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

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

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

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

The key objectives of this study are:

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

Catchment Characteristics

The Moores Creek catchment covers an area of approximately 30.5 km^2 starting within the upper reaches of Mount Archer National Park and serves as the border between the residential suburbs of Norman Gardens - Frenchville and Park Avenue – Berserker.

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

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

Hydrologic / Hydraulic Analysis

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

Anecdotal and recorded data was obtained and used to calibrate the model to a local flood event caused by TC Marcia in February 2015. Further model validations were undertaken for two other local flood events, namely Ex-TC Debbie in March 2017 and Ex-TC Oswald in January 2013. The model calibrated well to the 2015 event.

The validation to the 2017 event resulted in a reasonable comparison between modelled and recorded levels, with some points below tolerance. This was likely due to variability of the spatial distribution of rainfall across orographic features within the catchment.

The validation to the 2013 event revealed the majority of anecdotal records matched simulated levels within tolerance. Locations at which discrepancies exceeded allowable tolerances were expected to be a result of changes to the channel geometry due to ongoing geomorphological processes.

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

On completion of the calibration / validation process, various design flood events and durations were simulated and results extracted. The critical duration for the catchment was determined to be the 180 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.

The modelling has confirmed that there are a number of key hydraulic controls within the catchment – particularly the various bridges which cross Moores Creek and the culverts in the area of Sunset Drive, German Street and Norman Road. The area adjacent to the Stockland Shopping centre is also critical, involving several bridge crossings within a high velocity section of the creek reach.

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 Moores 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.

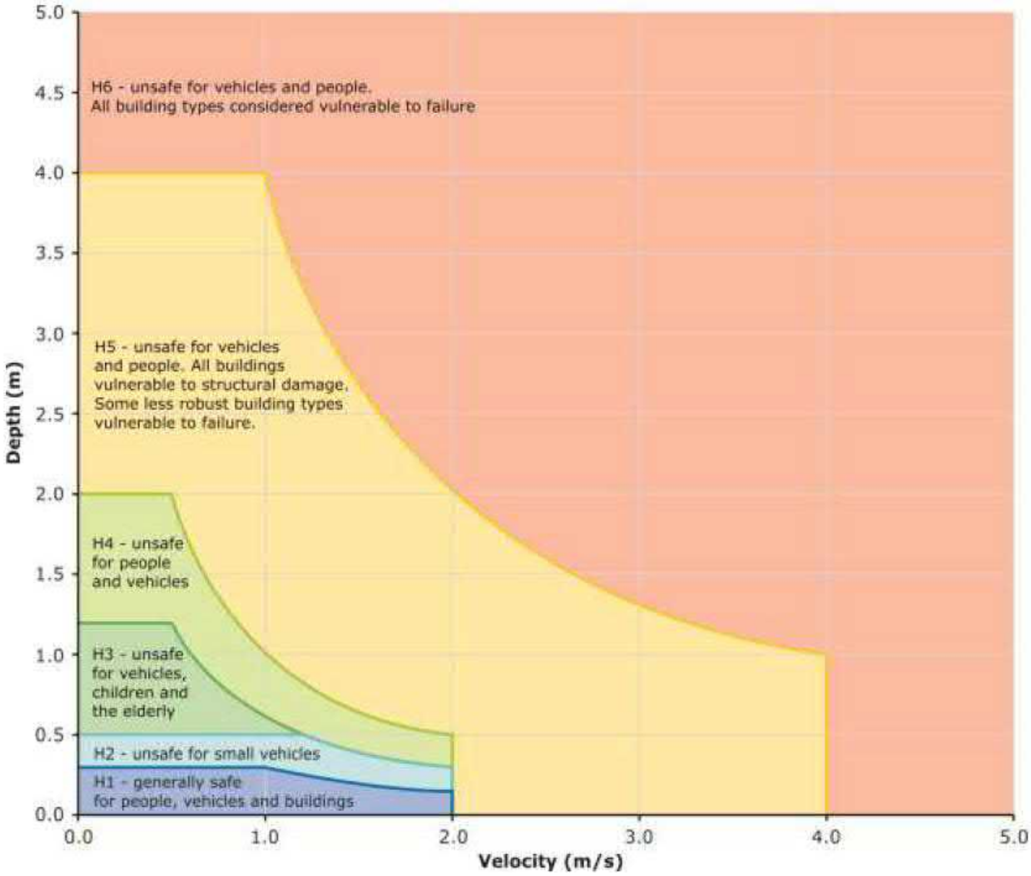

Figure E1 Hazard Vulnerability Classifications (Graphical)

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

- Low to medium hazard (H1 and H2) across the majority of urbanised areas within the catchment.
- High hazard (H3 and H4) within a majority of natural and man-made channels, as well as open spaces such as local parks and the Kershaw Gardens.
- High to extreme hazard (H4 and H5) within some natural and man-made open channels.
- High to extreme hazard (H4 and H5) in the overland flow path between Elphinstone Street and Musgrave Street, extending to the western side of Musgrave Street into Kirkellen Street.
- Extreme hazard (H5 or H6) within the Moores 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 Redhill Sewerage Pump Station (SPS, Ref: 639767) is predicted to have less than the desired 0.2% AEP flood immunity. It is noted however that this SPS is a below ground station and improvements to flood immunity would be very difficult to achieve. It is recommended this information be passed onto FRW as the asset owner.
- Inundation is predicted at Narnia Kindergarten and Preschool in the 0.2% AEP, however the low depth and velocity of flood waters is expected to presents a low hazard to pedestrians.
- The Yeppoon Branch Rail Line is predicted to have a high level of flood immunity to Top of Ballast, with inundation only predicted for a short section of rail during the PMF event.
- A number of roads within the catchment are predicted to experience inundation in the 1EY event and larger. Time of Submergence (TOS) ranges from 0.5 hours to approximately 6 hours.

Evacuation Routes

Generally local catchment flooding within the Moores 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 Moores 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:

- Danker Street à loses evacuation via Dodgson Street to Norman Road and/or via Rowe Street to Moores Creek Road.
- Warner Avenue à loses evacuation via Cheney Street to German Street.
- Rickart Street and Magee Street à loses evacuation via Waterloo Street to Kerrigan Street.
- Salamanca Street à loses evacuation via Waterloo Street to Kerrigan Street and/or via Stewart Street to Berserker Street.
- Main Street and Medcraft Street (between Twigg Street and Alexandra Street) à loses evacuation via Main Street to Alexandra Street and/or Yaamba Road.
- Kerr Street and Tynan Street (southern end) à loses evacuation via Main Street to Alexandra Street and/or Yaamba Road.
- Cowap Street and Martin Street à loses evacuation to Alexandra Street and/or Main Street.
- Stawell Court and Miles Street à loses evacuation via Victoria Place to High Street.
- Kirkellen Street and Bernard Street à loses evacuation to Queen Elizabeth Drive.

Building Impact Assessment

Council provided a building database, containing ~6,250 buildings digitised within the Moores Creek modelled area. Of these, ~1,050 buildings contained surveyed data, focussed on Creek flooding extents.

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

- Review of the digitised buildings, to remove erroneous data such as *footpaths*, *building demolished*, *no building* etc.
- Estimation of ~5,200 floor levels and ground levels within the Moores Creek modelled area, for buildings outside Council's surveyed database.
- Classification of ~6,250 buildings within the Moores 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 Moores 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	41 (5)	13 (7)
39.4	61 (10)	22 (11)
18.1	107 (27)	31 (18)
10	149 (42)	41 (24)
5	222 (63)	53 (33)
2	273 (77)	61 (42)
1	512 (198)	98 (75)
0.2	677 (295)	121 (95)
0.05	1064 (557)	162 (136)
-	2166 (1644)	302 (279)

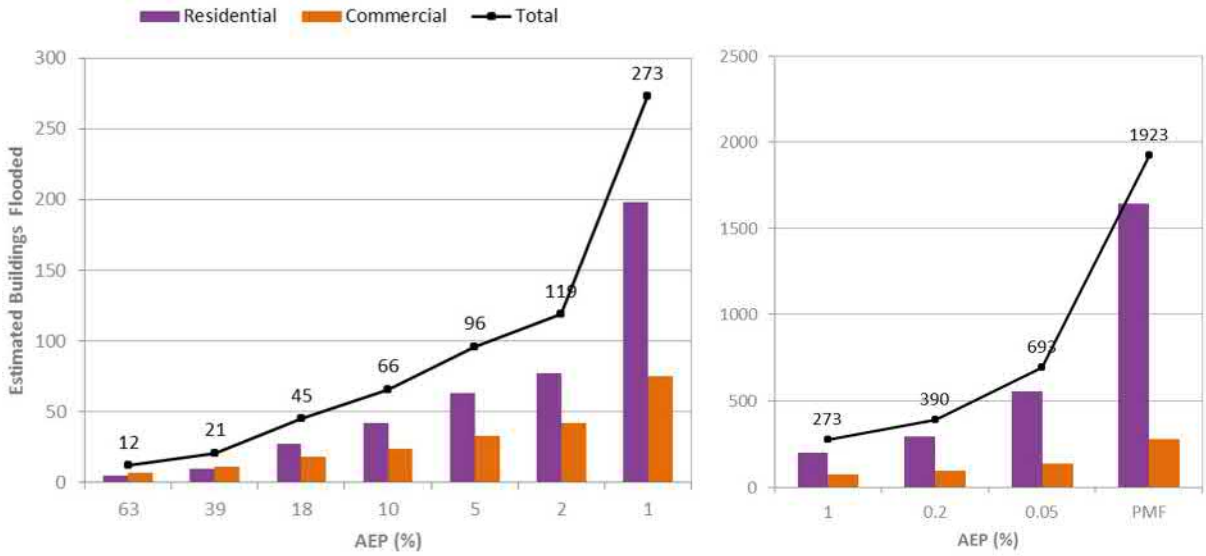

Figure E2 Estimated Buildings with Above Floor Flooding (Number of Buildings)

Figure E3 provides a breakdown of the number of buildings inundated in 'creek' and 'overland flow' areas. The graph confirms that the majority of existing buildings within the catchment (62%) are not inundated up to and including the PMF event. Of the 38% of buildings predicted to experience inundation, approximately half are impacted by overland flow and the other half are impacted by creek inundation.

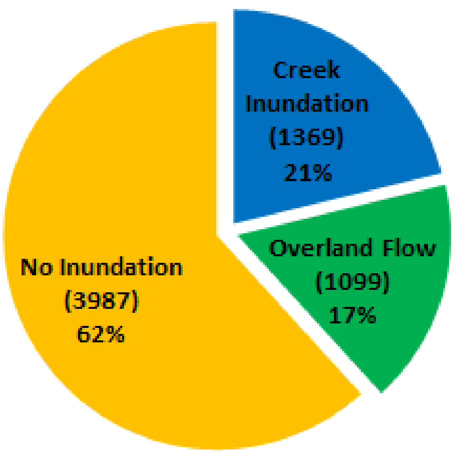

Figure E3 Inundation within Creek and Overland Flow Areas (Number of Buildings)

As shown in Figure E4, median flood depths are generally less than 0.1 metre for each flood event. This indicates that reductions in flood depths of 0.1 metre could significantly reduce overall damage. The figure also shows that a significant number of buildings experience flood depths of 0.3 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.

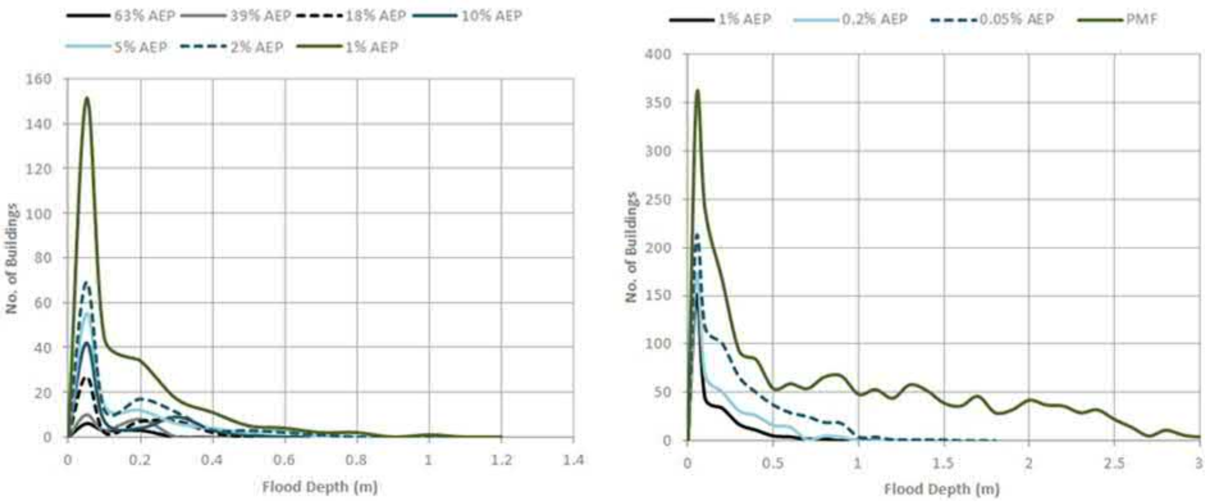

Figure E4 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

Flood Damages Assessment

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

Figure E5 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from $576,000 (1EY flood event) to $429M (PMF event) using the O2 Environmental Damage Curves. Figure E2 shows that 12 buildings are expected to be inundated above floor in the 1EY event, whilst 1,923 buildings are anticipated to be inundated above floor in the PMF event.

Figure E5 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 Moores 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 Moores Creek catchment is estimated to range from approximately $1,501,000 to $1,607,000 per annum.

Figure E6 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, 88% of all buildings exhibit less than $500 damage per annum and produce only 4% of the total damage, infrastructure damage excluded.

88% of damages are associated with less than 5% of all buildings. This demonstrates that a minority of buildings produce the majority of damages.

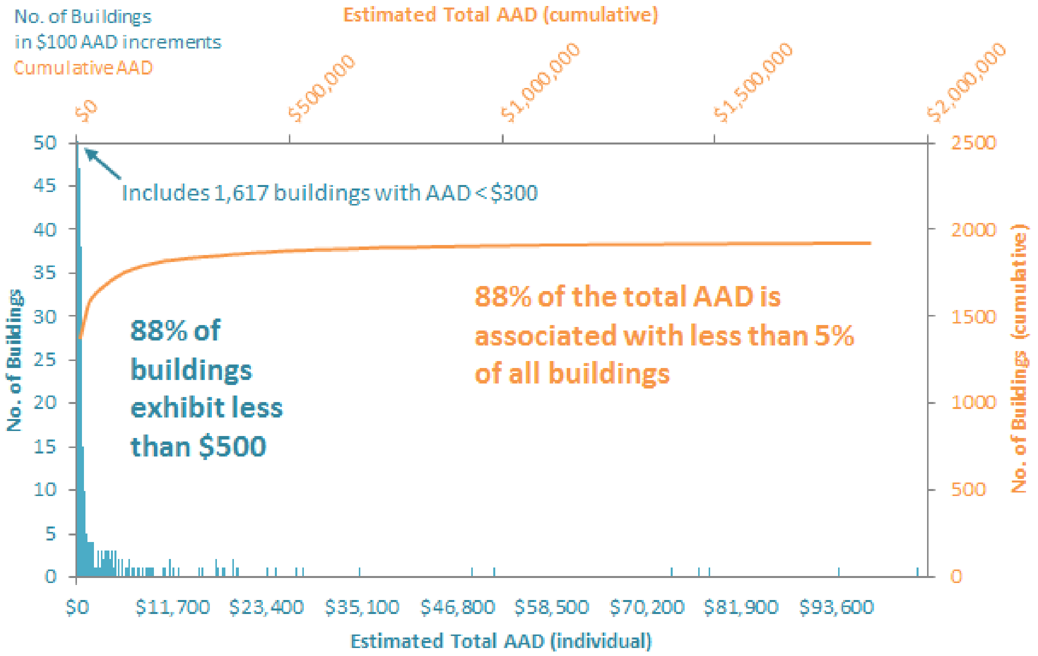

Figure E6 Individual Building vs. Cumulative Total Average Annual Damages

Rainfall Gauge, Maximum Flood Height Gauge and Flood Warning Network

A desktop review of the existing rainfall gauge, maximum flood height gauge and flood warning network yielded the following recommendations/findings for the Moores Creek catchment:

- Additional rain gauges should be installed at NRSTP and SRSTP.
- Additional maximum flood height gauges should be installed at Berserker Street (northern end), Simpson Street (western end), High Street bridge crossing and Macaree Street (western end).
- There is no current flood warning system within the Moores Creek catchment.

Recommendations

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

- Baseline flood mapping (i.e. peak depths, velocities and water surface elevations) provided in this study should be used to update Council’s current Planning Scheme layers, at the next available opportunity.
  - Final post-processing of the GIS flood layers is recommended in accordance with the procedures outlined in the ARR, Data Management and Policy Review (AECOM, 2017).
  - Appropriate freeboard provisions should be included, based on the findings of the sensitivity analyses outlined in this study.
- 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 Moores Creek catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained.
- It is recommended that Council continue to record rainfall and flood heights associated with future Moores 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.
- Updated creek cross sectional survey should be undertaken after major flood events, and prior to undertaking future updates to this study. It is recommended that cross sections be surveyed at the same locations undertaken in this study to assess longer term geomorphic changes, and potential implications to flood behaviour.
- 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 Moores Creek Local Catchment Study, which is the subject of this report.

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

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

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

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

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

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

1.2 Phased Approach

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

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

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

1.3 Phase 1 and 2 Study Objectives

The key objectives of this study are:

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

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

1.4 Report Structure

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

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

The structure of this Volume 1 report is as follows:

- Section 2.0 describes the characteristics of the local catchment, including rainfall distributions, historic events and impacts associated with riverine flood events.
- Section 3.0 outlines the data available for the development and calibration of the hydraulic model.
- Section 4.0 outlines the hydrologic inputs.
- Section 5.0 details the development of the Baseline hydrologic model.
- Section 6.0 details the development of the Baseline hydraulic model.
- Section 7.0 presents the results of the calibration and validation events.
- Section 8.0 presents the Baseline design flood depths, levels, velocities and extents for the study area.
- Section 9.0 presents results of the sensitivity analyses.
- Section 10.0 presents the flood hazard and risk assessment carried out within Phase 2.
- Sections 11.0 and 12.0 summaries the conclusions and outlines recommendations.
- Section 13.0 presents the references used during the study.

1.5 Notes on Flood Frequency

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

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

- 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 $\pm$ 0.15 m on clear, hard surfaces and a horizontal accuracy of $\pm$ 0.45 m.
- Where information gaps existed in the underground drainage network, assumptions were made to fill these gaps using desktop assessment methods.
- Assessment of the probability of coincident local rainfall and Fitzroy River flood events has not been undertaken.
- The hydraulic model has been calibrated to a single historical event, being the local flood event which occurred as a result of TC Marcia in February 2015. The model has been validated to two other local flood events, namely Ex-TC Debbie in March 2017 and Ex-TC Oswald in January 2013.
- 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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- Where information has been supplied by the Client or other external sources, the information has been assumed correct and accurate unless stated otherwise. No responsibility is accepted by AECOM for incorrect or inaccurate information supplied by others.

AR&R Revision Project 15 outlines several fundamental themes which are also particularly relevant:

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

2.0 Study Area Characteristics

2.1 General Description

The Moores Creek catchment covers an area of approximately 30.5 km^2 starting within the upper reaches of Mount Archer National Park and serves as the border between the residential suburbs of Norman Gardens - Frenchville and Park Avenue – Berserker.

The upper Moores Creek catchment varies in elevation from 605 mAHD to 55 mAHD, covering an area of approximately 21.7 km^2. The land use in the upper catchment is predominantly dense bushland with very little urbanisation. Overland runoff from the catchment quickly accumulates within the upper reach of Moores Creek due to the steep natural topography and is conveyed by the creek channel towards North Rockhampton.

Plate 1 Moores Creek Channel near Eichelberger Street

The land use in the mid and lower catchment is predominantly medium density urban residential, with several recreational parks (i.e. Kershaw Gardens), commercial parcels (i.e. Stockland Shopping Centre) and some industrial allotments.

Table 1 Moores Creek catchment Land Uses

Land Use	Proportion
Rural / Mountainous	70%
Urban	30%
· Industrial / Commercial	(10%)
· Residential	(90%)

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

Plate 2 Moores Creek Channel Characteristics – Dense Vegetation (top) / Exposed Rock (bottom)

The moderate to steep longitudinal slopes and smooth rock-laden sections of the channel provides significant hydraulic capacity and can result in high velocities, flood hazard and limited response times for crossings prone to flash flooding. Evidence of the floodwater velocity is observed in the lack of fine-grained soils throughout the creek bed in the upper and mid catchment.

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

Plate 3 Moores Creek Channel at Norman Road Bridge (note exposed piers resulting from 2013 & 2015 events)

2.2 Urban Sub-Catchments

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

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

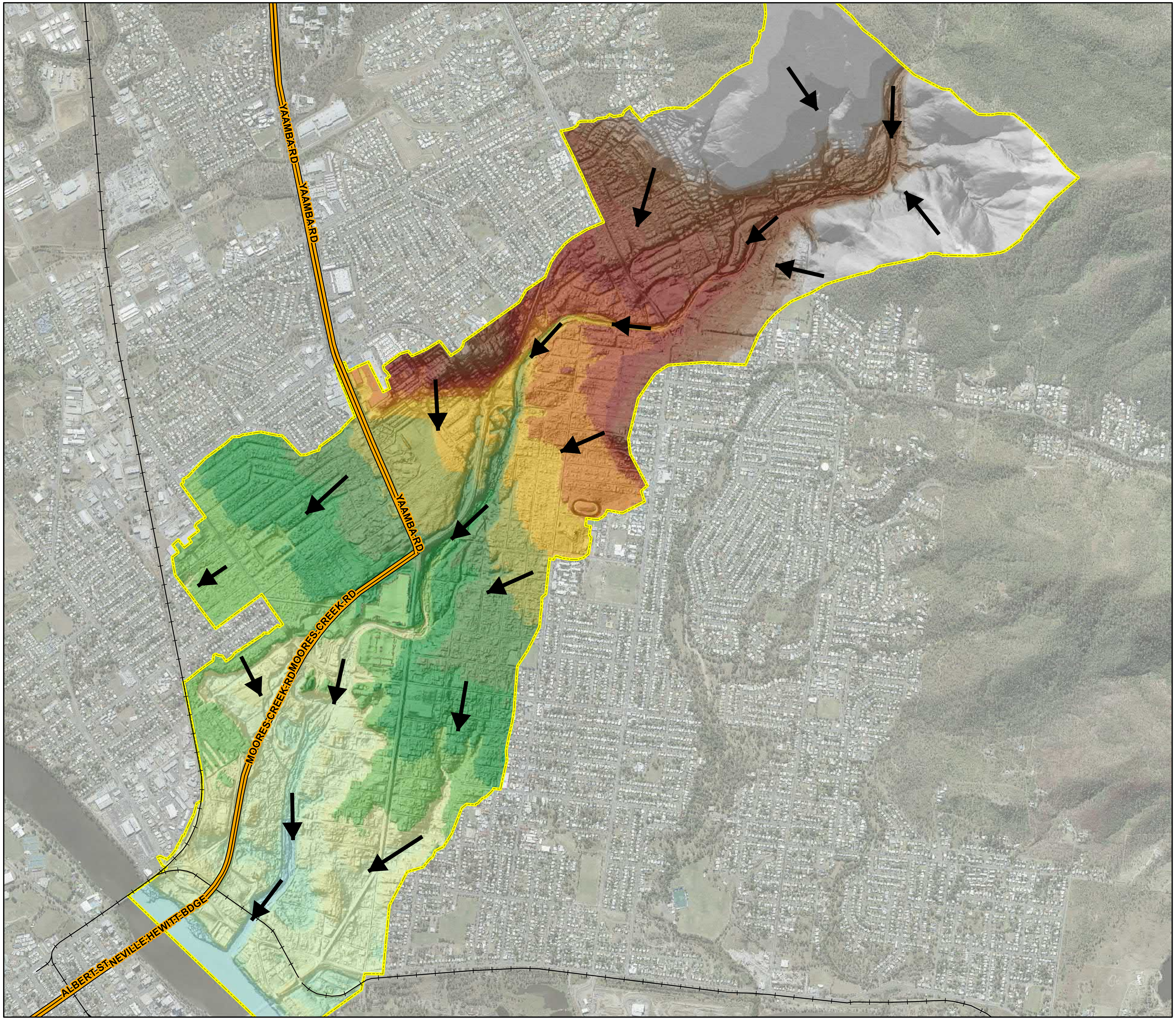
- Norman Road / German Street / Brumm Street;
- Moores Creek Road / Royes Crescent / Rowe Street / Danker Street; and
- Venables Street / Grosskopf Street.

Surface runoff originating from parcels south of Kerrigan Street attenuates along Berserker Street and progresses along Stewart Street, Waterloos Street and Salamanca Street towards Moores Creek. Notable flows are also evident along McColl Street and Yaamba Road under which the subsurface network assists in conveying runoff to Moores Creek.

As natural slopes diminish within the mid-segment of the Moores Creek urban catchment, flow lines are more evident along road corridors, especially those of Sheehy Street and Boland Street which discharge to the detention area upstream of Calder Street. Though the overland flow paths ultimately follow the terrain towards Wackford Street, the underground stormwater infrastructure relieves some of the floodwater via the trunk main along Alexandra Street and joins Moores Creek west of Aquatic Place.

Two natural flow paths are observed southeast of Stockland Shopping Centre which transverse Edington Street and Livingstone Street before joining upstream of Elphinstone Street. The flow path continues south across Burnett Street, Lucas Street and Charles Street before being attenuated by Musgrave Street just south of Armstrong Street. Surface storage on the western edge of Musgrave Street at Kirkellen Street is conveyed alongside the Armstrong Street storage south to the Fitzroy River via subsurface stormwater infrastructure.

Further discussion surrounding the existing flood behaviours during local catchment events are given in Sections 7.0 and 8.0. Figure 1 provides a visual representation of key flow patterns within the study area during local catchment events.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000

Metres

1:20,000
(when printed at A3)

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LEGEND

- 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

Moores Creek Model

Sub-catchment Delineation and Natural Flow Paths

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2017
VERSION:	2

Figure 1

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

2.3 Climate Characteristics

The Moores Creek local catchment is situated at latitude 23º 19’ 54.50” south, about 10 km north of the Tropic of Capricorn. The catchment centroid is about 25 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.

2.4 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.

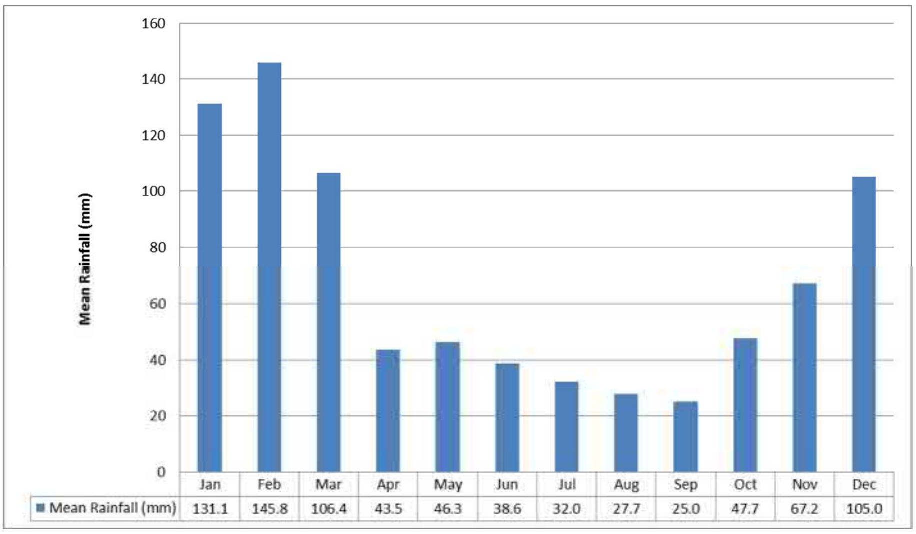


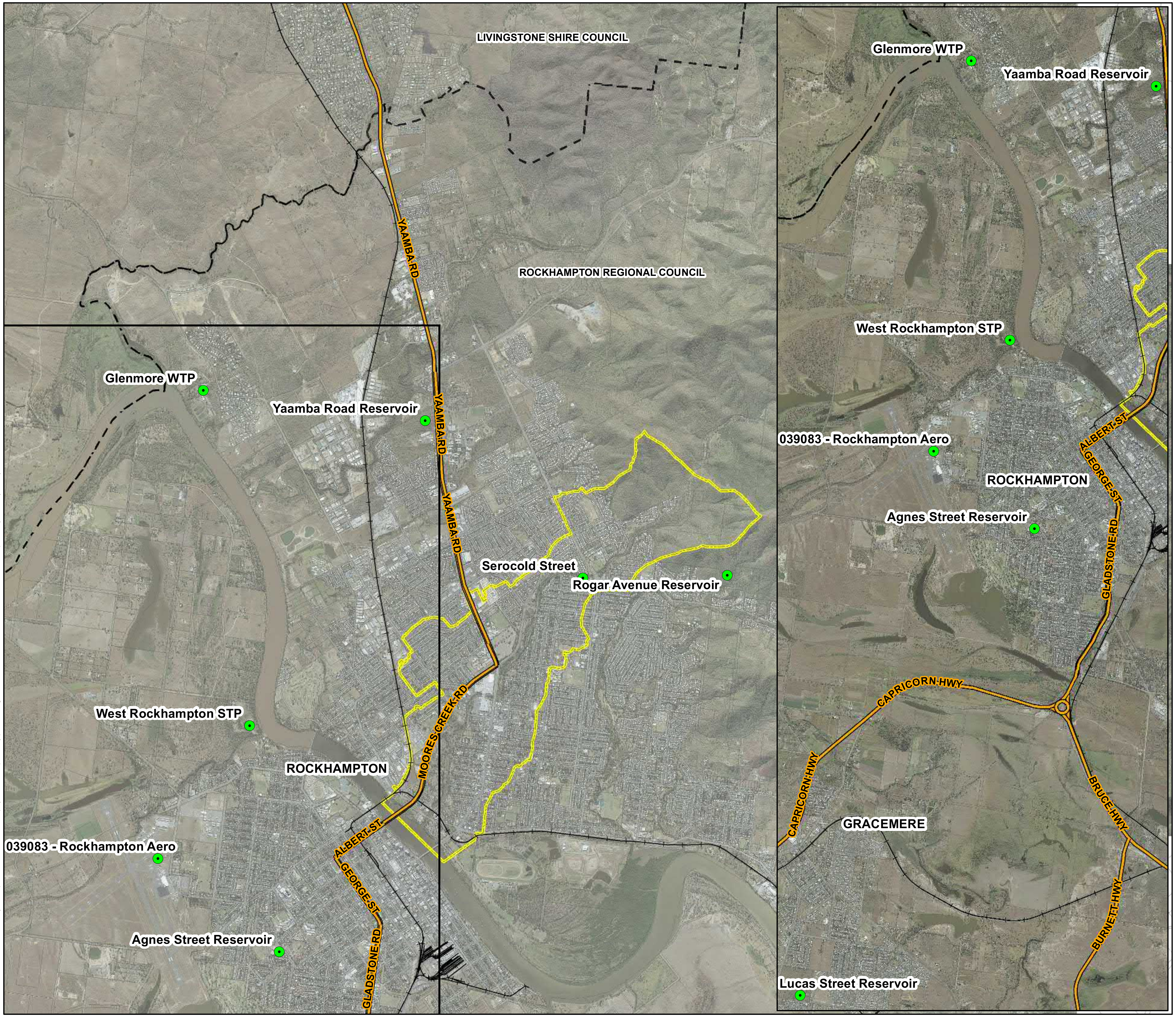
Figure 2 Mean Monthly Rainfall at the Rockhampton Airport Rainfall Station

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.



Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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

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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

Moores Creek Model

Rainfall Gauge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2017
VERSION:	2

Figure 3

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

Of the abovementioned gauges, Serocold Street is located within the upper urban segment of the catchment and is therefore likely to represent the best-estimate of historic rainfall events for the Moores Creek Local Creek model. It is also noted that the Rogar Avenue Reservoir gauge is within close proximity to the mountainous Moores Creek catchment area and is also expected to sufficiently represent rainfall contributing to Moores Creek.

2.5 Historic Local Catchment Events

Significant local rainfall events leading to overland flooding of the Moores 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 (refer to Plate 4) and 2017 events.

Other significant events including the 1991 and 2008 events are noted to have caused flooding in Moores Creek, although have not been assessed within this study. This is due to the lack of available data for the 1991 and 2008 events and the model topography being more representative of 2013, 2015 and 2017 topographic conditions.

Plate 4 February 2015 Event - Stockland Shopping Centre (source: Courier Mail Online)

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

2.6 Riverine Flooding Influence

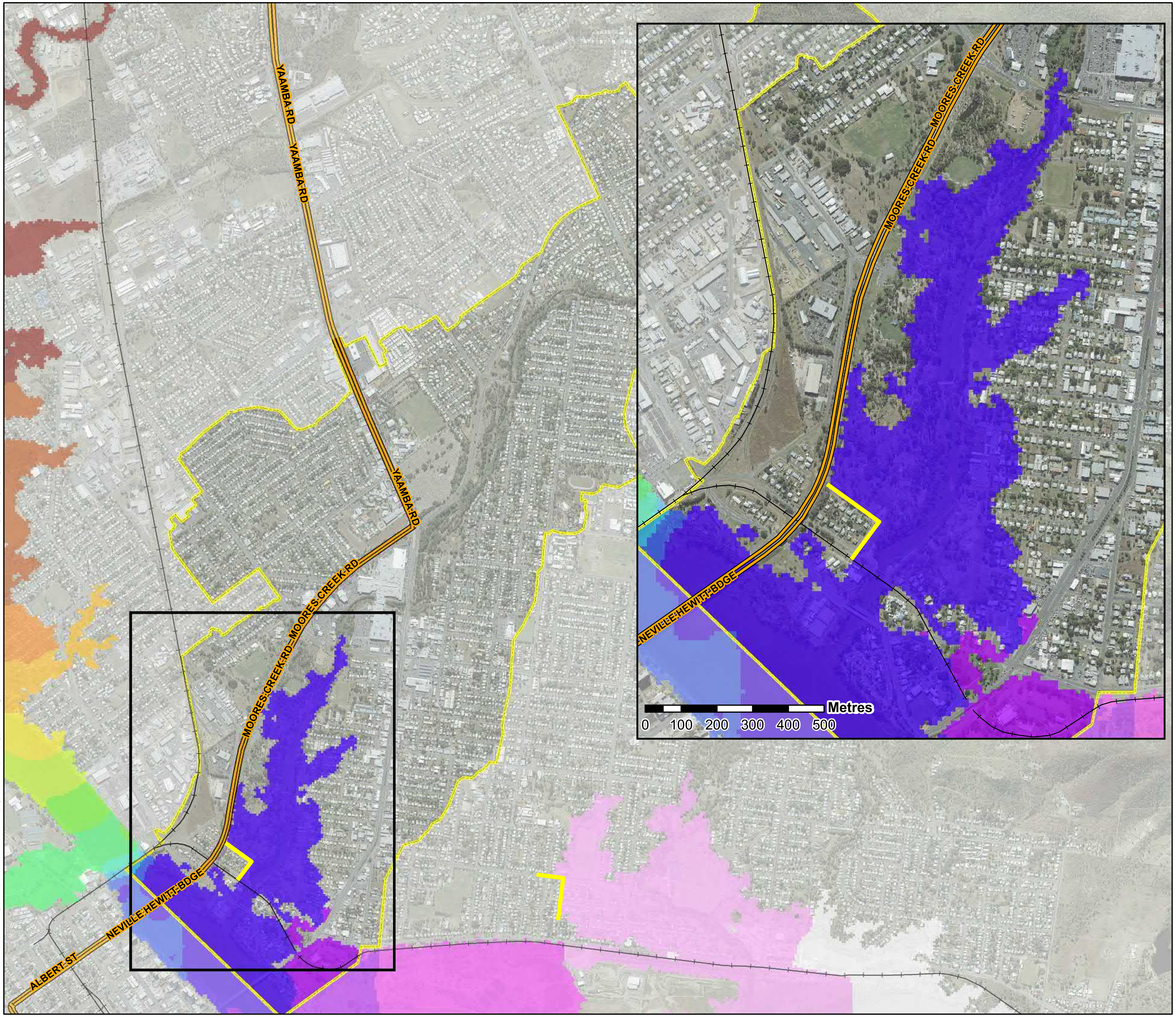
Riverine floods in Rockhampton can result from extended periods of rainfall within the 142,000 km^2 Fitzroy River basin. As peak discharge increases along the Fitzroy River, a key breakout occurs upstream of Rockhampton at the Pink Lily meander, which can result in the inundation of large areas of South Rockhampton. In addition, backwaters effects impact low-lying areas adjacent to creeks on the Northside and Southside of Rockhampton, including Moores 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 Moores Creek catchment become inundated by riverine flood waters in a flood event of this magnitude. Fitzroy River floodwaters extend along Moores Creek through Kershaw Gardens, to immediately upstream of the High Street bridge crossing Low-lying residential lots are also inundated between Musgrave Street and Moores Creek, from the River as far north as Elphinstone 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 9.4.

2.7 Flood Warning System

It is noted that a flood warning and classification system is not presently operated by BoM or RRC for the Moores 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)

- < 7.6
- 7.61 - 7.8
- 7.81 - 8
- 8.01 - 8.2
- 8.21 - 8.4
- 8.41 - 8.6
- 8.61 - 8.8
- 8.81 - 9
- 9.01 - 9.2
- 9.21 - 9.4
- 9.41 - 9.6
- 9.61 - 9.8
- 9.81 - 10
- 10.01 - 10.2
- 10.21 - 10.4
- > 10.41

Flood results are based on riverine catchment events

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

Moores Creek Model
Peak Fitzroy River Flood Heights

1% AEP Riverine Flood Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2017
VERSION:	2

Figure 4

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 4 Riverine Flood Extent.mxd

3.0 Available Data

3.1 General

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

- Previous studies (AECOM 2017, Aurecon 2014, BMT WBM 2014, AECOM 2014).
- Tidal data (MSQ, 2014).
- Topographical data in the form of LiDAR (AAM Pty Ltd, 2016)
- Aerial photography (RRC).
- Stormwater infrastructure network database (RRC).
- Details of hydraulic structures within the study area (RRC).
- Historical rainfall data for the 2013, 2015 and 2017 flood events (RRC).
- Historical flood records for the 2013, 2015 and 2017 flood events (RRC).

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

3.2 Previous Studies

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

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

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

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

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

- Ramsay Creek.
- Limestone Creek.
- Splitters Creek.
- Moores Creek (the focus of this report).
- 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% AEP, 18% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.5% AEP, 0.2% AEP and PMF local catchment flood events. Climate change scenarios were modelled for 20% and 30% increases in rainfall intensity, for the 1% AEP, 0.5% AEP and 0.2% AEP events.

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

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

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

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

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

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

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

- August 2013 à Discussion and review of model recalibration and design event modelling, following initial peer review findings provided by BMT WBM.
- December 2013 à 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 Local Catchments study.

3.2.4 SRFL Hydraulic Model Development (AECOM, 2014)

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

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

3.3 Tidal Data

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

It is noted that tidal data for the 2017 event was not yet available from Maritime Safety Queensland and hence predicted tidal levels for the event were applied.

For design events and sensitivities with no Fitzroy River flooding, tailwater levels used during this investigation were based on the MHWS level at Rockhampton (2.66 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 Moores 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.

Surveyed levels of the following have also been included:

- Stockland Shopping Centre car park survey.
- Creek channel cross-section survey.

Survey of the carparks at Stockland Shopping Centre was obtained from RRC to improve the misrepresentations evident in the filtered LiDAR. Boundaries of the surveyed levels were matched to the adjacent LiDAR DEM.

Surveyed cross-sections were obtained from RRC at locations where the LiDAR was expected to misrepresent the terrain. Comparisons between creek cross sections using the 2009 and 2016 topographic datasets were made to provide an indication of the locations where the creek channel had changed. This comparison was used in conjunction with the latest imagery in order to pinpoint areas which showed both differences in bed level and dense vegetation. These areas were inspected by AECOM staff to confirm the need for survey.

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

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

With this in mind, the 2016 LiDAR 1 m DEM (with inclusion of ground survey) is expected to provide good representation of the creek channel for the March 2017 event. The latest DEM is also expected to be suitable for the 2015 event, although less relevant for the 2013 event.

3.5 Aerial Photography

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

3.6 Stormwater Infrastructure Network Database

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

- All upstream invert levels are at a higher elevation than downstream invert levels.
- Congruent pipe slopes between known inverts.
- No fall across pit structures.
- Minimum depth of cover of 600 mm, where practicable.
- Upstream pipe diameter matched downstream pipe diameter

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

3.7 Hydraulic Structures

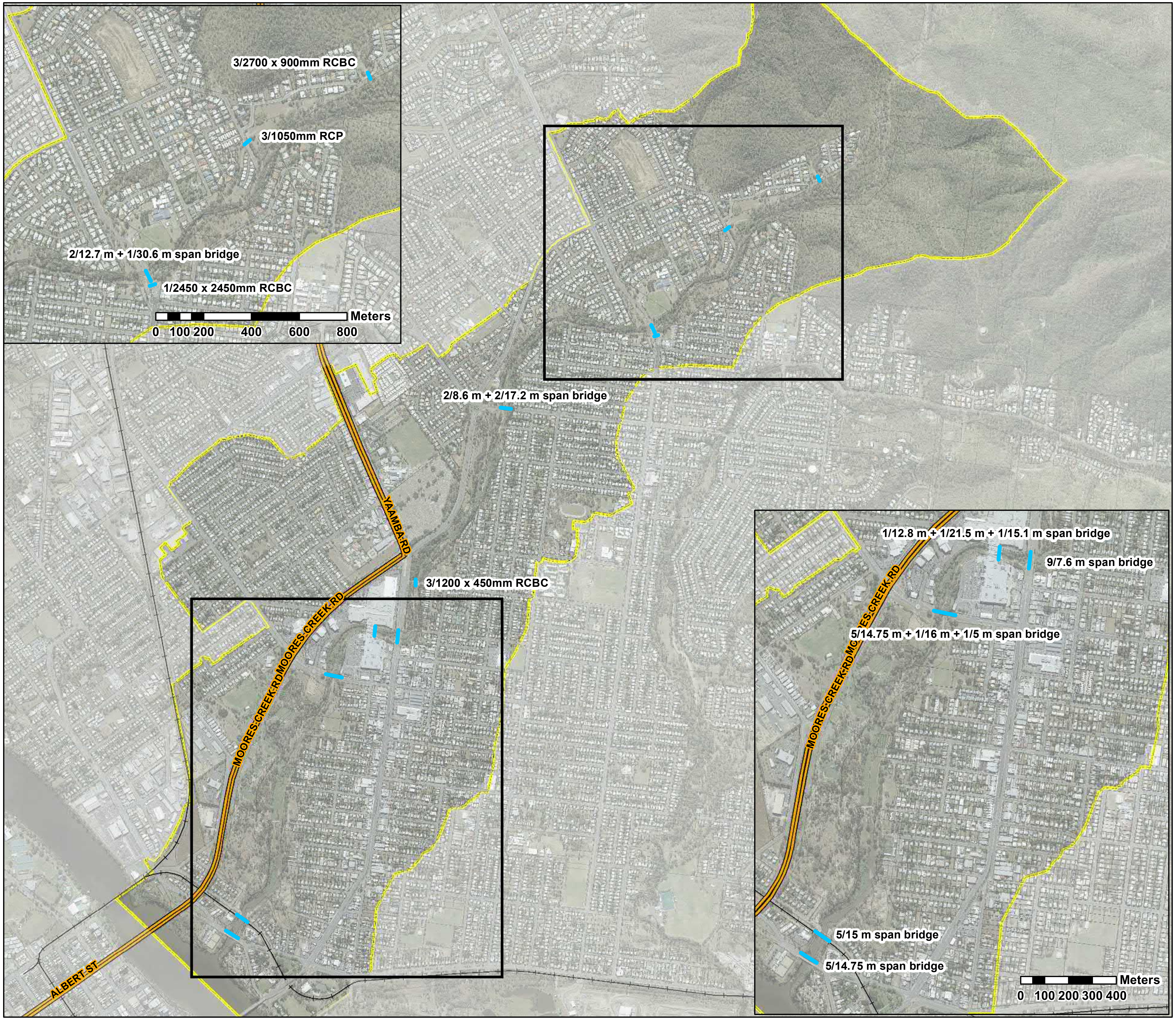
Identification of hydraulic structures associated with the major road / rail crossings within the study area was completed using a combination of council's stormwater infrastructure network database and site visits.

Approximately 34 culverts and 8 bridge structures were identified along Moores Creek. Minor structures which were not expected to convey significant flows or connect key flow paths were not incorporated in the hydraulic model.

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

Table 2 Key Hydraulic Structures Incorporated to the Model

Drainage Structure	Configuration	Model Representation
Bridges		
Norman Road	2/12.7 m + 1/30.6 m span bridge	2D
Kerrigan Street	2/8.6 m + 2/17.2 m span bridge	2D
Musgrave Street	9/7.6 m span bridge	2D
Stockland Shopping Centre	1/12.8 m + 1/21.5 m + 1/15.1 m span bridge	2D
High Street	5/14.75 m + 1/16 m + 1/5 m span bridge	2D
Yeppoon Branch Railway	10/5.5 m + 1/12.5 m span bridge	2D
Glenmore Road	5/15 m span bridge	2D
Glenmore Road Pedestrian	5/14.75 m span bridge	2D
Major Culverts		
Sunset Drive	3/2700 x 900mm RCBC	1D
German Street	3/1050mm RCP	1D
Norman Road	1/2450 x 2450mm RCBC	1D
Musgrave Street – Simpson Street Pedestrian Crossing	3/1200 x 450mm RCBC	1D



Data Sources:

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

Moores Creek Model

Location of Key Hydraulic Structures

PROJECT ID	60534898	**Figure 5**
CREATED BY	maultbyj	
LAST MODIFIED	4/08/2017	
VERSION:	1	

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

3.8 Site Inspection

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

3.9 Historical Rainfall Data

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

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

Table 3 Summary of Rainfall Data used in the Study

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

3.10 Historical Flood Records

3.10.1 Anecdotal Data

Anecdotal flood level data has been collected by RRC following the January 2013 and March 2015 rain events. Generally, observed flood levels and extents were recorded from debris marks, water stains and/or resident observations.

As can be seen from Table 5 many of the heights relate to debris marks, with some indicating the height of remaining debris post flood event. The use of debris presents limitations surrounding the accuracy of the data, noting that the height and extent of debris marks are highly variable depending on the type of debris, flow depth and other external factors such as surface turbulence and man-made waves. As such, each event's dataset has been reviewed in terms of logical locations and recorded levels in an attempt to ensure erroneous and/or unusable records do not skew the assessment and ultimately impact chosen model parameters. Furthermore, larger tolerances are made for older records, especially where the bulk of points correspond to debris marks and extents.

It is understood that the 2013 and 2015 events anecdotal data was collected by RRC using a Real Time Kinematic (RTK) satellite navigation device.

The anecdotal data locations are shown in Figure 6, with the collated data presented in Table 4 and Table 5.

Table 4 Anecdotal Data

Point ID	Easting (m)	Northing (m)	Reported Flood Event	Peak Flood Level (mAHD)
1	246525.3	7414943.4	2015	12.73
2	247349.1	7415984.6	2015	22.74
3	247226.5	7415543.9	2015	20.33
4	247295.6	7415568.2	2015	20.71
5	247027.9	7415129.0	2015	17.59
6	246225.9	7414284.1	2015	7.91
7	246959.1	7414967.0	2013	15.52
8	246878.5	7414972.5	2013	14.64
9	246879.2	7414973.3	2013	14.59
10	246762.3	7414971.5	2013	13.77
11	246732.9	7414979.0	2013	13.27
12	246739.7	7414934.3	2013	13.58
13	246783.4	7414916.2	2013	14.07
14	246956.7	7415171.3	2013	16.01
15	246902.5	7415157.7	2013	16.65[1]
16	246904.8	7415180.2	2013	16.68[1]
17	246906.9	7415205.5	2013	17.45[1]
18	246912.5	7415226.7	2013	17.26[1]
19	246916.2	7415243.4	2013	17.35
20	247006.6	7415241.5	2013	17.02
21	247424.1	7416187.4	2013	23.84
23	247414.3	7416169.9	2013	23.50
24	247387.3	7416060.6	2013	22.66
26	247345.7	7415922.3	2013	20.84
28	247338.2	7415821.0	2013	21.84
29	247356.3	7415970.2	2013	21.70
30	247809.2	7416701.8	2013	28.56
31	248280.7	7416620.6	2013	33.36
32	247322.2	7415680.2	2013	20.70

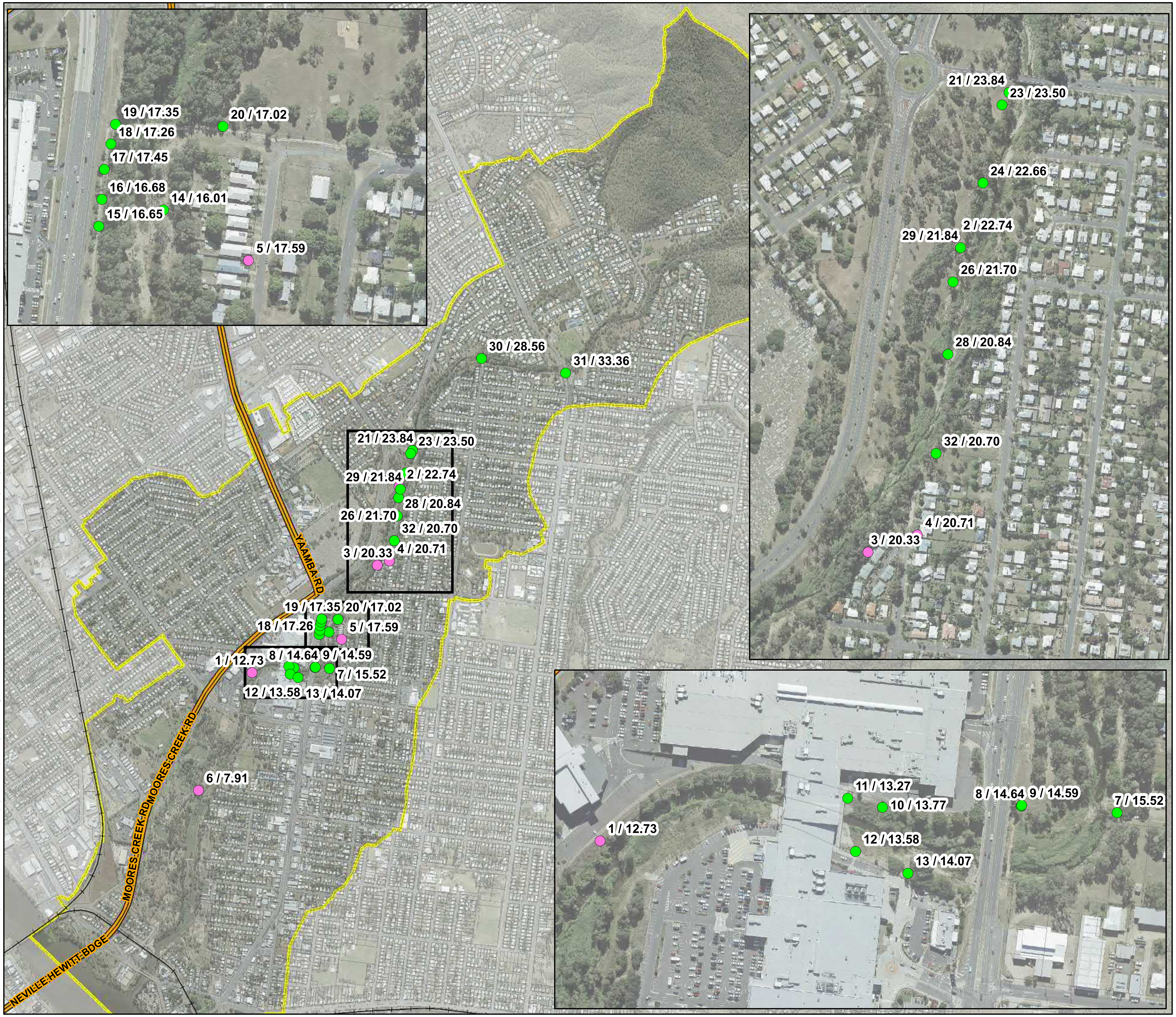
[1] A peak flood level was not supplied as these points represented the debris edge and were used as a check for the flood extent. Peak flood level comparisons were possible by the use of topographic levels at the extent location.

Table 5 Anecdotal Data Comments

Point ID	Comment
1	Debris on ground
2	Debris on ground
3	Mark on ground and resident observation
4	Owners observation
5	Mark on wooden fence and owner observation
6	Mark on wooden fence and owner observation
7	Debris Edge
8	Debris Edge
9	Debris Edge
10	Debris Edge
11	Debris Edge
12	Debris Edge
13	Debris Edge
14	Debris Top Centre
15	Debris Edge[2]
16	Debris Edge[2]
17	Debris Edge[2]
18	Debris Edge[2]
19	Debris Edge
20	Debris Edge
21	Debris Edge
23	Debris Edge
24	Debris Edge
26	Debris Top Centre
28	Debris Top Centre
29	Debris Top Centre
30	Debris Top Centre
31	Debris Edge
32	Debris Top Centre

Given the relative consistency of anecdotal evidence, a blanket ±0.30 m allowance has been adopted for comparison between anecdotal and modelled flood levels for the February 2015 event. A larger tolerance of ±0.50 m has been adopted for the January 2013 event to account for the reduced likelihood of the most recent topographic data representing the channel topographic at the time of the event.

[2] A peak flood level was not supplied as these points represented the debris edge and were used as a check for the flood extent. Peak flood level comparisons were possible by the use of topographic levels at the extent location.



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Anecdotal Data Locations (Label / mAHD)

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

Data Sources:

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

Moores Creek Model

Anecdoatal Records Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2017
VERSION:	2

Figure 6

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure Anecdotal Recorded Data Locations.mxd

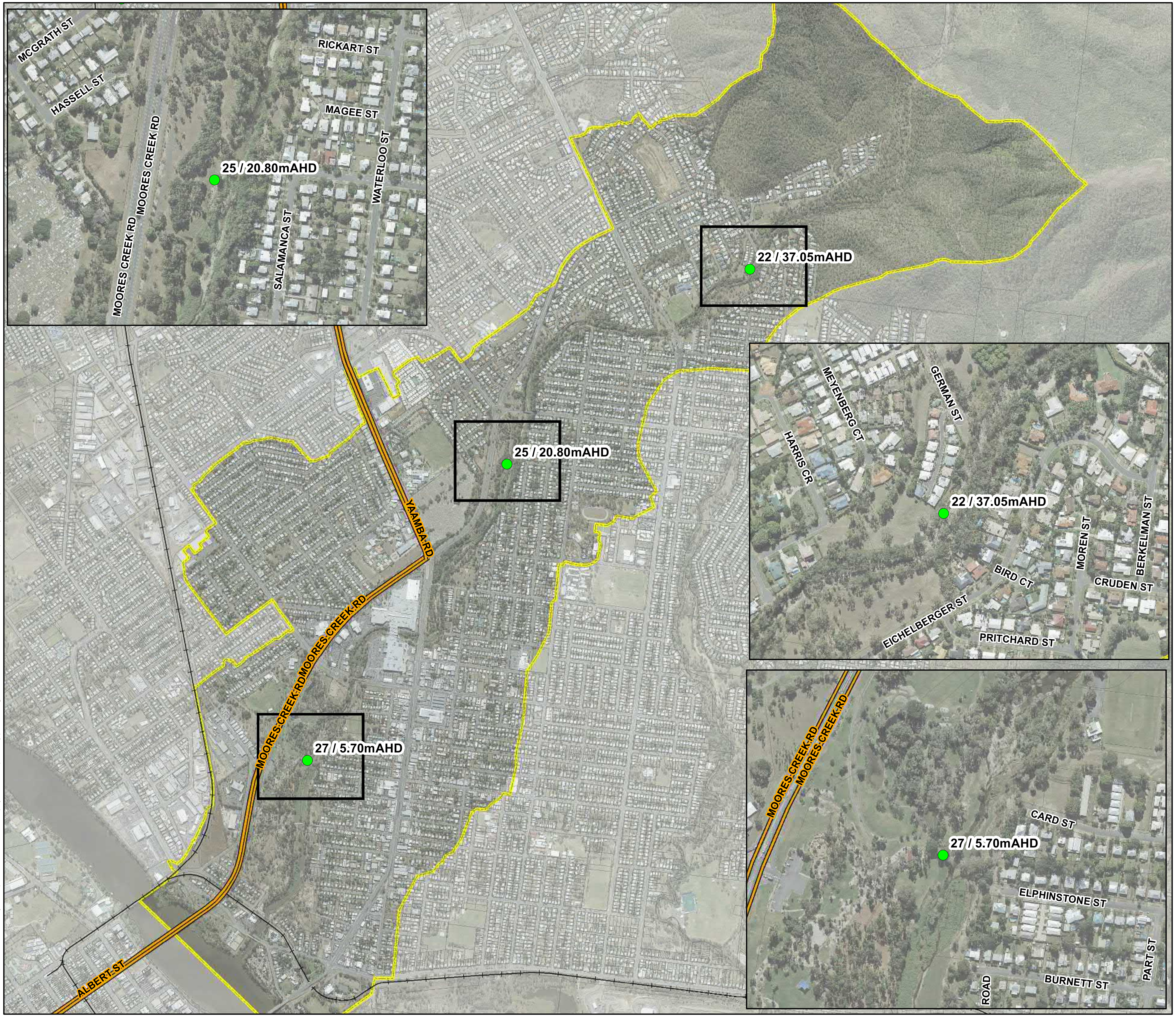
3.10.2 Recorded Data

Recorded data at key locations along Moores Creek were provided by Council for the 2017 event. The data included the locations and maximum readings of gauges shown in Figure 7.

Table 6 presents the spatial locations and peak heights of Council's gauges within the Moores Creek Local Catchment model for the 2017 event. Adopted validation tolerances in the 2017 event were ±0.15 m.

Table 6 Recorded Gauge Data

Gauge Label	Point ID	Easting (m)	Northing (m)	Zero Gauge Level (mAHD)	Peak Gauge Depth (m)
German Street	22	248697.90	7417001.90	37.050	1.19
Moores Creek Road	25	247338.55	7415910.14	20.797	1.16
Moores Creek Road (Kershaw Gardens)	27	246222.22	7414253.12	5.58	1.87



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

Data Sources:

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Imagery (c) 2016 RRC

Moores Creek Model

2017 Recorded Gauge Data Locations

PROJECT ID	60534898
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LAST MODIFIED	13/07/2017
VERSION:	2

Figure 7

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 2017 Recorded Gauge Data.mxd

4.0 Hydrologic Inputs

4.1 Runoff-Routing Approach

4.1.1 Overview

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

Use of the existing XP-RAFTS model was necessary as the hydraulic model did not cover the entire catchment, as can be seen by Figure 8 and therefore the direct rainfall approach could not estimate runoff from the portion of the catchment that was outside the hydraulic model extent.

4.1.2 Model Configuration

The upper Moores 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 14 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 Moores Creek Hydrologic Model (Aurecon, 2014).

4.2 Direct Rainfall Approach

4.2.1 Overview

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

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

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

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

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

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

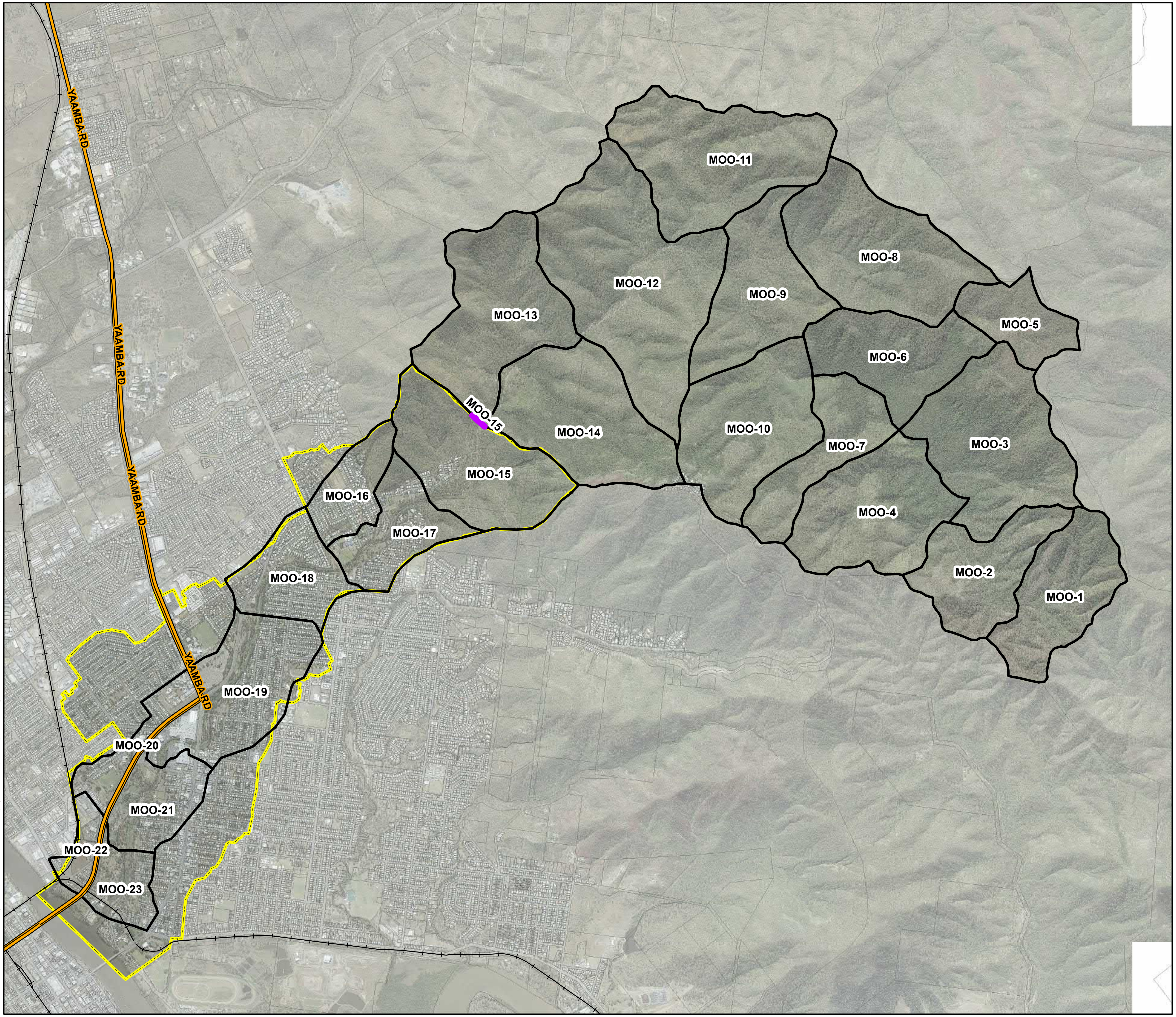
There are also several disadvantages associated with the use of the direct rainfall approach:

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

4.2.2 Approach

Two dimensional rainfall time series for each design storm event were created to represent the local precipitation for the study area. The rainfall excess was calculated by applying initial and continuing losses to the design rainfall to represent infiltration and storage of runoff in surface depressions. Losses chosen for this project are discussed in Section 4.4.5.

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



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

Data Sources:

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

Moores Creek Model

Hydrologic and Hydraulic Model Layout

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LAST MODIFIED	13/07/2017
VERSION:	2

Figure 8

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 8 Hydrologic and Hydraulic Model Layout Map.mxd

4.3 Historic Rainfall Data

Historic rainfall records for the 2013, 2015 and 2017 events were obtained for the Rockhampton Aero pluviograph station located approximately 6 km southwest of the study area. Records at Council-managed gauges were available for the 2015 and 2017 events, although the incremental 2015 data was noted as erroneous due to a suspected power failure. Records from the privately-owned gauge at Serocold Street were obtained by Council for the 2013 and 2015 events. Data was not available from the Serocold Street gauge for the 2017 event. Simulated rainfall plots of the events are included in subsequent sections.

4.3.1 2013 Event – Ex-TC Oswald

Tropical Cyclone Oswald passed over parts of Queensland and New South Wales towards the end of January 2013, reducing in intensity to a tropical low system before reaching Rockhampton. Ex-TC Oswald resulted in significant precipitation over a number of days across Rockhampton, resulting in local catchment flooding followed by a Fitzroy River flood peak of 8.61 m as a result of rainfall in the Fitzroy River catchment. The timeseries of rainfall data from the Serocold Street rainfall gauge is shown in Figure 9.

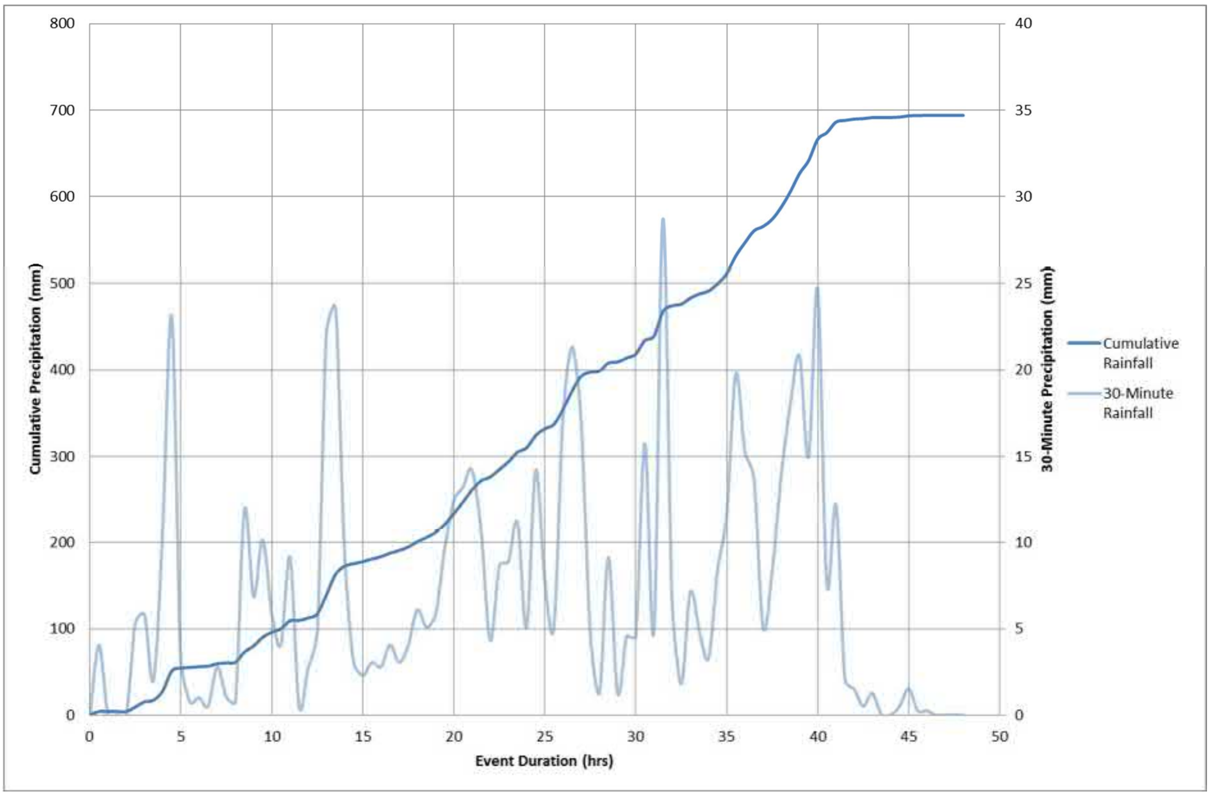


Figure 9 **2013 Event Rainfall (Serocold Street)**

Records from Serocold Street revealed 693.9 mm of rain fell within a 46 hour period. It is noted that the rainfall distribution varied between active gauges during the 2013 event, as detailed below in Table 7. Given that the Serocold Street gauge is situated within the Moores Creek Catchment, the 30-minute rainfall data was used for the 2013 validation event. It is noted that the Serocold Street gauge data was also used in the previous study (Aurecon, 2014).

Table 7 **Summary of 2013 Event Rainfall Data**

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

4.3.2 2015 Event – TC Marcia

Tropical Cyclone Marcia crossed the east coast of Queensland as a category 5 system on the 20th of February, 2015. The system weakened to a category 3 cyclone before delivering a total rainfall depth of 245.0 mm within the North Rockhampton catchment, with the peak 22 hour period totalling 225.0 mm.

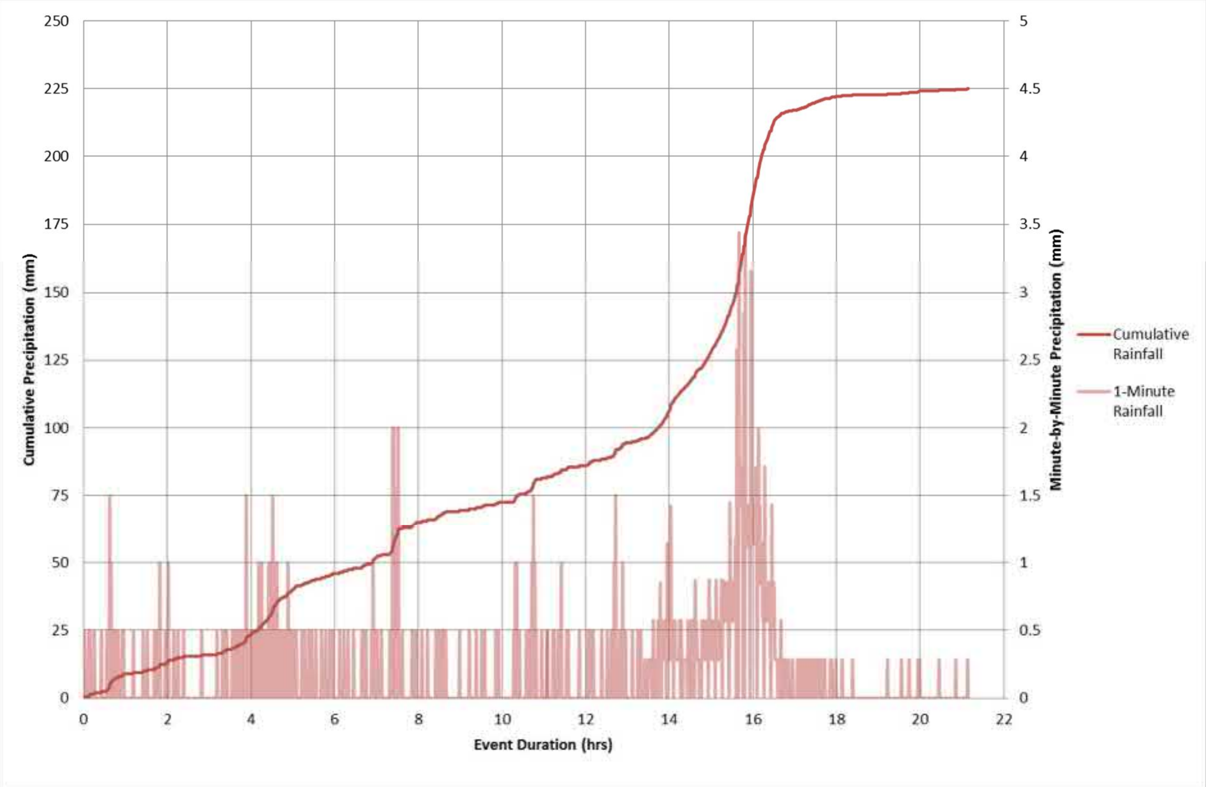


Figure 10 2015 Event Rainfall (Serocold Street)

Rainfall depths recorded at Serocold Street totalled 245 mm, approximately 19% more than that of the Rockhampton Aero. The timeseries of rainfall data at Serocold Street for the 2015 event is shown in Figure 10. A summary of the available rainfall data is included below in Table 8.

Table 8 Summary of 2015 Event Rainfall Data

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

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

4.3.3 2017 Event – Ex-TC Debbie

Ex-TC Debbie moved across the Fitzroy Catchment and Rockhampton in late March, 2017. Significant rainfall triggered a major Fitzroy River flood peak of 8.90m at Rockhampton, preceded by a local catchment flood event as a result of the 308.0 mm of rain across North Rockhampton, measured at the Rogar Avenue Reservoir.

Detailed 1-minute interval records were available for the Rogar Avenue Reservoir gauge. The location of the gauge is approximately 1.5km south east of the Moores Creek catchment and is the closest available source of rainfall data for the Moores Creek catchment. As such, the Rogar Avenue Reservoir rainfall data was adopted. The time series of rainfall data at Rogar Avenue Reservoir for the 2017 event is shown in Figure 11.

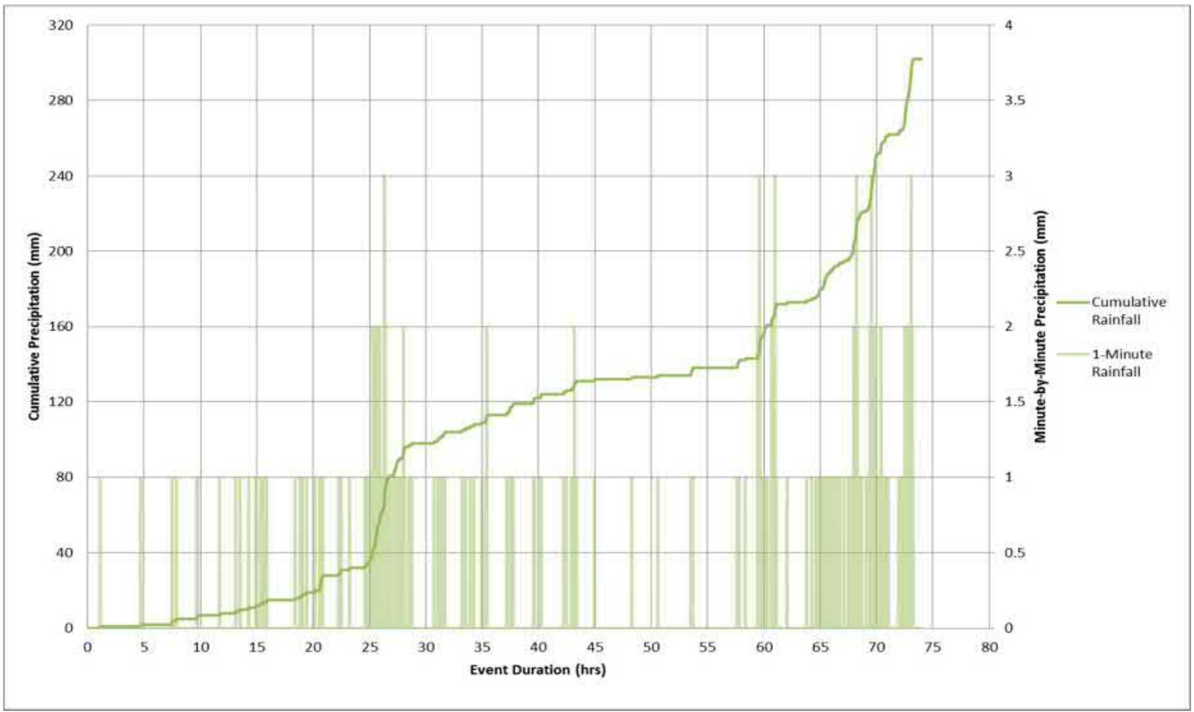


Figure 11 2017 Event Rainfall (Rogar Avenue Reservoir)

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

Table 9 Summary of 2017 Event Rainfall Data

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

Although the Rogar Avenue Reservoir was 65% higher than the surrounding rainfall stations, it is closest rainfall gauge to the Moores Creek catchment. Therefore it was adopted as the rainfall depth for the 2017 validation event.

4.4 Design Rainfall Data

4.4.1 IFD Parameters

Design rainfall data was sourced from the Bureau of Meteorology (BoM) online IFD tool (bom.gov.au/water/designRainfalls/ifd-arr87/index.shtml). IFD parameters required to determine rainfalls for events not previously modelled were sourced using a single set of parameters, derived at the location (150.500 E, 23.300 S). The IFD input data set obtained is shown in Table 10.

Table 10 Adopted IFD Input Parameters

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

Standard techniques from AR&R 87 were used to determine rainfall intensities up to the 12 hour duration for the 1EY (exceedance per year), and 39%, 18%, 10%, 5%, 2% and 1% AEP events. The calculated IFD data is shown in Table 11.

Table 11 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

4.4.2 Temporal Pattern

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

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

4.4.3 Areal Reduction Factors

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

4.4.4 Probable Maximum Precipitation Event

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

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

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

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

- The coastal GSDM Method is applicable as the catchment lies on the Queensland coast.
- The Roughness (R), Elevation Adjustment Factor (EAF) and Moisture Adjustment Factor (MAF) were calculated as 1.0, 1.0 and 0.90 respectively.
- PMP parameters were calculated as shown in Table 12.

Table 12 Adopted PMP Parameters

Duration (hrs)	Rainfall Total (mm)	Rainfall Intensity (mm/hr)
1	390	390
2	580	290
3	690	230

The AEP of the PMP event was calculated as recommended in AR&R (Pilgrim, et al, 1987). For a catchment area of 30.2 km^2, the PMP event is approximately a 1 in 10,000,000 AEP event.

4.4.5 Design Event Rainfall Loss Parameters

Design event losses were established based on the results of the calibration and validation events. The adopted losses vary from a maximum of 15 mm initial loss and 1.0 mm continuing loss for very pervious surfaces to a minimum of 0 mm for both the initial and continuing losses on impermeable materials, depending upon the material. They are presented in Table 47 in Appendix A.

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

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

5.0 Hydrologic Inflows

5.1 Overview

This section of the report discusses the further development of the existing XP-RAFTS hydrologic model previously used to inform the Moores Creek inflows as a part of the Moores Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014). The hydrologic model has been used to estimate inflows at the upstream boundary of this Moores Creek hydraulic model.

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

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

5.2 Hydrologic Inflow Comparison

An overview of the inflows applied to the previous (Aurecon, 2014) and updated model (AECOM, 2017) is provided in Table 13.

Table 13 Hydrologic Inflow Overview

Event (AEP)	Peak Inflows (m^3/s) (Node MOO-15)*		Difference
	Previous Study	This Study	
1EY	-	61	-
39%	87	95	9.2%
18%	-	141	-
10%	175	172	-1.7%
5%	230	214	-7.0%
2%	290	266	-8.3%
1%	338	312	-7.7%
0.2%	550	500	-9.1%
0.05%	-	652	-
PMF	1772	1757	-0.8%
January 2013	212	221	4.2%
February 2015	-	293	-
March 2017	-	127	-

* Note: Sub-catchment node reference as per Figure 8.

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

A lower total rainfall loss was applied for events smaller than a 10% AEP event, which is resembled in the 39% AEP inflows being 9.2% higher. In contrast, a higher total loss was applied to events larger than 18% AEP, resulting in lesser flows being applied to the model boundary, especially for events for 5% AEP and larger.

Given the lower value adopted of continuing loss and long duration of the event, the inflows applied to the January 2013 event were approximately 4% higher than those from the previous study.

6.0 Hydraulic Model Development

6.1 Overview

This section of the report discusses the further development of the existing hydraulic model previously used to assess creek flooding in the Moores Creek Local Catchment (Aurecon, 2014). The updated model has been used to assess key local catchment flood behaviours and deficiencies in the existing stormwater network leading to increased flood risk. These assessments will assist in the development of mitigation options in Phase 3.

In order to improve the representation of key hydraulic features, the model resolution was improved from a 5 m to 3 m grid. A time step of 1.0 second was adopted (2.0 second previously), giving an effective runtime of approximately 3.6 real-time hours to 1 simulation hour.

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

6.2 Hydraulic Model Parameters

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

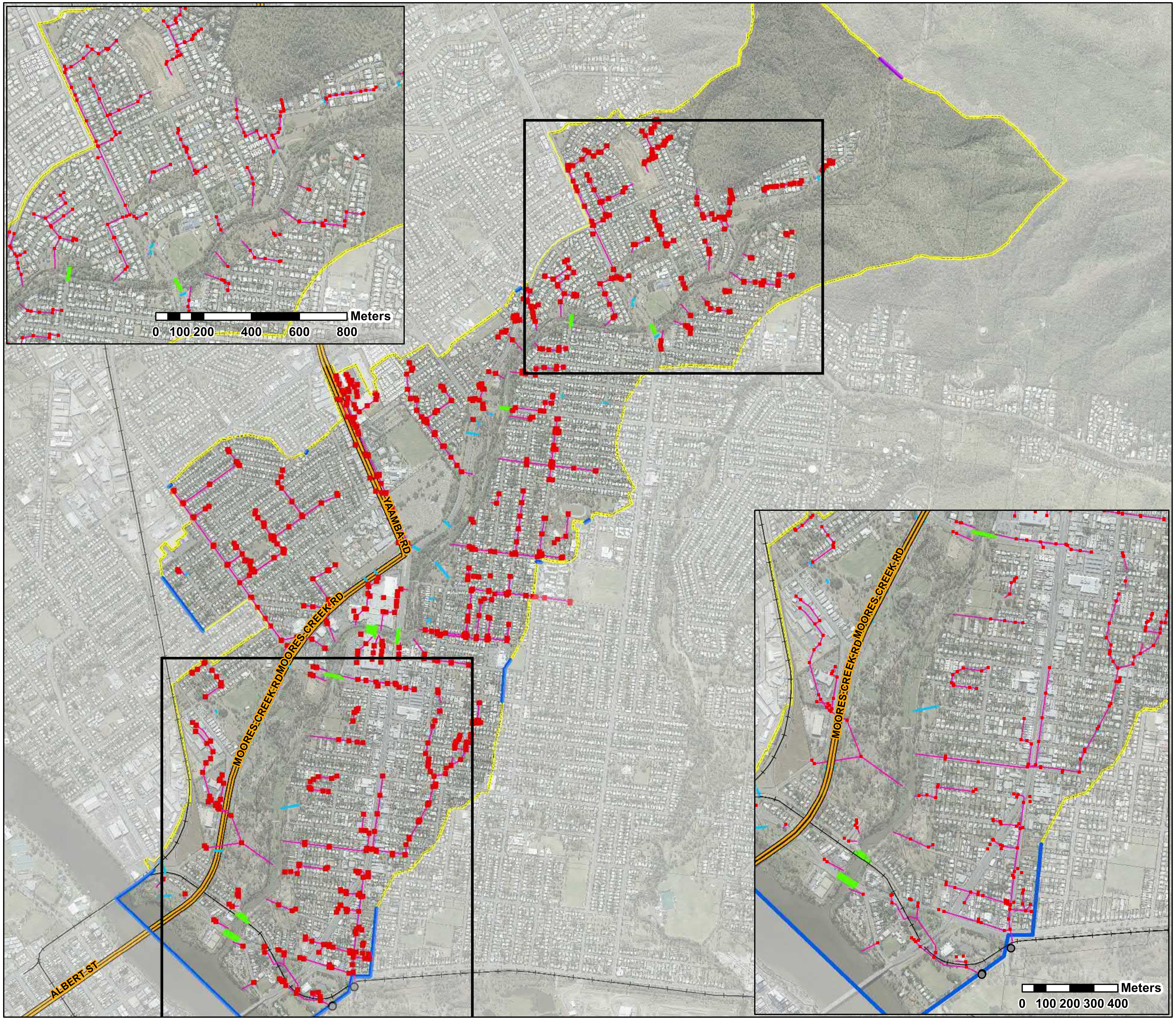
An overview of the model setup and key parameters for the model is provided in Table 14.

Table 14 Hydraulic Model Setup Overview

Parameter	Moores Creek Local Catchment Model
Completion Date	June 2017
AEP's Assessed	1EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF
Hydrologic Modelling	XP-RAFTS Inflow and Direct Rainfall Approach
IFD Input Parameters	Refer to Section 4.4.1
Hydraulic Model Software	TUFLOW version 2016-03-AE-w64-iDP
Grid Size	3 m
DEM (year flown)	2016
Roughness	Spatially varying and depth varying standard values – consistent with Moores Creek Model and Moores Creek Hydrologic and Hydraulic Modelling Report (Aurecon, 2014).
Eddy Viscosity	Smagorinsky
Model Calibration	Calibrated to 2015 event, verified to 2013 and 2017 events.
Downstream Model Boundary	1 inflow boundary along the north-eastern boundary, 16 rating curve boundary conditions along the north-western, south-western and eastern boundaries for all events, 1 tidal boundary on the south-western boundary.
Timesteps	1 second (3 m 2D) and 0.5 second (1D)
Wetting and Drying Depths	Cell centre 0.0002 m
Sensitivity Testing	Stormwater Infrastructure Blockage, ±15% Hydraulic Roughness, Riverine and Local Catchment Coincident Event, Inlet Structure Dimensions and Climate Change

6.3 Model Setup

A visual representation of the model setup including the code, boundaries, 1D network and hydraulic roughness delineation are included as Figure 12 and Figure 13 to supplement the detailed updates outlined in Appendix A.



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- Pit Inlet
- 1D Outflow Boundary Condition
- Pipe
- Culverts
- Inflow Boundary Conditions
- Outflow Boundary Conditions
- Layered Flow Constrictions
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

Moores Creek Model

Model Setup and 1D Network Map

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LAST MODIFIED	14/07/2017
VERSION:	2

Figure 12

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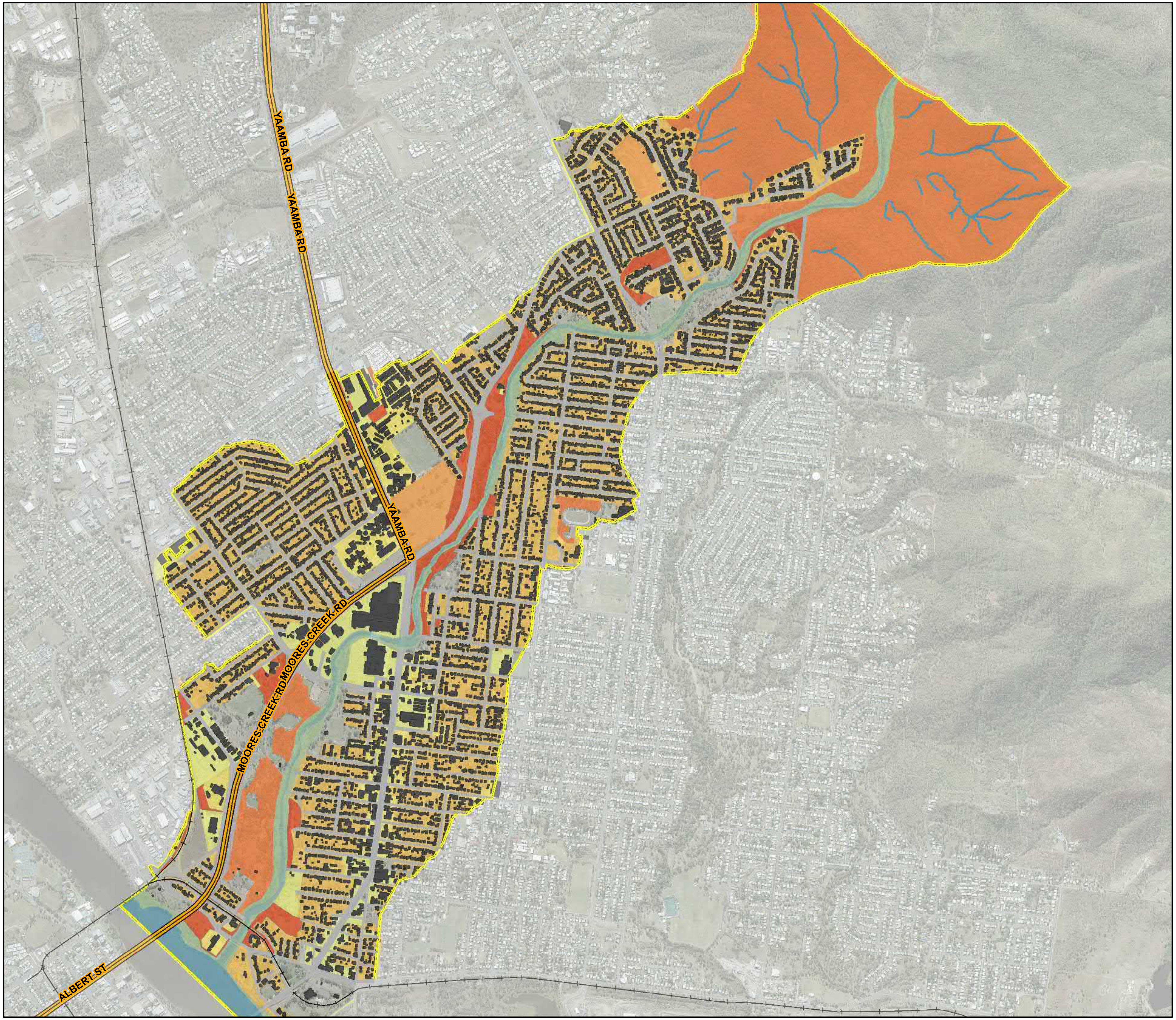

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LEGEND

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

Data Sources:

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

Moores Creek Model

Hydraulic Roughness Delineation

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Figure 13

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 13 Hydraulic Roughness Delineation.mxd

7.0 Calibration and Validation

7.1 Adopted Methodology

Calibration and validation of the TUFLOW model was undertaken by simulating historical flood events and comparing the model results to recorded / anecdotal data provided by Council. The model was calibrated to the 2015 flood event, during which time the 2017 event occurred. The model parameters have been varied to match anecdotal data by varying roughness, initial losses, continuing losses and stormwater infrastructure assumptions (roughness and blockage). The model has been further verified to the 2017 and 2013 events. Exclusion of the pre-burst rainfall was adopted in order to make model runtimes more manageable.

Varying tidal levels were applied to the 2013 and 2015 based on historic records, with the 2017 event utilising predicted tidal levels. Surveyed peak flood levels are generally based on flood debris marks or reported flood marks and are of varying levels of accuracy; therefore they are less reliable than recorded gauge levels. Adopted calibration tolerances for anecdotal records have been adopted as ±0.30 m.

7.2 Calibration to the 2015 Event

The 2015 rainfall gauge data at the Serocold Street gauge was applied to the TUFLOW model. Given the minor variability of rainfall across gauges, a 10% increase to rainfall intensity within the mountainous portion of the catchment was applied in order to account for orographic effects. The maximum water surface elevations were extracted from the hydraulic model and compared to anecdotal peak flood levels provided by RRC.

The following model configurations have been simulated for the 2015 event:

Table 15 February 2015 Event Calibration Model Iterations Summary

Model Iteration No.	Initial Loss (mm)	Continuing Loss (mm)	Other Changes
E001	0	1.0	-
E301	0	1.0	Improved implementation of channel survey across vegetated areas. Minor overland flow path amendment at Creek St based on site inspection. Verification of bridge losses to detailed 1D HEC-RAS models.
E401	0	1.0	Improved roughness delineation within channel. Minor topographic adjustments near vegetation fringes based on site visit. Additional 10% rainfall applied to mountainous sub-catchment based on a review of surrounding rainfall gauge records.

Peak flood levels were recorded at six locations within the Moores Creek corridor. The peak heights predicted within the above simulations were compared to the heights at the recorded locations and shown below in Table 16.

Table 16 February 2015 Calibration Events Results Comparison

Point ID	Recorded Level (mAHD)	Peak Flood Height (mAHD)		
		E001	E301	E401
1	12.73	12.42	12.52	12.68
2	22.74	22.63	22.71	22.71
3	20.33	20.26	20.27	20.32
4	20.71	20.42	20.48	20.58
5	17.59	17.19	17.20	17.21
6	7.91	7.99	8.05	8.06

Results from the final **E401** simulations are presented in Table 17.

Table 17 February 2015 E401 Calibration Event Results

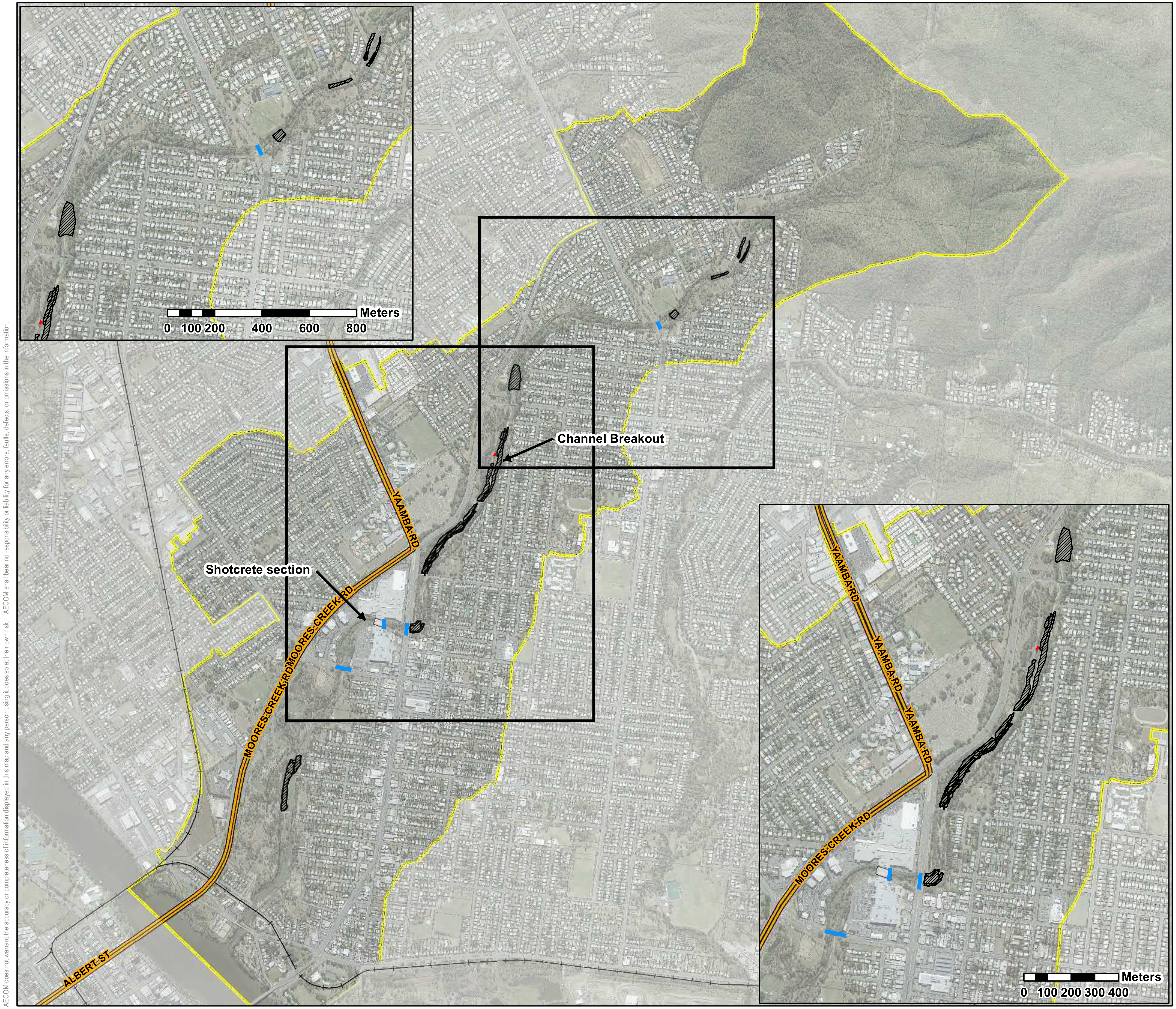
Point ID	Recorded Level (mAHD)	Peak Flood Height (mAHD)			Difference (m)	Tolerance
		E401	Lower Tolerance	Upper Tolerance		
1	12.73	12.68	12.43	13.03	-0.05	In tolerance
2	22.74	22.71	22.44	23.04	-0.03	In tolerance
3	20.33	20.32	20.03	20.63	-0.01	In tolerance
4	20.71	20.58	20.41	21.01	-0.13	In tolerance
5	17.59	17.21	17.29	17.89	-0.38	Below tolerance
6	7.91	8.06	7.61	8.21	0.15	In tolerance

Key outcomes from the final calibration are:

- Of the 6 recorded points, 5 were within the corresponding tolerances with 1 below tolerance.
- The average difference between modelled and recorded levels was calculated to be -0.08 m with standard deviation of 0.16 m.
- The modelled extents match well with the spatial distribution of the recorded flood heights.
- It is noted that Point 5 (simulated to be 0.38 m below the recorded level) is the result of an overland flow path (i.e. not related to Moores Creek flooding). The overland flow path is primary serviced by sub-grid features. Although modifications were made to the model based on site inspections, the larger scale of the model meant achieving a within-tolerance comparison at this location was not practical.

The adopted calibration settings are geographically presented in Figure 14 and relate to scenario E401 outlined and discussed above.

Calibration results are also represented in long section profiles in Appendix C. The results from the 2015 calibration are shown in sketches SK-MC-03 and SK-MC-04. The water surface profile shows a reasonably consistent hydraulic gradient with minor hydraulic jumps associated with topographic features, such as the raised pedestrian floodway at chainage 4,575m. Hydraulic losses at major road crossings such as Norman Road (chainage 2,250m) also create slight changes in the hydraulic gradient.



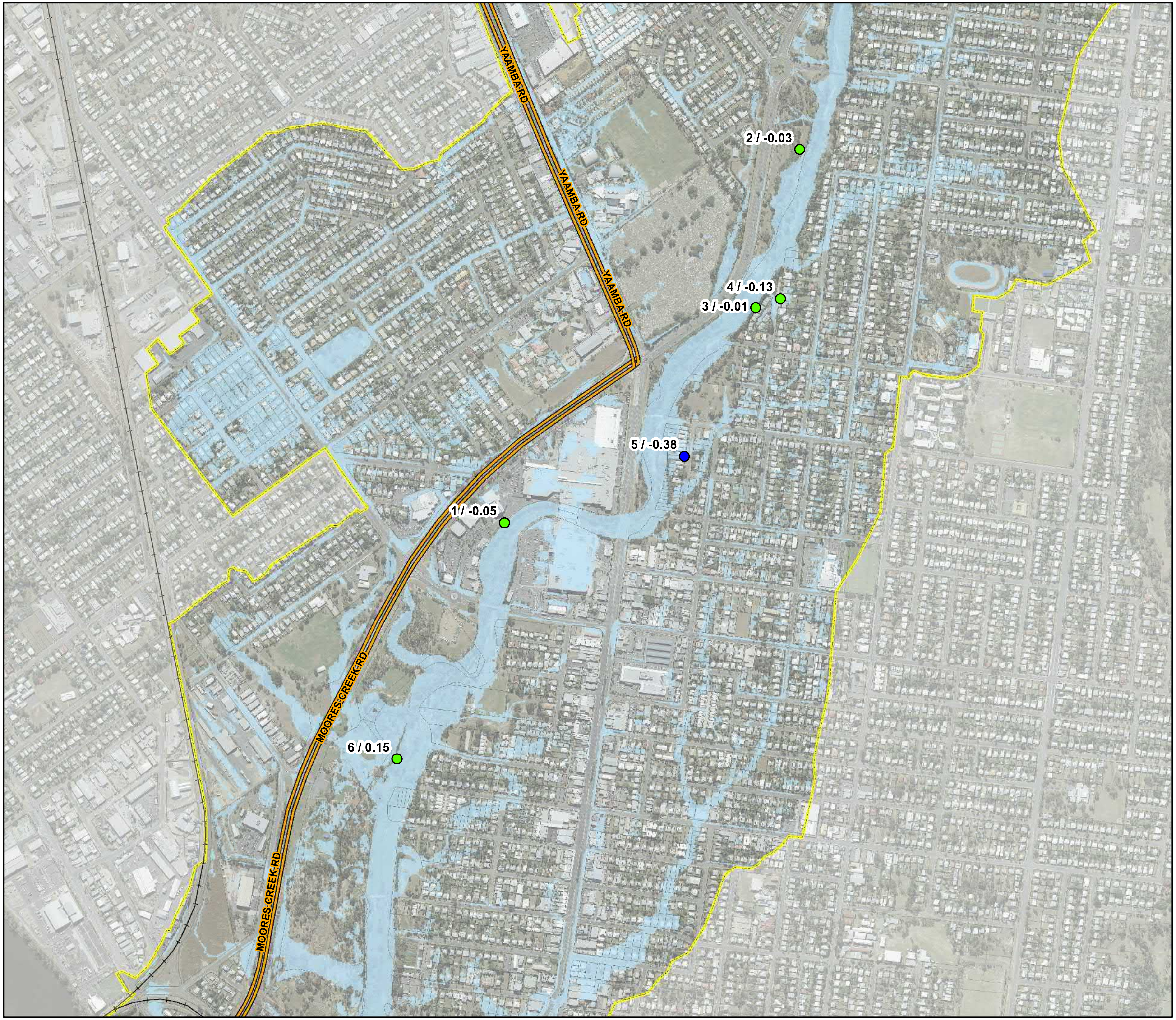
Moores Creek Model

Model Changes for the Final 2015 Calibration Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	14/07/2017
VERSION:	2

Figure 14

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 14 Infrastructure Changes for the Final 2015 Calibration Event.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500
Metres

1:10,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

Difference (m)

- < -0.30 (Below tolerance)
- -0.30 - -0.15 (In tolerance, low)
- -0.15 - 0.15 (In tolerance)
- 0.15 - 0.30 (In tolerance, high)
- > 0.30 (Above tolerance)
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- February 2015 Modelled 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
$100m^2$ Min. Area

Moores Creek Model

February 2015 Event Calibration Results

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 15

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 15 2015 Calibration Results.mxd

7.3 Validation to the 2017 Event

During calibration of the model to the 2015 event, Ex-TC Debbie occurred resulting in a moderate rainfall event in Rockhampton during late March 2017. Council supplied recorded gauge data at three points within the model which have been compared to the peak flood heights predicted during the simulation.

Given the variability of rainfall between urban gauges and Rogar Avenue Reservoir, a 30% increase to rainfall intensity within the mountainous portion of the catchment was applied in order to account for orographic effects.

In order to undertake the validation, some adjustment had to be made to the **E401** model. These are summarised below in Table 18.

Table 18 March 2017 Event Validation Event Model Iteration Summary

Model Iteration No.	Initial Loss (mm)	Continuing Loss (mm)	Other Changes
E401	0	1.0	As shown in Table 15, with additional 30% rainfall applied to external mountainous catchment.

The adjustments to the initial and continuing losses are due to the pre burst rainfall being removed from the hyetograph to reduce modelling times, the catchment is assumed to be saturated by the pre burst rainfall, and therefore no initial losses need to be applied during the validation event.

Peak flood levels were gauged at three locations within the Moores Creek corridor. The peak heights predicted within the above simulations were compared to the heights at the recorded locations and shown below in Table 19.

Table 19 March 2017 Validation Results Analysis

Point ID	Anecdotal Level (mAHD)	Peak Height (mAHD)			Difference (m)	Tolerance
		E401	Lower Tolerance	Upper Tolerance		
22	38.24	38.06	38.09	38.39	-0.18	Below tolerance
25	21.96	21.74	21.81	22.11	-0.21	Below tolerance
27	7.45	7.35	7.30	7.60	-0.10	In tolerance, low

Analysis of the validation results reveals the following:

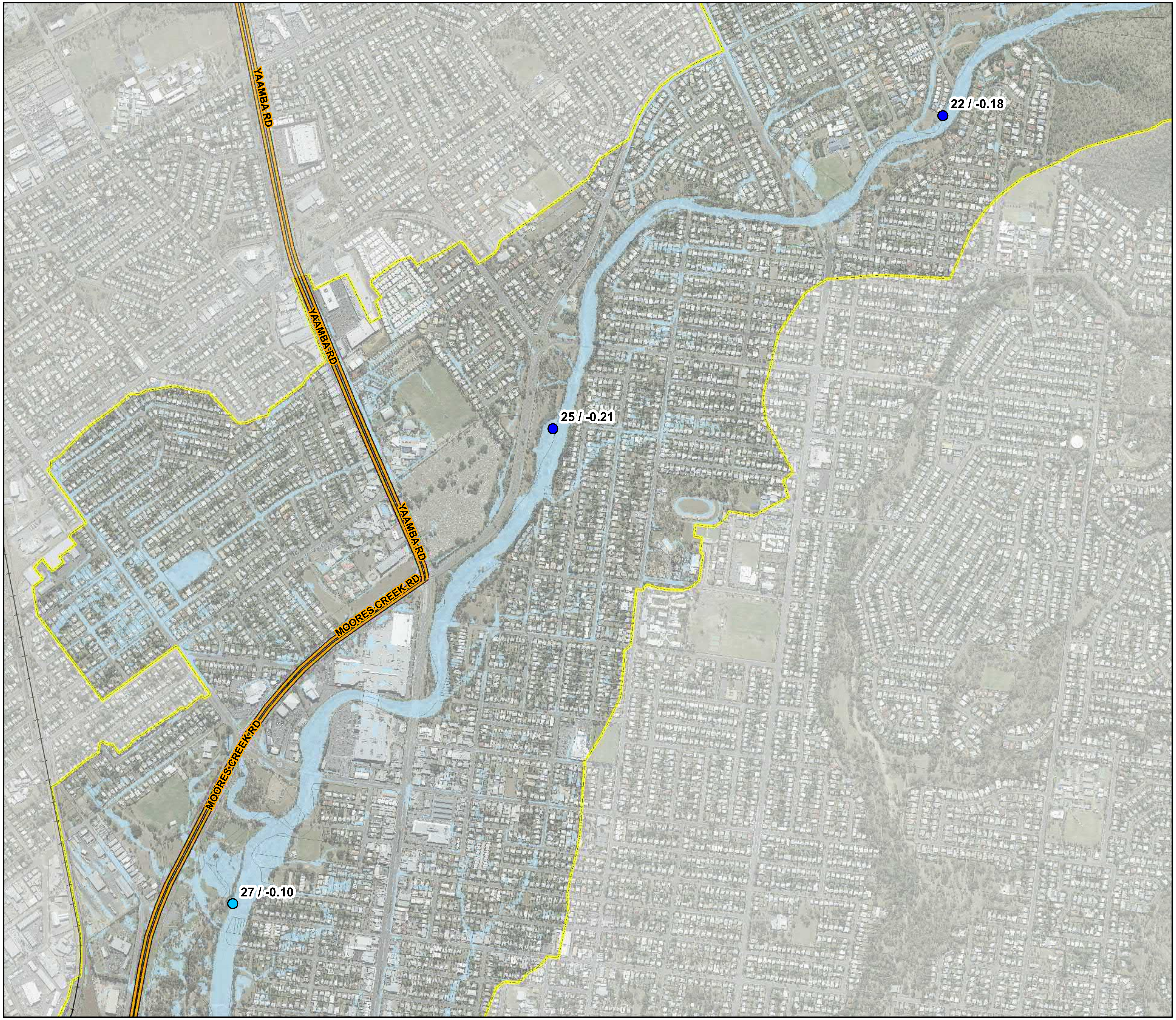
- Of the 3 recorded points, 1 was within the corresponding tolerances with 2 below the tolerance of ±0.15 m.
- The average difference between modelled and recorded levels was calculated to be -0.16 m with standard deviation of 0.05 m.

Discrepancies identified between the modelled and recorded levels are assumed to be a result of three key factors, these being:

- Vegetation density at the time of the flood event;
- Variation in the spatial distribution of rainfall across the rural and urban components of the catchment; and
- Changes in channel cross-section between the LiDAR date of capture and the date of the event.

Considering the stringent tolerances, lack of rainfall data across the catchment and increasing effect of vegetation on events of smaller magnitude, the 2017 model simulation serves as a suitable validation for the calibrated model.

The 2017 calibration results are also represented in long section profiles, provided as SK-MC-05 and SK-MC-06 in Appendix C. The water surface profile shown in the long sections indicates a consistent hydraulic gradient with minor changes in energy slopes at points of topographic variance such as road crossings. The proximity of the water surface profile to the calibration point tolerances shown on the drawing reflect the validation results summarised in Table 19.



DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500
Metres

1:12,500
(when printed at A3)

www.aecom.com

LEGEND

Difference (m)

- < -0.15 (Below tolerance)
- -0.15 - -0.10 (In tolerance, low)
- -0.10 - 0.10 (In tolerance)
- 0.10 - 0.15 (In tolerance, high)
- > 0.15 (Above tolerance)
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- March 2017 Modelled 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

Moores Creek Model

March 2017 Validation Results

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 16

7.4 Validation to the 2013 Event

In order to verify the model to the rainfall data for Ex-TC Oswald in January 2013 was obtained from the Serocold Street site. Council obtained anecdotal peak water elevations from residents in known hotspots, the limitations of this data have been discussed above in Section 3.10.1, and these heights have been compared to the peak flood heights predicted during the simulation. It is noted that some of the anecdotal heights are inconsistent with the surrounding data points.

In order to undertake the validation, some adjustment had to be made to the **E401** model. These are summarised below in Table 20.

Table 20 March 2013 Event Validation Event Model Iteration Summary

Model Iteration No.	Initial Loss (mm)	Continuing Loss (mm)	Other Changes
E401	0	1.0	As shown above in Table 15.

As the model was built using 2017 information and 2016 LiDAR some adjustments needed to be made to ensure the model represented 2013 conditions. The adjustments to the initial and continuing losses are due to the pre burst rainfall being removed from the hyetograph to reduce modelling times, the catchment is assumed to be saturated by the pre burst rainfall, and therefore no initial losses need to be applied during the validation event.

Table 21 March 2017 Validation Results Analysis

Point ID	Anecdotal Level (mAHD)	Peak Height (mAHD)			Difference (m)	Tolerance
		E401	Lower Tolerance	Upper Tolerance		
7	15.52	15.55	15.02	16.02	0.03	In tolerance
8	14.64	14.68	14.14	15.14	0.04	In tolerance
9	14.59	14.70	14.09	15.09	0.11	In tolerance
10	13.77	14.33	13.27	14.27	0.56	Above tolerance
11	13.27	14.09	12.77	13.77	0.82	Above tolerance
12	13.58	14.34	13.08	14.08	0.76	Above tolerance
13	14.07	14.53	13.57	14.57	0.46	In tolerance, high
14	16.01	16.54	15.51	16.51	0.53	Above tolerance
15	16.65	16.60	16.15	17.15	-0.05	In tolerance
16	16.68	16.69	16.18	17.18	0.01	In tolerance
17	17.45	16.86	16.95	17.95	-0.59	Below tolerance
18	17.26	16.89	16.76	17.76	-0.37	In tolerance, low
19	17.35	17.52	16.85	17.85	0.17	In tolerance
20	17.02	17.39	16.52	17.52	0.37	In tolerance, high
21	23.84	24.07	23.34	24.34	0.23	In tolerance
23	23.50	23.84	23.00	24.00	0.34	In tolerance, high
24	22.66	22.92	22.16	23.16	0.26	In tolerance

Point ID	Anecdotal Level (mAHD)	Peak Height (mAHD)			Difference (m)	Tolerance
		E401	Lower Tolerance	Upper Tolerance		
26	21.70	22.07	21.20	22.20	0.37	In tolerance, high
28	20.84	21.78	20.34	21.34	0.94	Above tolerance
29	21.84	22.34	21.34	22.34	0.50	In tolerance, high
30	28.56	29.34	28.06	29.06	0.78	Above tolerance
31	33.36	33.27	32.86	33.86	-0.10	In tolerance
32	20.70	21.09	20.20	21.20	0.39	In tolerance, high

Analysis of the validation results reveals the following:

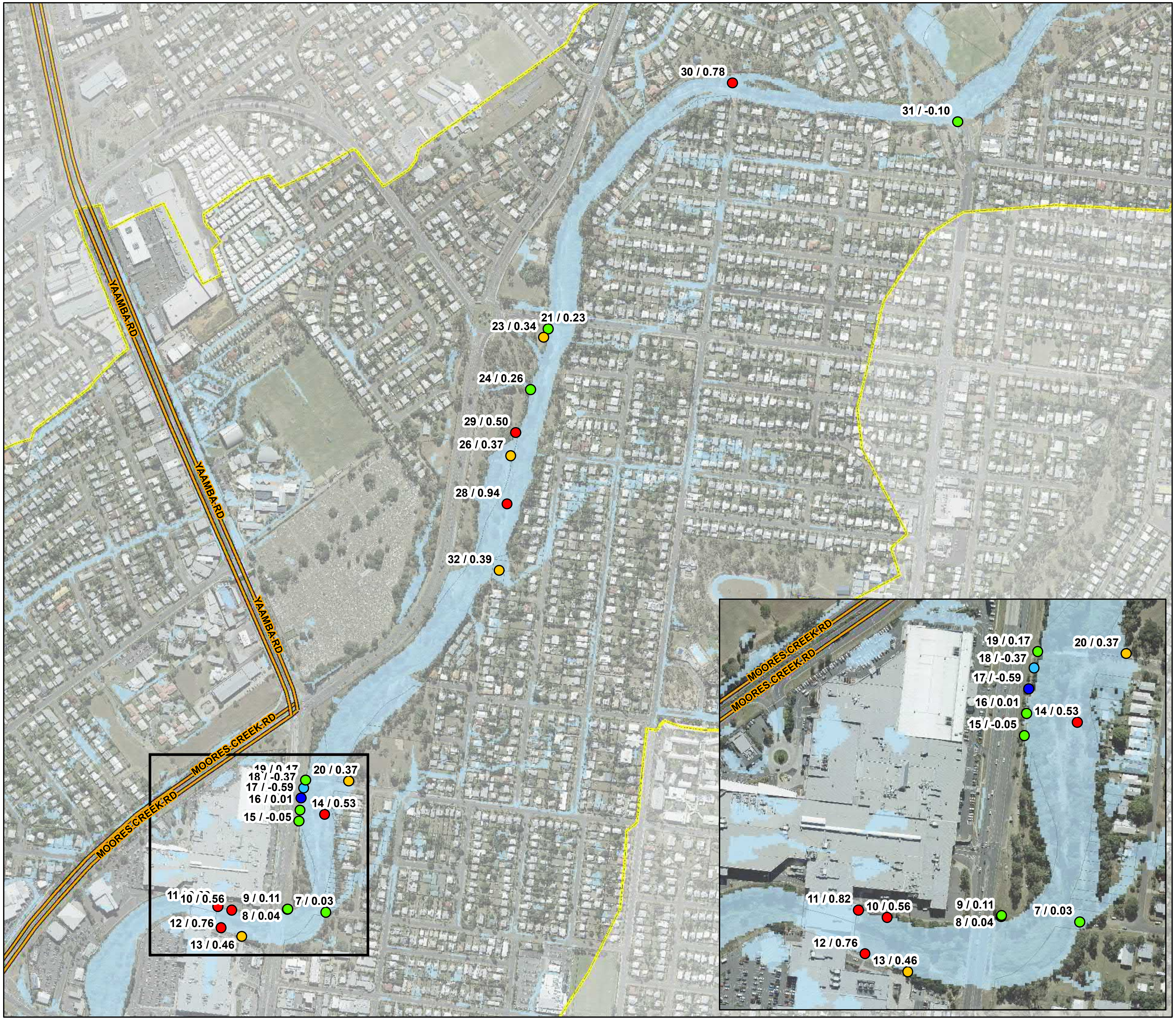
- Of the 23 recorded points, 16 were within the corresponding tolerances with 1 below and 6 above tolerance.
- The average difference between modelled and recorded levels was calculated to be 0.29m with standard deviation of 0.37 m.

Discrepancies identified between the modelled and recorded levels are assumed to be a result of three key factors, these being:

- Vegetation density at the time of the flood event;
- Variation in the spatial distribution of rainfall across the rural and urban components of the catchment; and
- Changes in channel cross-section between the LiDAR date of capture and the date of the event.

Considering the lack of rainfall data across the catchment and significant changes in channel geometry as a result of recent flood events, the 2013 model simulation serves as a suitable validation for the previously calibrated model.

Validation to the 2013 event has also been shown through the long section profiles (SK-MC-01 and SK-MC-02) shown in Appendix C. As can be seen from the long section plots, the modelled water surface profile passes within the tolerances of most calibration points. The hydraulic gradient is reasonably consistent and reflects changes in energy gradient at locations where sudden changes in topography would incur a change to flow regime.



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 50 100 200 300 400

Metres

1:7,500
(when printed at A3)

AECOM
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LEGEND

Difference (m)

- < -0.50 (Below tolerance)
- -0.50 - -0.30 (In tolerance, low)
- -0.30 - 0.30 (In tolerance)
- 0.30 - 0.50 (In tolerance, high)
- > 0.50 (Above tolerance)
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent
- January 2013 Modelled 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
$100m^2$ Min. Area

Moores Creek Model

January 2013 Validation Results

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 17

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 17 2013 Validation Results.mxd

7.5 Key Findings

Summarised below are the key calibration / validation parameters for the Moores Creek Local Catchment model.

7.5.1 Final Design Losses and Roughness

The final design losses adopted following the calibration and validation process is outlined in Table 47 in Appendix A. Pervious areas were modelled with an initial loss of 15 mm and continuing loss of 1 mm.

The adopted roughness values for each of the different land uses are outlined in Table 46 in Appendix A. Following the calibration and validation process the adopted roughness within the channel was delineated in more detail with increased roughness across heavily vegetated areas for shallow flows. Specifically, roughness was increased across channel vegetation by more than 40% for depths up to 100mm and 20% for depths up to 300mm.

7.5.2 Adopted Blockage

The adopted blockage for the final baseline design across major bridge structures follows best-estimates of piers and abutments within the bridge cross-section, with the Berserker Street pipeline crossing being the only major addition.

Site inspections revealed limited blockage within major culvert structures and as such, additional blockage was not incorporated.

7.5.3 Critical Areas

Critical areas within the creek influence are areas neighbouring major creek crossings, especially at the key crossings of Norman Road, Musgrave Street and Stockland Shopping Centre. Critical overland areas are those surrounding Alexandra Street, Yaamba Road and the major flow path traversing Elphinstone Street, Burnett Street and Armstrong Lane towards Musgrave Street.

8.0 Baseline Hydraulic Modelling

8.1 Overview

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

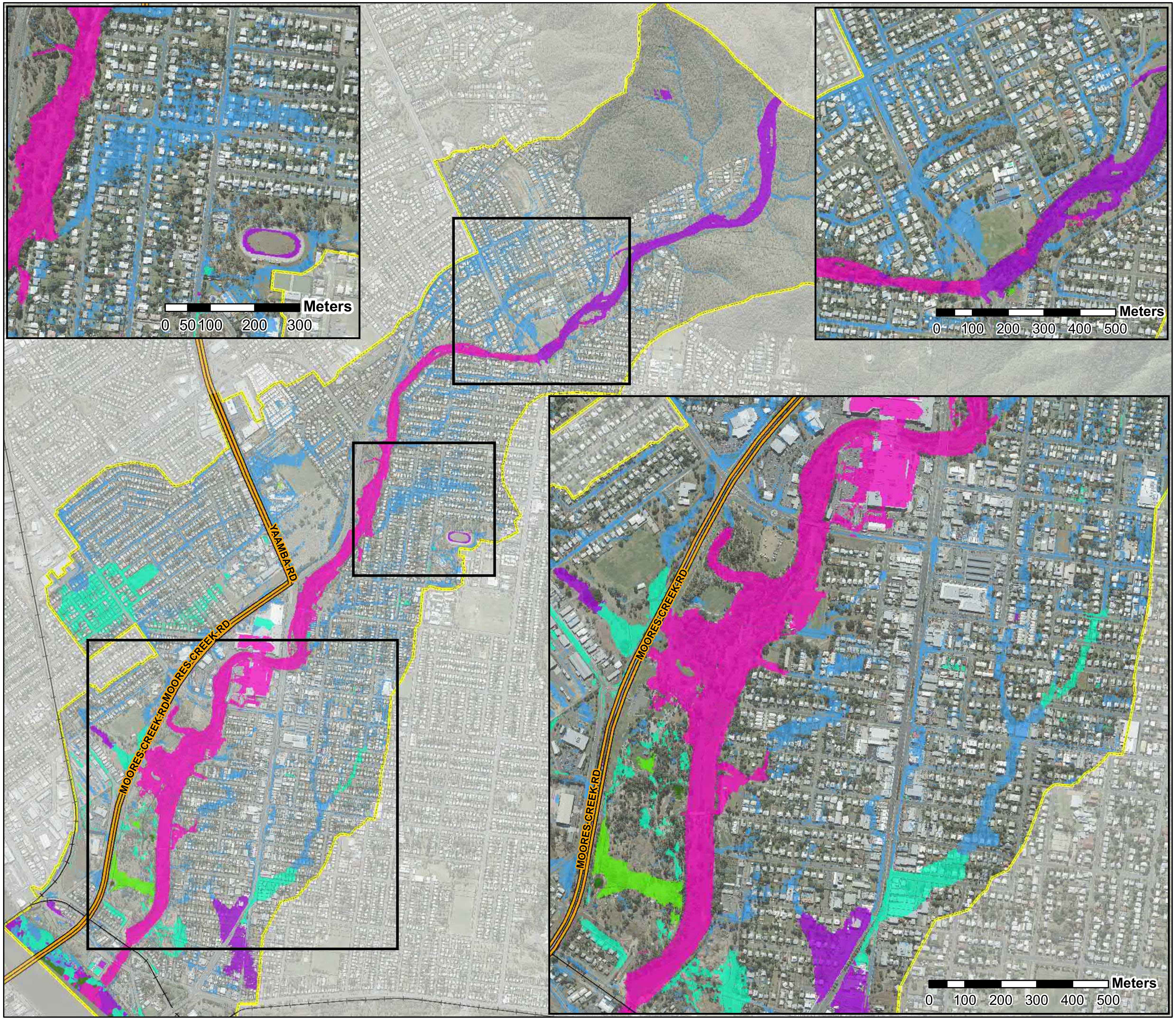
8.2 Critical Duration Assessment

The critical storm duration for the Moores Creek Local Catchment area was assessed by simulating the 60 min, 90 min, 120 min, 180 min, 270 min and 360 min durations for the 1% AEP event. Figure 18 shows that for a 1% AEP event, Moores Creek shares critical durations of 120 min upstream of and 180 min downstream of the Norman Road Bridge. The majority of overland urban flow paths are predicted to be critical in a 60 min storm event.

Analysis of differences between the 60 min and 180 min storm events revealed the 60 min was up to 225 mm higher in portions of the urban catchment, although more than 300 mm lower within the creek. Further investigation into the raster histogram revealed approximately 93% of the instances showed less than 75 mm difference. With this in mind and given the significance of the creek influence on flooding in larger events, a critical duration of 180 min was selected.

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

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



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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

Storm Duration

- 060min
- 090min
- 120min
- 180min
- 270min
- 360min

Flood results are based on local catchment events

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

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

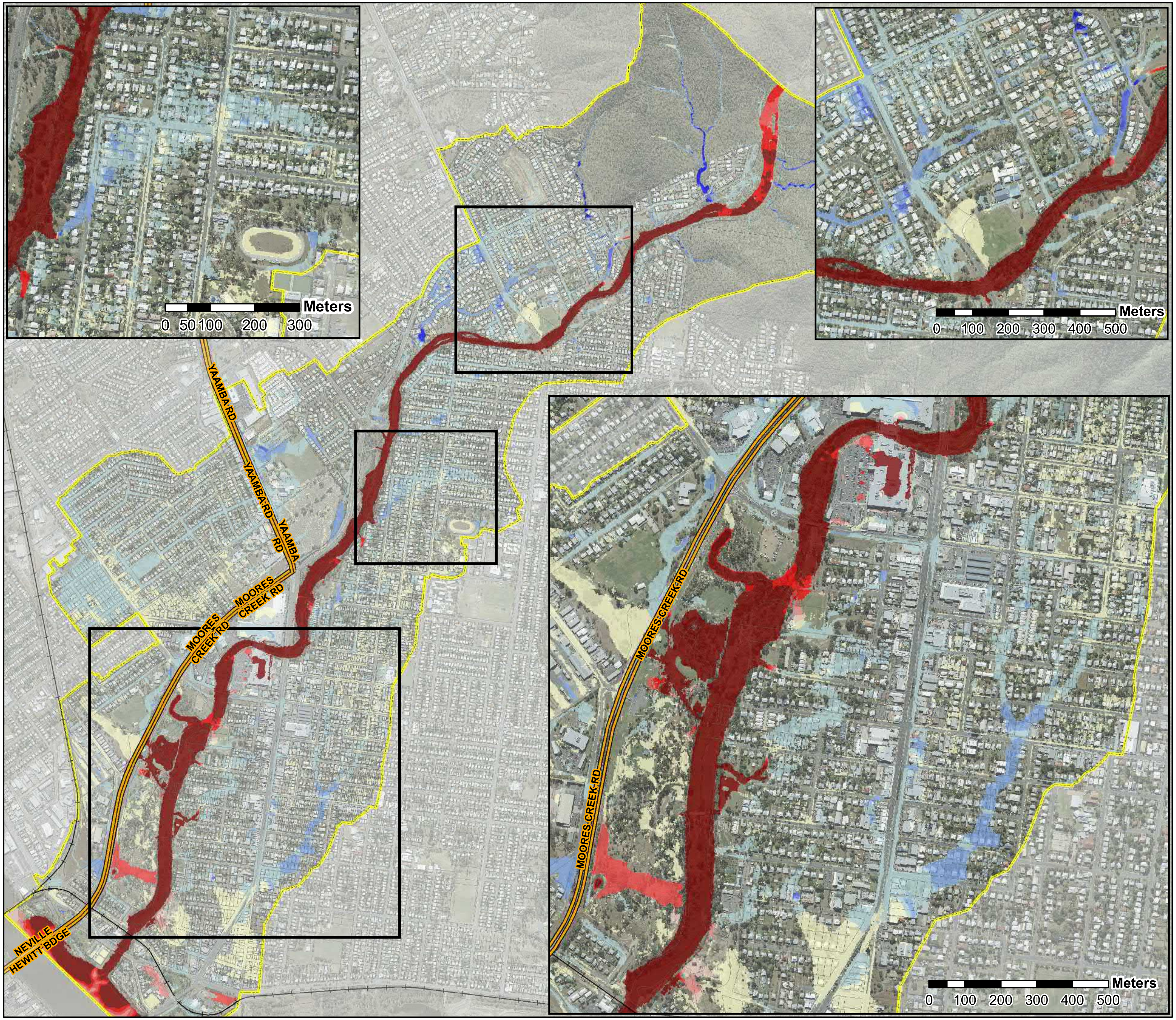
Moores Creek Model
Critical Storm Duration Assessment

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 18

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 18 Critical Duration.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000

Metres

1:20,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in PWSE (m)

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

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

Moores Creek Model
180m PWSE minus 60m PWSE

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 19

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 19 180m PWSE minus 60m PWSE.mxd

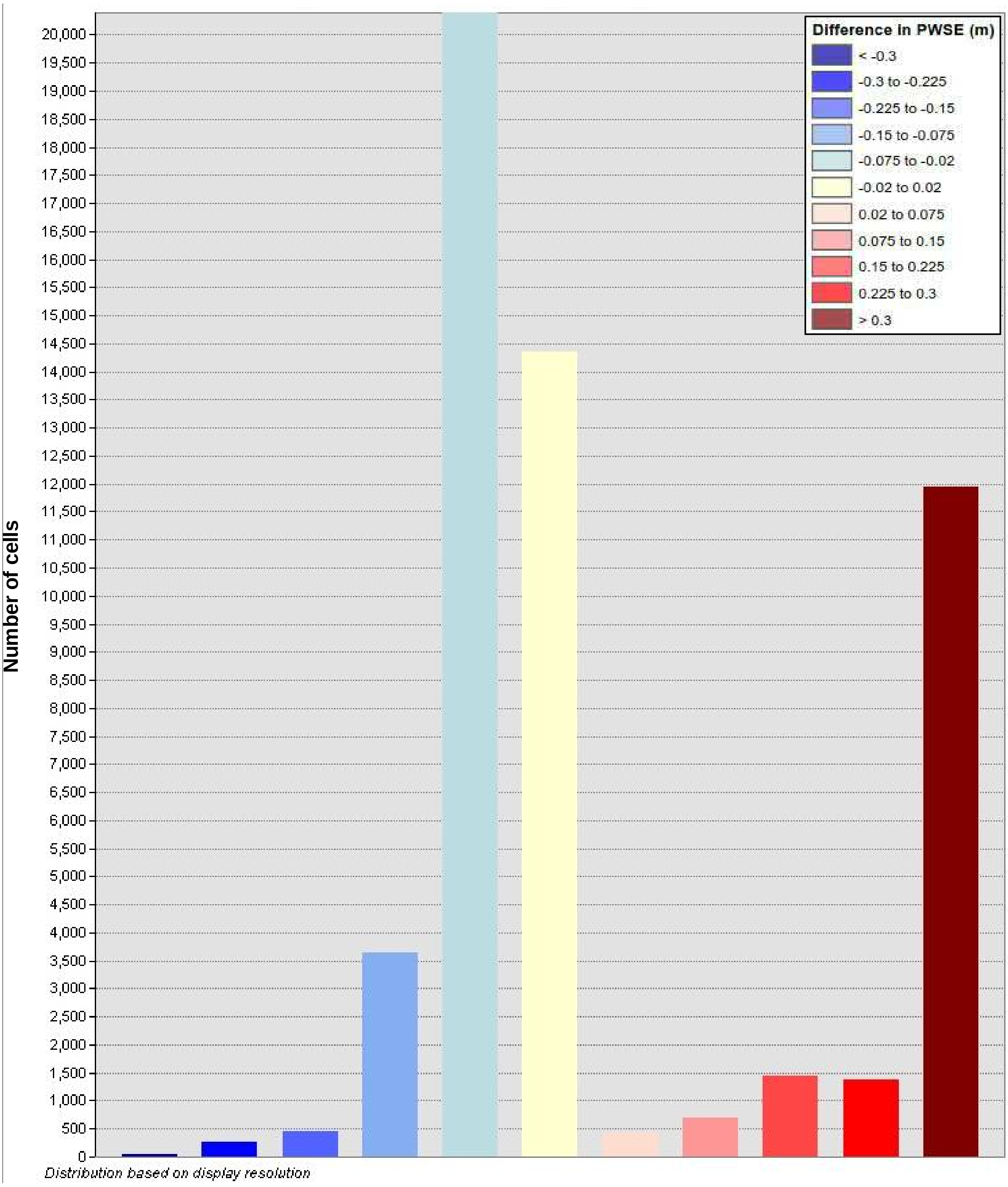


Figure 20   1% AEP – 180m PWSE minus 60m PWSE palette histogram

8.3 Baseline Flood Depths, Extents and Velocities

Rain-on-grid modelling uses a process whereby rainfall is applied to every model cell. Mapping of these results in their raw form would show that the entire model extent was flooded. For this reason, areas where the flow depth is less than 75 mm were removed from the mapping. In addition, a filtering process was completed whereby flooded areas of less than 100 m^2 were removed from the mapping. Note that these depths are not excluded in the computational scheme. This process is aligned to guidance from AR&R Project 15 (Engineers Australia, 2012).

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

- **Maps 1 to 3** – 1EY Baseline

Within the upper sections of Moores Creek the flood waters are largely contained within drainage reserves, roads and Creek extents. In the middle and lower sections of the Creek, flood waters extend across some properties which are situated in topographical low points. The flow paths include a section from the corner of Berserker Street and Stewart Street in a south westerly direction towards the middle of Salamanca Street. Within this flow path some ponding is present in private property, albeit the depth of this flow path is less than 0.3 m. Another overland flow path again follows a topographic low section from Edington Street, at Elphinstone Street two paths join and continue towards the corner of Musgrave Street and Armstrong Lane. Depths within this flow path reach up to 0.9 m. Other flow paths also exist but they mainly flow through park lands or drainage reserves.

The depth of water within Moores Creek can exceed 3 m depth in narrow sections, with wider sections experiencing up to 1 m depth of flow. The extent of the flows within the creek appears to remain within the Creek banks, aside from some sections within the parklands. The depth of water crossing the low flow path at Armstrong Street is less than 0.3 m.

The elevation of the water surface on the upstream side of the Musgrave Street Bridge is up to 14 mAHD. Velocities within the creek reach upwards of 2 m/s for large portions of the reach length. Whereas in most of the urban areas the peak depth averaged velocity is less than 0.25 m/s. Some flows along road corridors (Brumm Street) in the upper sections of the catchment reach velocities of 1.5 m/s.

- **Maps 4 to 6** – 39% AEP Baseline

The flood extent remains similar to the 1EY baseline, but the depth of water within the Creek becomes greater, with significantly more portions of the reach having depths greater than 3 m. Again the flow paths in the upper catchment are confined to the road reserves and the drainage paths. The overland flow path from Berserker Street corner remains at a similar depth of less than 0.3 m but the flood extent is greater and more water is expected to pond within private property. The overland flow path from Edington Street becomes more pronounced, and is expected to inundate additional properties. The depth of water crossing the low flow path at Armstrong Street is up to 0.6 m.

Additional inundation can be observed within the Kershaw Gardens. The water surface elevation on the upstream side of the Musgrave Street Bridge is approximately 14 mAHD. Peak depth averaged velocities within the creek are again higher than 2 m/s. Notably, within both the overland flow paths discussed above, the velocity vectors reach up to 1 m/s though some private properties.

- **Maps 7 to 9** – 18% AEP Baseline

Again the flow paths in the upper catchment are confined to the road reserves and the drainage paths. Significant ponding is expected to occur and affect private property at the corner of Kirkellen Street and Queen Elizabeth Drive. Another overland flow path begins to develop from the corner of Part Street and Elphinstone Street towards the grassland at the end of Lucas Street. The depth of water crossing the low flow path at Armstrong Street is greater than 0.6 m.

The water surface elevation on the upstream side of the Musgrave Street Bridge is 14 mAHD. A very large majority of the creeks reach has a peak depth average velocity of 2 m/s. The velocity of the overland water flowing down Boland Street is up to 1.5 m/s.

- **Maps 10 to 12** –10% AEP Baseline

Similar to the 18% AEP baseline discussed above, the flood extent continues to extend along the overland flow paths. Slight ponding within some properties can now be observed in the upper urban catchment of Moores Creek. The flood extent along the Creek is still maintained within parkland, with no impact on private properties. Depths of 1.2 m occur in some portions of Kershaw Gardens and the depth of flow over the culverts at the end of Charles Street is up to 0.9 m. Significant overland flow paths cross the following road links: Norman Road, Salamanca Street, Elphinstone Street, Burnett Street, Charles Street and Armstrong Street.

The surface water elevation on the upstream side of the Musgrave Street Bridge exceeds 14 mAHD. The full length of the Creek has a peak depth averaged velocity of 2 m/s or greater. Velocities within some road corridors reach 2 m/s and up to 1.5 m/s in some of the overland flow paths.

- **Maps 13 to 15** – 5% AEP Baseline

Significant private property inundation occurs in the allotments below Alexandra Street. Across most of the catchment the majority of the road corridors have some form flood inundation. Depths of up to 1.2 m occur at the corner of Kirkellen Street and Queen Elizabeth Drive. The flow of water down the creek is still maintained within the Creek reserve and does not affect private properties. The depth of water over the low flow culverts at the end of Charles Street is 0.9 m.

The peak flood height at the upstream portion of the Musgrave Street Bridge is up to 16 mAHD. Peak depth averaged velocities within the creek are maintained at velocities greater than 2 m/s for the full length of the reach. Velocities in the overland flow paths reach up to 2 m/s in the steeper sections of the catchment.

- **Maps 16 to 18** – 2% AEP Baseline

The creek flood extent is still maintained within the Creek reserve area. For nearly the full width of the Creek the depth of the water up to the culvert crossing at the end of Charles Street is greater than 3 m.

The water surface elevation just upstream of the Musgrave Street Bridge is up to 16 mAHD. The peak depth average velocities of the overland flows increase, especially in the sections where the flow path crosses a road; again steeper portions of the catchment experience higher velocities.

- **Maps 19 to 21** – 1% AEP Baseline

In the 1% AEP baseline, the flows are expected to break out of the main channel and inundate properties along Creek Street. The extent of the overland flow paths continue to expand and deepen, resulting in additional impacts to existing properties. The depth of water crossing the culverts at the end of Charles Street greater than 3 m and the water surface elevation at the Musgrave Street Bridge is up to 16 mAHD. Peak flood depths at the corner of Kirkellen Street and Queen Elizabeth Drive are predicted reach up to 1.5 m.

Significant portions of the creek channel cross-section are expected to see peak velocities in excess of 2 m/s. Peak velocities at Danker Court are predicted to exceed 2 m/s within the road reserve.

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

The 0.2% AEP baseline results show larger breakouts from the creek which affects properties in the following locations: Danker Street, Serocold Street, Mitchell Street, Grosskopf Street, Balaclava Street, Creek Street, Burnett Street, Kirkellen Street and Franks Street. Musgrave Street is overtopped to the north of the bridge.

Levels exceeding 16 mAHD are predicted to occur at the upstream side of the Musgrave Street Bridge with flood extents breaching the channel bank capacity. Flow depths across the culverts at the end of Charles Street are greater than 3 m. From the velocity map it can be seen that an additional path had been created for the flow to move around the Norman Road Bridge, with flows crossing the road to the north.

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

Depths of up to 1.2 m are expected over Musgrave Street (north of the bridge) in the 0.05% AEP baseline condition. The overland flow path from Woods Park to Burnett Street has significantly increased in extent between the 0.2% AEP baseline and the 0.05% AEP baseline; this overland flow is providing another avenue for water to progress towards the Fitzroy River. Inundation of private property also significantly increases in this event with most of the creek reach breaking one or both of its banks. The water surface elevation upstream of the Musgrave Street Bridge now exceeds 17 mAHD. Peak depth averaged velocities across some of the roads are greater than 2.0 m/s.

From the velocity vectors it can be noted that some portion of the flow is extending around the southern side of the Stockland's shopping centre and then re-joining the Creek on the other side.

- **Maps 28 to 30** – PMF Baseline

The flood extent of the PMF event follows the topography very closely, with some large portions of the flows being conveyed through the floodplains adjacent to the Creek channel. Depths greater than 3 m can be observed for the full extent and width of Moores Creek. Many properties become inundated by overland flow paths and / or main flows through the Creek. Levels upstream of the Musgrave Street Bridge exceed 19 mAHD during the PMF event.

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

Predicted peak flood extents are shown to be largely contained within the main Channel up to events of magnitude 1% AEP and above. Minor differences are noted between peak flood extents of the 1EY up to the 2% AEP event along the urban overland flow paths.

Events of magnitude 1% AEP and above begin to exceed the channel capacity and inundate adjacent floodplain areas. The southern carpark under Stockland Shopping Centre is predicted to be overtopped in events of magnitude 1% AEP and above, whilst the northern carpark and Musgrave Street are expected to overtop in a 0.2% AEP event.

Large increases in expected inundation extent are visible throughout urban flow paths adjacent the creek in a 1 in 2000 AEP event, with major breakouts occurring along the Creek meander southwest of Norman Road Bridge. Significant increases to impacted residential and commercial areas are predicted within a PMF event.

8.4 Baseline Peak Discharges

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

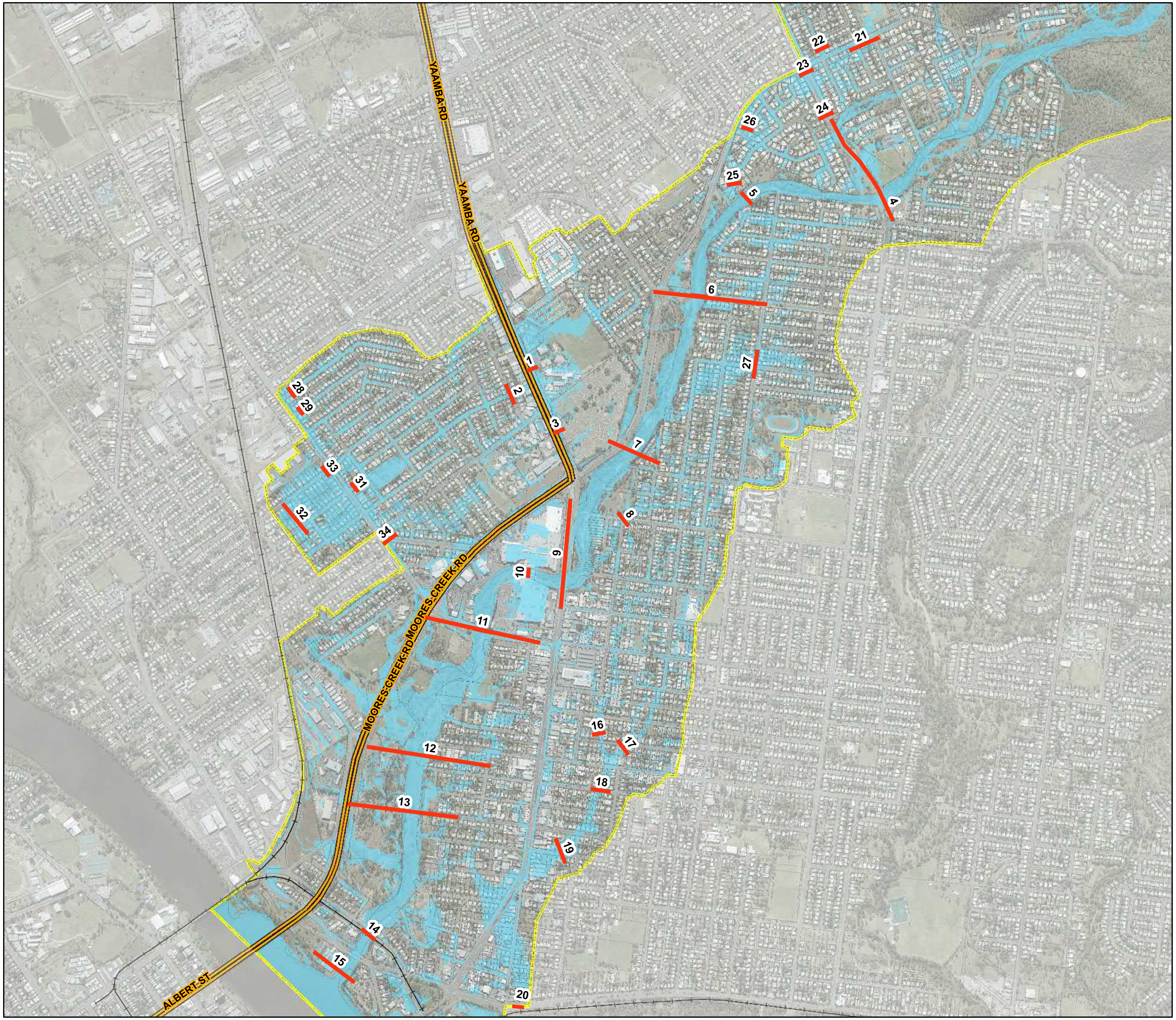
- Moores Creek major crossings;
- Moores Creek at Kershaw Gardens;
- Yaamba Road;
- Simpson Street;
- Burnett Street; and
- Armstrong Street.

The flow from the trunk main adjacent Musgrave Street conveying runoff to the Fitzroy River has also been included. Refer to Figure 21 for extraction cross-section locations. Table 22 below presents the results at corresponding locations.

Table 22 Summary of Baseline Peak Discharges

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP									
		1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Yaamba Road	1	0.7	1.1	1.8	2.3	3.0	3.5	4.4	7.2	8.6	11.8
Denning Street	2	0.3	0.6	1.3	1.6	1.8	2.1	2.3	3.4	4.9	11.1
Yaamba Road	3	0.2	0.3	0.5	1.0	1.7	2.2	2.8	4.8	5.7	7.9
Norman Road	4	64.6	100.3	149.9	182.8	228.0	284.4	330.9	523.6	677.5	1884.0
Berserker Street	5	66.0	102.8	152.0	185.2	231.2	289.4	339.1	527.3	637.8	1256.5
Kerrigan Street	6	66.4	103.9	154.1	187.8	234.4	293.2	344.0	546.8	707.7	1936.6
Moores Creek at North Rockhampton Cemetery	7	67.2	104.9	156.2	190.5	237.8	297.9	349.3	553.9	716.8	1969.2
Simpson Street	8	0.4	0.9	1.7	2.2	2.9	3.5	4.2	7.7	21.1	218.0
Musgrave Street	9	68.4	106.9	159.8	194.8	243.1	304.8	357.0	563.0	727.0	1948.4
Stockland Shopping Centre	10	68.5	106.9	160.0	195.0	243.1	301.7	346.0	494.2	599.7	1137.3
High Street	11	70.7	109.3	162.9	198.2	247.1	307.5	359.2	557.7	725.5	1884.4
Kershaw Gardens	12	71.1	110.1	164.5	200.1	249.4	310.5	360.3	561.6	728.1	2014.0
	13	71.2	110.3	167.6	200.8	250.4	311.6	361.3	562.0	725.7	2013.1
Yeppoon Branch Railway	14	72.5	112.8	168.7	205.0	255.1	317.5	367.5	563.2	720.2	1289.1
Glenmore Road	15	72.4	112.5	168.7	205.6	255.0	317.0	367.2	562.5	718.8	1509.8
Livingstone Street	16	0.6	0.9	1.4	1.7	2.2	2.5	3.0	5.1	6.5	13.1
	17	0.2	0.4	1.1	1.6	2.3	2.8	3.4	5.8	7.7	14.9
Burnett Street	18	0.7	1.2	2.2	3.4	4.8	5.8	7.4	13.5	17.9	35.9
Armstrong Street	19	0.7	1.1	2.1	3.4	5.0	6.6	8.4	15.2	20.5	43.7
Trunk Main Outlet	20	0.5	0.7	1.1	1.3	1.6	1.8	2.1	3.3	4.2	6.2
Hume Street	21	0.5	0.7	0.9	1.0	1.2	1.3	1.4	2.1	2.6	4.1
Wright Street	22	0.4	0.7	0.9	1.3	1.8	2.1	2.7	4.9	6.6	12.1
Norman Road	23	0.3	0.5	0.7	0.8	1.0	1.1	1.2	1.7	2.1	2.9
	24	0.7	1.2	2.2	2.8	3.8	4.6	5.8	10.8	14.6	57.3
Danker Crescent	25	0.4	0.7	1.1	1.3	1.6	1.8	2.1	3.8	5.0	9.0
Royal Crescent	26	1.2	1.7	2.3	2.7	3.3	3.6	4.1	5.9	7.1	10.1

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP									
		1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Berserker Street	27	0.6	0.9	1.2	1.5	1.7	1.9	2.1	3.0	3.6	5.0
Rice Street	28	0.4	0.6	0.8	0.9	1.1	1.2	1.3	1.7	1.9	2.6
Menzies Street	29	0.4	0.6	0.9	1.2	1.6	2.0	2.3	3.7	5.1	12.1
Sheehy Street	30	0.0	0.0	0.6	0.9	1.3	1.7	2.2	4.3	5.9	13.9
Henderson Street	31	1.2	2.5	4.5	6.3	9.0	11.2	13.5	21.2	27.3	57.4
	32	0.6	1.2	1.9	2.4	3.1	3.6	4.2	6.4	8.1	15.3
Thomasson Street	33	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.7	1.3	2.8
Cowap Street	34	0.7	1.1	1.8	2.3	3.0	3.5	4.4	7.2	8.6	11.8



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 150 300 450 600 750

Metres

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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

Moores Creek Model

Key Flow Path Discharge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	1

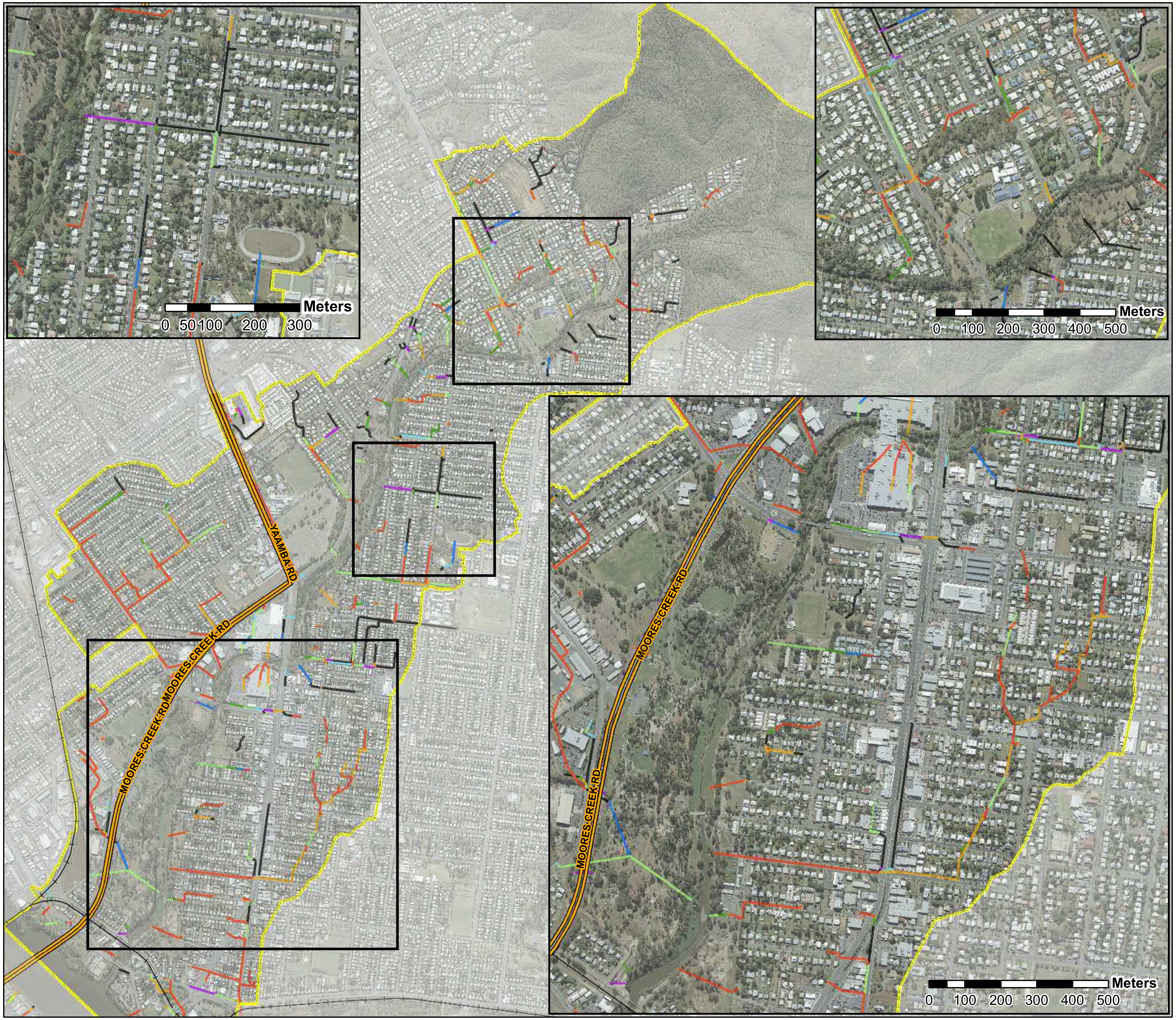
Figure 21

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 21 Plot Outputs Map.mxd

8.5 Stormwater Network Capacity

Figure 22 provides a spatial analysis of the existing underground network capacity during the 180 minute critical storm duration. It shows the event at which the capacity of the pipe/culvert is reached. It is noted that culverts were considered to have reached capacity once they exceeded 80% of their full flow capacity.

It can be seen that several segments of the network have less than 1EY immunity – an estimated 40% of the modelled network. Approximately 65% of the network has less than 10% AEP immunity, including the trunk main along Alexandra Street, pipes between High Street and Burnett Street and the trunk main following Musgrave Street towards the Fitzroy River. In a 1% AEP event, approximately 73% of the network is considered as flowing at full capacity.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000
Metres

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(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Pipe Flowing Full in

- 1EY
- 39% AEP
- 18% AEP
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- > 1% AEP

Flood results are based on local catchment events

Data Sources:

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

Moores Creek Model

Baseline 1D Network Capacity Analysis

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 22

8.6 Comparison with Previous Study Results

8.6.1 Recommended Changes from Previous Study Peer Review

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

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

8.6.2 Changes Implemented in this Study

The updated model has been upgraded to a rain-on-grid model with a reduced grid size of 3 m. The combination of a reduced grid size and rain applied across the urban catchment provides significantly more detail on local catchment flow paths and better informs future planning. Bridge structures have been digitized as layered flow constrictions in the 2D domain and applied a head loss to a single row of cells. This approach ensures a constant head loss is applied across the width of the structure. The cross-creek pipeline at the North end of Berserker Street has also been included in a similar fashion.

The 1D network was updated to match Council's current GIS database. More than 750 pipes and several key culverts were added to the TUFLOW model within the 1D domain. The implementation of the stormwater network indicated that there were instances where the subsurface network conveyed surface runoff not previously included in the hydrologic model, to Moores Creek.

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

Areas suspected to be inaccurately represented by the LiDAR 1 m DEM were surveyed and compared to the relevant LiDAR cross-section which revealed thick weed and trees caused the channel conveyance to be underestimated in several locations. To mitigate this, survey was incorporated into the model and matched back to the surrounding LiDAR where dense vegetation was not expected to have impacted the DEM precision.

Further misrepresentations in the LiDAR terrain were evident across the Stockland Shopping Centre. To represent the surface of the carpark, spot survey was undertaken and used to digitize the carpark levels. Additionally, a site inspection was undertaken in which locations of impervious walls and accesses were digitized as ineffective flow areas. This is particularly important for large events which overtop the carpark and surrounding roads.

The rainfall losses applied to both the urban catchment and XP-RAFTS hydrologic model were revised and updated to consistent values across the suite of design events as per standard industry practice. A comparison between the maximum losses applied is shown in Table 23.

Table 23 Adopted Maximum Losses Comparison

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

Event (AEP)	Previous Study		This Study	
	Maximum Initial Loss (mm)	Maximum Continuing Loss (mm/h)	Maximum Initial Loss (mm)	Maximum Continuing Loss (mm/h)
PMF	0.0	0.0	0.0	1.0

The February 2015 calibration event was adopted as the calibration event, with the January 2013 and March 2017 serving as validation events to confirm the performance of the hydraulic model over a range of events.

8.6.3 Results Comparison between Previous and Current Study

Figure 23 to Figure 26 show the differences in predicted peak flood heights and depths as a result of the changes listed above. The comparison shows:

- **Figure 23** – 18% AEP Height Difference Map

Several key overland flow paths previously modelled as inflows within the creek channel are identifiable. Flow paths generally follow pre-defined channels and road corridors as runoff progresses towards Moores Creek.

Comparison shows the predicted peak flood heights upstream of Norman Road Bridge have increased by more than 300 mm in sections. Despite the increase, minor reductions in extents are visible. It is expected that this is caused by the differences between the topographic data. As flood water reaches Norman Road Bridge, heights are predicted to decrease across known areas of recent scour which generally continues along the reach to Kerrigan Street. The reduction in predicted flood heights through this section are accompanied by reduced extents. Although surface turbulence is still predicted downstream of Norman Road Bridge, the previous hydraulic jump has diminished.

As flows follow Moores Creek Road adjacent the North Rockhampton Cemetery, levels are predicted to increase across sections of dense vegetation which stretch across the entire width of the creek channel.

Peak water surface elevations are predominantly predicted to increase through the channel from Stockland Shopping Centre to the outlet. Despite increases, flood extents are predicted to decrease slightly, again due to the changes in overall topographic data. Significant increases are noted over sections of dense vegetation which have increased roughness, especially for shallow flows.

- **Figure 24** – 18% AEP Depth Difference Map

Inspection of the depth comparison shows significant changes to the depth and an indication of change in conveyance of the creek channel. Areas of scour (especially those digitized using surveyed levels) predict increases in depth of more than 300 mm. The conveyance of the channel is seen to have increased throughout the channel between Norman Road and Kerrigan Street.

Notable differences are also observed throughout the channel at Stockland Shopping Centre. Lesser differences are noted in the channel downstream of the carpark bridge where the batters have been stabilised using shotcrete. However, the channel adjacent to Musgrave Street Bridge and downstream of the shopping centre overpass show significant increases in depth where the creek bed is known to have been impacted by scour. This narrow section typically sees higher velocities which coincide with the increase in conveyance.

Increases in predicted flood heights are accompanied by increase in flood depths through the channel adjacent Kershaw Gardens with predicted depths mostly increasing towards the outlet without observable increases to flood extents, indicating the capacity of the channel has increased in the updated model.

- **Figure 25** – 1% AEP Height Difference Map

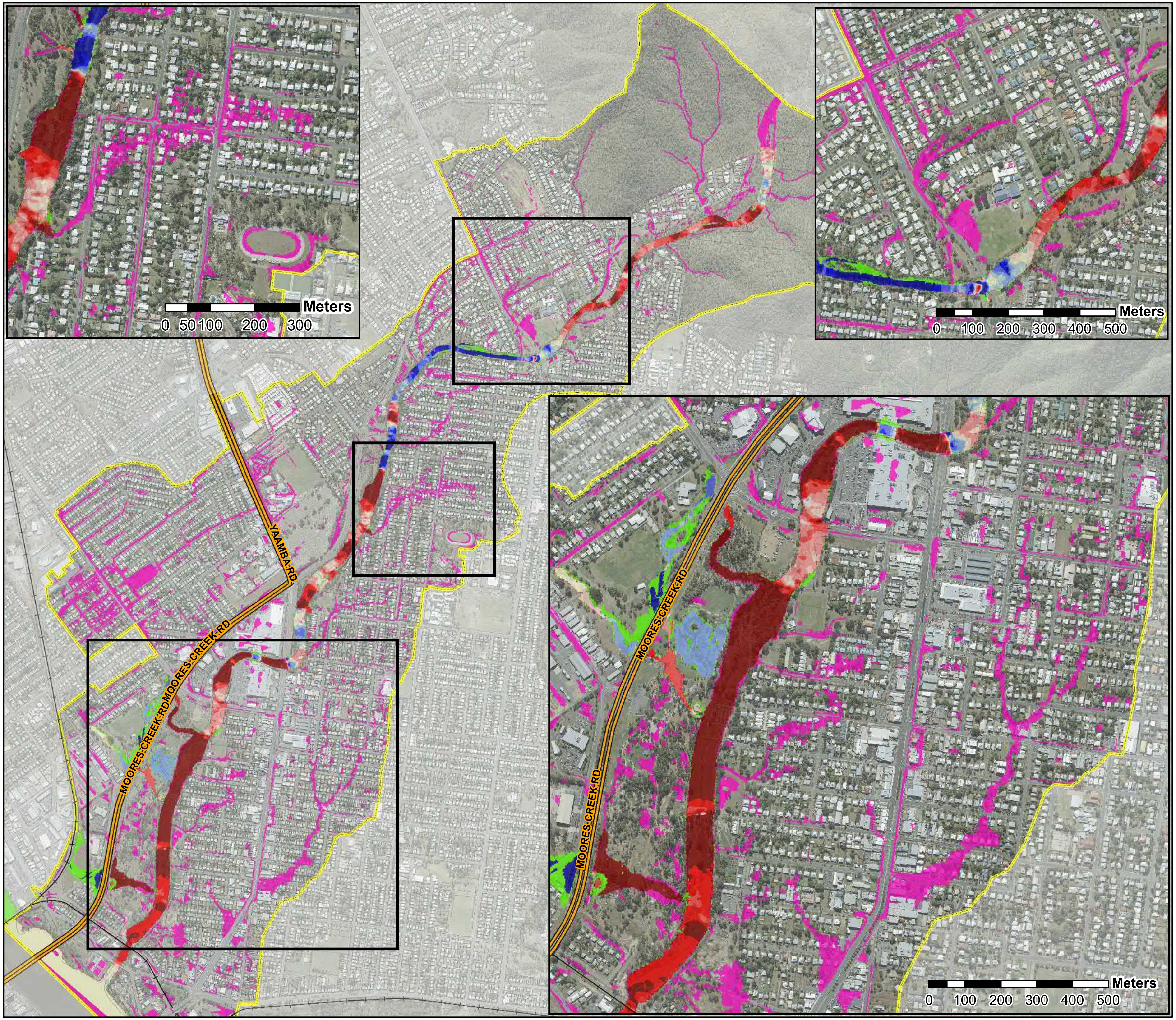
Predicted changes to peak flood heights resemble those of the 18% AEP. Peak flood extents are predicted to decrease throughout the majority of the creek reach due to scour occurring post-2009 and improved representation of the Moores Creek bed profile.

Significant reductions to flood extents are evidence both up and downstream of Norman Road Bridge. The breakout of flood waters at Serocold Street is no longer predicted for a 1% AEP event, with the adjacent breakout on the northern side of the creek shown to be largely confined to existing natural flow paths. An increased predicted flood height is noted at the end of Berserker Street where the pipeline structure has been included as a layered flow constriction.

Peak flood heights and extents are further predicted to decrease across Stockland Shopping Centre, with Musgrave Street no longer predicted to overtop. It is expected this is due to a combination of creek channel scour and manual inclusion of the road crest elevations in the model.

- **Figure 26** – 1% AEP Depth Difference Map

Peak flood depths are predicted to increase largely through the main channel, resulting in higher conveyance within the creek channel and reduced flood depths in the overbank floodplains. Areas of scour outlined in the discussions above result in notably deeper flood depths in the 1% AEP event, especially through Norman Road Bridge and Stockland Shopping Centre. As previously noted, peak flood depths within the channel are expected to increase, despite minor reductions to flood extents in some areas.



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Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in PWSE (m)

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

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

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

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

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

18% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 23

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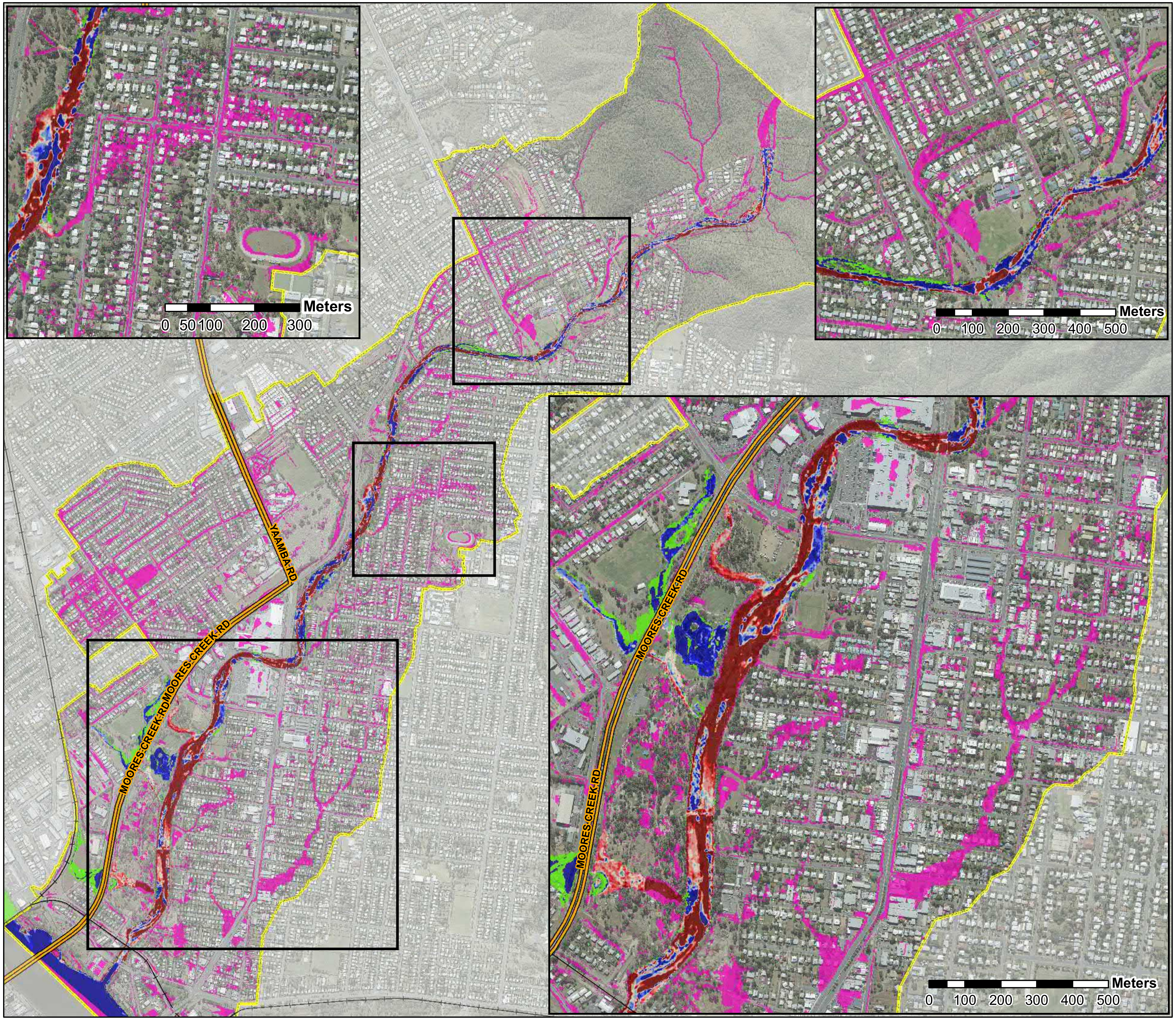

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Metres

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in Depth (m)

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

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

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

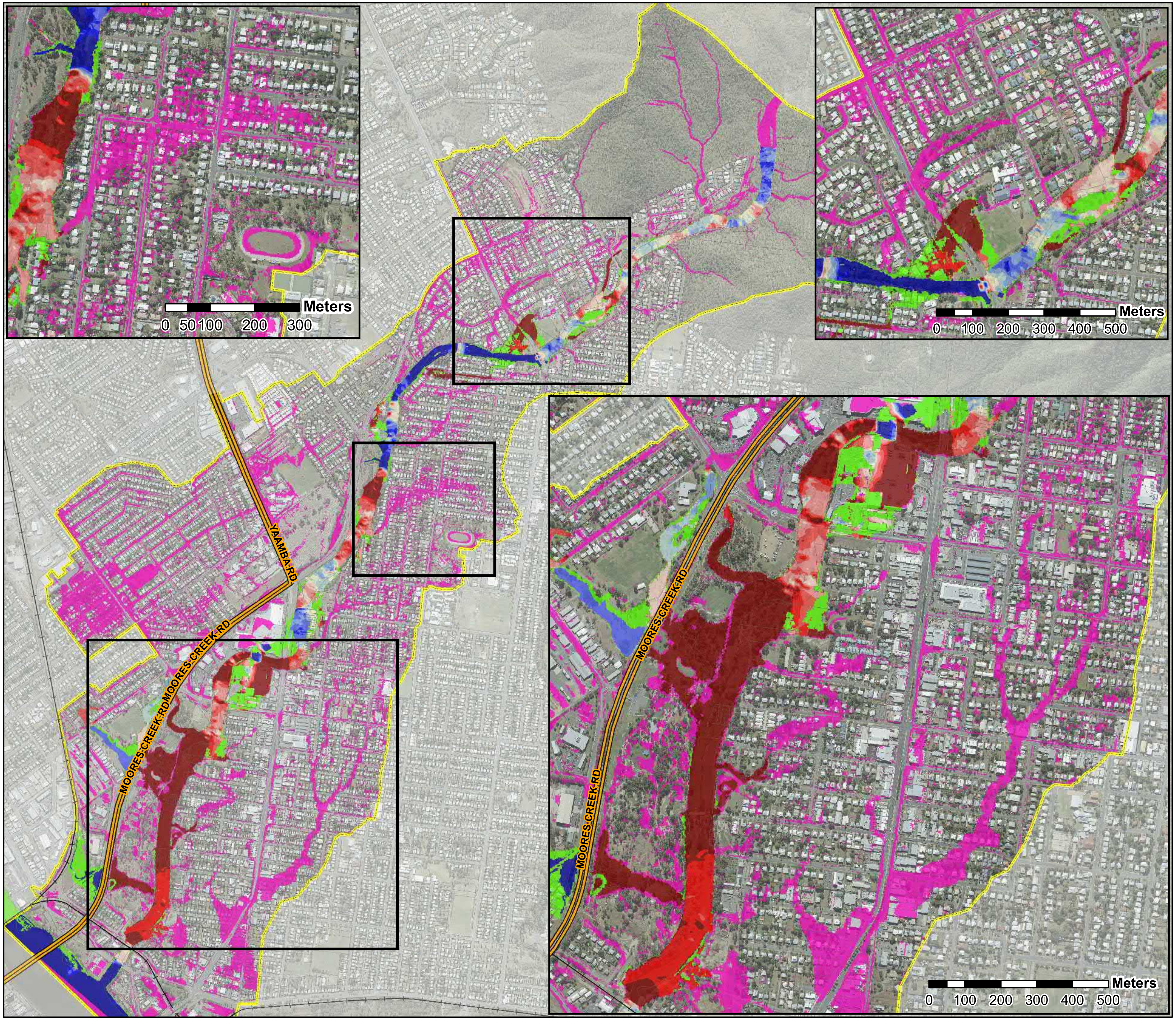
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Moores Creek Model
Difference in Peak Flood Depths
Curent Study minus Previous Study

18% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 24



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

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(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in PWSE (m)

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

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

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

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

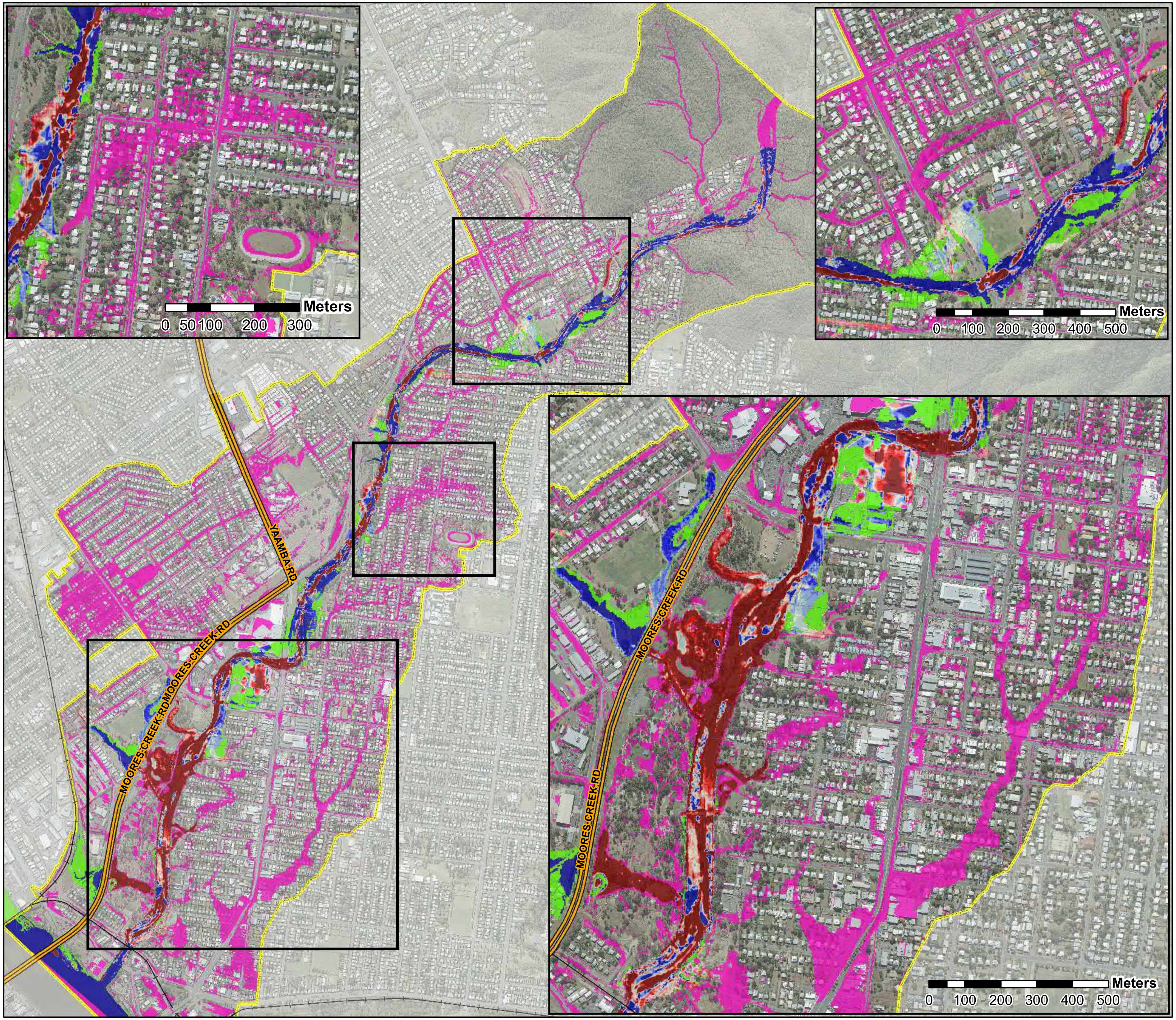
Moores Creek Model
Difference in Peak Flood Heights
Current Study minus Previous Study

1% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 25

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 25 Results Comparison 1% AEP.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

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(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Difference in Depth (m)

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

* May be due to previously unmodelled overland flow

Flood results are based on local catchment events

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

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

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

1% AEP 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure 26

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Figure 26 Results Comparison 1% AEP (Depth).mxd

9.0 Sensitivity Analysis

9.1 Overview

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

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

Further discussion on each sensitivity analysis is provided below.

9.2 Hydraulic Roughness

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

The following maps represent the results of the sensitivity testing.

- 15% Increase in Roughness à **Map MC-56**
- 15% Decrease in Roughness à **Map MC-57**

Map MC-56 indicates that with a uniformly increased roughness value across all material types, there is a corresponding overall increase in peak flood heights and overland flood extents. The majority of the urban areas within the catchment experience negligible increases in peak water surface elevations. Residential areas adjacent to Alexandra Street are predicted to have minor increases in peak flood heights (average of 20mm). The most significantly impacted areas within the Moores Creek catchment are that of the creek channel and neighbouring floodplain areas, with increases of peak flood heights by up to 0.25m.

The result from the sensitivity analysis which applies a 15% decrease in manning's roughness values are shown in **Map MC-57**. The decrease in roughness indicates a corresponding decrease in peak flood heights. The reduction in peak flood heights is negligible throughout most of the catchment area however some residential areas adjacent to Alexandra Street and Elphinstone Street are predicted to experience reductions in peak flood height (average of 25mm). Within the creek channel and the upper tributaries, the peak flood height reduces by up to 0.3m.

9.3 Climate Change

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

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

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

- 2°Celsius by 2050;
- 3°Celsius by 2070; and
- 4°Celsius by 2100.

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

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

Map MC-58 indicates that the 30% increase in applied rainfall significantly increases peak flood heights and extents throughout the catchment. The peak flood height throughout the majority of the creek channel increased between 0.5m and 0.7m with the peak increase of 1.2 m predicted upstream of the pipeline crossing at Berserker St. Results indicate that for smaller tributaries of the creek system, peak flood heights will increase between 0.1m and 0.25m. In the residential areas adjacent to Alexandra Street and Musgrave Street, it is predicted that peak flood heights will increase by between 0.1m and 0.2m.

9.4 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 (6.2 mAHD) to coincide with a 1% AEP design storm event in the Moores Creek catchment. The Fitzroy River flood height of 6.2 mAHD has been determined based upon results from RRC's Fitzroy River model (refer to Section 3.2.4).

As can be seen from **Map MC-59** the effect of this tailwater level is confined to the lower catchment area. The results indicate that in the lower catchment area, the peak flood height increases by between 0.05m and 2.5m and the levels within the Fitzroy are approximately 3.5m higher. The variation in peak water surface elevation in most residential areas is negligible, however it is predicted that residential areas adjacent to Armstrong Street and Lakes Creek Road will experience increases between 0.02m and 0.03m.

9.5 Stormwater Infrastructure Blockage

Testing of the model sensitivity to the underground stormwater infrastructure being blocked by debris, was undertaken for the 18% AEP event using an increasing percentage blockage on the underground stormwater network. This excluded cross drainage structures which was the subject of a specific sensitivity analysis (refer to Section 9.7).

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

- 20% Increase in Blockage à **Map MC-60**
- 50% Increase in Roughness à **Map MC-61**
- 100% Increase in Roughness à **Map MC-62**

9.5.1 20% Blockage of Stormwater Infrastructure

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

The results presented in map **MC-60** indicate that across the majority of the catchment, applying a 20% blockage to the stormwater network causes negligible change in peak water surface elevation with most areas being between ± 0.02 m of the baseline peak flood height results. However, specific areas in the vicinity of Musgrave Street (at the Lakes Creek Road end) and the residential areas between Spike Street and Musgrave Street are predicted to have increases in peak flood heights by between 0.02m and 0.1m when the stormwater network is 20% blocked.

9.5.2 50% Blockage of Stormwater Infrastructure

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

Blockage of the stormwater infrastructure by 50% results in higher peak flood heights in a number of areas. The residential areas around Alexandra Street are expected to have increases in peak flood heights of approximately 0.04m, while the overland flow path which runs between Spike Street and Musgrave Street is expected to have increases of up to 0.23m when the stormwater network is 50% blocked. A small area on the western side of Musgrave Street, is expected to have increases of up to 0.53 m when the stormwater network is 50% blocked.

9.5.3 100% Blockage of Stormwater Infrastructure

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

The results shown in **Map MC-62** indicate that several areas experience increases in peak flood heights. Areas which are predicted to experience the largest increases are those surrounding Norman Road, Alexandra Street, Yaamba Road and Musgrave Street where the peak flood extents propagate further throughout the residential area and peak flood heights increase from between 0.03 to 0.74m. The overland flow path which overtops Armstrong Street is also predicted to have notable increases in peak flood heights in the order of 0.33m.

9.6 Inlet Structure Dimensions

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

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

As indicated in map **MC-63**, the difference in peak flood height is between ± 0.02 m across the majority of the catchment. These results indicate that enabling larger portions of flow to enter the 1D system via the pit structures results in negligible differences to the peak flood height in most areas, however some small residential areas surrounding Armstrong Street show reductions in peak flood heights by approximately 20mm. The majority of areas where peak flood heights are shown to undergo a reduction in levels are in non-residential areas. Therefore, the assumption which has been made regarding inlet sizes will make minimal impacts to flood levels within the majority of the catchment.

9.7 Key Cross Drainage Culvert Blockage

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

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

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

9.7.1 Factors influencing blockage

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

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

9.7.2 Common Blockages

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

9.7.2.1 Floating Debris

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

9.7.2.2 Non-Floating Debris

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

9.7.2.3 Urban Debris

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

9.7.3 Design Blockage Level

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

9.7.3.1 Debris Availability

Table 24 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 **High** classification of debris availability for Moores Creek has been selected as:

- 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.
- 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.

9.7.3.2 Debris Mobility

Table 25 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 Moores Creek has been selected as source areas generally falling between the High and Low categories.

9.7.3.3 Debris Transportability

Table 26 Debris Transportability - Ability to Transport Debris to the Structure (Table 6.6.3 ARR, 2016)

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

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

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

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

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

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

9.7.3.4 Debris Potential

Table 27 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 **High** classification of debris potential for Moores Creek has been selected as the combination of individual factors is HMH.

9.7.3.5 AEP Adjusted Debris Potential

Table 28 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 **Medium** classification of AEP Adjusted Debris Potential for Moores Creek has been selected as the Event AEP assessed is 18%.

9.7.3.6 Design Blockage Level

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

Table 29 Most Likely Inlet Blockage Levels - B_{DES}% (Table 6.6.6 ARR, 2016)

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

Inlet Blockage Levels based on the structure clear width was assessed for each culvert individually which can be reviewed in more detail within Table 32.

9.7.3.7 Sediment Deposition

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

Table 30 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 32.

Table 31 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 32.

Table 32 Moores 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
2/1350mm RCP	W < L10	Medium	50%	1.9	M	40%	50%
1/750mm RCP	W < L10	Medium	50%	2.4	M	40%	50%
1/600mm RCP	W < L10	Medium	50%	2.5	M	40%	50%
3/1050mm RCP	W < L10	Medium	50%	1.1	M	40%	50%
3/600mm RCP	W < L10	Medium	50%	1.8	M	40%	50%
1/750mm RCP	W < L10	Medium	50%	1.2	M	40%	50%

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 Moores Creek is 50%.

9.7.4 Results of Sensitivity Analysis

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

- Culvert under Moores Creek Road (North of Yaamba Road) – up to 0.05m increase in peak flood height.
- Culvert under Lucas Street– up to 0.10m increase in peak flood height.
- Culvert under Moores Creek Road (Yaamba Road intersection) – up to 0.20m increase in peak flood height.
- Culvert under Bruce Highway (adjacent to Kershaw Gardens) - up to 0.05m increase in peak flood height.

9.8 Summary of Sensitivity Analysis Results

The results from the sensitivity analyses which were undertaken indicate that the most influential parameters are the manning's roughness values and the applied rainfall. As shown in Table 33, the 15% increase roughness caused an increase of peak flood heights throughout a large portion of the catchment. Similarly, the climate change sensitivity can be seen to have increased the peak flood heights throughout almost the entire catchment, with levels rising between 0.1m and 1.2m as previously discussed in Section 9.2.

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

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

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 33 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 Moores Creek catchment.

Table 33 Summary of Sensitivity Analysis Results

Change in Peak Water Surface Elevation (m)	Percentage Area of Peak Flood Extent								
	15% Increased Roughness	15% Decreased Roughness	Climate Change to 2100	20% Blockage of Stormwater Infrastructure	50% Blockage of Stormwater Infrastructure	100% Blockage of Stormwater Infrastructure	Fitzroy River Tailwater Condition	Increased Pit Dimensions	Blockage of Key Cross Drainage Structures
< -0.3	4%	0%	0%	0%	0%	0%	0%	0%	0%
0.299 to -0.225	1%	2%	0%	0%	0%	0%	0%	0%	0%
-0.225 to -0.150	1%	11%	0%	0%	0%	0%	0%	0%	0%
-0.150 to -0.075	0%	10%	0%	0%	0%	0%	0%	1%	0%
-0.075 to -0.02	0%	6%	0%	0%	0%	4%	0%	7%	0%
-0.02 to 0.02	64%	64%	8%	94%	85%	69%	80%	91%	99%
0.02 to 0.074	3%	2%	28%	4%	10%	15%	6%	1%	1%
0.075 to 0.150	12%	2%	16%	1%	2%	5%	2%	0%	0%
0.150 to 0.225	13%	1%	8%	1%	1%	3%	0%	0%	0%
0.225 to 0.299	0%	1%	4%	0%	0%	2%	1%	0%	0%
>0.3	0%	2%	34%	0%	1%	2%	12%	0%	0%

10.0 Flood Hazard and Vulnerability Assessment

10.1 Overview

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

10.2 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 34 and Table 35.

Table 34 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 35 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 27.

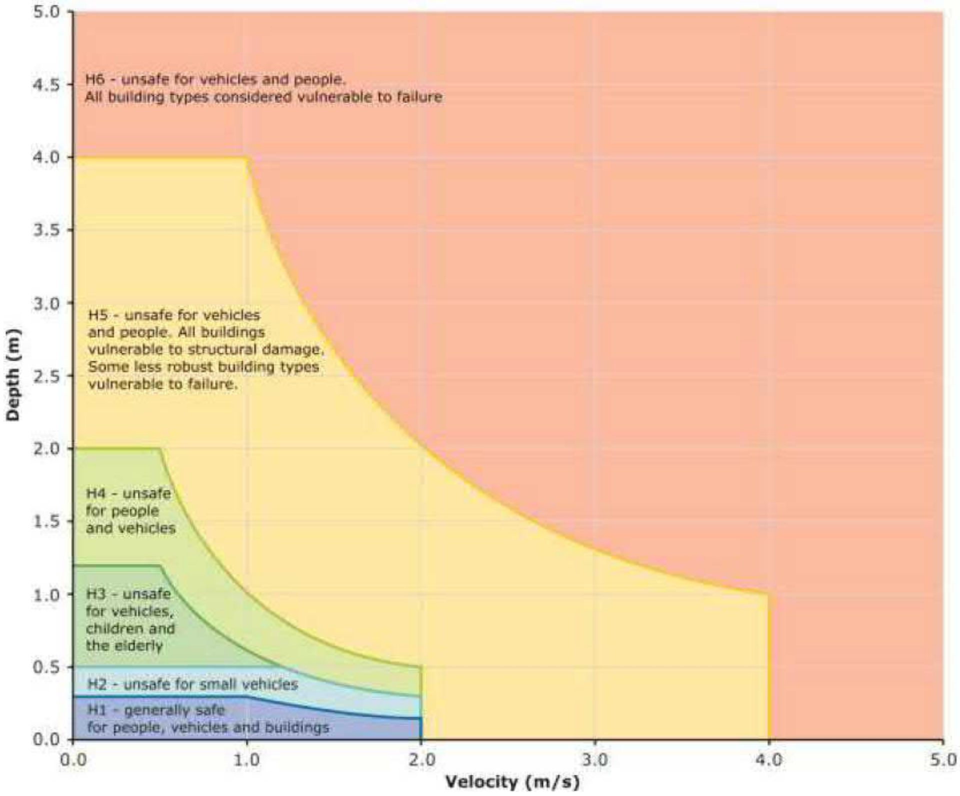


Figure 27 Hazard Vulnerability Classifications (Graphical)

Flood hazard mapping for the 18% and 1% AEP event has been included as maps **MC-65** to **MC-74** in the Volume 2 report. The 1% AEP hazard analysis generally shows:

- Low to medium hazard (H1 and H2) across the majority of urbanised areas within the catchment.
- High hazard (H3 and H4) within a majority of natural and man-made channels, as well as open areas such as local parks and Kershaw Gardens.
- High to extreme hazard (H4 and H5) within some natural and man-made open channels.
- High to extreme hazard (H4 and H5) in the overland flowpath between Elphinstone Street and Musgrave Street, extending to the western side of Musgrave Street into Kirkellen Street.
- Extreme hazard (H5 or H6) within the Moores Creek channel and adjacent overbank areas.

10.3 Baseline Sewerage Infrastructure Flood Risk

Maps **MC-75** to **MC-79** 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.

10.4 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 36 summarises the criterion used for each category, along with the corresponding reference to the specific table of results and locality figure.

Table 36 Vulnerability Assessment Criterion

Category	Criterion	Table	Figure
Water and Sewerage Infrastructure	Any electrified water or sewerage assets within the Moores Creek catchment, experiencing flooding up to the baseline PMF event.	Table 37	Figure 28
Emergency Services	Any emergency services facilities within the Moores Creek catchment, experiencing flooding up to the baseline PMF event.	Table 38	Figure 28
Community Infrastructure	Any community and critical infrastructure within the Moores Creek catchment, experiencing flooding up to the baseline PMF event.	Table 38	Figure 28
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 Moores Creek.*	Table 39	Figure 29
Bridge Assets	All bridge crossings of Moores Creek were assessed.	Table 40	Figure 29
Rail Assets	Rail segments that have inundation above top of ballast level (segments where rail ballast will be inundated)	Table 41	Figure 29

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 10.5.

Table 37 Water and sewage infrastructure - inundation depths for all events

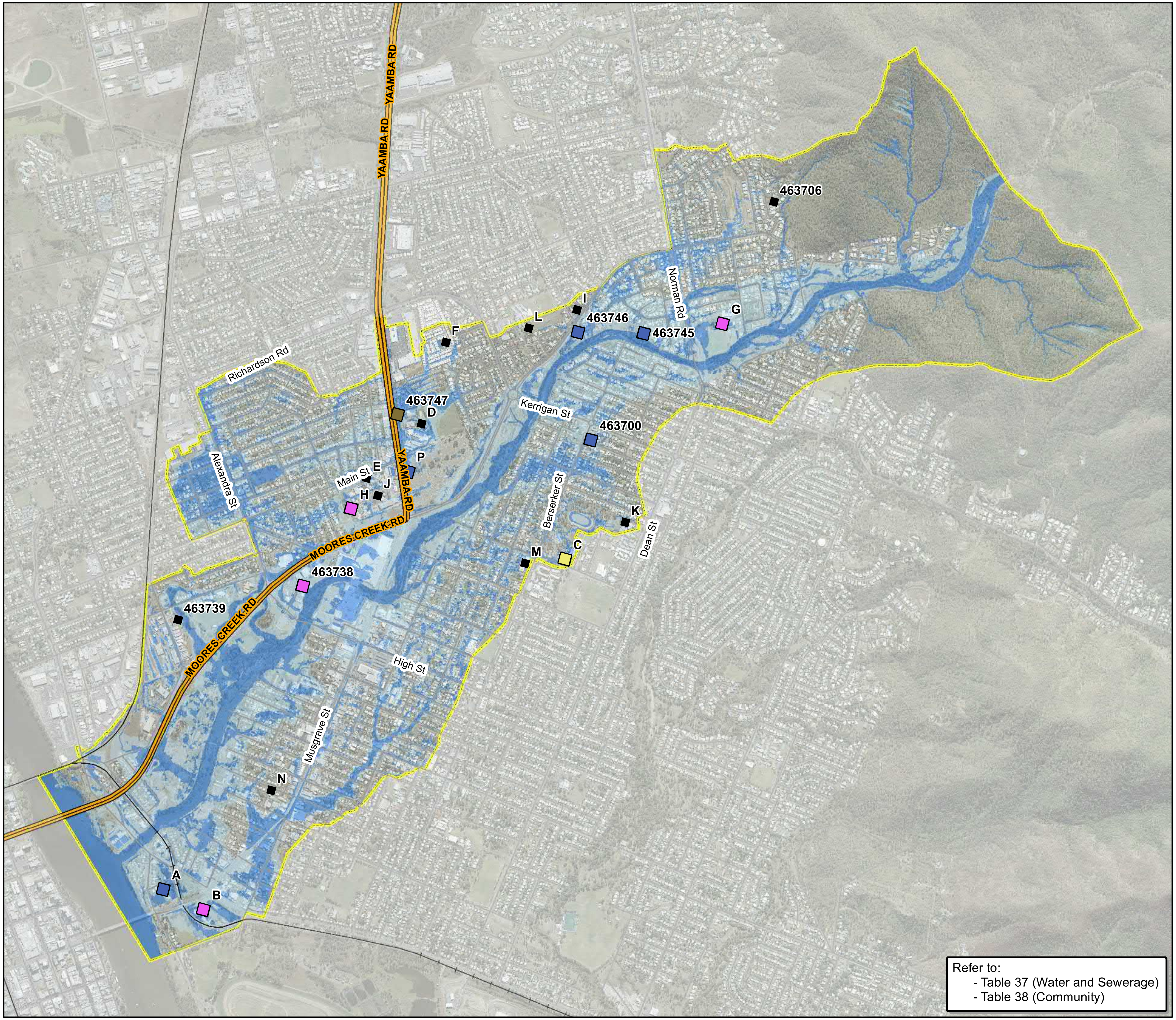
Infrastructure Type (Asset ID)	Suburb	Location	Inundation Depths at Design AEP Events (m) – 180 minute storm										1% AEP Hazard Category *
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
Sewerage Pump Station (463738)	Norman Gardens	Aquatic Place	-	-	-	-	-	-	-	-	0.46	2.17	-
Sewerage Pump Station (463745)	Norman Gardens	Bodero Street	-	-	-	-	-	-	-	-	-	0.37	-
Sewerage Pump Station (463746)	Norman Gardens	Danker Court	-	-	-	-	-	-	-	-	-	1.71	-
Sewerage Pump Station (463747)	Norman Gardens	Redhill (Emmaus)	-	-	-	-	0.11	0.13	0.22	0.23	0.27	0.34	H1
Sewerage Pump Station (463739)	Park Avenue	Knight Street	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (463706)	Norman Gardens	Selwyn Crescent	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (463700)	Frenchville	Guymer Street	-	-	-	-	-	-	-	-	-	0.10	-

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

Table 38 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) – 180 minute storm										1% AEP Hazard Category *
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
A	CQ Christian College (Admin)	Berserker	19 Reaney St	-	-	-	-	-	-	-	-	-	1.17	-
B	Police Citizens Youth Club (PCYC - Front Entrance)	Berserker	16-20 Bridge St	-	-	-	-	-	-	-	-	0.12	1.99	-
C	Narnia Kindergarten & Preschool	Frenchville	133 Robinson St	-	-	-	-	-	-	-	0.06	0.07	0.11	-
D	Emmaus College - Yaamba Road Campus (Hall)	Norman Gardens	362 Yaamba Rd	-	-	-	-	-	-	-	-	-	-	-
E	Emmaus College – Main Street Campus (Admin)	Norman Gardens	185 Main St	-	-	-	-	-	-	-	-	-	-	-
F	Rockhampton North Lifestyle Resort (Main Building)	Norman Gardens	19 Schuffenhauer St	-	-	-	-	-	-	-	-	-	-	-
G	Lighthouse Christian School (Main Building)	Norman Gardens	480 Norman Rd	-	-	-	-	-	-	-	-	0.14	1.32	-
H	Leinster Place	Park Avenue	3 Pearce St	-	-	-	-	-	-	-	-	0.09	0.12	-
I	Keetslee Child Care Centre	Norman Gardens	21 Bruigom St	-	-	-	-	-	-	-	-	-	-	-
J	Seventh Day Adventist School	Park Avenue	343 Yaamba Rd	-	-	-	-	-	-	-	-	-	-	-
K	North Rockhampton Special School	Frenchville	353-359 Dean St	-	-	-	-	-	-	-	-	-	-	-
L	St Anthony's School	Norman Gardens	390 Feez St	-	-	-	-	-	-	-	-	-	-	-
M	Illoura Child Care Centre	Frenchville	321 Berserker St	-	-	-	-	-	-	-	-	-	-	-
N	Capricorn Training Company	Berserker	38 Armstrong St	-	-	-	-	-	-	-	-	-	-	-
P	North Rockhampton Cemetery (Entrance Road)	Norman Gardens	350-360 Yaamba Rd	-	-	-	-	-	-	-	-	-	0.1	-

* 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.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000
Metres

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LEGEND

Critical Infrastructure Inundation (Lowest Immunity)

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

Moores Creek Model
Critical Infastruncture Inundation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	29/08/2017
VERSION:	1

Figure 28

Table 39 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) – 180 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
1	Edwin Street (West)	Berserker	34	6.3	0.12	0.24	0.38	0.59	0.84	1.07	1.12	1.19	1.23	1.46	H3
2	Edwin Street (East)	Berserker	81	4.8	0.13	0.22	0.32	0.38	0.43	0.47	0.60	0.83	0.94	2.13	H3
3	Burnett Street	Berserker	66	3.0	0.17	0.24	0.32	0.40	0.48	0.53	0.59	0.80	0.92	1.32	H3
4	Berserker Street	Frenchville	132	3.3	0.28	0.33	0.36	0.38	0.41	0.42	0.43	0.48	0.78	2.10	H2
5	Grosskopf Street	Frenchville	320	4.2	0.47	0.50	0.52	0.53	0.55	0.55	0.57	0.80	1.25	3.20	H3
6	Victoria Place	Berserker	38	4.1	0.39	0.42	0.45	0.46	0.48	0.49	0.51	0.58	0.63	1.18	H3
7	Armstrong Street	Berserker	212	3.7	0.22	0.38	0.54	0.65	0.78	0.85	0.90	1.13	1.27	1.64	H3
8	Part Street	Berserker	43	2.9	0.56	0.61	0.64	0.66	0.68	0.69	0.70	0.82	1.32	3.38	H3
9	Armstrong Lane	Berserker	115	5.8	0.70	0.86	1.02	1.13	1.26	1.33	1.38	1.60	1.74	2.09	H3
10	Yaamba Road	Norman Gardens	410	2.8	0.29	0.37	0.49	0.53	0.58	0.61	0.64	0.73	0.75	0.82	H3
11	Kerr Street	Park Avenue	109	2.7	0.17	0.34	0.39	0.41	0.42	0.44	0.45	0.49	0.52	0.67	H2
12	Moren Street	Frenchville	35	2.9	0.30	0.34	0.37	0.40	0.43	0.44	0.47	0.58	0.64	0.72	H3
13	Harris Crescent	Norman Gardens	113	1.0	0.29	0.31	0.33	0.34	0.36	0.36	0.37	0.42	0.54	1.96	H2
14	Norman Road North (Western Lanes Only)	Norman Gardens	730	1.4	0.37	0.41	0.45	0.46	0.48	0.49	0.50	0.56	0.59	0.67	H3
15	Norman Road South	Norman Gardens	150	0.5	-	-	0.11	0.16	0.20	0.22	0.23	0.27	0.30	1.77	H2
16	Royes Crescent	Norman Gardens	180	2.0	0.43	0.56	0.61	0.64	0.66	0.69	0.72	0.83	0.90	1.05	H3
17	Danker Court	Norman Gardens	370	2.4	0.51	0.63	0.84	0.91	1.00	1.07	1.13	1.33	1.49	2.47	H4
18	Salamanca Street	Frenchville	100	4.2	0.54	0.60	0.68	0.72	0.76	0.78	0.72	0.92	0.99	1.16	H4
19	Linnett Street	Berserker	105	2.1	0.26	0.28	0.31	0.32	0.34	0.34	0.35	0.38	0.41	2.85	H2
20	Knight Street	Park Avenue	45	2.2	-	-	0.17	0.23	0.29	0.32	0.35	0.45	0.51	0.68	H2
21	Calder Street	Park Avenue	260	3.1	0.17	0.27	0.40	0.44	0.48	0.52	0.55	0.67	0.75	1.00	H3

ID	Road | Street Name	Suburb	1% AEP Inundation Length (m)^	1% AEP TOS (hrs)^	Inundation Depths at Design AEP Events (m) – 180 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
22	Alexandra Street (Eastern Lanes Only)	Park Avenue	1,145	4.7	0.44	0.51	0.56	0.59	0.61	0.63	0.65	0.71	0.74	0.84	H3
23	Booker Street	Park Avenue	175	4.4	0.28	0.29	0.31	0.32	0.33	0.34	0.35	0.38	0.40	0.44	H2
24	Boland Street	Park Avenue	645	2.8	0.23	0.27	0.31	0.34	0.38	0.40	0.44	0.53	0.63	0.94	H4
25	McColl Street	Park Avenue	235	3.5	0.22	0.29	0.37	0.42	0.46	0.47	0.50	0.59	0.69	0.82	H3
26	Plahn Street	Park Avenue	115	3.4	0.26	0.28	0.30	0.31	0.33	0.34	0.35	0.40	0.43	1.42	H2

^Note: inundation lengths and TOS values are approximate only, and can vary depending on actual rainfall patterns and antecedent conditions.
* Maximum flood depth at road centreline extracted within the flooded road segment. Flood depths will vary at road shoulders and therefore results are approximate only.

Table 40 Bridge Assets - Inundation depths for all events

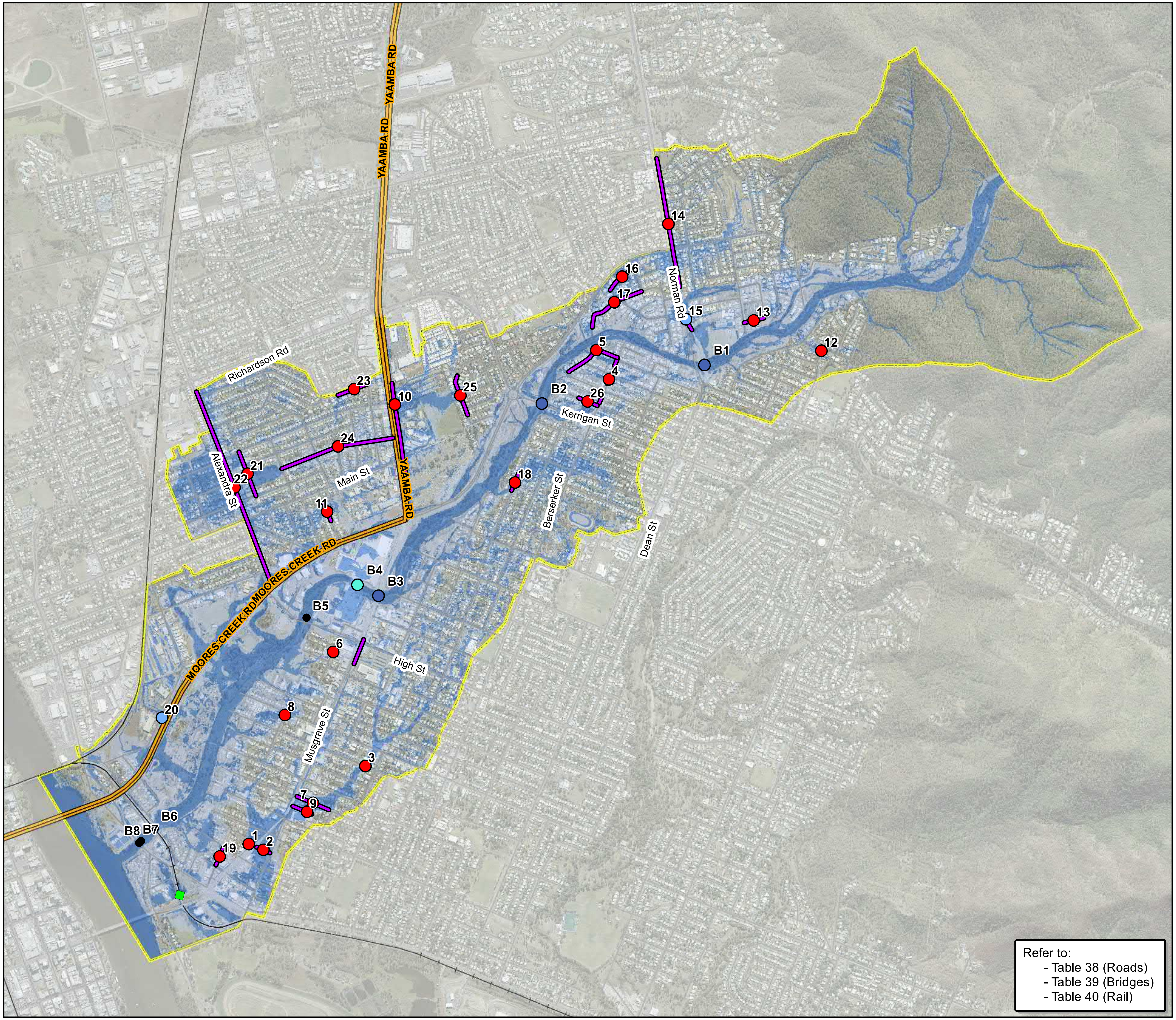
ID	Bridge Name	Deck Height (mAHD) #	Inundation Depths Above Deck at Design AEP Events (m) – 180 minute storm *										1% AEP Hazard Category **
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
B1	Dean Street Bridge (Reaney's Crossing)	35.79	-	-	-	-	-	-	-	-	-	0.85	-
B2	Kerrigan Street Bridge	27.58	-	-	-	-	-	-	-	-	-	0.24	-
B3	Musgrave Street Bridge	16.85	-	-	-	-	-	-	-	-	-	2.35	-
B4	Stockland Carpark Bridge	14.40	-	-	-	-	-	-	-	0.76	1.28	3.29	-
B4	High Street Bridge	12.07	-	-	-	-	-	-	-	-	-	1.71	-
B6	Railway Bridge	8.63	-	-	-	-	-	-	-	-	-	0.81	-
B7	Glenmore Road Bridge	7.87	-	-	-	-	-	-	-	-	-	0.41	-
B8	Pedestrian Bridge at Glenmore Road	7.95	-	-	-	-	-	-	-	-	-	-	-

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 41 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) – 180 minute storm *										1% AEP Hazard Category **
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
R1	Yeppoon Branch Rail Line	Park Avenue	35	-	-	-	-	-	-	-	-	-	1.50	-

^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.



Refer to:
- Table 38 (Roads)
- Table 39 (Bridges)
- Table 40 (Rail)

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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

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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
- Road Centrelines
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Flood results are based on local catchment events

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

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

Moores Creek Model
Road, Bridges and Rail Inundation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure 29

10.4.1 Vulnerability Assessment Summary

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

- The Redhill Sewerage Pump Station (SPS, Ref: 463747) is predicted to have less than 0.2% AEP flood immunity. It is noted however that this SPS is a below ground station and improvements to flood immunity would be very difficult to achieve. It is recommended this information be passed onto FRW as the asset owner.
- Flood inundation is predicted at Narnia Kindergarten and Preschool in the 0.2% AEP, however the low depth and velocity of flooding is expected to present a low risk to pedestrians.
- The Yeppoon Branch Rail Line is predicted to have high level flood immunity to Top of Ballast, with inundation only predicted for a short section of rail during the PMF event.
- A number of roads are predicted to experience inundation in the 1EY event and larger. Estimated TOS ranges from 0.5 hours to approximately 6 hours.

10.5 Evacuation Routes

Generally local catchment flooding within the Moores 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 Moores Creek catchment, the warning time between the commencement of the rain event and subsequent flood inundation can be short (refer Figure 35 to Figure 39). 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 42 provides a summary of the isolated areas and key evacuation routes, assessed up to the PMF event.

Table 42 Isolated Areas Summary

Isolated Area	Key Evacuation Route/s	Accessed Via	Warning Time Until Evac. Route Cut	Figure Reference
Danker Street	Norman Road Moores Creek Road	Dodgson Street Rowe Street	Up to 0.5 hour Up to 0.5 hour	Figure 30
Warner Avenue	German Street	Cheney Street	Up to 0.5 hour	Figure 30
Rickart Street and Magee Street	Kerrigan Street	Waterloo Street	Up to 0.5 hour	Figure 31
Salamanca Street	Kerrigan Street Berserker Street	Waterloo Street Stewart Street	Up to 0.5 hour Up to 0.5 hour	Figure 31
Main Street & Medcraft Street (between Twigg Street and Alexandra Street)	Alexandra Street Yaamba Road	Main Street Main Street	Up to 0.5 hour Up to 0.5 hour	Figure 32
Kerr Street and Tynan Street (southern end)	Alexandra Street Yaamba Road	Main Street Main Street	Up to 0.5 hour Up to 0.5 hour	Figure 32
Cowap Street	Alexandra Street	Main Street	Up to 0.5 hour	Figure 32
Stawell Court and Miles Street	High Street	Victoria Place	Up to 0.5 hour	Figure 33
Kirkellen Street and Bernard Street	Queen Elizabeth Drive	Direct Access	Up to 0.5 hour	Figure 34

Figure 30 Isolated Area – Danker Street, Warner Avenue (Note: PMF flood extents shown)

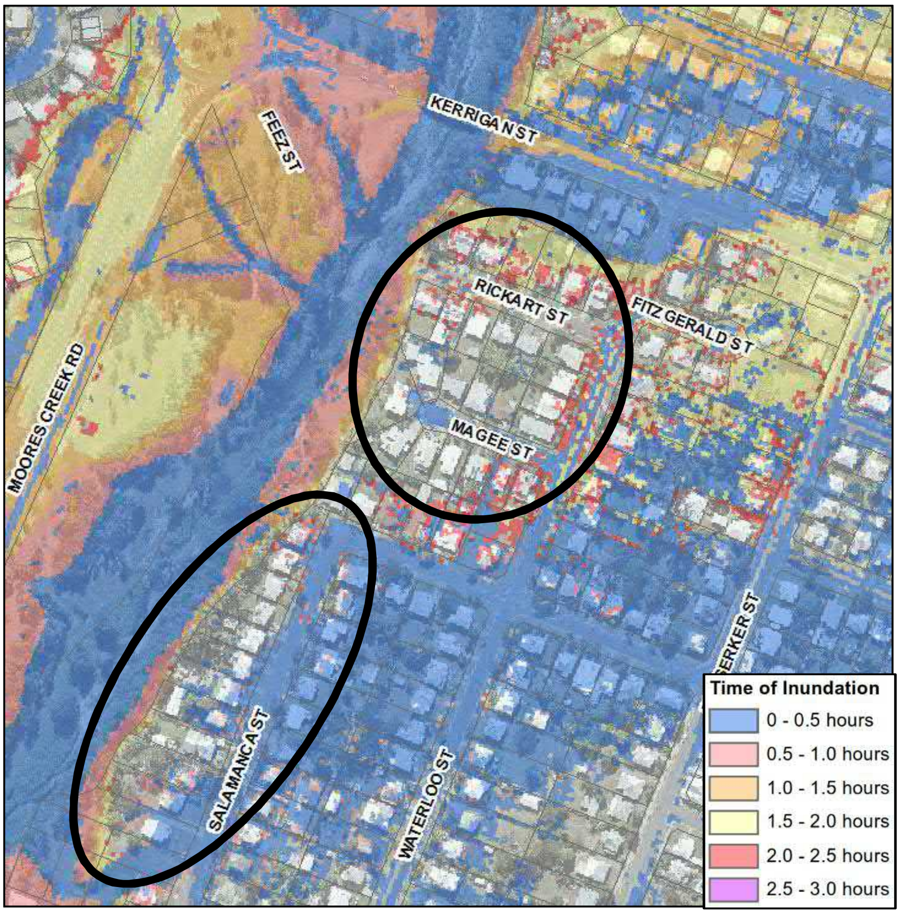


Figure 31 Isolated Area – Rickart Street and Magee Street, Salamanca Street (Note: PMF flood extents shown)

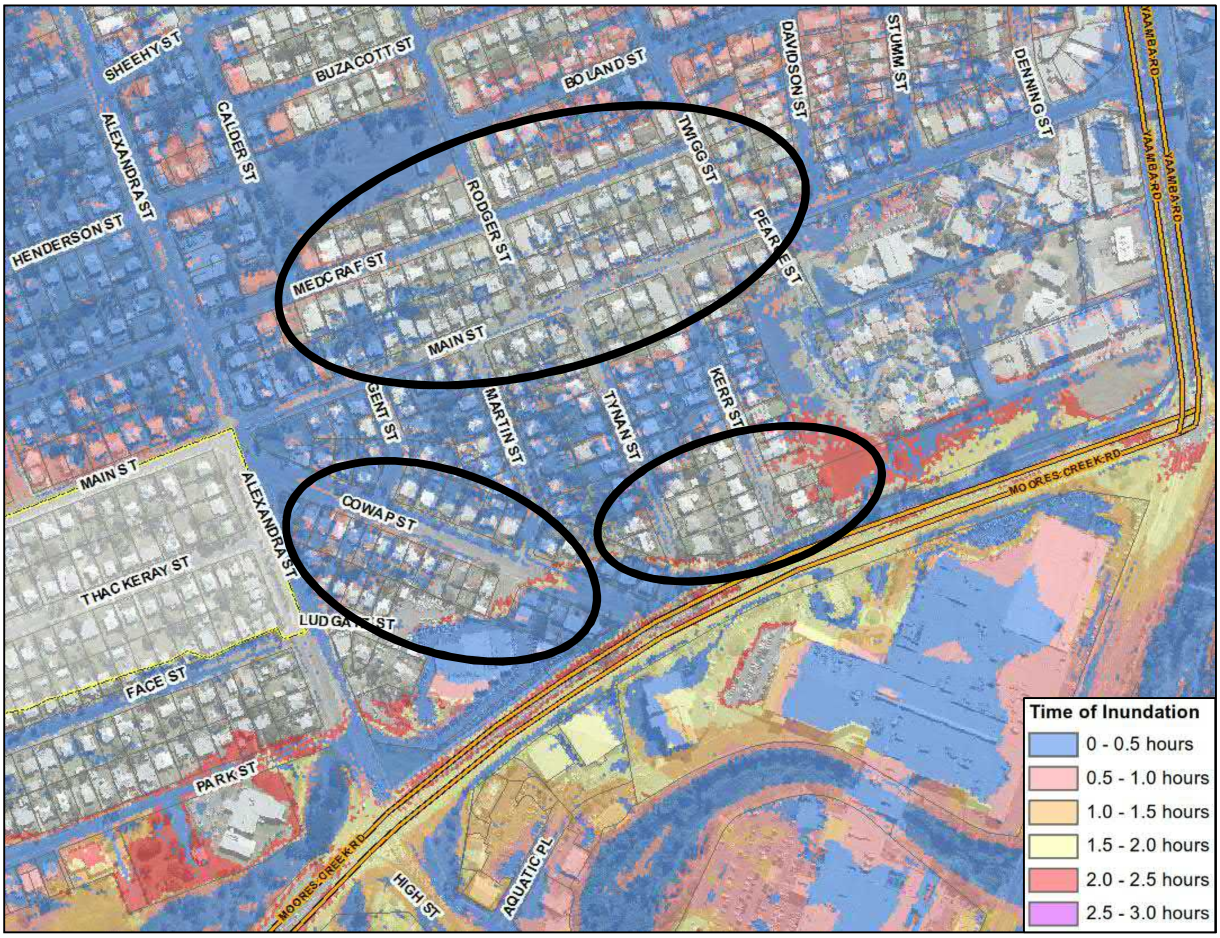


Figure 32 Isolated Areas – Main Street and Medcraft Street, Kerr Street and Tynan Street, Cowap Street (Note: PMF flood extents shown)

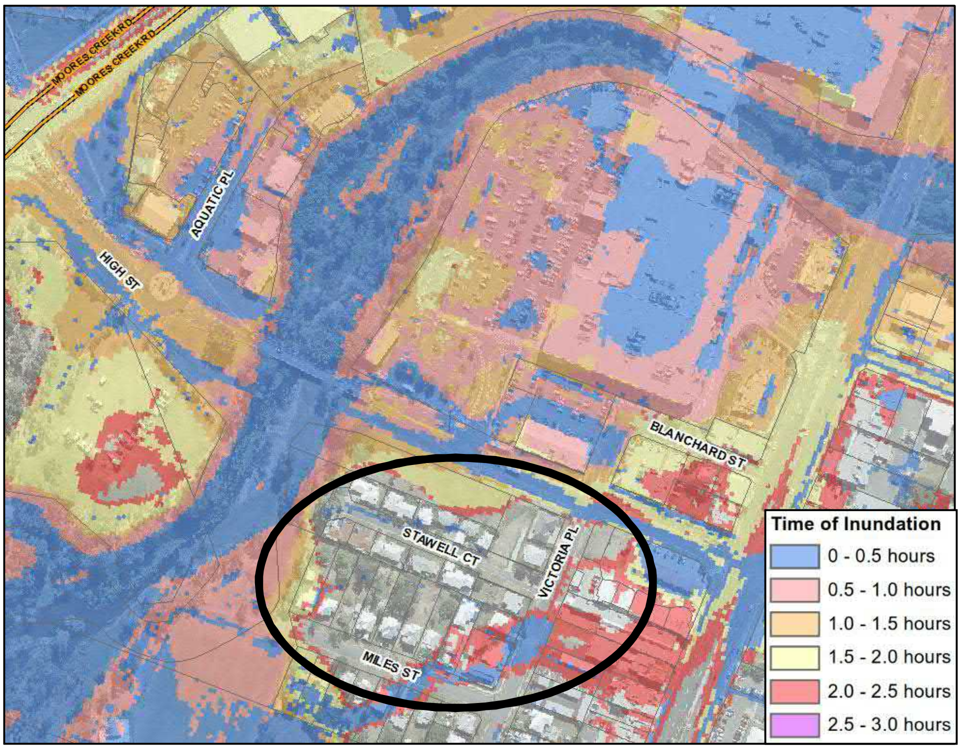


Figure 33 Isolated Area – Stawell Court and Miles Street (Note: PMF flood extents shown)

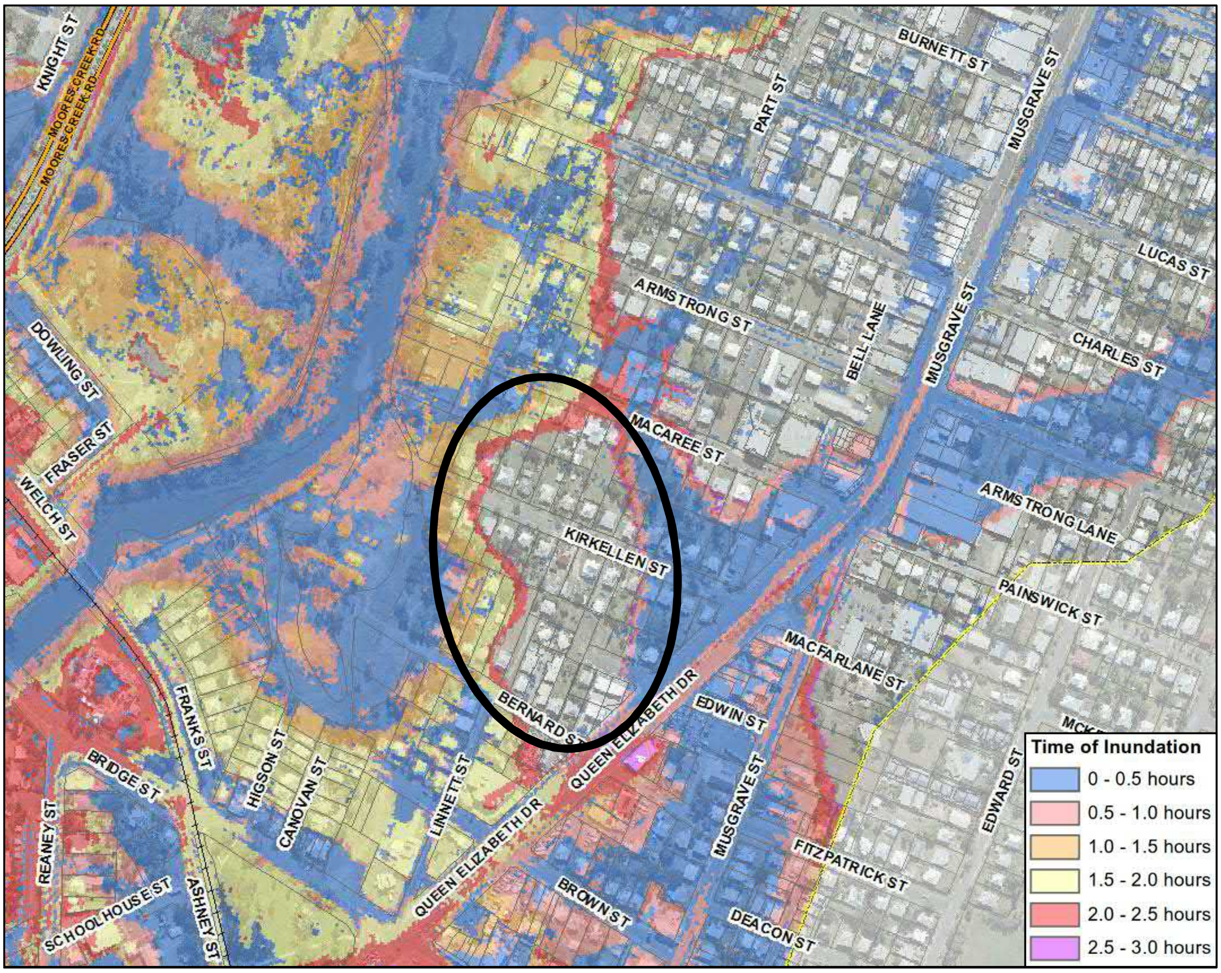
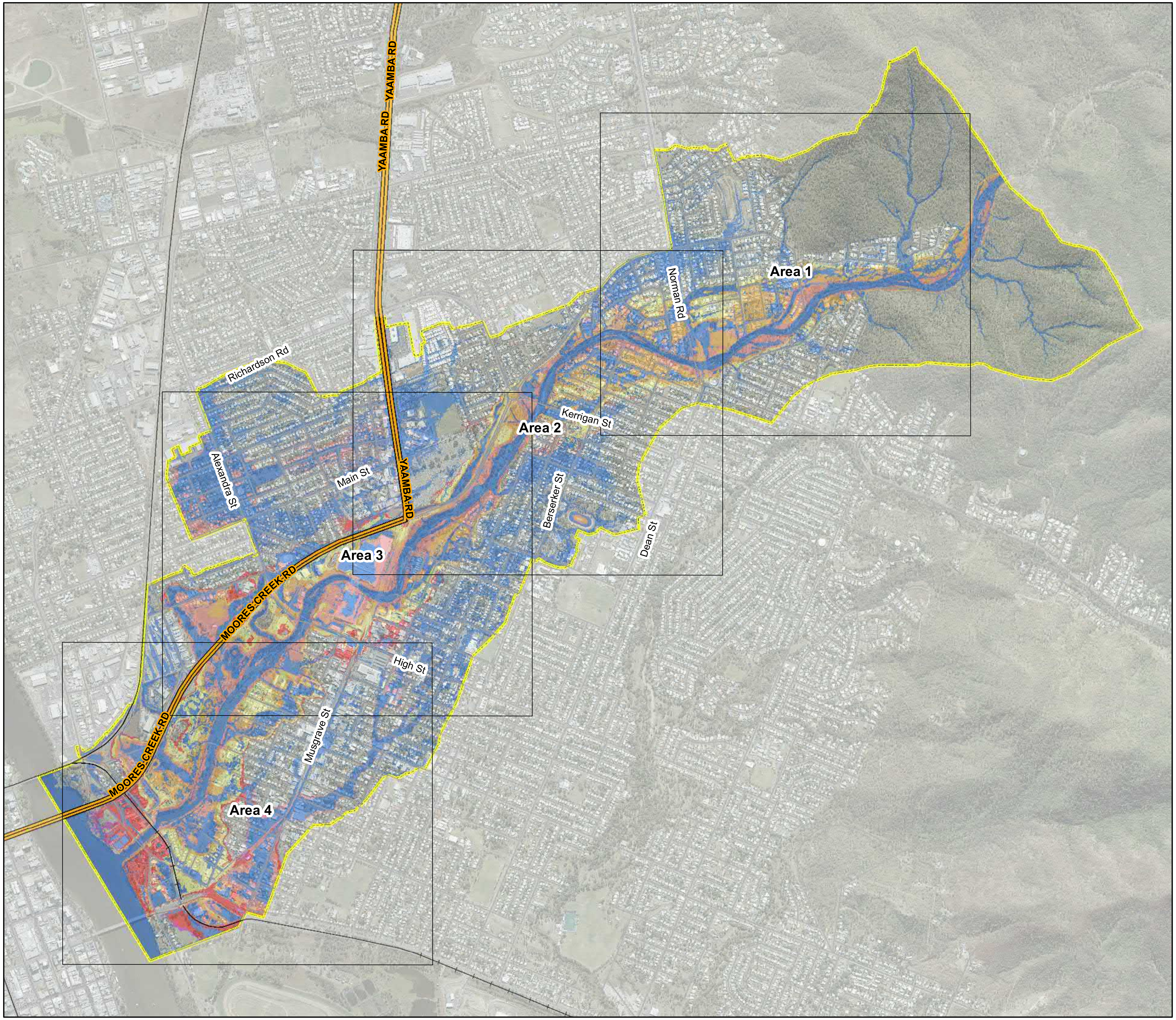


Figure 34 Isolated Area – Kirkellen Street and Bernard Street (Note: PMF flood extents shown)



LEGEND

- Highways
- Railway Lines
- Road Centrelines
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

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

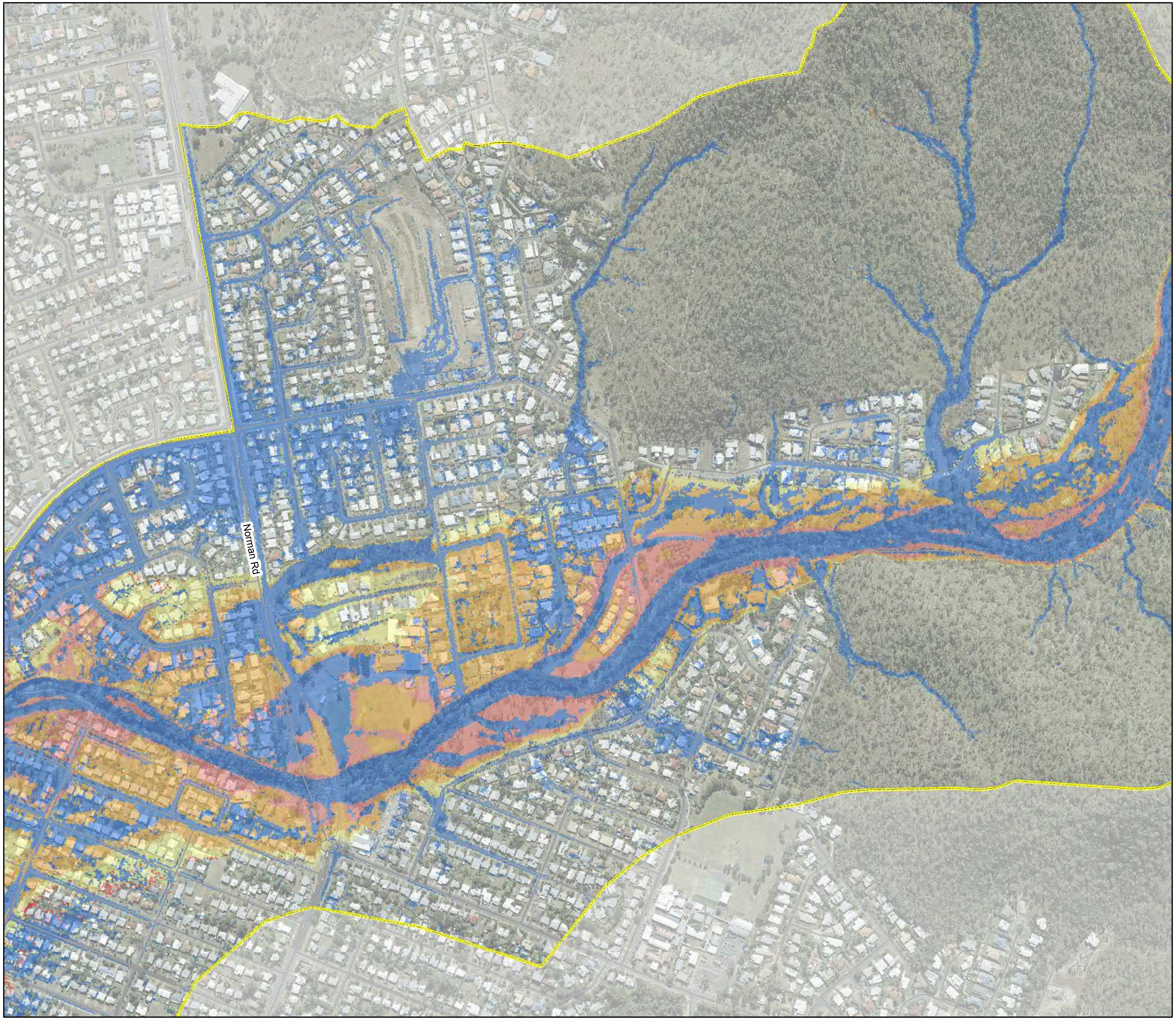
Moores Creek Model
Time of Inundation - Catchment Overview

PMF 180min Storm Event

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 8/08/2017
VERSION: 1

Figure 35

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure30_Phase_2_Inundation_Time.mxd



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0 100 200 300 400

Metres

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LEGEND

- Highways
- Railway Lines
- Road Centrelines
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

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

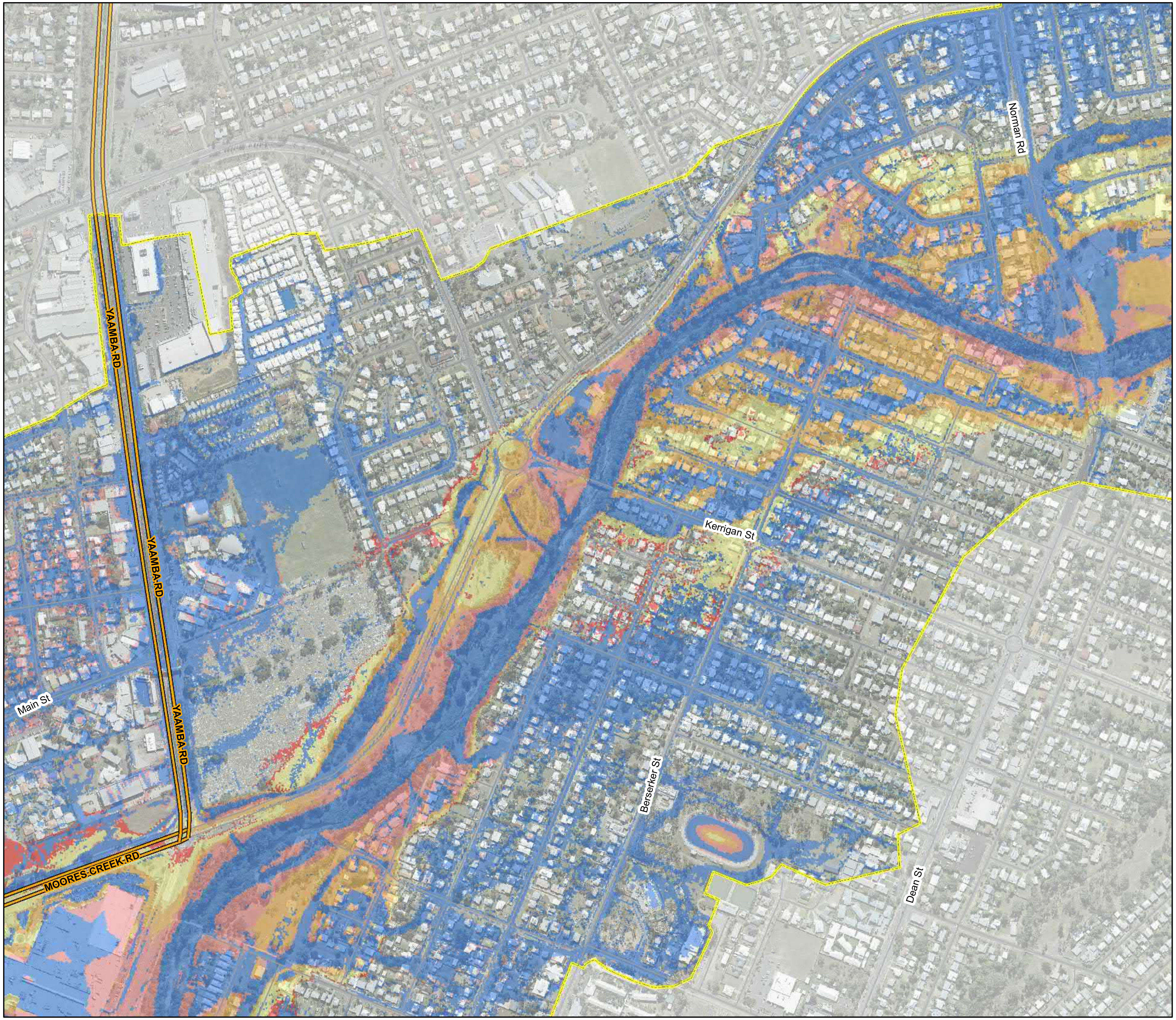
Moores Creek Model
Time of Inundation - Area 1

PMF 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure
36

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure31_Phase_2_Inundation_Time - Area 1.mxd



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Metres

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(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Road Centrelines
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

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

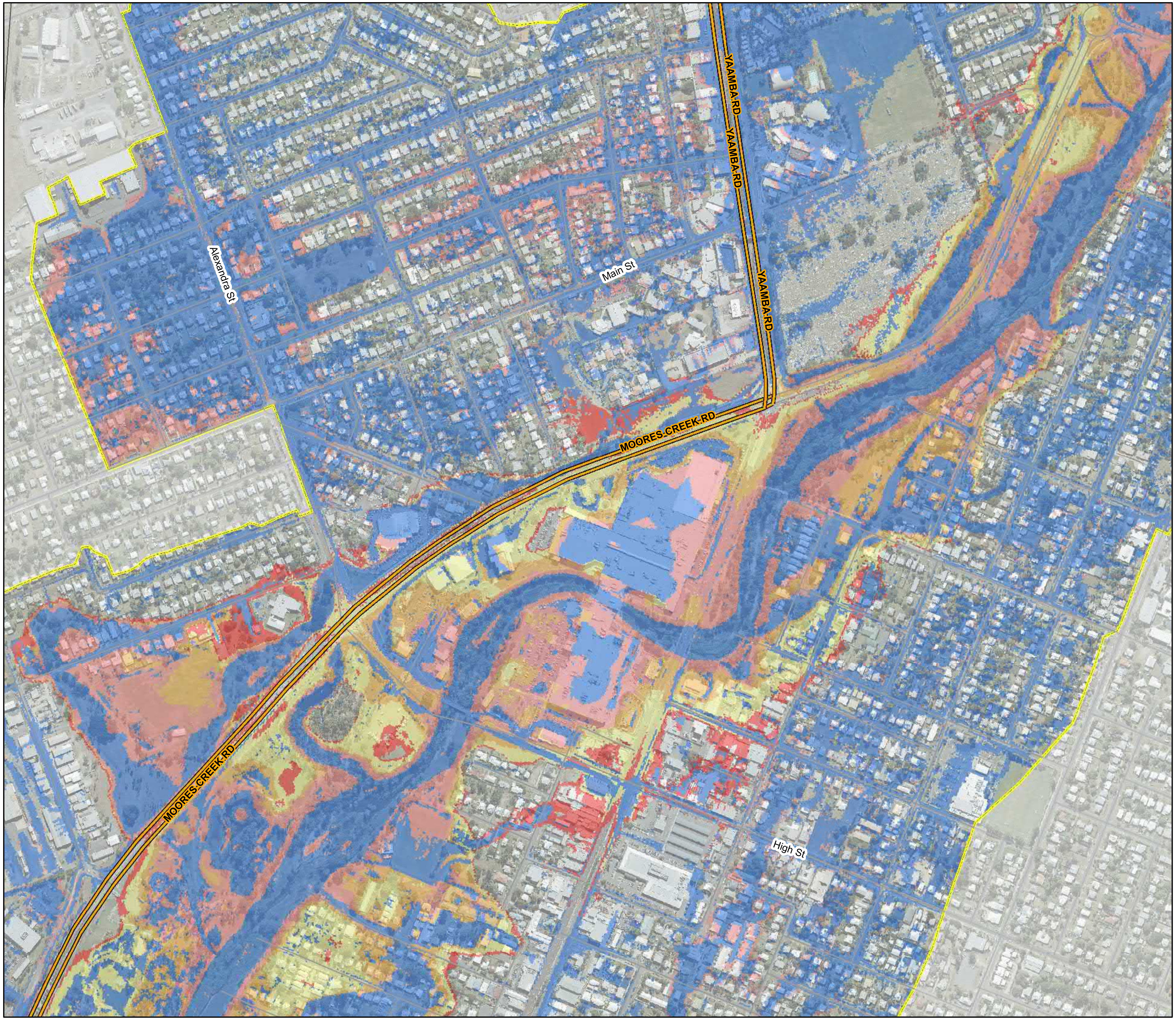
Moores Creek Model
Time of Inundation - Area 2

PMF 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure 37

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure32_Phase_2_Inundation_Time - Area 2.mxd



Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:6,500
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Road Centrelines
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

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

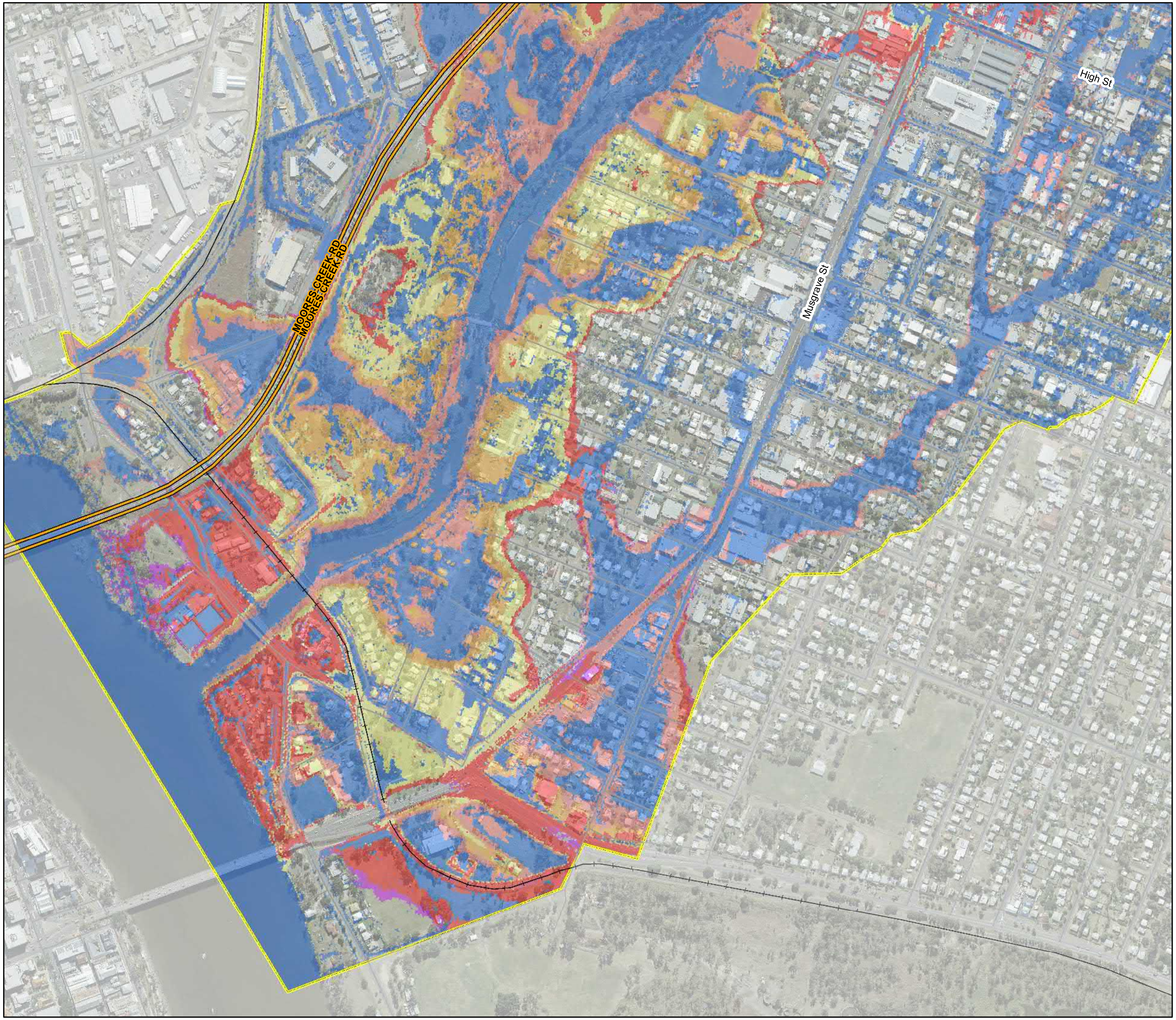
Moores Creek Model
Time of Inundation - Area 3

PMF 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure 38

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Mapping Rev2 (E3)\MC_Figure33_Phase_2_Inundation_Time - Area 3.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:6,500
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Road Centrelines
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

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

Moores Creek Model
Time of Inundation - Area 4

PMF 180min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure 39

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10.6 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 D.

10.6.1 Baseline Building Impact Assessment

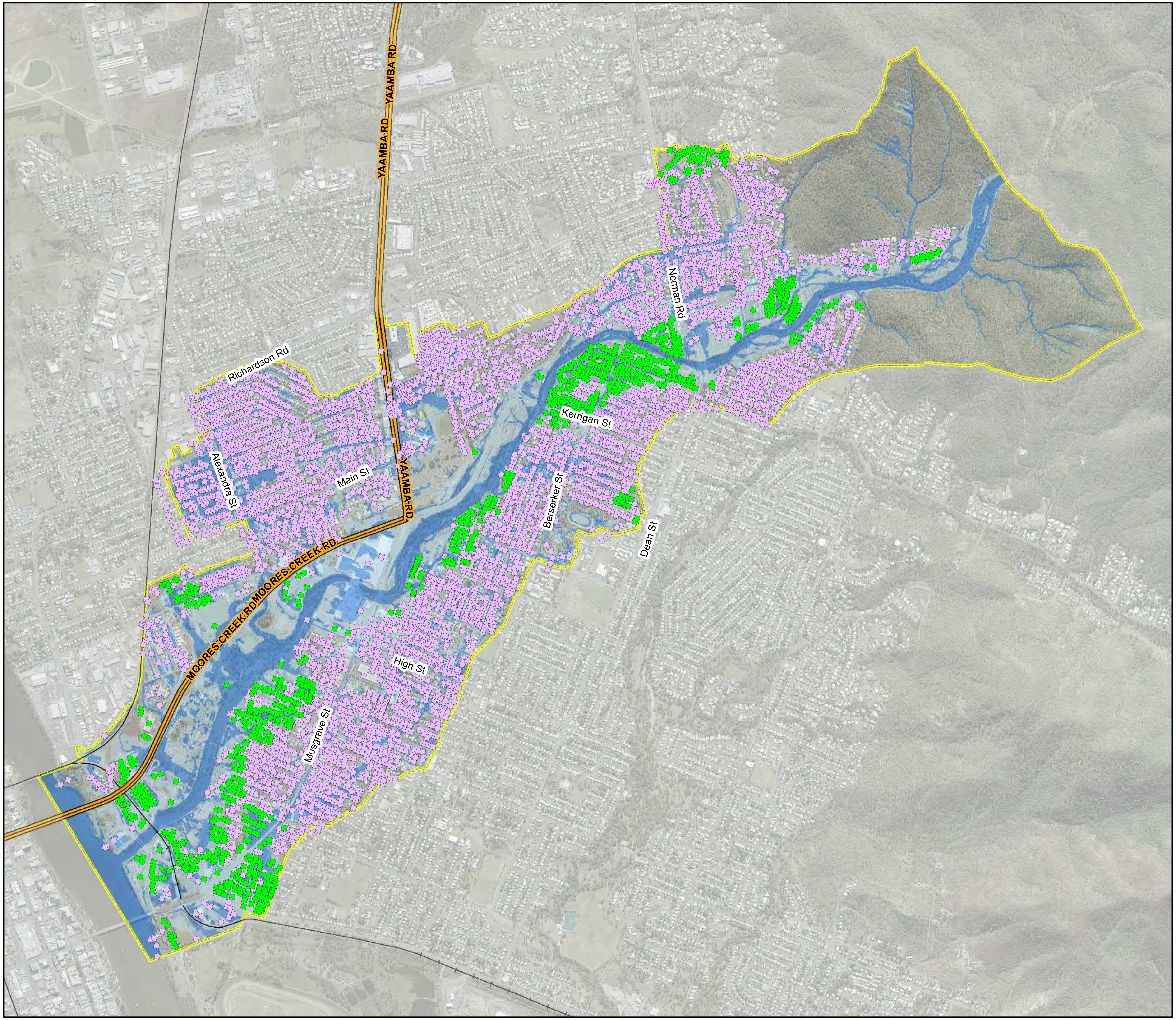
Council provided a building database, containing ~28,000 buildings digitised within the modelled area. Of these, ~5,900 buildings contained surveyed data, focussed on Creek flooding extents in North Rockhampton and Fitzroy River flood extents in South Rockhampton (refer Figure 40).

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

- Review of the digitised buildings, to remove erroneous data such as *footpaths*, *building demolished*, *no building* etc.
- Estimation of floor levels and ground levels for buildings outside Council's surveyed database (~22,100 buildings in total, with ~5,200 within Moores 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 ~6,250 within Moores 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.



N

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

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

FLOOR LEVEL SUMMARY

Surveyed Floor Levels = 1,020
GIS-Derived Floor Levels = 5,237

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

Moores Creek Model
Building Database Summary

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure
40

Table 43 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Moores Creek catchment. These results are also shown graphically in Figure 41.

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 43 № 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	41 (5)	13 (7)
39.4	61 (10)	22 (11)
18.1	107 (27)	31 (18)
10	149 (42)	41 (24)
5	222 (63)	53 (33)
2	273 (77)	61 (42)
1	512 (198)	98 (75)
0.2	677 (295)	121 (95)
0.05	1064 (557)	162 (136)
PMF	2166 (1644)	302 (279)

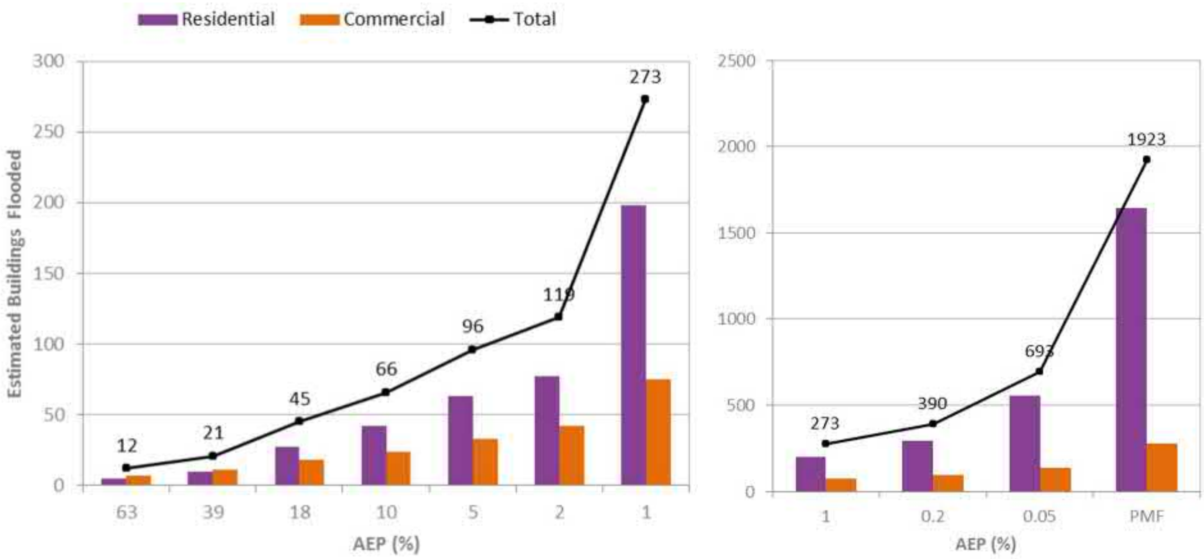


Figure 41 Estimated Buildings with Above Floor Flooding (Number of Buildings)

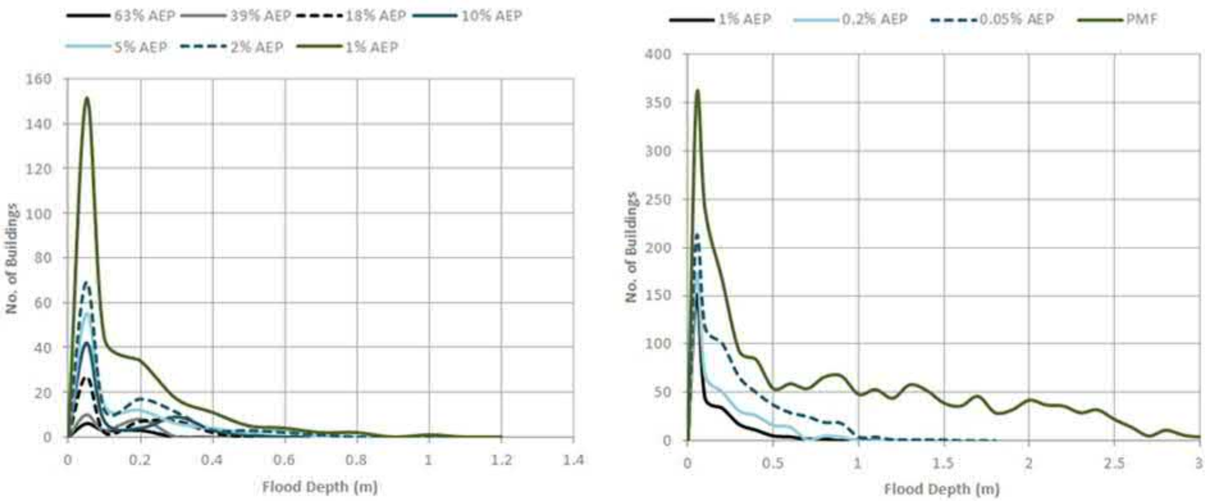


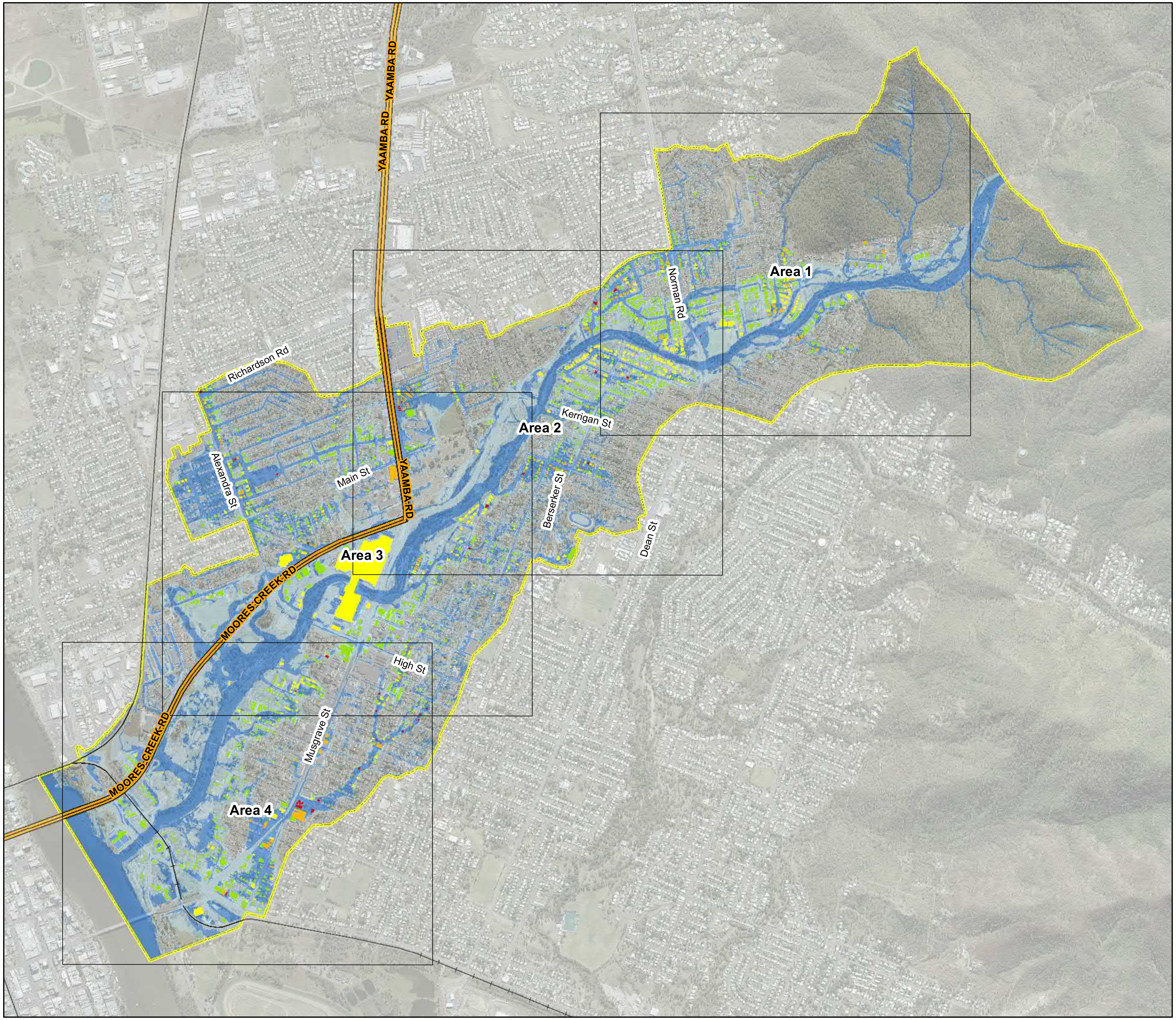
Figure 42 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

As shown in Figure 42, median flood depths are generally less than 0.1 metre for each flood event. This indicates that reductions in flood depths of 0.1 metre could significantly reduce overall damage.

The figure also shows that a significant number of buildings experience flood depths of 0.3 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 43 to Figure 47 shows the location of buildings predicted to experience above floor flooding, grouped by the earliest AEP upon which they become inundated.



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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
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Inundation of Buildings with Above Floor Flooding

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

Flood results are based on local catchment events

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

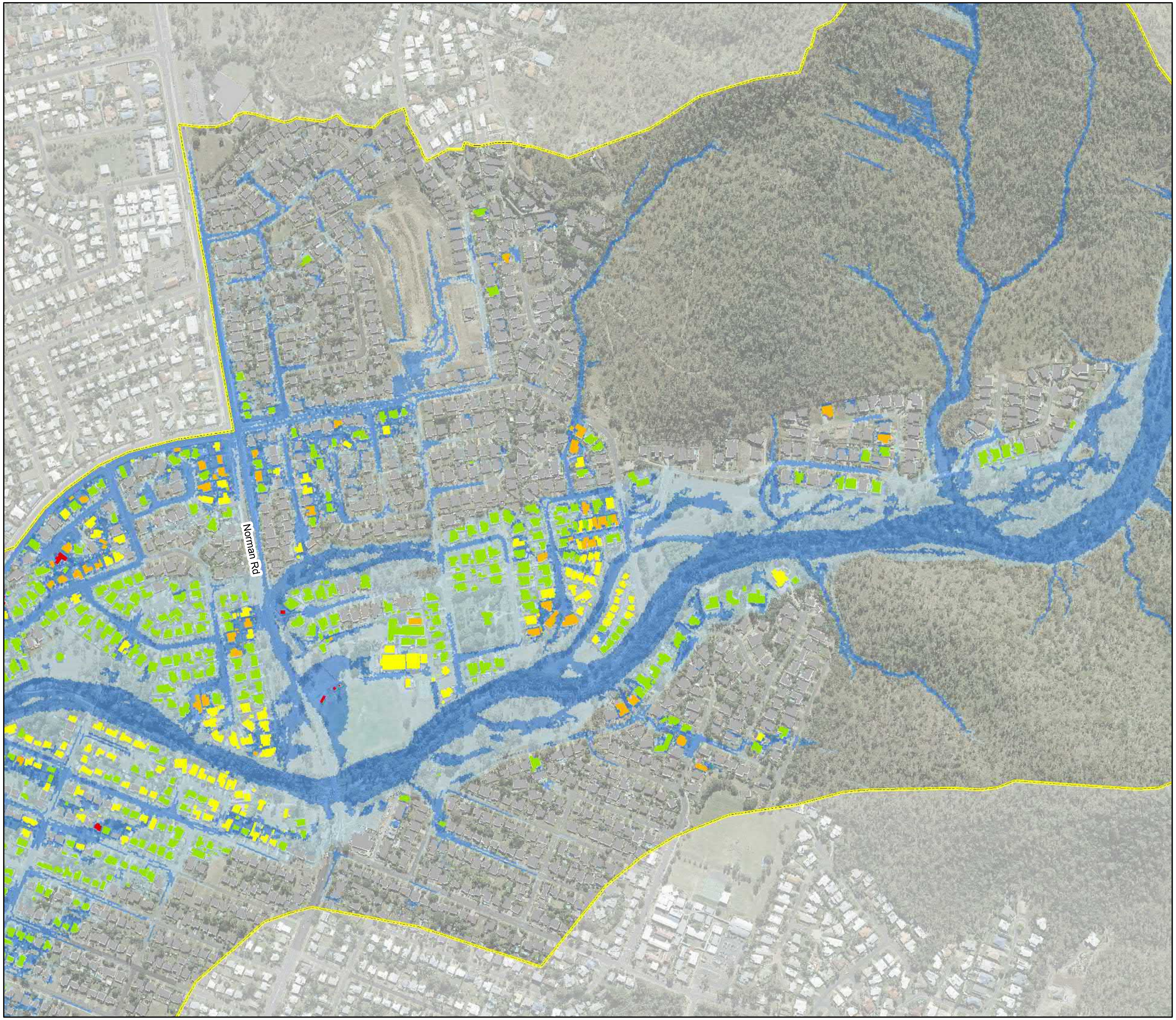
Results Filtering:
75mm Min. Depth
100m² Min. Area

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

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure 43

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure38_Phase_2_Property_Inundation - Catchment Overview.mxd



N

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:6,500
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Inundation of Buildings with Above Floor Flooding

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

Flood results are based on local catchment events

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

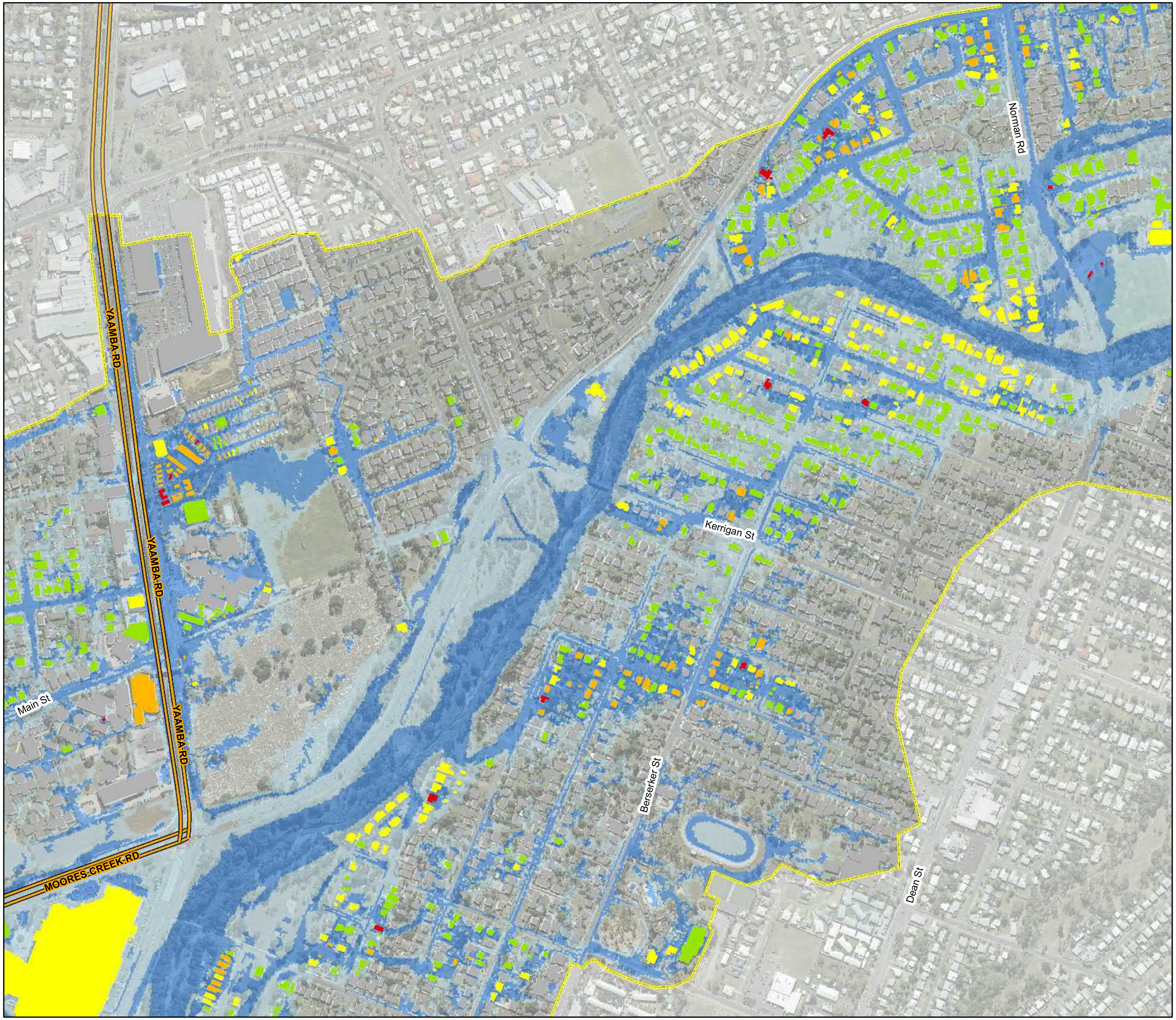
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

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

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure
44

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure39_Phase_2_Property_Inundation - Area 1.mxd



Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400

Metres

1:6,500
(when printed at A3)

AECOM
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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Inundation of Buildings with Above Floor Flooding

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

Flood results are based on local catchment events

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

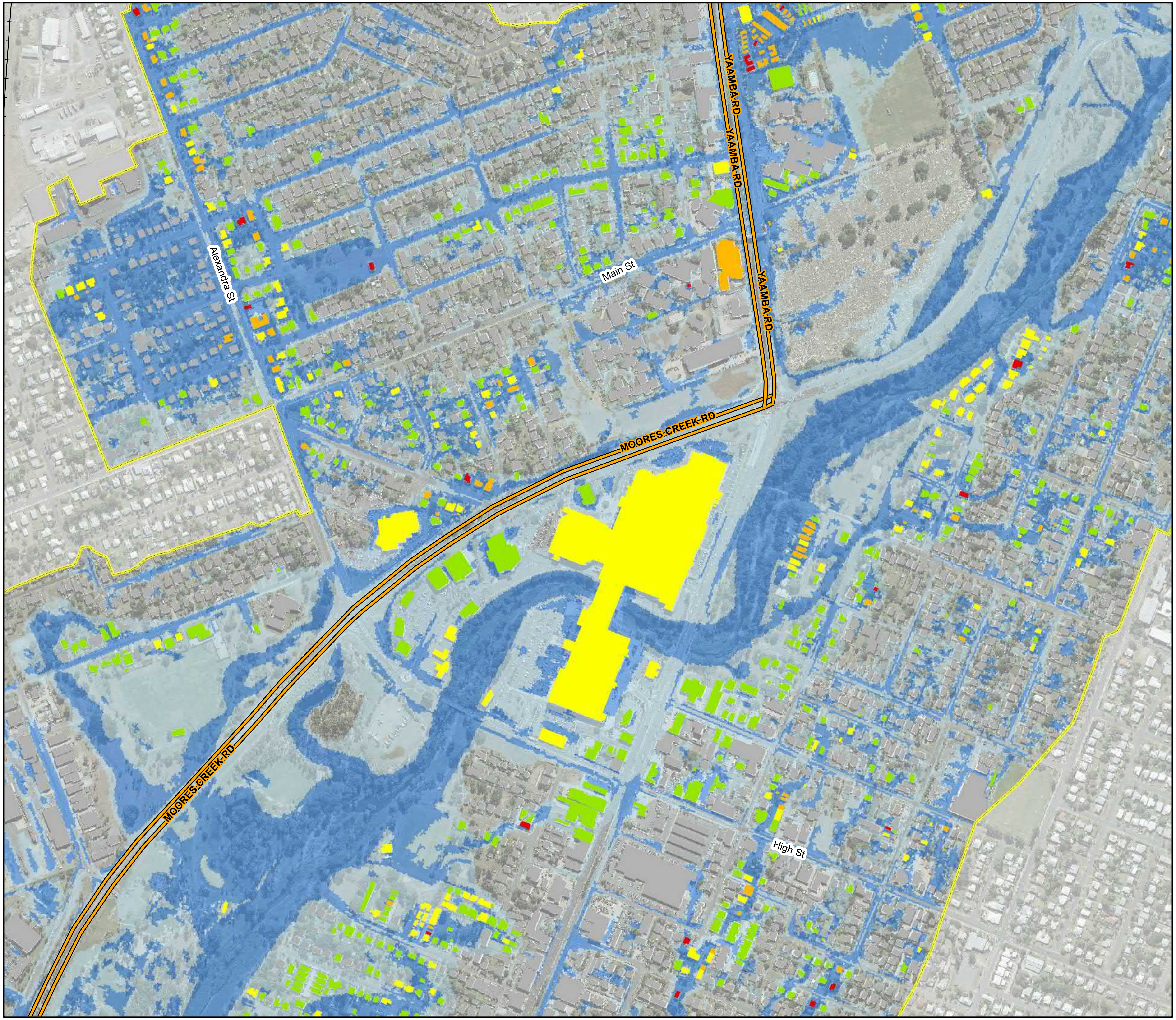
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Moores Creek Model
Inundation of Buildings with Above Floor Level Flooding - Area 2

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure 45

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure40_Phase_2_Property_Inundation - Area 2.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:6,500
(when printed at A3)

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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Inundation of Buildings with Above Floor Flooding

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

Flood results are based on local catchment events

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

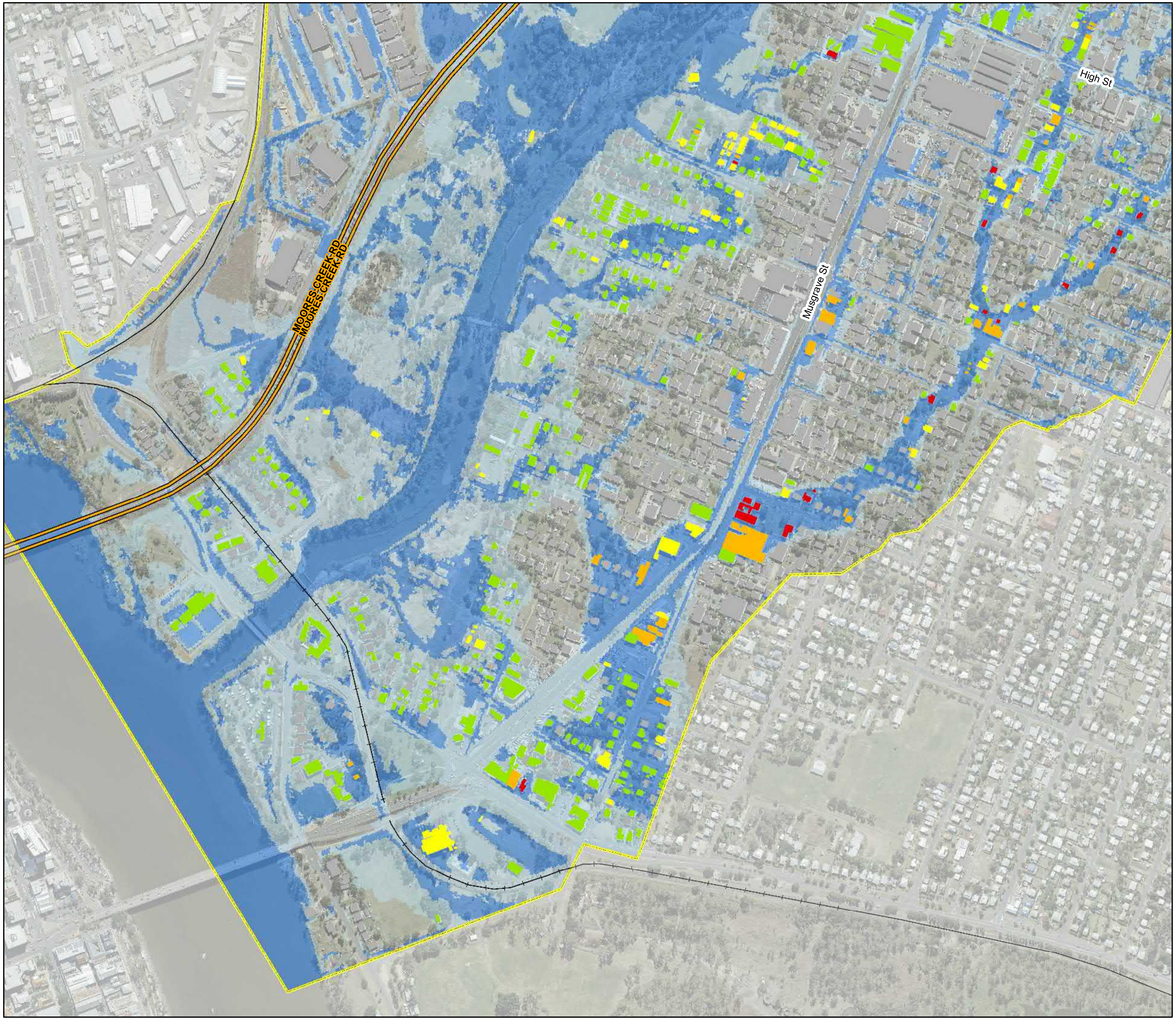
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

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

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/08/2017
VERSION:	1

Figure 46

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure41_Phase_2_Property_Inundation - Area 3.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400
Metres

1:6,500
(when printed at A3)

AECOM
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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Inundation of Buildings with Above Floor Flooding

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

Flood results are based on local catchment events

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

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

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

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 8/08/2017
VERSION: 1

Figure
47

10.6.2 Baseline Flood Damages Assessment

Table 44 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 45 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 44 Summary of flood damages using WRM stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$456	$40	$63	**$559**
39	$746	$157	$112	**$1,015**
18	$1,530	$294	$228	**$2,052**
10	$2,276	$368	$333	**$2,977**
5	$3,947	$520	$565	**$5,032**
2	$5,004	$621	$713	**$6,337**
1	$11,418	$1,891	$1,672	**$14,982**
0.2	$18,368	$2,754	$2,662	**$23,784**
0.05	$39,201	$8,678	$5,953	**$53,832**
PMF	$161,969	$121,700	$32,904	**$316,572**

Table 45 Summary of flood damages using O2 Environmental stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$471	$40	$65	**$576**
39	$773	$157	$116	**$1,045**
18	$1,593	$294	$236	**$2,123**
10	$2,370	$368	$345	**$3,083**
5	$4,102	$520	$585	**$5,207**
2	$5,255	$621	$745	**$6,621**
1	$12,186	$1,891	$1,773	**$15,850**
0.2	$21,535	$2,754	$3,075	**$27,364**
0.05	$51,742	$8,678	$7,589	**$68,009**
PMF	$261,613	$121,700	$45,901	**$429,213**

Figure 48 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

Figure 48 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from $576,000 (1EY flood event) to $429M (PMF event). Figure 41 shows that 12 buildings are expected to be inundated above floor in the 1EY event, whilst 1,923 buildings are anticipated to be inundated above floor in the PMF event.

These figures also demonstrate that Residential buildings make up the large majority of impacted buildings, and consequently estimated flood damages, within the Moores Creek catchment across the full range of design events assessed.

10.6.3 Average Annual Damages

While the above provides an estimate of potential damages during specific flood events, understanding what damages may be expected on an annual basis is often an easier way to relate risk to residents and businesses. As such, the above damages were converted to Average Annual Damages (AAD) based on the likelihood of the flood event and the total estimated damage during that event. The AAD is determined by taking the estimated damage for each AEP event and multiplying it by the likelihood of the event. The process is repeated and AAD values are summed for the total AAD. For instance, the AAD for a 10% AEP event is based on the estimated $3.08M damages and 10% or 0.01 likelihood, corresponding to an AAD of $308,000. As a result, low-likelihood events such as the PMF have minor influence due to their low probability of occurrence.

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

The probability-damage curves used to calculate AAD are displayed in Appendix D. Using the WRM damage curves results in an AAD of approximately **$1,501,000** and using those from O2 Environmental gives an AAD of approximately **$1,607,000**. The difference of approximately 7% provides a relatively narrow range for the estimated AAD.

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

Figure 49 provides a breakdown of the number of buildings inundated in 'creek' and 'overland flow' areas. The graph confirms that the majority of buildings within the catchment (62%) are not inundated up to and including the PMF event. Of the 38% of buildings predicted to experience inundation, approximately half are impacted by overland flow and the other half are impacted by creek inundation.

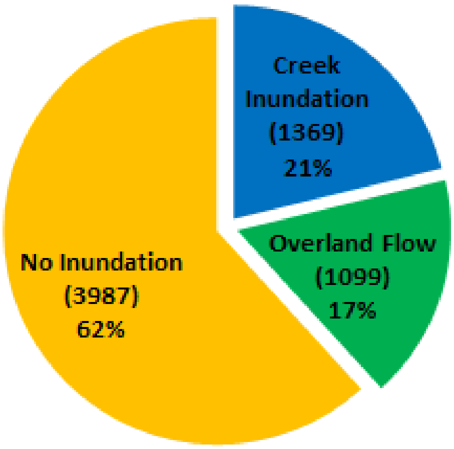


Figure 49 Inundation within Creek and Overland Flow Areas (Number of Buildings)

Figure 50 shows the total AAD split between flooding caused by Moores Creek and flooding which occurs due to overland runoff through urbanised areas of the catchment. It can be seen that approximately 73% of AAD within the Moores Creek catchment is attributed to overland flooding.

This would indicate that mitigation efforts to reduce AAD within the catchment should also be focussed on overland flooding areas, and not just areas within or directly adjacent to the creek.

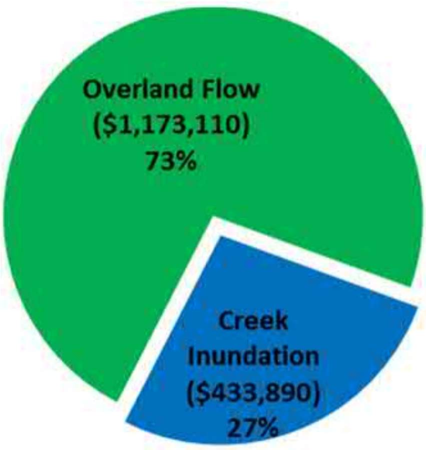


Figure 50 Total AAD within Creek and Overland Flow Areas

Figure 51 shows the breakdown of residential, non-residential and infrastructure AAD over the entire catchment. As shown, a total AAD cost of $1.6M is estimated, with the vast majority (77%) being attributed to residential buildings.

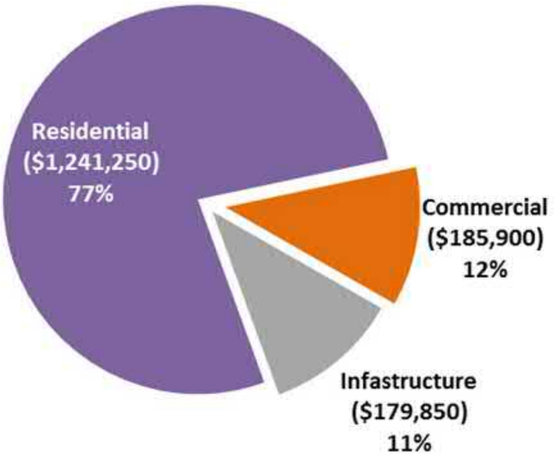


Figure 51 Total AAD by Building Type

Figure 52 and Figure 53 breakdown the AAD for residential and non-residential properties. It can be seen that 88% of residential and 90% of non-residential properties experience a damage cost of less than $500 per annum. As a result, 88% of the total AAD is associated with only 5% of all buildings, or approximately 240 buildings, demonstrating that a minority of buildings produce the majority of damages within the catchment.

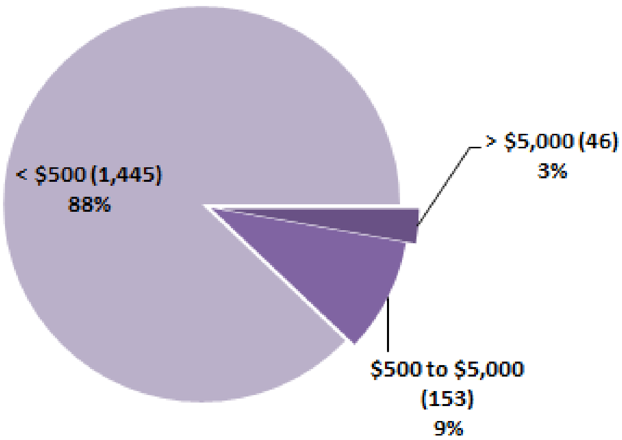


Figure 52 Residential AAD (Number of Buildings)

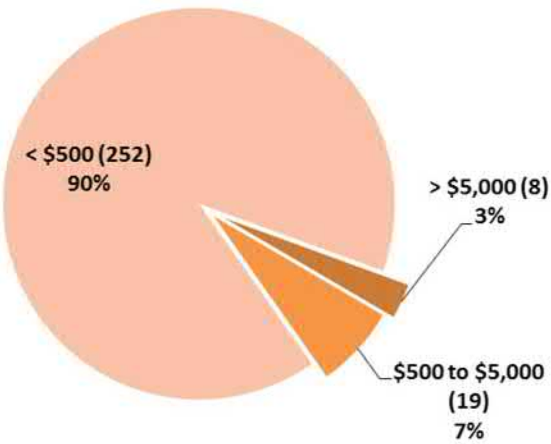


Figure 53 Non-Residential AAD (Number of Buildings)

10.6.4 AAD Summary

Figure 54 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, 88% of all buildings exhibit less than $500 damage per annum and produce only 4% of the total damage, infrastructure damage excluded. In addition 88% of damages are associated with less than 5% of all buildings. Again, this demonstrates that a minority of buildings produce the majority of damages.

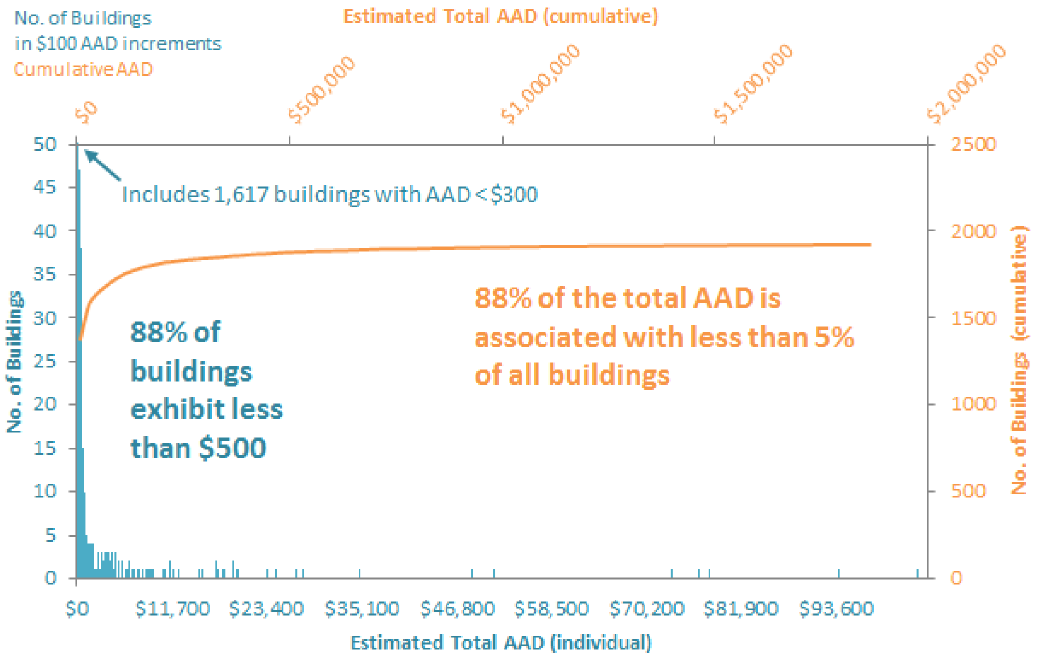


Figure 54 Individual Building vs. Cumulative Total Average Annual Damages

10.7 Rainfall Gauge and Maximum Flood Height Gauge Network Coverage

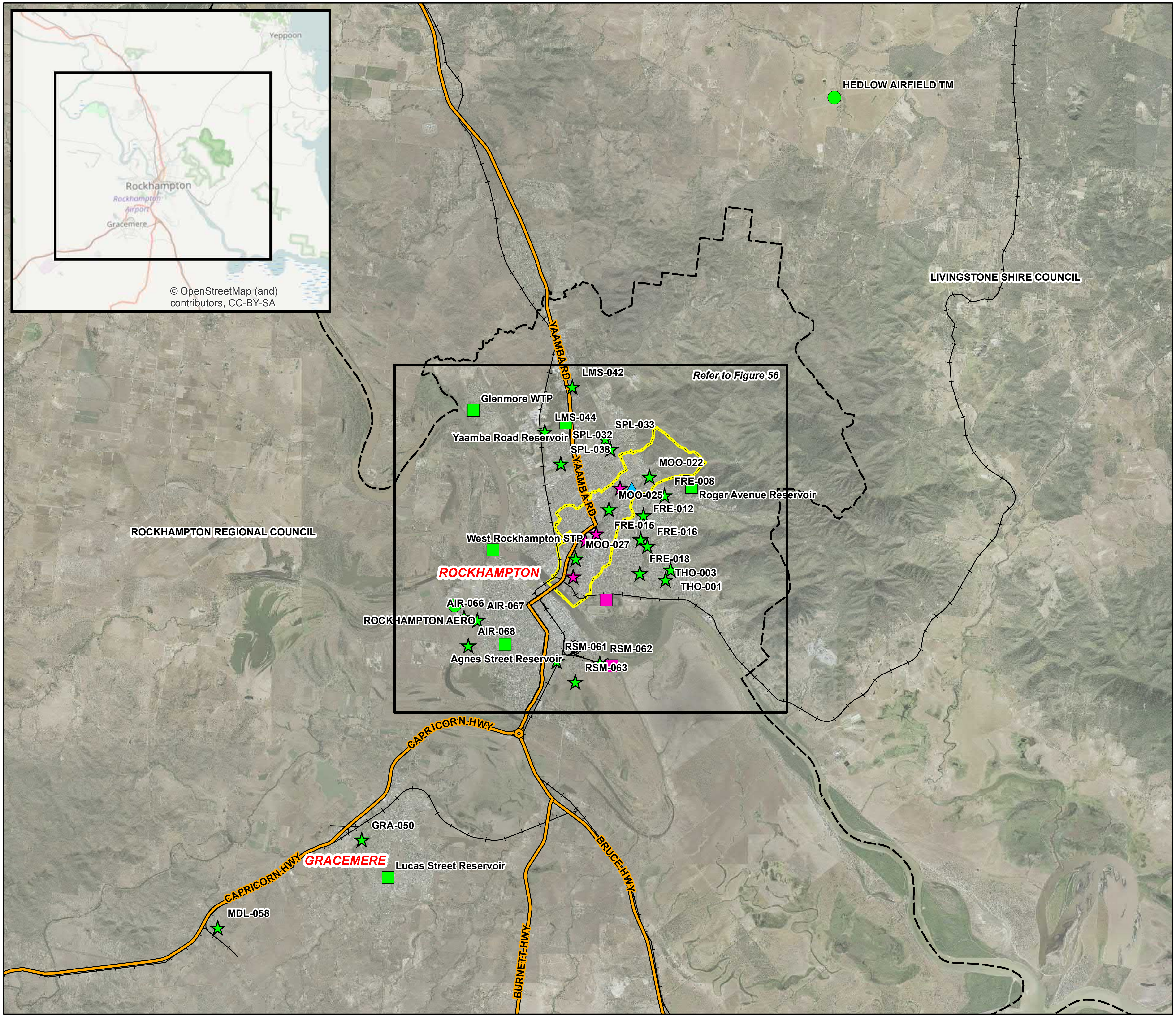
Figure 55 and Figure 56 show the location of existing rainfall gauges within the Rockhampton region, plus Council's maximum flood height gauges.

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 Moores Creek catchment, it is recommended that gauges be installed at the following locations (as shown on Figure 56):
  - Northern end of Berserker Street, at least 50m downstream of the pipe crossing.
  - Western end of Simpson Street (opposite Stockland Shopping Centre), at least 50m either upstream or downstream of the existing pedestrian walkway (floodway).
  - Upstream of the High Street bridge crossing, potentially opposite the Cinema.
  - Western end of Macaree Street, which could be accessed through Council's depot.

10.8 Flood Warning Network Coverage

As noted in Section 2.7, there is currently no flood warning network for the Moores Creek catchment.



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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
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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:

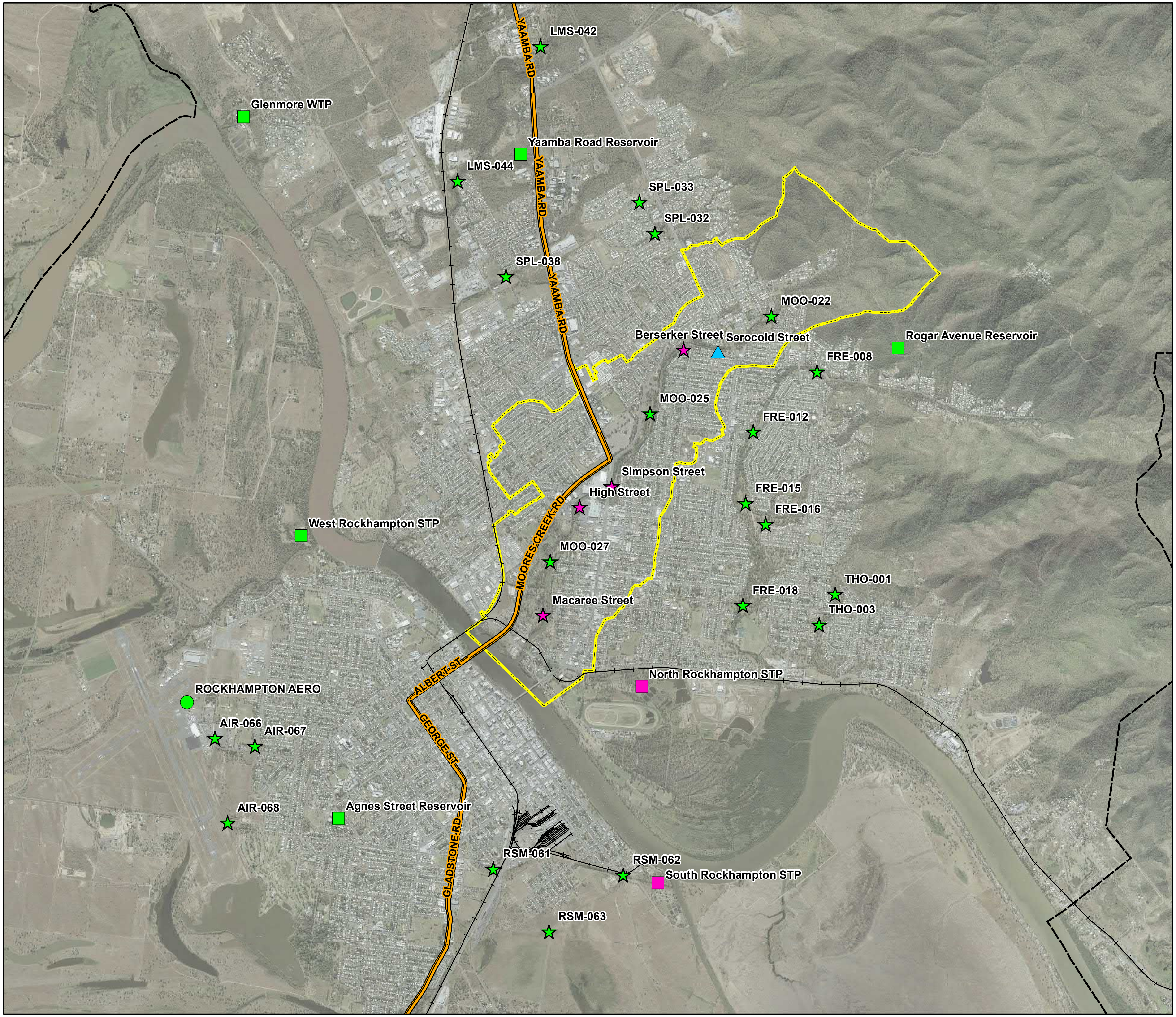
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Moores Creek Model
Rainfall Gauge and Flood Record Network

Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/08/2017
VERSION:	2

Figure 55



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 0.5 1 1.5 2
Kilometers

1:40,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

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

Moores Creek Model
Rainfall Gauge and Flood Record Network

Figure 55 Inset - Rockhampton

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	9/08/2017
VERSION:	2

Figure 56

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure56_Phase_2_Gauges.mxd

11.0 Conclusion

11.1 Baseline Model Development

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

11.1.1 Model Calibration

Anecdotal and recorded data was received and used to calibrate the model to a local flood event caused by TC Marcia in February 2015. Further model validations were undertaken for two other local flood events, namely Ex-TC Debbie in March 2017 and Ex-TC Oswald in January 2013. The model calibrated well to the 2015 event. The validation to the 2017 event resulted in a reasonable comparison between modelled and recorded levels, with some points below tolerance. This was likely due to variability within the spatial distribution of rainfall across orographic features within the catchment.

The validation to the 2013 event revealed the majority of anecdotal records matched simulated levels within tolerance. Locations at which discrepancies exceeded allowable tolerances were expected to be a result of the ever-changing channel geomorphology, making it difficult to validate historic events using the latest terrain data.

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

11.1.2 Design Event Modelling

On completion of the calibration / validation process, various design flood events and durations were simulated and results extracted. The critical duration for the catchment was determined to be the 180 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.

The modelling has confirmed that there are a number of key hydraulic controls within the catchment – particularly the various bridges which cross Moores Creek and the culverts in the area of Sunset Drive, German Street and Norman Road. The area adjacent to the Stockland Shopping centre is also critical, involving several bridge crossings within a high velocity section of the creek reach.

11.1.3 Sensitivity Analysis

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

11.2 Baseline Flood Hazard and Vulnerability Assessment

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

11.2.1 Flood Hazard

As can be seen on maps **MC-70** to **MC-74** the 1% AEP baseline flood hazard within the Moores Creek catchment generally shows:

- Low to medium hazard (H1 and H2) across the majority of urbanised areas within the catchment.
- High hazard (H3 and H4) within a majority of natural and man-made channels, as well as open spaces such as local parks and Kershaw Gardens.
- High to extreme hazard (H4 and H5) within some natural and man-made open channels.

- High to extreme hazard (H4 and H5) in the overland flow path between Elphinstone Street and Musgrave Street, extending to the western side of Musgrave Street into Kirkellen Street.
- Extreme hazard (H5 or H6) within the Moores Creek channel and adjacent overbank areas.

11.2.2 Vulnerability Assessment

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

- The Redhill Sewerage Pump Station (SPS, Ref: 463747) is predicted to have less than 0.2% flood immunity. It is noted however that this SPS is a below ground station and improvements to flood immunity would be very difficult to achieve. It is recommended this information be passed onto FRW as the asset owner.
- Low depth flooding is predicted at Narnia Kindergarten and Preschool in the 0.2% AEP.
- The Yeppoon Branch Rail Line is predicted to have high level flood immunity to Top of Ballast, with inundation only predicted for a short section of rail during the PMF event.
- 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 6 hours.

11.2.3 Evacuation Routes

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

- Danker Street à loses evacuation via Dodgson Street to Norman Road and/or via Rowe Street to Moores Creek Road.
- Warner Avenue à loses evacuation via Cheney Street to German Street.
- Rickart Street and Magee Street à loses evacuation via Waterloo Street to Kerrigan Street.
- Salamanca Street à loses evacuation via Waterloo Street to Kerrigan Street and/or via Stewart Street to Berserker Street.
- Main Street and Medcraft Street (between Twigg Street and Alexandra Street) à loses evacuation via Main Street to Alexandra Street and/or Yaamba Road.
- Kerr Street and Tynan Street (southern end) à loses evacuation via Main Street to Alexandra Street and/or Yaamba Road.
- Cowap Street and Martin Street à loses evacuation to Alexandra Street and/or Main Street.
- Stawell Court and Miles Street à loses evacuation via Victoria Place to High Street.
- Kirkellen Street and Bernard Street à loses evacuation to Queen Elizabeth Drive.

11.2.4 Building Impact Assessment

The building impact assessment shows the following:

- 54 buildings (12 with above floor flooding) predicted to be impacted in the 1EY event.
- 148 buildings (45 with above floor flooding) predicted to be impacted in the 18% AEP event.
- 610 buildings (273 with above floor flooding) predicted to be impacted in the 1% AEP event.
- 2,468 buildings (1,923 with above floor flooding) predicted to be impacted in the PMF event.
- Significant number of buildings with less than 0.3m flood depth in frequent events, such as 1EY.
- Of the 38% of the buildings impacted by flooding, 45% are associated with overland flow.

11.2.5 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:
  - $559,000 to $576,000 damages estimated in 1EY event.
  - $2,052,000 to $2,123,000 damages estimated in 18% AEP event.
  - $14,982,000 to $15,850,000 damages estimated in 1% AEP event.
  - $316,572,000 to $429,213,000 damages estimated in PMF event.
- AAD ranging from **$1,501,000 to $1,607,000** for WRM and O2 damage curves respectively.
- 77% of the total AAD is associated with residential buildings.
- 73% of the total AAD is attributed to overland flooding.
- 88% of residential buildings and 90% of commercial buildings exhibit less than $500 damage per annum.
- 88% of the total AAD is attributed to less than 5% of all buildings.

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

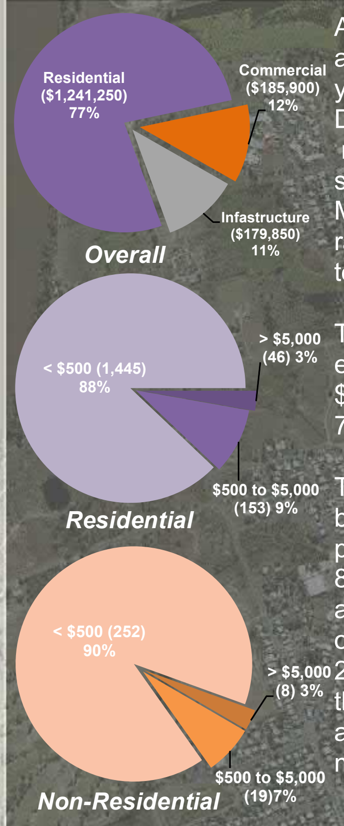
Review of the existing rainfall gauge, maximum flood height gauge and flood warning network yielded the following recommendations/findings for the Moores Creek catchment:

- Additional rain gauges should be installed at NRSTP and SRSTP.
- Additional maximum flood height gauges should be installed at Berserker Street (northern end), Simpson Street (western end), High Street bridge crossing (near Cinema) and Macaree Street (western end).
- There is no current flood warning system within the Moores Creek catchment.

An overview of building impacts and flood damages is provided in Figure 57.

Moores Creek Catchment Overview

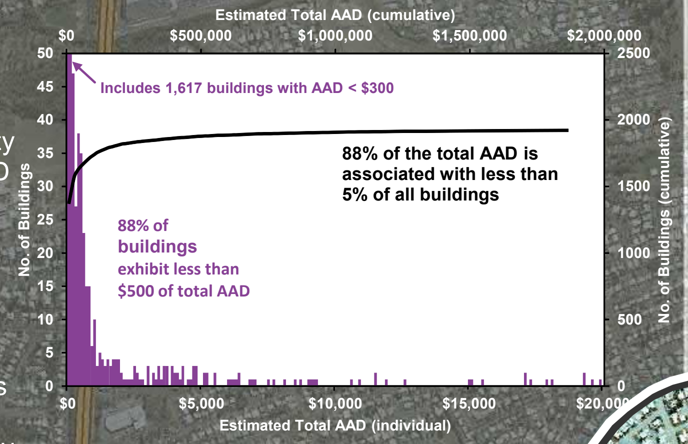
Average Annual Damages



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 Moores Creek catchment is estimated to range from approximately $1,501,000 to $1,607,000 per annum. The difference of approximately 7% provides a relatively narrow range for the estimated AAD.

The vast majority (77%) of AAD is attributed to residential buildings. 88% of residential and 90% of non-residential properties experience less than $500 of AAD. As a result, 88% of the total AAD is associated with only 5% of all buildings (approx. 240 buildings), revealing that a minority of buildings are responsible for the majority of damages.



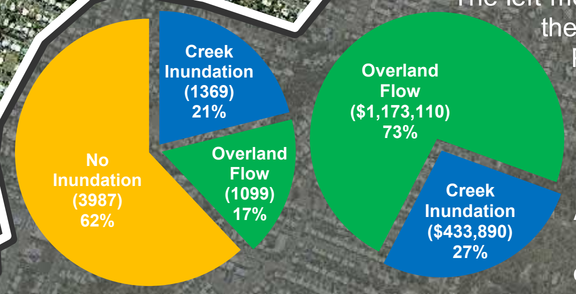
Legend

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

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

Inundation Breakdown



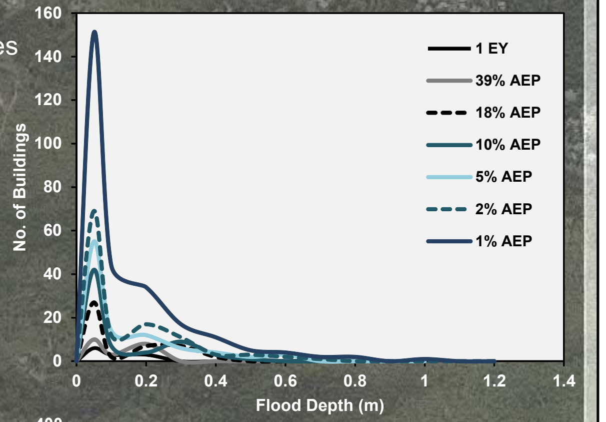
The left-most graph confirms that the majority of buildings within the catchment are not inundated up to and including the PMF event. Of the 38% of the catchment predicted to experience inundation, more than 45% is associated with overland flow.

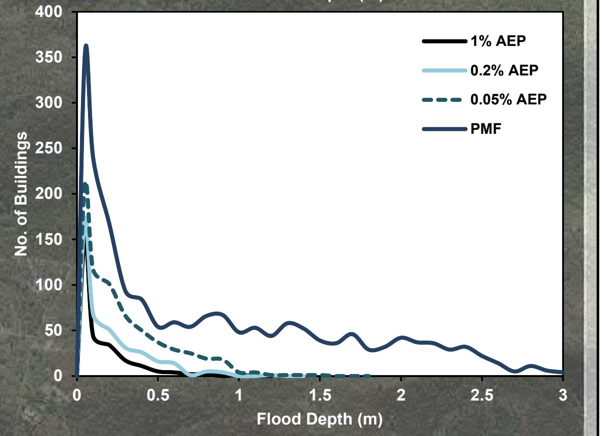
It can further be seen that approximately 73% of AAD within the Moores Creek catchment is attributed to overland flooding. This indicates that mitigation efforts to reduce AAD within the catchment should be focused on overland flooding areas.

Depth of Inundation

Median flood depths are less than 0.1 m for each flood event. This indicates that reductions in flood depths of 0.1 m could significantly reduce overall damage.

The figures also show that a significant number of buildings experience flood depths of 0.3 m or less during frequent events such as the1 EY flood event, generally corresponding to higher flood damages.

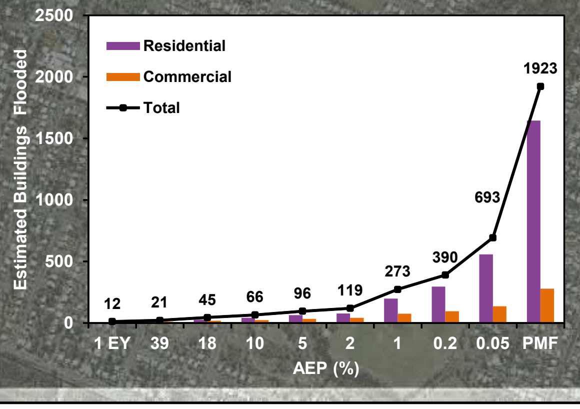


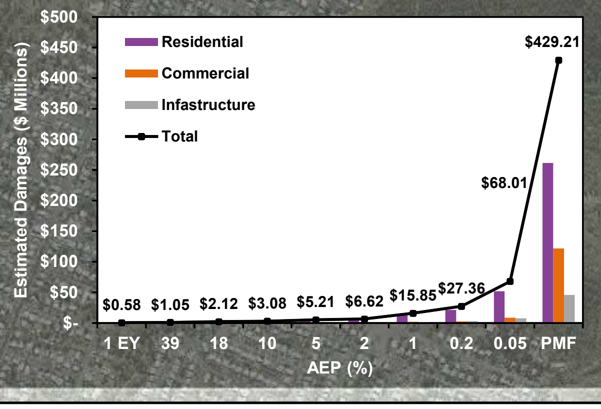


Flood Damages

The figure below provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Moores Creek catchment.

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





Flood results are based on local catchment events

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Moores Creek Publishing\Final Figures\Phase_2\MC_Figure57_Phase_2_Overview.mxd

12.0 Recommendations

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

- Baseline flood mapping (i.e. peak depths, velocities and water surface elevations) provided in this study should be used to update Council's current Planning Scheme layers, at the next available opportunity.
  - Final post-processing of the GIS flood layers is recommended in accordance with the procedures outlined in the ARR, Data Management and Policy Review (AECOM, 2017).
  - Appropriate freeboard provisions should be included, based on the findings of the sensitivity analyses outlined in this study.
- 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 Moores Creek catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained.
- It is recommended that Council continue to record rainfall and flood heights associated with future Moores 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.
- Updated creek cross sectional survey should be undertaken after major flood events, and prior to undertaking future updates to this study. It is recommended that cross sections be surveyed at the same locations undertaken in this study to assess longer term geomorphic changes, and potential implications to flood behaviour.
- 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.

13.0 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), Moores Creek Hydrologic and Hydraulic Modelling Report, prepared by Aurecon Australia Pty Ltd, 2014.

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

Appendix A

Hydraulic Model Development

Appendix A Hydraulic Model Development

Model Setup Parameters

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

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

One-Dimensional Network Development

As detailed in Section 3.6, RRC provided a large amount of data related to the existing stormwater drainage network within the study area. Underground pipes were incorporated into the model as 1D elements, which are dynamically linked to the 2D domain via pit and outlet structures. All pits have been represented using assumed dimensions of 900 mm by 600 mm. Pit inlet elevations have been adopted using surveyed levels where possible and corresponding LiDAR levels where data gaps exist.

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

Bridge Structure Losses

Bridges were digitised as 2D layered flow constrictions. Standard form loss coefficients were calibrated using HEC-RAS models. Losses in the TUFLOW model were increased / decreased based on the velocity head in order to better match the head loss predicted across the bridge structure in the HEC-RAS model.

Model Topography

Base model topography was derived from LiDAR survey flown in 2016 and supplied by RRC. The data was supplied as a 1 m resolution Digital Elevation Model (DEM). Within reference to Figure 59, a number of surveyed levels have been obtained and incorporated into the model:

- Moores Creek channel cross-sections.
- Stockland Shopping Centre carparks.

Surveyed cross-sections through areas of dense vegetation compared to the LiDAR elevations and incorporated into the model using 2d_zsh layers to lower the vegetated areas (visible in the imagery) by the calculated discrepancies. Cross-sections across areas of combined scour and dense vegetation were digitized within the model through tinning the surveyed cross-section back to LiDAR elevations upstream and downstream of the surveyed cross-section. Examples instances of the ‘before and after’ creek channels are presented below in Figure 58.

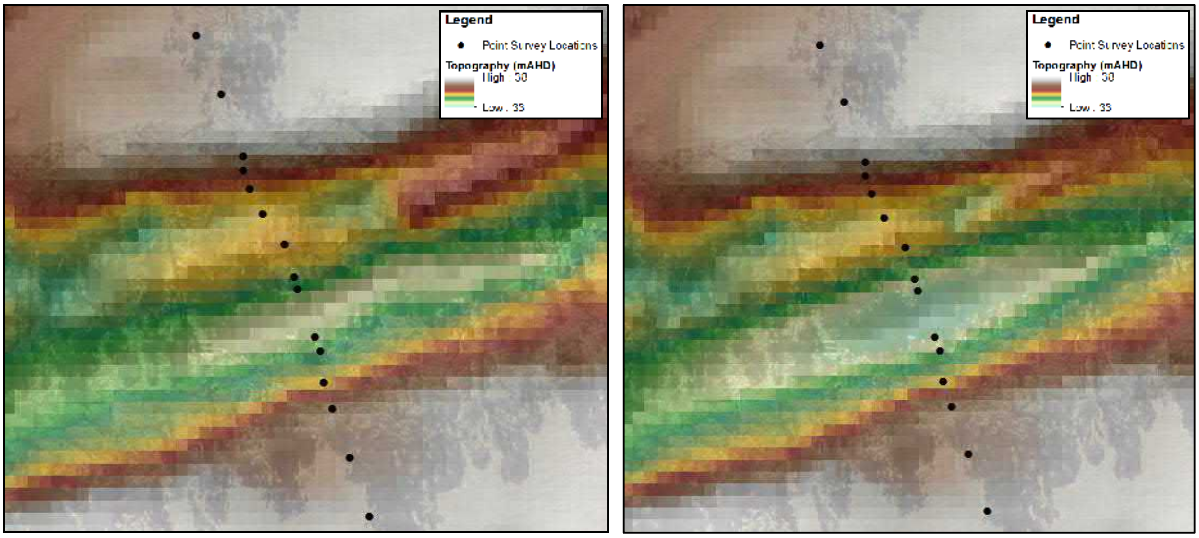
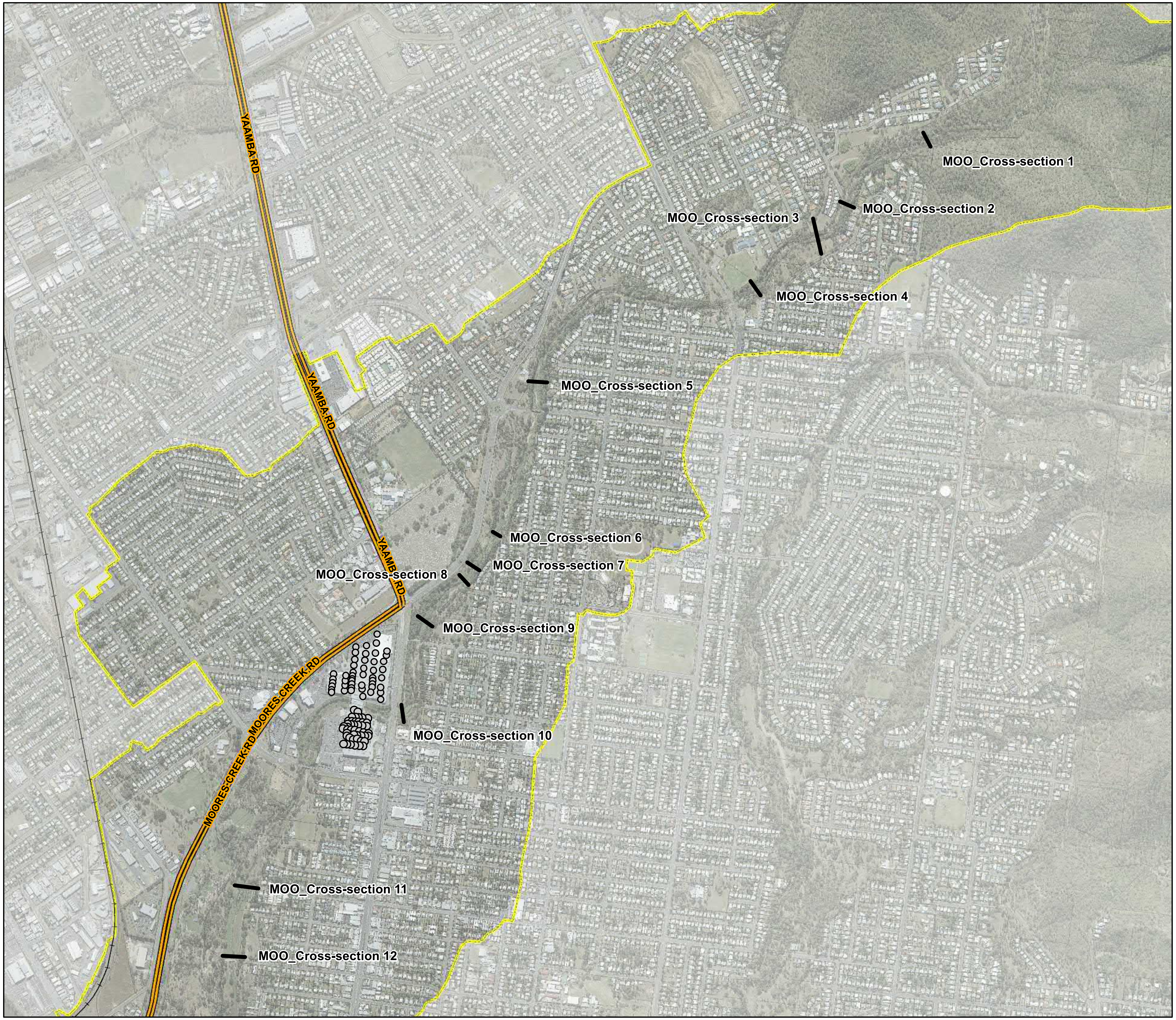


Figure 58 Model Topography using LiDAR (left) versus Model Topography using LiDAR + Survey (right)



Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Stocklands Shopping Centre Carpark Survey
- Cross-section Survey Locations
- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

Moores Creek Model

Cross-section Survey Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	4/08/2017
VERSION:	2

Figure
59

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

Hydraulic Roughness and Losses

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

Specific roughness values for each category as applied in the model are outlined in Table 46.

Table 46 Adopted Roughness Values

Material Description	Manning's 'n'			
	Depth 1 (m)	Manning's 'n' 1	Depth 2 (m)	Manning's 'n' 2
High Density Residential	0.1	0.07	0.3	0.15
Low Density Residential	0.1	0.05	0.3	0.09
Commercial/Industrial	0.1	0.03	0.3	0.06
Dense Vegetation	0.1	0.09	0.3	0.06
Medium Vegetation	0.1	0.075	0.3	0.05
Light Vegetation	0.1	0.06	0.3	0.045
Channel with Rocks and Pools	0.05			
Riparian Corridor	0.07			
Maintained grass	0.035			
Road Reserve	0.025			
Fitzroy River Bed (at DS boundary)	0.022			
Smooth Channel Used for lower reaches	0.035			
Channel: Cobbles with few boulders	0.04			
Medium Density Residential	0.1	0.06	0.3	0.12
Rail Reserve	0.03			
Buildings	0.1	0.018	0.3	0.5
Open space	0.1	0.04	0.3	0.03
Dense rock / trees throughout meandering channels on steep slopes	0.1	0.09	0.5	0.075

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

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

The initial losses and continuing losses applied to this model are indicated below in Table 47.

Table 47 Adopted Initial and Continuing Loss Values

Material Description	Initial Loss (mm)	Continuing Loss (mm/h)
High Density Residential	7.5	0.5
Low Density Residential	7.5	0.5
Commercial/Industrial	7.5	0.5
Dense Vegetation	15	1
Medium Vegetation	15	1
Light Vegetation	15	1
Channel with Rocks and Pools	0	0
Riparian Corridor	0	0
Maintained grass	15	1
Road Reserve	0	0
Fitzroy River Bed (at DS boundary)	0	0
Smooth Channel Used for lower reaches	0	0
Channel: Cobbles with few boulders	0	0
Medium Density Residential	7.5	0.5
Rail Reserve	15	1
Buildings	0	0
Open space	15	1
Dense rock / trees throughout meandering channels on steep slopes	15	1

Initial Conditions

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

Boundary Conditions

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

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

Direct rainfall has been applied to the 2D domain; background to this approach is described in Section 4.1. The QT inflow boundaries apply the predicted inflow over time as generated by the XP-RAFTS hydrologic model for the catchment area external to the 2D domain. HQ type boundaries allow flood waters to discharge from the model relative to the water surface elevation. Using a downstream slope value established using the 1 m DEM, TUFLOW automatically generates a height versus discharge curve (rating curve) which is applied to the model boundary. A HT boundary applies a water level to the boundary cells based on a water level versus time curve. MHWS was adopted for design events and historic tidal data during the calibration and validation events was adopted for the Fitzroy River channel.

A summary of the boundary conditions applied to the three models are summarised in Table 48.

Table 48 Summary of Boundary Conditions

Boundary Type	Details
Direct rainfall	Applied across entire 2D domain
QT	Inflows for the external catchment of Mount Archer National Park (northeast)
HT	Fitzroy River outflow boundary (south-western boundary)
HQ	· 6 outflow boundaries applied along the north-western model boundary · 3 outflow boundaries applied along the south-western model boundary · 7 outflow boundaries applied along the eastern model boundary

Appendix B

Surveyed Cross-section Comparison

Appendix B Surveyed Cross-section Comparison

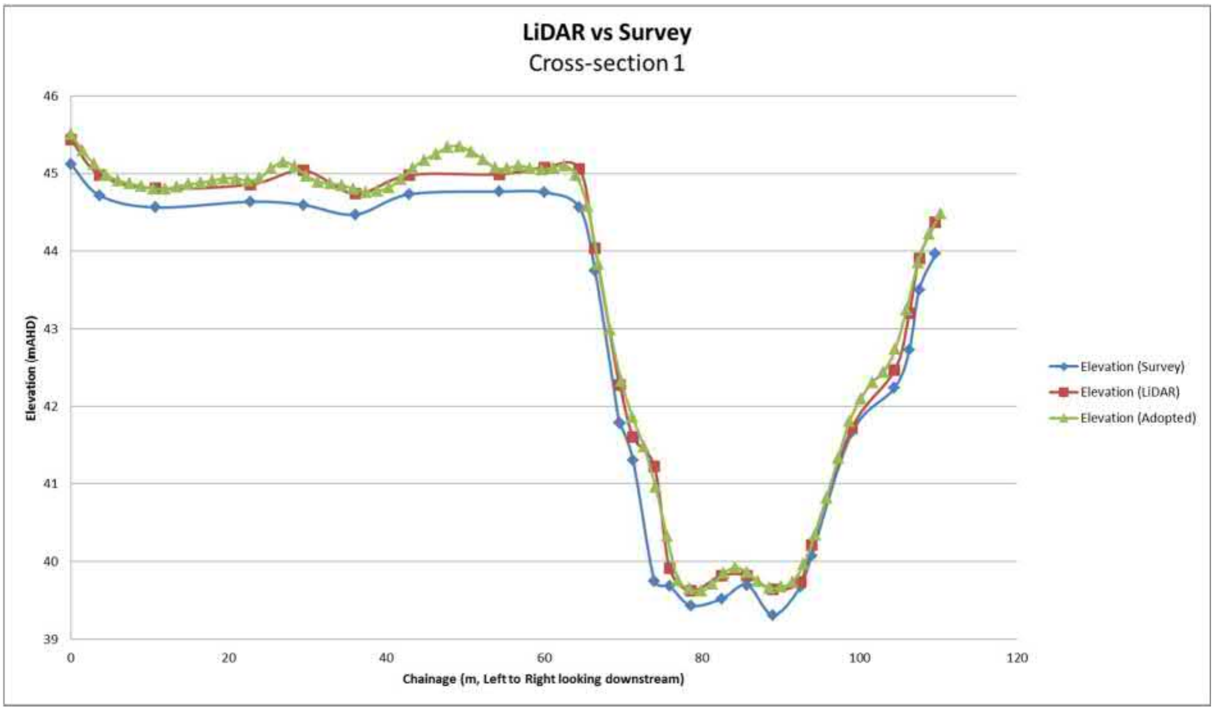


Figure 60 LiDAR verses Survey comparison at Cross-section 1

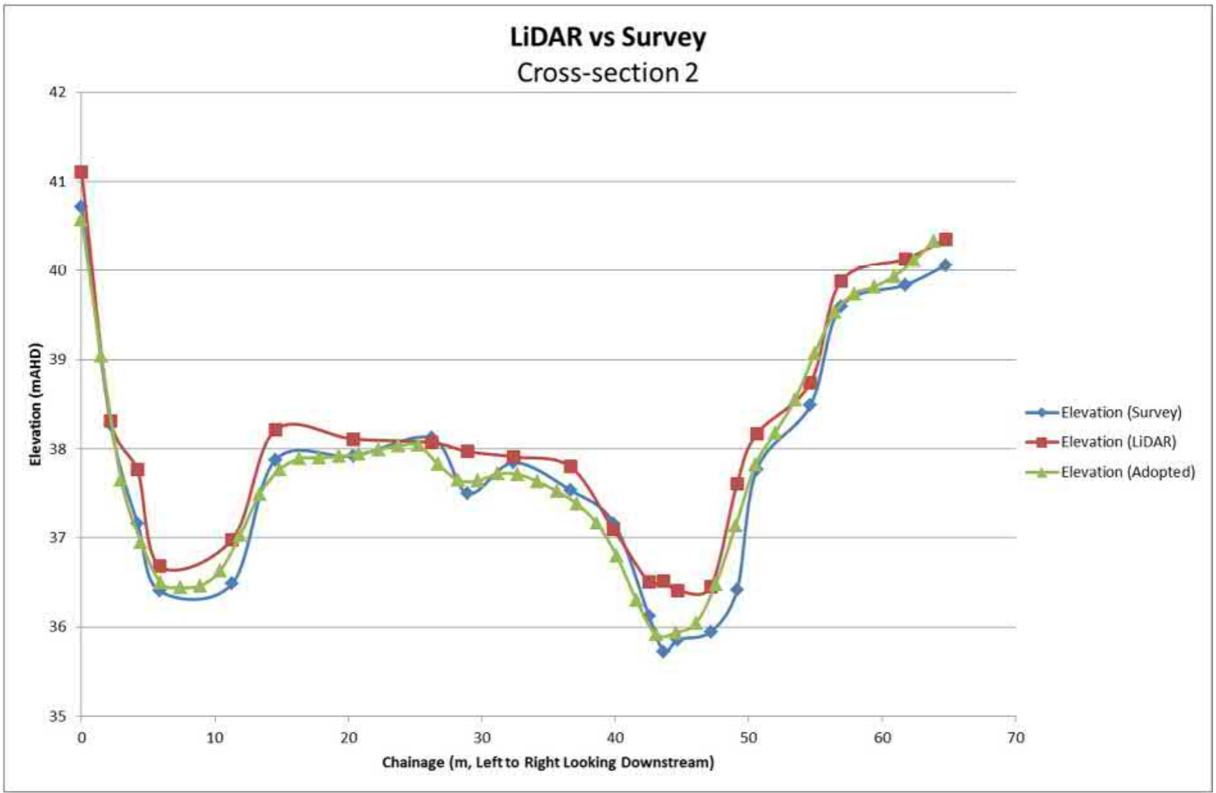


Figure 61 LiDAR verses Survey comparison at Cross-section 2

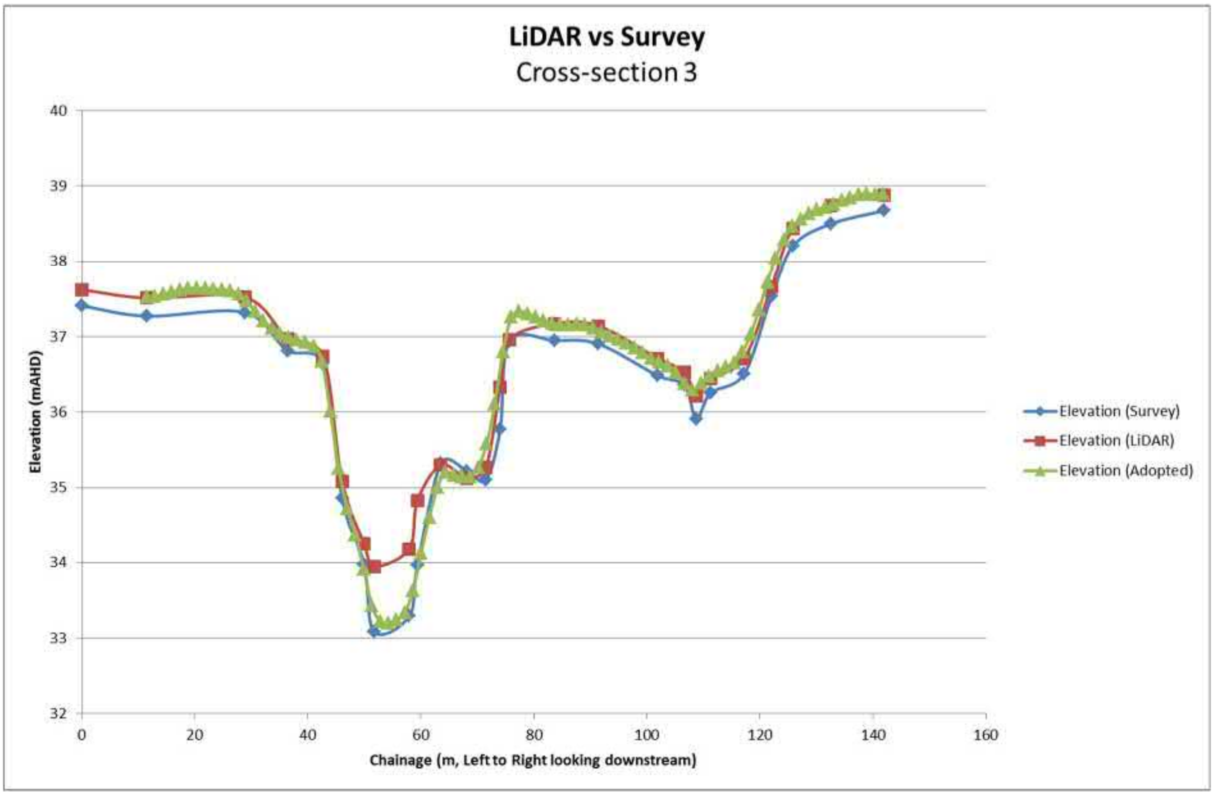


Figure 62 LiDAR verses Survey comparison at Cross-section 3

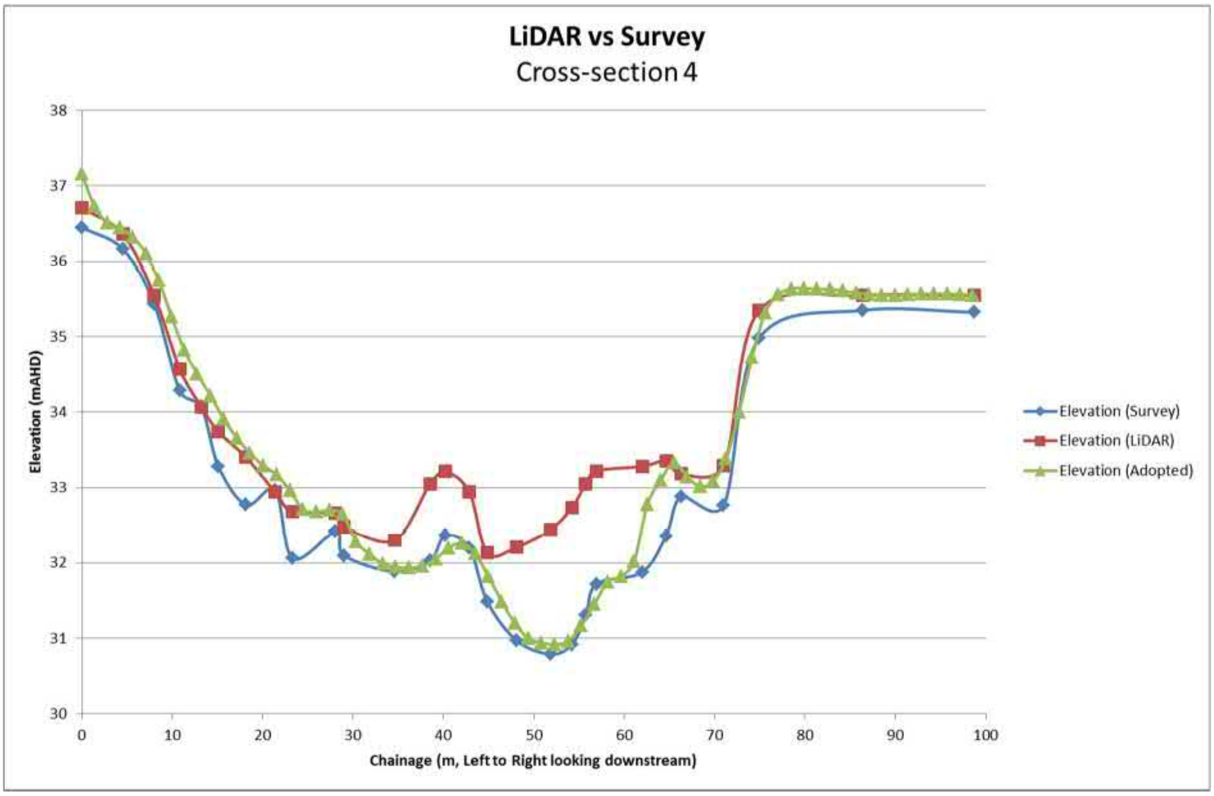


Figure 63 LiDAR verses Survey comparison at Cross-section 4

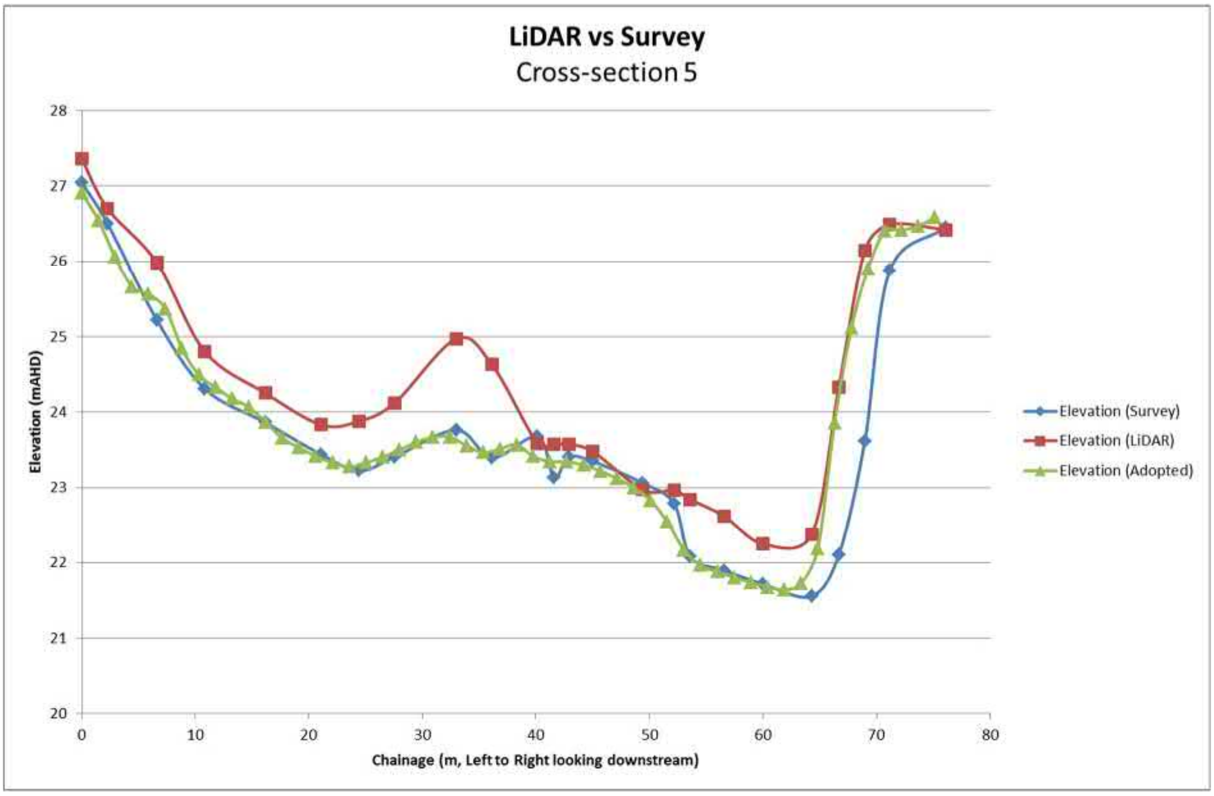


Figure 64 LiDAR verses Survey comparison at Cross-section 5

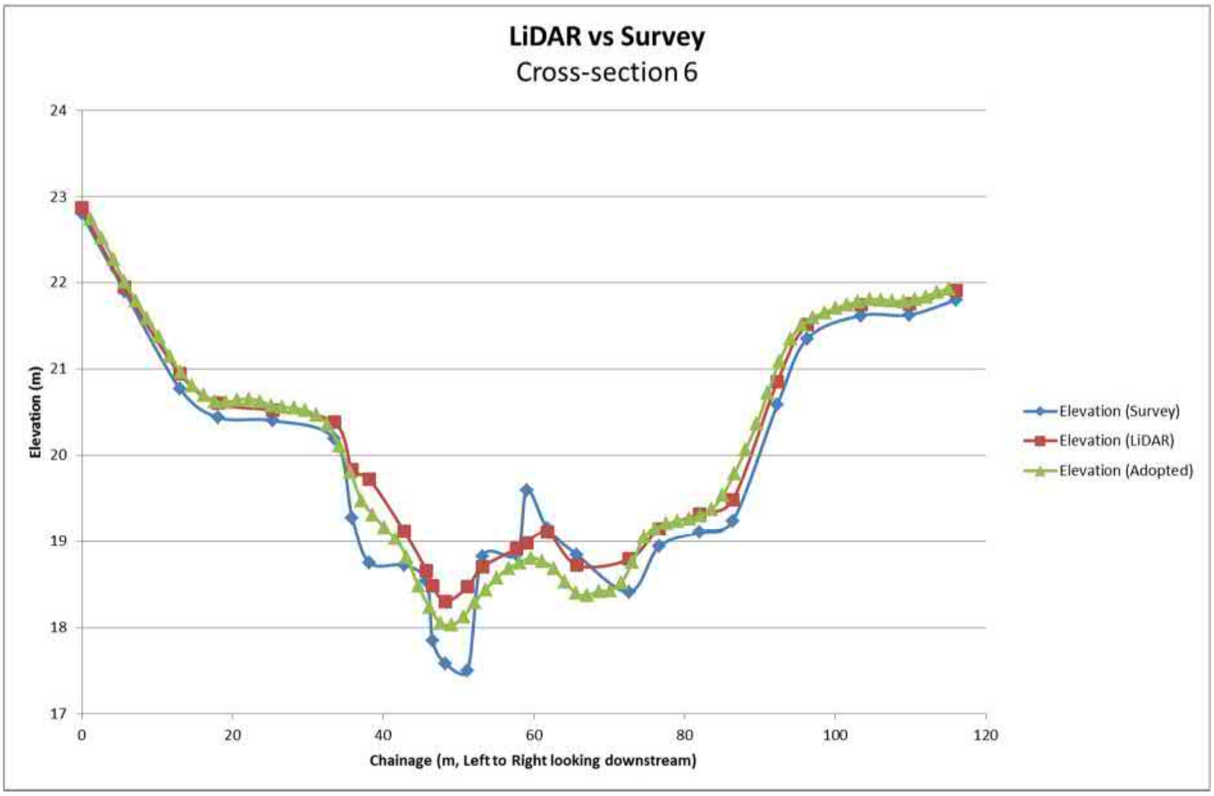


Figure 65 LiDAR verses Survey comparison at Cross-section 6

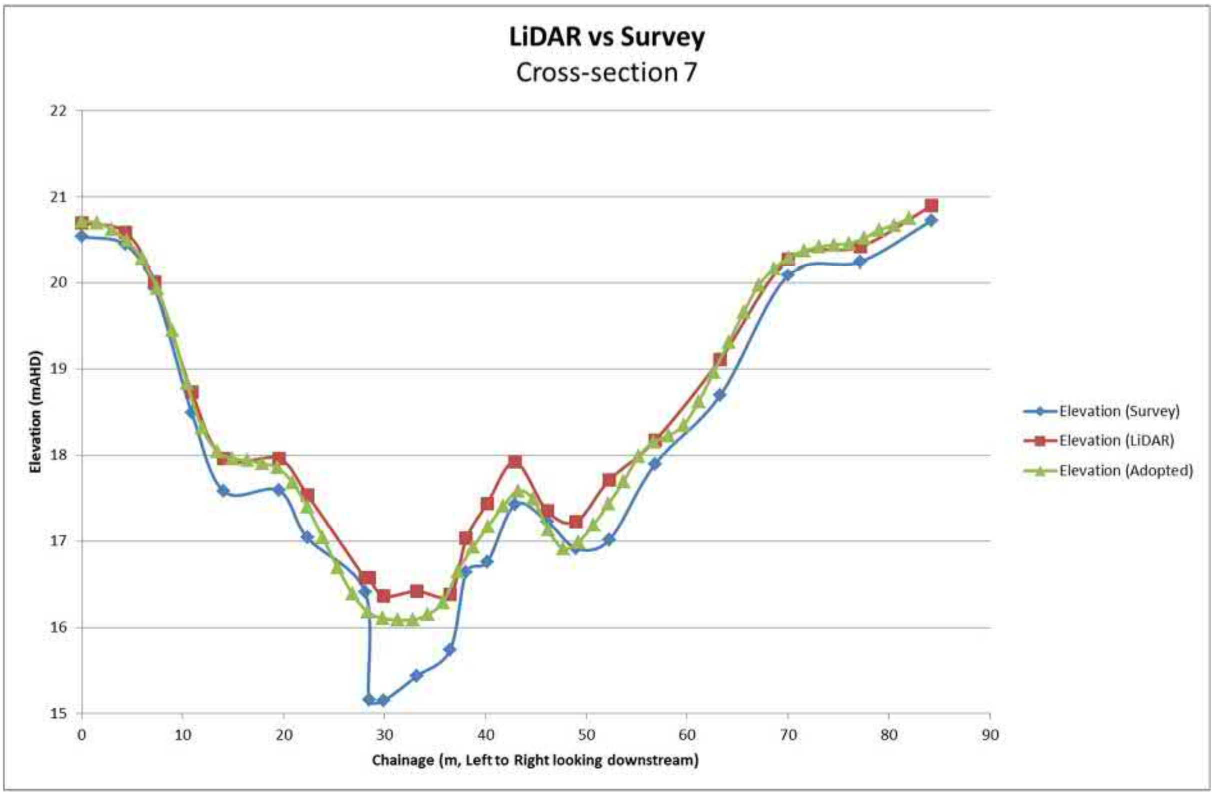


Figure 66 LiDAR verses Survey comparison at Cross-section 7

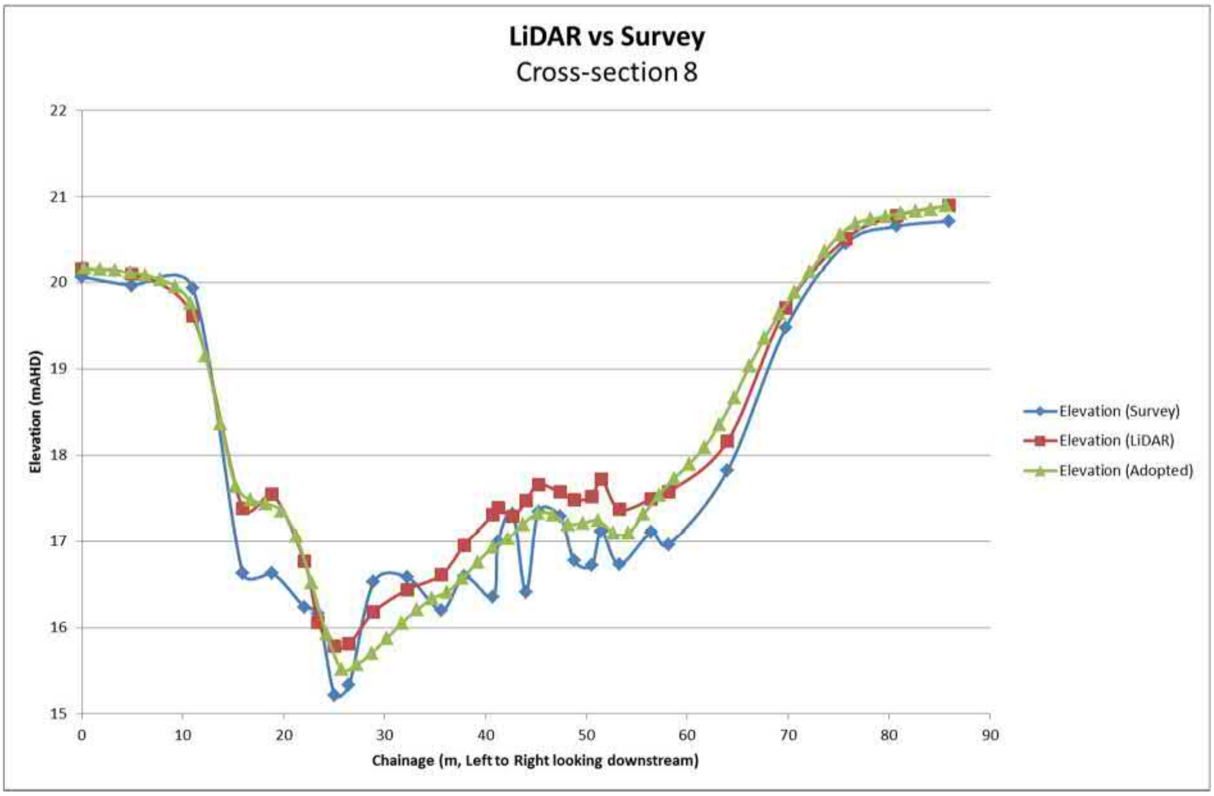


Figure 67 LiDAR verses Survey comparison at Cross-section 8

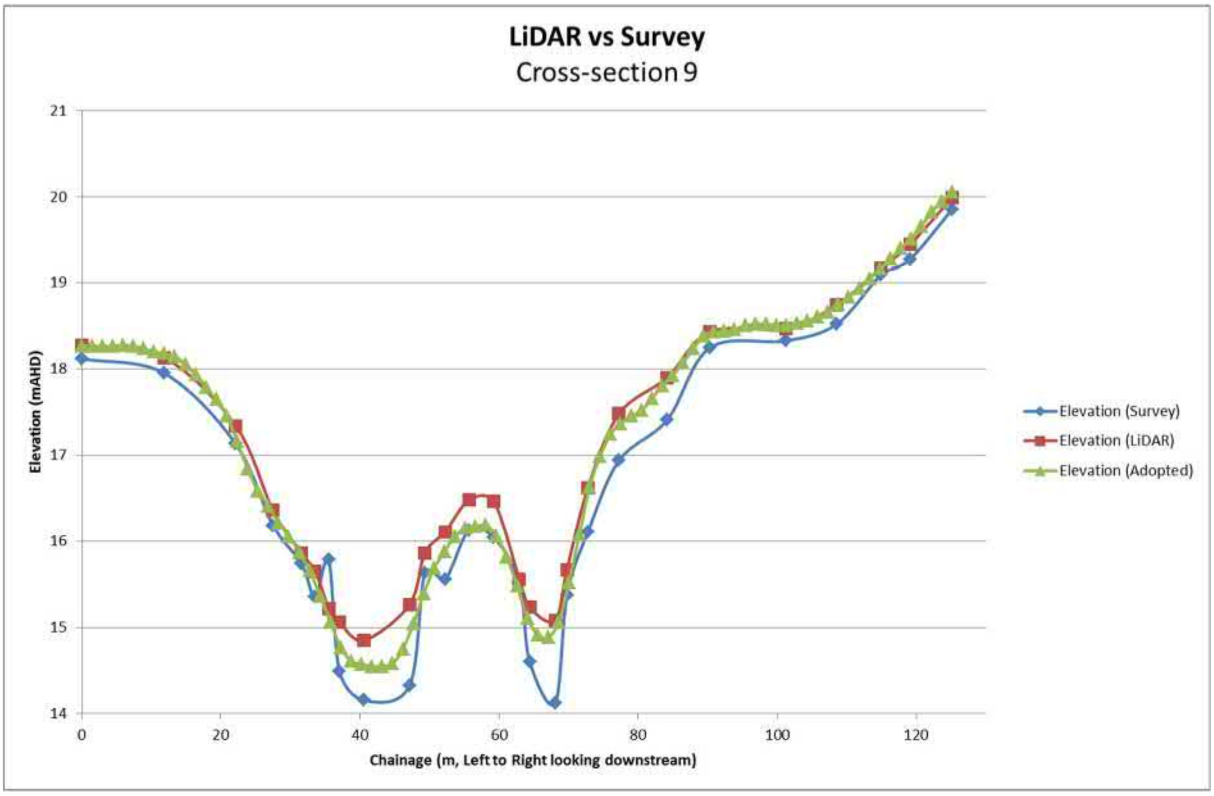


Figure 68 LiDAR verses Survey comparison at Cross-section 9

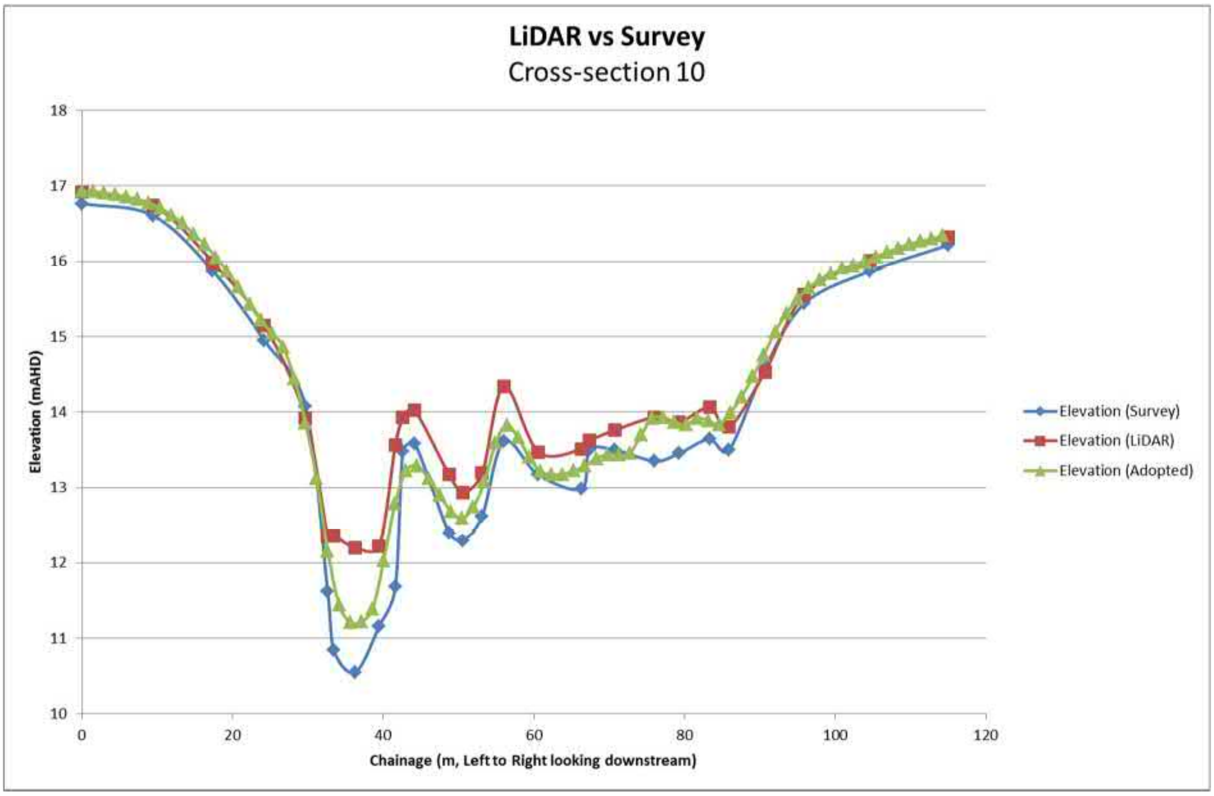


Figure 69 LiDAR verses Survey comparison at Cross-section 10

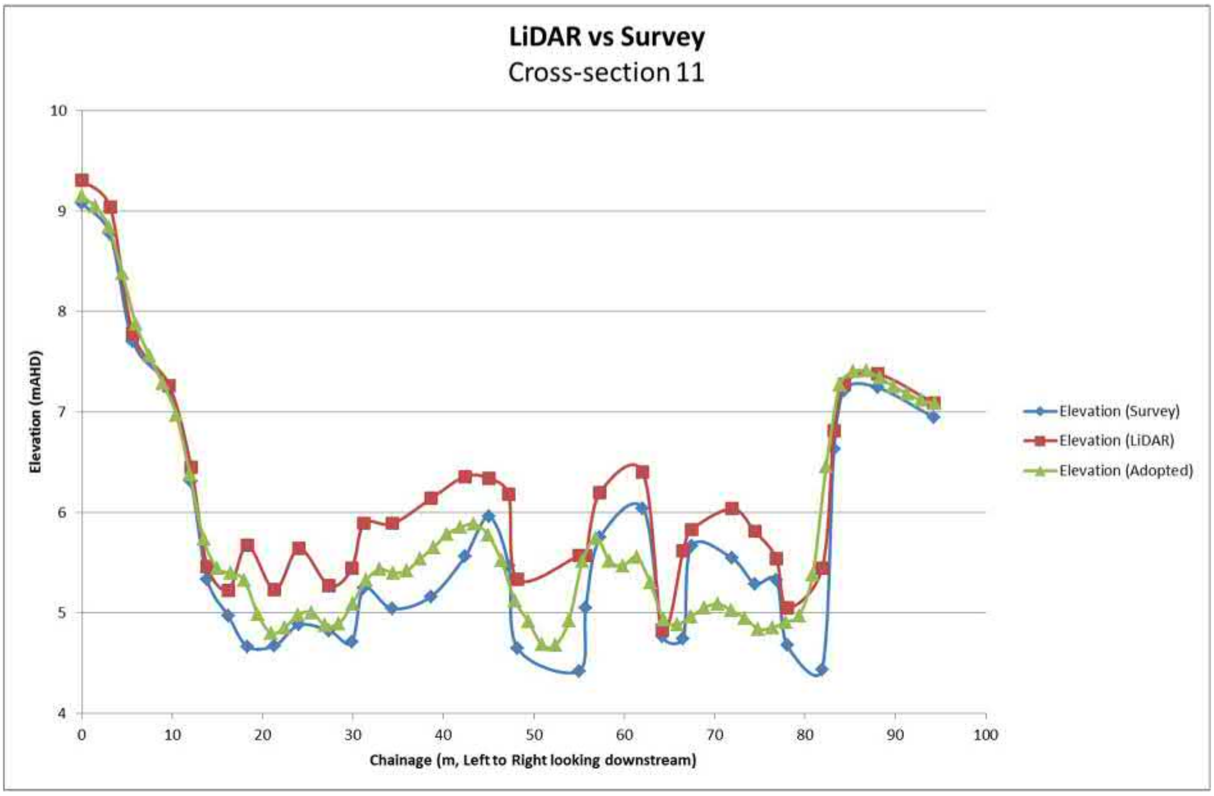


Figure 70 LiDAR verses Survey comparison at Cross-section 11

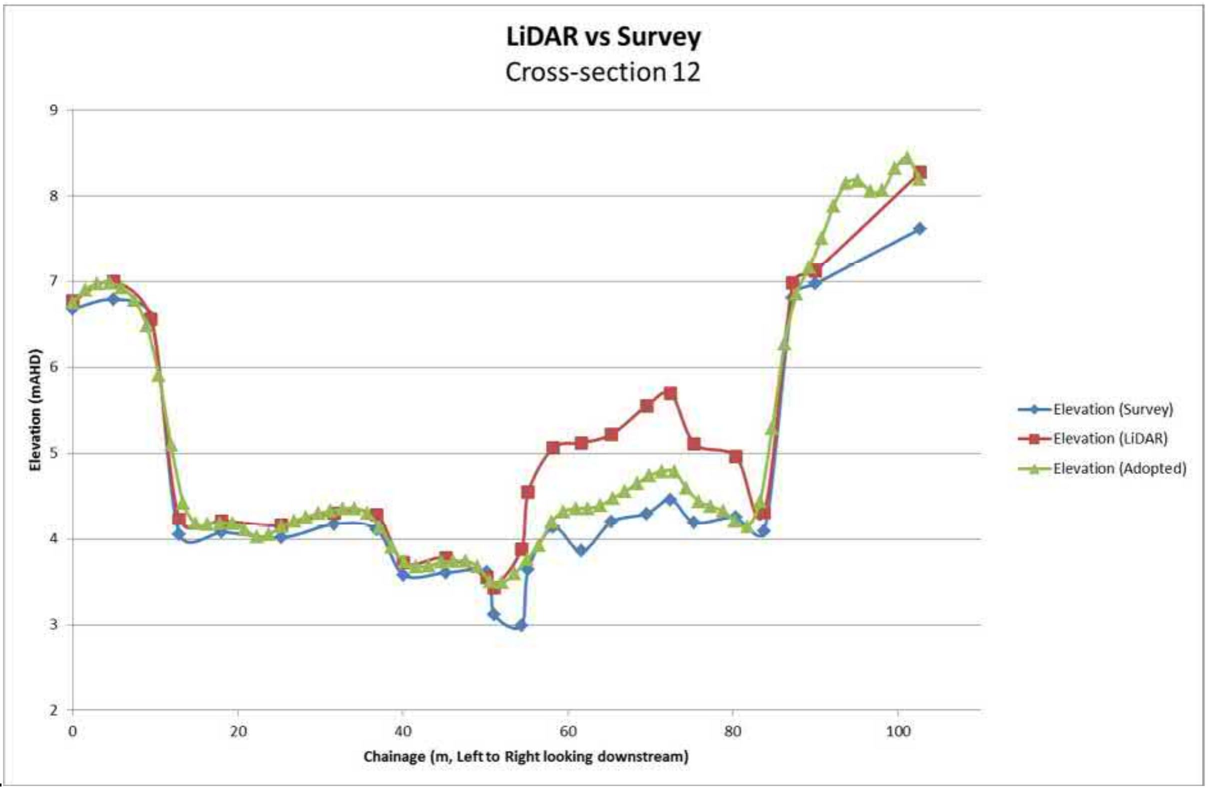


Figure 71 LiDAR verses Survey comparison at Cross-section 12

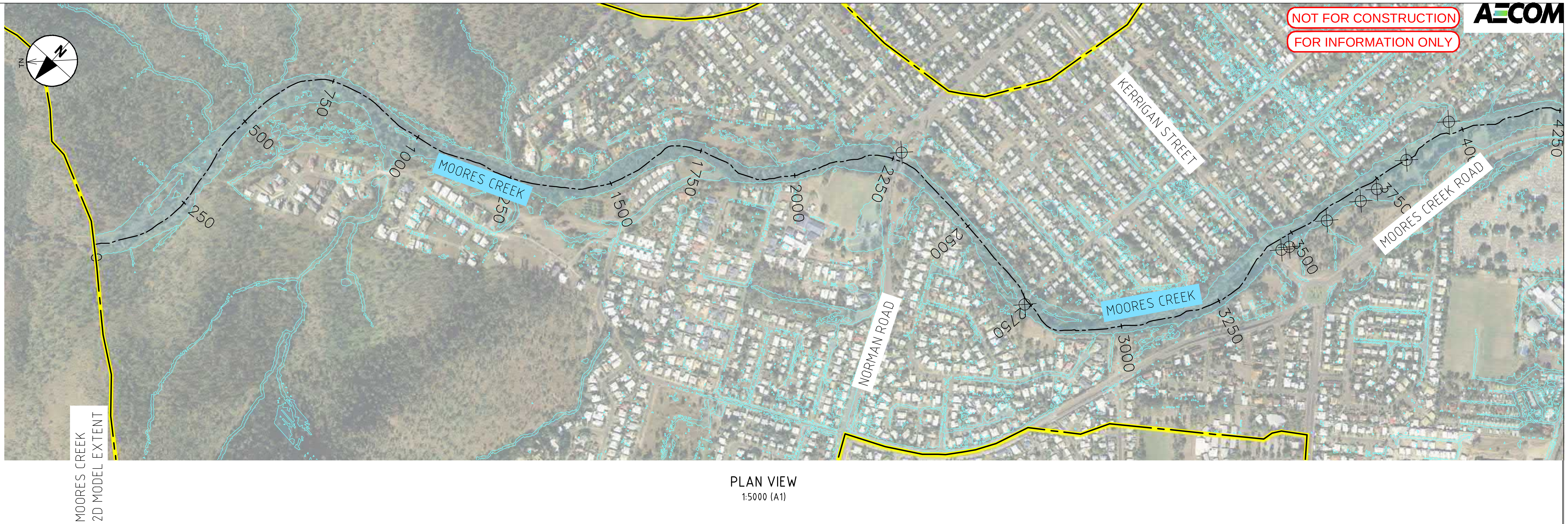
Appendix C

Water Surface Profiles for Historic Events

NOT FOR CONSTRUCTION

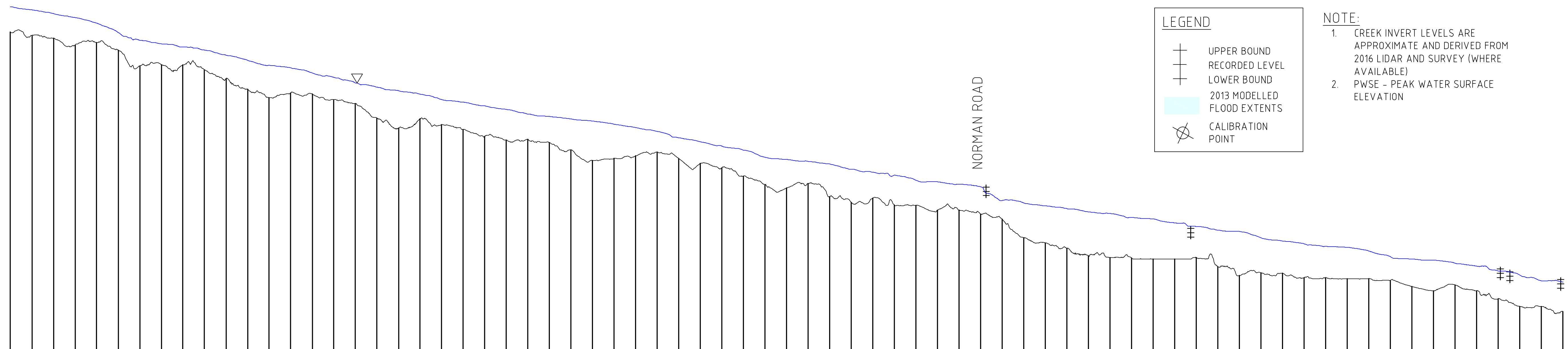
FOR INFORMATION ONLY

AECOM



PLAN VIEW

1:5000 (A1)



LEGEND

- UPPER BOUND / RECORDED LEVEL / LOWER BOUND
- 2013 MODELLED FLOOD EXTENTS
- CALIBRATION POINT

NOTE:

1. CREEK INVERT LEVELS ARE APPROXIMATE AND DERIVED FROM 2016 LIDAR AND SURVEY (WHERE AVAILABLE)
2. PWSE - PEAK WATER SURFACE ELEVATION

CHAINAGE	2013 MODELLED PWSE	CREEK INVERT LEVELS
0.000	54.795	51.865
50.000	54.426	51.421
100.000	53.990	51.145
150.000	53.534	50.353
200.000	52.891	50.639
250.000	51.797	49.748
300.000	50.907	47.912
350.000	50.493	48.054
400.000	50.125	48.021
450.000	49.756	47.454
500.000	49.172	46.443
550.000	48.567	45.189
600.000	47.987	44.225
650.000	47.694	44.764
700.000	47.102	44.661
750.000	46.593	43.998
800.000	45.944	43.565
850.000	45.453	41.857
900.000	45.037	40.709
950.000	44.645	41.783
1000.000	44.008	41.105
1050.000	43.715	40.543
1100.000	43.286	39.726
1150.000	42.874	39.310
1200.000	42.325	39.414
1250.000	42.055	39.019
1300.000	41.769	38.183
1350.000	41.523	36.933
1400.000	41.147	37.192
1450.000	40.756	37.475
1500.000	40.306	37.926
1550.000	39.568	37.172
1600.000	39.112	36.595
1650.000	38.609	36.102
1700.000	38.139	35.119
1750.000	37.315	34.124
1800.000	37.055	33.746
1850.000	36.835	34.277
1900.000	36.539	32.730
1950.000	35.923	32.049
2000.000	35.581	32.550
2050.000	35.231	31.761
2100.000	34.652	31.729
2150.000	34.471	31.181
2200.000	34.195	31.176
2250.000	33.900	30.722
2300.000	32.296	30.128
2350.000	32.001	27.968
2400.000	31.674	27.382
2450.000	31.343	26 732
2500.000	30.975	25.876
2550.000	30.778	25.680
2600.000	30.325	25 614
2650.000	30.158	25 500
2700.000	29.702	25.503
2750.000	29.284	25.667
2800.000	28.853	24.592
2850.000	28.703	23 587
2900.000	27.970	23.891
2950.000	27.588	23.859
3000.000	27.267	23 326
3050.000	26.969	23 330
3100.000	26.866	23 214
3150.000	26.436	23 220
3200.000	25.775	23 011
3250.000	25.504	22 295
3300.000	25.373	21.804
3350.000	25.024	22 493
3400.000	24 680	21.811
3450.000	24 114	20 880
3500.000	23.637	19.996
3550.000	22.971	19.972
3600.000	22.831	19.411

LONGITUDINAL SECTION

1:5000 (A1)

CAD REF:P:\605X\60534898\5. CAD\25-SKETCHES\60534898_SK_02.DWG

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14/07/2017

MODELLED PEAK WATER SURFACE PROFILE
2013 FLOOD EVENT-MOORES CREEK
ROCKHAMPTON REGIONAL COUNCIL

SK-MC-01

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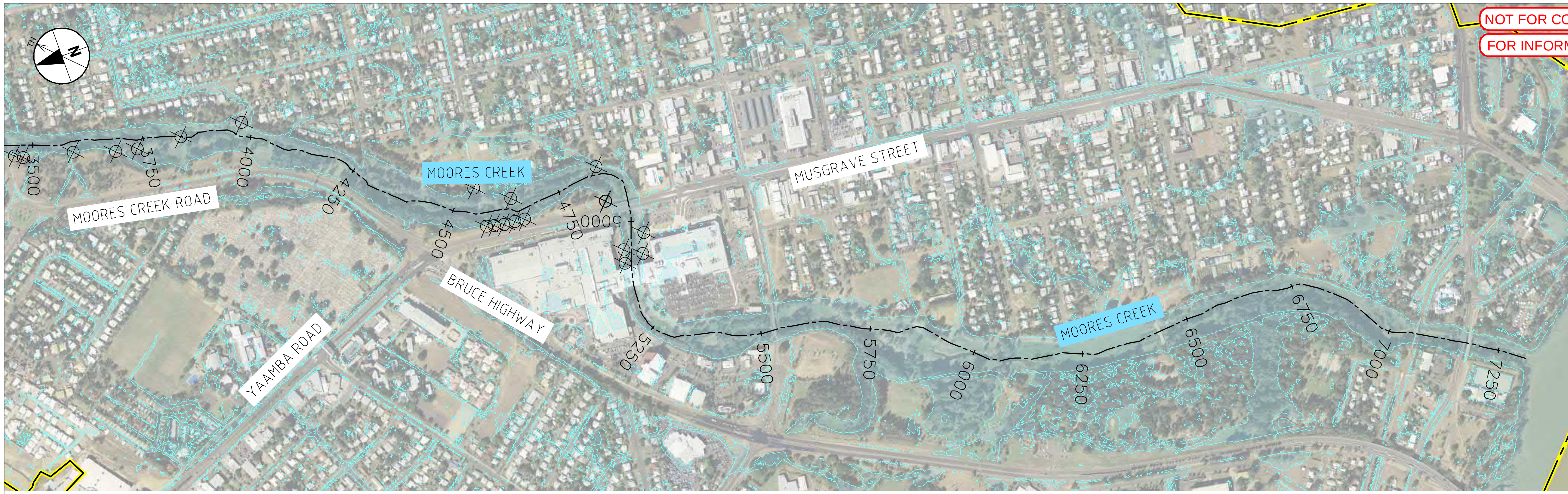
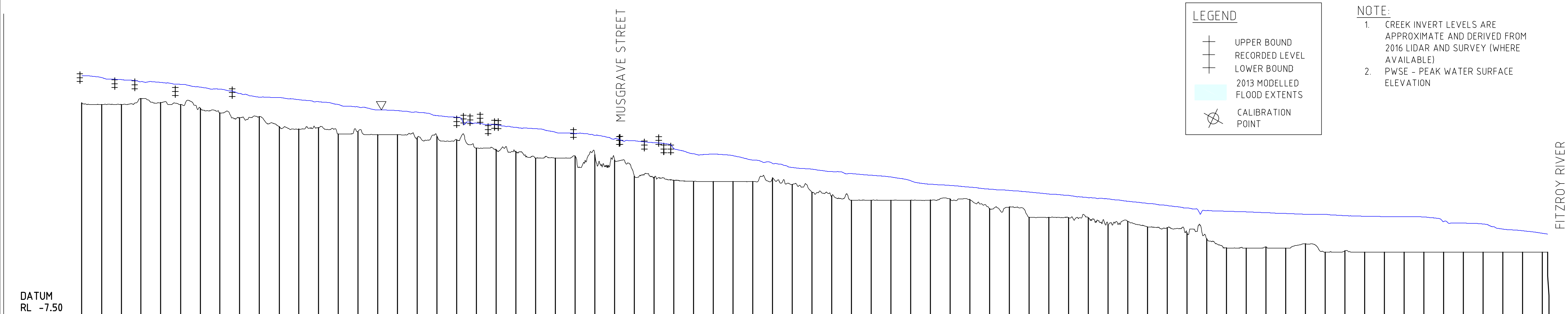


PLAN VIEW

1:5000 (A1)



NOTE:

1. CREEK INVERT LEVELS ARE APPROXIMATE AND DERIVED FROM 2016 LIDAR AND SURVEY (WHERE AVAILABLE)
2. PWSE - PEAK WATER SURFACE ELEVATION

CHAINAGE	2013 MODELLED PWSE	CREEK INVERT LEVELS
3600.000	22.831	19.411
3650.000	22.615	19.199
3700.000	22.357	19.219
3750.000	22.100	19.950
3800.000	22.004	19.437
3850.000	21.757	19.213
3900.000	21.396	18.718
3950.000	21.140	18.140
4000.000	20.603	17.509
4050.000	20.125	17.652
4100.000	20.076	16.404
4150.000	19.815	16.078
4200.000	19.561	16.263
4250.000	19.201	15.472
4300.000	18.899	15.773
4350.000	18.497	15.370
4400.000	18.426	15.381
4450.000	18.225	15.014
4500.000	17.777	15.171
4550.000	17.568	14.718
4600.000	16.827	13.690
4650.000	16.615	13.475
4700.000	16.309	13.245
4750.000	16.129	12.426
4800.000	15.681	12.422
4850.000	15.523	12.664
4900.000	15.286	12.820
4950.000	14.855	12.162
5000.000	14.604	10.133
5050.000	14.374	9.974
5100.000	13.604	9.612
5150.000	12.975	9.463
5200.000	12.908	9.428
5250.000	12.727	9.426
5300.000	12.181	9.430
5350.000	11.741	9.900
5400.000	11.233	9.068
5450.000	11.016	8.078
5500.000	10.735	7.608
5550.000	10.464	7.079
5600.000	10.252	7.081
5650.000	10.017	7.079
5700.000	9.532	7.086
5750.000	9.094	7.098
5800.000	8.952	7.238
5850.000	8.727	7.161
5900.000	8.483	6.001
5950.000	8.318	6.204
6000.000	8.114	4.894
6050.000	7.862	4.897
6100.000	7.688	4.856
6150.000	7.390	4.855
6200.000	7.251	3.955
6250.000	6.951	4.407
6300.000	6.666	3.701
6350.000	6.414	3.613
6400.000	6.102	2.966
6450.000	5.772	2.183
6500.000	5.682	1.029
6550.000	5.611	1.000
6600.000	5.501	1.158
6650.000	5.401	1.000
6700.000	5.304	1.557
6750.000	5.287	0.508
6800.000	5.118	0.651
6850.000	5.056	0.500
6900.000	5.008	0.500
6950.000	4.994	0.500
7000.000	4.962	0.500
7050.000	4.371	0.500
7100.000	4.173	0.500
7150.000	4.077	0.500
7200.000	3.430	0.500
7250.000	3.219	0.500
7300.000	2.902	0.500
7314.045	2.792	0.500

LONGITUDINAL SECTION

1:5000 (A1)

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MODELLED PEAK WATER SURFACE PROFILE

2013 FLOOD EVENT-MOORES CREEK

ROCKHAMPTON REGIONAL COUNCIL

SK-MC-02

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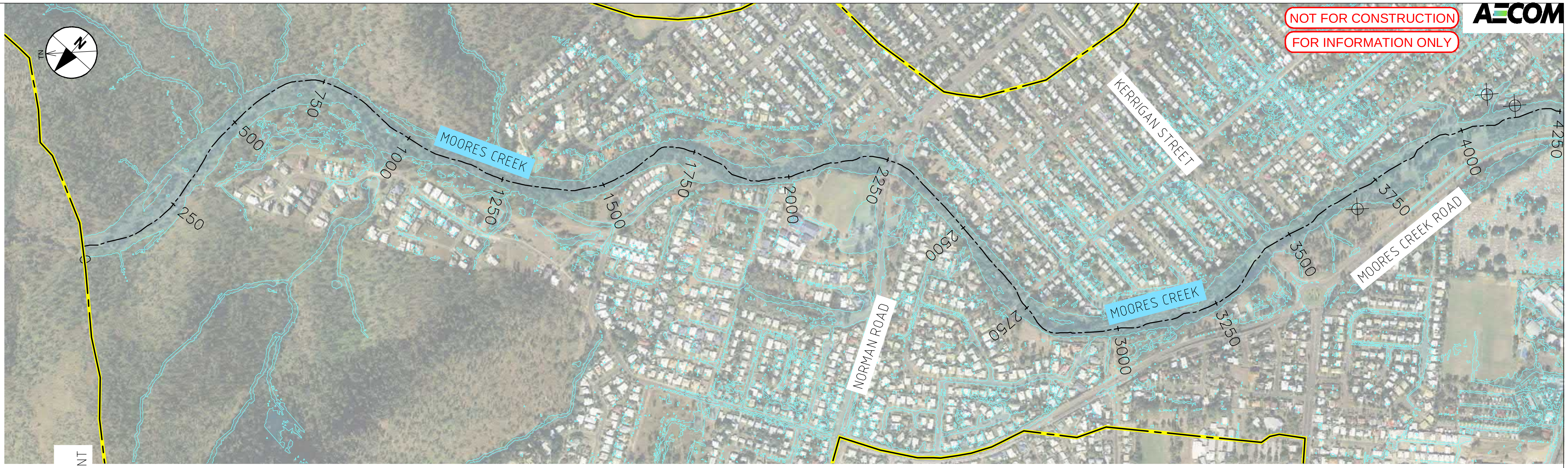


PLAN VIEW

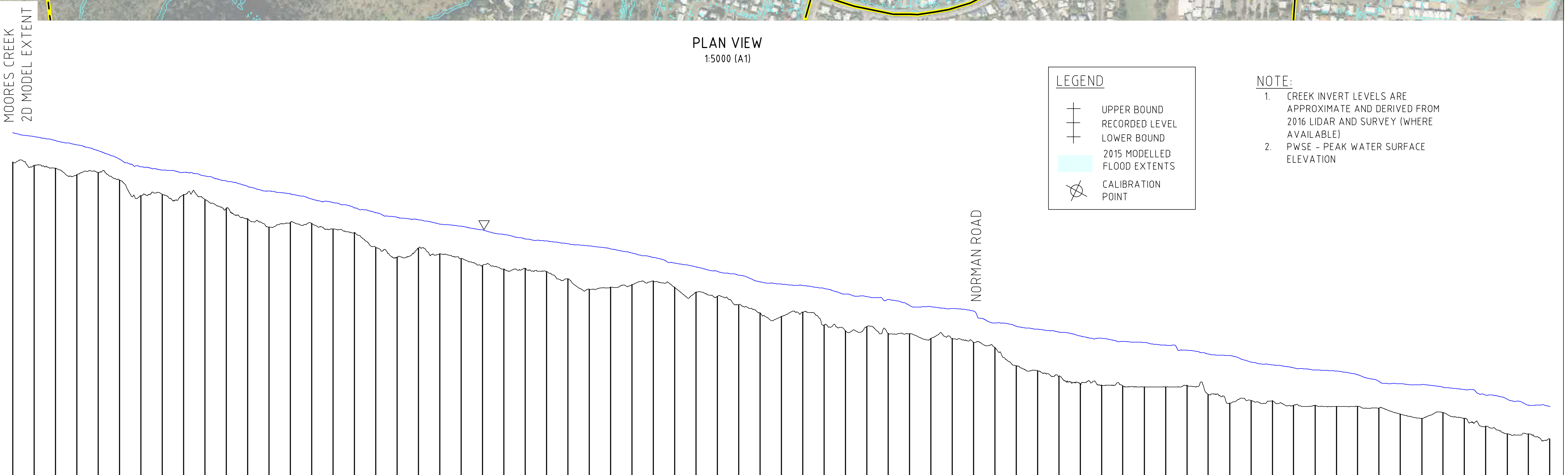
1:5000 (A1)

LEGEND

- UPPER BOUND
- RECORDED LEVEL
- LOWER BOUND
- 2015 MODELLED FLOOD EXTENTS
- CALIBRATION POINT

NOTE:

1. CREEK INVERT LEVELS ARE APPROXIMATE AND DERIVED FROM 2016 LIDAR AND SURVEY (WHERE AVAILABLE)
2. PWSE - PEAK WATER SURFACE ELEVATION



DATUM RL 15.00

CHAINAGE	2015 MODELLED PWSE	CREEK INVERT LEVELS
0.000	55.276	51.865
50.000	54.849	51.421
100.000	54.381	51.145
150.000	53.889	50.353
200.000	53.190	50.639
250.000	52.178	49.748
300.000	51.287	47.912
350.000	50.918	48.054
400.000	50.652	48.021
450.000	50.235	47.454
500.000	49.636	46.443
550.000	49.000	45.189
600.000	48.464	44.225
650.000	48.133	44.764
700.000	47.526	44.661
750.000	47.114	43.998
800.000	46.497	43.565
850.000	45.921	41.857
900.000	45.391	40.709
950.000	45.098	41.783
1000.000	44.583	41.105
1050.000	44.331	40.543
1100.000	43.908	39.726
1150.000	43.364	39.310
1200.000	42.844	39.414
1250.000	42.603	39.019
1300.000	42.278	38.183
1350.000	42.021	36.933
1400.000	41.687	37.192
1450.000	41.199	37.475
1500.000	40.678	37.926
1550.000	40.013	37.172
1600.000	39.563	36.595
1650.000	39.053	36.102
1700.000	38.600	35.119
1750.000	37.821	34.124
1800.000	37.552	33.746
1850.000	37.390	34.277
1900.000	37.055	32.730
1950.000	36.385	32.049
2000.000	36.084	32.550
2050.000	35.747	31.761
2100.000	35.049	31.729
2150.000	34.902	31.181
2200.000	34.689	31.176
2250.000	34.391	30.722
2300.000	32.991	30.128
2350.000	32.606	27.968
2400.000	32.265	27.382
2450.000	31.931	26.732
2500.000	31.467	25.876
2550.000	31.195	25.680
2600.000	30.843	25.614
2650.000	30.720	25.500
2700.000	30.392	25.503
2750.000	29.796	25.667
2800.000	29.359	24.592
2850.000	29.191	23.587
2900.000	28.406	23.891
2950.000	28.080	23.859
3000.000	27.747	23.326
3050.000	27.491	23.330
3100.000	27.360	23.214
3150.000	26.915	23.220
3200.000	26.144	23.011
3250.000	25.868	22.295
3300.000	25.763	21.804
3350.000	25.448	22.493
3400.000	25.180	21.811
3450.000	24.543	20.880
3500.000	24.060	19.996
3550.000	23.355	19.972
3600.000	23.206	19.411

LONGITUDINAL SECTION

1:5000 (A1)

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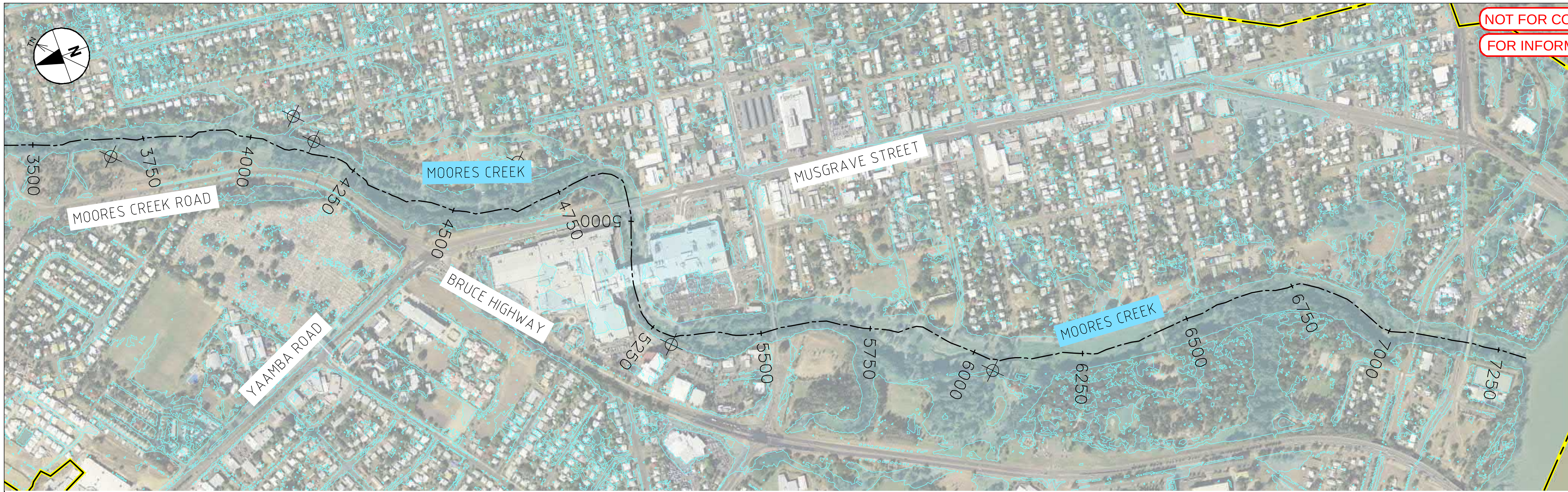
14/07/2017

MODELLED PEAK WATER SURFACE PROFILE

2015 FLOOD EVENT-MOORES CREEK

ROCKHAMPTON REGIONAL COUNCIL

SK-MC-03



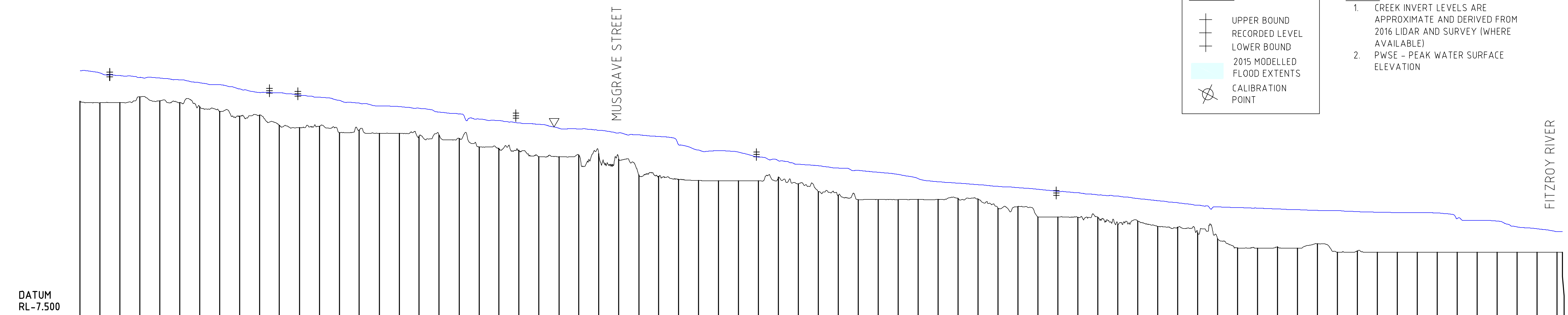
PLAN VIEW
1:5000 (A1)

LEGEND

- UPPER BOUND
- RECORDED LEVEL
- LOWER BOUND
- 2015 MODELLED FLOOD EXTENTS
- CALIBRATION POINT

NOTE:

1. CREEK INVERT LEVELS ARE APPROXIMATE AND DERIVED FROM 2016 LIDAR AND SURVEY (WHERE AVAILABLE)
2. PWSE - PEAK WATER SURFACE ELEVATION



2015 MODELLED PWSE	23.206	22.943	22.620	22.378	22.303	22.071	21.715	21.462	20.935	20.474	20.446	20.167	19.901
CREEK INVERT LEVELS	19.411	19.199	19.219	19.950	19.437	19.213	18.718	18.140	17.509	17.652	16.404	16.078	16.263
CHAINAGE	3600.000	3650.000	3700.000	3750.000	3800.000	3850.000	3900.000	3950.000	4000.000	4050.000	4100.000	4150.000	4200.000

2015 MODELLED PWSE	19.506	19.152	18.778	18.726	18.512	18.023	17.802	17.162	16.967	16.692	16.501	16.015	15.908
CREEK INVERT LEVELS	15.472	15.773	15.370	15.381	15.014	15.171	14.718	13.690	13.475	13.245	12.426	12.422	12.664
CHAINAGE	4250.000	4300.000	4350.000	4400.000	4450.000	4500.000	4550.000	4600.000	4650.000	4700.000	4750.000	4800.000	4850.000

2015 MODELLED PWSE	15.732	15.430	15.190	14.989	13.936	13.290	13.204	13.032	12.413	11.929	11.511	11.322	11.035
CREEK INVERT LEVELS	12.820	12.162	10.133	9.974	9.612	9.463	9.428	9.426	9.430	9.900	9.068	8.078	7.608
CHAINAGE	4900.000	4950.000	5000.000	5050.000	5100.000	5150.000	5200.000	5250.000	5300.000	5350.000	5400.000	5450.000	5500.000

2015 MODELLED PWSE	10.737	10.498	10.232	9.700	9.310	9.138	8.948	8.738	8.576	8.375	8.111	7.946	7.668
CREEK INVERT LEVELS	7.079	7.081	7.079	7.086	7.098	7.238	7.161	6.001	6.204	4.894	4.897	4.856	4.855
CHAINAGE	5550.000	5600.000	5650.000	5700.000	5750.000	5800.000	5850.000	5900.000	5950.000	6000.000	6050.000	6100.000	6150.000

2015 MODELLED PWSE	7.520	7.211	6.930	6.688	6.400	6.166	6.079	6.013	5.910	5.818	5.731	5.717	5.565
CREEK INVERT LEVELS	3.955	4.407	3.701	3.613	2.966	2.183	1.029	1.000	1.158	1.000	1.557	0.508	0.651
CHAINAGE	6200.000	6250.000	6300.000	6350.000	6400.000	6450.000	6500.000	6550.000	6600.000	6650.000	6700.000	6750.000	6800.000

2015 MODELLED PWSE	5.509	5.457	5.444	5.413	4.704	4.492	4.403	3.660	3.426	3.080	3.069
CREEK INVERT LEVELS	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
CHAINAGE	6850.000	6900.000	6950.000	7000.000	7050.000	7100.000	7150.000	7200.000	7250.000	7300.000	7314.045

LONGITUDINAL SECTION
1:5000 (A1)

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LAST MODIFIED:7/18/2017 12:39 PM

MODELLED PEAK WATER SURFACE PROFILE
2015 FLOOD EVENT-MOORES CREEK
ROCKHAMPTON REGIONAL COUNCIL
SK-MC-04

14/07/2017

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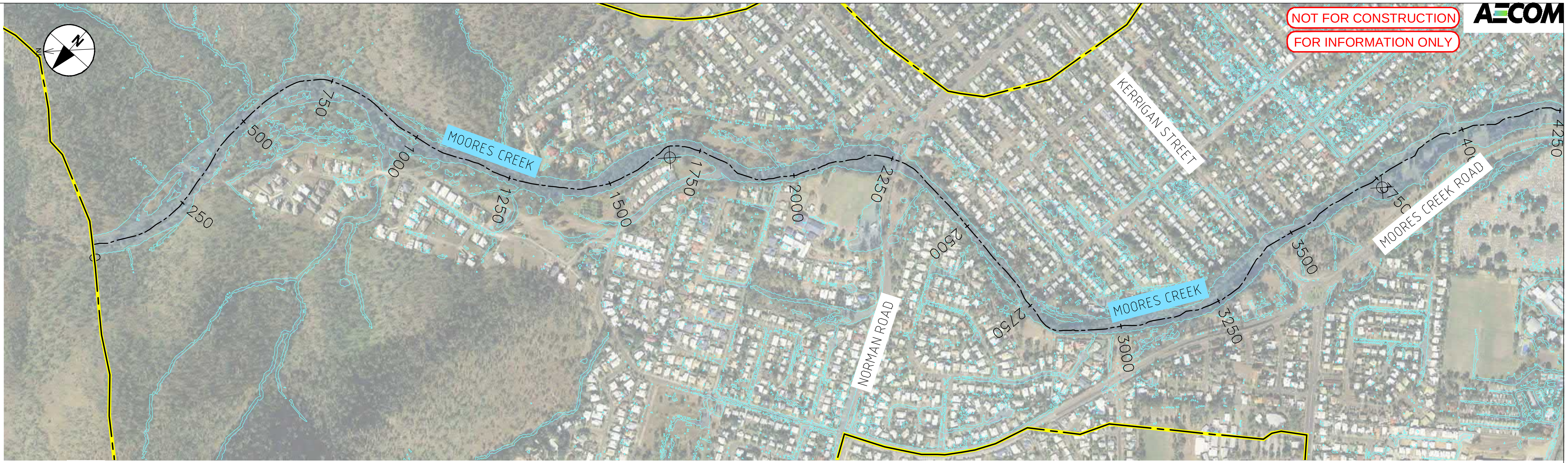
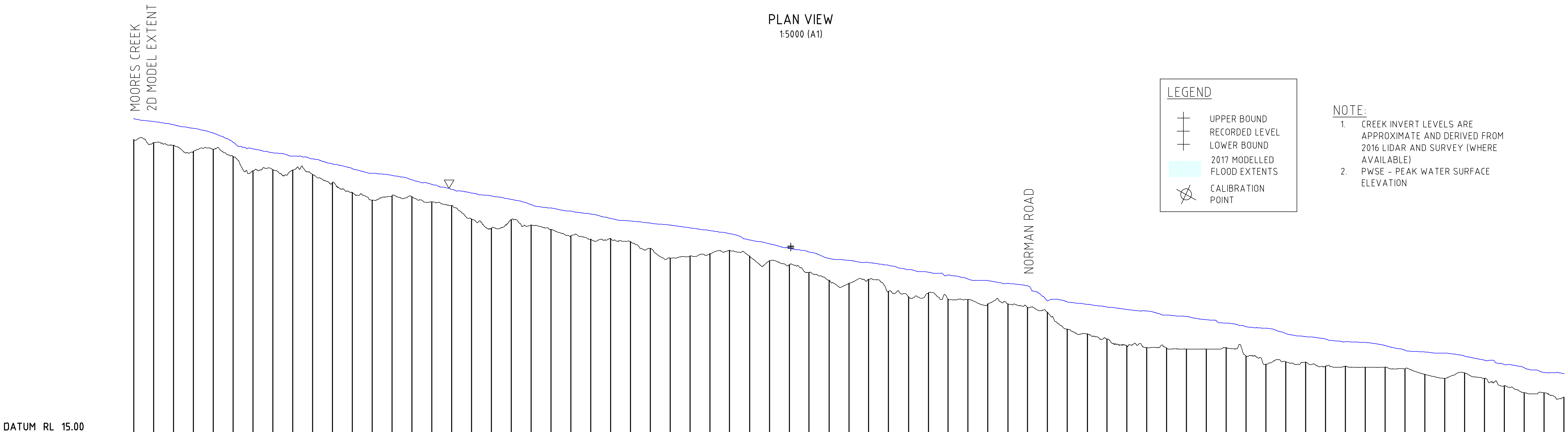


PLAN VIEW

1:5000 (A1)



LEGEND

- UPPER BOUND / RECORDED LEVEL / LOWER BOUND
- 2017 MODELLED FLOOD EXTENTS
- CALIBRATION POINT

NOTE:

1. CREEK INVERT LEVELS ARE APPROXIMATE AND DERIVED FROM 2016 LIDAR AND SURVEY (WHERE AVAILABLE)
2. PWSE - PEAK WATER SURFACE ELEVATION

CHAINAGE	0.000	50.000	100.000	150.000	200.000	250.000	300.000	350.000	400.000	450.000
2017 MODELLED PWSE	54.460	54.126	53.719	53.269	52.685	51.519	50.676	50.198	49.783	49.433
CREEK INVERT LEVELS	51.865	51.421	51.145	50.353	50.639	49.748	47.912	48.054	48.021	47.454

CHAINAGE	500.000	550.000	600.000	650.000	700.000	750.000	800.000	850.000	900.000	950.000
2017 MODELLED PWSE	48.804	48.202	47.625	47.364	46.804	46.228	45.577	45.128	44.767	44.326
CREEK INVERT LEVELS	46.443	45.189	44.225	44.764	44.661	43.998	43.565	41.857	40.709	41.783

CHAINAGE	1000.000	1050.000	1100.000	1150.000	1200.000	1250.000	1300.000	1350.000	1400.000	1450.000
2017 MODELLED PWSE	43.678	43.241	42.849	42.496	41.918	41.618	41.348	41.098	40.747	40.413
CREEK INVERT LEVELS	41.105	40.543	39.726	39.310	39.414	39.019	38.183	36.933	37.192	37.475

CHAINAGE	1500.000	1550.000	1600.000	1650.000	1700.000	1750.000	1800.000	1850.000	1900.000	1950.000
2017 MODELLED PWSE	40.017	39.222	38.745	38.222	37.706	36.896	36.652	36.370	36.036	35.484
CREEK INVERT LEVELS	37.926	37.172	36.595	36.102	35.119	34.124	33.746	34.277	32.730	32.049

CHAINAGE	2000.000	2050.000	2100.000	2150.000	2200.000	2250.000	2300.000	2350.000	2400.000	2450.000
2017 MODELLED PWSE	35.167	34.811	34.313	34.105	33.746	33.455	31.567	31.425	31.135	30.788
CREEK INVERT LEVELS	32.550	31.761	31.729	31.181	31.176	30.722	30.128	27.968	27.382	26.732

CHAINAGE	2500.000	2550.000	2600.000	2650.000	2700.000	2750.000	2800.000	2850.000	2900.000	2950.000
2017 MODELLED PWSE	30.481	30.290	29.792	29.606	29.198	28.751	28.305	28.119	27.439	27.053
CREEK INVERT LEVELS	25.876	25.680	25.614	25.500	25.503	25.667	24.592	23.587	23.891	23.859

CHAINAGE	3000.000	3050.000	3100.000	3150.000	3200.000	3250.000	3300.000	3350.000	3400.000	3450.000
2017 MODELLED PWSE	26.749	26.414	26.328	25.936	25.355	25.130	24.981	24.611	24.090	23.541
CREEK INVERT LEVELS	23.326	23.330	23.214	23.220	23.011	22.295	21.804	22.493	21.811	20.880

CHAINAGE	3500.000	3550.000	3600.000
2017 MODELLED PWSE	23.131	22.545	22.405
CREEK INVERT LEVELS	19.996	19.972	19.411

LONGITUDINAL SECTION

1:5000 (A1)

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MODELLED PEAK WATER SURFACE PROFILE

2017 FLOOD EVENT-MOORES CREEK

ROCKHAMPTON REGIONAL COUNCIL

SK-MC-05

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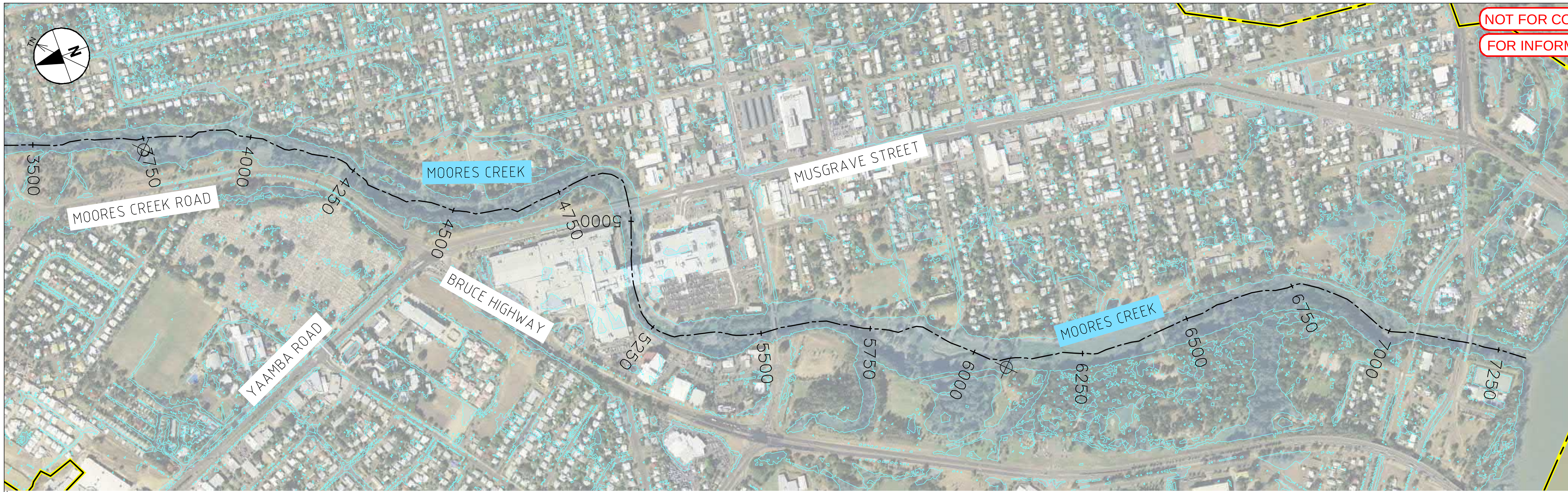

PLAN VIEW

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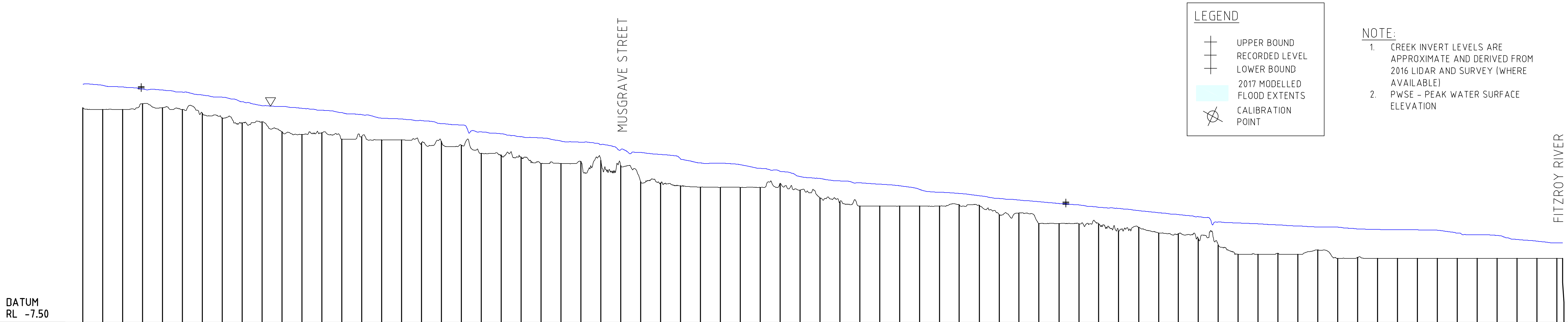

LEGEND

- UPPER BOUND
- RECORDED LEVEL
- LOWER BOUND
- 2017 MODELLED FLOOD EXTENTS
- CALIBRATION POINT

NOTE:

1. CREEK INVERT LEVELS ARE APPROXIMATE AND DERIVED FROM 2016 LIDAR AND SURVEY (WHERE AVAILABLE)
2. PWSE - PEAK WATER SURFACE ELEVATION

DATUM RL -7.50

CHAINAGE	CREEK INVERT LEVELS	2017 MODELLED PWSE
3600.000	19.411	22.405
3650.000	19.199	22.242
3700.000	19.219	22.043
3750.000	19.950	21.779
3800.000	19.437	21.654
3850.000	19.213	21.391
3900.000	18.718	21.020
3950.000	18.140	20.754
4000.000	17.509	20.190
4050.000	17.652	19.684
4100.000	16.404	19.597
4150.000	16.078	19.364
4200.000	16.263	19.123
4250.000	15.472	18.815
4300.000	15.773	18.559
4350.000	15.370	18.105
4400.000	15.381	18.011
4450.000	15.014	17.816
4500.000	15.171	17.428
4550.000	14.718	17.239
4600.000	13.690	16.394
4650.000	13.475	16.163
4700.000	13.245	15.794
4750.000	12.426	15.632
4800.000	12.422	15.247
4850.000	12.664	15.077
4900.000	12.820	14.809
4950.000	12.162	14.157
5000.000	10.133	13.814
5050.000	9.974	13.572
5100.000	9.612	13.010
5150.000	9.463	12.508
5200.000	9.428	12.467
5250.000	9.426	12.285
5300.000	9.430	11.816
5350.000	9.900	11.446
5400.000	9.068	10.799
5450.000	8.078	10.538
5500.000	7.608	10.243
5550.000	7.079	10.007
5600.000	7.081	9.833
5650.000	7.079	9.632
5700.000	7.086	9.178
5750.000	7.098	8.807
5800.000	7.238	8.663
5850.000	7.161	8.373
5900.000	6.001	8.038
5950.000	6.204	7.842
6000.000	4.894	7.633
6050.000	4.897	7.402
6100.000	4.856	7.230
6150.000	4.855	6.928
6200.000	3.955	6.792
6250.000	4.407	6.511
6300.000	3.701	6.237
6350.000	3.613	6.019
6400.000	2.966	5.749
6450.000	2.183	5.082
6500.000	1.029	4.955
6550.000	1.000	4.856
6600.000	1.158	4.717
6650.000	1.000	4.581
6700.000	1.557	4.462
6750.000	0.508	4.438
6800.000	0.651	4.212
6850.000	0.500	4.147
6900.000	0.500	4.108
6950.000	0.500	4.098
7000.000	0.500	4.054
7050.000	0.500	3.690
7100.000	0.500	3.497
7150.000	0.500	3.396
7200.000	0.500	2.892
7250.000	0.500	2.681
7300.000	0.500	2.486
7314.045	0.500	2.486

LONGITUDINAL SECTION

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MODELLED PEAK WATER SURFACE PROFILE

2017 FLOOD EVENT-MOORES CREEK

ROCKHAMPTON REGIONAL COUNCIL

SK-MC-06

Appendix D

Tangible Flood Damages Assessment Methodology

Appendix D Tangible Flood Damages Assessment Methodology

1.0 Introduction

As part of the Moores 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 72. 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.

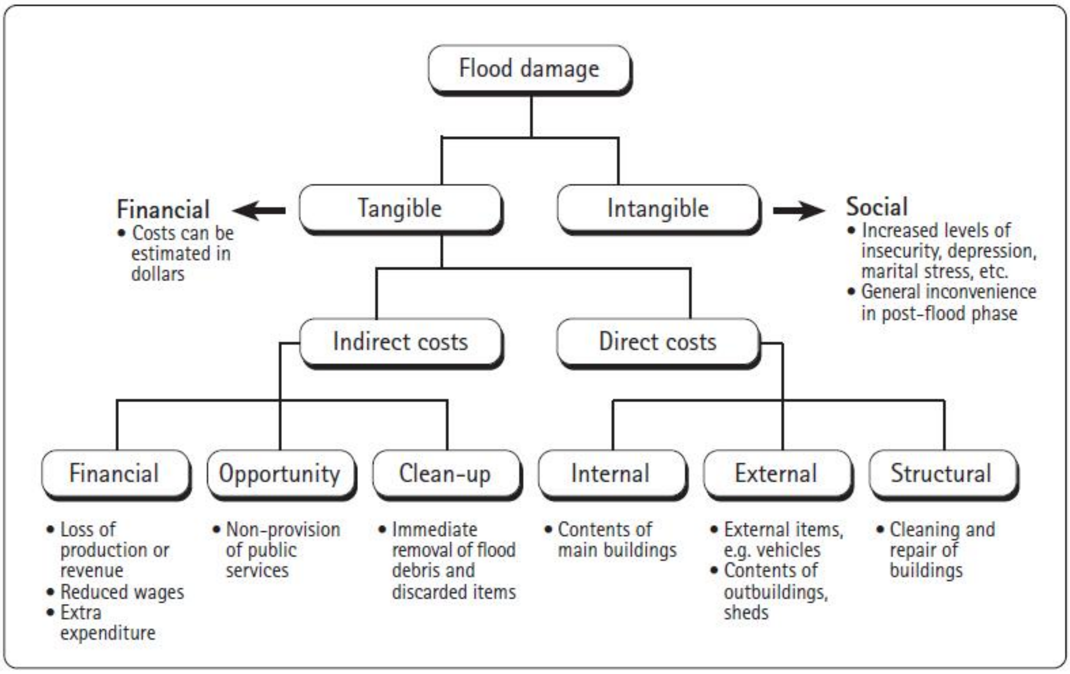

Figure 72 Breakdown of flood damage categories (source: DNRM, 2002)

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 49 to Table 51. Individual curves are given for external, contents and structural damages. Figure 73 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 56), 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 49 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 50 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 51 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

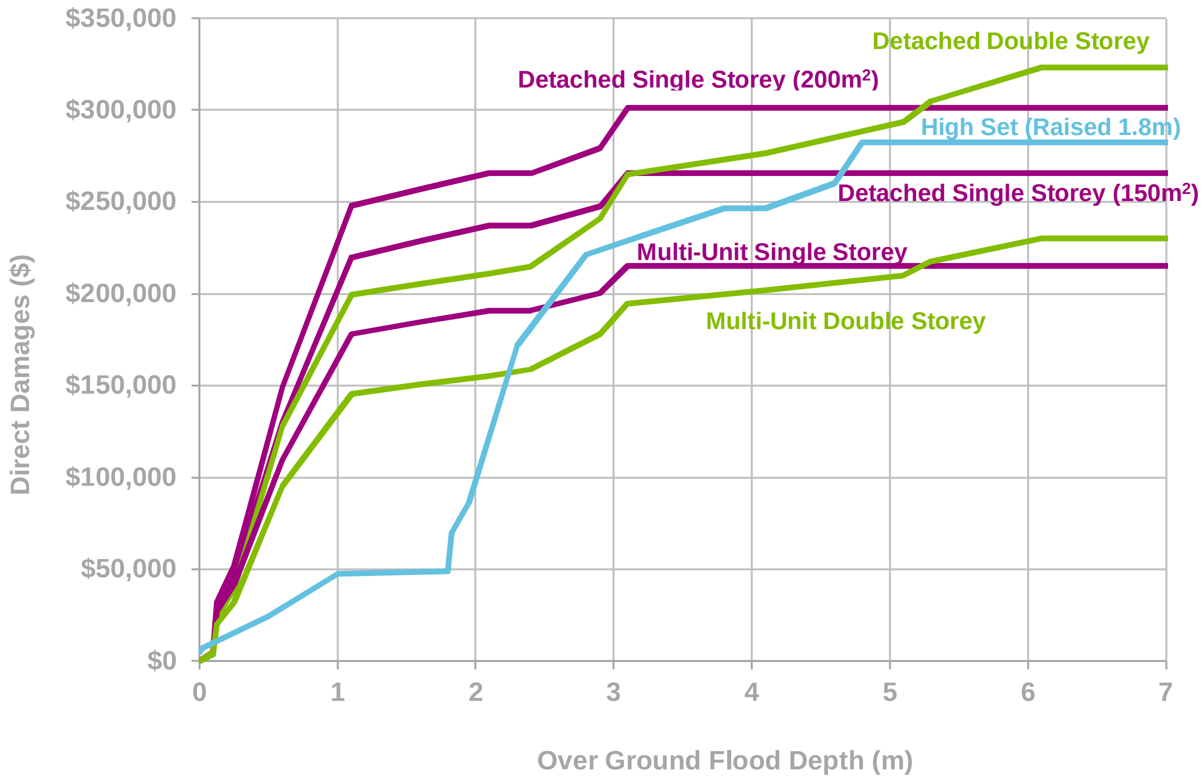

Figure 73 Total residential stage-damage curves based on O2 Environmental curves (March 2017 $)

WRM Stage Damage Curves

Direct residential damages were estimated using the WRM (2006a) stage-damage curves presented in Table 52 to Table 54. 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 74 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 52 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 53 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 54 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

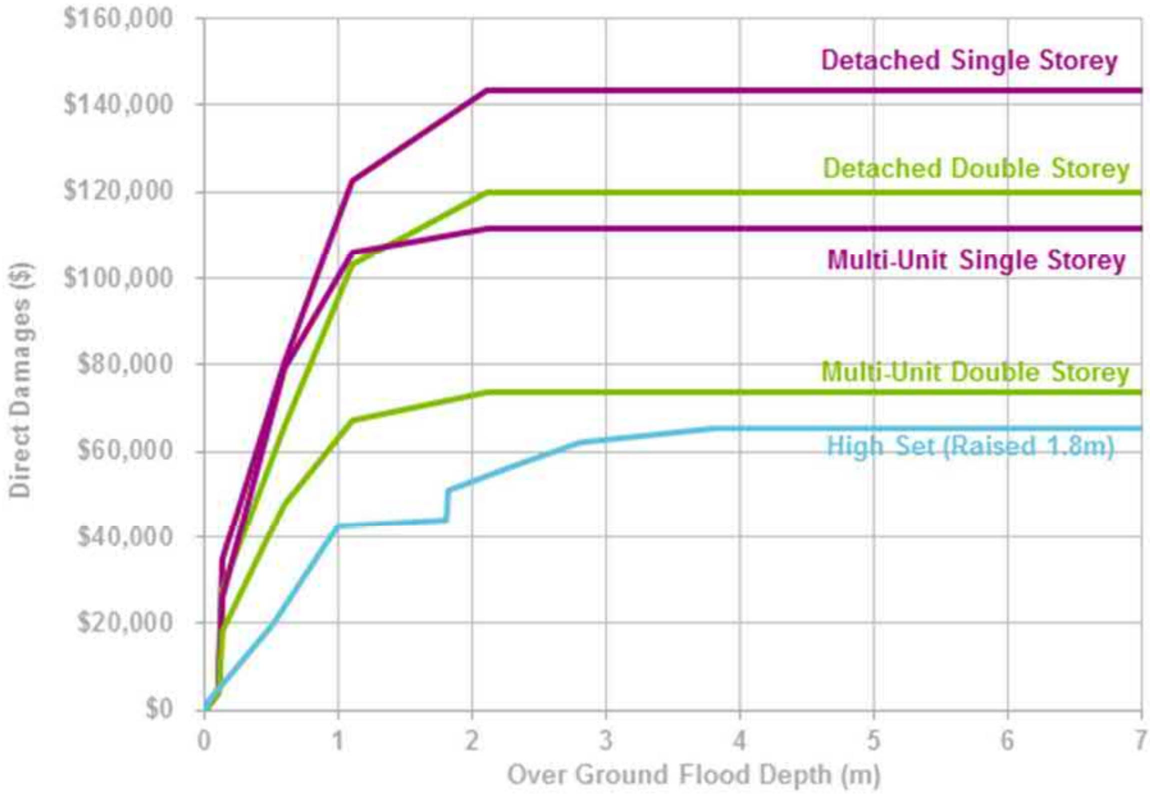

Figure 74 Total residential stage-damage curves based on WRM curves (March 2017 $)

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 55 and Figure 75. 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 55 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.

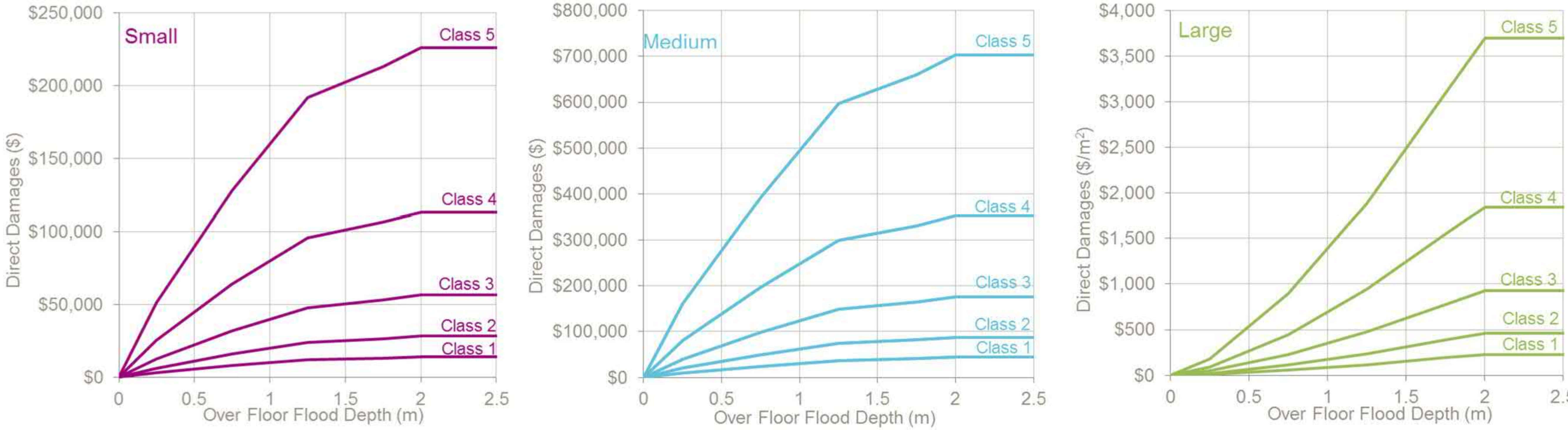

Figure 75 ANUFLOOD Stage-Damage curves for commercial properties (March 2017 $)

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 56 presents an overview of the CPI adjustments.

Table 56 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 76.

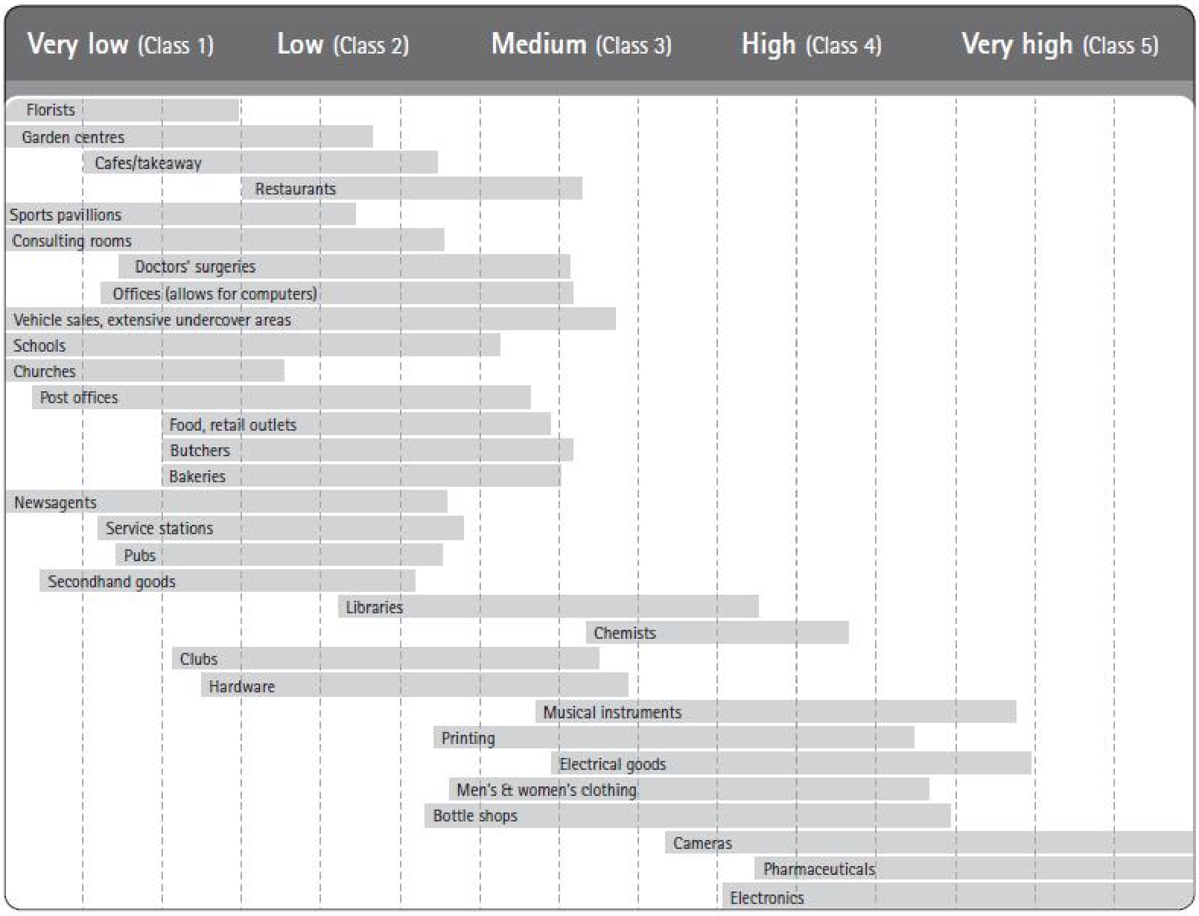

Figure 76 ANUFLOOD commercial damage value classes (source: DNRM, 2002)

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 57 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 57 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.

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