table 4. These 1987 AR&R IFD Coefficients were applied as Geographic Factors within the XP-Rafts model in order to calculate rainfall intensities for the range of design events.

Table 4 Adopted IFD Input Parameters

Parameter	Value
1 hour, 2 year intensity (mm/hr)	45.4
12 hour, 2 year intensity (mm/hr)	9.3
72 hour, 2 year intensity (mm/hr)	2.7
1 hour, 50 year intensity (mm/hr)	87.4
12 hour, 50 year intensity (mm/hr)	18.6
72 hour, 50 year intensity (mm/hr)	6.5
Average Regional Skewness	0.21
Geographic Factor, F2	4.22
Geographic Factor, F50	17.74

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

Table 5 Intensity Frequency Duration Data for Rockhampton

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

4.3.2 Temporal Pattern

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

Temporal pattern for the Probable Maximum Precipitation (PMP) event were sourced from data provided with the Generalised Short Duration Method (GSDM) guidebook (refer Section 4.3.4).

4.3.3 Areal Reduction Factors

The IFD rainfall values derived in Section 4.3.1 are applicable strictly only to one point; however AR&R state that they may be taken to represent IFD values over a small area (up to 4 km^2). No reduction of the IFD rainfall was undertaken due to the relatively small catchment areas associated with this investigation.

4.3.4 Probable Maximum Precipitation Event

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

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

The Generalised Short-Duration Method (GSDM), as revised in 2003, was applied to derive estimates of PMP for short duration storms. The GSDM applies to catchments up to 1,000 km^2 in area and durations up to 6 hours, which makes the method applicable to the Splitters Creek Local Catchment Study which has a catchment area of approximately 13.1 km^2 and a critical duration of 1 hour (refer Section 6.2).

As per the Splitters Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014), the rainfall intensities presented in Table 6 were derived for the PMP event.

Table 6 PMP Rainfall Intensities

Duration (hrs)	Rainfall Total (mm)	Rainfall Intensity (mm/hr)
1	410	410
2	610	305
3	740	247

4.3.5 Design Event Rainfall Loss Parameters

Initial and continuing losses were adopted as per the Splitters Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014). These are provided in Table 7. It is noted that impervious areas were given initial and continuing losses of zero.

Table 7 Adopted Losses

Event (AEP)	Initial Loss (mm)	Continuing Loss (mm/hr)
≥ 18%	15	2.5
10%	10	
5%	5	
> 5%	0	

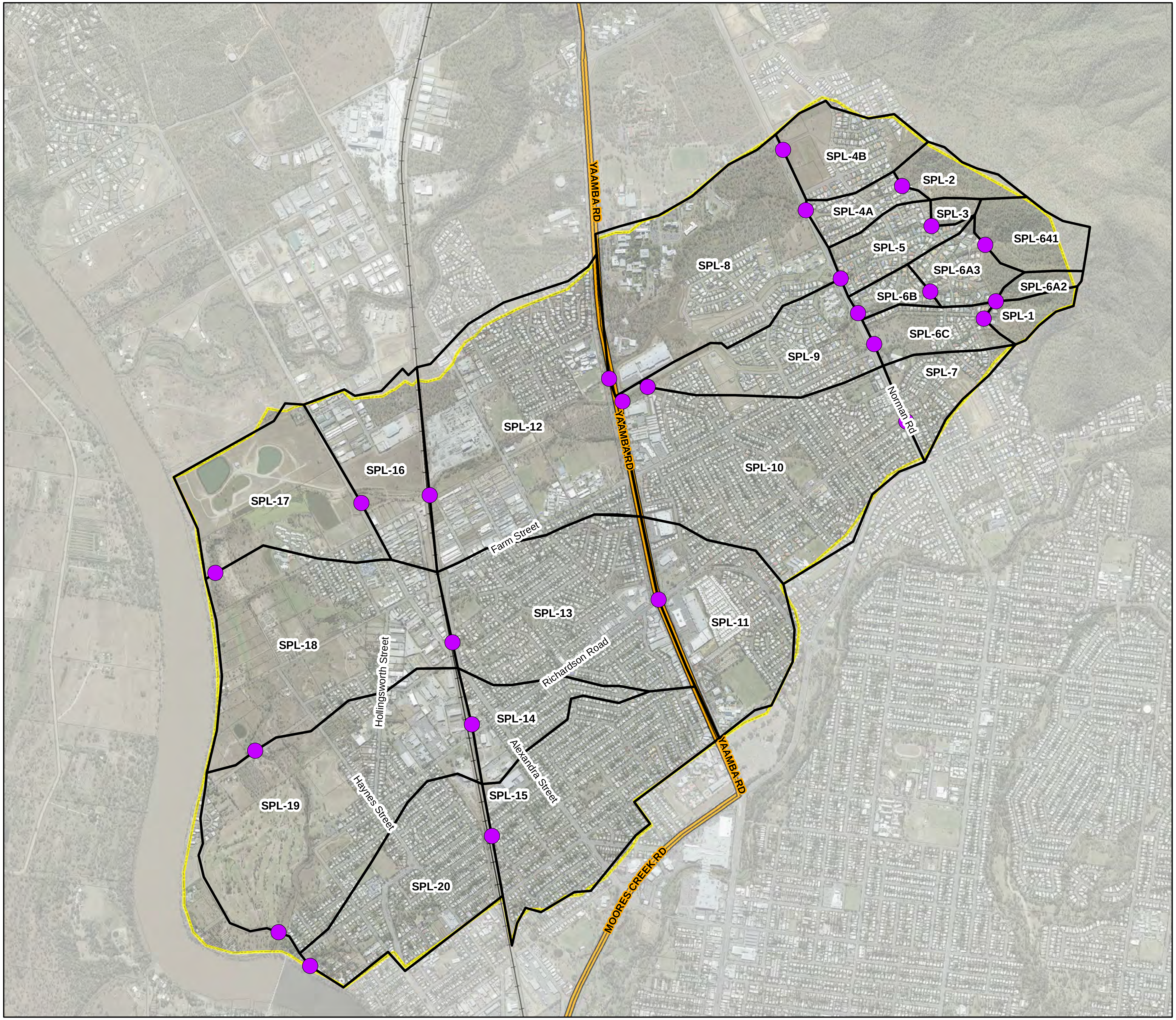
4.4 Hydrologic Inflows

The inflows applied at key locations within the updated hydraulic model is provided in Table 8.

Table 8 Hydrologic Inflow Overview

Event (AEP)	Peak Total Flow (m^3/s)								
	Norman Road					Yaamba Road			NCRL
	SPL-4A	SPL-4B	SPL-5	SPL-6B	SPL-6C	SPL-8	SPL-9	SPL-10	SPL-12
1EY	3.0	4.6	5.1	5.1	3.5	12.8	12.9	19.7	51.2
39%	4.0	6.8	6.9	7.2	5.3	18.9	18.0	27.1	69.2
18%	5.5	9.7	9.3	10.4	7.6	27.6	25.0	37.0	94.1
10%	6.7	11.7	11.0	13.4	9.2	34.2	30.9	42.8	111.4
5%	8.2	14.0	13.2	17.5	11.2	42.6	38.0	51.0	133.7
2%	9.9	16.0	15.0	21.3	13.0	51.7	45.3	59.9	159.4
1%	11.3	18.2	17.1	24.3	14.8	59.2	51.4	68.0	180.9
0.2%	17.8	28.2	26.3	38.2	23.0	94.6	78.6	106.5	278.5
0.05%	21.7	33.9	31.4	46.1	27.6	116.2	94.1	129.0	334.6
PMF	36.4	50.0	40.6	74.3	43.6	225.5	177.8	223.7	696.6

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



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Metres

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LEGEND

- Hydrologic Model Nodes
- Highways
- Railway Lines
- Cadastre
- Hydrologic Model Subcatchments
- Hydraulic Model Extent

Flood results are based on creek flooding only

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

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

Splitters Creek Model
Hydrologic and Hydraulic Model Layout

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	1

Figure
6

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 6 Hydrologic and Hydraulic Model Layout.mxd

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 creek flooding in the Splitters Creek Local Catchment (Aurecon, 2014 & 2016). The updated model has been used to assess key local catchment flood behaviour. These assessments will assist in the development of mitigation options in Phase 3.

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

5.2 Model Updates

Prior to utilising the 2016 Splitters Creek TUFLOW hydraulic model in this current study to assess baseline flood hazard, the following updates were completed:

- Incorporation of Council’s 2016 LiDAR topographic data.
- Refinement of grid resolution to 3 m.
- Removal of ‘instability fixes’ in steep terrain areas.
- Removal of 1D channels, with the exception of the 1D channel between Africander Avenue and Rosewood Drive. A review of Council’s 2016 LiDAR showed adequate channel representation could be achieved within the two-dimensional (2D) domain for most of the 1D channels.
- Re-digitisation of 1D channel between Africander Avenue and Rosewood Drive was undertaken to improve model stability.
- Inclusion of surveyed levels at Anna Street, Walnut Avenue, Springfield Drive and Rosewood Drive.
- Road crests were ‘stamped’ into the topography.
- Channel inverts were ‘stamped’ into the topography.
- Review of all culvert structures within the TUFLOW model, in comparison to Council’s latest drainage network database. Updates were completed where necessary.
- Culvert invert levels were updated to approximately match topographic levels.
- Updated culvert boundary conditions to ensure 1D elements were correctly connected to 2D cells.
- Checked 1D-2D connections and culvert stability and updated where necessary, which resulted in significantly improved numerical stability in some cases.
- Updated initial water levels, as follows:
    - Mean High Water Springs (MHWS) level of 2.66mAHD, for sections downstream of the Fitzroy River Barrage (Barrage).
    - Barrage spillway crest level of 3.65mAHD, for sections upstream of the Barrage.
- Raised embankments in LiDAR where structures had caused the topography to ‘drop out’.
- Lowered some areas of topography (limited extent due to a lack of survey) where it was obvious LiDAR had picked up dense vegetation.
- Updated digitization of 2D Layered Flow Constriction Shape (2d_lfcsh) features to ensure head loss was consistent across the structure.
- Implementation of depth-varying roughness, in line with neighbouring local catchments.
- Updated output features and formats to be consistent with other creeks modelled in this study.
- Simulation of the 1EY and 0.05% Annual Exceedance Probability (AEP) events in hydrologic model, to provide flows for the TUFLOW hydraulic model.

- Simulation of a full range of design events including the 1EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and Probable Maximum Flood (PMF) events.

5.3 Hydraulic Model Parameters

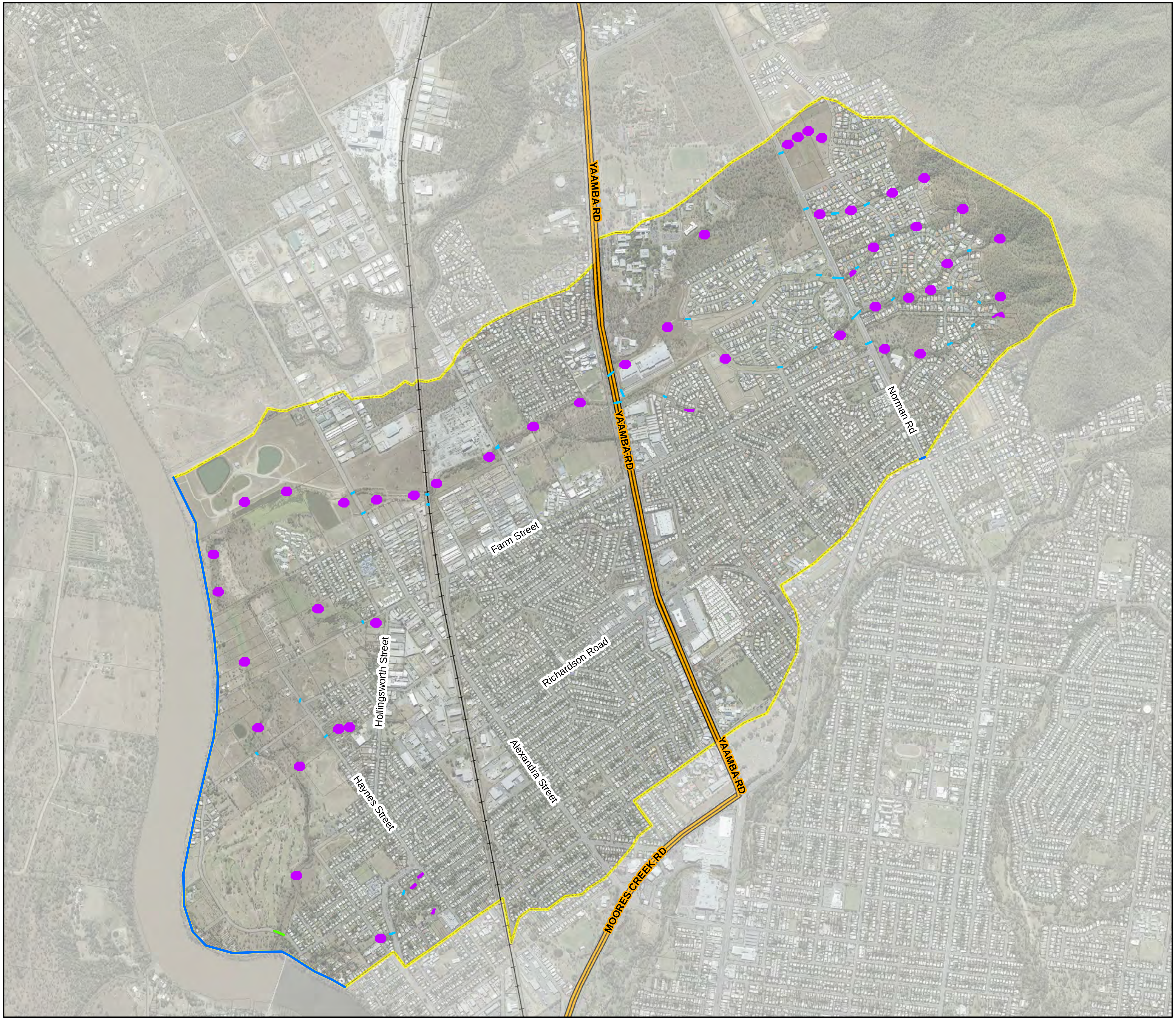
An overview of the model setup and key parameters is provided in Table 9.

Table 9 Hydraulic Model Setup Overview

Parameter	Splitters Creek Local Catchment Model
Completion Date	October 2017
AEP's Assessed	1EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF
Hydrologic Modelling	XP-Rafts Inflows
Hydraulic Model Software	TUFLOW version 2016-03-AE-w64-iDP
Grid Size	3 m
DEM (year flown)	2016
Roughness	Spatially varying standard values – as per Splitters Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014).
Eddy Viscosity	Smagorinsky
Model Calibration	Previously calibrated to 2013 event. No re-calibration undertaken in this study.
Downstream Model Boundary	50 inflow points distributed throughout the primary flow paths, 1 rating curve boundary conditions along the south-eastern boundary, 1 static height boundary upstream of the barrage and 1 tidal boundary downstream of the barrage.
Timesteps	1.5 second (3 m 2D) and 0.5 second (1D)
Wetting and Drying Depths	N/A
Sensitivity Testing	Stormwater Infrastructure Blockage, ±15% Hydraulic Roughness, Riverine and Local Catchment Coincident Event and Climate Change

5.4 Model Setup

A visual representation of the model setup including the code, boundaries, 1D network and hydraulic roughness delineation are included as Figure 7 and Figure 8.



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LEGEND

- Culverts
- Outflow Boundary Conditions
- Layered Flow Constrictions
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- Inflow Boundary Locations

Data Sources:

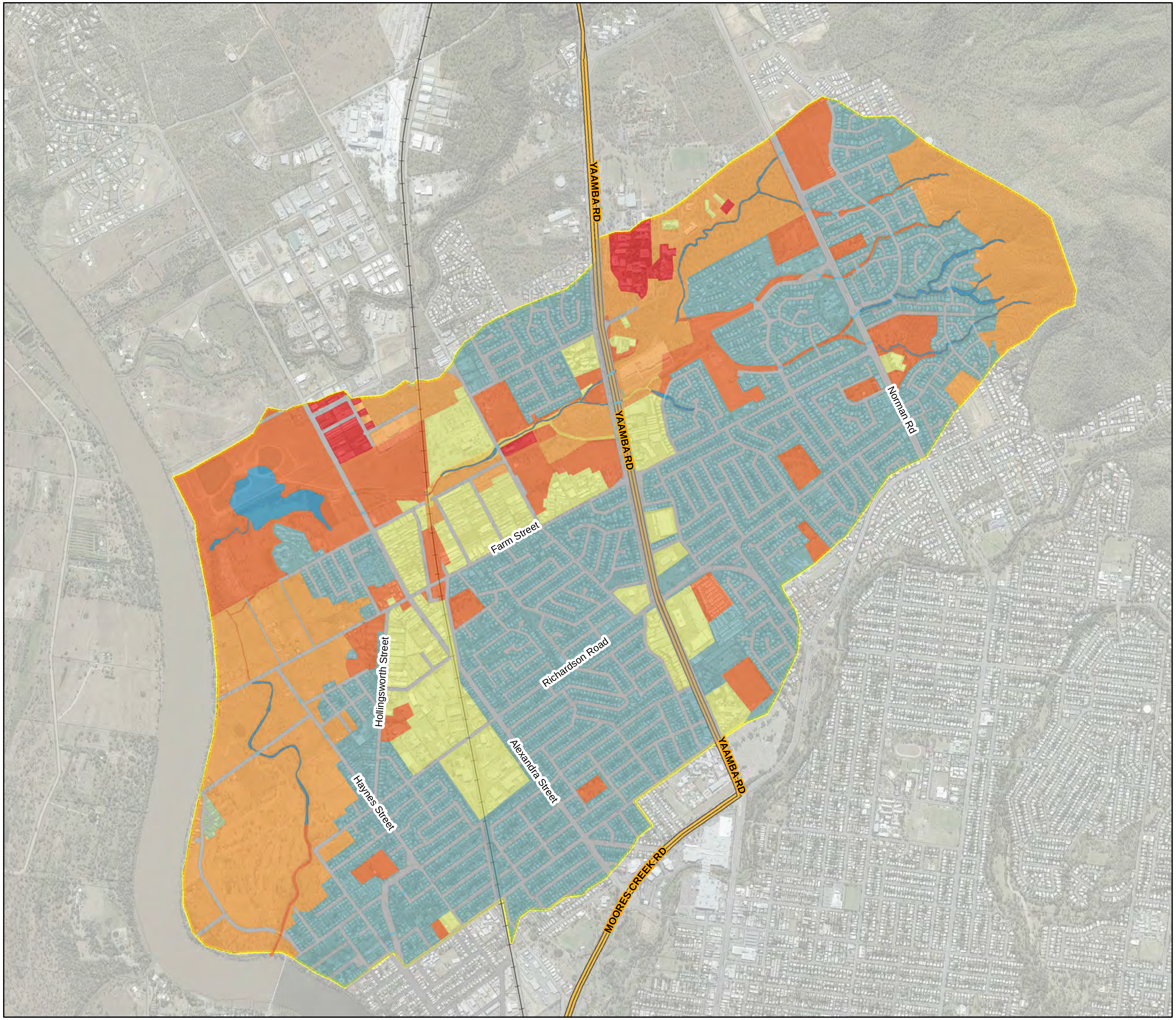
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Splitters Creek Model
Model Setup and 1D Network

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	1

Figure
7

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 7 Model Setup and 1D Network Map.mxd



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Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- Road Corridor
- Channels
- High Density Residential
- Low Density Residential
- Industrial
- Medium Vegetation
- Low Vegetation
- Maintained grass
- Medium Density Residential

Data Sources:

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

Splitters Creek Model
Hydraulic Roughness Delineation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	2

Figure 8

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 8 Hydraulic Roughness.mxd

6.0 Baseline Hydraulic Modelling

6.1 Overview

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

6.2 Critical Duration Assessment

The critical storm duration for the Splitters Creek Local Catchment area was assessed by simulating the 30 minute, 60 minute, 90 minute, 120 minute, 180 minute and 270 minute durations for the 1% AEP event. Figure 10 shows that for a 1% AEP event, Splitters Creek is dominated by the 60 minute storm event, with the 30 minute duration present in the steeper portions of the upper catchment and the 90 and 120 minute durations in the lower rural catchment downstream of Alexandra Street.

Analysis of differences between the 60 minute and 90 minute storm events (refer Figure 11) revealed the 60 minute was up to 200mm higher in portions of the urban catchment, although 50mm lower within the creek at the south-western end of Maloney Street. Further investigation into the raster histogram (refer Figure 9) revealed approximately 71% of the instances showed less than a 75mm difference. With this in mind, a critical duration of 60 minutes was selected.

With the exception of the 1% AEP event, the 60 minute critical duration was applied to all design flood events noted in Section 6.1. For the 1% AEP a 'Max:Max' analysis was undertaken, whereby results from the 30 minute, 60 minute, 90 minute, 120 minute, 180 minute and 270 minute storm durations were compared and the maximum flood levels extracted at each cell within the model domain.

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

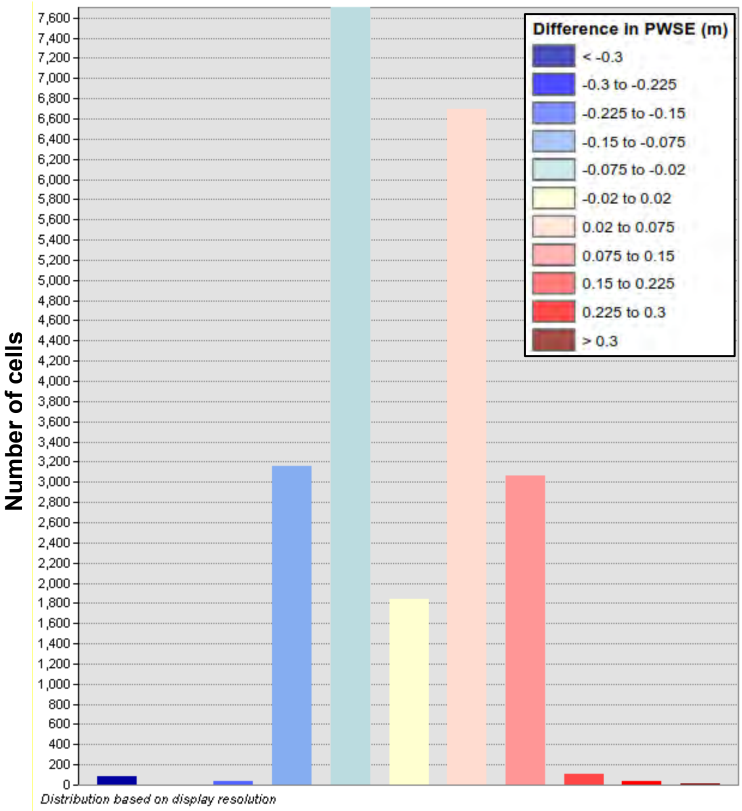
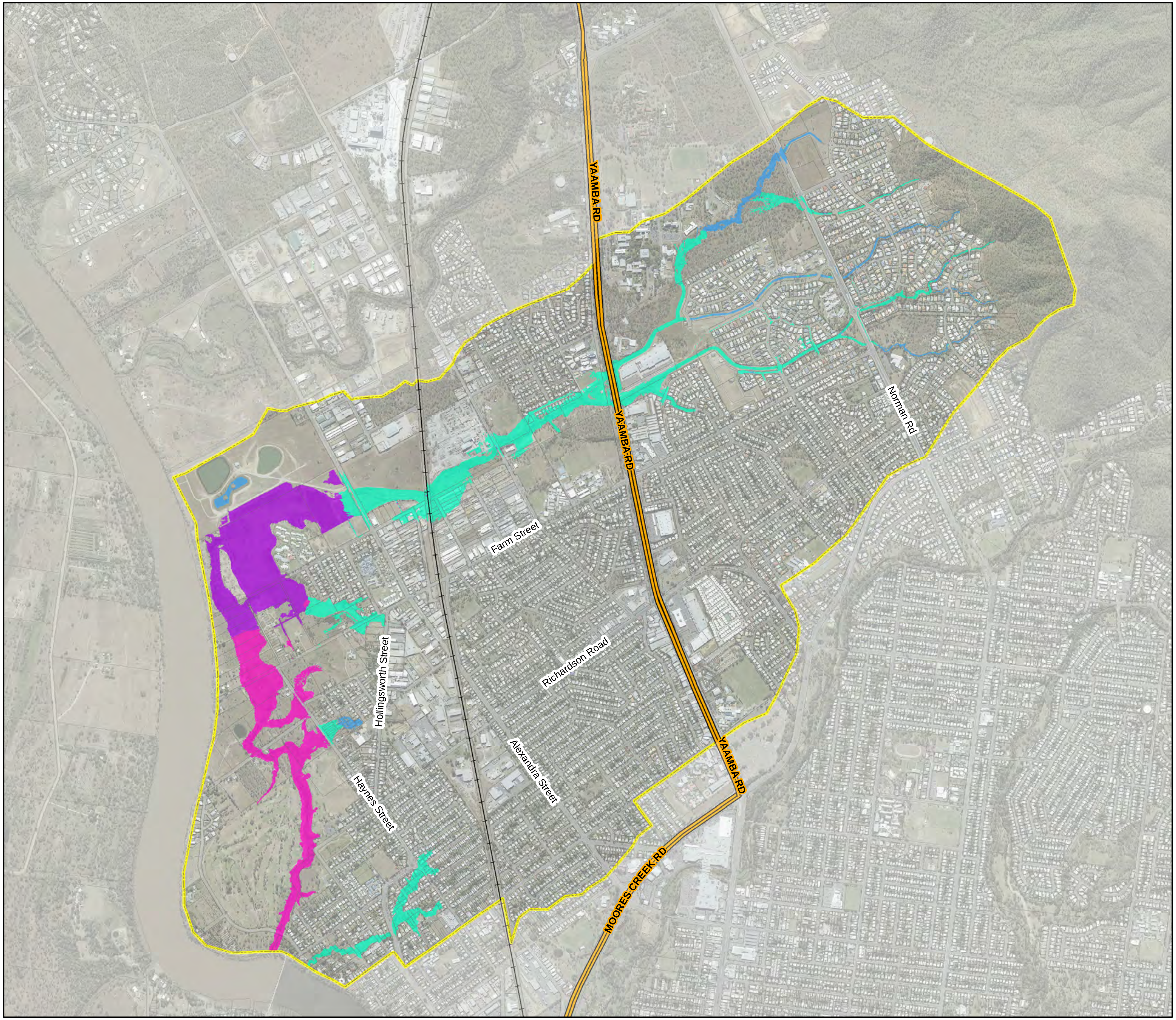


Figure 9 1% AEP – 90 minute PWSE minus 60 minute PWSE palette histogram



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Metres

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(when printed at A3)

LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Storm Duration

- 030min
- 060min
- 090min
- 120min
- 180min
- 270min

Flood results are based on creek flooding only

Data Sources:

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

Results Filtering:

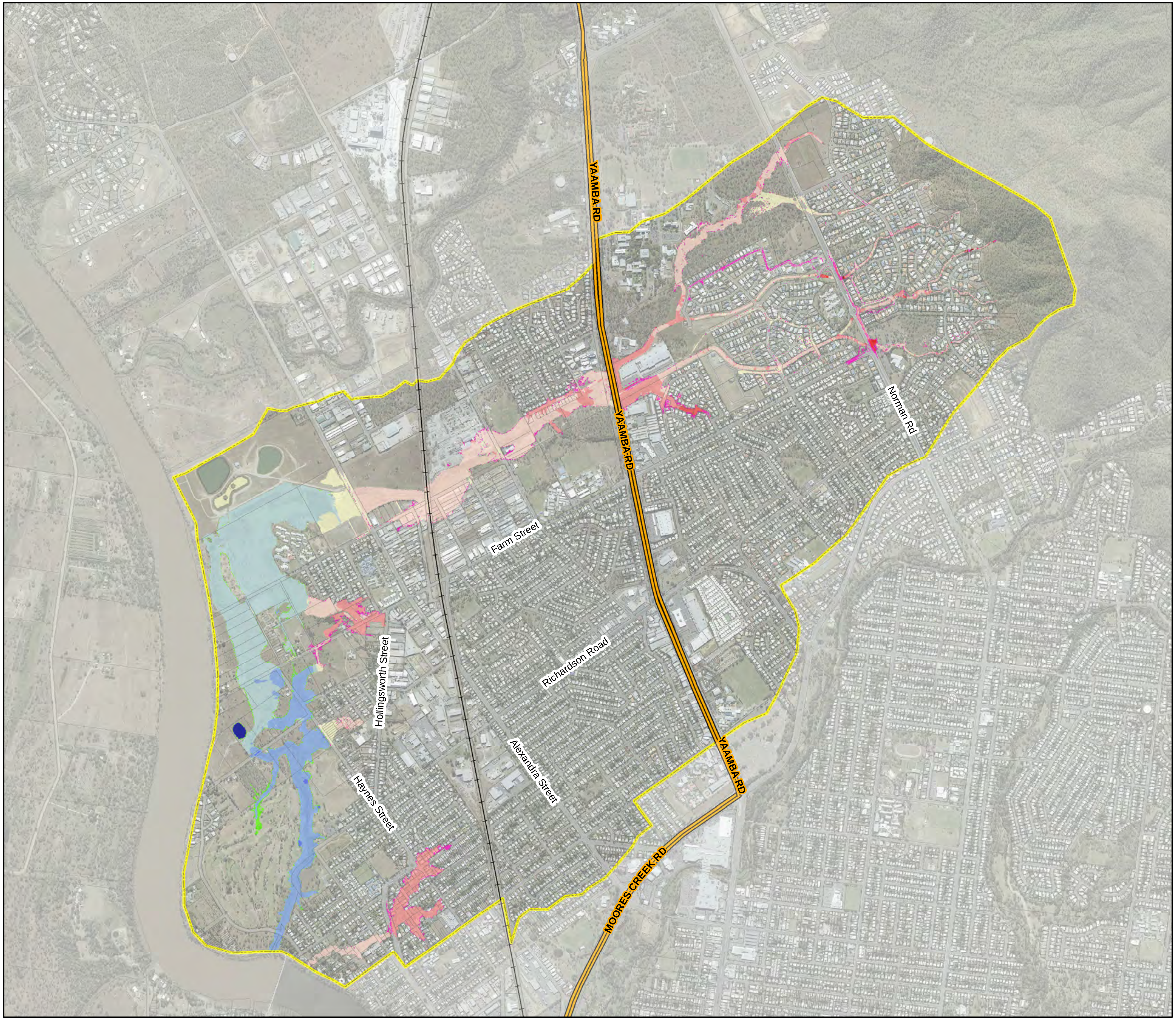
75mm Min. Depth
$100m^2$ Min. Area

Splitters Creek Model
Critical Storm Duration Assessment

1% AEP event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	2

Figure 10



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Rockhampton Regional Council

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Metres

1:20,000
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in Height (m)

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

Flood results are based on creek flooding only

Data Sources:

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

Results Filtering:

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

Splitters Creek Model
Difference in Peak Flood Heights
60 min minus 90 min storm duration

1% AEP event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	26/10/2017
VERSION:	2

Figure 11

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 11 90min minus 60min.mxd

6.3 Baseline Flood Depths, Extents and Velocities

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

- **Maps 1 to 3** – 1 EY Baseline

Peak flood extents during a 1 EY event are largely confined to the natural and constructed channels upstream of Yaamba Road. Some flow expansion is anticipated across the Norman Road embankment at the two northernmost cross-drainage structures. Peak flood depths are generally 0.6 m or less within channels upstream of Norman Road and up to 1.2 m upstream of Yaamba Road. The Bulman Street channel is an exception with a peak flood depth of more than 1.8 m. As the tributaries merge, predicted peak flood depths increase, with up to 2.4 m of flood water predicted within the main channel between the NCRL and Yaamba Road. Downstream of the rail, flood water rapidly expands across the natural floodplain, resulting in reduced depths of 1.2 m. As flows progress beyond Farm Street, the natural channel capacity limits the flood extents as it meanders towards the Fitzroy River. Peak flood depths within the natural channel from Haynes Street (near Wackford Street) are predicted to reach up to 2.4 m.

The peak flood heights adjacent to the Norman Road embankment are generally within the 41 mAHD to 41.5 mAHD range. Flood heights are predicted to be 20.3 mAHD at Yaamba Road, 14.9 mAHD at McLaughlin Street and 10.2 mAHD at Alexandra Street. Peak flood heights predicted at Glenmore Road are approximately 8.5 mAHD.

Peak flood velocities through the upper and central catchment reach and often exceed 2.0 m/s, due to the efficient delivery of flows through the step network of channels. Velocities adjacent to Cant Street range between 1.5 – 2.0 m/s with a 100 m section exceeding 2.0 m/s. As flood waters expand downstream of the NCRL, peak flood velocities rapidly reduce to 1.0 m/s or less (with the exception being flows overtopping embankments of low-immunity local roads). Flood velocities downstream of Wackford Street are expected to peak between 1.0 – 1.5 m/s with over 2.0 m/s predicted for flows overtopping Kluver Street.

Maps 4 to 6 – 39% AEP Baseline

The flood extent remains similar to the 1 EY baseline, but the depth of water within the creek and channels becomes greater. As before, the flow paths in the upper catchment are confined to the natural drainage paths. The overland flow path at Bulman Street remains at a similar depth of greater than 1.8 m. Peak flood extents increase upstream of the NCRL with the overflow box culverts being utilised more. Peak flood depths within the natural channel from Haynes Street (near Wackford Street) are predicted to reach up to 2.7 m.

The water surface elevation on the upstream side of the Norman Road is approximately 41.5 mAHD within most channels. The peak flood height upstream of McLaughlin Street is predicted to increase by 300 mm to 15.2 mAHD in comparison to a 1 EY event. Peak flood velocities throughout the catchment are predicted to be slightly higher than that of a 1 EY event with most sections of the confined channel being 1.5 m/s or more.

- **Maps 7 to 21** – 18% AEP Baseline

Again the flow paths in the upper catchment are confined to the drainage paths, though depths are noted to exceed 900 mm in some instances. The embankments of Rosewood Drive, Norman Road (north of Springfield Drive), Satinwood Avenue, Bramble Street (near Farm Street) and Bulman Street are predicted to be overtopped by up to 300 mm. Peak flood extents at the NCRL now encroach onto commercial and industrial lots, impacting several parcels upstream and downstream of the rail corridor. Peak flood depths within the Wackford Street flow path upstream of Glenmore Road are anticipated to exceed 3.0 m.

Peak flood heights upstream of Norman Road now approach 42 mAHD within the southernmost channels with portions of the channels almost reaching bankfull capacities (Anna Street). The PWSE at Yaamba Road is expected to reach 21 mAHD in the southern channel. The peak flood heights at McLaughlin Street and Alexandra Street are 15.4 mAHD and 10.7 mAHD, respectively.

Peak depth averaged flood velocities within the channels in the central and upper catchments are predicted to largely exceed 2.0 m/s. A large proportion of the channel between Yaamba Road and Alexandra Street is predicted to experience velocities of more than 2.0 m/s. The majority of flood velocities within the floodplain downstream of Alexandra Street are expected to be within 0.5 – 1.5 m/s.

Maps 22 to 24 –10% AEP Baseline

Flood extents remain similar to the 18% AEP baseline discussed above, with flow overtopping Satinwood Avenue beginning to extend laterally and impact residences. The majority of lateral flow follows the Primrose Avenue road corridor towards Bramble Street. Flow overtopping Bramble Street is conveyed along the adjacent corridor of Plumb Drive; private landowners along Plumb Drive are not expected to be impacted. Flood extents downstream of Yaamba Road are anticipated to impact properties at the extremities of Cant Street. As previously observed, peak flood extents either side of the NCRL continue to propagate through commercial and industrial parcels.

Peak flood heights at the NCRL are predicted to reach 13.2 mAHD which results predicted overtopping of the rail corridor. The peak flood heights at McLaughlin Street and Alexandra Street are 15.6 mAHD and 10.9 mAHD, respectively.

As stated above, peak depth averaged flood velocities within the channels in the central and upper catchments are predicted to largely exceed 2.0 m/s with some points exceed 3.5 m/s in grassed open channels.

- **Maps 25 to 27** – 5% AEP Baseline

Significant private property inundation is predicted to occur in the allotments on the southern side of Cant Street and commercial / industrial parcels within 2 blocks of the NCRL. McLaughlin Street and Alexandra Street are predicted to overtop with less than 300 mm of flood water. Haynes Street is observed to be impacted by stored flood waters west of Hollingsworth Street and overtopped by up to 900 mm near Wackford Street.

Peak flood heights near Capricorn Animal Aid (upstream of Yaamba Road) are expected to range from 23.0 mAHD to 21.7 mAHD (at Yaamba Road), resulting in the southern carriageway of River Rose Drive being overtopped. Peak flood heights at McLaughlin Street and Alexandra Street are 16.0 mAHD and 11.1 mAHD, respectively.

Peak flood velocities across inundated properties are expected to be 0.5 m/s or less.

- **Maps 28 to 30** – 2% AEP Baseline

Peak flood depths and extents within the central and upper catchment channels observably increase in comparison to the 5% AEP event, with depths commonly exceeding 900 mm and reaching 3.0 m in one location. Several natural channel and cross-drainage structure capacities are predicted to be exceeded, resulting in some local roads east of Norman Road being overtopped (by up to 300 mm) and flood extents traversing the lower portions of private properties. Peak flood depths upstream of McLaughlin Street, NCRL and downstream of Haynes Street (within both Splitters Creek and the Wackford Street flow path) are expected to exceed 3.0 m.

The PWSE at Yaamba Road is expected to reach 22 mAHD in the southern channel and fully overtop River Rose Drive. The peak flood heights at McLaughlin Street and Alexandra Street are 16.3 mAHD and 11.2 mAHD, respectively.

Peak flood velocities within the channel adjacent Cant Street are predicted to reach up to 3.5 m/s with floodwaters overtopping Cant Street exceeding 1.5 m/s. Much of the main channel downstream of Farm Street is predicted to exceed 1.5 m/s.

- **Maps 31 to 45** – 1% AEP Baseline

Noticeable increases to peak flood depths and extents are noted when comparing to the 2% AEP event. Portions of the steep, narrow channels servicing the upper catchment are expected to see peak flood depths in excess of 1.5 m. The rapid accumulation of runoff at Norman Road is seen to exceed the capacity of cross-drainage structures and inundate the eastern lanes of Norman Road, between River Rose Drive and Farm Street.

Channels downstream of Norman Road are anticipated to convey depths of 1.5 – 1.8 m with depths upstream of Satinwood Avenue and Bramble Street in excess of 1.8 m. Inundation of several private properties is seen near Bulman Street where the capacity of the culvert beneath Bulman Street is greatly exceeded. The entirety of Cant St and properties on the southern side are predicted to experience flood depths of 300 – 600 mm. Haynes Street is anticipated to be cut in three locations:

- Griffith Street (north of York Street);
- Southeast of Byrne Street (south of York Street); and
- Wackford Street.

Overtopping depths along Haynes Street near York Street are expected to be 300 – 600 mm, whereas those further south near Wackford Street are anticipated reach up to 1.5 m.

Due to the restricting capacity of the NCRL cross-drainage, peak flood heights upstream of the rail corridor continue to increase and affect additional parcels along Chappell Street. The peak flood heights at McLaughlin Street and Alexandra Street are 16.4 mAHD and 11.3 mAHD, respectively.

Velocities overtopping Satinwood Avenue, Bramble Street, Bulman Street and within the road reserve of Plumb Drive are predicted to exceed 2.0 m/s. Peak flood velocities within the channel adjacent Cant Street are predicted to exceed 3.5 m/s, with floodwaters overtopping Cant Street reaching 2.0 m/s.

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

The 0.2% AEP baseline results show significantly larger breakouts from the constructed open channels downstream of Norman Road. Much of the overtopping flows are confined to road surfaces, including:

- Springfield Drive;
- Belbowrie Avenue;
- River Road Drive; and
- Farm Street.

Additional impacts to properties are noted between Farm Street / Cypress Avenue and residences near Bulman Street where peak flood extents are seen to increase significantly. Properties on the northern side of Cant Street are shown to experience depths of more than 300 mm. Overtopping depths through the abovementioned parcels and road reserves are not anticipated to exceed 300 mm.

The Norman Road carriageway is predicted to be cut in five locations as peak flood heights reach up to 43.7 mAHD (Norman Road / Springfield Drive roundabout). Flood levels between 22.1 – 22.4 mAHD continue to balance across River Rose Drive upstream of Yaamba Road. As peak flood heights exceed 10.5 mAHD upstream of Glenmore Road, private residences fronting MacAlister Street and Thompson Street are expected to experience impacts, though depths are predicted to be shallow at 150 mm or less.

Peak flood velocities within the main channels downstream of Norman Road are predicted to reach up to 4.0 m/s, with flows overtopping Satinwood Avenue reaching 4.5 m/s. Peak velocities along Cant Street reach 2.7 m/s with the adjacent Splitters Creek channel ranging from 3.0 – 4.0 m/s. Velocities across the western end of Farm Street (near Withers Street) and Kluver Street are noted to exceed 3.5 m/s.

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

Flood depths and extents are predicted to increase throughout with significant changes noted through Forest Park Estate, Bulman Street and Glenmore Road / Thompson Street.

The PWSE at Yaamba Road is expected to exceed 22.5 mAHD. The peak flood heights at McLaughlin Street, NCRL and Alexandra Street are 16.9 mAHD, 13.9 mAHD and 11.7 mAHD, respectively. Peak flood heights across Glenmore Road are expected to increase by 150 mm to 10.65 mAHD, resulting in additional properties west of Glenmore Road being impacted by approximately 300 mm of floodwater.

Peak flood velocities throughout the catchment upstream of Alexandra Street are predicted to be consistently more than 2.0 m/s. Where floodwater overtops Rosewood Drive and is diverted along Springfield Drive and Parkside Place, velocities of 3.0 – 3.5 m/s are anticipated.

- **Maps 52 to 54** – PMF Baseline

The flood extent of the PMF event follows the natural topographic contours as peak flood extents inundate significant proportions of road crossings. The majority of the floodplain downstream of Alexandra Street is inundated with only the higher ridges of Shalom Village and the Capricorn Country Club (golf course) remaining above the PMF extent.

The capacity of all channels is expected to be exceeded in the upper and central catchments with notable impacts in residential estates downstream of Norman Road. It is noted the (previous) Masters Rockhampton site is inundated as flows from the southern channel overtop River Rose Drive and the carpark towards the main Splitters Creek channel in the north. Downstream of Yaamba Road, three rows of residences near Cant Street are predicted to experience impacts, with the southernmost properties experiencing depths of more than 1.2 m. A large proportion of the Humes site in McLaughlin Street is also predicted to experience depths between 300 – 900 mm.

All established channels report velocities in excess of 2.0 m/s, with some segments reaching 4.0 m/s. Roads inundated within the flood extents are predicted to see velocities greater than 2.0 m/s with adjacent parcels experiencing speeds of 0.5 – 1.0 m/s.

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

Predicted peak flood extents are shown to be largely contained within the main Channel up to the 1% AEP event. Minor differences are noted between peak flood extents of the 1EY up to the 1% AEP event along some road reserves and adjacent channels. Notable differences between the minor and major events are noted through Cant Street and Maloney Street / Chappell Street near the NCRL.

Events of magnitude 1% AEP and above begin to rapidly exceed the channel capacity and inundate adjacent road reserves and downstream properties. All road crossings within the creek and major channels are predicted to overtop in the rare design events, resulting in significant upstream attenuation and increases to flood extent.

Large increases in expected inundation extent are visible throughout urban flow paths adjacent the creek in a PMF event, with major breakouts occurring in the 0.2% and 0.05% AEP events exacerbated, affecting significantly more properties near Norman Road, Bulman Street, Cant Street, Maloney Street and Glenmore Road.

6.4 Baseline Peak Discharges

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

- Norman Road major crossings;
- Forest Park Estate;
- Bulman Street
- Yaamba Road;
- NCRL; and
- Glenmore Road.

Table 10 presents the results at corresponding locations.

Table 10 Summary of Baseline Peak Discharges

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Norman Road	1	3.2	4.7	6.8	8.0	9.6	11.0	12.7	19.6	23.6	35.3
Springfield Drive	2	1.0	1.5	2.8	3.4	4.5	5.7	6.7	11.1	13.6	24.3
Norman Road	3	2.3	2.9	4.6	5.6	7.5	8.3	9.6	13.6	16.4	25.6
Springfield Drive	4	1.9	4.0	6.0	6.3	7.2	7.5	8.2	11.3	13.2	20.6
Norman Road	5	3.6	4.6	6.1	7.7	9.7	11.1	12.5	19.5	23.0	31.0
Fairfield Avenue	6	2.4	5.2	6.2	7.7	10.5	14.1	14.2	23.7	29.1	44.7
Woodford Way	7	0.5	0.8	1.3	1.8	2.2	2.6	2.9	4.6	5.5	8.3
Rosewood Drive	8	4.5	5.7	9.1	12.8	17.0	20.4	24.2	37.7	45.4	70.5
Norman Road	9	4.9	6.2	9.6	13.3	17.4	20.6	23.4	37.8	45.1	69.9
Africander Avenue	10	0.9	1.4	2.2	2.8	3.5	4.0	4.5	7.1	8.6	13.0
Norman Road	11	2.1	3.0	4.2	5.0	6.2	7.4	8.3	11.4	13.8	21.4
Norman Road (Overtopping)	12	2.3	5.2	9.3	12.5	16.3	19.9	23.6	66.4	91.3	174.8
D/S of Norman Road	13	6.5	9.6	13.6	16.7	20.6	24.2	27.6	41.5	49.6	74.6
Stringybark Avenue	14	6.2	8.7	13.4	17.2	21.5	26.2	29.9	45.6	57.1	104.5
River Rose Drive	15	4.6	6.2	8.0	9.7	12.0	13.2	13.5	23.2	29.6	43.8
Bramble Street	16	4.6	6.0	7.8	9.1	11.5	12.8	13.1	25.0	31.7	45.5
Stringybark Avenue	17	4.6	6.1	7.6	9.1	11.4	13.0	13.2	24.6	31.4	50.2
Satinwood Avenue	18	8.5	11.6	17.9	23.5	28.8	32.5	34.8	49.0	58.5	87.0
Bramble Street	19	8.5	11.5	17.6	22.6	27.4	30.9	33.0	44.7	51.6	75.1
Tamarind Avenue	20	9.8	13.6	19.4	24.1	31.1	34.9	37.3	52.7	61.0	109.4
Yaamba Road	21	8.2	12.2	18.6	23.7	29.2	37.7	44.3	73.3	90.8	180.6
Capricorn Animal Aid	22	9.5	13.4	19.1	23.6	30.0	34.5	37.1	51.7	58.8	89.8
Bulman Street	23	17.0	23.4	31.9	37.5	44.9	52.8	60.0	92.0	108.2	160.5
Yaamba Road	24	25.3	35.0	47.6	57.3	69.6	83.4	94.0	140.0	164.4	262.8
Cant Street	25	30.4	43.2	58.8	73.4	90.6	118.9	138.8	218.3	264.6	469.0
McLaughlin Street (Overtopping)	26	0.0	0.0	0.0	0.0	5.8	29.8	48.4	134.9	187.5	457.1

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
North Coast Rail Line	27	37.1	50.5	66.4	82.7	100.7	124.9	148.6	247.3	304.8	620.1
Maloney Street	28	37.0	51.1	65.7	80.1	95.7	119.7	141.2	222.6	261.6	431.5
Alexandra Street (Overtopping)	29	0.0	0.0	0.0	0.1	17.1	40.2	61.1	164.5	224.9	583.7
York Street (Overtopping)	30	16.4	31.3	50.7	63.1	78.6	104.2	122.6	216.9	279.3	678.7
Thompson Street	31	18.4	24.3	30.3	33.2	35.9	39.6	42.0	69.0	83.5	158.7
Larcombe Street	32	21.5	35.2	54.2	67.3	83.5	108.2	125.0	201.1	243.9	519.2

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LEGEND

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

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

Splitters Creek Model

Key Flow Path Discharge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	1

Figure
12

6.5 Comparison with Previous Study Results

6.5.1 Recommended Changes from Previous Study Peer Review

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

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

6.5.2 Changes Implemented in this Study

Although not all of BMT WBM's recommendations have been addressed in this current study, the following updates have been applied:

- **Fully Addressing Recommendation 1** → Refinement of hydraulic model grid size from 5 m to 3 m, allowing for improved representation of confined channel conveyance.
- **Partially addressing Recommendation 2** → Adoption of depth-varying roughness values to align with neighbouring local catchments.
- **Partially addressing Recommendation 3** → Application of MHWS tidal boundary, for the portion of the model discharging downstream of the Fitzroy River Barrage.
- **Partially addressing Recommendation 4** → culvert stability has been improved and 1D channels have been either replaced in more detail or removed if channels can be adequately represented in the 2D domain.
- **Recommendation 5 not addressed in this current study**.

It is recommended that Council undertake further baseline model development work in the future, to address the remainder of BMT WBM's recommendations and align the Splitters Creek model with detailed updates made to the other North Rockhampton creek studies.

6.5.3 Results Comparison between Previous and Current Study

Figure 13 and Figure 14 show the differences in predicted peak flood heights for the current study compared to the previous study, for the 18% AEP and 1% AEP events respectively.

- **Figure 13** – 18% AEP Height Difference Map

Comparison of peak flood heights and extents between the previous and current iterations of the Splitters Creek model reveals instances where predicted flood behaviours have changed.

Implementation of the 2016 LiDAR data has resulting in areas upstream of Norman Road showing an increase in predicted peak flood height by more than 300 mm. Despite this, minimal increase to peak flood extents is observed, with some segments of the channels showing a reduction in peak flood extent despite an increase to peak flood height. It was deduced that this is a result of both the new terrain data and improved representation of the open channel conveyance areas.

Road embankments predicted to be "was wet now dry" are likely to be a direct result of digitising the channels in the 2D domain, rather than as a 1D channel.

The flow path adjacent the Baptist Tabernacle (along Norman Road) is predicted to be confined to the channel banks upstream of the site, with an increase in peak flood extent and height downstream of the property as the confined flow reaches the Norman Road crossing. Open channels throughout the urban allotments southwest of Norman Road are now expected to mostly contain 18% AEP runoff.

Updates to the terrain across the (previous) Masters development on Yaamba Road, result in an increase to predicted peak flood heights. The 18% AEP flood extents are predicted to be largely contained to the channel between the highway and rail corridors, with a significant portion of the previously impacted residential area along Cant Street now predicted to be outside the peak flood extent.

Improvements to hydraulic structure stability result in some variance in peak flood heights around crossings, with Alexandra Street now predicted as dry during an 18% AEP event. Modifications to privately-owned dams between topographic datasets are the primary cause of differences downstream of Alexandra Street.

The peak flood height and extent are predicted to reduce upstream of Kluver Street and increase between Thompson Street and Kluver Street.

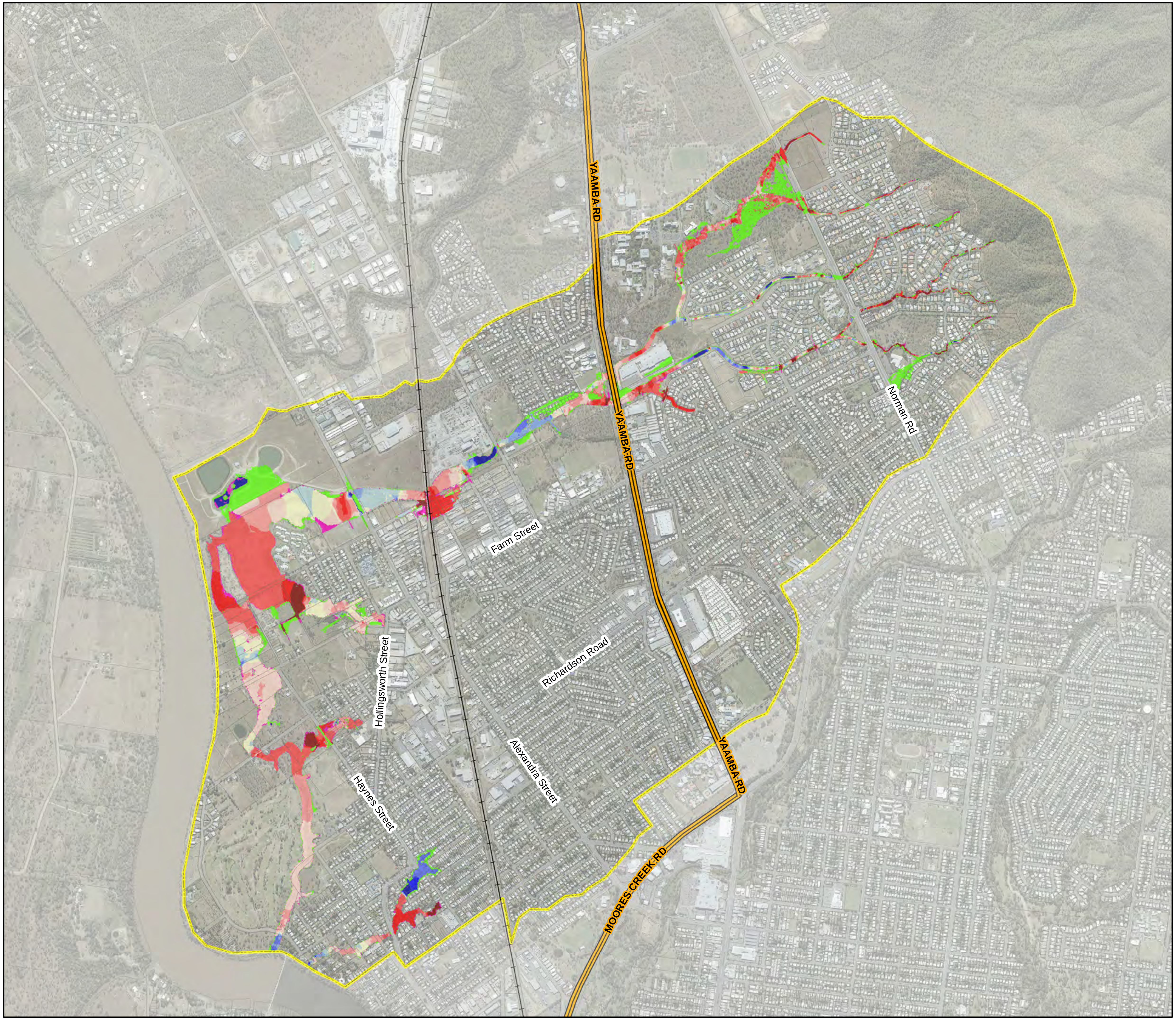
- **Figure 14** – 1% AEP Height Difference Map

Comparison of the 1% AEP results reveals similar differences noted in the 18% AEP event.

Several key differences are identified in the residential allotments northeast and southwest of Norman Road. Generally, the peak flood height is predicted to increase within the open channel upstream of Norman Road, although this is generally accompanied by a reduction in peak flood extent, likely as a result of the updated terrain data.

A significant reduction in the peak flood extent is modelled across the developed area between Farm Street and Cypress Avenue, correlating to the new urban flow paths on the opposite side of the open channel traversing Bramble Street. Inspection of the differences between topographic datasets indicates the recent development of Forest Park Estate is the cause of the differences in some locations. The differences near Satinwood Avenue are a result of removing the 1D channel which was not conveying flow across the embankment appropriately.

Other reductions in peak flood extent throughout the catchment are primarily a result of reducing the model grid size and stamping in invert levels to ensure channels were conveying flows accurately.



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- 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
- Was Dry Now Wet
- Was Wet Now Dry

Flood results are based on creek flooding only

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

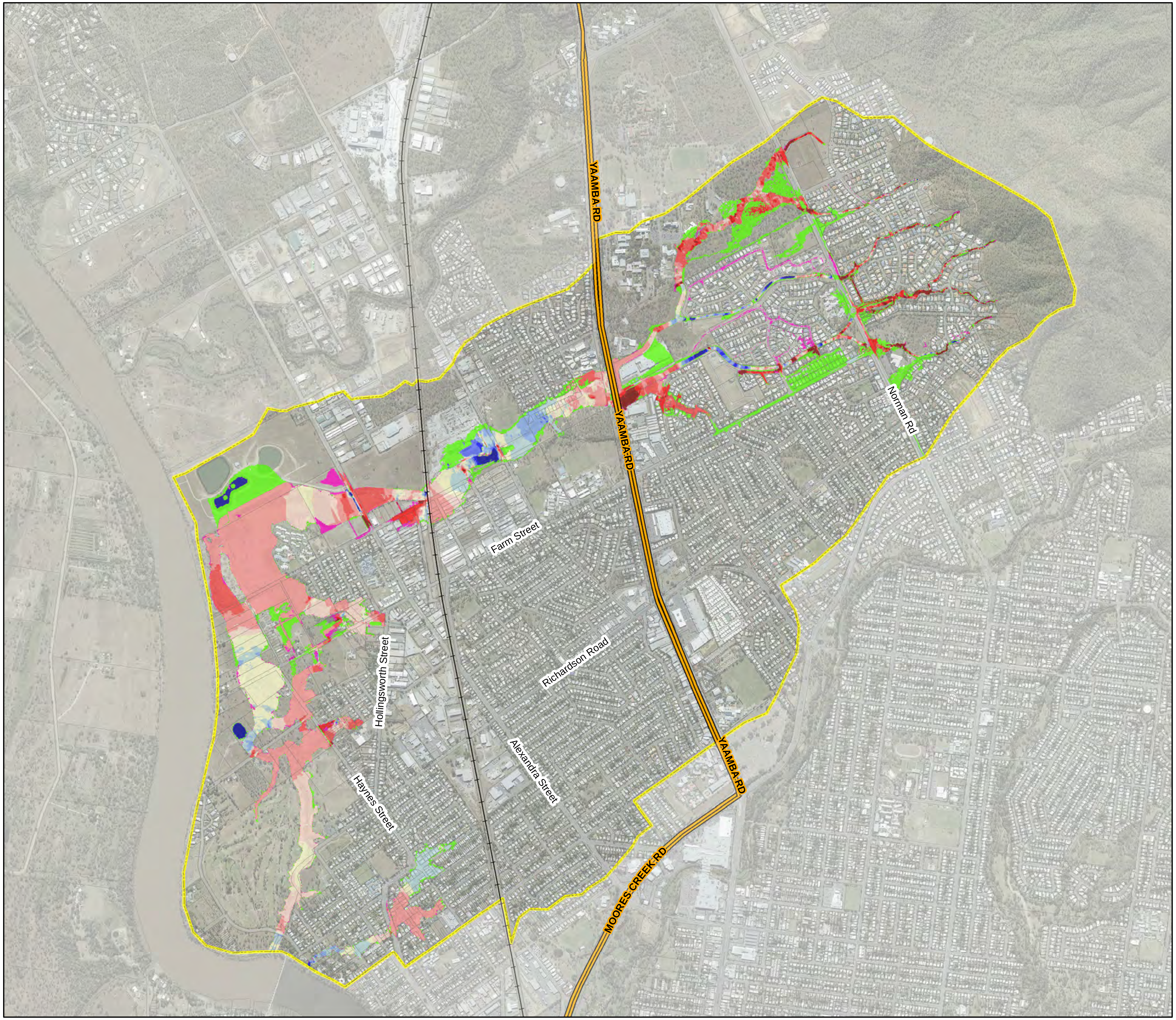
Results Filtering:
75mm Min. Depth
100m^2 Min. Area

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

18% AEP 60min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 13



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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
- Was Dry Now Wet
- Was Wet Now Dry

Flood results are based on creek flooding only

Data Sources:

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

Results Filtering:

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

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

1% AEP 60min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 14

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7.0 Sensitivity Analysis

7.1 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 – Key Cross Drainage Culvert Blockage.

Further discussion on each sensitivity analysis is provided below.

7.2 Hydraulic Roughness

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

The following maps represent the results of the sensitivity testing.

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

Map SPL-56 indicates that with a uniformly increased roughness value across all material types, there is a corresponding overall increase in peak flood heights and overland flood extents. A large proportion of the urban areas within the catchment experience negligible increases in peak water surface elevations. Residential areas surrounding to Wormald Street, Cant Street and Farm Street (at Wither Street) are predicted to have moderate increases in peak flood heights (up to 90 mm at each site). Privately owned parcels adjacent the primary flow path along Wackford Street, Kluver Street and Glenmore Road are also predicted to experience moderate increases in peak flood heights of up to 75 mm. The majority of other impacted areas within the Splitters Creek catchment are within the creek channel and neighbouring floodplain areas, with increases of peak flood heights by up to 100 mm.

The result from the sensitivity analysis which applies a 15% decrease in manning's roughness values are shown in **Map SPL-57**. The decrease in roughness indicates a corresponding decrease in peak flood heights in most instances. The reduction in peak flood heights is negligible throughout most of the catchment area however some increases to the peak flood extent through residential areas between Farm Street and Cypress Avenue are noted. Minor increases to peak flood heights (in the order of 20 mm) are predicted along Maloney Street, downstream of the rail corridor.

7.3 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 across the Splitters Creek catchment was increased by 30% to represent the predicted rainfall patterns in 2100.

Map SPL-58 indicates that the 30% increase in applied rainfall significantly increases peak flood heights and extents throughout the catchment. The peak flood height throughout the majority of the creek channel increased between 0.20 m and 0.35 m with the peak increase of 0.44 m predicted downstream of Wackford Street. Results indicate that for smaller tributaries of the creek system, peak flood heights will increase between 0.10 m and 0.20 m. Several additional groups of residential properties are predicted to be impacted, including properties facing:

- Farm Street and Cypress Avenue;
- Wormald Street, Bulman Street and Dunbavan Place;
- Cant Street;
- Harriette Street, Wackford Street, Glenmore Road, Kluver Street and Bourke Street; and
- Macalister Street and Thompson Street, adjacent Glenmore Road.

7.4 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 (7.2 mAHD upstream and 7.1 mAHD downstream of the barrage) to coincide with a 1% AEP design storm event in the Splitters Creek catchment. The Fitzroy River flood heights have been determined based upon results from RRC's Fitzroy River model.

As can be seen from **Map SPL-59** the effect of this tailwater level is confined to the lower catchment area, including the flow path downstream of Glenmore Road. The results indicate that in the lower catchment area, the peak flood height increases by between 0.2 m and 0.7 m and the levels neighbouring the Fitzroy are approximately 2.0m higher. The variation in peak water surface elevation in residential areas is negligible.

7.5 Key Cross Drainage Culvert Blockage

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

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

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

7.5.1 Factors influencing blockage

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

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

7.5.2 Common Blockages

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

7.5.2.1 Floating Debris

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

7.5.2.2 Non-Floating Debris

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

7.5.2.3 Urban Debris

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

7.5.3 Design Blockage Level

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

7.5.3.1 Debris Availability

Table 11 Debris Availability - in Source Area of a Particular Type/Size of Debris (Table 6.6.1 ARR, 2016)

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

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

7.5.3.2 Debris Mobility

Table 12 Debris Mobility - Ability of a Particular Type/Size of Debris to be Moved into Streams (Table 6.6.2 ARR, 2016)

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

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

7.5.3.3 Debris Transportability

Table 13 Debris Transportability - Ability to Transport Debris to the Structure (Table 6.6.3 ARR, 2016)

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

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

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

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

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

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

7.5.3.4 Debris Potential

Table 14 1% AEP Debris Potential (Table 6.6.4 ARR, 2016)

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

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

7.5.3.5 AEP Adjusted Debris Potential

Table 15 AEP Adjusted Debris Potential (Table 6.6.5 ARR, 2016)

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

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

7.5.3.6 Design Blockage Level

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

Table 16 Most Likely Inlet Blockage Levels - B_{DES}% (Table 6.6.6 ARR, 2016)

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

Inlet Blockage Levels based on the structure clear width was assessed for each culvert individually which can be reviewed in more detail within Table 19.

7.5.3.7 Sediment Deposition

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

Table 17 Likelihood of Sediment Being Deposited in Barrel/Waterway (Table 6.6.7 ARR, 2016)

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

This was assessed for each culvert individually which can be reviewed in more detail within Table 19.

Table 18 Most Likely Depositional Blockage Levels – B_{DES}% (Table 6.6.8 ARR, 2016)

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

As above, this was assessed for each culvert individually which can be reviewed in Table 19.

Table 19 Splitters Creek Culvert Blockage Assessment

Culvert Specification	Control Dimension	AEP Adjusted Debris Potential	Most Likely Inlet Blockage Levels	Peak Velocity (m/s)	Sediment Likelihood	Most Likely Depositional Blockage Levels	Highest Blockage Factor
3/1200mm RCP	W < L10	Low	25%	2	M	15%	25%
3/1350mm RCP	W < L10	Low	25%	2.5	M	15%	25%
2/2100x1200mm RCBC	L10 < W < 3*L10	Low	0%	2.1	M	15%	15%

Culvert Specification	Control Dimension	AEP Adjusted Debris Potential	Most Likely Inlet Blockage Levels	Peak Velocity (m/s)	Sediment Likelihood	Most Likely Depositional Blockage Levels	Highest Blockage Factor
2/1500x600mm RCBC	L10 < W < 3*L10	Low	0%	2.7	M	15%	15%
3/1200mm RCP	W < L10	Low	25%	2.7	M	15%	25%
2/900mm RCP	W < L10	Low	25%	2.1	M	15%	25%
2/2100x750mm RCBC	L10 < W < 3*L10	Low	0%	2.1	M	15%	15%
2/1050x600mm RCBC	W < L10	Low	25%	2.4	M	15%	25%
2/1200x750mm RCBC	W < L10	Low	25%	1.3	M	15%	25%
2/1800x900mm RCBC	L10 < W < 3*L10	Low	0%	2.5	M	15%	15%
3/900mm RCP	W < L10	Low	25%	1.6	M	15%	25%
3/900mm RCP	W < L10	Low	25%	1	M	15%	25%
2/1200mm RCP	W < L10	Low	25%	1.3	M	15%	25%
2/2700x1200mm RCBC	L10 < W < 3*L10	Low	0%	2.6	M	15%	15%
2/2700x1200mm RCBC	L10 < W < 3*L10	Low	0%	2.6	M	15%	15%
3/2100x900mm RCBC	L10 < W < 3*L10	Low	0%	3.9	L	0%	0%
3/2100x900mm RCBC	L10 < W < 3*L10	Low	0%	2.4	M	15%	15%
1/4200x2400mm RCBC	L10 < W < 3*L10	Low	0%	3.3	L	0%	0%
3/900mm RCP	W < L10	Low	25%	2.8	M	15%	25%
1/1800x1200mm RCBC	L10 < W < 3*L10	Low	0%	3	M	15%	15%
8/1500mm RCP	L10 < W < 3*L10	Low	0%	2.7	M	15%	15%
7/1500mm RCP	L10 < W < 3*L10	Low	0%	1.3	M	15%	15%
8/1500mm RCP	L10 < W < 3*L10	Low	0%	2.4	M	15%	15%
8/1500mm RCP	L10 < W < 3*L10	Low	0%	2.5	M	15%	15%
2/1050mm RCP	W < L10	Low	25%	2.3	M	15%	25%
6/1650mm RCP	L10 < W < 3*L10	Low	0%	3.1	L	0%	0%
4/3000x1500mm RCBC	L10 < W < 3*L10	Low	0%	2	M	15%	15%
1/1050mm RCP	W < L10	Low	25%	1.7	M	15%	25%
1/1050mm RCP	L10 < W < 3*L10	Low	0%	2.7	M	15%	15%

Culvert Specification	Control Dimension	AEP Adjusted Debris Potential	Most Likely Inlet Blockage Levels	Peak Velocity (m/s)	Sediment Likelihood	Most Likely Depositional Blockage Levels	Highest Blockage Factor
3/1800x1200mm RCBC	L10 < W < 3*L10	Low	0%	0.6	M	15%	15%
6/1500x900mm RCBC	L10 < W < 3*L10	Low	0%	1.5	M	15%	15%
7/1200x900mm RCBC	W < L10	Low	25%	1.9	M	15%	25%
7/2400x2400mm RCBC	L10 < W < 3*L10	Low	0%	1.6	M	15%	15%
1/300mm RCP	W < L10	Low	25%	0	H	25%	25%
2/1500x750mm RCBC	L10 < W < 3*L10	Low	0%	1.9	M	15%	15%

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

The adopted blockage factor for Splitters Creek is 25%.

7.5.4 Results of Sensitivity Analysis

The results which are presented on **Map SPL-60** show that there are instances where 25% culvert blockage results in notable increases to the predicted peak flood height and flood extent. Specific areas where flood heights have increased due to the blockage of downstream culverts are:

- Culvert under Satinwood Avenue – up to 0.11 m increase in peak flood height corresponding with additional urban overland flow paths.
- Culvert under Bramble Street– up to 0.08 m increase in peak flood height.
- Culverts under Yaamba Road – up to 0.31 m increase in peak flood height.
- Culverts under North Coast Rail Line - up to 0.18 m increase in peak flood height.
- Culvert under Glenmore Road – up to 0.19 m increase in peak flood height.

7.6 Summary of Sensitivity Analysis Results

The results from the sensitivity analyses which were undertaken indicate that the most influential parameters are the manning's roughness values and the applied rainfall. As shown in Table 20, the 15% increase roughness caused an increase of peak flood heights throughout a large portion of the catchment. Similarly, the climate change sensitivity can be seen to have increased the peak flood heights throughout almost the entire catchment, with levels rising more than 0.4 m, as previously discussed in Section 7.3.

The Fitzroy River sensitivity indicates that the lower portion of the catchment is predicted to experience significant increases in flood heights and extents. The areas influenced by the increased tailwater conditions are primarily non-developed and would not cause damage to properties.

It is expected that Council will apply an appropriate freeboard allowance to the PWSE's provided from this study, noting that this freeboard allowance should account for modelling uncertainty and the implications of the sensitivity analyses undertaken and discussed above.

Table 20 provides a summary of the percentage of the peak flood extent which is increased or decreased as a result of each sensitivity analysis. The results indicate that, apart from the climate change scenario and the Fitzroy River tailwater scenario, the resulting peak flood heights are generally within ±0.3m of the baseline flood results. It is clear that climate induced changes to rainfall intensities would have the most significant impact to predicted flood heights in the Splitters Creek catchment.

Table 20 Summary of Sensitivity Analysis Results

Change in Peak Water Surface Elevation (m)	Percentage Area of Peak Flood Extent				
	15% Increased Roughness	15% Decreased Roughness	Climate Change to 2100	Fitzroy River Tailwater Condition	Blockage of Key Cross Drainage Structures
< -0.3	0%	0%	0%	0%	0%
0.299 to -0.225	0%	0%	0%	0%	0%
-0.225 to -0.150	0%	0%	0%	0%	0%
-0.150 to -0.075	0%	8%	0%	0%	2%
-0.075 to -0.02	1%	64%	0%	0%	23%
-0.02 to 0.02	32%	27%	2%	78%	62%
0.02 to 0.074	62%	1%	7%	5%	3%
0.075 to 0.150	5%	0%	13%	2%	5%
0.150 to 0.225	0%	0%	37%	1%	4%
0.225 to 0.299	0%	0%	26%	2%	1%
>0.3	0%	0%	15%	12%	0%

8.0 Flood Hazard and Vulnerability Assessment

8.1 Overview

Following completion of baseline model updates, design event modelling and sensitivity analyses; a flood hazard and vulnerability assessment was completed for the Splitters Creek 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.

8.2 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 21 and Table 22.

Table 21 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 22 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 15.

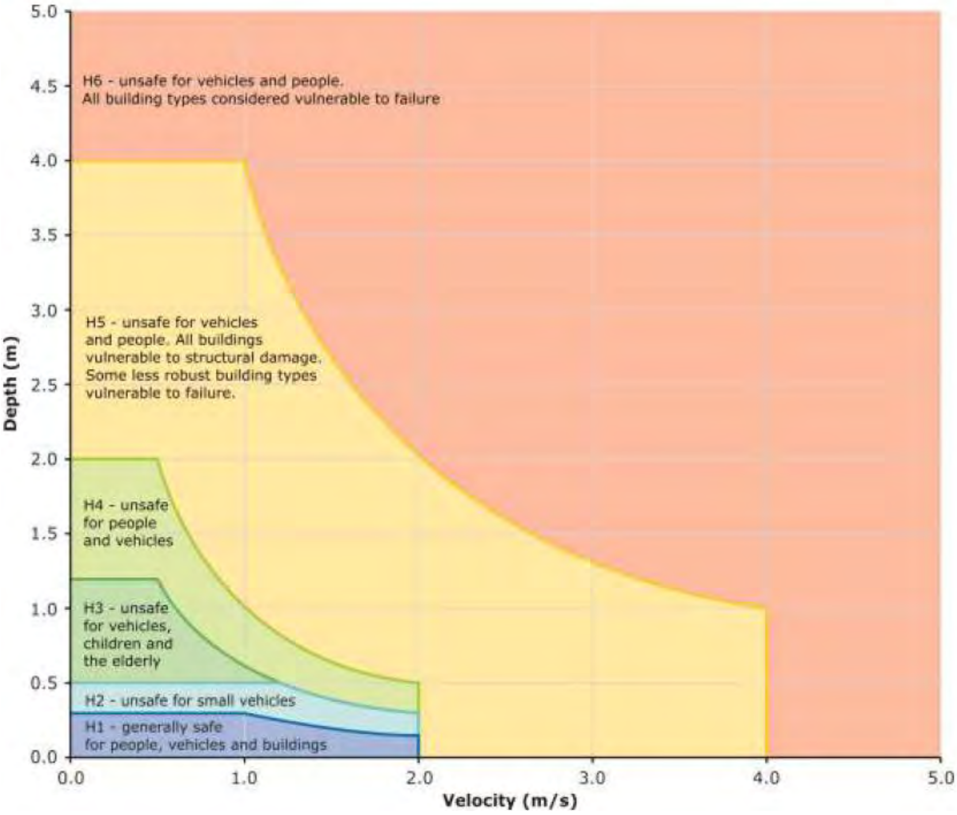


Figure 15 Hazard Vulnerability Classifications (Graphical)

Flood hazard mapping for the 18% and 1% AEP event has been included as maps **SPL-61** to **SPL-70** in the Volume 2 report. The 1% AEP hazard analysis generally shows:

- Low to medium hazard (H1 and H2) in some urbanised areas.
- High hazard (H3 and H4) within the floodplain area to the west of Alexandra Street Extended.
- High to extreme hazard (H4 and H5) within some natural and man-made open channels.
- Extreme hazard (H5 or H6) within the Splitters Creek channel and adjacent overbank areas.

8.3 Baseline Sewerage Infrastructure Flood Risk

Maps **SPL-71** to **SPL-75** 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 potential locations for 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.

8.4 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 23 summarises the criterion used for each category, along with the corresponding reference to the specific table of results and locality figure.

Table 23 Vulnerability Assessment Criterion

Category	Criterion	Table	Figure
Water and Sewerage Infrastructure	Any electrified water or sewerage assets within the Splitters Creek catchment, experiencing flooding up to the baseline PMF event.	Table 24	Figure 16
Emergency Services	Any emergency services facilities within the Splitters Creek catchment, experiencing flooding up to the baseline PMF event.	Table 25	Figure 16
Community Infrastructure	Any community and critical infrastructure within the Splitters Creek catchment, experiencing flooding up to the baseline PMF event.	Table 25	Figure 16
Road Assets	Roads that have inundation depth greater than 0.3m in the 18% AEP event. *Note that there are some exceptions included in the table which have less than 0.3m of inundation in the 18% AEP event, which represent critical road crossings of Splitters Creek.*	Table 26	Figure 17
Bridge Assets	All bridge crossings of Splitters Creek were assessed.	Table 27	Figure 17
Rail Assets	Rail segments that have inundation above top of ballast level (segments where rail ballast will be inundated)	Table 28	Figure 17

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 8.5.

Table 24 Water and sewage infrastructure - inundation depths for all events

Infrastructure Type (Asset ID)	Suburb	Location	Inundation Depths at Design AEP Events (m) – 60 minute storm **										1% AEP Hazard Category *
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
Sewerage Pump Station (463733)	Park Avenue	Hadgraft Street	-	-	-	-	-	-	-	0.21	0.48	1.44	-
Sewerage Pump Station (463750)	Kawana	York Street	-	-	-	-	-	-	-	-	-	0.09	-
Sewerage Pump Station (463751)	Norman Gardens	Stringybark Ave (Forest Park)	-	-	-	-	-	-	-	0.15	0.25	0.39	-
Sewerage Pump Station (463747)	Norman Gardens	Yaamba Road (Redhill)	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (463719)	Norman Gardens	Africander Ave	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (463705)	Norman Gardens	Norman Road	-	-	-	-	-	-	-	-	0.06	0.09	-
Water Pump Station (463721)	Kawana	Ibis Avenue	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (463712)	Norman Gardens	Braddy Street	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (463718)	Norman Gardens	Ridgedale Ave	-	-	-	-	-	-	-	-	-	-	-

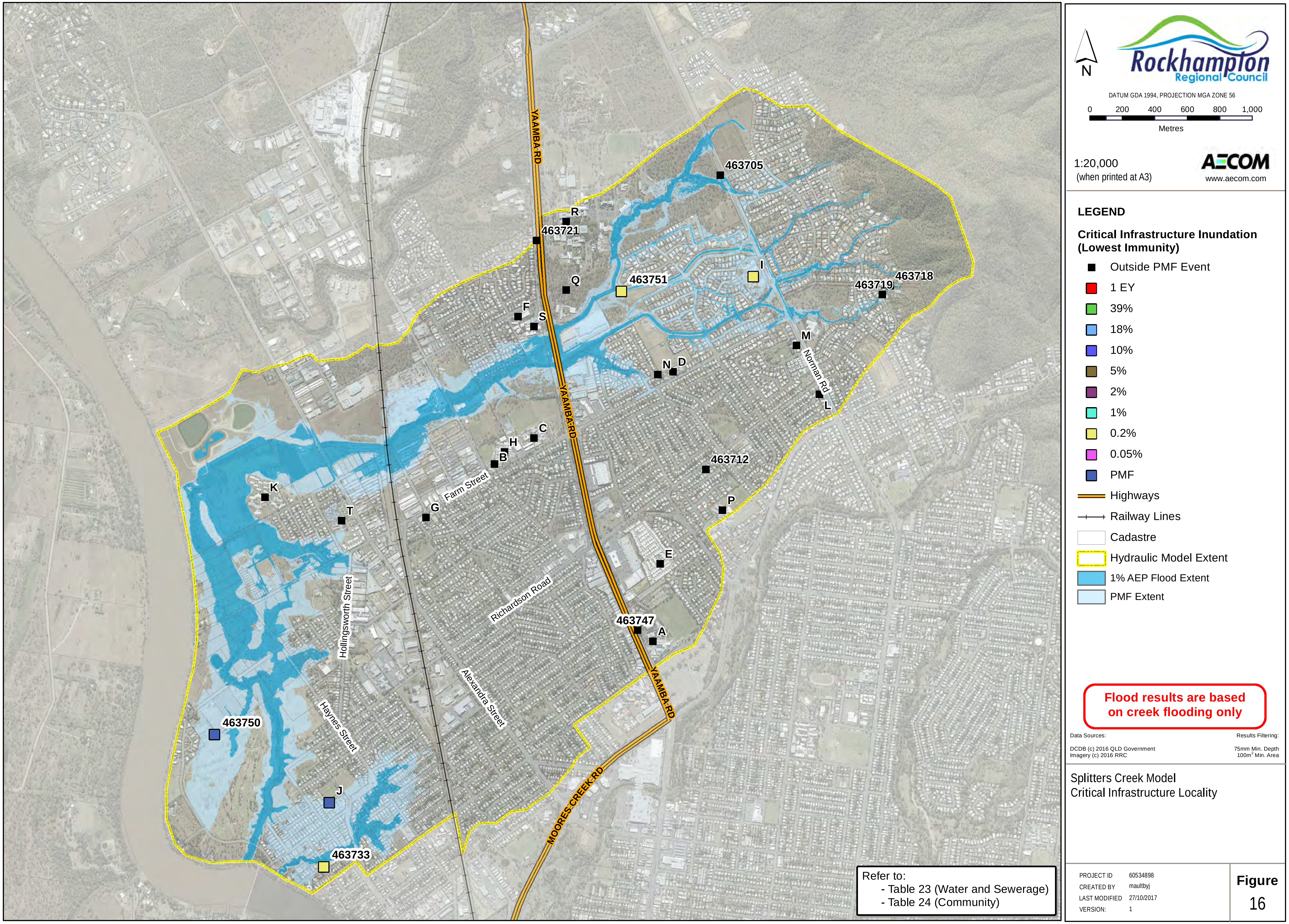
* Where there is no inundation predicted in the 1% AEP event, the 1% AEP Hazard Category is shown as a dash. There may however be some residual hazard in events greater than 1% AEP.
**** Inundation depths shown are related to Creek flooding only. Flooding from overland flows have not been modelled or reported.**

Table 25 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) – 60 minute storm **										1% AEP Hazard Category *
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
A	Emmaus College	Norman Gardens	362 Yaamba Rd	-	-	-	-	-	-	-	-	-	-	-
B	Glenmore Primary School	Kawana	241-259 Farm St	-	-	-	-	-	-	-	-	-	-	-
C	Glenmore High School	Kawana	261-299 Farm St	-	-	-	-	-	-	-	-	-	-	-
D	Farm Street Care Homes	Norman Gardens	349 Farm St	-	-	-	-	-	-	-	-	-	-	-
E	Rockhampton North Lifestyle Resort	Norman Gardens	19 Schuffenhauer St	-	-	-	-	-	-	-	-	-	-	-
F	Heights College	Kawana	276 Carlton St	-	-	-	-	-	-	-	-	-	-	-
G	Farm St Early Learning Centre	Kawana	188 Farm St	-	-	-	-	-	-	-	-	-	-	-
H	Capricornia School of Distance Education	Kawana	241-259 Farm St	-	-	-	-	-	-	-	-	-	-	-
I	Norman Road Hospital	Norman Gardens	691 Norman Rd	-	-	-	-	-	-	-	0.16	0.26	0.60	-
J	Oak Tree Retirement Village	Park Avenue	155 Glenmore Rd	-	-	-	-	-	-	-	-	-	0.22	-
K	Shalom Good Samaritan Care	Kawana	121 Maloney St	-	-	-	-	-	-	-	-	-	-	-
L	Kallahra Childcare Centre	Norman Gardens	621 Norman Rd	-	-	-	-	-	-	-	-	-	-	-
M	Early Learning Centre	Norman Gardens	653 Norman Rd	-	-	-	-	-	-	-	-	-	-	-
N	Kinta Kids Child Care Centre	Norman Gardens	8 Smithwick St	-	-	-	-	-	-	-	-	-	-	-
P	St Anthony's Church & School	Norman Gardens	390 Feez St	-	-	-	-	-	-	-	-	-	-	-
Q	Endeavour Foundation School	Norman Gardens	552 Yaamba Rd	-	-	-	-	-	-	-	-	-	-	-
R	Central Queensland University	Norman Gardens	554 Yaamba Rd	-	-	-	-	-	-	-	-	-	-	-
S	Prescare Alexandra Gardens	Kawana	20 Withers St	-	-	-	-	-	-	-	-	-	-	-
T	Heights Kindergarten	Kawana	276 Carlton St	-	-	-	-	-	-	-	-	-	-	-

* 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 flood hazard in events greater than the 1% AEP.

**** Inundation depths shown are related to Creek flooding only. Flooding from overland flows have not been modelled or reported.**



Splitters Creek Model
Critical Infrastructure Locality

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	1

Figure 16

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 16 Critical Infrastructure Locality.mxd

Table 26 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) – 60 minute storm * **										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
1	Norman Road	Norman Gardens	90	1.0	0.23	0.28	0.32	0.35	0.37	0.40	0.43	0.50	0.55	0.68	H2
2	Lilydale Close	Norman Gardens	40	0.5	-	-	0.11	0.18	0.24	0.26	0.31	0.40	0.45	0.53	H2
3	Rosewood Drive	Norman Gardens	40	0.5	-	-	0.05	0.11	0.14	0.16	0.18	0.26	0.29	0.42	H3
4	Satinwood Avenue	Norman Gardens	95	0.6	-	-	0.12	0.22	0.29	0.34	0.36	0.48	0.55	0.74	H4
5	Bramble Street	Norman Gardens	80	0.6	-	-	0.24	0.29	0.32	0.35	0.37	0.45	0.49	0.62	H5
6	Plumb Drive	Norman Gardens	230	0.5	-	-	0.32	0.41	0.47	0.5	0.52	0.57	0.59	0.64	H5
7	Bulman Street	Norman Gardens	160	0.5	-	-	0.18	0.25	0.34	0.41	0.47	0.66	0.74	0.94	H4
8	Maloney Street	Kawana	225	1.5	-	-	0.63	1.02	1.29	1.49	1.63	1.87	1.99	2.59	H4
9	Farm Street	Kawana	240	3.5	0.36	0.62	0.84	0.97	1.13	1.32	1.52	1.87	2.04	2.73	H5
10	Farm Street (near Withers Street)	Kawana	195	1.0	1.01	1.13	1.31	1.34	1.33	1.40	1.47	1.69	1.81	2.21	H5
11	Haynes Street (near Byrne Street)	Kawana	125	0.7	-	-	0.13	0.15	0.17	0.20	0.21	0.37	0.69	2.14	H1
12	Haynes Street (Wackford Street)	Park Avenue	90	1.2	0.57	0.75	0.96	1.08	1.22	1.38	1.51	1.90	2.06	2.48	H4
13	Kluver Street	Park Avenue	80	1.3	0.43	0.54	0.81	0.97	1.15	1.38	1.53	1.93	2.06	2.49	H5
14	York Street	Park Avenue	85	2.5	0.39	0.50	0.61	0.68	0.75	0.90	1.29	1.78	2.10	3.62	H6

^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.
**** Inundation depths shown are related to Creek flooding only. Flooding from overland flows have not been modelled or reported.**

Table 27 Bridge Assets - Inundation depths for all events

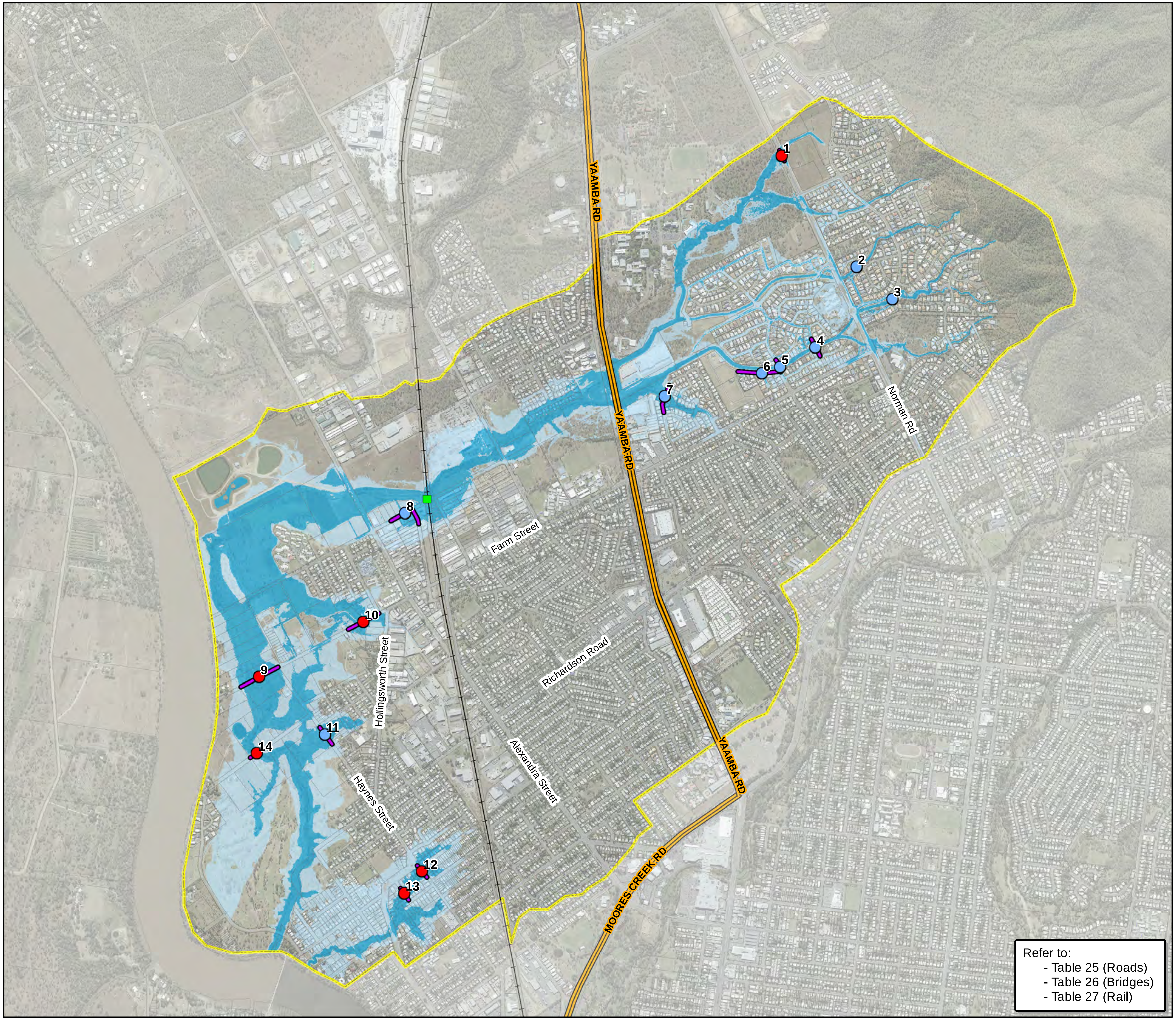
ID	Bridge Name	Deck Height (mAHD) #	Inundation Depths Above Deck at Design AEP Events (m) – 60 minute storm *										1% AEP Hazard Category **
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
B1	Larcombe Street	9.469	-	-	-	-	-	-	-	-	-	-	-

Bridge deck heights are based on LiDAR levels and are approximate only.
* Maximum flood depth at bridge centreline extracted within the flooded road segment. Flood depths will vary at bridge shoulders and therefore results are approximate only.
** 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 flood hazard in events greater than the 1% AEP.

Table 28 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) – 60 minute storm *										1% AEP Hazard Category **
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
R1	North Coast Rail Line	Park Avenue	165	-	-	-	0.11	0.19	0.27	0.31	0.49	0.58	0.91	H5

^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.
** 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 flood hazard in events greater than the 1% AEP.



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
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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
- Rail Inundation
- 1% AEP Road Inundation Extent (Lengths >75m shown)
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extent
- PMF Extent

Flood results are based on creek flooding only

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

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

Splitters Creek Model
Road, Bridges and Rail Inundation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	1

Figure
17

8.4.1 Vulnerability Assessment Summary

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

- The Hadgraft Street Sewerage Pump Station (SPS, Ref: 463733) and Stringybark Avenue - Forest Park SPS (Ref: 463751) are predicted to have less than 0.2% flood immunity. It is noted that the predicted flood levels and hazard are low in the 0.2% AEP event. It is recommended this information be passed onto FRW as the asset owner.
- Low depth flooding is predicted at the Norman Road Hospital in the 0.2% AEP.
- The North Coast Rail Line is predicted to be inundated over ballast level in the 10% AEP event and larger.
- A number of road segments are predicted to experience inundation in the 1EY event and larger. Approximate TOS values ranges from 0.5 hours to approximately 3.5 hours.

8.5 Evacuation Routes

Generally local catchment flooding within the Splitters Creek catchment is due to short duration, high intensity rainfall events. The relatively steep upper catchment to the east of Norman Road can result in inundation of residential and commercial buildings.

Due to the short critical duration of the Splitters Creek catchment, the warning time between the commencement of the rain event and subsequent flood inundation can be short (refer Figure 20 to Figure 24). 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 29 provides a summary of the isolated areas and key evacuation routes, assessed up to the PMF event.

Table 29 Isolated Areas Summary

Isolated Area	Key Evacuation Route/s	Accessed Via	Warning Time Until Evac. Route Cut	Figure Reference
Bulman Street and Smithwick Street	Farm Street	Wormald Street	Up to 0.5 hour	Figure 18
Foxglove Avenue, Bushpea Court, Snow Gum Street and Plumb Drive	Farm Street	Bramble Street	Up to 0.5 hour	Figure 18
Primrose Avenue, Frangipani Court, Red Penda Court, Saintwood Avenue, Lace Flower Court and Silky Oak Court	Farm Street	Bramble Street	Up to 0.5 hour	Figure 18
Bramble Street, Mistletoe Avenue, Stringybark Avenue, Waratah Court, Messmate Court and Aspen Court	Norman Road	River Rose Drive	Up to 0.5 hour	Figure 18
Larcombe Street and Sandys Place	Glenmore Road Haynes Street	Macalister Street York Street	Up to 0.5 hour Up to 0.5 hour	Figure 19

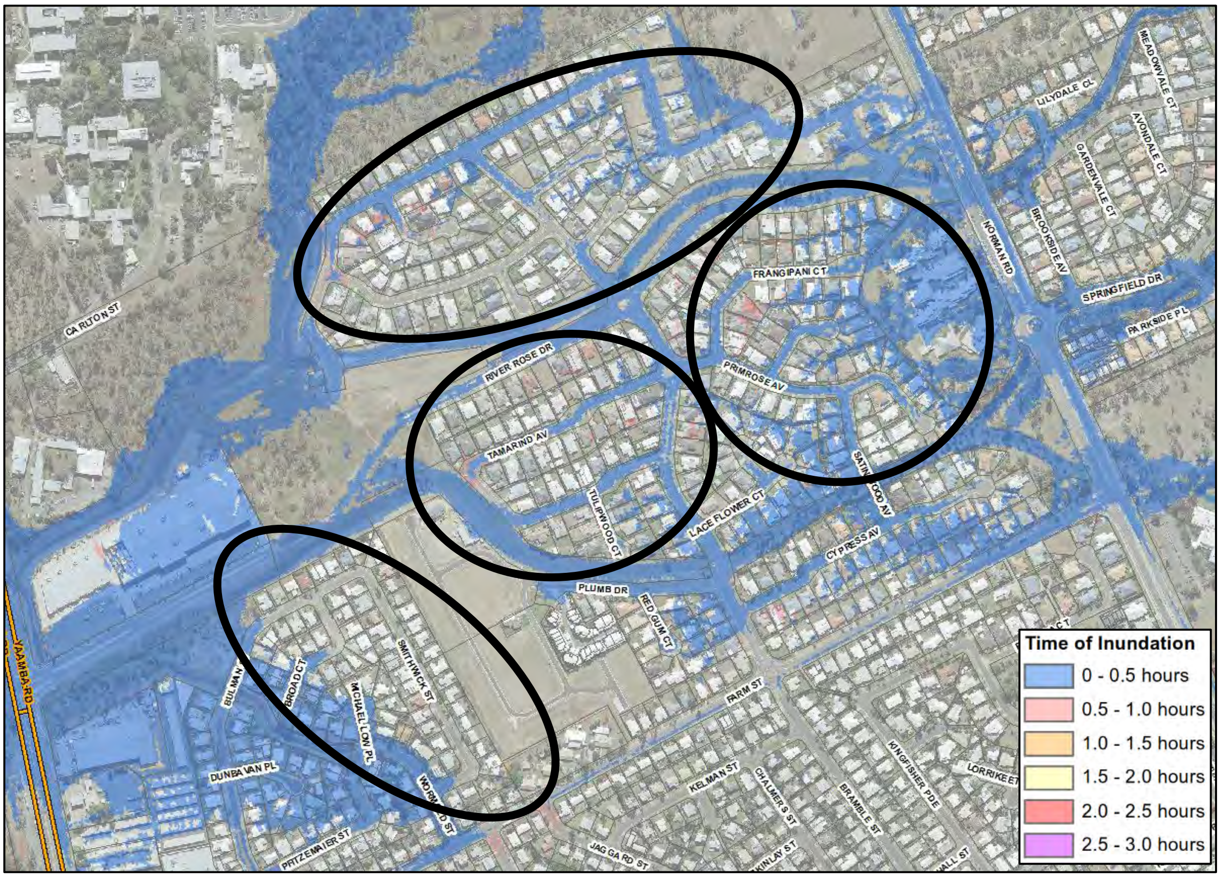
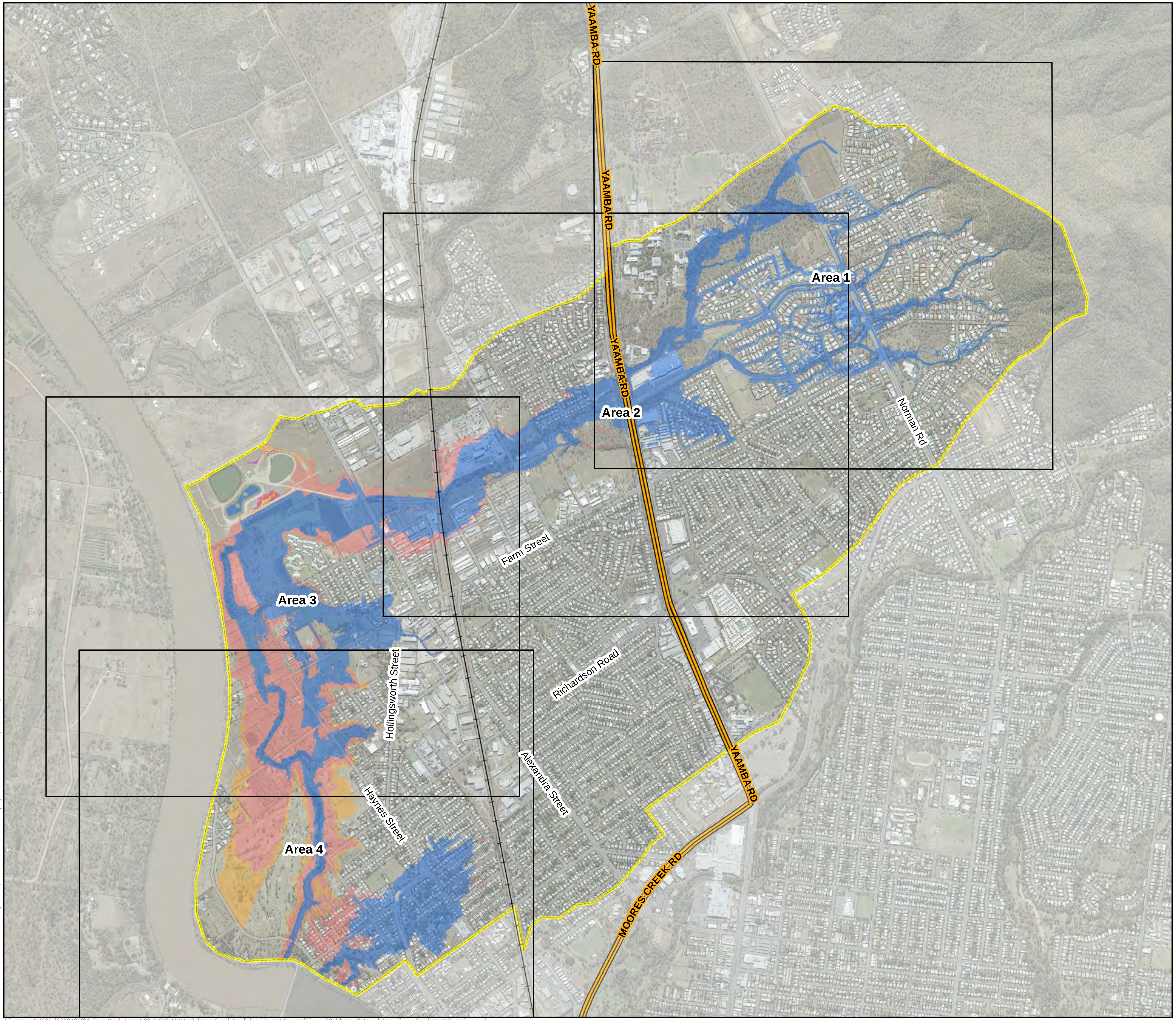


Figure 18 Isolated Area – Bulman Street, Plumb Drive, Tamarind Avenue, Primrose Avenue, Mistletoe Avenue areas

Figure 19 Isolated Area – Larcombe Street and Sandys Place



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000
Metres

1:20,000
(when printed at A3)

AECOM
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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 creek flooding only

Data Sources:

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

Results Filtering:

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

Splitters Creek Model
Time of Inundation - Catchment Overview

PMF 60min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 20

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 20_Phase_2_Inundation_Time - Catchment Overview.mxd

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Rockhampton Regional Council

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0 100 200 300 400
Metres

1:8,000
(when printed at A3)

AECOM
www.aecom.com

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 creek flooding only

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

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

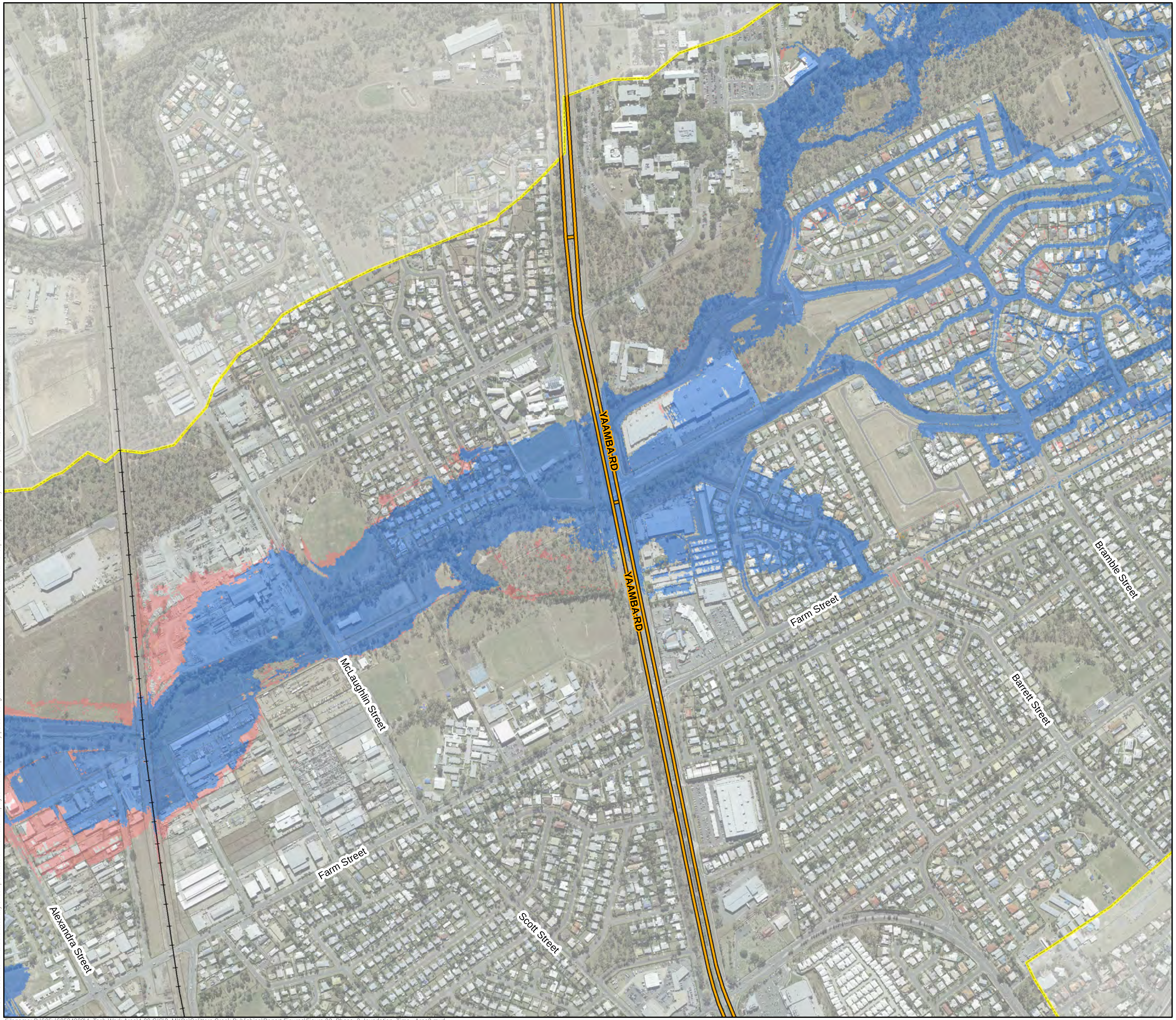
Splitters Creek Model
Time of Inundation - Area 1

PMF 60min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 21

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 21_Phase_2_Inundation_Time - Area1.mxd



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Rockhampton Regional Council

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0 100 200 300 400

Metres

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AECOM
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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 creek flooding only

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

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

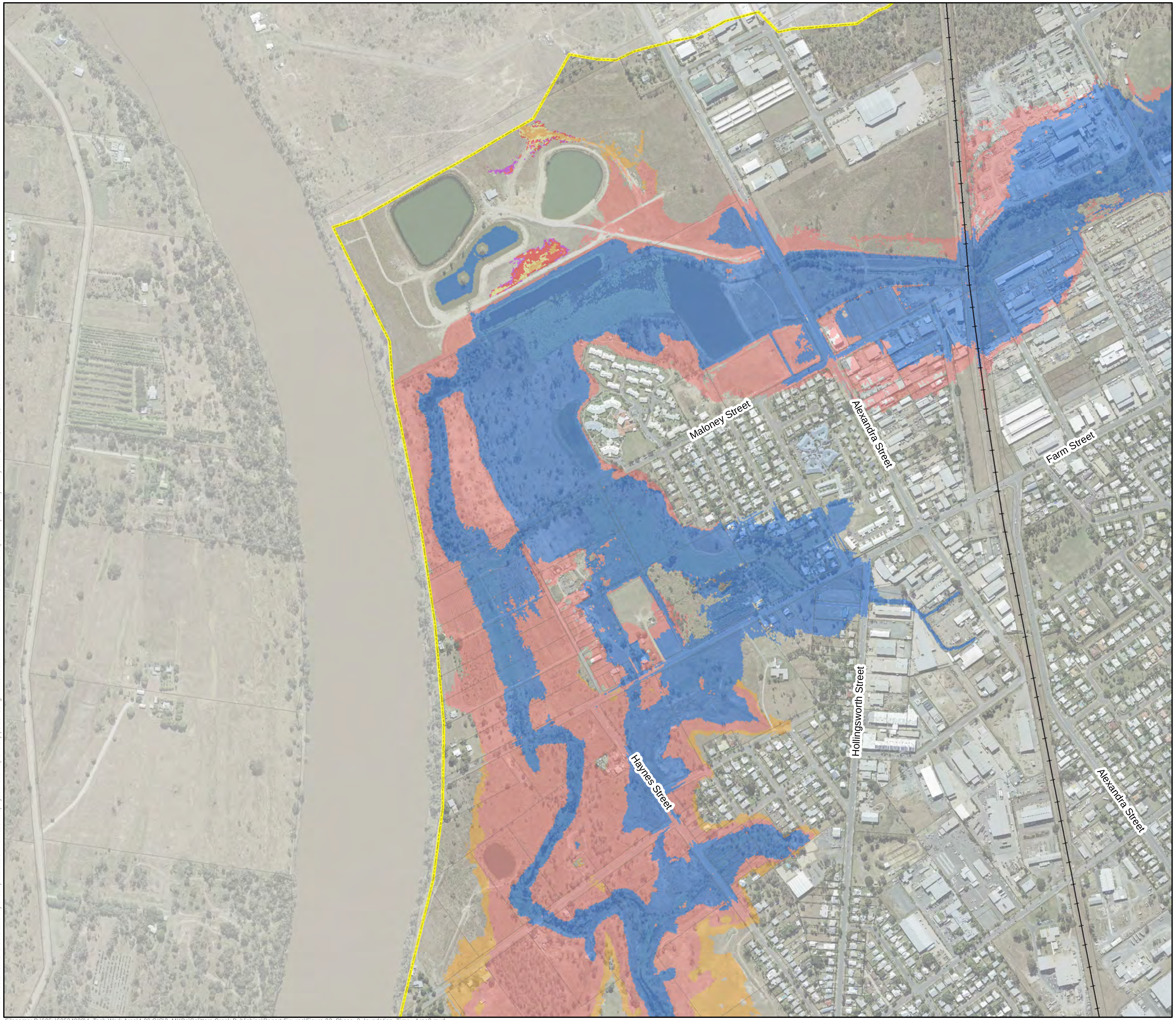
Splitters Creek Model
Time of Inundation - Area 2

PMF 60min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure
22

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 22_Phase_2_Inundation_Time - Area2.mxd



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DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:8,000
(when printed at A3)

www.aecom.com

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 creek flooding only

Data Sources:

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

Results Filtering:

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

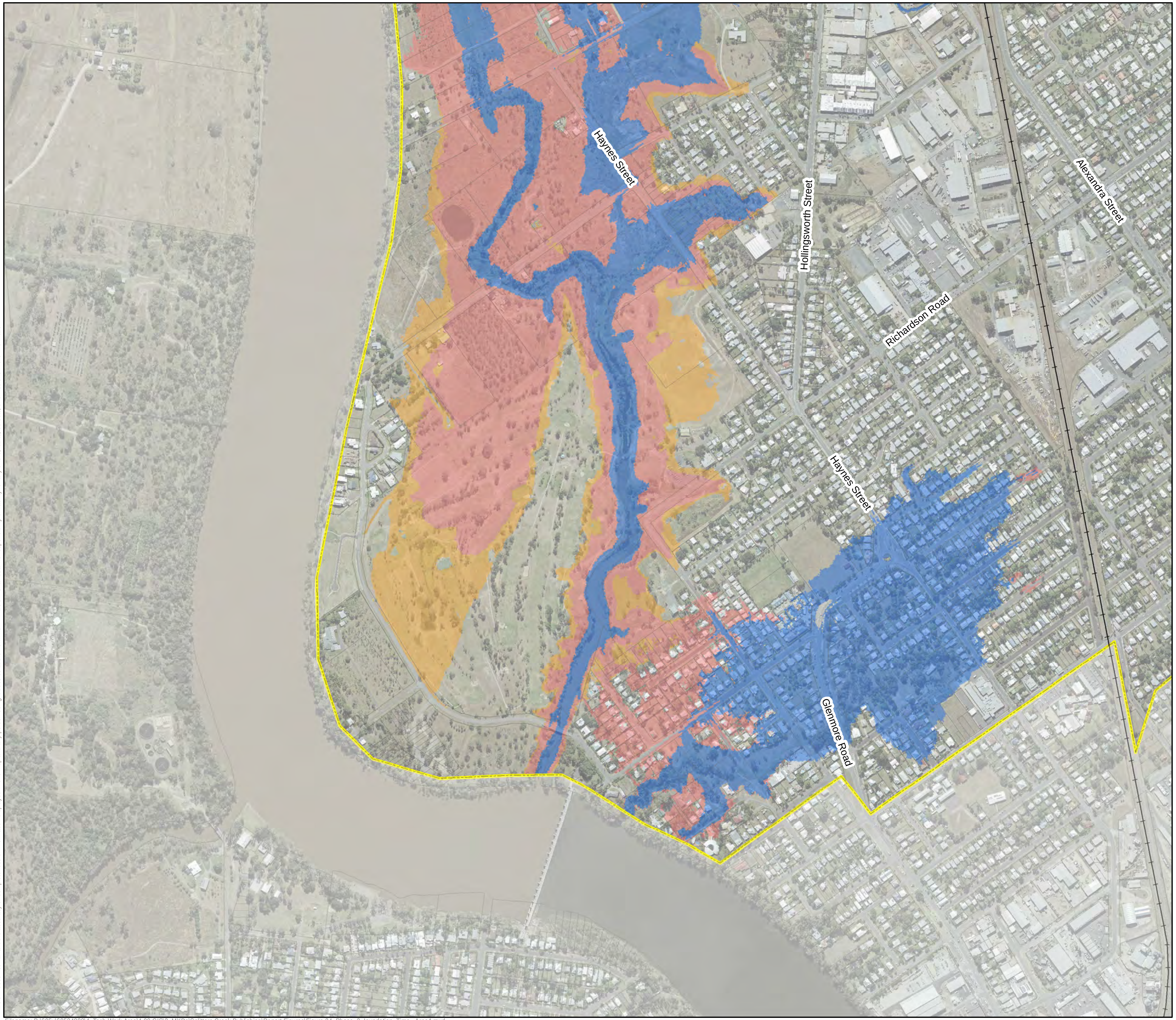
Splitters Creek Model
Time of Inundation - Area 3

PMF 60min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 23

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 23_Phase_2_Inundation_Time - Area3.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
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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 creek flooding only

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

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

Splitters Creek Model
Time of Inundation - Area 4

PMF 60min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 24

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 24_Phase_2_Inundation_Time - Area4.mxd

8.6 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 A.

8.6.1 Baseline Building Impact Assessment

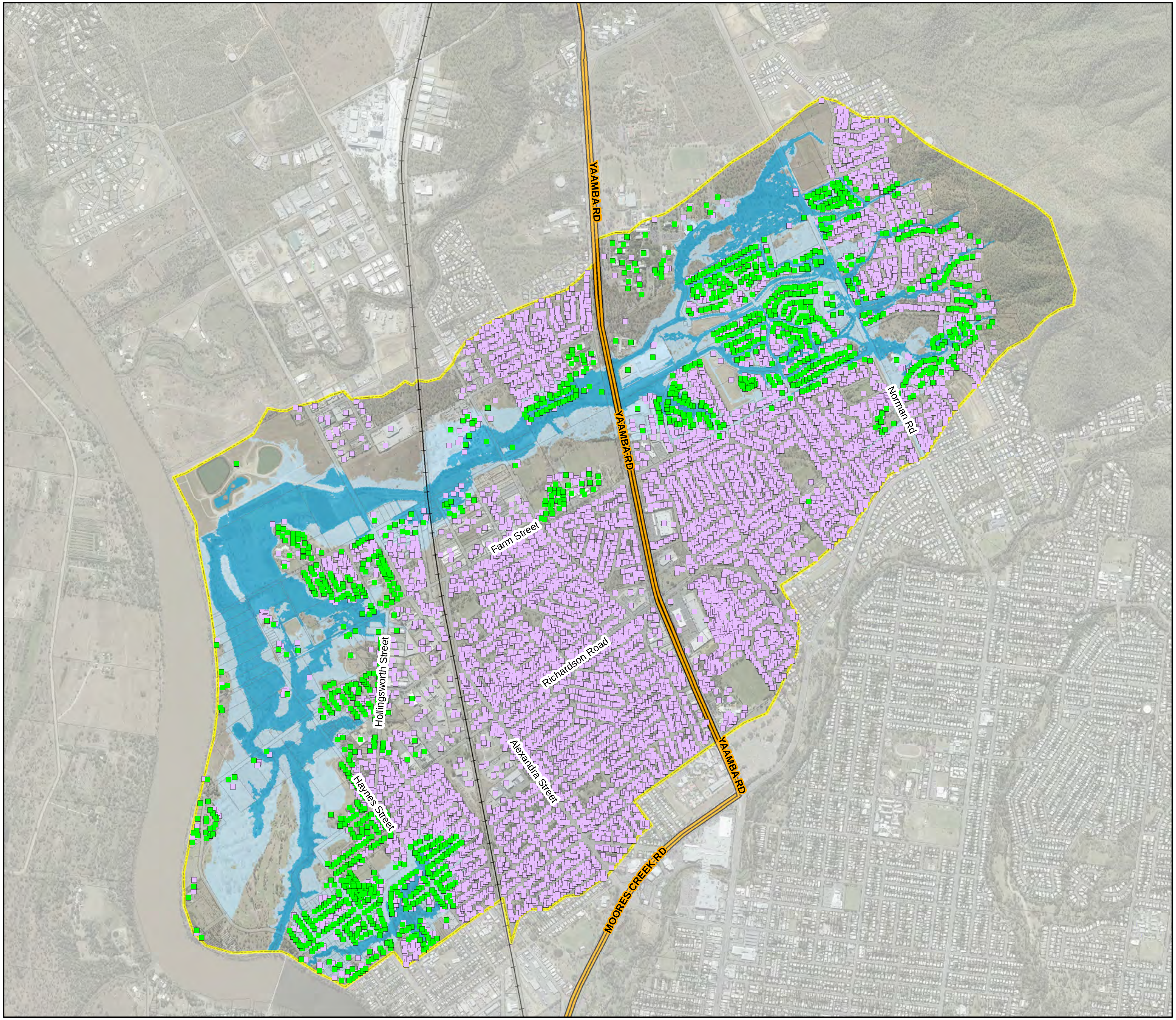
Council provided a building database, containing ~28,000 buildings digitised within the modelled area. Of these, ~5,900 buildings contained surveyed data, focussed on Creek flooding extents in North Rockhampton and Fitzroy River flood extents in South Rockhampton (refer Figure 25).

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 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 ~8,540 within Splitters Creek 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 ~10,000 within Splitters Creek catchment):
  - Buildings were divided into residential and commercial based on a combination of attribute 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.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000

Metres

1:20,000
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LEGEND

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

FLOOR LEVEL SUMMARY

Surveyed Floor Levels = 1,488
GIS-Derived Floor Levels = 8,538

Data Sources:

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

Splitters Creek Model
Building Database Summary

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	1

Figure 25

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 25 Surveyed Buildings.mxd

Table 30 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Splitters Creek catchment. These results are also shown graphically in Figure 26.

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 30 № 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	3 (0)	0 (0)
39	9 (0)	0 (0)
18	18 (2)	8 (4)
10	33 (7)	13 (7)
5	72 (24)	18 (12)
2	107 (34)	23 (19)
1	132 (42)	24 (21)
0.2	324 (154)	51 (37)
0.05	457 (222)	68 (51)
PMF	864 (470)	164 (143)

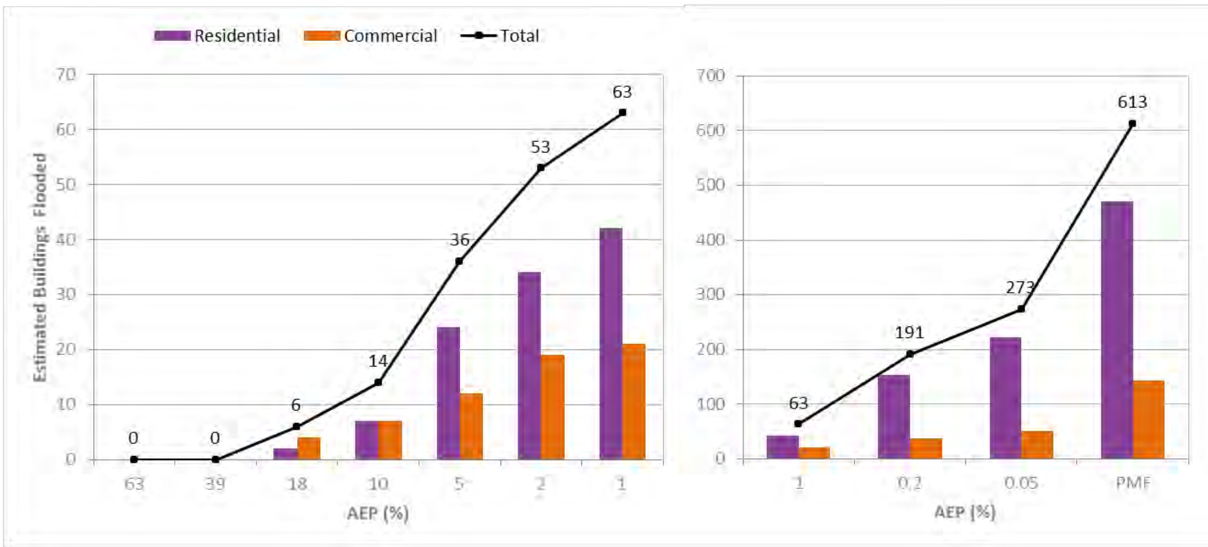


Figure 26 Estimated Buildings with Above Floor Flooding (Number of Buildings)

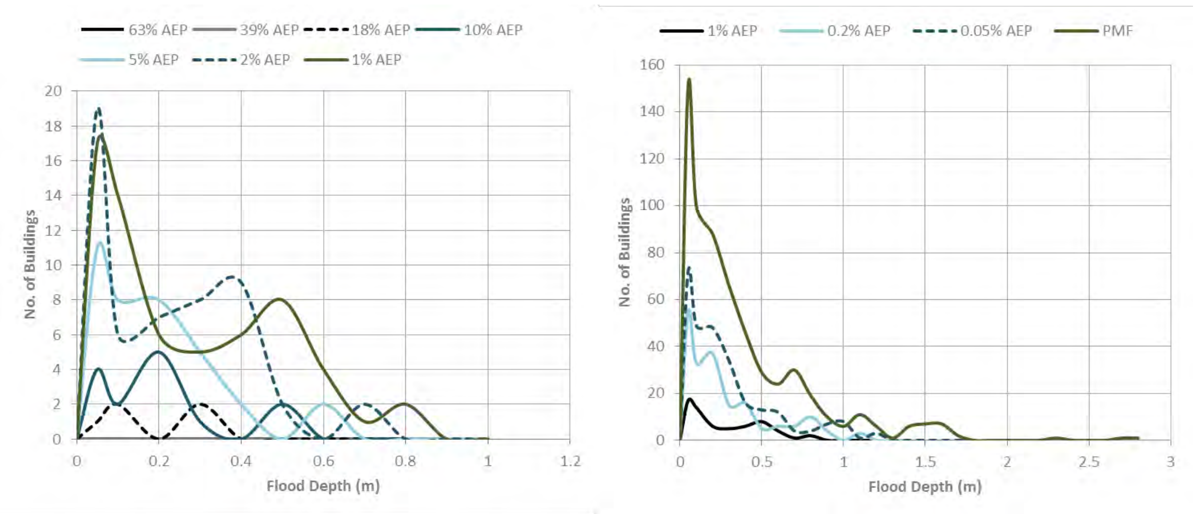
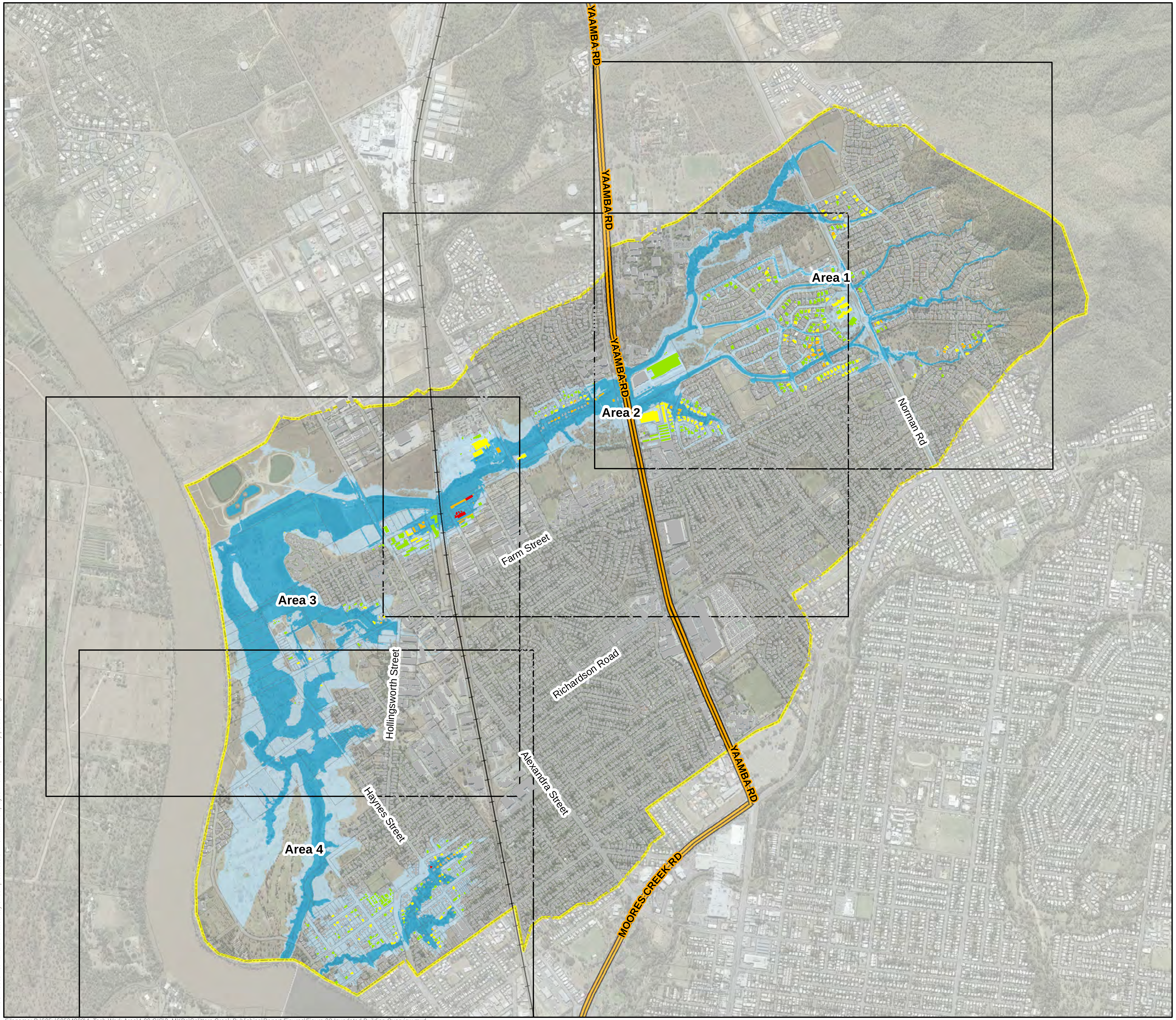


Figure 27 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings). Note: curves for the 63% AEP and 39% AEP events are not shown as there is not predicted to be above floor flooding in these events.

As shown in Figure 27, median flood depths are generally less than 0.5 metre for each flood event. This indicates that reductions in flood depths of 0.5 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 28 to Figure 32 shows the location of buildings predicted to experience above floor flooding, grouped by the earliest AEP upon which they become inundated.



Rockhampton Regional Council

N

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000
Metres

1:20,000
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside Creek Flood Extent
- 1% AEP Flood Extent
- PMF Extent

Flood results are based on creek flooding only

Data Sources:

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

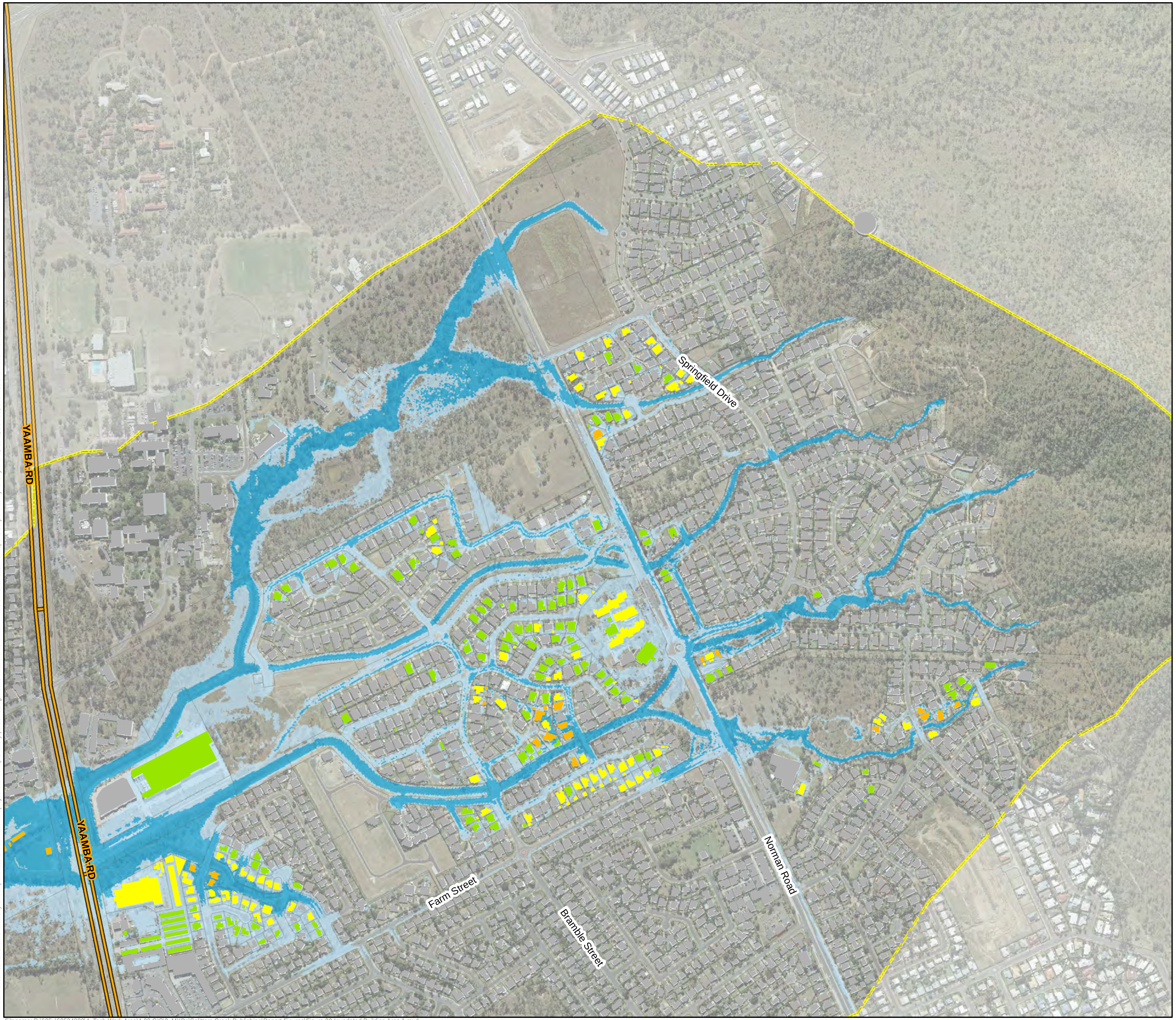
Results Filtering:

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

Splitters Creek Model
Inundation of Buildings with Above Floor Level Flooding
Catchment Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure
28



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400

Metres

1:8,000
(when printed at A3)

AECOM
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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside Creek Flood Extent
- 1% AEP Flood Extent
- PMF Extent

Flood results are based on creek flooding only

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

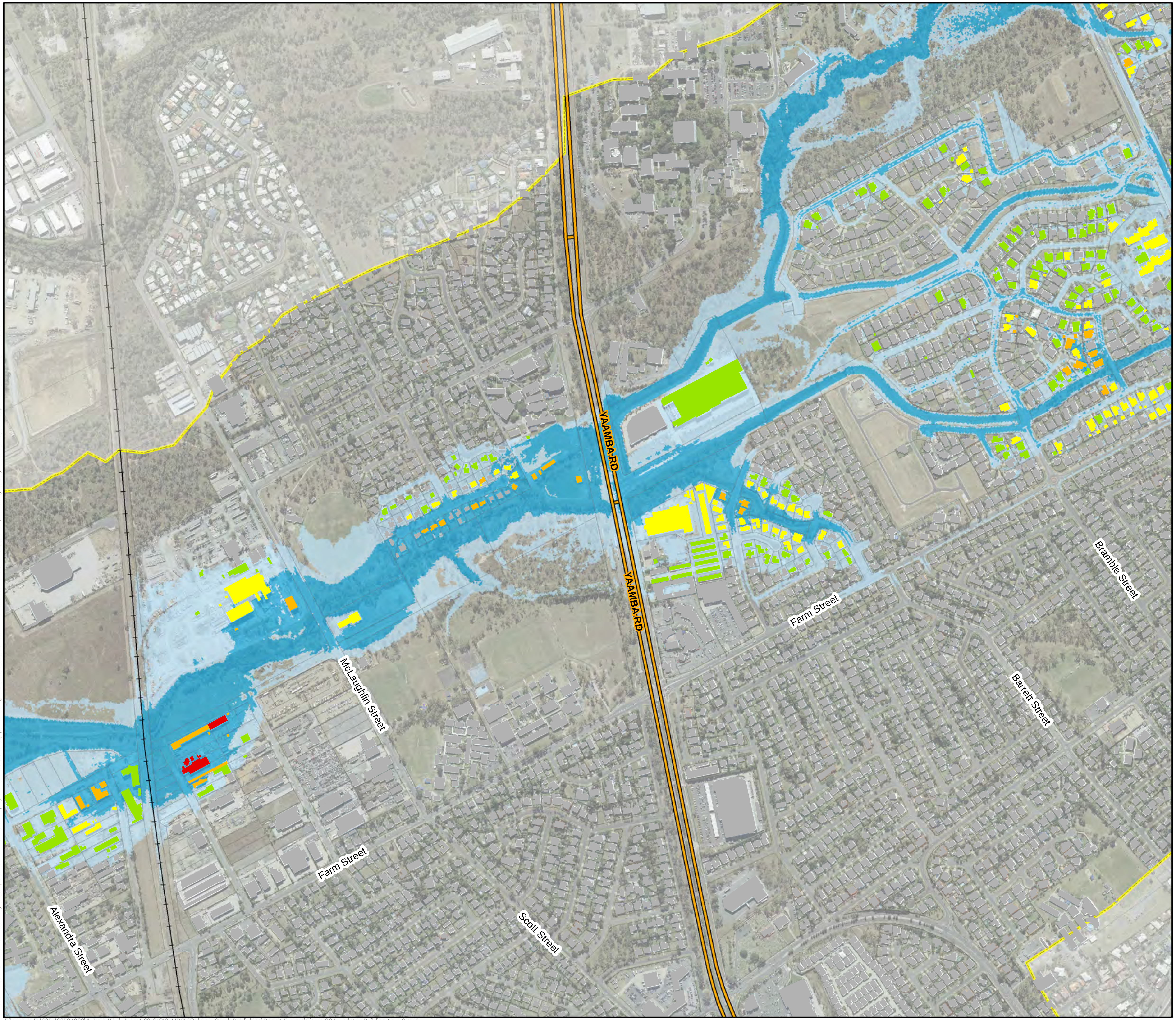
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Splitters Creek Model
Inundation of Buildings with Above Floor Level Flooding
Area 1

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 29

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 29 Inundated Building Area 1.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:8,000
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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside Creek Flood Extent
- 1% AEP Flood Extent
- PMF Extent

Flood results are based on creek flooding only

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

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

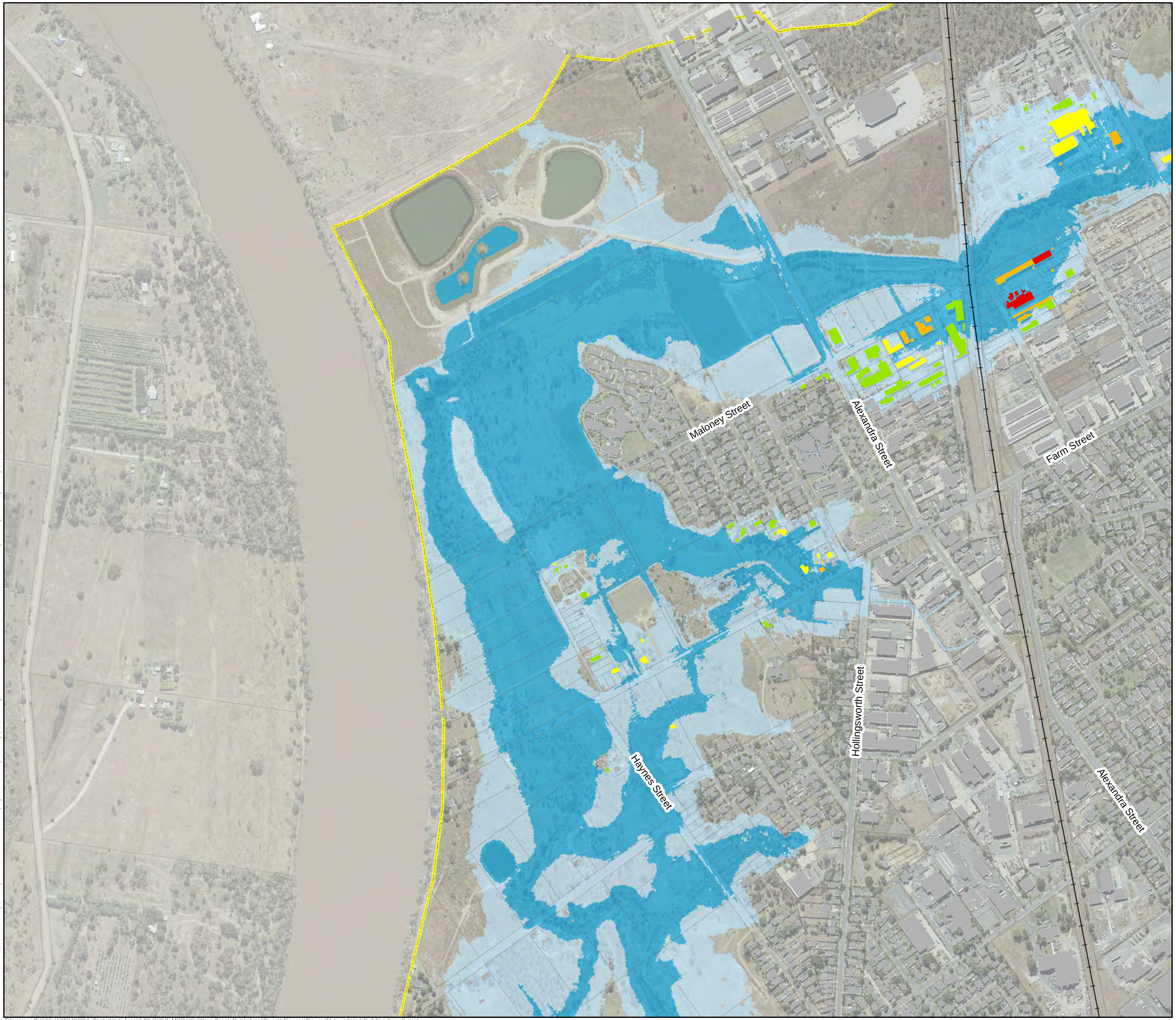
Splitters Creek Model
Peak Flood Depths
Area 2

18% AEP 60min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 30

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 30 Inundated Building Area 2.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

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(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside Creek Flood Extent
- 1% AEP Flood Extent
- PMF Extent

Flood results are based on creek flooding only

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

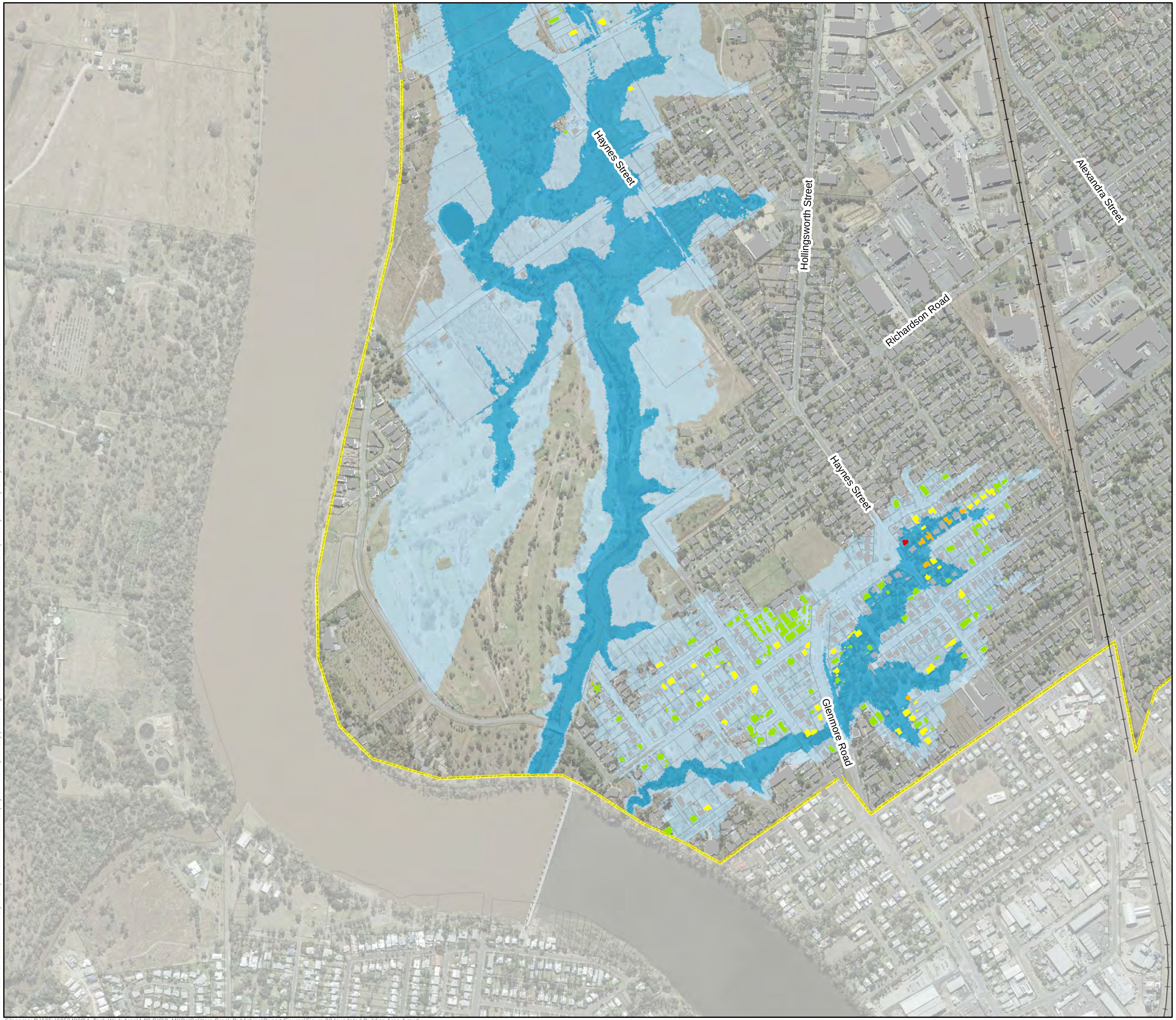
Results Filtering:
75mm Min. Depth
100m² Min. Area

Splitters Creek Model
Inundation of Buildings with Above Floor Level Flooding
Area 3

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure
31

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 31 Inundated Building Area 3.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:8,000
(when printed at A3)

AECOM
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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

- Minor (1EY - 18%AEP)
- Major (10% - 1%AEP)
- Extreme (0.2% - 0.05%AEP)
- PMF
- Outside Creek Flood Extent
- 1% AEP Flood Extent
- PMF Extent

Flood results are based on creek flooding only

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

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

Splitters Creek Model
Inundation of Buildings with Above Floor Level Flooding
Area 4

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure
32

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Splitters Creek Publishing\Report Figures\Figure 32 Inundated Building Area 4.mxd

8.6.2 Baseline Flood Damages Assessment

Table 31 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 32 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 31 Summary of flood damages using WRM stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$37	$0	$5	$42
39	$84	$0	$11	$95
18	$214	$68	$35	$317
10	$672	$397	$126	$1,195
5	$1,823	$699	$305	$2,828
2	$2,888	$1,187	$492	$4,566
1	$3,902	$1,681	$672	$6,255
0.2	$13,948	$3,645	$2,172	$19,765
0.05	$20,408	$4,799	$3,126	$28,333
PMF	$49,562	$15,574	$7,972	$73,108

Table 32 Summary of flood damages using O2 Environmental stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$37	$0	$5	$42
39	$84	$0	$11	$95
18	$214	$68	$34	$316
10	$681	$397	$127	$1,204
5	$1,987	$699	$327	$3,013
2	$3,345	$1,187	$551	$5,084
1	$4,651	$1,681	$769	$7,102
0.2	$17,145	$3,645	$2,589	$23,378
0.05	$25,932	$4,799	$3,847	$34,578
PMF	$66,914	$15,574	$10,235	$92,724

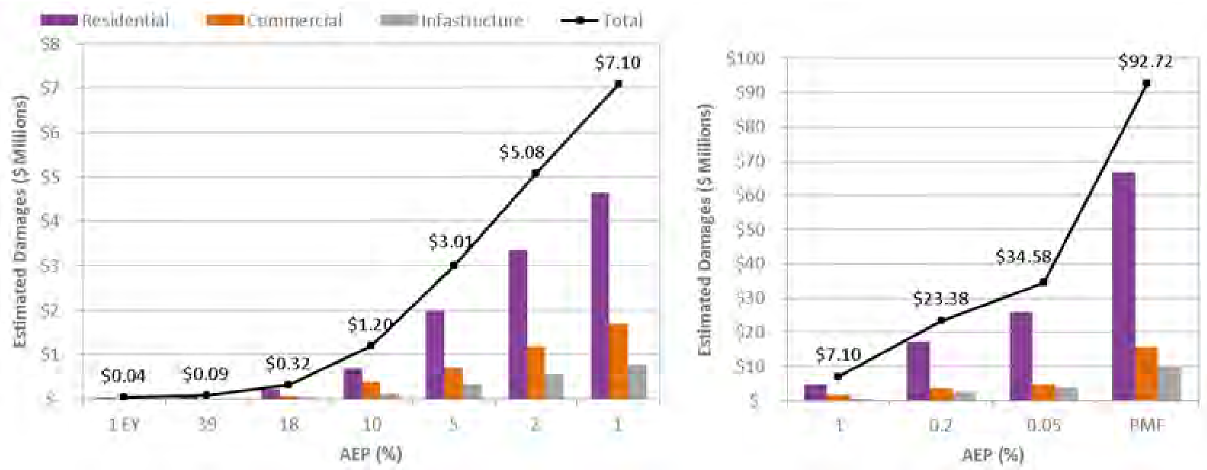


Figure 33 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

Figure 33 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from $42,000 (1EY flood event) to $92.7M (PMF event). The figure also demonstrates that residential buildings make up the large majority of impacted buildings, and consequently estimated flood damages, within the Splitters catchment across the full range of design events assessed.

Figure 26 shows that zero buildings are expected to be inundated above floor in the 1EY event, whilst 613 buildings are anticipated to be inundated above floor in the PMF event.

8.6.3 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 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 $1.204M damages and 10% or 0.01 likelihood, corresponding to an AAD of $120,400. 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 A. Using the WRM damage curves results in an AAD of approximately **$552,000** and using those from O2 Environmental gives an AAD of approximately **$606,000**. The difference of approximately 10% provides a relatively narrow range for the estimated AAD.

It should be noted that the estimated AAD for the Splitters Creek catchment is comparatively low when compared with the AAD estimates derived for other North Rockhampton Creek catchments. There are two primary reasons for this:

- There is generally a lesser extent and lower density of urbanisation within the Splitters Creek catchment, in comparison to the other North Rockhampton catchments.
- More importantly, the AAD estimates for the other North Rockhampton catchments have included damages due to overland flooding. The current Splitters Creek model does not simulate overland flood impacts, and therefore this flood damage component can't be estimated.

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

Figure 34 shows the breakdown of residential, non-residential and infrastructure AAD over the entire catchment. As shown, a total AAD cost of $606,000 per annum is estimated, with the vast majority (68%) being attributed to residential buildings.

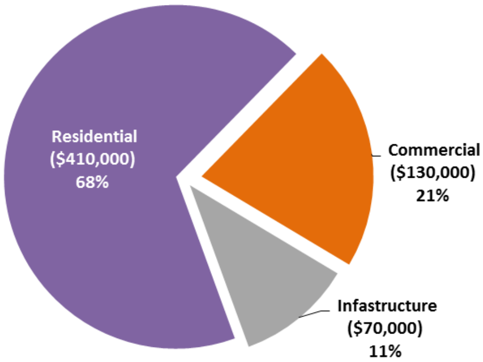


Figure 34 Total AAD by Building Type

Figure 35 and Figure 36 breakdown the AAD for residential and non-residential properties. It can be seen that 77% of residential and 91% of non-residential properties experience a damage cost of less than $500 per annum. As a result, 72% 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.

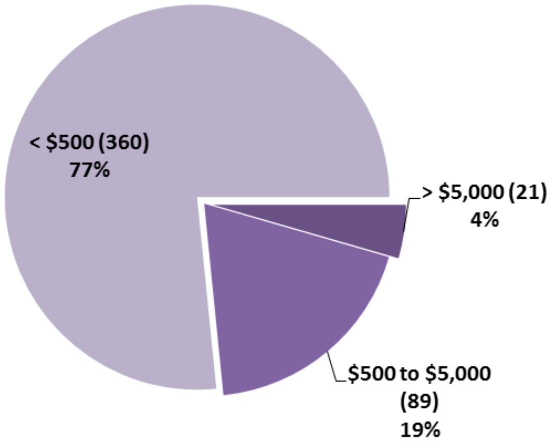


Figure 35 Residential AAD (Number of Buildings)

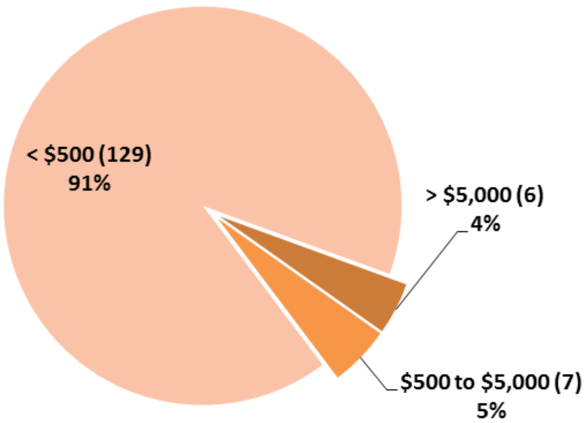


Figure 36 Non-Residential AAD (Number of Buildings)

8.6.4 AAD Summary

Figure 37 summarizes 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, infrastructure damage excluded. In addition 72% of damages are associated with less than 5% of all buildings. Again, this demonstrates that a minority of buildings produce the majority of damages.

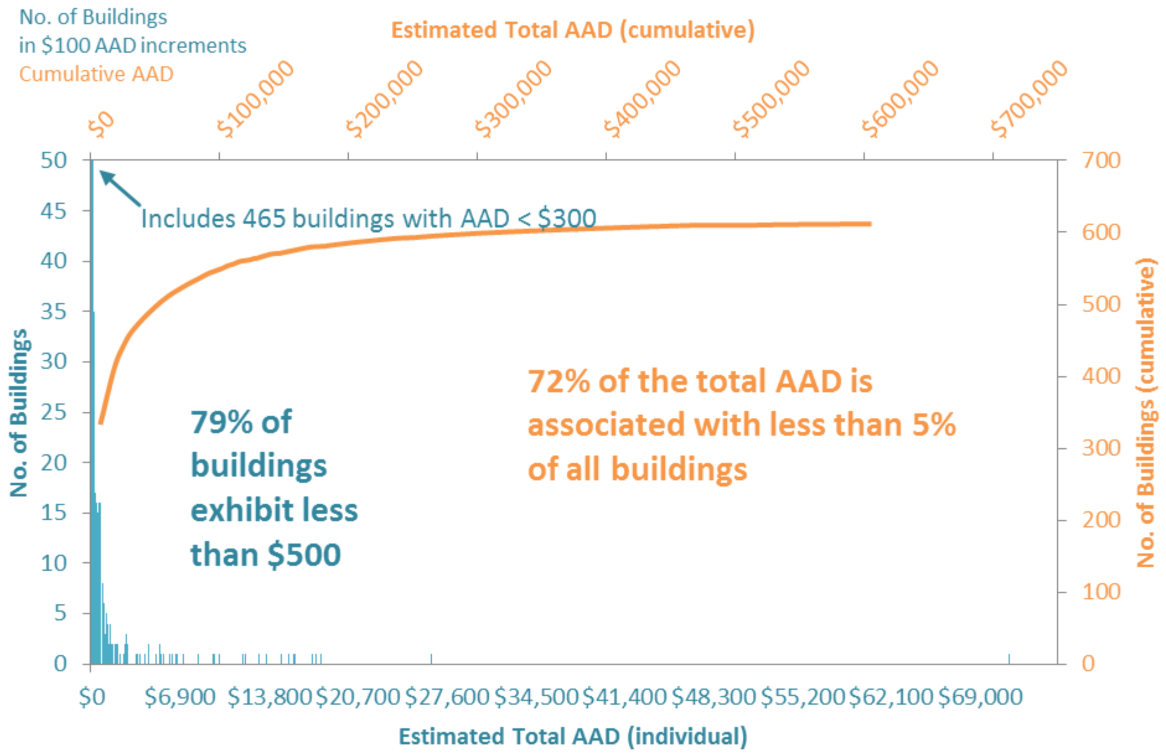


Figure 37 Individual Building vs. Cumulative Total Average Annual Damages

8.7 Rainfall Gauge and Maximum Flood Height Gauge Network Coverage

Figure 38 and Figure 39 show the location of existing rainfall gauges within the Rockhampton region, plus Council's maximum flood height gauges.

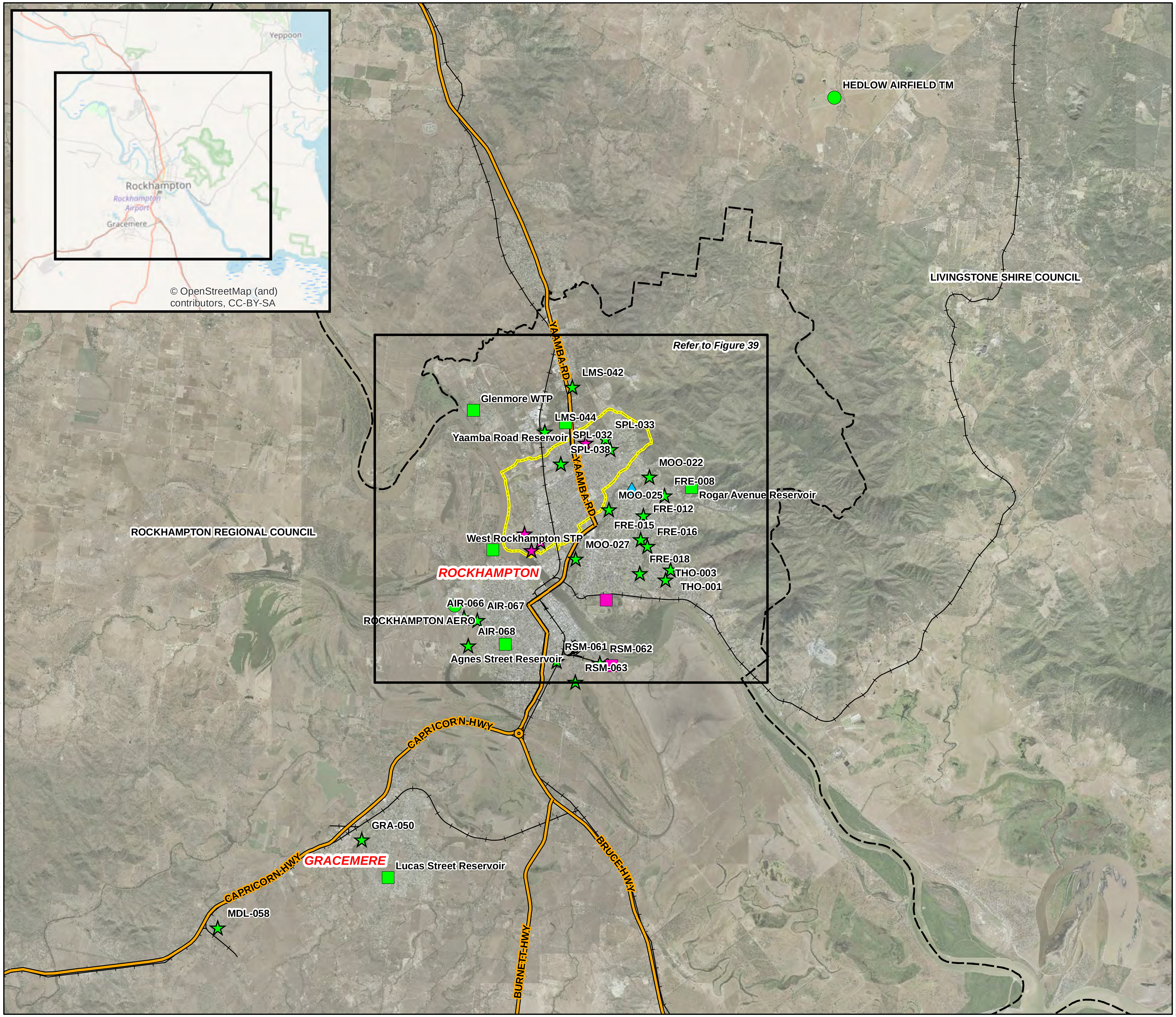
A high level desktop review of the coverage provided by the existing gauges has been undertaken, with the following recommendations provided for future upgrades to the system:

- Additional Council rainfall 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 Splitters Creek catchment, it is recommended that gauges be installed at the following locations (refer Figure 39):
  - Stringybark Avenue, in the vicinity of the Mistletoe Avenue intersection.
  - In the vicinity of the Richardson Road and Thompson Street intersection.
  - Kluver Street, on the Haynes Street side of the main flowpath.
  - Hadgraft Street, in the vicinity of the Hadgraft Street SPS.

8.8 Flood Warning Network Coverage

There is currently no flood warning network for the Splitters Creek catchment.

It is recommended that Council liaise with BoM to assess the need for an integrated flood warning network across all major catchments in Rockhampton.



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

Maximum Height 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

Splitters Creek Model
Rainfall Gauge and Flood Record Network

Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 38

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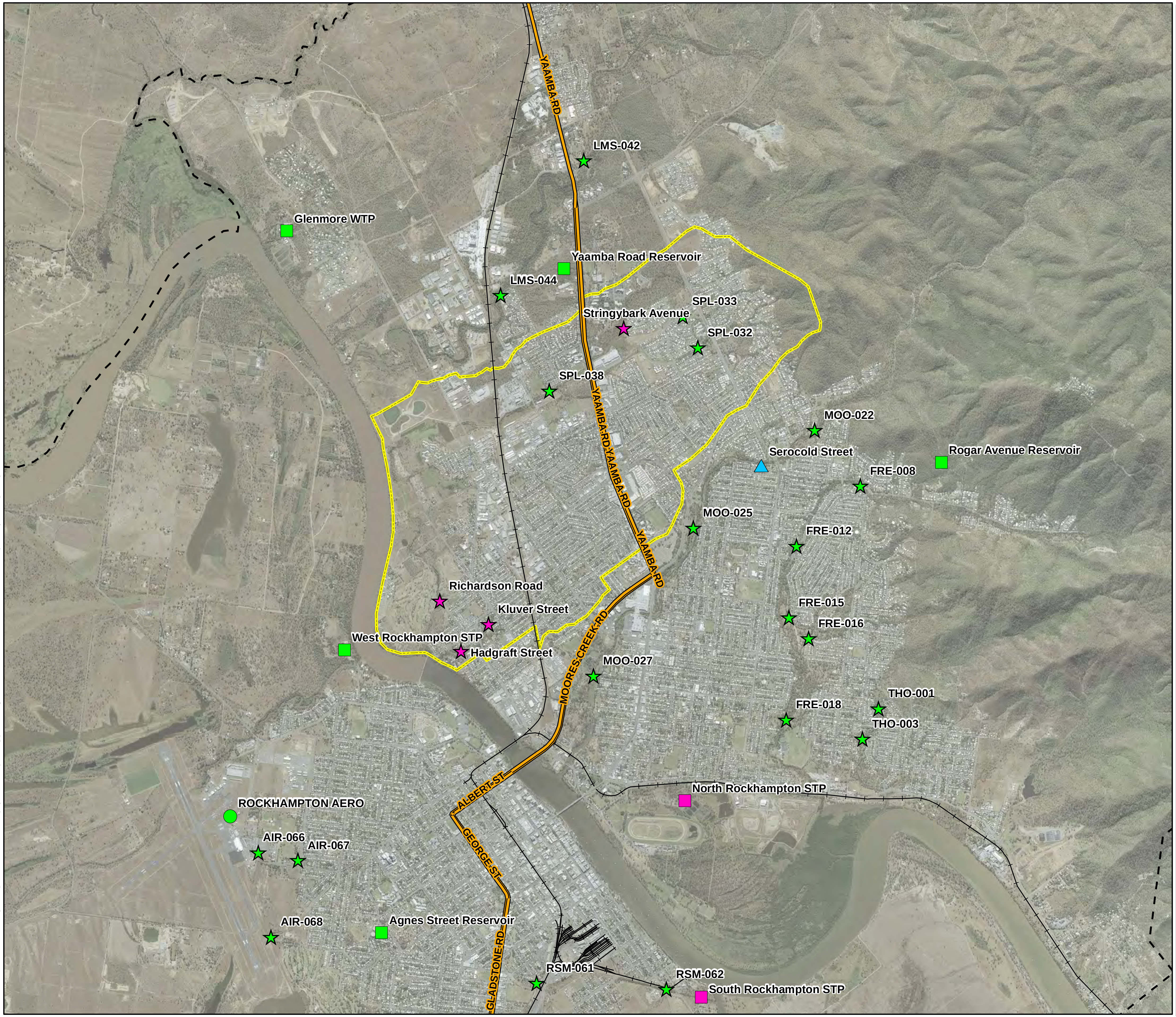

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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 0.5 1 1.5 2
Kilometers

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(when printed at A3)

AECOM
www.aecom.com

LEGEND

Maximum Height 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

Splitters Creek Model
Rainfall Gauge and Flood Record Network

Figure 38 Inset - Rockhampton

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	27/10/2017
VERSION:	2

Figure 39

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9.0 Conclusions

9.1 Baseline Model Development

Council's Splitters Creek TUFLOW model, developed by Aurecon as part of the *Rockhampton Local Catchments Flood Study - Splitters Creek Hydrologic and Hydraulic Modelling Report* (Aurecon, May 2014) and updated by Aurecon in June 2016, was used as the basis for this current study.

A number of model updates were completed as part of this current study, prior to assessing baseline flood hazard within the Splitters Creek catchment. These included topographic updated to incorporate latest LiDAR and aerial imagery, plus more refined representation of model grid, road crowns and channel invert levels. In addition, 1D network configuration and setup changes resulted in a more stable model fit for the purposes of this study.

9.1.1 Design Event Modelling

On completion of the model updates, various design flood events and durations were simulated and results extracted. The critical duration for the catchment was determined to be the 60 minute event.

The modelling has confirmed that there are a number of key hydraulic controls within the catchment – particularly the various bridges which cross Splitters Creek.

9.1.2 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.

9.2 Baseline Flood Hazard and Vulnerability Assessment

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

9.2.1 Flood Hazard

As can be seen on maps **SPL-66** to **SPL-70** the 1% AEP baseline flood hazard within the Splitters Creek catchment generally shows:

- Low to medium hazard (H1 and H2) in some urbanised areas.
- High hazard (H3 and H4) within the floodplain area to the west of Alexandra Street Extended.
- High to extreme hazard (H4 and H5) within some natural and man-made open channels.
- Extreme hazard (H5 or H6) within the Splitters Creek channel and adjacent overbank areas.

9.2.2 Vulnerability Assessment

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

- The Hadgraft Street Sewerage Pump Station (SPS, Ref: 463733) and Stringybark Avenue - Forest Park SPS (Ref: 463751) are predicted to have less than 0.2% flood immunity. It is noted however that the predicted flood levels and hazard are low in the 0.2% AEP event. It is recommended this information be passed onto FRW as the asset owner.
- Low depth flooding is predicted at the Norman Road Hospital in the 0.2% AEP.
- The North Coast Rail Line is predicted to be inundated over ballast level in the 10% AEP event and larger.
- A number of road segments are predicted to experience inundation in the 1EY event and larger. Approximate TOS values ranges from 0.5 hours to approximately 3.5 hours.

9.2.3 Evacuation Routes

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

- Bulman Street and Smithwick Street → loses evacuation via Wormald Street to Farm Street.
- Foxglove Avenue, Bushpea Court, Snow Gum Street and Plumb Drive → loses evacuation via Bramble Street to Farm Street.
- Primrose Avenue, Frangipani Court, Red Penda Court, Saintwood Avenue, Lace Flower Court and Silky Oak Court → loses evacuation via Bramble Street to Farm Street.
- Bramble Street, Mistletoe Avenue, Stringybark Avenue, Waratah Court, Messmate Court and Aspen Court → loses evacuation via River Rose Drive to Norman Road.
- Larcombe Street and Sandys Place → loses evacuation vis Macalister Street to Glenmore Road and/or via York Street to Haynes Street

9.2.4 Building Impact Assessment

The building impact assessment shows the following:

- 3 buildings (none with above floor flooding) buildings predicted to be impacted in the 1EY event.
- 26 buildings (6 with above floor flooding) predicted to be impacted in the 18% AEP event.
- 156 buildings (63 with above floor flooding) predicted to be impacted in the 1% AEP event.
- 1,028 buildings (613 with above floor flooding) predicted to be impacted in the PMF event.
- Median flood depths are generally less than 0.5 metre for each flood event.

9.2.5 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:
  - $42,000 damages estimated in 1EY event.
  - $316,000 to $317,000 damages estimated in 18% AEP event.
  - $6,255,000 to $7,102,000 damages estimated in 1% AEP event.
  - $73,108,000 to $92,724,000 damages estimated in PMF event.
- AAD ranging from **$552,000 to $606,000** for WRM and O2 damage curves respectively.
- 68% of the total AAD is associated with residential buildings.
- 77% of residential buildings and 91% of commercial buildings exhibit less than $500 damage per annum.
- 72% of the total AAD is attributed to less than 5% of all buildings.

9.2.6 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 Splitters Creek catchment:

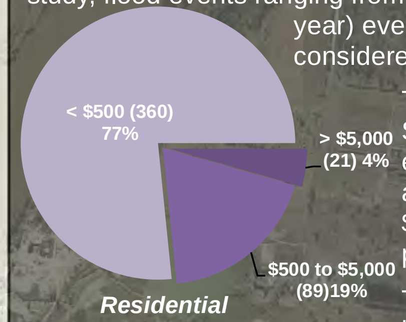
- Additional rain gauges should be installed at NRSTP and SRSTP.
- Additional maximum flood height gauges should be installed at Stringybark Avenue (Mistletoe Avenue intersection), Richardson Road and Thompson Street intersection, Kluver Street and Hadgraft Street (in the vicinity of the Hadgraft Street SPS).
- There is no current flood warning system within the Splitters Creek catchment.

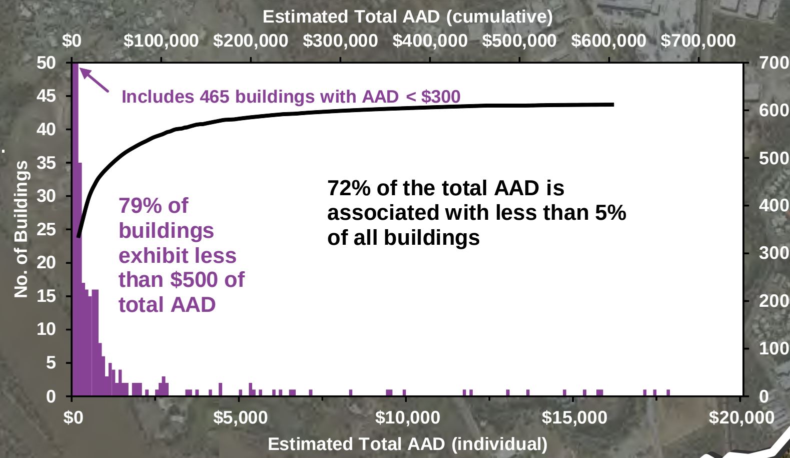
An overview of building impacts and flood damages is provided in Figure 40.

Splitters Creek Catchment Overview

Average Annual Damages

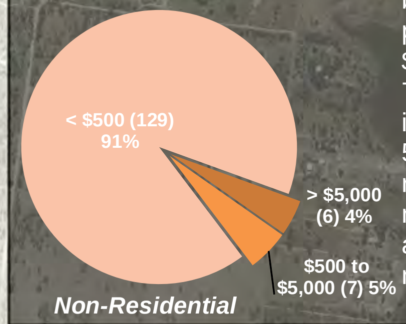
Average Annual Damage (AAD) is a measure of the average tangible flood damages experienced each year, and is calculated as the area under the Probability Damages Curve. Therefore, accurate estimates of AAD require consideration of flood events ranging from the smallest flood that causes damage up to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

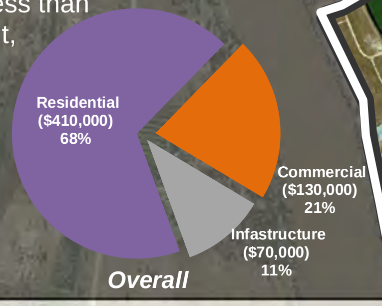




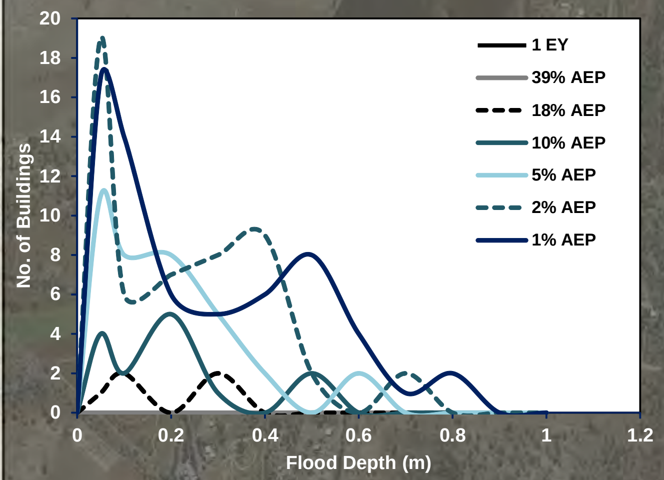
The calculated AAD for the Splitters Creek catchment is estimated to range from approximately $552,000 to $606,000 per annum. The difference of approximately 10% provides a relatively narrow range for the estimated AAD.

The vast majority (68%) of AAD is attributed to residential buildings. 77% of residential and 91% of non-residential properties experience less than $500 of AAD. As a result, 72% 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.



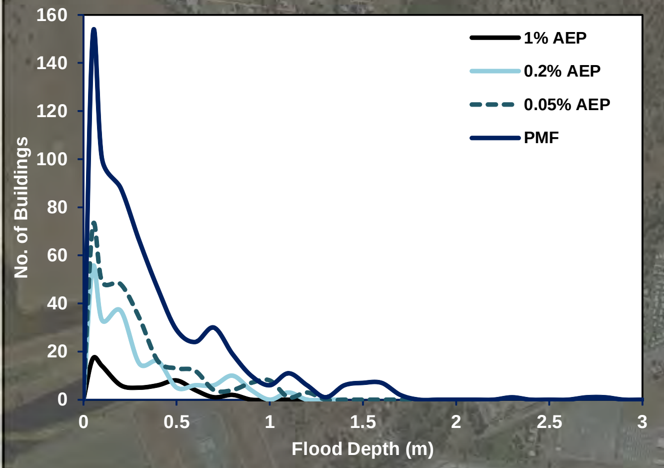


Depth of Inundation

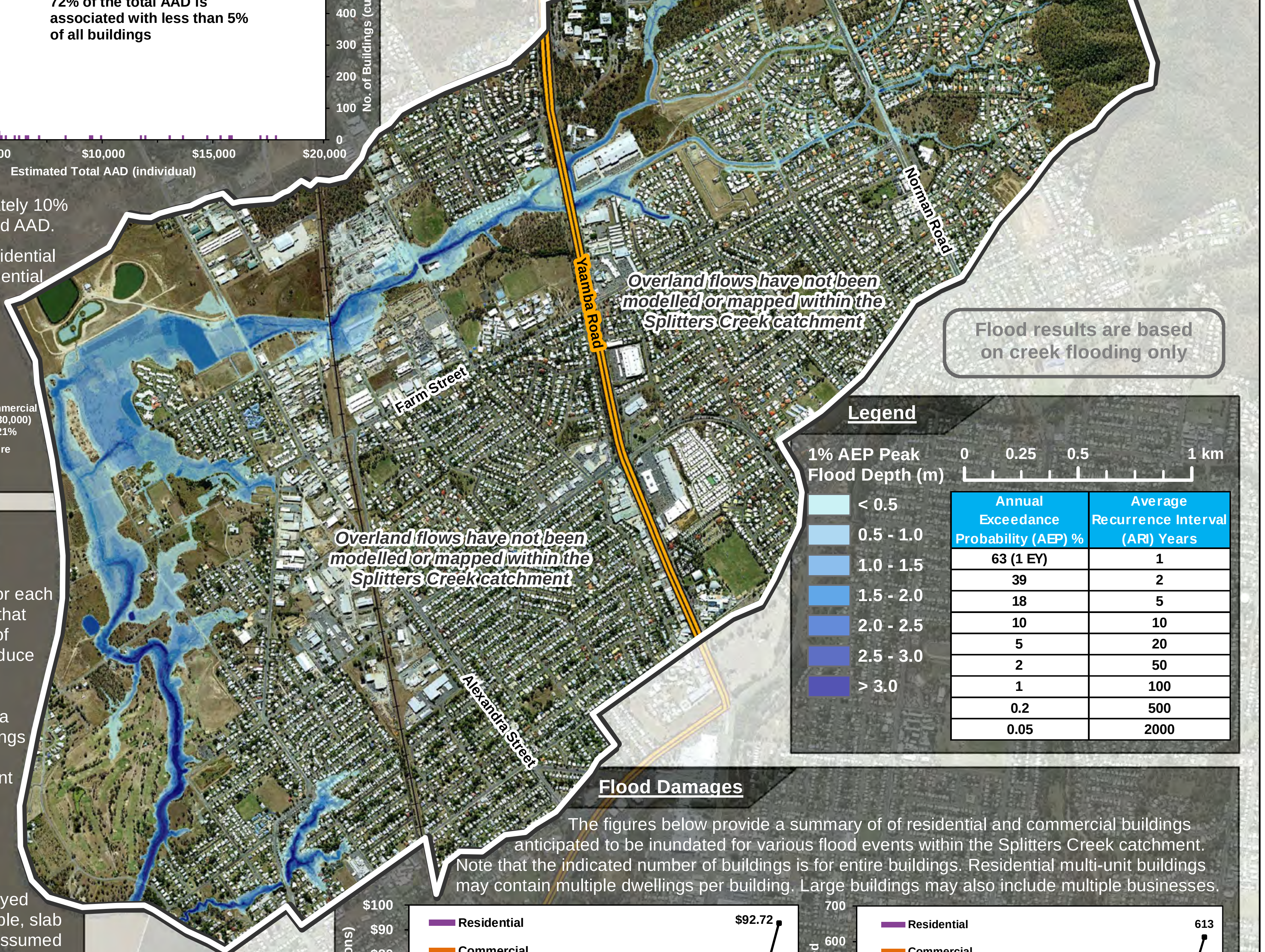


Median flood depths are generally less than 0.5 m for each flood event. This indicates that reductions in flood depths of 0.5 m could significantly reduce overall damage.

The figures also show that a significant number of buildings experience flood depths of 0.2 m or less during frequent events such as the1 EY 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.



Legend

1% AEP Peak Flood Depth (m)

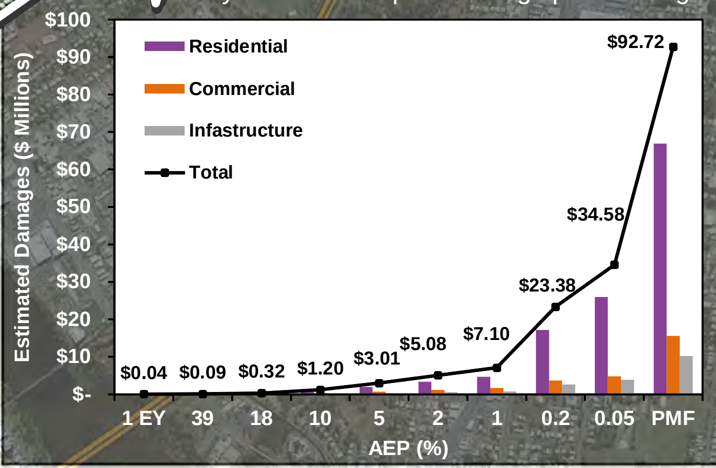
- < 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- > 3.0

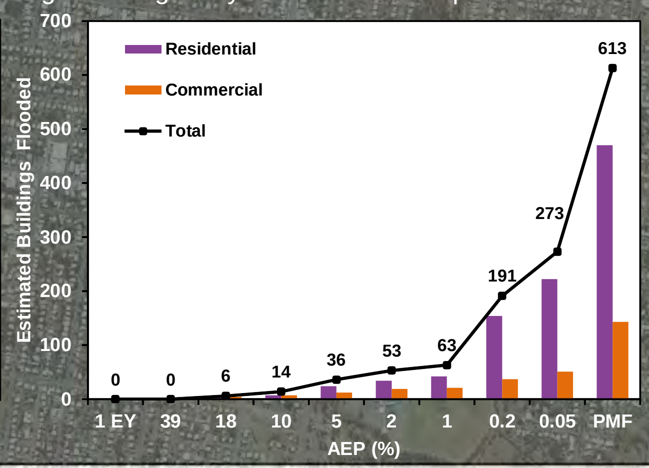
0 0.25 0.5 1 km

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

Flood Damages

The figures below provide a summary of of residential and commercial buildings anticipated to be inundated for various flood events within the Splitters Creek catchment. Note that the indicated number of buildings is for entire buildings. Residential multi-unit buildings may contain multiple dwellings per building. Large buildings may also include multiple businesses.





10.0 Recommendations

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

- It is highly recommended that the TUFLOW model be upgraded to a direct rainfall hydrologic methodology in the future, to align with the remainder of Creek catchments within North and South Rockhampton. Within this scope of works, calibration and validation of the model should be undertaken to historical local catchment events.
- 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.
- 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 Splitters Creek catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained and the TUFLOW model has been upgraded to the direct rainfall methodology.
- It is recommended that Council continue to record rainfall and flood heights associated with future Splitters Creek 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 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). Potential mitigation options should be focussed on both creek and overland flooding.

11.0 References

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

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

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

Maritime Safety Queensland (2014) QLD Tide Tables book.

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

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

Appendix A

Tangible Flood Damages Assessment Methodology

Appendix A Tangible Flood Damages Assessment Methodology

Introduction

As part of the Splitters Creek 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 41. 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.

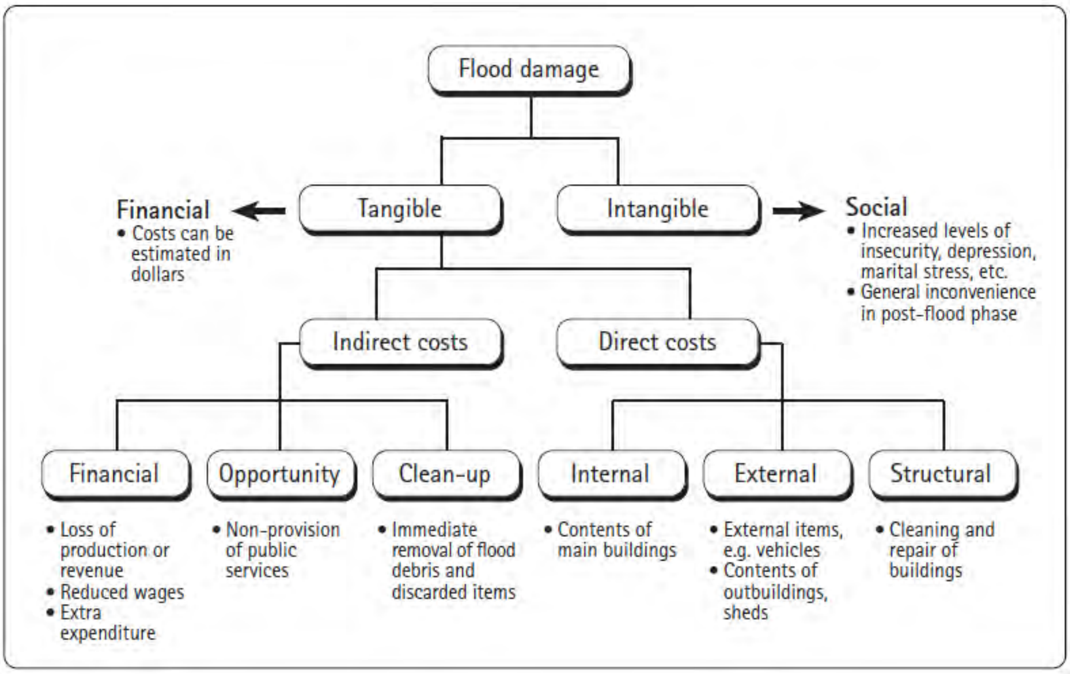


Figure 41 Breakdown of flood damage categories (source: DNRM, 2002)

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 33 to Table 35. Individual curves are given for external, contents and structural damages. Figure 42 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 40), 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 33 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 34 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 35 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

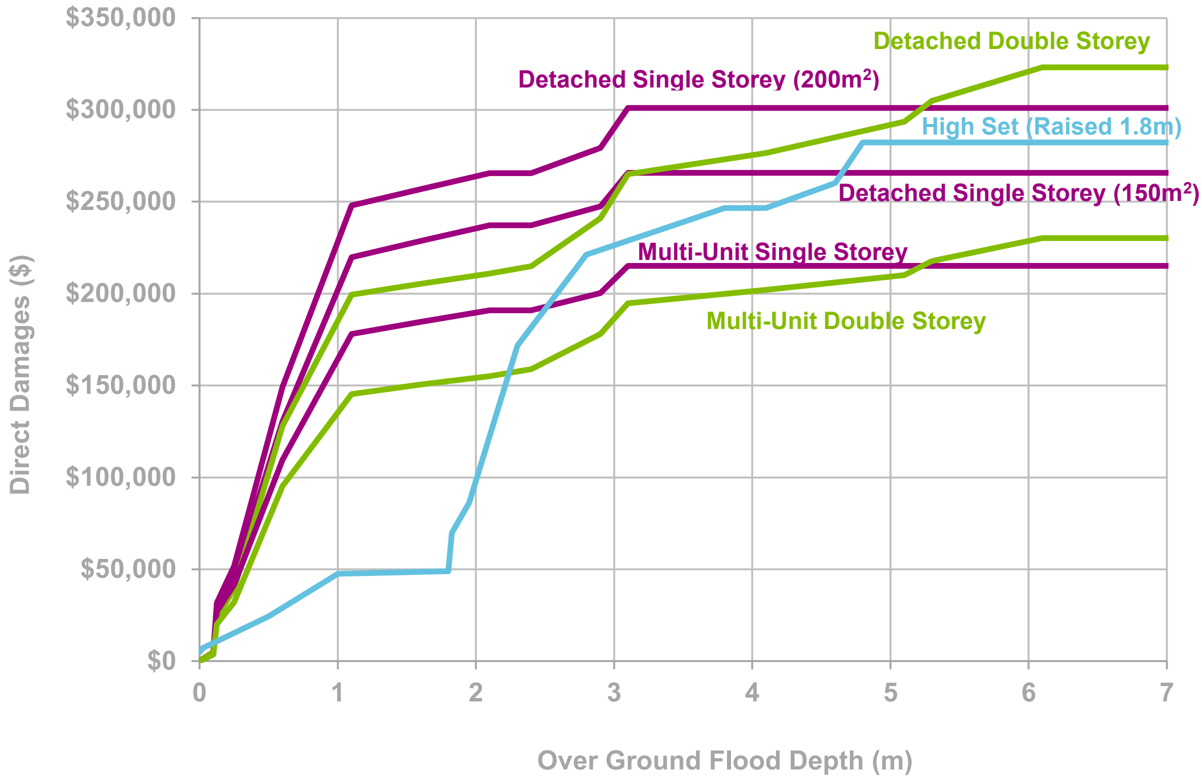


Figure 42 Total residential stage-damage curves based on O2 Environmental curves (March 2017 $)

WRM Stage Damage Curves

Direct residential damages were estimated using the WRM (2006a) stage-damage curves presented in Table 36 to Table 38. 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 43 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 36 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 37 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 38 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

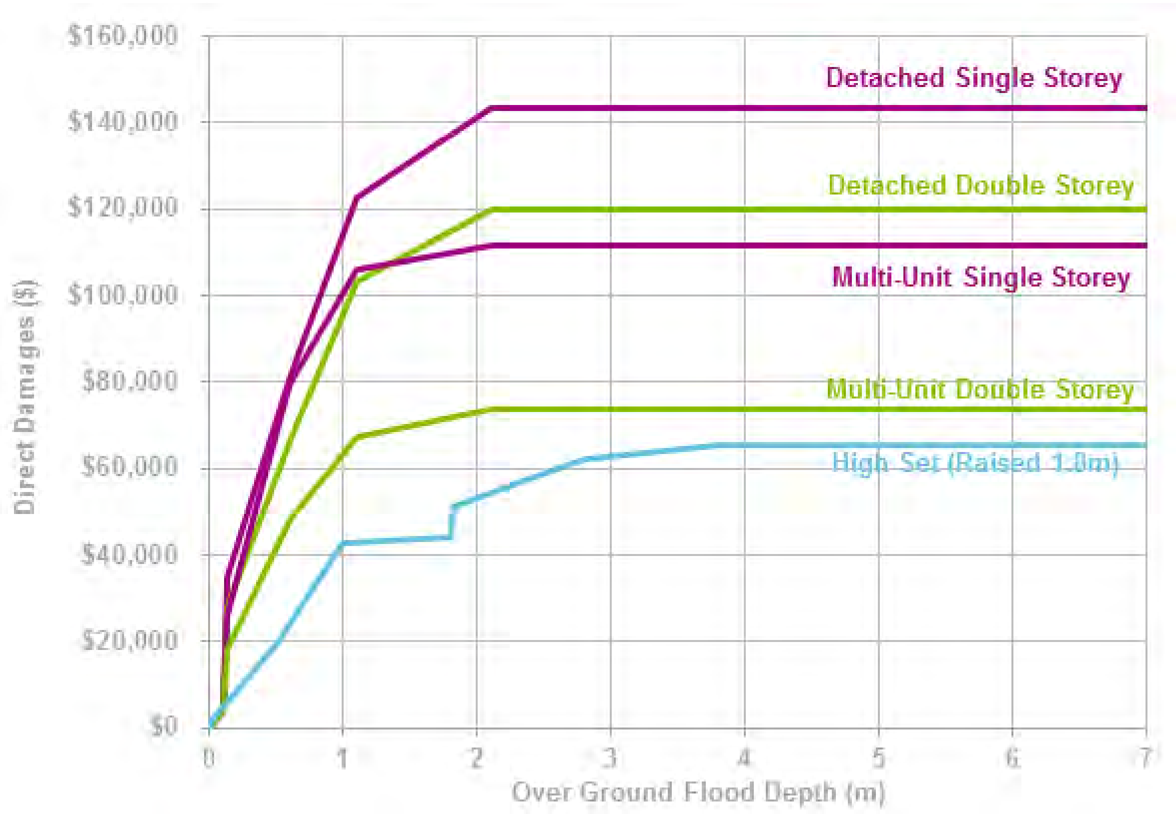


Figure 43 Total residential stage-damage curves based on WRM curves (March 2017 $)

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 39 and Figure 44. 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 39 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.

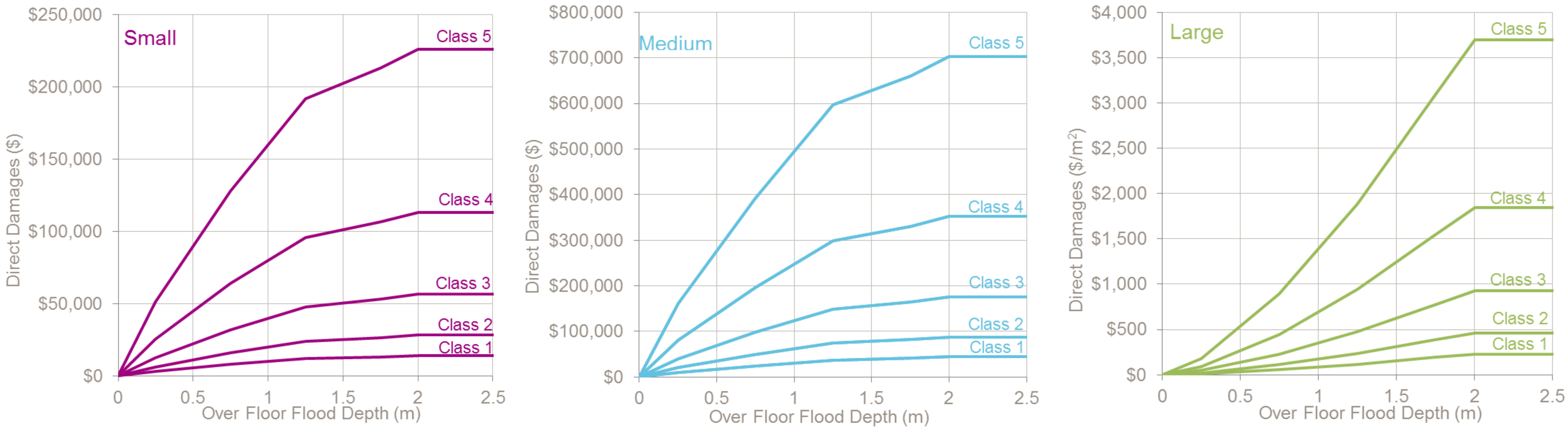


Figure 44 ANUFLOOD Stage-Damage curves for commercial properties (March 2017 $)

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 40 presents an overview of the CPI adjustments.

Table 40 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 45.

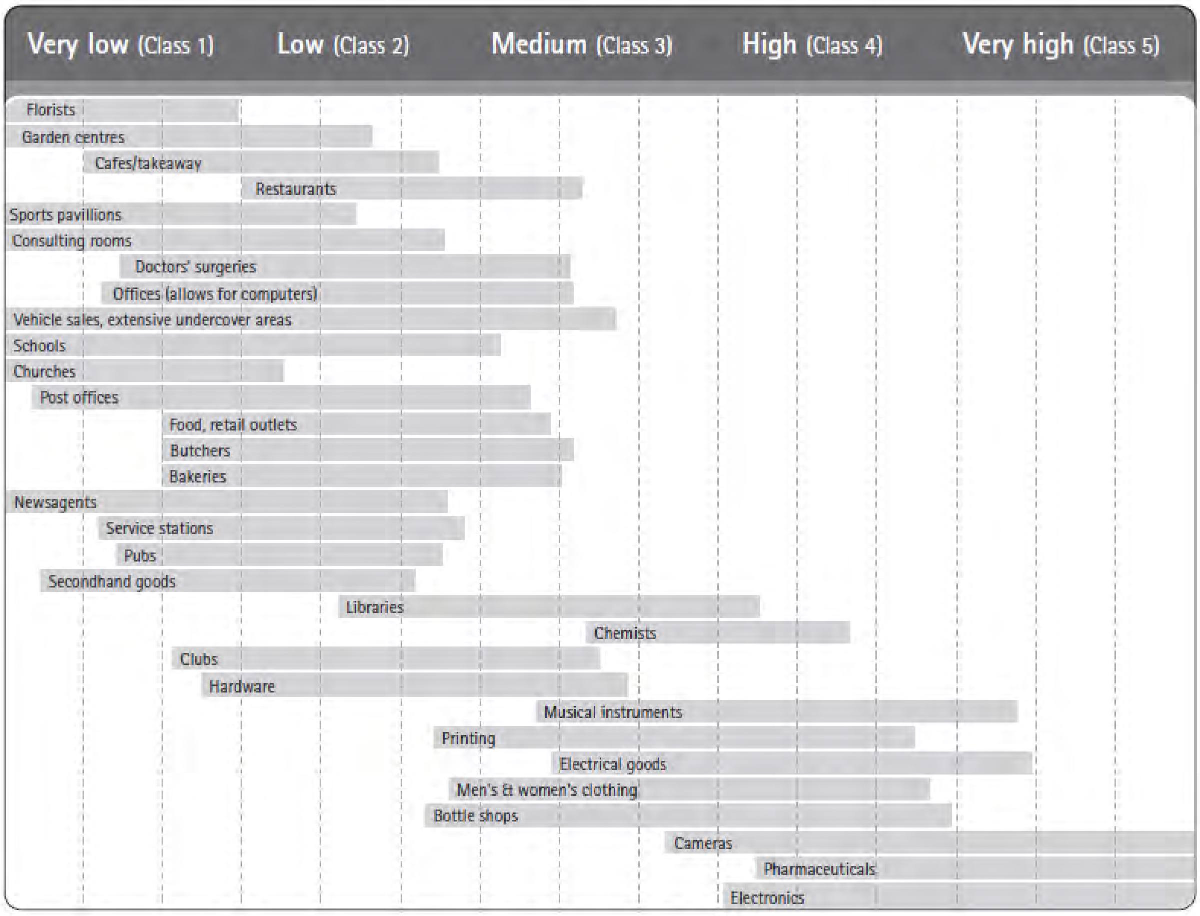


Figure 45 ANUFLOOD commercial damage value classes (source: DNRM, 2002)

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 41 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 41 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

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