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Wandal & West Rockhampton Local Catchment Study

Baseline Flooding and Hazard Assessment - Volume 1

Wandal & West Rockhampton Local Catchment Study

Baseline Flooding and Hazard Assessment - Volume 1

Client: Rockhampton Regional Council

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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 Wandal and West Rockhampton Local Catchment Study, which is the subject of this report.

Flooding in Wandal and West Rockhampton can occur as a result of two different flood mechanisms:

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

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

The key objectives of this study are:

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

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

Catchment Characteristics

The Wandal and West Rockhampton urban catchment covers approximately 16.3 km^2 within the suburbs of The Range, Wandal, Pink Lily and West Rockhampton which also encompasses the Rockhampton Airport.

The western catchment boundary follows Nine Mile Road and continues along Old Nine Mile Road to form the southern boundary. Further east, the southern boundary crosses Crescent lagoon, the fringes of Murray Lagoon and extends to the southern tip of The Range near Yeppen Lagoon. From this southernmost point the catchment boundary tends north along the crest of The Range until it meets the Rockhampton Base Hospital. After this point the catchment roughly follows North Street to the Fitzroy River. The eastern boundary continues up the Fitzroy River to just north of the Lion Creek outlet. The northern boundary extends from the Fitzroy River along Dargel Road to Ridgelands Road at the Nine Mile Road turnoff.

Hydrologic / Hydraulic Analysis

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

Data for the catchment was sourced and utilised within this process, the anecdotal and recorded data was vital in the model development. Anecdotal and recorded data was received and used to calibrate the model to a local flood event caused by Ex-TC Debbie in March 2017. The model calibrated well to the 2017 event. At this stage, it is recommended that additional verification events are assessed in the future to gain further confidence in the modelling outputs.

On completion of the calibration, various design events and durations were run and results extracted. The critical duration for the catchment was determined to be the 90 minute event. A comparison of the design events found that for events up until the 39% AEP event the road and subsurface drainage infrastructure was able to prevent runoff from entering private property. For larger flood events, the overland flow paths continue to develop.

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 Wandal and West Rockhampton 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 (Book 6, Chapter 7: General Flood Hazard Curves, Section 7.2.7), 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.

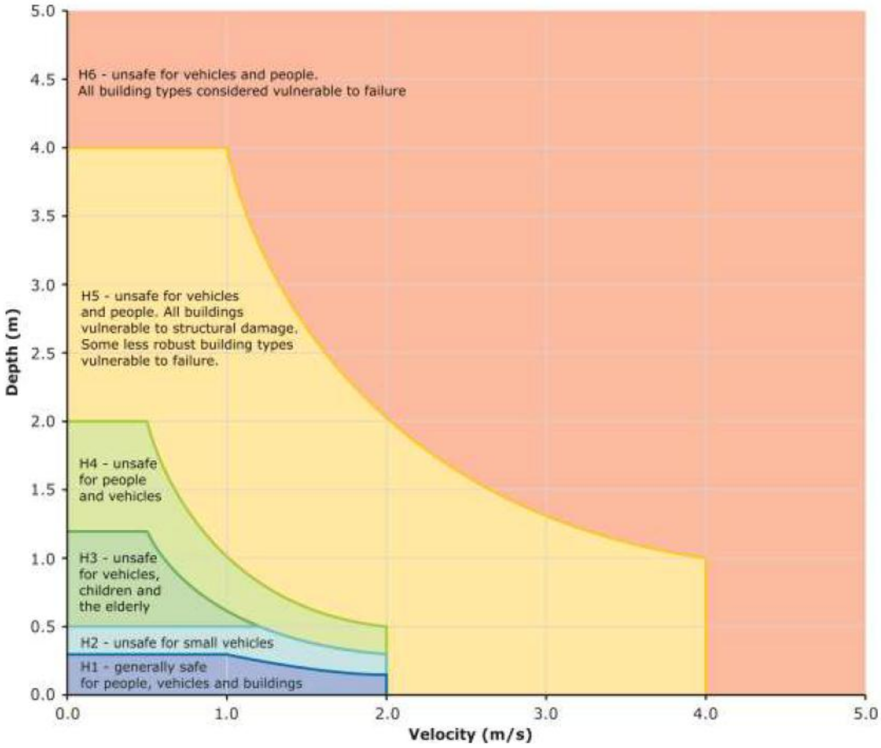


Figure E1 Hazard Vulnerability Classifications (Graphical)

Analysis of the 1% AEP baseline flood hazard within the Wandal and West Rockhampton 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 and open areas such as Jardine Park and Alf Kele Memorial Rotary Park.
- High to extreme hazard (H4 and H5) within major natural and man-made flowpaths between Heilbronn Street and Western Street, along Pearson Street, along North Street and along the flowpath traversing Ann Street.
- Extreme hazard (H5 or H6) within the Lion Creek channel.

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 sewerage pump stations at Jardine Park and Kele Park are predicted to have less than 39% AEP flood immunity, with the Melbourne Street Sewerage Pump Station having less than 18% AEP flood immunity. It is noted that in a 1% AEP event, the pump station at Jardine Park is predicted to reach hazard class 4 which is unsafe for both people and vehicles. It is recommended this information be passed onto FRW as the asset owner.
- Flood inundation is predicted at Rockhampton State High School in the 39% AEP event, however the low depth and velocity of flooding is expected to present a low risk until larger events where the hazard reaches Class 2.
- A number of roads are predicted to experience inundation in the 1EY event and larger. Predicted TOS generally ranges from 1 to 2 hours, with Canoona Road predicted to be inundated for almost 1 day in a 1% AEP 90min event.

Evacuation Routes

Generally local catchment flooding within the Wandal and West Rockhampton catchment is due to short duration, high intensity rainfall events. The relatively steep upper catchment and urbanisation throughout the upper and middle catchment can result in inundation of key roads as well as 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 Wandal and West Rockhampton catchment, the warning time between the commencement of the rain event and subsequent flood inundation can be short. This limits the opportunity for evacuation, and generally the action taken by the community is to '*shelter in place*' until the flooding has passed.

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

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

- Ann Street / Pennycuick Street à lose evacuation to Denham Street.
- Western Street / Melbourne Street à lose evacuation via Melbourne Street to Hunter Street.
- Pearson Street / Kalare Street / Peterson Street à lose access to Western Street.
- Cannona Road / Western Street à lose access to Lion Creek Road.
- Lion Creek Road / Dally Street à lose access to Lion Creek Road via Duncan Street, Barry Street and Bedden Avenue.
- Lion Creek Road / Harman Street / Hall Street à lose access to Lion Creek Road via Luck Avenue and Savage Street.

Building Impact Assessment

Council provided a building database, containing ~4,300 buildings digitised within the Wandal and West Rockhampton modelled area. Of these, ~1,800 buildings contained surveyed data, focussed on Fitzroy River 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 ~2,500 floor levels and ground levels within the Wandal and West Rockhampton modelled area, for buildings outside Council's surveyed database.
- Classification of ~4,300 buildings within the Wandal and West Rockhampton modelled area, in accordance with ANUFLOOD requirements.

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

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

Table E2 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Wandal and West Rockhampton 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	11 (3)	0 (0)
39.4	25 (7)	2 (2)
18.1	45 (13)	3 (3)
10	70 (22)	5 (5)
5	92 (29)	8 (8)
2	107 (36)	12 (11)
1	129 (40)	18 (15)
0.2	194 (67)	23 (20)
0.05	273 (99)	33 (30)
PMF	593 (232)	65 (61)

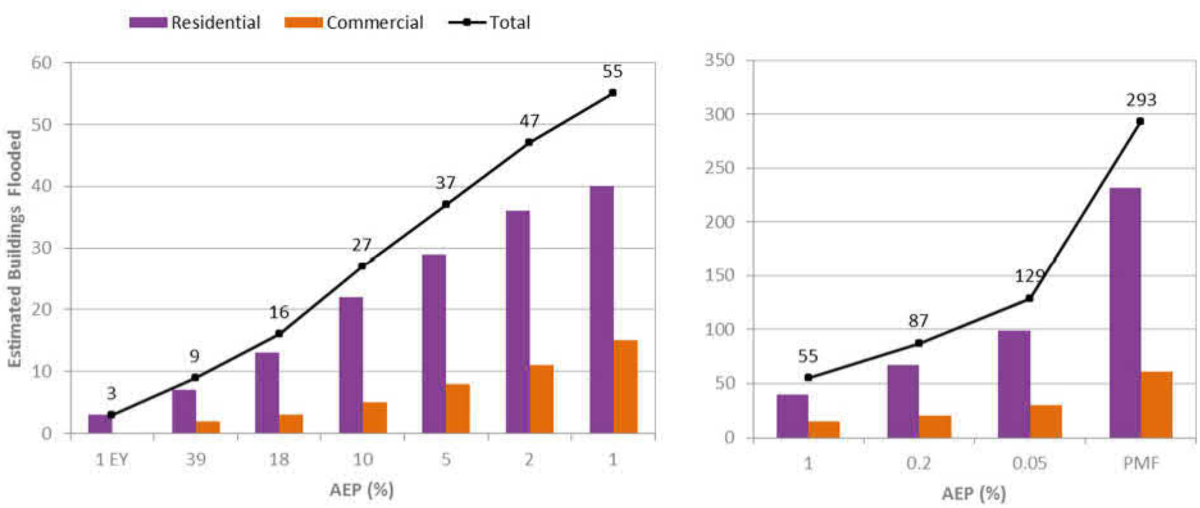


Figure E2 Estimated Buildings with Above Floor Flooding (Number of Buildings)

As shown in Figure E3, median flood depths are generally less than 0.3 metre for each flood event. This indicates that reductions in flood depths of 0.3 metre could significantly reduce overall damage. The figure also shows that a significant number of buildings experience flood depths of 0.1 metre or less during frequent events such as the 1EY flood event, generally corresponding to higher flood damages.

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

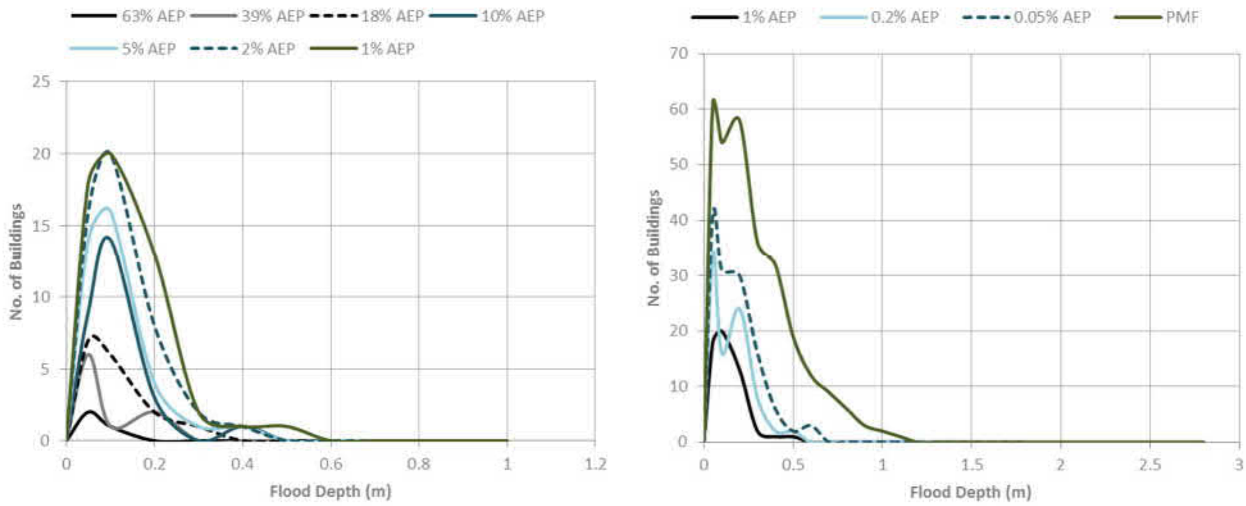


Figure E3 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

Flood Damages Assessment

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

Figure E4 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from $265,000 (1EY flood event) to $47M (PMF event) using the O2 Environmental Damage Curves. 3 buildings are expected to be inundated above floor in the 1EY event, whilst 293 buildings are anticipated to be inundated above floor in the PMF event.

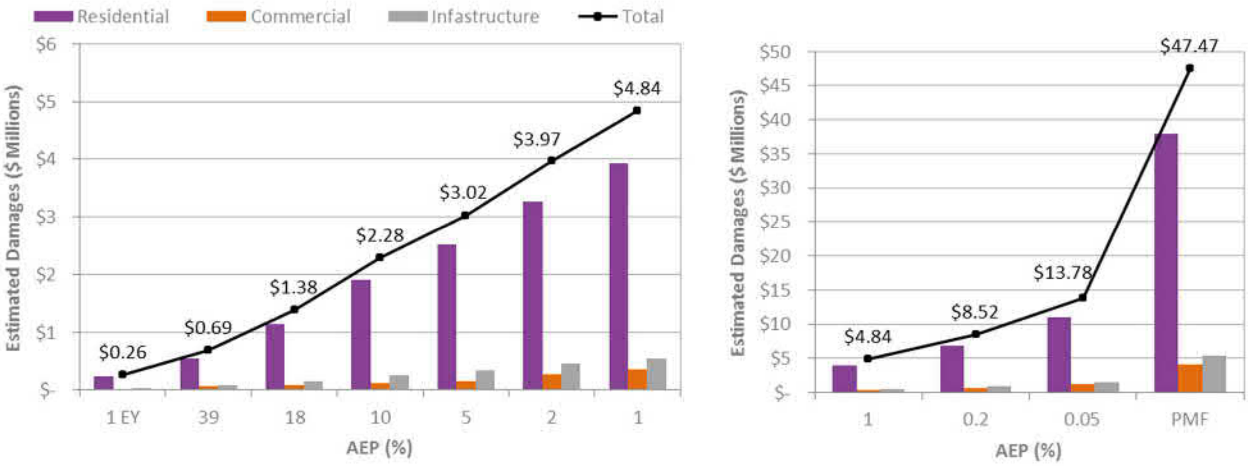


Figure E4 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

These figures also demonstrate that Residential buildings make up the large majority of impacted buildings, and the estimated flood damages, within the Wandal and West Rockhampton 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 Wandal and West Rockhampton catchment is estimated to range from approximately $850,000 to $860,000 per annum.

Figure E5 provides a breakdown of the AAD and building impact assessment. The area in blue corresponds to individual building AAD (residential and non-residential combined) in brackets of $100 per annum. The orange line corresponds to the cumulative AAD for residential and non-residential buildings combined.

As shown, 81% of all buildings exhibit less than $500 damage per annum and produce only 3% of the total damage, infrastructure damage excluded.

58% of damages are associated with less than 5% of all buildings. This demonstrates that a minority of buildings produce the majority of damages.

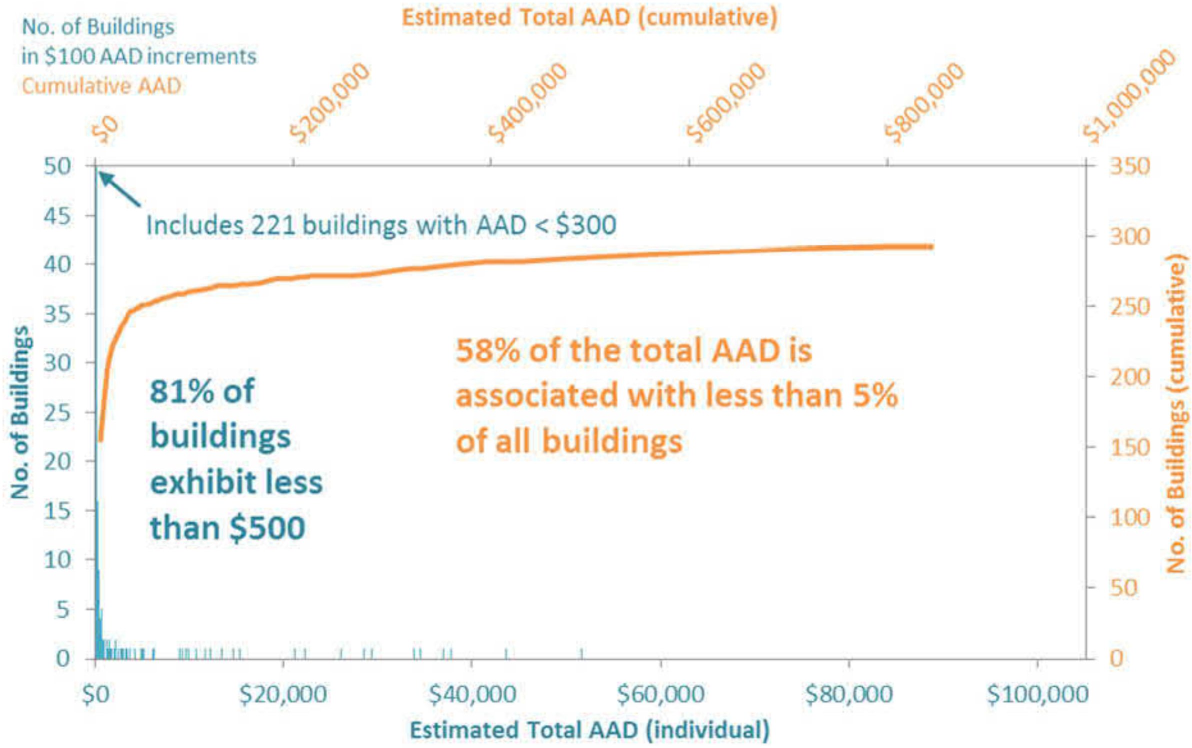


Figure E5 Individual Building vs. Cumulative Total Average Annual Damages

Rainfall Gauge, Maximum Flood Height Gauge and Flood Warning Network

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

- A sufficient spread of rainfall gauges are installed within the catchment to provide a confident record of rainfall depths and patterns across Wandal and West Rockhampton.
- In addition to the three existing maximum flood height gauges within the Wandal and West Rockhampton catchment, it is recommended that gauges be installed at the following locations (as shown on Figure 50):
  - South-western face of Lion Creek Road (at the low point) between Sir Raymond Huish Drive and South Rockhampton SHS Access Road.
  - Eastern side of the concrete inverted spoon drain running into Jardine Park, accessible via Morgan Street. Gauge should be placed just prior to the end of the upper soccer fields, south of the netball courts on Allenby Street.

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 Wandal and West Rockhampton catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained.
- It is recommended that Council continue to record rainfall and flood heights associated with future Wandal and West Rockhampton catchment flood events. This data will support ongoing model calibration / validation works that should be undertaken in future updates to this study. The implementation of additional gauges identified in this study is also recommended.
- The baseline vulnerability and flood hazard assessment outputs from this report should be used to support a future Phase 3 of the Study (Flood Mitigation Options Development and Assessment).

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 Wandal and West Rockhampton Local Catchment Study, which is the subject of this report.

Flooding in Wandal and West Rockhampton can occur as a result of two different flood mechanisms:

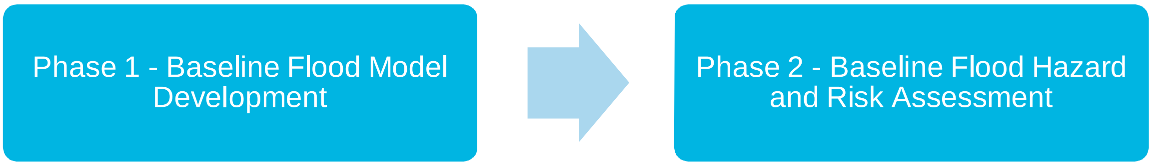
- Riverine flooding due to rainfall over the Fitzroy River catchment.
- Flash flooding due to rainfall over the local urban catchment.

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

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

1.2 Phased Approach

The Wandal and West Rockhampton Local Catchment Study has been split into two 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. Future Phase 3 works will involve the assessment of a range of structural and non-structural flood mitigation options to reduce the hazard and risk posed by future local catchment flood events.

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

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 future 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 Wandal and West Rockhampton Local Catchment Study – Baseline Flooding and Hazard Assessment Report has been separated into 2 volumes:

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

The structure of this Volume 1 report is as follows:

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

1.5 Notes on Flood Frequency

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

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

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

1.6 Limitations and Exclusions

The following limitations apply to this study:

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

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

2.0 Study Area Characteristics

2.1 General Description

The Wandal and West Rockhampton urban catchment covers approximately 16.3 km^2 within the suburbs of The Range, Wandal, Pink Lily and West Rockhampton which also encompasses the Rockhampton Airport.

The western catchment boundary follows Nine Mile Road and continues along Old Nine Mile Road to form the southern boundary. Further east, the southern boundary crosses Crescent lagoon, the fringes of Murray Lagoon and extends to the southern tip of The Range near Yeppen Lagoon. From this southernmost point the catchment boundary tends north along the crest of The Range until it meets the Rockhampton Base Hospital. After this point the catchment roughly follows North Street to the Fitzroy River. The eastern boundary continues up the Fitzroy River to just north of the Lion Creek outlet. The northern boundary extends from the Fitzroy River along Dargel Road to Ridgelands Road at the Nine Mile Road turnoff.

The upper urban catchments within Wandal and West Rockhampton contain moderately steep overland flow paths similar to those within the neighbouring catchment of South Rockhampton, though flow paths are generally more formalised. Closer to Wandal's primary arterial Lion Creek Road, the slope flattens rapidly and, in most instances, delivers runoff to multi-purpose detention basins like Alf Kele Memorial Rotary Park and Jardine Park which are serviced by trunk mains outletting to the Fitzroy River or Lion Creek.

Runoff travelling west through the steep overland flow paths reaches the Western Street road embankment and is primarily directed to the detention basin at Garland Park (for the northern segment of West Rockhampton) or a major table drain traversing Hunter Street (for the southern segments). From this point flows are directed to the nearest waterbodies, being Lion Creek or Murray Lagoon.

Rural and commercial (including Rockhampton Airport) catchments west of Western Street have very limited slope and are well vegetated, leading to slower overland velocities and a wider inundation extents. Overland runoff within the airport and industrial precincts is conveyed to Lion Creek or high flow drains, whereas flows north of Lion Creek generally accumulate within lagoons, such as Lotus Lagoon.

The external creek systems of Lion Creek and Neerkol Creek were also shown to impact the lower lying floodplains near the western and southern catchment boundaries. Though the Lion Creek channel intersects the model at the western boundary, most short duration design events were predicted to dissipate and fill the surrounding lagoons and floodplains before impacting the catchment of interest. Longer duration events for both Lion and Neerkol Creeks are expected to result in higher flood peaks and inundation extents near the catchment boundary and result in widespread inundation of the lower, rural floodplains. The flooding behaviour of these catchments is described further in Section 2.2.

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

2.2 External Catchment Influence

The external creek catchments situated southwest of Wandal and West Rockhampton introduce additional complexity when developing an understanding of the flood behaviour in the focus area.

2.2.1 Neerkol Creek

Neerkol Creek is the largest system, stretching more than 21 km west and conveying flows from several minor systems, including Gracemere Creek and Middle Creek at Gracemere. Flows from Neerkol Creek can quickly exceed the naturally-leveed creek banks and overtop towards the neighbouring lagoons and the broad lower Fitzroy floodplains (particularly the Yeppen Floodplain).

Major expansion of the Neerkol Creek influence area occurs at Fairy Bower Road where a significant proportion of flow crosses Fairy Bower Road to the west of the Neerkol Creek crossing in large flood events. In such events, flows ultimately fill the Yeppen Floodplain and overtop Nine Mile Road into Lion Creek.

Some of this water later returns to the Yeppen Floodplain when it overtops Nine Mile Road for the second time (south of Nine Mile Road Bridge). Flows remaining within Neerkol Creek split downstream of Fairy Bower Road, with low flows directed to Scrubby Creek by the man-made weir situated at the end of Neerkol Creek. Floodwaters within the Yeppen Floodplain recede in a similar fashion to a Fitzroy River breakout event, in which waters traverse the Bruce Highway and follow Gavial Creek to join the Fitzroy River west of Depot Hill. Large events which result in widespread inundation of floodplains and rural assets occur following long storm durations of more than 24 hours.

2.2.2 Lion Creek

The smaller catchment of Lion Creek meanders between the mountainous ranges (which entails Mount Lion) northwest of Gracemere and tends west towards Malchi Nine Mile Road. A large proportion of flows in large events tend to overtop the natural banks of Lion Creek and cross the low-lying Malchi Nine Mile Road which then recharge the downstream wetlands, including Lower Gracemere Lagoon (a.k.a. Paradise Lagoons). Flows reaching this point follow a similar pattern through the Yeppen Floodplain as described above.

Lion Creek flows remaining within the channel cross the floodway at Nine Mile Road and replenish storage levels within Lion Lagoons. As floodwaters exceed the available storage (large or long duration events involving high volumes of runoff) flows roughly follow Nine Mile Road towards the Rockhampton Airport, with much of the flow filling the Lotus Lagoons at Pink Lily. Rare events result in a second overtopping of Nine Mile Road (as with the Neerkol Creek catchment) south of Nine Mile Road Bridge, following the system of lagoons towards Gavial Creek and ultimately Fitzroy River.

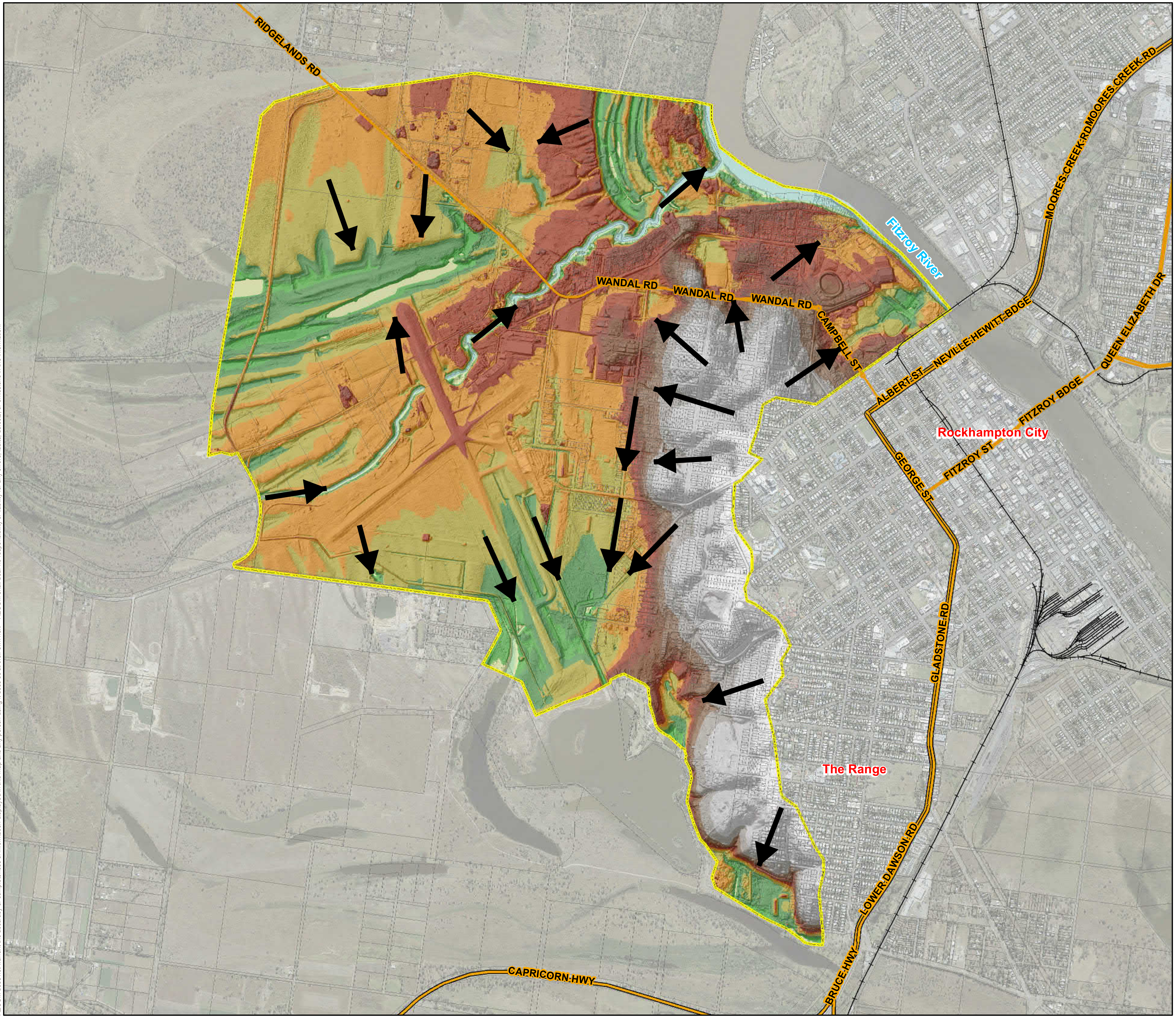
2.2.3 Influence on the Wandal and West Rockhampton Catchment

During events within either system, a majority of runoff is attenuated within the vast Yeppen Floodplain, resulting in only a small proportion of flows (though still notable) reaching the bebo arch culvert under the runway at Rockhampton Airport. More significant influence from the external catchments occurs at the:

- Pink Lily Lagoon;
- Lotus Lagoons;
- Lion Creek at Nine Mile Road Bridge;
- Crescent Lagoon;
- Murray Lagoon; and
- Yeppen Lagoon.

For the purposes of modelling design events between external catchments and the Wandal and West Rockhampton Local Catchment, the same storm duration has been modelled across each catchment (i.e. internal and external catchments). This duration is based on the selected critical duration for the Wandal and West Rockhampton Local Catchment, which is a significantly shorter duration than those which are critical for Lion Creek and Neerkol Creek. As such, a significantly smaller volume of runoff is generated; meaning flood extents are commonly captured within floodplains outside the focus area. Within these shorter storm durations the Lion Creek system becomes dominant when considering the influence on the Wandal and West Rockhampton catchment.

A visual representation of both Lion Creek and Neerkol Creek’s flood behaviour (during their critical storm durations) has been provided in Figure 2 and Figure 3.



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250

Metres

1:25,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Topography (mAHD)

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

Data Sources:

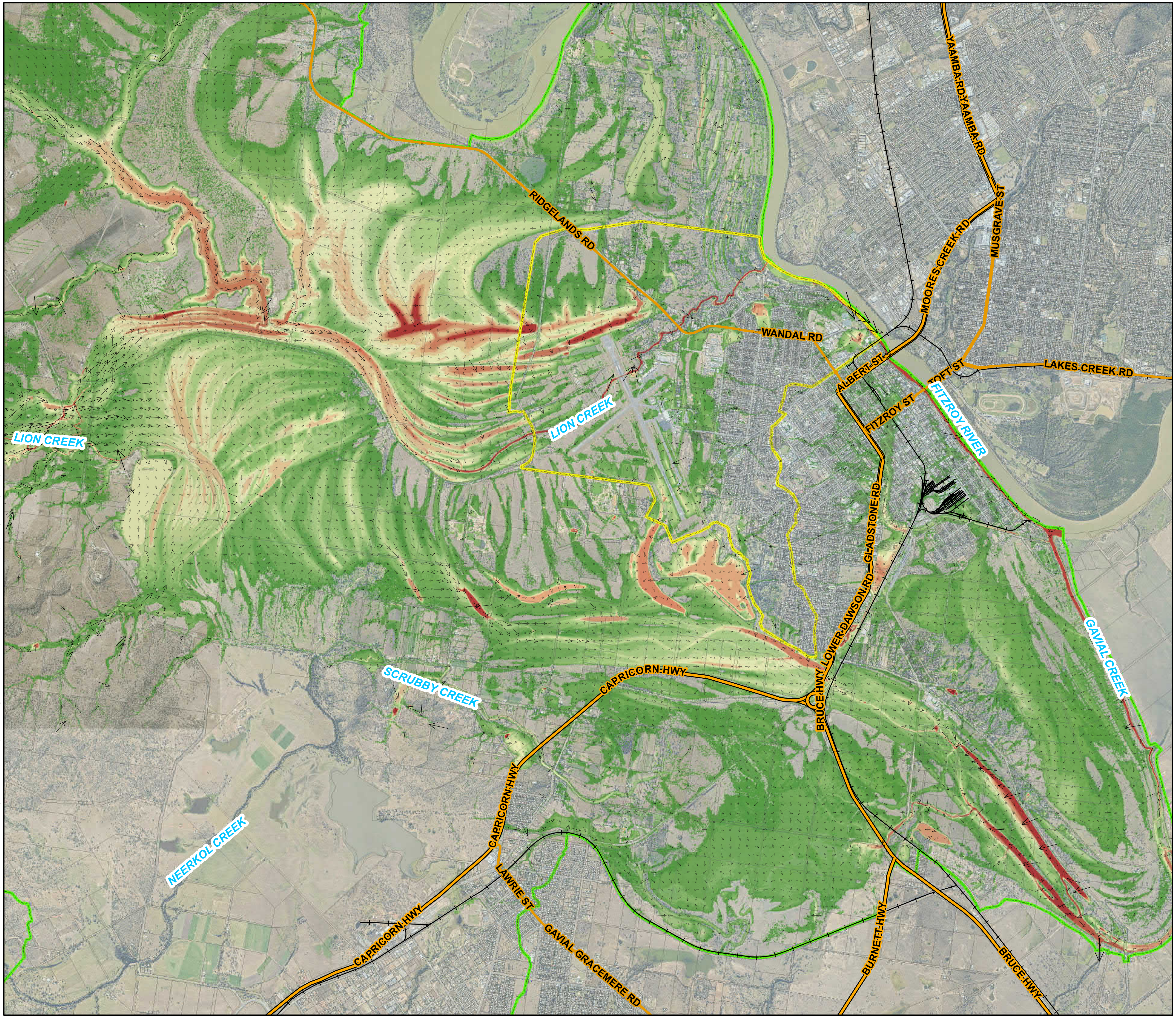
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Wandal & West Rockhampton Model

Sub-catchment Delineation and Natural Flow Paths

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	1

Figure 1



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 0.5 1 1.5 2 2.5

Kilometers

1:50,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

Vector Velocity (m/s)

- 0.00 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- > 2.50

- Highways
- Main Roads
- Railway Lines
- Cadastre
- CPU Hydraulic Model Extent
- GPU Hydraulic Model Extent

Peak Flood Depth (m)

- 0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- 1.2 - 1.5
- 1.5 - 1.8
- 1.8 - 2.1
- 2.1 - 2.4
- 2.4 - 2.7
- 2.7 - 3
- > 3.0

Data Sources:

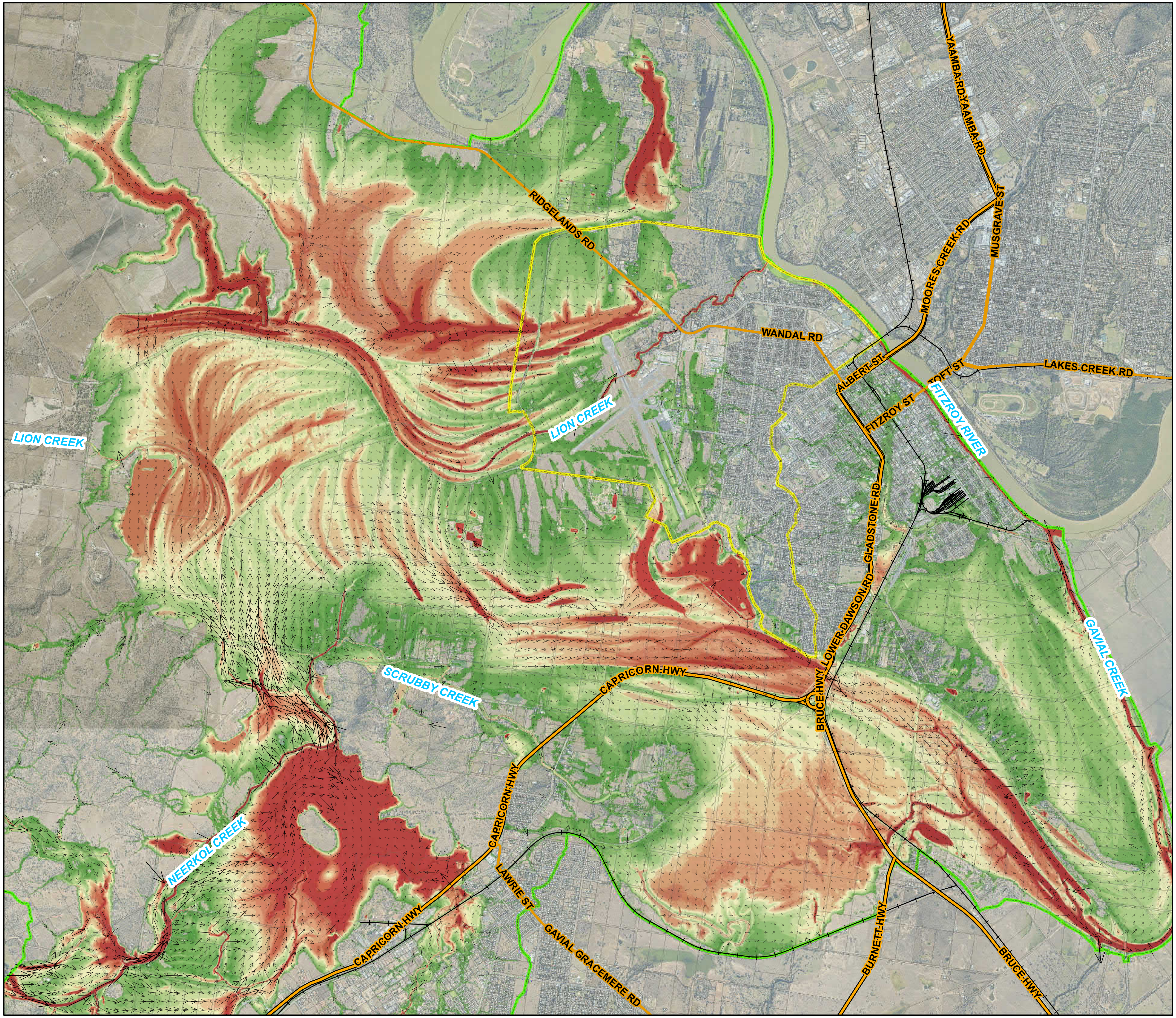
Wandal & West Rockhampton Model

External Catchment Flood Behaviour
Lion Creek
1% AEP 1440min storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/02/2018
VERSION:	1

Figure 2

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 2 External Catchment Flood Behaviour.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 0.5 1 1.5 2 2.5

Kilometers

1:50,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

Vector Velocity (m/s)

- 0.00 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- > 2.50

- Highways
- Main Roads
- Railway Lines
- Cadastre
- CPU Hydraulic Model Extent
- GPU Hydraulic Model Extent

Peak Flood Depth (m)

- 0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- 1.2 - 1.5
- 1.5 - 1.8
- 1.8 - 2.1
- 2.1 - 2.4
- 2.4 - 2.7
- 2.7 - 3
- > 3.0

Data Sources:

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

Wandal & West Rockhampton Model

External Catchment Flood Behaviour
Neerkol Creek
1% AEP 2160min storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/02/2018
VERSION:	1

Figure 3

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 3 External Catchment Flood Behaviour.mxd

2.3 Climate Characteristics

The Wandal and West Rockhampton local catchment is centred on latitude 23º 22' 55.81" south, about 6.4km north of the Tropic of Capricorn. The catchment centroid is about 32km 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 800mm. The highest mean monthly rainfall of 145mm generally occurs in February. The highest and lowest annual rainfall recorded at the Rockhampton Airport is 1631mm (in 1973) and 360mm (in 2002) respectively which shows a significant variation in annual rainfall, year on year.

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

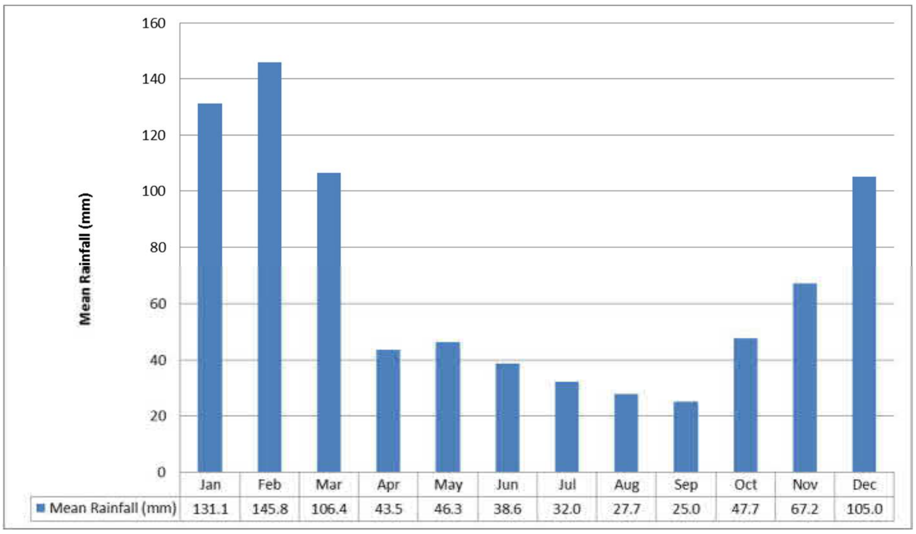


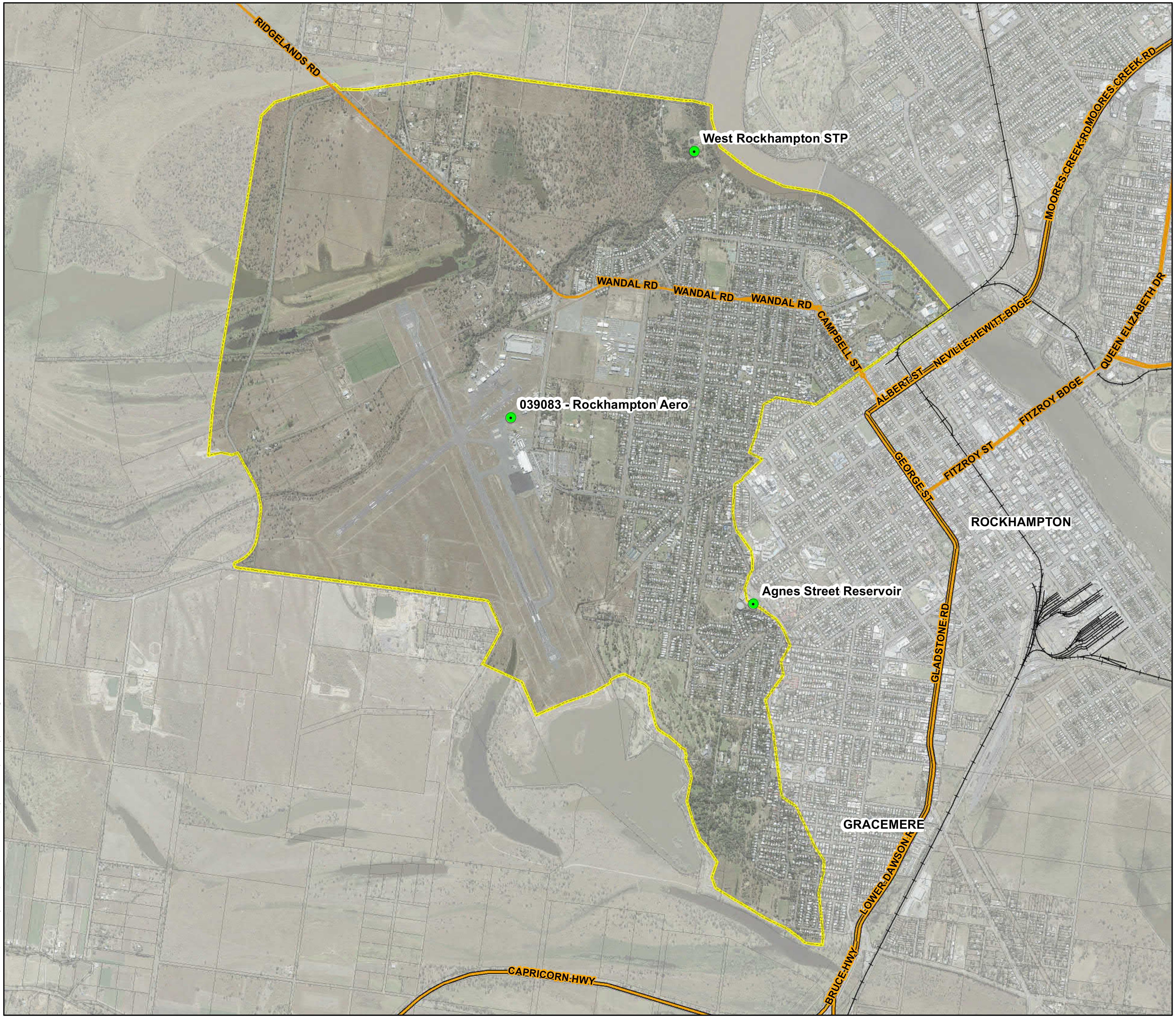
Figure 4 Mean Monthly Rainfall at the Rockhampton Airport Rainfall Station

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

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

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

In addition to the above, Council have in the past also obtained 30 minute rainfall data from a private residence at Serocold Street, Frenchville. The rainfall stations are represented spatially in Figure 5.



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250
Metres

1:25,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

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

Data Sources:

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

Wandal & West Rockhampton Model

Rainfall Gauge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	1

Figure 5

Filename: \\aurok1fp001\Projects\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 4 Rainfall Gauge Station Locations.mxd

Of the abovementioned gauges, Agnes Street Reservoir borders the eastern boundary of the study area and Rockhampton Aero sits well within the catchment approximately 0.8km west of the urban catchment. Considering the location of existing peak flood height gauges, the Agnes Street Reservoir rainfall station is most likely to represent the best-estimate of historic rainfall events for the Wandal and West Rockhampton Local Catchment model. As such, this gauge will be used to inform hydrologic inputs for historic events where available data permits.

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

2.5 Historic Local Catchment Events

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

This study included the simulation of 2017 local catchment events, which served as the calibration event for the study. No validation event simulations were completed, due to a lack of available data.

2.6 Riverine Flooding Influence

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

Figure 6 outlines the riverine flood heights for a 1% AEP flood event. It is evident that significant portions of the Wandal and West Rockhampton local catchment become inundated by riverine flood waters in a flood event of this magnitude.

The effect of riverine backwater levels on local catchment flood behaviour have not been modelled as a part of the sensitivity analysis due to the confined extent of the 18% AEP event within Lion Creek.

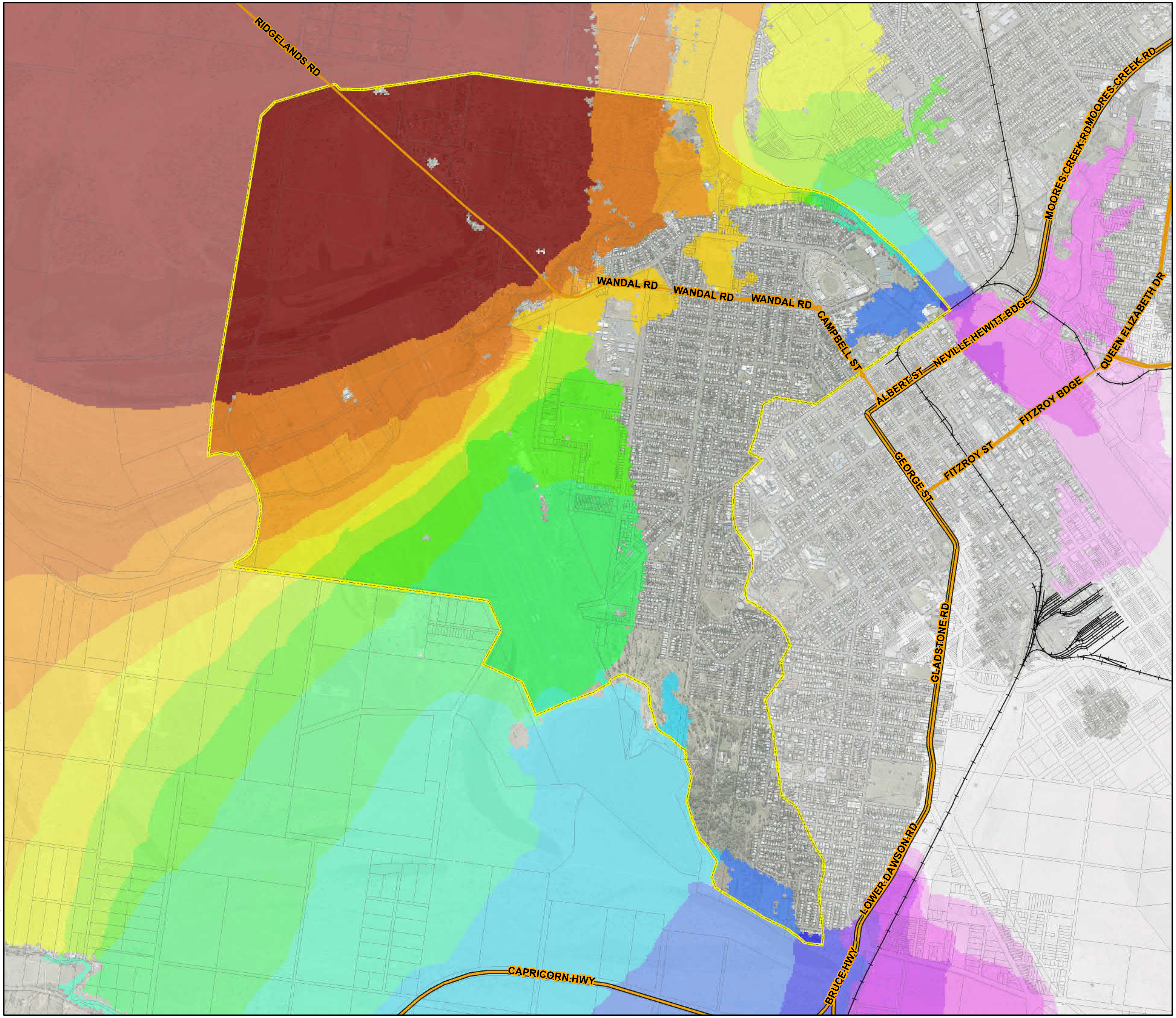
2.7 Creek Flooding Influence

Creek flooding in the study area can result from rainfall over the rural, mountainous catchments of Lion Creek and Neerkol Creek west of the study area. The lower lying floodplains within the model extent are particularly susceptible to longer duration events where Neerkol Creek is the dominating system.

To assess the impact of these systems on local catchment flood behaviours, sensitivities of each creek system's critical duration have been simulated in a coincident event with the local catchment critical duration. The results form a component of the discussion made in Sections 8.4 and 8.5.

2.8 Flood Warning System

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



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 210 420 630 840 1,050 1,260

Metres

1:25,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Peak Riverine Flood Height (mAHD)

- < 8
- 8.0 - 8.2
- 8.2 - 8.4
- 8.4 - 8.6
- 8.6 - 8.8
- 8.8 - 9.0
- 9.0 - 9.2
- 9.2 - 9.4
- 9.4 - 9.6
- 9.6 - 9.8
- 9.8 - 10.0
- 10.0 - 10.2
- 10.2 - 10.4
- 10.4 - 10.6
- 10.6 - 10.8
- 10.8 - 11
- 11.0 - 11.2
- > 11.2

Flood results are based on riverine catchment events

Data Sources:

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

Wandal & West Rockhampton Model
Peak Fitzroy River Flood Heights

1% AEP Riverine Flood Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	A

Figure 6

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 and 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 2017 flood events (RRC).

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

3.2 Previous Studies

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

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

The recommendations of the report were to move to the AR&R 2016 hydrologic methodology. Council have consequently resolved to maintain the use of AR&R 1987 hydrologic methodologies whilst developing an implementation plan for the adoption of the AR&R 2016 methodology. It is Council's intent to finalise this implementation plan over the coming two years. A further recommendation of the review was to adopt current industry mapping standards as per DNRM 2016 Guidelines, which Council have agreed to adopt where applicable within the Floodplain Management Services Program.

3.2.2 SRFL Hydraulic Model Development (AECOM, 2014)

The South Rockhampton Flood Levee (SRFL) planning and for tender design project was completed by AECOM throughout 2014, and included assessment of Fitzroy River and interior drainage 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 for use in this study. Reference should be made to the SRFL Hydraulic Model Development and Comparison report (AECOM, 2014) for further details.

3.3 Tidal Data

Tidal data for the March 2017 event was not currently 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 (2.66m AHD). The MHWS level was sourced from the 2014 QLD Tide Tables book (MSQ, 2014).

3.4 Topographic Data

The topographical information used for the Wandal and West Rockhampton Local Catchment model was provided by RRC in the form of LiDAR survey, which was undertaken between 30 September 2015 and 23 January 2016 by AAM Pty Ltd. The LiDAR points were used to generate a base Digital Elevation Model (DEM) with a grid spacing of 1m. It is stated in the report provided by AAM Pty Ltd that the Horizontal Spatial Accuracy is estimated to be ±0.40m and the Vertical Spatial Accuracy is estimated to be ±0.15m, on clear open ground. Council undertook elevation checks and commented that the accuracy of the LiDAR is within the ±0.15m vertical tolerance on hard surfaces.

Surveyed cross-sections were obtained from RRC at locations where the LiDAR was expected to encounter standing water, misrepresent the terrain or not provide sufficient detail. Final areas were nominated for surveyed cross-sections which revealed up to 0.5 m vertical discrepancies in overland flow paths and up to 3.8 m vertical discrepancies within Lion Creek.

Ideal circumstances call for topographic data preceding significant events in an attempt to best represent the catchment terrain 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 overland flow paths for the March 2017 event.

As Constructed plans were provided by Council for the Ann Street units and RACQ Capricorn Helicopter Rescue Service extension which were not present at the time of the LiDAR. In order to appropriately represent these areas in the hydraulic model, finished levels and impermeable surfaces were stamped into the model topography.

3.5 Aerial Photography

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

3.6 Stormwater Infrastructure Network Database

Drainage asset information was supplied by RRC in the form of GIS layers containing location, size and invert data for culvert, pit and pipe assets. Where stormwater infrastructure data was absent, details were estimated using the following assumptions:

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

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

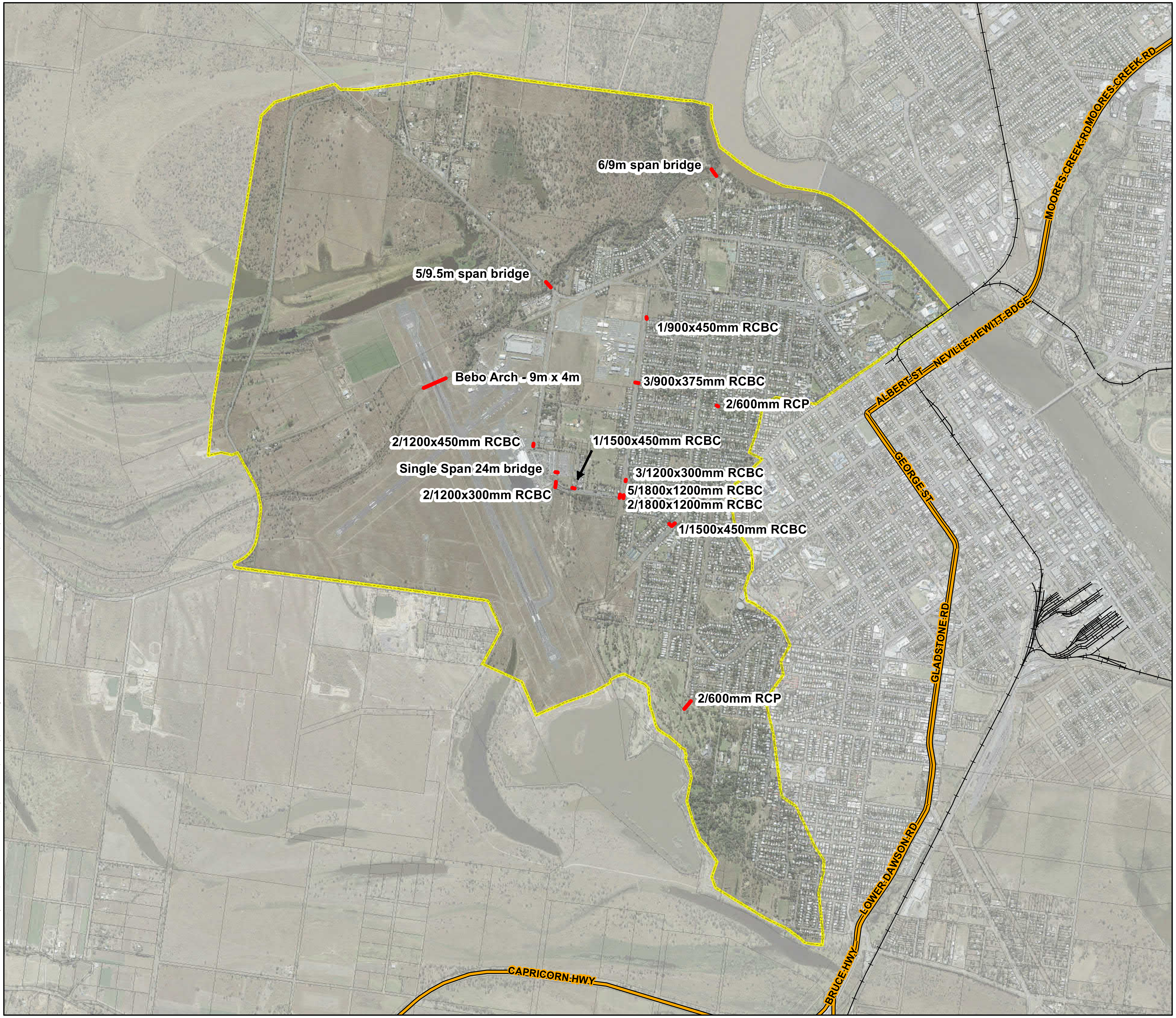
3.7 Hydraulic Structures

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

Approximately 150 culverts and 3 bridge structures were identified within the hydraulic model extent. Although the majority of structures were digitized in the model, some minor structures which were not expected to convey significant flows or connect key flow paths were excluded. Table 1 presents a list of major structures within the study area which were incorporated into the hydraulic model.

Table 1 Key Hydraulic Structures Incorporated to the Model

Drainage Structure	Configuration	Model Representation
Bridges		
Ridgelands Road Bridge	5/9.5m span bridge	2D
Harman Street Bridge	6/9m span bridge	2D
Airport Carpark Footbridge	Single 24m span bridge	2D
Major Culverts		
Lion Creek	Bebo Arch – 9m x 4m	1D
Hunter Street	5/1800 x 1200mm RCBC	1D
	2/1800 x 1200mm RCBC	1D
Stickley Street	3/1200 x 300mm RCBC	1D
Western Street	3/900x375mm RCBC	1D
Jones Street	1/900x450mm RCBC	1D
Canoona Road (Access)	2/1200x450mm RCBC	1D
Hunter Street (Airport Carpark)	2/1200x300mm RCBC	1D
Canoona Road	1/1500x450mm RCBC	1D
Charlotte Street	2/600mm RCP	1D
Golf Course	2/600mm RCP	1D
North Street	1/1500x450mm RCBC	1D



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

Data Sources:

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

Wandal & West Rockhampton Model

Key Hydraulic Structures

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	A

Figure
7

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3.8 Historical Rainfall Data

Historical rainfall records for 2013, 2015 and 2017 events were acquired from BoM and provided by Council in the form of 1-minute intervals for the range of rainfall stations shown in Figure 5. A list of rainfall gauging stations, their locations, type of data and applicable events is provided in Table 2, where:

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

Table 2 Summary of Rainfall Data used in the Study

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

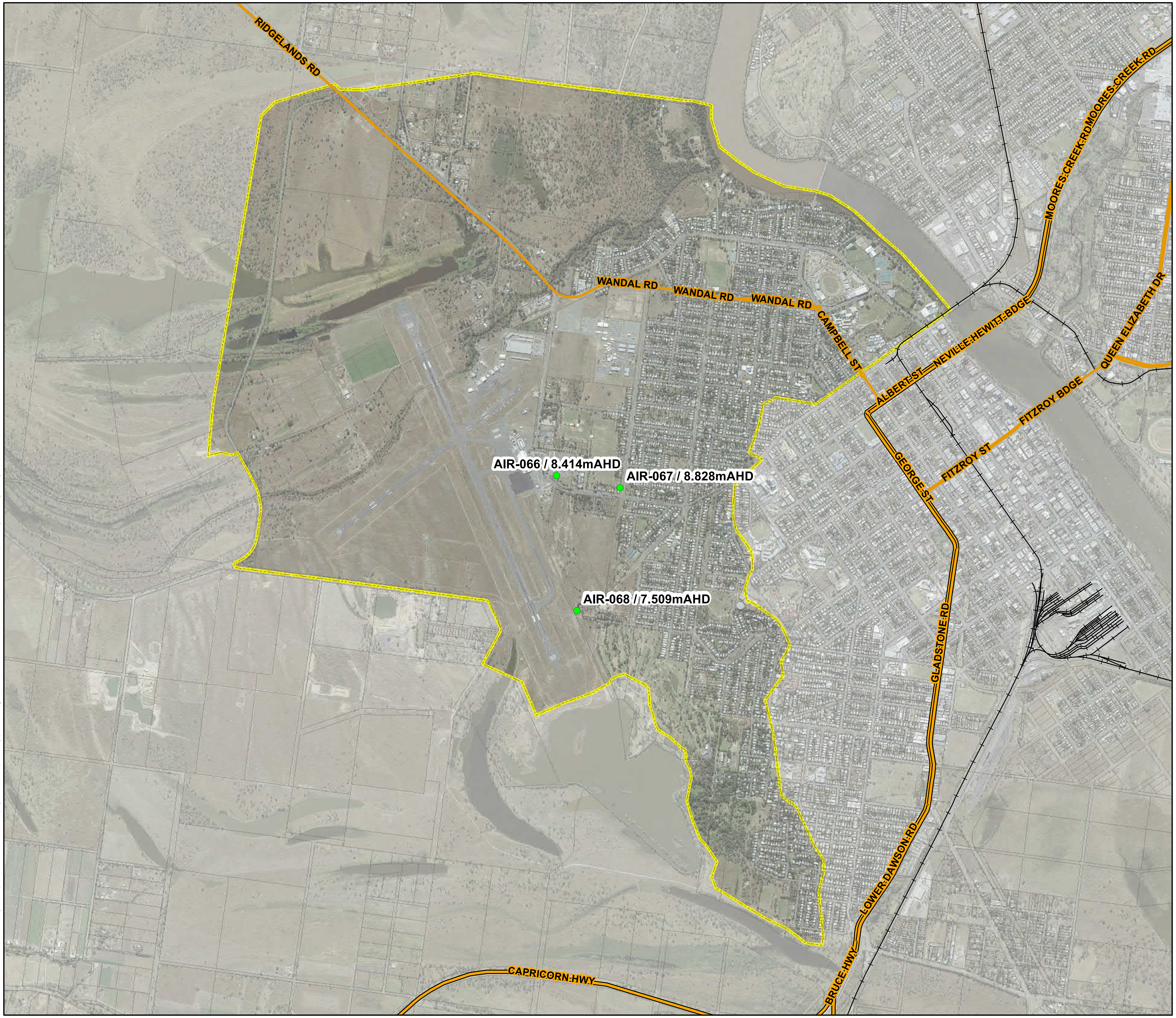
3.9 Historical Flood Records

3.9.1 Recorded Water Level Data

Water level data recorded at key locations in major table drains upstream and downstream of Hunter Street and were provided by Council for the 2017 event. The data included the locations and maximum readings of gauges shown in Figure 8. Table 3 presents the spatial locations and peak heights of Council's gauges within the Wandal and West Rockhampton Local Catchment model for the 2017 event. Adopted verification tolerances in the 2017 event were ±0.15m.

Table 3 Recorded Gauge Data for 2017 flood event

Gauge Label	Gauge ID	Easting (m)	Northing (m)	Zero Gauge Level (mAHD)	Peak Gauge Depth (m)
Connor Dr-Airport	AIR-066	242467.30	7412276.10	7.704	0.71
Western/Hunter St	AIR-067	242913.54	7412189.80	8.653	0.14
Denham St Ext	AIR-068	242611.60	7411330.50	6.628	0.83



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LEGEND

- 2017 Recorded Levels
- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

Wandal & West Rockhampton Model

Recorded Gauge Data Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	22/12/2017
VERSION:	1

Figure
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4.0 Hydrologic Inputs

4.1 Direct Rainfall Approach

4.1.1 Overview

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

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

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

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

- Use of the direct rainfall approach can negate the need to develop and calibrate a separate hydrological model, thus reducing overall model setup time.
- Assumptions on catchment outlet locations are not required. When a traditional hydrological model is utilised, an assumption is required on where the application of catchment outflows are made to the hydraulic model.
- Assumptions on catchment delineation are not required. Flow movement is determined by 2D model topography and hydraulic principles, rather than on the sub catchment discretisation, which is sometimes based on best judgement and can be difficult to define in flat terrains.
- Cross catchment flow is facilitated in the model. In flat catchments, flow can cross a catchment boundary during higher rainfall events. This can be difficult to represent in a traditional hydrological model.
- Overland flow is incorporated directly. Overland flow models in traditional hydrological packages require a significant number of small sub-catchments, to provide sufficient flow information to be applied to a hydraulic model.

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

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

4.1.2 Approach

Two dimensional rainfall excess time series for each AEP event and duration were created to represent the local net precipitation for the **local catchment**. This rainfall excess was calculated by applying initial and continuing losses to the design rainfall to represent infiltration and storage of runoff in surface depressions. Losses chosen for this project are discussed in Section 4.3.5.

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

For the **Lion Creek** and **Neerkol Creek** external catchments, a TUFLOW GPU model utilising the direct rainfall approach was developed in order to establish flow hydrographs and height-time series within these catchment. Lion Creek is calculated to have a critical duration of 1440mins, whereas Neerkol Creek has a longer critical duration of 2160mins. As highlighted in Section 2.2.3, when modelling a coincident design event to establish baseline flood behaviour within Wandal and West Rockhampton, the same storm duration (based on the local catchment critical duration) was applied to both exterior and interior catchments. When modelling external catchments under this shorter duration, considerably lower runoff volumes were generated from Lion Creek and Neerkol Creek. This resulted in Lion Creek becoming the primary influence on the Wandal and West Rockhampton local catchment.

In order to logically incorporate the external catchment influence within the local catchment model, detailed review of the flood behaviour at the model boundary was warranted. The majority of areas influenced by Lion Creek (i.e. low-lying floodplains) within the modelled area were observed to be low-energy areas where backwater filled natural contours in the land, such as Lotus Lagoons. In such areas, it was deemed suitable to apply a varying height-time (HT) boundary which would ensure the heights and peak flood extents predicted from the external catchment would be replicated during a coincident event. In order to carry out this process, a height-time series was extracted from the TUFLOW GPU model (which models the external catchment flood behaviour of Lion Creek and Neerkol Creek) and applied directly to the edge of the TUFLOW CPU model (which models the local catchment flood behaviour within Wandal and West Rockhampton). This approach is similar to applying a tidal boundary.

Within Lion Creek itself floodwaters carried a much higher energy, meaning that when runoff reaches the boundary of the smaller CPU model, it carries a significant amount of momentum. In order to conserve the total volume of flow and energy present in Lion Creek’s main channel, a flow-time (QT) boundary was selected. In order to apply this type of boundary to the smaller CPU TUFLOW model, a flow hydrograph across the creek section was extracted from the GPU TUFLOW model and applied directly to the same channel cross-section in the CPU TUFLOW model.

Using a combination of the abovementioned boundaries, it was possible to model the influence of the external catchments on the Wandal and West Rockhampton local catchment. Each of the boundary types and extents developed for the CPU TUFLOW model is shown in Figure 10.

4.2 Historic Rainfall Data

Historic rainfall records for the 2013, 2015 and 2017 events were obtained for the Rockhampton Aero pluviograph station located within 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. A rainfall plot of the 2017 rainfall event is included in the subsequent section.

4.2.1 2017 Event – Ex-TC Debbie

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

Although Rockhampton Aero records were obtained (totalling 186.6mm), detailed 1-minute interval records were available for Agnes St Reservoir gauges and as such was adopted. The timeseries of rainfall data at Agnes Street Reservoir for the 2017 event is shown in Figure 9.

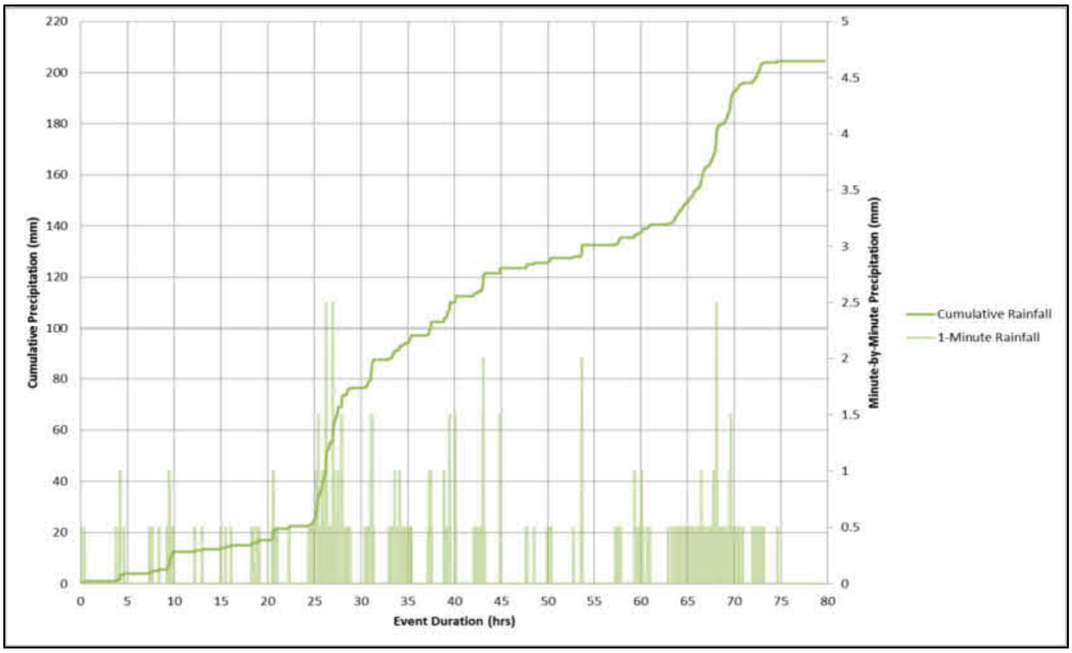

Figure 9 2017 Event Rainfall (Agnes St Reservoir)

Total rainfall depths between the gauges in Wandal and West Rockhampton varied by 10%, indicating limited variability in rainfall between the upper and lower catchments of Wandal and West Rockhampton. In addition to the proximity of the gauges to the catchment and flood gauges, the limited variability in rainfall further justifies the adoption of Agnes Street Reservoir rainfall data for use in the model calibration.

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Boundary Conditions

- HQ
- HT
- QT
- Highways
- Main Roads
- Railway Lines
- Cadastre
- CPU Hydraulic Model Extent
- GPU Hydraulic Model Extent

Peak Depth Averaged Velocity (m/s)

- < 0.25
- 0.25 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- > 2.00

Data Sources:

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

Wandal & West Rockhampton Model

External Catchment Influence
Lion Creek
1% AEP 1440min storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	23/01/2018
VERSION:	1

Figure 10

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Volume2\Figure 10 CPU Model Boundaries.mxd

Table 4 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%

4.3 Design Rainfall Data

4.3.1 IFD Parameters

Design rainfall data was sourced from the Bureau of Meteorology (BoM) online IFD tool (bom.gov.au/water/designRainfalls/ifd-arr87/index.shtml). IFD parameters required to determine rainfalls for events not previously modelled were sourced using a single set of parameters, derived at the location (150.500 E, 23.375 S) for Rockhampton and (150.350 E, 23.400 S) for Lion Creek and Neerkol Creek. The IFD input data set obtained is shown in Table 5.

Table 5 Adopted IFD Input Parameters

Parameter	Rockhampton	Lion Creek and Neerkol Creek
1 hour, 2 year intensity (mm/hr)	44.54	44.08
12 hour, 2 year intensity (mm/hr)	8.7	7.74
72 hour, 2 year intensity (mm/hr)	2.47	2.25
1 hour, 50 year intensity (mm/hr)	83.29	78.92
12 hour, 50 year intensity (mm/hr)	17.63	16.96
72 hour, 50 year intensity (mm/hr)	5.90	5.68
Average Regional Skewness	0.22	0.22
Geographic Factor, F2	4.22	4.21
Geographic Factor, F50	17.69	17.63

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

Table 6 Intensity Frequency Duration Data for Rockhampton

Duration (hr)	Intensity (mm/hr)						
	1 EY	39% AEP	18% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1	33.6	43.4	55.5	63.0	73.0	86.7	97.5
2	21.8	28.2	36.2	41.2	47.8	56.9	64.1
3	16.6	21.6	27.8	31.7	37	44.1	49.7
6	10.4	13.6	17.7	20.3	23.7	28.4	32.2
12	6.54	8.55	11.3	13.0	15.4	18.6	21.1

Table 7 Intensity Frequency Duration Data for Lion Creek and Neerkol Creek

Duration (hr)	Intensity (mm/hr)						
	1 EY	39% AEP	18% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1	33.3	42.8	53.9	60.6	69.8	82.2	91.9
2	21.0	27.1	34.7	39.3	45.6	54.1	60.8
3	15.7	20.4	26.4	30.2	35.2	42.1	47.5
6	9.5	12.4	16.5	19.1	22.5	27.3	31.1
12	5.8	7.6	10.4	12.2	14.6	17.9	20.6

4.3.2 Temporal Pattern

Temporal patterns for Zone 3 were adopted for events up to the 0.2% AEP using the standard methodology outlined in AR&R (1987). Temporal pattern for the Probable Maximum Precipitation (PMP) event were sourced from data provided with the Generalised Short Duration Method (GSDM) guidebook (refer Section 0).

4.3.3 Areal Reduction Factors

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

Reduction of the IFD rainfall was undertaken in accordance with ARR 16 Book 2, Chapter 4 for the wider GPU model, with the resultant factors used listed in the table below.

Table 8 Areal Reduction Factors for Lion Creek and Neerkol Creek

Event AEP	Duration (mins)	Areal Reduction Factors	
		Lion Creek	Neerkol Creek*
1 EY	90	0.8132	-
39%	90	0.8027	-
18%	90	0.7857	-
10%	90	0.7729	-
5%	90	0.7577	-
2%	90	0.7376	-
1%	60	0.6792	-
	90	0.7224	-
	120	0.7502	-
	180	0.7849	-
	270	0.8107	-
	360	0.8234	-
	1440	0.9465	-
	2160	-	0.9474
0.2%	90	0.6871	-
0.05%	90	0.6567	-

** Neerkol Creek simulated within sensitivity analysis for the 1% AEP 2160min event (critical duration) only.*

4.3.4 Probable Maximum Precipitation Event

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

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

The Generalised Short-Duration Method (GSDM), as revised in 2003, was applied to derive estimates of PMP for short duration storms. The GSDM applies to catchments up to 1,000 km^2 in area and durations up to 6 hours, which makes the method applicable to the Wandal and West Rockhampton Local Catchment Study which has a catchment area of approximately 16.3 km^2 and a critical duration of 1.5 hours (refer Section 7.2). Similarly, for a storm duration of 1.5hrs, the method also applies to the external Lion Creek catchment. Neerkol Creek influence was incorporated within the sensitivity analysis only and was not assessed for a PMP event.

Using the methodology set out in the GSDM Guidebook (BoM, 2003), the PMP parameters were calculated as shown in Table 9.

Table 9 Adopted PMP Parameters

Duration (hrs)	Wandal and West Rockhampton		Lion Creek*	
	Rainfall Total (mm)	Rainfall Intensity (mm/hr)	Rainfall Total (mm)	Rainfall Intensity (mm/hr)
1	400	400	300	300
1.5	520	347	390	260
2	610	305	440	220
3	730	243	540	180

**Note that the Neerkol Creek catchment was not simulated for the PMF event. It was simulated within sensitivity analysis for the 1% AEP critical duration only*

The AEP of the PMP event was calculated as recommended in AR&R (Pilgrim, et al, 1987). For a catchment area of 16.3km^2, the PMP event is approximately a 1 in 10,000,000 AEP event. For a catchment area of 250km^2 (Lion Creek), the PMP event is approximately a 1 in 4,000,000 AEP event.

4.3.5 Design Event Rainfall Loss Parameters

Design event losses were established based on the results of the calibration event. An initial loss of 15mm and continuing loss of 1.0mm were applied to pervious areas, for all design events. This is discussed in more detail in Section 6.0.

5.0 Hydraulic Model Development

5.1 Overview

This section of the report discusses the development of a new hydraulic model for the Wandal and West Rockhampton local catchment as well as the hydraulic model for the external creek catchments.

The smaller, more detailed model spanning the Wandal and West Rockhampton local catchment has been used to assess key local catchment flood behaviour and deficiencies in the existing stormwater network leading to increased flood risk. These assessments will assist in the future development of mitigation options in Phase 3. In order to adequately resolve key hydraulic controls, a 3m numerical Cartesian grid resolution was adopted. A timestep of 1.5 second was adopted, giving an effective runtime of approximately 6 real-time hours to 1 simulation hour. TUFLOW build version 2016-03-AE (CPU) was used for this assessment. See Appendix A for more details surrounding the development of the CPU hydraulic model.

The broader model encompassing the external catchments of Lion Creek and Neerkol Creek has been used to assess key flood behaviours impacting the lower floodplains and systems within the smaller CPU model. In order to strike a balance between computational effort and model detail, a 10m numerical Cartesian grid resolution was adopted. In order to adequately represent the key hydraulic controls, natural and man-made levees, channel invert levels and major road embankments were stamped into the model grid. A timestep of 5 seconds was adopted, giving an effective runtime of approximately 1 real-time hour to 9.5 simulation hours. TUFLOW build version 2017-03-AC (GPU) was used for this assessment.

5.2 Hydraulic Model Parameters

Crucial details surrounding development of the CPU TUFLOW model are located within Appendix A. An overview of the model setup and key parameters for the model is provided in Table 10.

Table 10 CPU Hydraulic Model Setup Overview

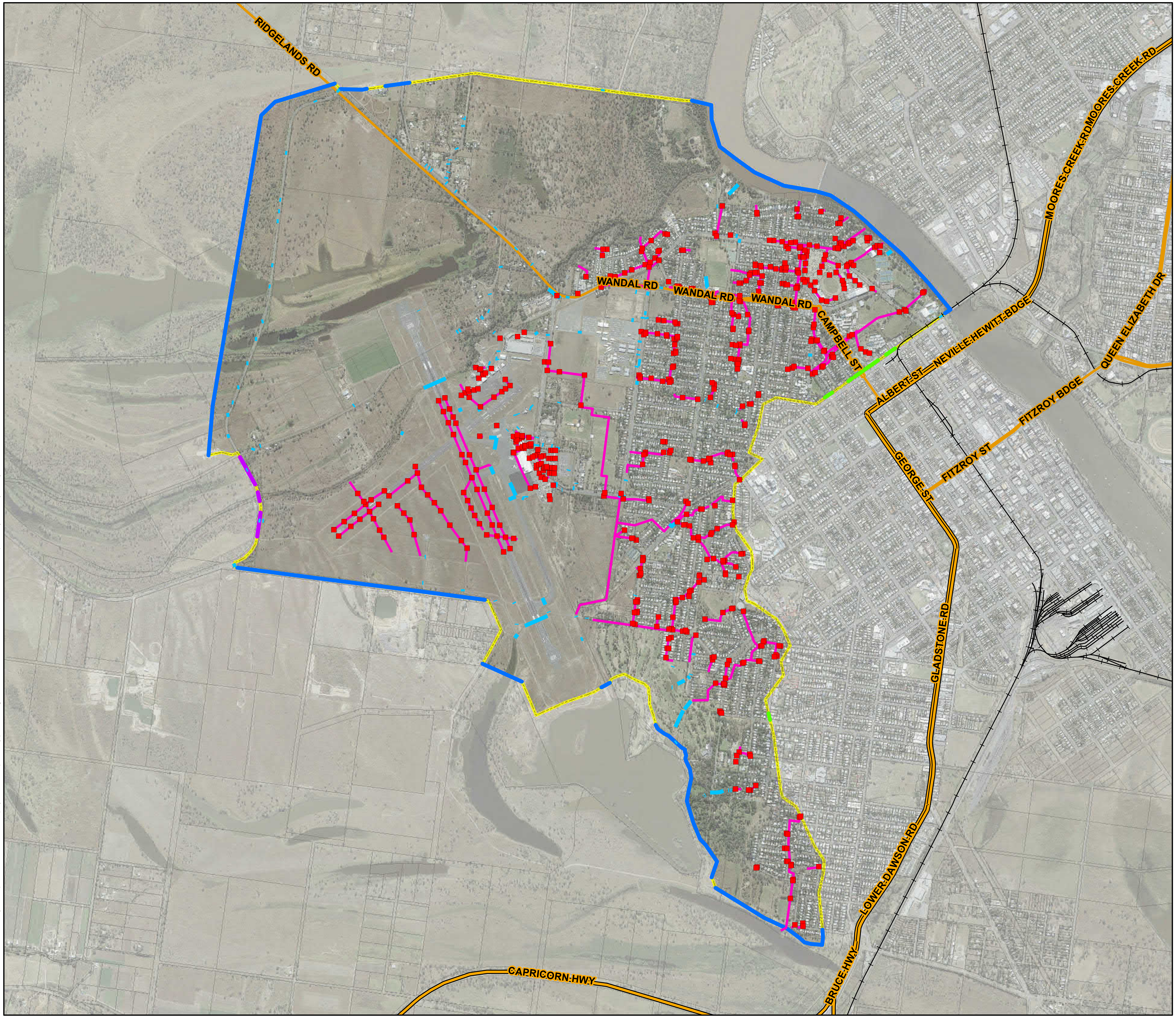
Parameter	Wandal and West Rockhampton Local Catchment Model
Completion Date	December 2017
AEP's Assessed	1 EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF
Hydrologic Modelling	Direct Rainfall Approach
IFD Input Parameters	Refer to Section 4.3.1
Hydraulic Model Software	TUFLOW version 2016-03-AE-w64-iDP
Grid Size	3m
DEM (year flown)	2016
Roughness	Spatially varying and depth varying standard values.
Eddy Viscosity	Smagorinsky
Model Calibration	Calibrated to 2017 event.
Downstream Model Boundary	1 inflow boundary and 1 height-time boundary on the western boundary, 5 height time boundaries on the southern boundary, 6 rating curve boundary conditions, 1 static height-time boundary and 1 tidal boundary on the eastern boundary. Additional 2 height-time boundary conditions on the northern boundary and additional 2 inflow boundaries on the eastern boundary in PMF and external creek catchment sensitivity simulations.
Timesteps	1.5 second (3m 2D) and 0.2 second (1D)
Wetting and Drying Depths	Cell centre 0.0002 m
Sensitivity Testing	Stormwater Infrastructure Blockage, ±15% Roughness, Riverine and Local Catchment Coincident Event, Inlet Structure Dimensions and Climate Change

Table 11 GPU Hydraulic Model Setup Overview

Parameter	Lion Creek and Neerkol Creek Model
Completion Date	December 2017
AEP's Assessed	1 EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF for Lion Creek. 1% AEP for Neerkol Creek.
Hydrologic Modelling	Direct Rainfall Approach
IFD Input Parameters	Refer to Section 4.3.1
Hydraulic Model Software	TUFLOW version 2017-09-AC-w64-iSP
Grid Size	10m
DEM (year flown)	2016
Roughness	Spatially varying and depth varying standard values – consistent with the West & Wandal Local Catchment model as well as Gracemere Regional and Fitzroy River models.
Eddy Viscosity	Smagorinsky
Model Calibration	Model calibration not undertaken.
Downstream Model Boundary	14 inflow boundaries on the western boundary, 2 height time boundaries and 6 rating curve boundary conditions on the eastern boundary, 5 rating curve boundary conditions on the eastern boundary and 8 rating curve boundary conditions on the northern boundary.
Timesteps	5 second (10m 2D)
Wetting and Drying Depths	Cell centre 0.0002 m
Sensitivity Testing	Sensitivity testing not undertaken.

5.3 Model Setup

A visual representation of the model setup including the code, boundaries, 1D network and hydraulic roughness delineation are included as Figure 11 and Figure 12 to supplement the detailed updates outlined in Appendix A. Model setup maps for the wider GPU model are also included as Figure 13 and Figure 14.



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LEGEND

- Pit Intlet
- Culvert
- Pipes

Boundary Conditions

- HQ
- HT
- QT
- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Data Sources:

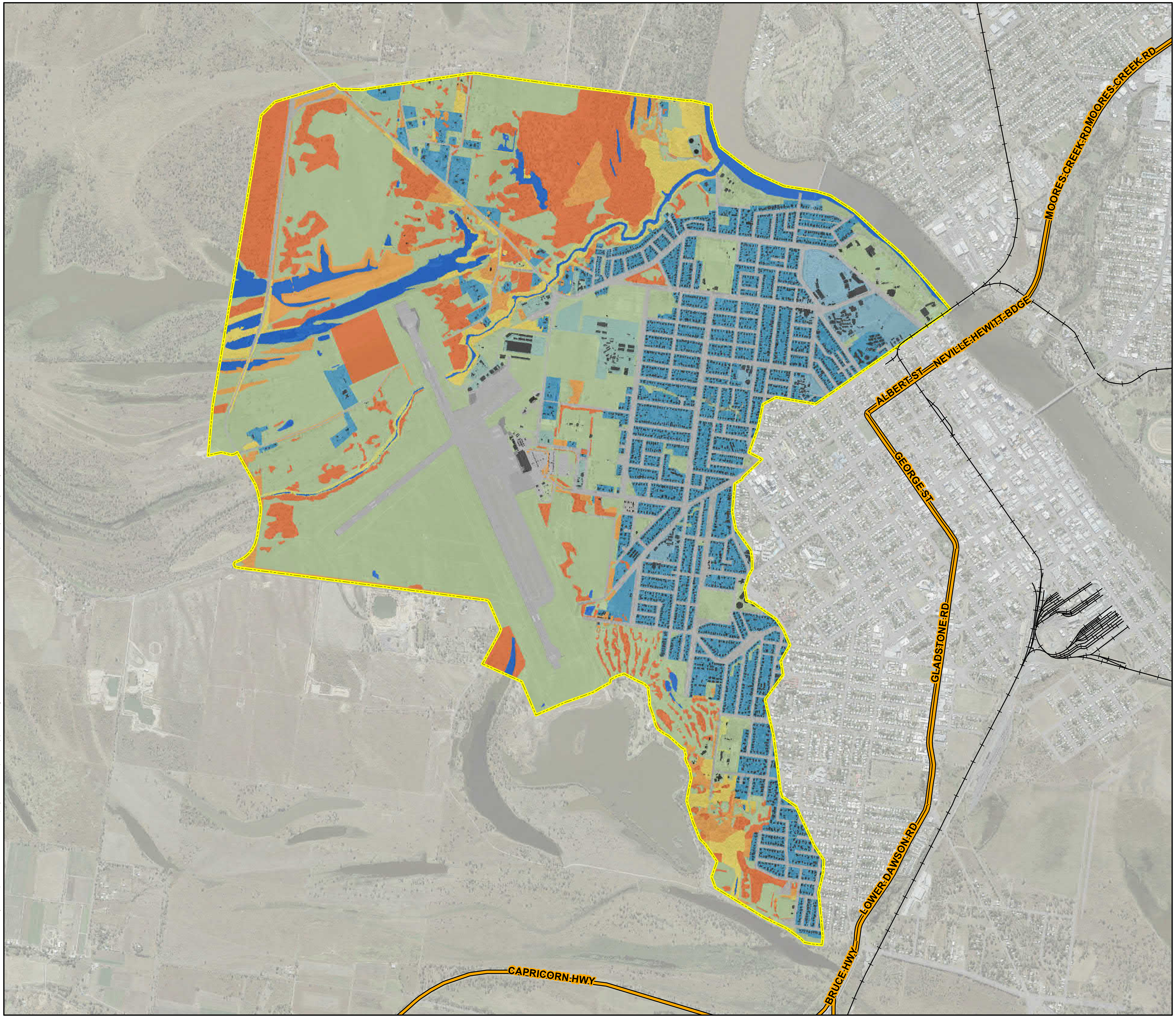
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Wandal & West Rockhampton Model

Model Setup and 1D Network Map

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	16/01/2018
VERSION:	1

Figure 11



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250 1,500
Metres

1:25,000
(when printed at A3)

AECOM
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LEGEND

- Highways
- Railway Lines
- Hydraulic Model Extent
- Road Corridor
- Open space
- Building Footprints
- High Density Residential
- Commercial/Industrial block
- Low Density Residential
- Riparian Corridor
- Light Vegetation
- Medium Vegetation Dense
- Vegetation Watercourses
- Road Reserve
- Airport Runway

Data Sources:

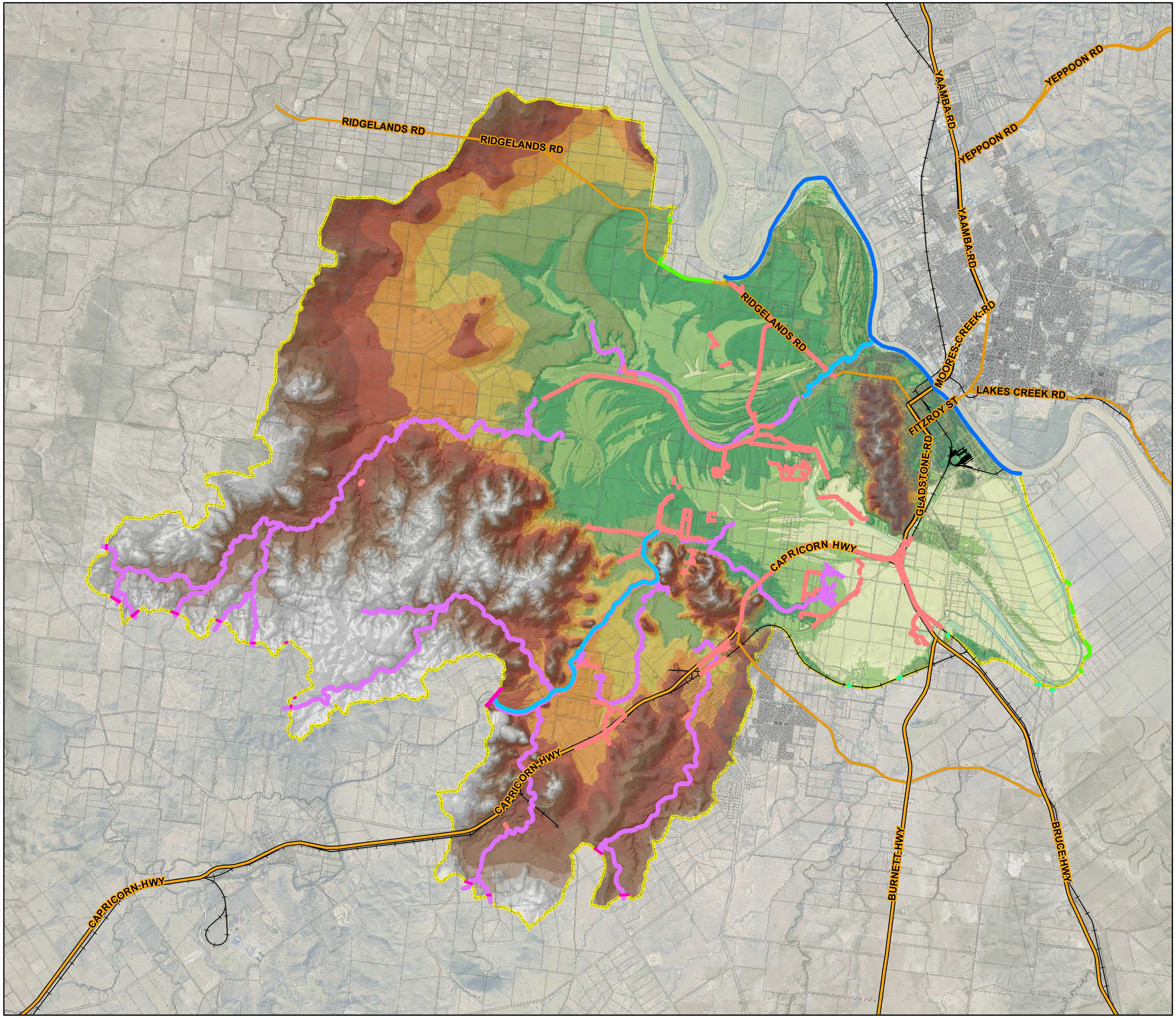
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Wandal & West Rockhampton Model

Hydraulic Roughness

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	A

Figure 12



Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 1 2 3 4 5 6
Kilometers

1:100,000
(when printed at A3)

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LEGEND

- Embankments / Crests
- Inverts
- Inflow Boundaries
- Lowered (Standing Water)

Outlet Boundaries

- HQ
- HT
- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Topography (mAHD)

- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 13
- 13 - 16
- 16 - 21
- 21 - 26
- 26 - 32
- 32 - 37
- 37 - 45
- 45 - 54
- 54 - 65
- 65 - 84
- > 84

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

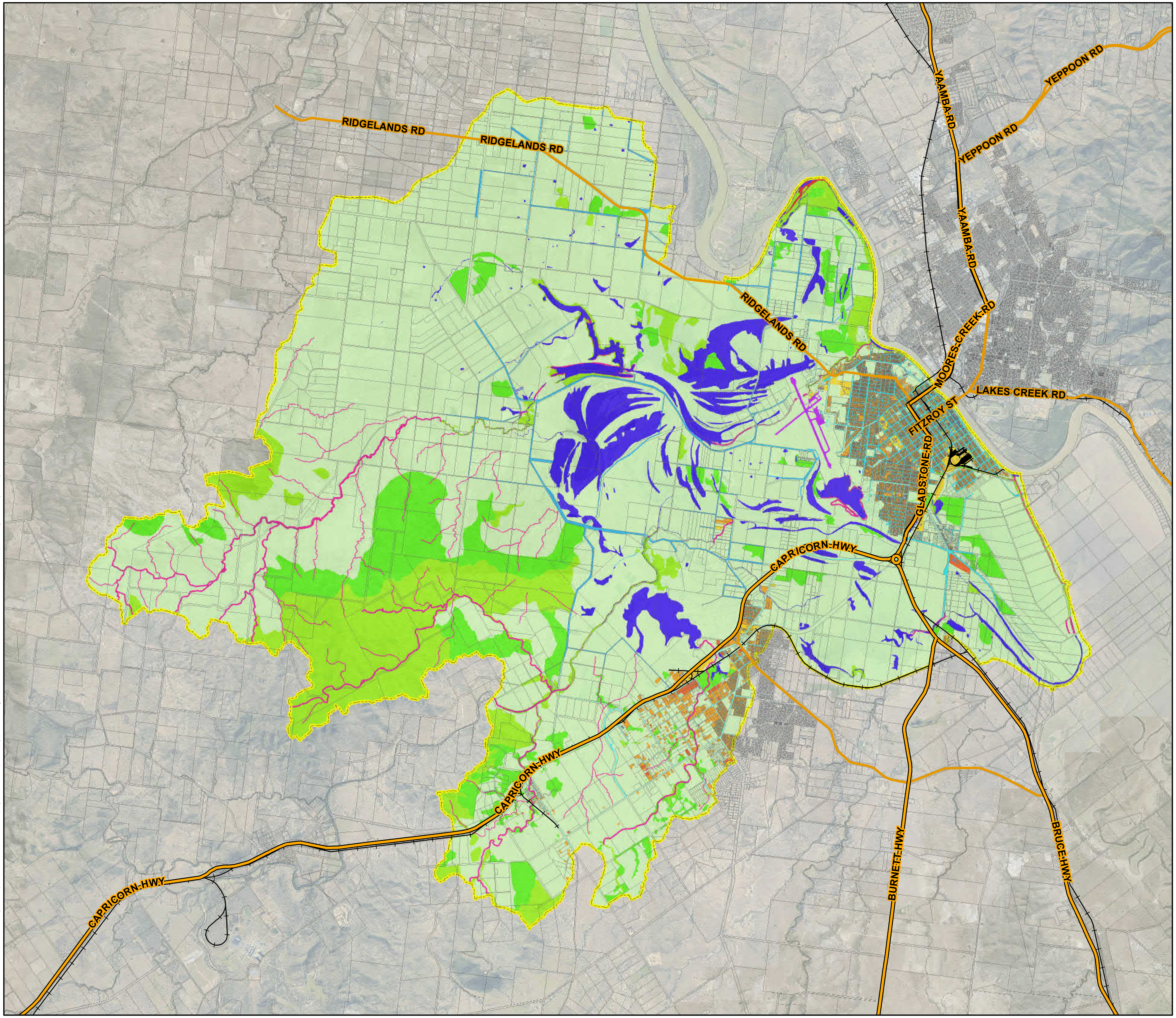
Wandal & West Rockhampton Model

GPU Model Setup Map

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 16/01/2018
VERSION: 1

Figure 13

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 12 GPU Model Setup_10P3.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 1 2 3 4 5 6

Kilometers

1:100,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Material

- Low Density Vegetation / Low Density Residential & Rural
- Buildings
- High Density Residential / Heavy Industrial
- Medium Density Residential
- Sparse Commercial / Hardstand Surfaces
- Steep, Course Slopes
- Medium Vegetation
- Heavy Vegetation
- Sealed Roads
- Rural Roads
- Rail Reserve
- Bodies of Water
- Airport Runway
- Riparian Corridor
- Wetlands

Data Sources:

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

Wandal & West Rockhampton Model

GPU Hydraulic Roughness

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 16/01/2018
VERSION: 1

Figure
14

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 13 GPU Hydraulic Roughness_10P3.mxd

6.0 Model Calibration

6.1 Adopted Methodology

Calibration of the TUFLOW model was undertaken by simulating a historical flood event (ex-TC Debbie) and comparing the results against Council records at MHG.

The model was calibrated to the 2017 flood event, in which the model parameters were varied to better match recorded data by varying roughness, initial losses, continuing losses and stormwater infrastructure assumptions (connectivity, roughness and blockage). Synthetic varying tidal levels were applied for the 2017 event in the absence of available recorded data.

In the absence of anecdotal flood heights, the model was unable to be verified to other historical events. It is a key recommendation that further model verification be undertaken for future local catchment flood events to improve confidence in the model outputs.

6.2 Calibration to the 2017 Event

Ex-TC Debbie occurred resulting in a moderate rainfall event in Wandal and West 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. The initial calibration run adopted an initial loss of 15mm and continuing loss of 1.0mm/hr.

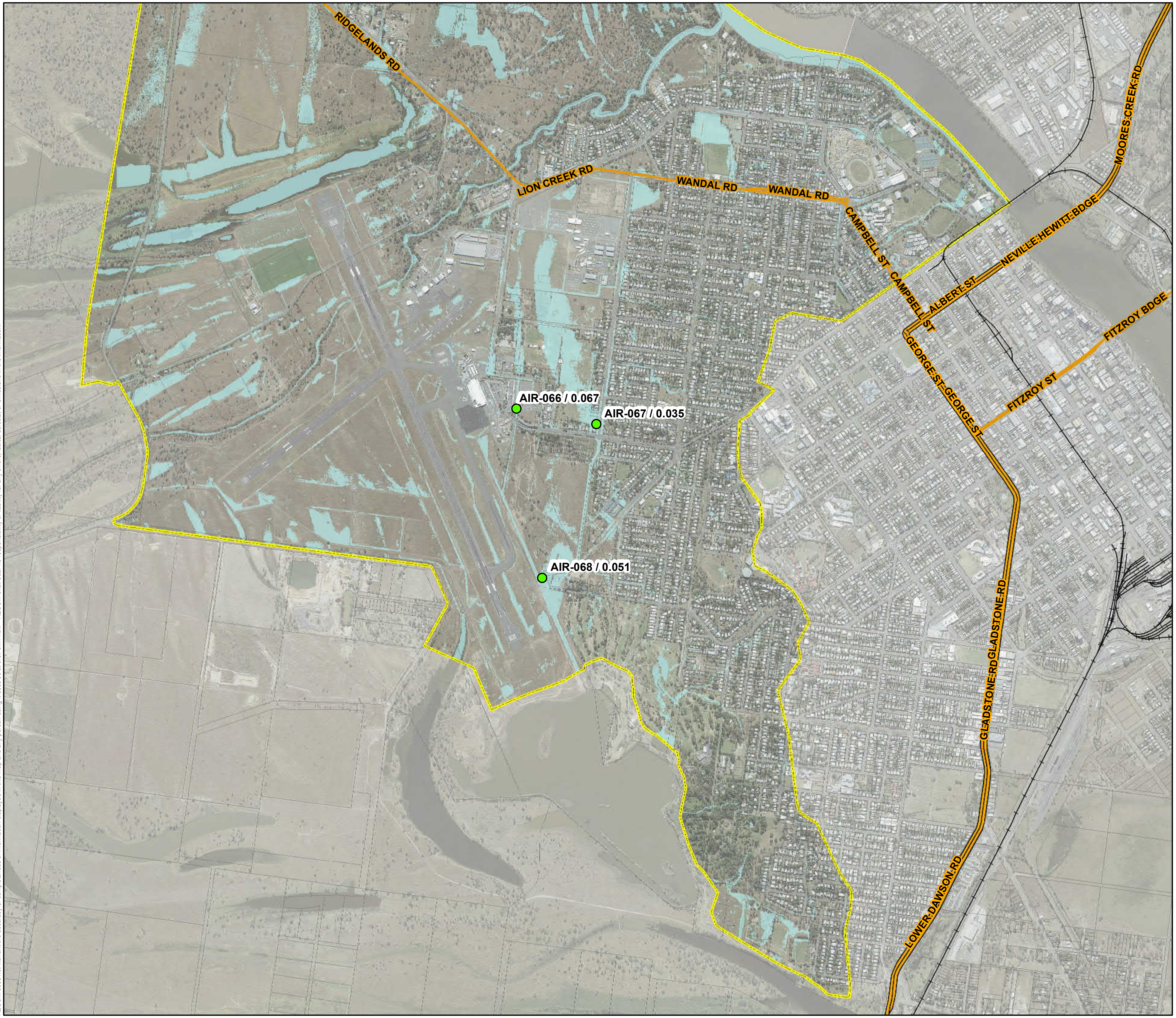
Table 12 March 2017 Verification Results Analysis

Point ID	Recorded Level (mAHD)	Peak Height (mAHD)	Difference (m)	Tolerance
		E6		
AIR - 066	8.414	8.481	0.067	In tolerance
AIR - 067	8.793	8.828	0.035	In tolerance
AIR - 068	7.458	7.509	0.051	In tolerance

Analysis of the calibration results reveals the following:

- Points AIR – 066, 067 and 068 closely match the gauged level.
- The average difference between simulated and recorded levels is 0.051m, with a standard deviation of 0.013m.

Figure 15 presents the comparison of water levels at recorded height locations for scenario E6. Given the close match between simulated and recorded peak flood heights, the E6 model is considered to be an excellent calibration to the 2017 event; although more recorded levels are desirable to develop holistic confidence in the model performance.



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)

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LEGEND

Difference in PWSE (m)

- < -0.30 (Below tolerance)
- -0.30 - -0.16 (In tolerance, low)
- -0.15 - 0.15 (In tolerance)
- 0.16 - 0.30 (In tolerance, high)
- > 0.30 (Above tolerance)
- Highways
- Main Roads
- 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

Wandal & West Rockhampton Model

March 2017 Calibration Results

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	1

Figure 15

Filename: \\aurok1fp001\Projects\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 11 March 2017 Calibration Event.mxd

6.3 Key Findings

Summarised below are the key calibration / verification parameters for the Wandal and West Rockhampton Local Catchment model.

6.3.1 Final Design Losses and Roughness

The final design losses adopted following the calibration and verification process is outlined in Table 36 in Appendix A. Most pervious areas were modelled with an initial loss of 15 mm and continuing loss of 1 mm. The adopted roughness values for each of the different land uses are outlined in Table 35 in Appendix A.

6.3.2 Critical Areas

Critical areas within this catchment surround the key urban flow paths and storage areas, namely:

- Urban Flow Paths:
  - Campbell Street (near South Rockhampton State High School);
  - Oakley Street;
  - Knutsford Street / Peterson Street;
  - Livermore Street / Pearson Street;
  - North Street / Eton Street;
  - Airport Drain; and
  - Ann Street.
- Detention Areas:
  - Alf Kele Memorial Rotary Park;
  - Victoria Park;
  - Jardine Park;
  - Garland Park;
  - Kele Park; and
  - Pearson Street Detention Basins.

In addition to the above, key controls also exist at Lion Creek Road / New Exhibition Road, Western Street, Hunter Street and the Rockhampton Airport Carpark.

In undertaking the calibration process, it was noted that the cross-drainage structures and confined, winding, urban flow paths were performing well and showed excellent consistency with the recorded peak flood heights. Also of note was the lack of recorded data in the Wandal Catchment, specifically within Jardine Park and along Lion Creek Road.

At this stage, it is recommended that additional verification events are assessed in the future to gain further confidence in the modelling outputs in this area.

N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500

Metres

1:12,500
(when printed at A3)

AECOM
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LEGEND

- Key Controls
- Key Flowpaths
- Highways
- Main Roads
- Railway Lines
- Key Detention Areas
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents

Data Sources:

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

Wandal & West Rockhampton Model

Critical Areas

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/02/2018
VERSION:	1

Figure 16

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 16 Critical Areas.mxd

7.0 Baseline Hydraulic Modelling

7.1 Overview

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

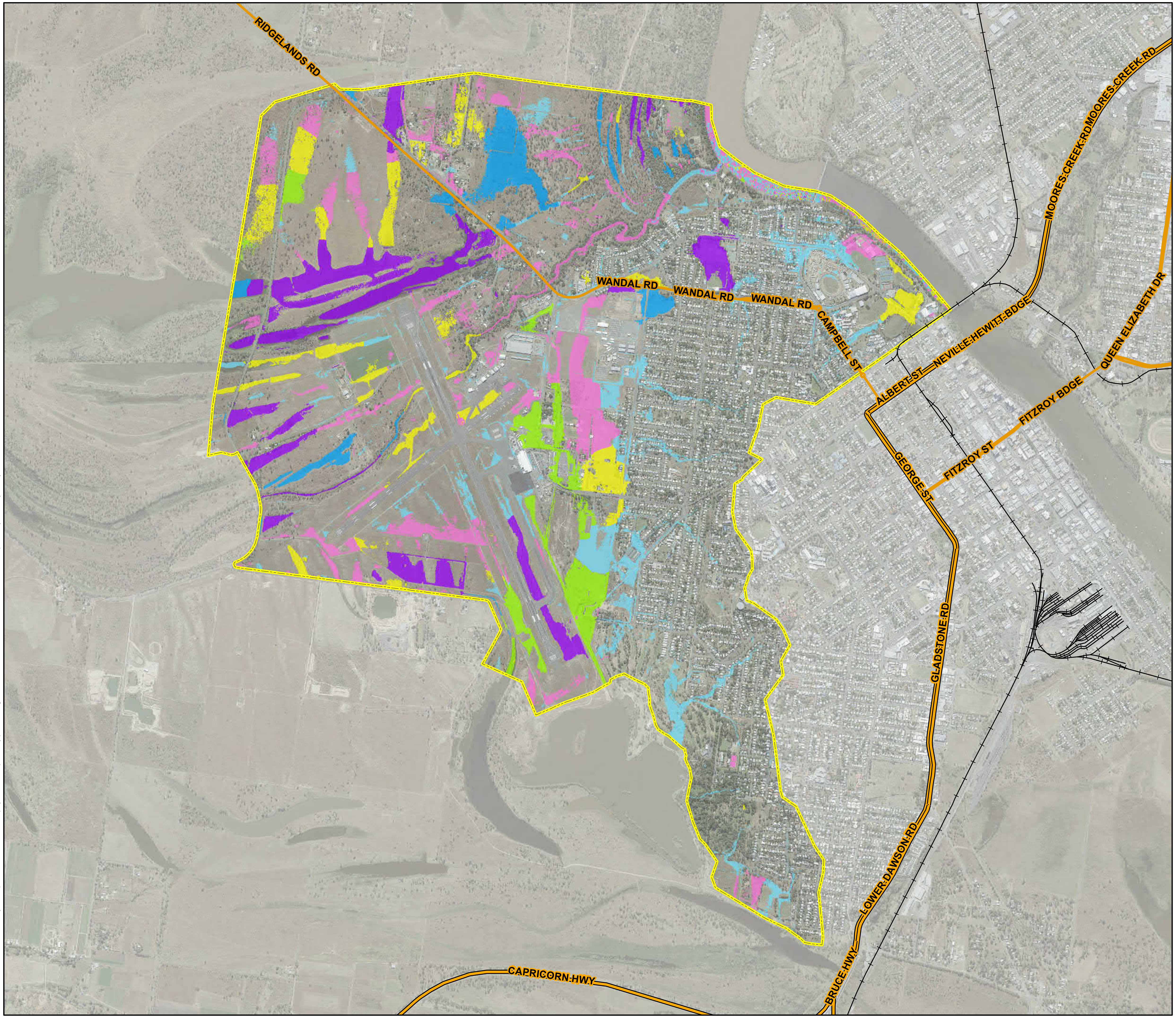
7.2 Critical Duration Assessment

The critical storm duration for the Wandal and West Rockhampton Local Catchment area was assessed by simulating the 60min, 90min, 120min, 180min, 270min and 360min durations for the 1% AEP event. Figure 17 shows that for a 1% AEP event, the steep flow paths have a 60min critical duration which, as the slope flattens, transitions to a 90min critical duration and longer (180min to 360min) within the detention areas.

Analysis of differences between the 60min, 90min and 120min storm events (refer Figure 18 and Figure 19) in the upper reaches of the catchment indicated peak water surface elevations generally varied by 40mm or less. Further downstream in the floodplains and storage areas, the 90min duration was up to 125mm higher than the 60min duration and the 120min duration being up to 250mm higher than the 60min duration. As such, peak flood extent differences and key areas were reviewed to confirm the 90min duration provided a sufficient balance between the peak flood heights in the steepest slopes and detention areas.

With the exception of the 1% AEP event, the critical duration was applied to all design flood events mentioned in Section 7.1. For the 1% AEP a 'Max:Max' analysis was undertaken, whereby results from the 60m, 90m, 120m, 180m, 270m and 360m storm durations were compared and the maximum flood levels extracted at each cell within the model domain.

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



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250
Metres

1:25,000
(when printed at A3)

AECOM
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LEGEND

- Highways
- Main Roads
- Railway Lines
- Hydraulic Model Extent

Critical 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

Wandal & West Rockhampton Model

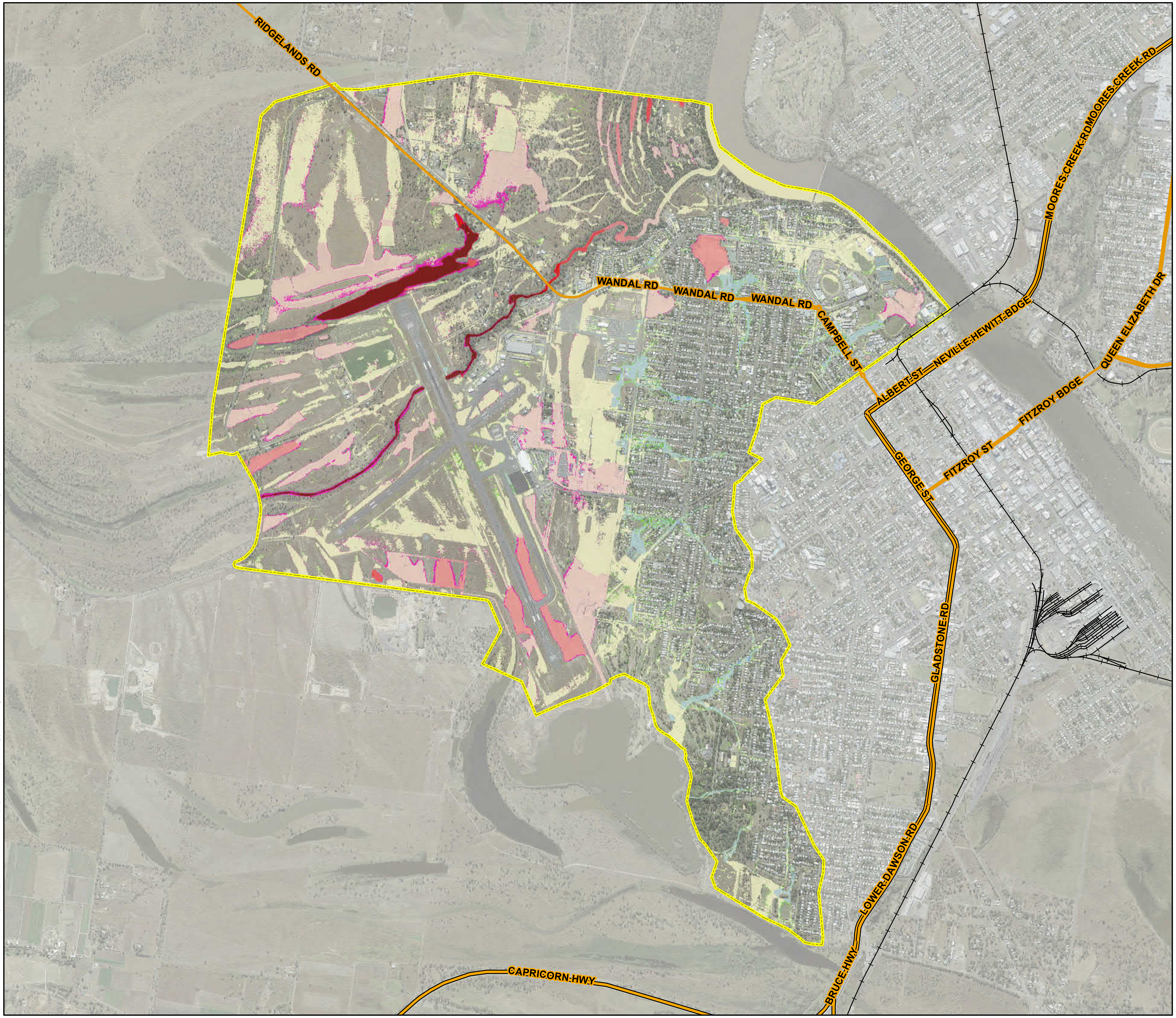
Critical Duration Assessment

1% AEP Event

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 15/01/2018
VERSION: 2

Figure 17

Filename: \\aurok1fp001\Projects\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 12 Critical Duration.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250
Metres

1:25,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Main Roads
- Railway Lines
- 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

Wandal & West Rockhampton Model

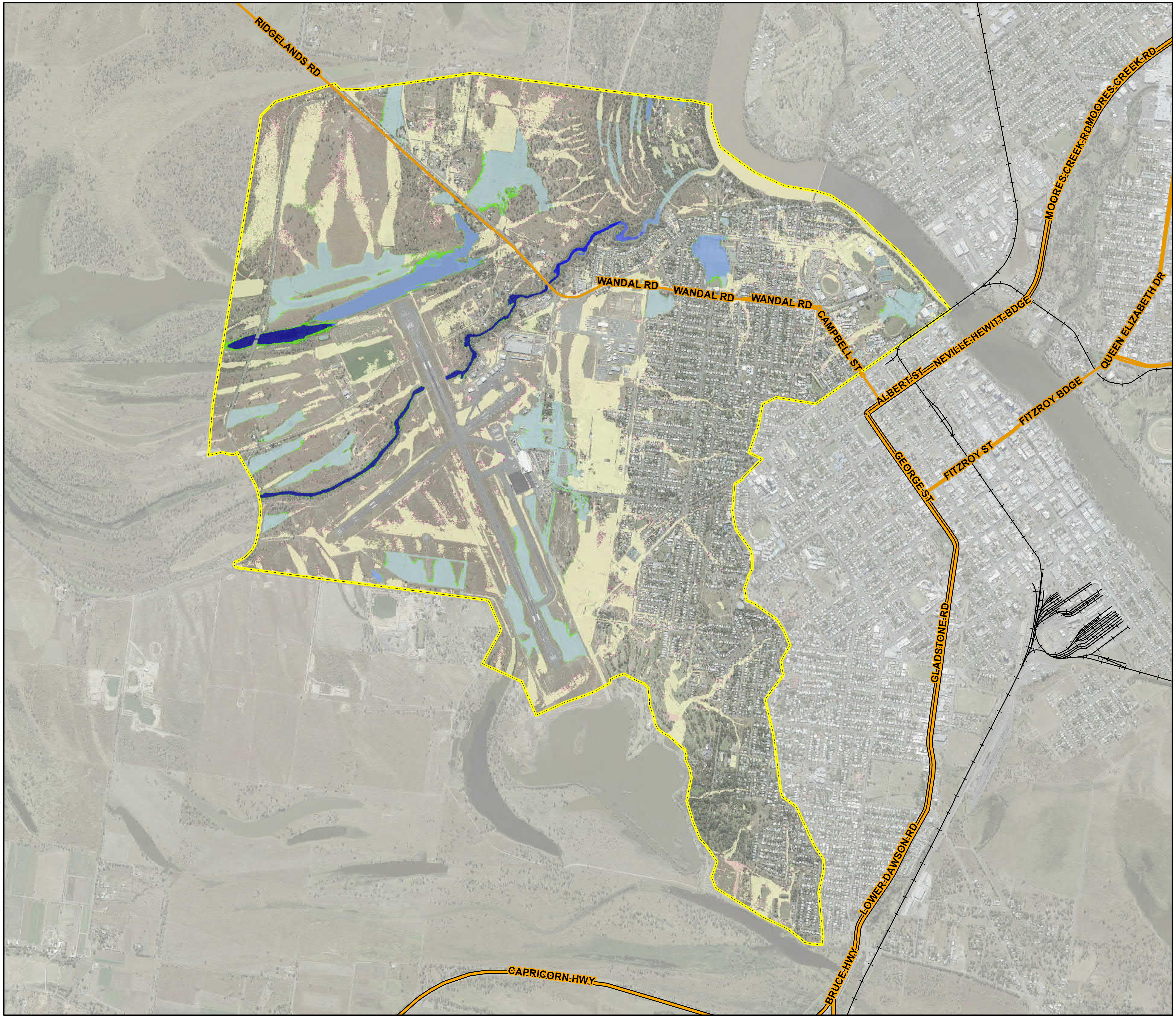
90min minus 60min

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	22/12/2017
VERSION:	1

Figure 18

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 12 90min minus 60min.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250

Metres

1:25,000
(when printed at A3)

AECOM
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LEGEND

- Highways
- Main Roads
- Railway Lines
- 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

Wandal & West Rockhampton Model

90min minus 120min

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	22/12/2017
VERSION:	2

Figure 19

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 13 90min minus 120min.mxd

7.3 Baseline Flood Depths, Extents and Velocities

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

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

- **Maps 1 to 3** – 1 EY Baseline

Flood waters are largely contained within the underground drainage network and road / drainage reserves, with some ponding occurring in some low lying area between Western Street and Canoona Road, Jardine Park, Garland Park and within the floodplain area north of the airport.

Peak flood depths are generally less than 300 mm throughout urban flow paths due to the steep natural slopes. Depths in the park and floodplain areas reach up to 900mm.

Peak depth average flood velocities reach 1-1.5m/s in the upper reaches of the catchment with a lower peak of up to 0.25 m/s predicted in low-lying flat terrain.

- **Maps 4 to 6** – 39% AEP Baseline

The flood extent remains similar to the 1 EY Baseline, with the flood extent becoming wider in low-lying areas such as Alf Kele Memorial Rotary Park, Jardine Park, Garland Park, within the Rockhampton Airport and floodplain areas.

Flood depths remain shallow throughout urban areas, with some low-lying areas now predicting depths above 1.0m.

Peak depth averaged velocities are again similar to the 1 EY Baseline event, most notably increasing along steep flow paths throughout urban areas. However velocities remain relatively low.

- **Maps 7 to 21** – 18% AEP Baseline

Again the flood extent continues to become wider along the main flow paths in the 18% AEP event, especially within the Western Street, Wandal Road and North Street Extended areas. Depths remain shallow across the majority of the urban catchment, although some key flow paths are beginning to show small breakout flows.

Peak depth averaged velocities are increasing within road areas and within overland flow paths in the steep upper catchment. Velocities remain relatively slow in areas of flatter terrain.

- **Maps 22 to 24** –10% AEP Baseline

More significant breakouts are predicted in the 10% AEP event, as overland flows exceed the capacity of the road corridor and subsurface network along several natural flow paths from the eastern extent of the model, with runoff notably overtopping Western Street, Campbell Street, Wandal Road, North Street Extended, Canoona Road, Lion Creek Road, New Exhibition Road, Melbourne Street and Pearson Street.

Notable ponding of up to 1.5 m is predicted within Jardine Park, with depths in Alf Kele Memorial Rotary Park, Garland Pak and within the Rockhampton Airport shown to be up to 1.2m. Peak depth averaged velocities are predicted to reach more than 2.0m/s in some road reserve and overland flow paths and are predicted to increases to 0.5m/s in low-lying areas.

- **Maps 25 to 27** – 5% AEP Baseline

Predicted flooding in the 5% AEP event is similar to the 10% AEP event, although peak flood depths and velocities continue to increase in key locations. Overland flow paths through urban areas continue to exceed channel capacity and inundation of private property increases.

- **Maps 28 to 30** – 2% AEP Baseline

The 2% AEP event is predicted to further increase flood depths and extents, with significant portions of low-lying areas now shown to be inundated. Flood depths in Jardine Park have increased to 1.8m and flood extents in Kele Park have increased to the point where private property inundation is evident.

Flooding within Rockhampton High School is predicted to increase, as is flooding within Rockhampton Bowls Club, the Rockhampton Showgrounds and across Lion Creek Road into the park located on Sir Raymond Huish Drive. Flow along key urban flow paths continues to increase, with private property inundation evident along most of the notable drainage paths.

- **Maps 31 to 44** – 1% AEP Baseline

Flood depths and extents are predicted to be extensive in the 1% AEP event, particularly in low-lying and park / recreational areas. Flood depths in Jardine Park have increased to more than 2.0m, as are depths in the Sir Raymond Huish Drive park. The majority of Kele Park is shown to be inundated, with adjacent private properties experiencing increased flood levels.

The Rockhampton Airport runway remains flood free, however surrounding drainage channels and low-lying areas are predicted to be inundated. Flood depths across major road connections are increased, as is the flooding within adjacent properties. Urban flow path channels are showing significant areas of breakout, with flows predicted to discharge across private property along a number of key drainage paths.

- **Maps 45 to 47** – 0.2% AEP Baseline

The 0.2% AEP event shows similar flow patterns to the 1% AEP event, although flood extents and depths have increased. The Rockhampton Airport taxiway areas are starting to show encroachment of floodwaters, however remain dry in the 0.2% AEP event.

Flood depths within Parks and inundated road areas continue to increase, as do the extent of inundation and consequently the time of closure. Flows within Lion Creek remain largely contained within the main channel.

- **Maps 48 to 50** – 0.05% AEP Baseline

The 0.05% AEP event shows the majority of major roads within the Wandal and West Rockhampton catchment to be inundated, with key connect such as Lion Creek Road now predicted to have flood depths greater than 2.1m.

Flooding of the Rockhampton Airport taxiway areas is predicted, with the main runway also showing encroachment of shallow flooding. Lion Creek flood levels continue to increase, with some areas beginning to reach bank full flows. Minor breakouts are predicted in the vicinity of the Rockhampton Airport Bebo Arch.

- **Maps 51 to 53** – PMF Baseline

Significant flood extents, depths and velocities are predicted in the PMF event, with the majority of low-lying areas predicted to be inundated. Lion Creek is showing significant areas of breakout, particularly in the area west of the Rockhampton Airport. Flood depths within Jardine Park and the Sir Raymond Huish Drive Park are now exceeding 3.0m.

The Rockhampton Airport taxiways are fully inundated, as is the southern end of the main runway. The east-west runway is also predicted to be flooded along with the entire public carpark area. Some flooding is predicted within the Western Street Army Barracks.

Flooding within urban areas is predicted to significantly increase in bot extent and depth, with peak depth averaged velocities now exceeding 2.0m/s along key flow paths.

Map 54 – Design Event Extent Comparison

Flood extents for events from 1EY to 1% AEP show similar patterns, with relatively small incremental increases as flood magnitudes increase. The majority of key flow paths are well defined in the 1EY event, with some road inundation predicted in very frequent events.

Floods of 0.2% AEP and 0.05% AEP magnitude are shown to increase flood extents more predominately than the lower order events, however they generally maintain similar flow patterns across the Wandal and West Rockhampton catchment.

The PMF event results in a significant increase in flood extents, particularly in the low-lying floodplain and Rockhampton Airport areas, as well as Parks such as Jardine Park and Sir Raymond Huish Drive Park.

7.4 Baseline Peak Discharges

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

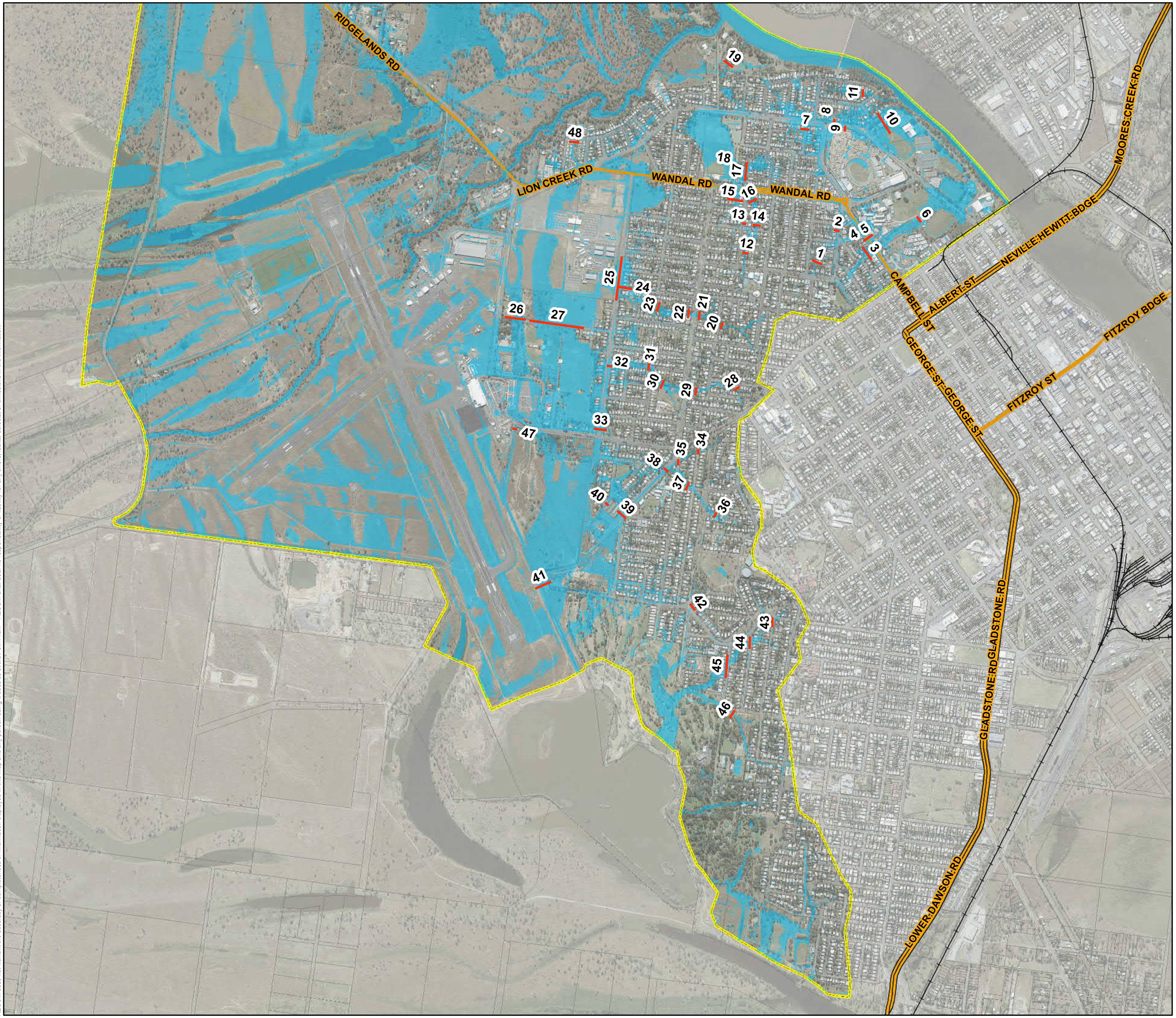
- Campbell Street (near South Rockhampton State High School);
- Lion Creek Road / New Exhibition Road;
- Oakley Street;
- Knutsford Street / Peterson Street;
- Livermore Street / Pearson Street;
- North Street / Eton Street; and
- Ann Street.

Refer to Figure 20 for extraction cross-section locations. Table 13 below presents the results at corresponding locations.

Table 13 Summary of Baseline Peak Discharges

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (90 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Callan St	1	0.2	0.3	0.5	0.6	0.8	0.9	1.0	1.5	2.1	3.6
Baden Powell St	2	0.5	0.8	1.0	1.2	1.3	1.4	1.5	1.8	2.1	3.0
Campbell St	3	0.9	1.3	1.9	2.2	2.7	2.9	3.5	5.2	6.9	13.6
	4	1.5	1.8	2.1	2.1	2.3	2.4	2.4	2.7	3.1	5.8
	5	0.1	0.5	1.2	1.7	2.3	2.8	3.4	5.5	7.3	12.8
South Rockhampton SHS	6	2.1	3.8	5.8	7.3	9.2	10.7	12.5	16.4	19.7	32.5
Curtis St	7	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.5	1.6
Lion Creek Rd	8	0.1	0.3	0.8	1.2	1.9	2.6	3.3	4.9	6.1	10.6
	9	0.0	0.4	0.6	0.7	0.8	0.8	0.9	1.6	2.3	6.2
Hall St	10	0.1	0.1	0.5	1.1	1.8	2.8	3.9	7.2	10.2	21.5
Pattison Ln	11	0.3	0.5	0.7	0.8	0.9	1.0	1.2	1.7	2.5	8.5
Lanigan St	12	0.5	0.8	1.1	1.3	1.6	1.7	2.0	3.1	4.0	6.8
Jones St	13	0.6	0.8	1.1	1.2	1.4	1.4	1.6	1.9	2.3	3.6
	14	0.4	0.7	1.3	1.6	2.1	2.4	2.9	4.5	6.1	11.5

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (90 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Wandal Rd	15	0.7	1.1	1.5	1.8	2.2	2.5	2.9	4.1	5.3	10.1
	16	0.7	1.1	1.8	2.3	2.8	3.3	3.8	5.8	7.9	15.6
Dibdin St	17	0.2	0.5	1.1	1.4	1.7	2.0	2.4	3.3	4.3	10.5
Jardine Park	18	3.9	5.3	7.4	8.6	10.2	11.2	12.4	16.0	19.5	32.0
Ramsden St	19	0.9	1.1	1.4	1.5	1.6	1.7	1.9	2.3	2.8	8.3
Charlotte St	20	1.5	2.0	2.7	3.1	3.6	3.9	4.5	6.3	8.2	14.1
Jardine St	21	2.3	3.2	4.2	4.9	6.0	6.3	7.2	10.2	13.1	22.7
	22	0.8	1.9	2.9	3.6	4.7	5.2	6.2	9.4	12.7	23.6
Peterson St	23	3.0	4.1	5.4	6.3	7.4	8.0	9.2	12.6	16.2	28.2
Meade St	24	1.9	2.7	3.4	3.8	4.4	4.7	5.3	7.1	9.1	13.9
Western St	25	1.7	3.5	5.6	6.8	8.5	9.5	11.1	16.0	21.1	41.6
Kalare St	26	0.1	0.4	0.9	1.2	1.7	2.3	2.8	4.7	7.5	23.2
	27	2.5	4.5	7.3	9.1	11.4	13.2	14.8	20.1	26.9	67.0
Livermore St	28	0.1	0.2	0.4	0.6	0.7	0.8	1.0	1.5	2.0	3.6
Jardine St	29	0.6	1.0	1.4	1.7	2.2	2.5	3.0	4.5	6.1	11.3
Bencke St	30	2.9	3.8	5.1	5.8	6.8	7.3	8.3	11.3	14.5	25.2
Pearson St	31	1.9	3.2	4.6	5.4	6.3	6.9	7.7	10.1	12.5	20.5
Western St	32	1.4	1.9	2.2	2.4	2.6	2.7	2.8	3.4	3.9	5.4
Hunter St	33	2.8	4.6	5.7	6.5	7.8	9.2	10.2	12.5	14.7	19.4
Harrow St	34	0.3	0.4	0.6	0.7	0.9	1.0	1.3	2.3	3.4	6.1
Eton St	35	0.5	0.7	1.1	1.3	1.5	1.6	1.9	3.2	4.4	8.0
Pennycuick St	36	1.2	1.5	1.9	2.3	2.7	2.9	3.3	4.7	6.1	10.1
Considine St	37	1.2	1.8	2.6	3.1	3.8	4.2	5.0	7.5	9.9	18.2
North St	38	0.2	1.6	3.1	4.1	5.2	5.9	6.9	10.3	12.9	19.7
	39	0.8	1.5	3.1	4.2	5.4	6.4	7.4	10.0	12.2	21.2
Melbourne St	40	0.7	1.0	1.4	1.7	2.0	2.2	2.5	3.4	4.2	7.5
Denham St Extended	41	8.0	9.9	12.4	13.9	15.9	17.6	19.0	23.2	31.4	83.6
	42	0.6	0.9	1.2	1.3	1.5	1.6	1.8	2.3	3.0	4.4
Wentworth Tce	43	0.8	1.0	1.4	1.6	1.9	2.0	2.2	3.1	4.1	6.4
Mary St	44	2.0	2.9	4.1	4.9	5.8	6.2	7.1	9.8	12.9	21.5
Ann St	45	2.0	3.2	4.9	5.8	7.0	7.8	9.0	12.6	16.3	29.0
	46	1.8	2.5	3.4	3.9	4.7	5.1	5.8	8.0	10.7	17.6
Hunter St	47	1.0	1.1	1.3	1.3	1.5	1.7	2.5	7.5	12.3	31.9
Bedden Av	48	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.5	0.9



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Metres

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LEGEND

- Discharge Cross-sections
- Highways
- Main Roads
- Cadastre
- Hydraulic Model Extent
- 1% AEP Peak Flood Extent

Data Sources:

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

Wandal & West Rockhampton Model

Key Flowpath Discharge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	1

Figure
20

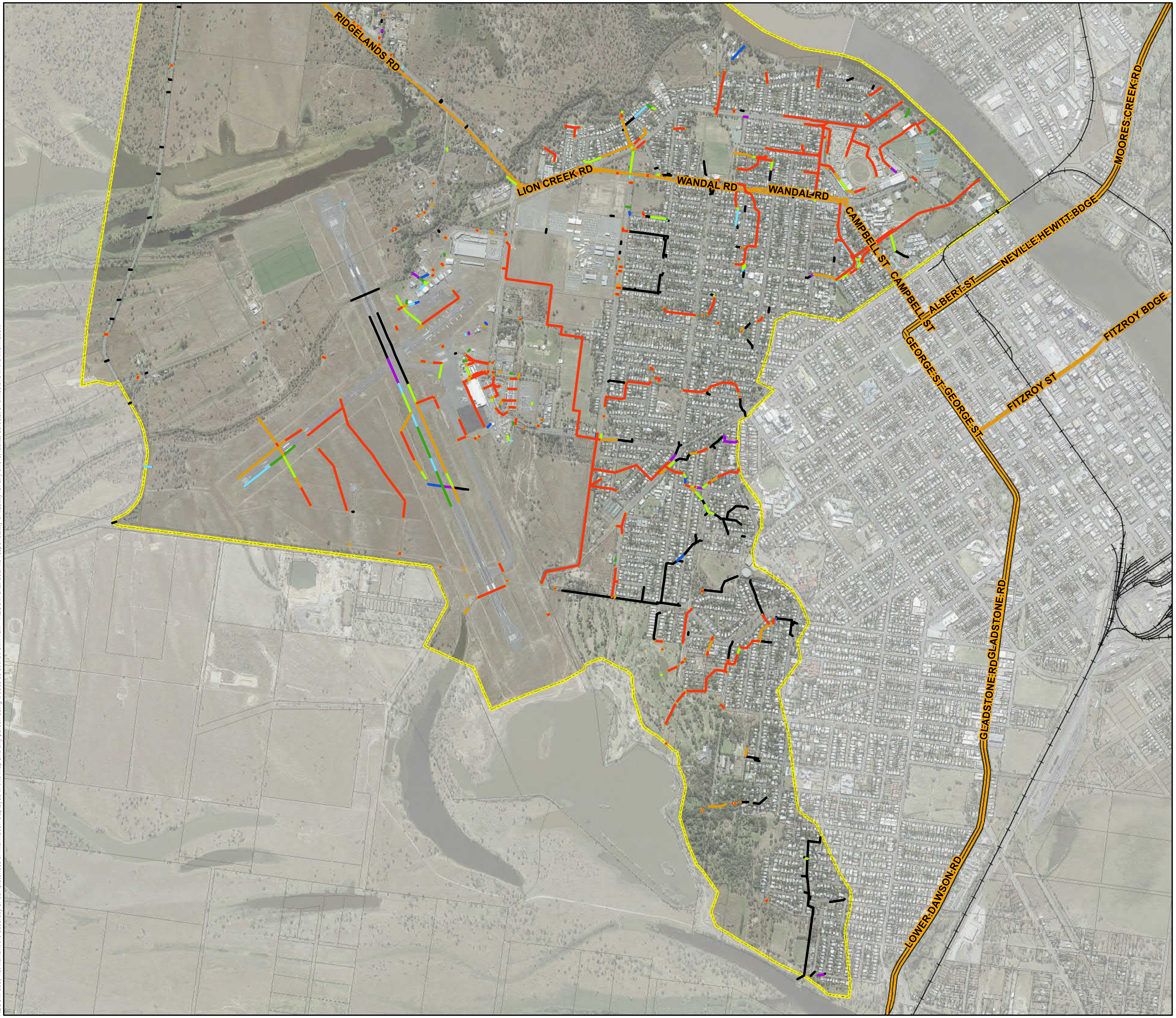
Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Volume2\Figure 14 Key Flow Path Discharge Locations.mxd

7.5 Stormwater Network Capacity

Figure 21 provides a spatial analysis of the existing underground network capacity, for the 90 minute storm duration.

It can be seen that a significant proportion of trunk mains are performing at capacity in a 1EY event, with an estimated 51% of the network at or above 80% capacity in a 1EY event. As the events progress in magnitude, mains at capacity continue to convey slightly more flow as the upstream energy head increases.

In a 10% AEP event, 68% of the network is predicted to be at capacity. In a 1% AEP event, up to 74% of the network is at 80% or more capacity.



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Rockhampton Regional Council

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Metres

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(when printed at A3)

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LEGEND

Pipe Flowing Full in

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

Data Sources:

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

Wandal & West Rockhampton Model

1D Network Capacity Analysis

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	22/12/2017
VERSION:	1

Figure
21

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 15 Basecase 1D Network Capacity Analysis.mxd

8.0 Sensitivity Analyses

8.1 Overview

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

- Sensitivity 1 – Increase in manning's roughness values (+15%).
- Sensitivity 2 – Decrease in manning's roughness values (-15%).
- Sensitivity 3 – Increase in rainfall intensities to replicate potential climate change impacts to the year 2100 (30% increase in rainfall intensity).
- Sensitivity 4 – Coincident 1% AEP Lion Creek Tailwater Level (1440min Storm Event) with 1% AEP Local Catchment (90min Storm Event).
- Sensitivity 5 – Coincident 1% AEP Neerkol Creek Tailwater Level (2160min Storm Event) with 1% AEP Local Catchment (90min Storm Event).
- Sensitivity 6 – 20% Underground Stormwater Infrastructure Blockage.
- Sensitivity 7 – 50% Underground Stormwater Infrastructure Blockage.
- Sensitivity 8 – 100% Underground Stormwater Infrastructure Blockage.
- Sensitivity 9 – Increased Inlet Structure Dimensions.
- Sensitivity 10 – Key Cross Drainage Culvert Blockage.

Further discussion on each sensitivity analysis is provided below.

8.2 Hydraulic Roughness

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

The following maps represent the results of the sensitivity testing.

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

Map WW-56 indicates that with a uniformly increased roughness value across all material types, there is a corresponding increase in peak flood heights in the upper reaches of the main urban drainage paths including south of Wandal Road near Oakley Street, along Dibden Street to the north of Wandal Road, west of Campbell Street, east of Western Street and near Mary Street. Notwithstanding this, the majority of the urban areas within the catchment experience negligible increases in peak water surface elevations. The results also show a minor increase in peak flood heights in Lotus Lagoon to the west of the airstrip. A minor reduction in peak flood heights is evident in storage areas at the northern and southern ends of the Airport runway.

The result from the sensitivity analysis which applies a 15% decrease in manning's roughness values are shown in **Map WW-57**. The decrease in roughness indicates a corresponding decrease in peak flood heights in Lotus Lagoon near the Airport. The reduction in peak flood heights is negligible throughout most of the catchment area however some residential areas adjacent Wandal Road, Campbell Street, Western Street and Mary Street are predicted to experience reductions in peak flood height of up to 25 mm.

8.3 Climate Change

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

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

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

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

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

As a conservative approach, the overall rainfall in the Wandal and West Rockhampton TUFLOW model was increased by 30% to represent the predicted rainfall patterns in 2100.

Map WW-58 indicates that the 30% increase in applied rainfall significantly increases peak flood heights and extents throughout the urban catchment. The largest increase to peak flood height for a 1% AEP event is predicted to be 310 mm within Victoria Park. Residential areas near Lion Creek Road and Wandal Road are predicted to have an increase in peak flood height of up to 100 mm. Properties at the western end of Hunter Street are also expected to have up to 100 mm increased peak flood heights.

8.4 Lion Creek and Local Catchment Coincident Event

As can be seen from **Map WW-59** the effect of a major flood event in the Lion Creek catchment coincident with local rainfall has negligible impact on the peak flood heights across the urban catchment areas. Flooding across the West Rockhampton and Wandal areas is independent of water levels in Lion Creek. Some storage areas outside of the urban catchment are predicted to have increased peak flood heights as a result of Lion Creek flooding.

8.5 Neerkol Creek and Local Catchment Coincident Event

There is expected to be negligible impact on peak flood heights in the urban catchment in the event of coincident Neerkol Creek flooding and local rainfall, as demonstrated in **Map WW-60**. The tailwater levels are not anticipated to change peak flood heights by any appreciable amount (greater than ±0.02 m). Storage areas outside of the urban catchment are predicted to have increased peak flood heights of up to 4 m as a result of Neerkol Creek flooding.

8.6 Stormwater Infrastructure Blockage

Testing of the model sensitivity to the underground stormwater infrastructure being blocked by debris, was undertaken for the 18% AEP event using an increasing percentage blockage on the underground stormwater network.

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

- 20% Increase in Blockage à **Map WW-61**
- 50% Increase in Roughness à **Map WW-62**
- 100% Increase in Roughness à **Map WW-63**

8.6.1 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 **WW-61** indicate that across the majority of the catchment, applying a 20% blockage to the stormwater network causes visible change in peak water surface elevation.

Residential areas and the sporting facilities at the eastern end of Lion Creek Road near Hall Street are expected to experience a minor increase in peak flood height of up to 75 mm and a corresponding increase in peak flood extents. Increases in peak flood height of up to 150 mm are predicted for the southern end of Victoria Park. A maximum increase in peak flood heights of up to 75 mm is expected in residential properties near Knutsford Street.

8.6.2 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 as shown in map **WW-62**. Peak flood heights are predicted to increase by up to 150 mm across properties located near Hall Street at the eastern end of Lion Creek Road and additional properties are anticipated to experience flooding as a result of the wider flood extents. Minor increases in peak flood heights are expected for residential areas both north and south of Wandal Road and adjacent Campbell Street (up to 50 mm). Near North Street, peak flood heights are predicted to increase by up to 100 mm.

8.6.3 100% 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 WW-63** indicate that several areas experience significant increases in peak flood heights. Key areas influenced by blockage of the stormwater infrastructure network include

- Victoria Park;
- Eastern end of Lion Creek Road;
- Graeme Action Way;
- Jardine Park
- Western end of Wandal Road;
- Beside Campbell Street;
- North Street and Melbourne Street;
- Near Mary Street;
- Intersections of:
  - Lion Creek Road / Duncan Street
  - Lion Creek Road / Hall Street
  - Hall Street / Crew Street
  - Crew Street / Hartley Lane
  - Wandal Road / Oakley Street

The peak flood heights across Hall Street are particularly sensitive to blockage of the stormwater network, with predicted increases of up to 225 mm and a corresponding increase to flood extents.

In addition, it is noted that peak flood heights along the Hunter Street drain are expected to reduce as a result of overland flows meeting trunk mains being attenuated.

8.7 Inlet Structure Dimensions

As indicated in map **WW-64**, the difference in peak flood height is between ± 0.02 m across the majority of the catchment. These results indicate that enabling larger portions of flow to enter the 1D system via the pit structures results in negligible differences to the peak flood heights. Minor decreases in peak flood heights (up to 75 mm) are predicted for some areas including Hall Street, Victoria Park, Considine Street and north of Wandal Road. Along North Street, minor increases of up to 75 mm in peak flood heights are expected as a result of increasing the pit sizes.

8.8 Key Cross Drainage Culvert Blockage

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

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

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

8.8.1 Factors influencing blockage

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

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

8.8.2 Common Blockages

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

8.8.2.1 Floating Debris

Floating debris in rural or forested streams is generally vegetation of various types. Small floating debris, less than 150mm long, can include small tree branches, sticks, leaves and refuse from yards such as litter and lawn clippings and all types of rural vegetation. Medium floating debris, typically between 150mm and 3m long, mainly consists of tree branches of various sizes. Large floating debris, more than 3m long, consists of logs or trees, typically from the same sources as for medium floating debris.

Small items of vegetation will usually pass through drainage structures during floods, while larger items may be caught in the structure. Once larger items are caught, this then allows smaller debris to collect on the structure.

8.8.2.2 Non-Floating Debris

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

8.8.2.3 Urban Debris

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

8.8.3 Design Blockage Level

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

8.8.3.1 Debris Availability

Table 14 Debris Availability - in Source Area of a Particular Type/Size of Debris (Table 6.6.1 ARR, 2016)

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

A **Medium** classification of debris availability for Wandal and West Rockhampton Local Catchment has been selected as debris availability generally falling between the High and Low categories.

8.8.3.2 Debris Mobility

Table 15 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 Wandal and West Rockhampton Local Catchment has been selected as source areas generally falling between the High and Low categories.

8.8.3.3 Debris Transportability

Table 16 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 **Medium** classification of debris transportability for Wandal and West Rockhampton Local Catchment has been selected as the typical stream characteristics generally fall between High and Low categories.

8.8.3.4 Debris Potential

Table 17 1% AEP Debris Potential (Table 6.6.4 ARR, 2016)

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

A **Medium** classification of debris potential for Wandal and West Rockhampton Local Catchment has been selected as the combination of individual factors is MMM.

8.8.3.5 AEP Adjusted Debris Potential

Table 18 AEP Adjusted Debris Potential (Table 6.6.5 ARR, 2016)

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

A **Low** classification of AEP Adjusted Debris Potential for Wandal and West Rockhampton Local Catchment has been selected as the Event AEP assessed is 18%.

8.8.3.6 Design Blockage Level

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

Table 19 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 22.

8.8.3.7 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 20 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 22.

Table 21 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 22.

Table 22 West Rockhampton Local Catchment Culvert Blockage Assessment

Culvert Specification	Control Dimension	AEP Adjusted Debris Potential	Most Likely Inlet Blockage Levels	Peak Velocity (m/s)	Sediment Likelihood	Most Likely Depositional Blockage Levels	Highest Blockage Factor
5/1800x1200mm RCBC	L10 < W < 3*L10	Low	0%	1.4	M	15%	15%
2/1800x1200mm RCBC	L10 < W < 3*L10	Low	0%	1.9	M	15%	15%
3/1200x300mm RCBC	W < L10	Low	25%	0.9	M	15%	25%
3/900x375mm RCBC	W < L10	Low	25%	1.7	M	15%	25%
1/900x450mm RCBC	W < L10	Low	25%	1.7	M	15%	25%
2/1200x450mm RCBC	W < L10	Low	25%	0.7	M	15%	25%
2/1200x300mm RCBC	W < L10	Low	25%	1.7	M	15%	25%

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
1/1500x450mm RCBC	L10 < W < 3*L10	Low	0%	1.2	M	15%	15%
2/600mm RCP	W < L10	Low	25%	3.0	L	0%	25%
2/600mm RCP	W < L10	Low	25%	2.9	M	15%	25%
1/1500x450mm RCBC	L10 < W < 3*L10	Low	0%	1.5	M	15%	15%

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

The adopted blockage factor for Wandal and West Rockhampton Local Catchment is 25%.

8.8.4 Results of Sensitivity Analysis

The results which are presented on **Map MC-65** 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 Western St – up to 0.01m increase in peak flood height.
- Culvert under Hunter Street– up to 0.05m increase in peak flood height.
- Culvert under Airport Access – up to 0.03m increase in peak flood height.
- Culvert under Canoona Road – up to 0.03m increase in peak flood height.
- Culvert under North Street - up to 0.01m increase in peak flood height.

8.9 Summary of Sensitivity Analysis Results

The results from the sensitivity analyses which were undertaken indicate that the most influential parameters are applied rainfall. As shown in Table 23, the 30% increase to rainfall resulted in an increase of more than 20 mm across almost 80% of the catchment with a peak increase of up to 0.31m at Alf Kele Memorial Rotary Park.

The 20%, 50% and 100% blockage analysis indicate that significant portions of the flooded area are impacted, especially residential areas which are relieved by the subsurface drainage. Several hotspots which are sensitive to stormwater infrastructure blockage were identified, including the eastern end of Lion Street and adjacent North Street.

The Lion Creek and Neerkol Creek sensitivities indicate that the lower portion of the catchment is predicted to experience significant increases in flood heights. However, the urbanised areas of the catchment are not predicted to experience impacts.

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 23 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 external creeks tailwater scenarios, the resulting peak flood heights are generally within ±0.3m of the baseline flood results. It is clear that climate induced changes to rainfall intensities has the most significant impact to predicted flood heights.

Table 23 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	Lion Creek Coincident Event	Neerkol Creek Coincident Event	20% Blockage of Stormwater Infrastructure	50% Blockage of Stormwater	100% Blockage of Stormwater	Increased Pit Dimensions	Key Culvert Blockage
< -0.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
0.299 to -0.225	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0.225 to -0.150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0.150 to -0.075	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%
-0.075 to -0.02	4%	1%	0%	0%	0%	0%	1%	2%	2%	0%
-0.02 to 0.02	95%	97%	22%	76%	50%	97%	92%	86%	98%	99%
0.02 to 0.074	1%	2%	41%	3%	1%	2%	5%	5%	0%	1%
0.075 to 0.150	0%	0%	20%	1%	4%	1%	1%	3%	0%	0%
0.150 to 0.225	0%	0%	10%	1%	2%	0%	0%	1%	0%	0%
0.225 to 0.299	0%	0%	3%	1%	3%	0%	1%	1%	0%	0%
>0.3	0%	0%	4%	18%	40%	0%	0%	1%	0%	0%

9.0 Flood Hazard and Risk Assessment

9.1 Overview

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

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

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

9.2 Baseline Flood Hazard Analysis

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

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

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

The hazard curves and classification names in Book 6, Chapter 7: General Flood Hazard Curves (Section 7.2.7) of 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 24 and Table 25.

Table 24 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 25 ARR 2016 Hazard Classification Limits

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

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

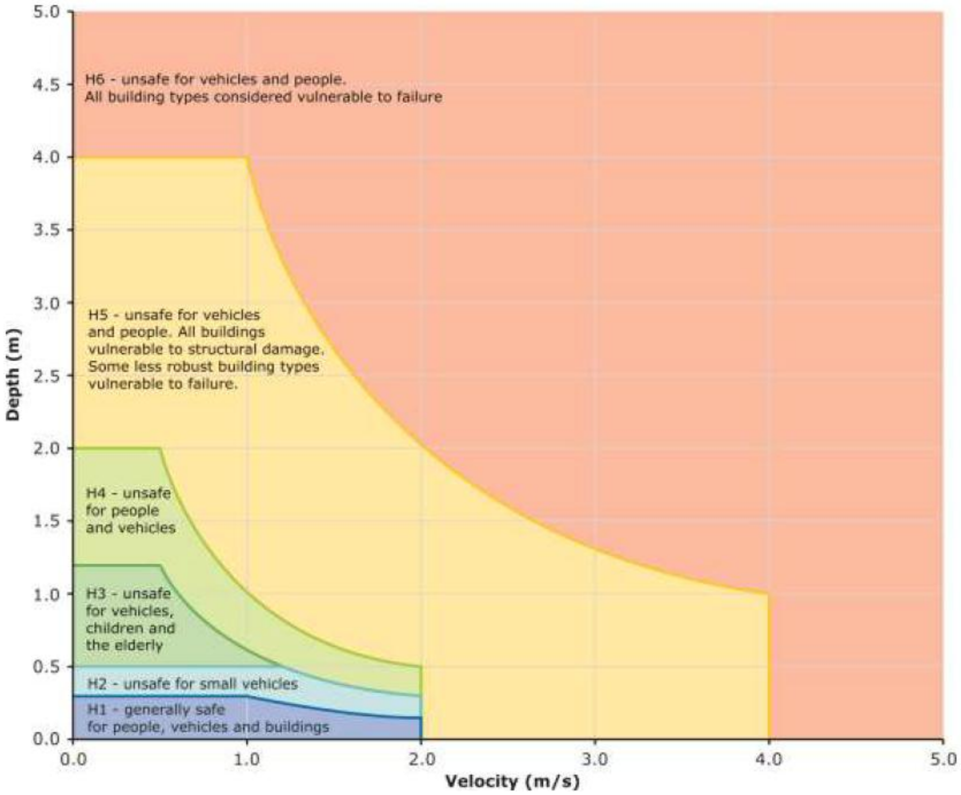


Figure 22 Hazard Vulnerability Classifications (Graphical)

Flood hazard mapping for the 18% and 1% AEP event has been included as maps **WW-66** to **WW-75** 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 and open areas such as Jardine Park and Alf Kele Memorial Rotary Park.
- High to extreme hazard (H4 and H5) within major natural and man-made flowpaths between Heilbronn Street and Western Street, along Pearson Street, along North Street and along the flowpath traversing Ann Street.
- Extreme hazard (H5 or H6) within the Lion Creek channel.

9.3 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.

9.4 Baseline Vulnerability Assessment

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

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

Table 26 summarises the criterion used for each category, along with the corresponding reference to the specific table of results and locality figure.

Table 26 Vulnerability Assessment Criterion

Category	Criterion	Table	Figure
Water and Sewerage Infrastructure	Any electrified water or sewerage assets within the Wandal and West Rockhampton catchment, experiencing flooding up to the baseline PMF event.	Table 27	Figure 23
Emergency Services	Any emergency services facilities within the Wandal and West Rockhampton catchment, experiencing flooding up to the baseline PMF event.	Table 28	Figure 23
Community Infrastructure	Any community and critical infrastructure within the Wandal and West Rockhampton catchment, experiencing flooding up to the baseline PMF event.	Table 28	Figure 23
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.*	Table 29	Figure 24
Bridge Assets	All bridge crossings within the catchment were assessed.	Table 30	Figure 24
Rail Assets	Rail segments were not present within the Wandal and West Rockhampton catchment.	N/A	

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

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

Table 27 Water and sewage infrastructure - inundation depths for all modelled events

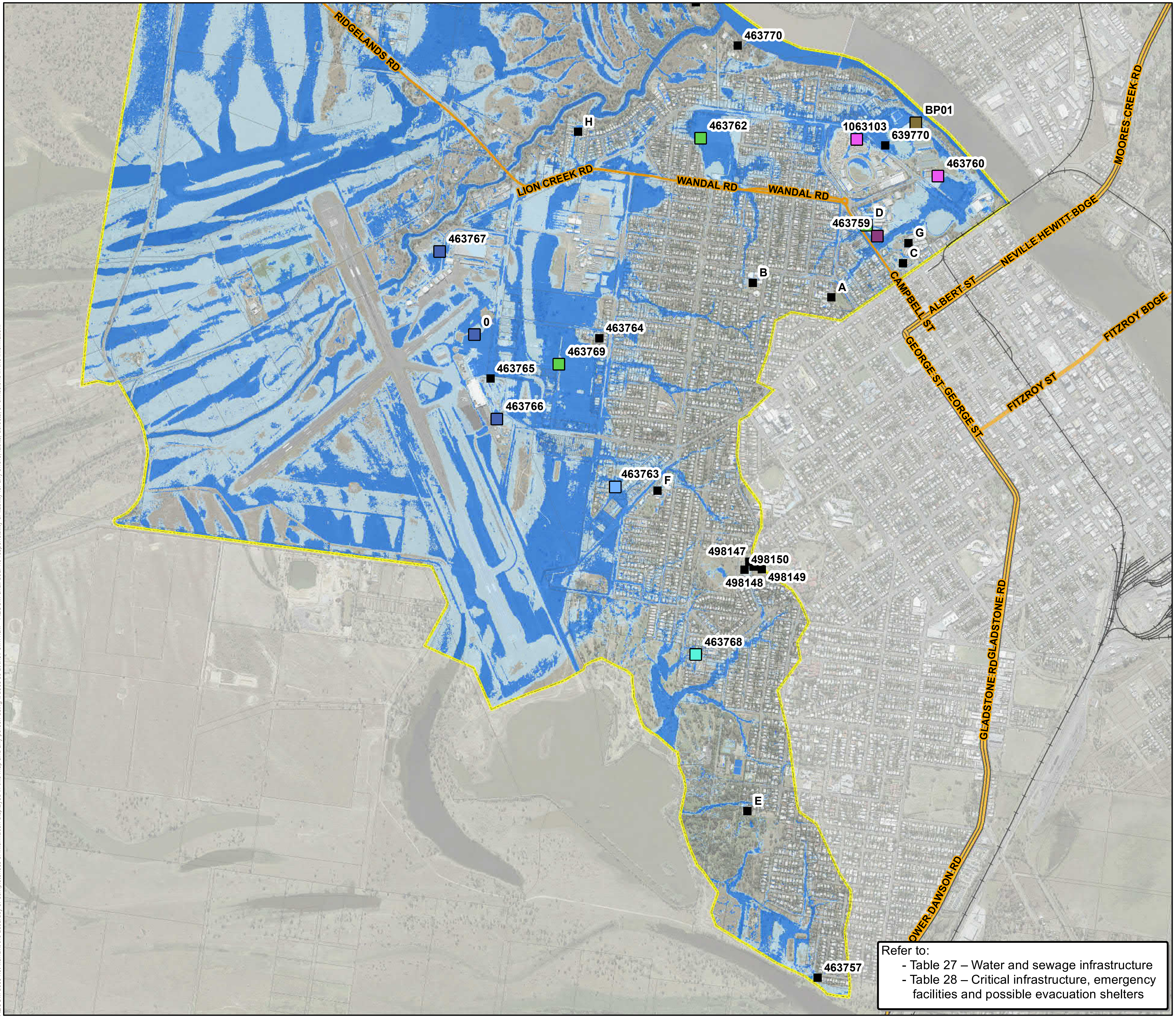
Infrastructure Type (Asset ID)	Suburb	Location	Inundation Depths at Design AEP Events (m) – 90 minute storm										1% AEP Hazard Category *
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
West Rockhampton Treatment Plant (639537)	Pink Lily	Harman Street	-	-	-	-	-	-	-	-	-	-	-
Sewerage Pump Station (463759)	Wandal	Campbell Street	-	-	-	-	-	0.08	0.09	0.13	0.17	0.33	H1
Sewerage Pump Station (463757)	The Range	Blackall Street	-	-	-	-	-	-	-	-	-	-	-
Sewerage Pump Station (463763)	West Rockhampton	Melbourne Street	-	-	0.15	0.18	0.22	0.25	0.27	0.34	0.38	0.54	H2
Sewerage Pump Station (463765)	West Rockhampton	Hunter Street	-	-	-	-	-	-	-	-	-	-	-
Sewerage Pump Station (463766)	West Rockhampton	Hunter Street	-	-	-	-	-	-	-	-	-	0.26	-
Sewerage Pump Station (463770)	Wandal	Harman Street	-	-	-	-	-	-	-	-	-	-	-
Sewerage Pump Station (463762)	Wandal	Jardine Park	-	0.24	0.46	0.58	0.71	0.86	0.97	1.24	1.45	2.41	H4
Sewerage Pump Station (463767)	West Rockhampton	Canoona Road	-	-	-	-	-	-	-	-	-	0.20	-
Sewerage Pump Station (463769)	West Rockhampton	Kele Park	-	0.07	0.11	0.13	0.15	0.18	0.20	0.25	0.29	0.54	H1
Sewerage Pump Station (463768)	West Rockhampton	Pennycuick Street	-	-	-	-	-	-	0.1	0.11	0.14	0.28	H1
Sewerage Pump Station (463764)	West Rockhampton	Kalare Street	-	-	-	-	-	-	-	-	-	-	-
Sewerage Pump Station (463760)	Wandal	Lion Creek Road	-	-	-	-	-	-	-	-	0.03	0.60	-
Sewerage Pump Station (1063103)	Wandal	Showgrounds	-	-	-	-	-	-	-	-	0.11	0.29	-
Sewerage Pump Station (BOM No. 4)	West Rockhampton	Canoona Road	-	-	-	-	-	-	-	-	-	0.25	-
Sewerage Pump Station (639770)	Wandal	Victoria Park	-	-	-	-	-	-	-	0.08	0.13	0.30	-
Booster Cabinet (BP01)	Wandal	Sir Raymond Huish Drive	-	-	-	-	0.11	0.21	0.25	0.31	0.35	0.47	H1

* 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 28 Critical infrastructure, emergency facilities and possible evacuation shelters - Inundation depths for all modelled events

ID	Infrastructure | Facility Name	Suburb	Location	Inundation Depths at Design AEP Events (m) – 90 minute storm										1% AEP Hazard Category *
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
A	The Hall State School	Wandal	2-32 Murray Street	-	-	-	-	-	-	-	-	-	-	-
B	St Joseph's Primary School Wandal	Wandal	67 Rundle Street	-	-	-	-	-	-	-	-	-	-	-
C	Eventide Home	Wandal	97 Campbell Street	-	-	-	-	-	-	-	-	-	-	-
D	Rockhampton State High School	Wandal	1 Campbell Street	-	0.10	0.19	0.23	0.27	0.29	0.32	0.40	0.45	0.62	H2
E	Rockhampton South Kindergarten	The Range	12 Phyllis Street	-	-	-	-	-	-	-	-	-	-	-
F	Crescent Lagoon State School	West Rockhampton	99-109 North Street Extended	-	-	-	-	-	-	-	-	-	-	-
G	Rockhampton Gardens	Wandal	14 Pauline Martin Drive	-	-	-	-	-	-	-	-	-	-	-
H	Talbot Estate	Wandal	228-230 Lion Creek Road	-	-	-	-	-	-	-	-	-	-	-

* 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 27 – Water and sewage infrastructure
- Table 28 – Critical infrastructure, emergency facilities and possible evacuation shelters

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LEGEND

Critical Infrastructure Inundation (Lowest Immunity)

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

Flood results are based on local catchment events

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

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

Wandal & West Rockhampton Model
Critical Infastructure Inundation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	16/01/2018
VERSION:	1

Figure 23

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Table 29 Roads Assets - Inundation Lengths and TOS for 1% AEP event and Inundation depths for all modelled events

ID	Road | Street Name	Suburb	1% AEP Inundation Length (m)^	1% AEP TOS (hrs)^	Inundation Depths at Design AEP Events (m) – 90 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
1	Ann Street	The Range	105	1.2	0.15	0.20	0.26	0.29	0.33	0.35	0.38	0.45	0.51	0.69	H2
2	Ann Street	The Range	55	1.4	0.15	0.19	0.23	0.25	0.27	0.28	0.30	0.35	0.39	0.49	H2
3	Bedden Avenue	Wandal	200	1.8	0.25	0.31	0.35	0.37	0.39	0.41	0.43	0.46	0.49	0.62	H2
4	Boreham Street	West Rockhampton	60	2.0	0.32	0.36	0.38	0.40	0.42	0.44	0.46	0.50	0.53	0.66	H2
5	Campbell Street	Wandal	35	1.2	0.11	0.13	0.15	0.15	0.16	0.16	0.17	0.19	0.20	0.25	H1
6	Canoona Road	West Rockhampton	430	20.6	0.24	0.38	0.52	0.60	0.73	0.87	0.94	1.06	1.16	1.57	H3
7	Curtis Street	Wandal	120	2.3	0.22	0.26	0.30	0.32	0.34	0.36	0.37	0.41	0.45	0.61	H2
8	Eton Street	West Rockhampton	30	1.5	0.15	0.18	0.22	0.23	0.25	0.26	0.28	0.32	0.36	0.46	H2
9	Graeme Acton Way	Wandal	250	4.0	0.15	0.39	0.66	0.81	0.97	1.16	1.30	1.64	1.91	2.67	H4
10	Hall Street	Wandal	340	2.0	0.00	0.16	0.32	0.36	0.41	0.45	0.48	0.55	0.59	0.77	H2
11	Heath Street	Wandal	60	2.0	0.53	0.57	0.60	0.62	0.64	0.66	0.69	0.77	0.85	1.08	H3
12	Heilbronn Street	West Rockhampton	25	1.8	0.26	0.31	0.36	0.38	0.41	0.42	0.44	0.51	0.56	0.77	H4
13	Jardine Street	Wandal	20	1.0	0.12	0.16	0.21	0.23	0.26	0.27	0.29	0.36	0.41	0.51	H3
14	Jardine Street	Wandal	15	1.6	0.21	0.24	0.28	0.30	0.32	0.33	0.36	0.41	0.47	0.61	H3
15	Lanigan Street	Wandal	25	1.5	0.34	0.40	0.45	0.47	0.50	0.52	0.54	0.62	0.68	0.82	H3
16	Lund Street	West Rockhampton	70	1.8	0.26	0.35	0.43	0.46	0.50	0.53	0.55	0.62	0.66	0.82	H3
17	Macgregor Street	The Range	20	1.6	0.24	0.27	0.31	0.33	0.36	0.36	0.39	0.44	0.51	0.63	H2
18	Melbourne Street	West Rockhampton	130	1.4	0.13	0.23	0.30	0.34	0.38	0.40	0.43	0.49	0.54	0.70	H2

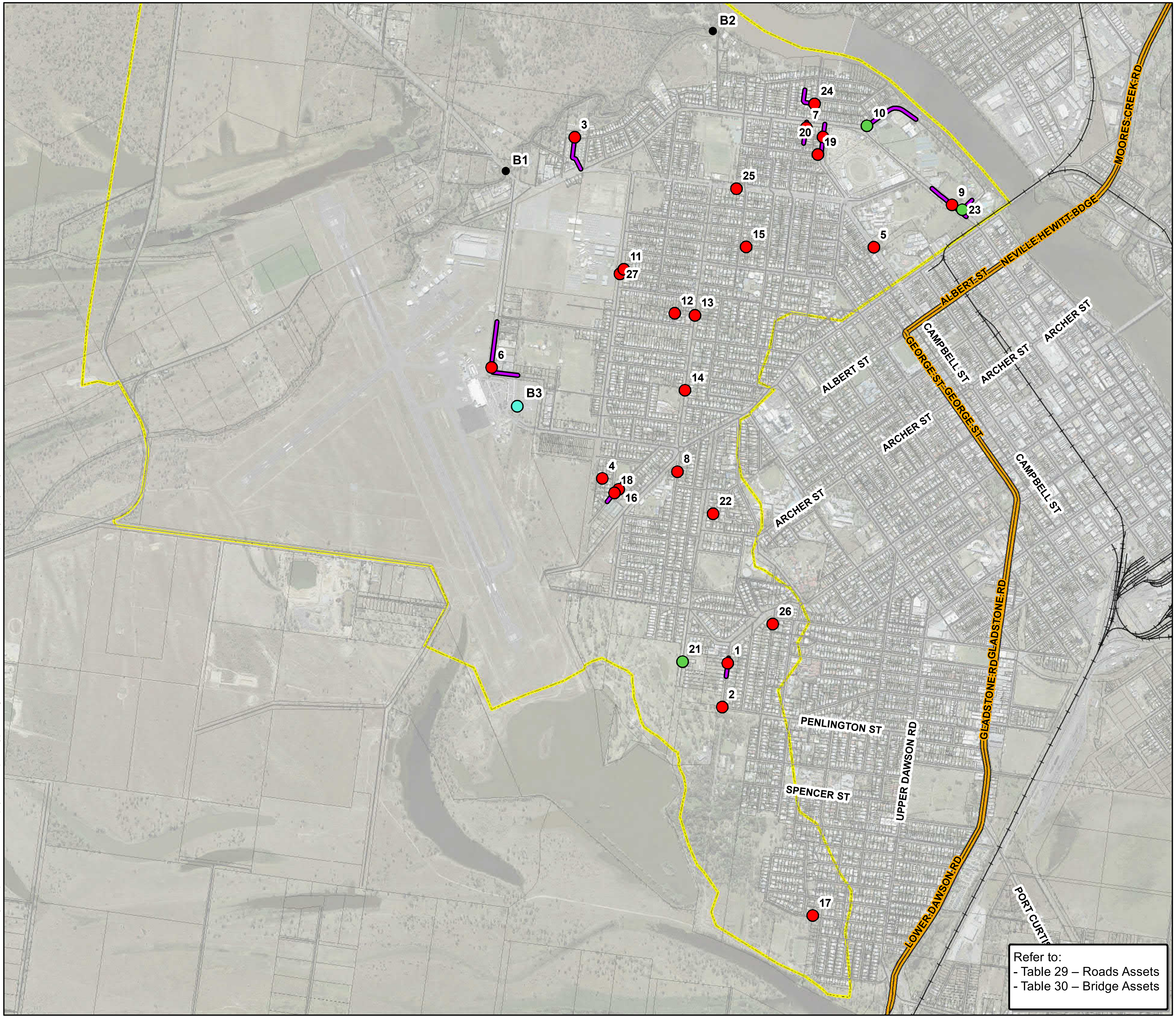
ID	Road | Street Name	Suburb	1% AEP Inundation Length (m)^	1% AEP TOS (hrs)^	Inundation Depths at Design AEP Events (m) – 90 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
19	Morgan Street	Wandal	65	1.7	0.20	0.25	0.28	0.30	0.33	0.34	0.36	0.40	0.44	0.58	H2
20	New Exhibition Road	Wandal	165	2.1	0.13	0.22	0.27	0.28	0.30	0.32	0.33	0.37	0.41	0.59	H2
21	Pennycuick Street	West Rockhampton	35	2.1	-	0.11	0.13	0.13	0.14	0.15	0.15	0.18	0.20	0.29	H1
22	Schofield Street	The Range	27	1.6	0.53	0.56	0.60	0.62	0.65	0.66	0.68	0.74	0.79	0.91	H3
23	Sir Raymond Huish Drive	Wandal	90	3.6	-	0.20	0.47	0.61	0.78	0.97	1.11	1.45	1.72	2.48	H3
24	Skyring Street	Wandal	135	2.8	0.29	0.31	0.34	0.35	0.37	0.38	0.39	0.41	0.42	0.45	H2
25	Wandal Road	Wandal	50	0.8	0.08	0.11	0.13	0.14	0.16	0.16	0.18	0.21	0.23	0.32	H1
26	Wentworth Terrace	The Range	35	2.5	0.22	0.24	0.26	0.26	0.27	0.28	0.29	0.32	0.35	0.40	H1
27	Western Street	Wandal	65	1.2	0.10	0.13	0.15	0.17	0.19	0.21	0.24	0.34	0.42	0.66	H1

^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 30 Bridge Assets - Inundation depths for all modelled events

ID	Bridge Name	Deck Height (mAHD) #	Inundation Depths Above Deck at Design AEP Events (m) – 90 minute storm *										1% AEP Hazard Category **
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
B1	Ridgelands Road Bridge	10.063	-	-	-	-	-	-	-	-	-	-	-
B2	Harman Street Bridge	7.985	-	-	-	-	-	-	-	-	-	-	-
B3	Airport Carpark Pedestrian Bridge	9.15	-	-	-	-	-	-	0.03	0.14	0.22	0.53	H4

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.



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Road, Rail and Bridge Infrastructure (Lowest Immunity)

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

Flood results are based on local catchment events

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

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

West Rockhampton Model
Critical Infastructure Inundation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/02/2018
VERSION:	2

Figure 24

9.4.1 Vulnerability Assessment Summary

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

- The sewerage pump stations at Jardine Park and Kele Park are predicted to have less than 39% AEP flood immunity, with the Melbourne Street Sewerage Pump Station having less than 18% AEP flood immunity. It is noted that in a 1% AEP event, the pump station at Jardine Park is predicted to reach hazard class 4 which is unsafe for both people and vehicles. It is recommended this information be passed onto FRW as the asset owner.
- Flood inundation is predicted at Rockhampton State High School in the 39% AEP event, however the low depth and velocity of flooding is expected to present a low risk until larger events where the hazard reaches Class 2.
- A number of roads are predicted to experience inundation in the 1EY event and larger. Predicted TOS generally ranges from 1 to 2 hours, with Canoona Road predicted to be inundated for almost 1 day in a 1% AEP 90min event.

9.5 Evacuation Routes

Generally local catchment flooding within the Wandal and West Rockhampton catchment is due to short duration, high intensity rainfall events. The relatively steep upper catchment and urbanisation throughout the upper and middle catchment can result in inundation of key roads as well as 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 Wandal and West Rockhampton catchment, the warning time between the commencement of the rain event and subsequent flood inundation can be short (refer Figure 31 to Figure 35). 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 31 provides a summary of the isolated areas and key evacuation routes, assessed up to the PMF event.

Table 31 Isolated Areas Summary

Isolated Area	Key Evacuation Route/s	Accessed Via	Warning Time Until Evac. Route Cut	Figure Reference
Ann St and Pennycuick St	Denham St	Ann St Pennycuick St	Up to 0.5 hour Up to 0.5 hour	Figure 25
Western St and Melbourne St	Hunter St	Melbourne St	Up to 0.5 hour	Figure 26
Pearson St, Kalare St and Peterson St	Western St	Kalare St	Up to 0.5 hour	Figure 27
Canoona Rd and Western St	Lion Creek Rd	Canoona Rd Western St	Up to 0.5 hour Up to 0.5 hour	Figure 28
Lion Creek Rd and Dally St	Lion Creek Rd	Dally St Duncan St Barry St Bedden Av	Up to 0.5 hour Up to 0.5 hour	Figure 29
Lion Creek Rd, Harman St and Hall St	Lion Creek Rd	Harman St Luck Av Savage St Hall St	Up to 0.5 hour Up to 1.0 hour	Figure 30

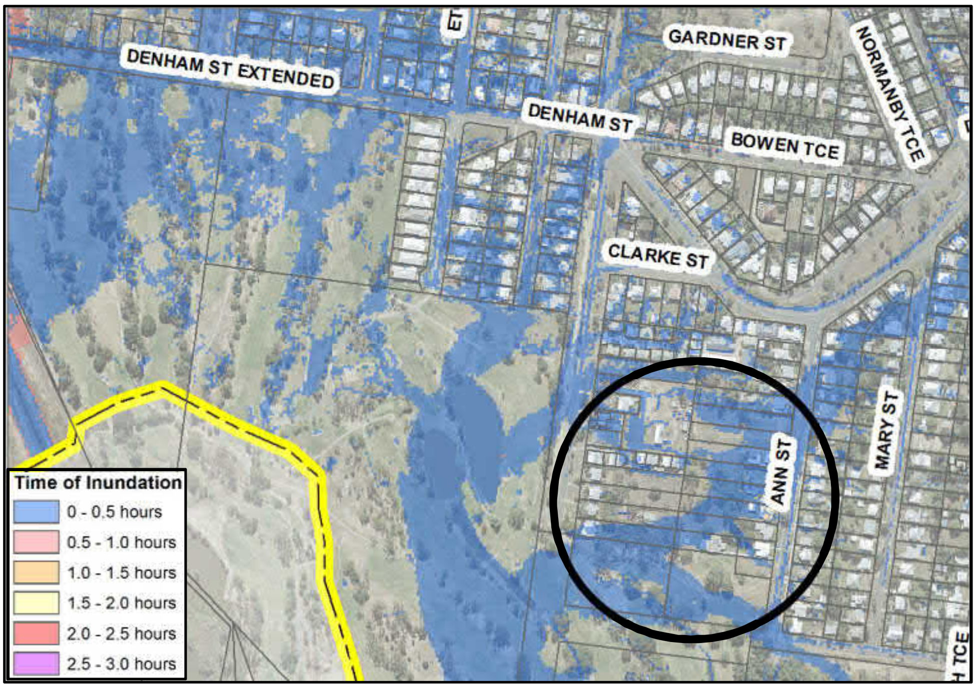


Figure 25 Isolated Area - Bounded by Ann St and Pennycuick St (Note: PMF flood extents shown)

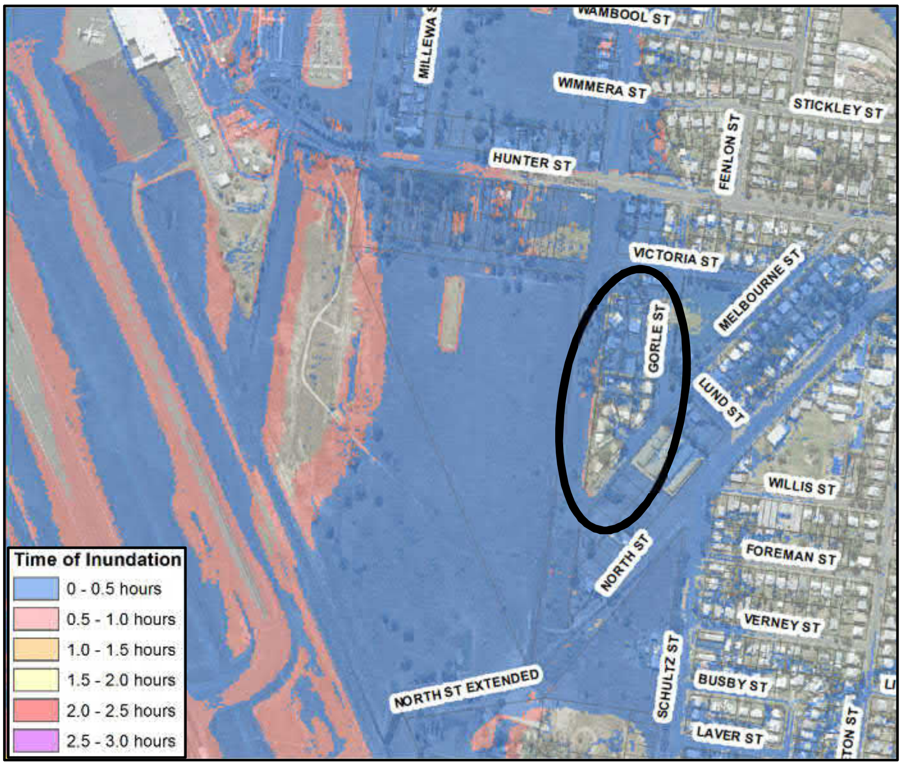


Figure 26 Isolated Area - Bounded by Western St and Melbourne St (Note: PMF flood extents shown)

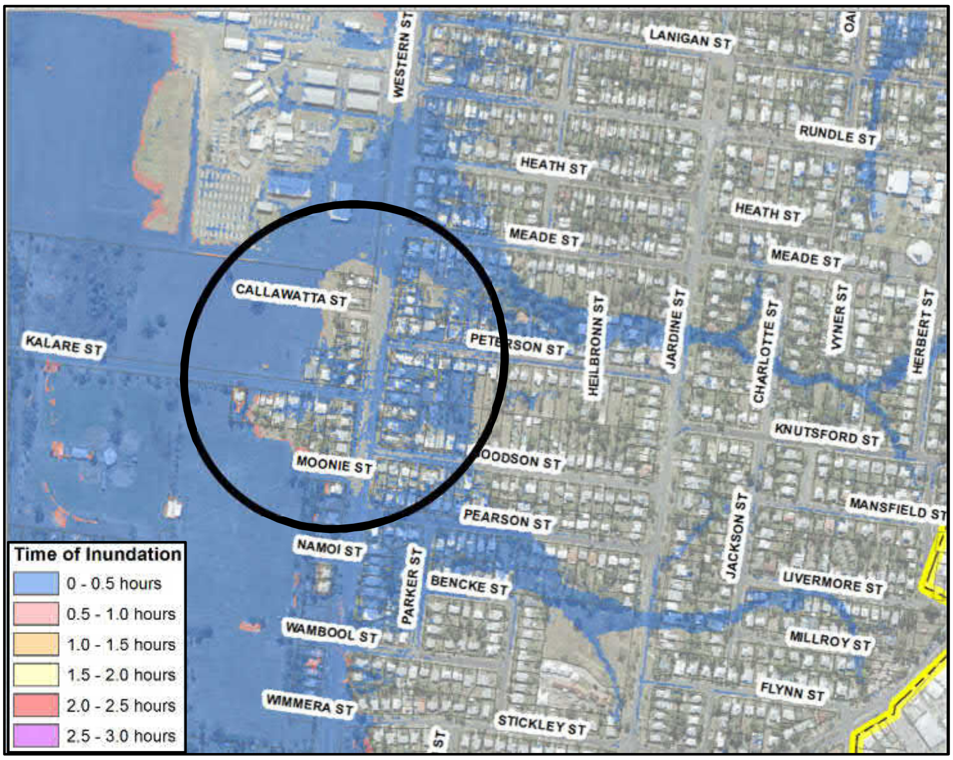


Figure 27 Isolated Area - Bounded by Pearson St, Kalare St and Peterson St (Note: PMF flood extents shown)

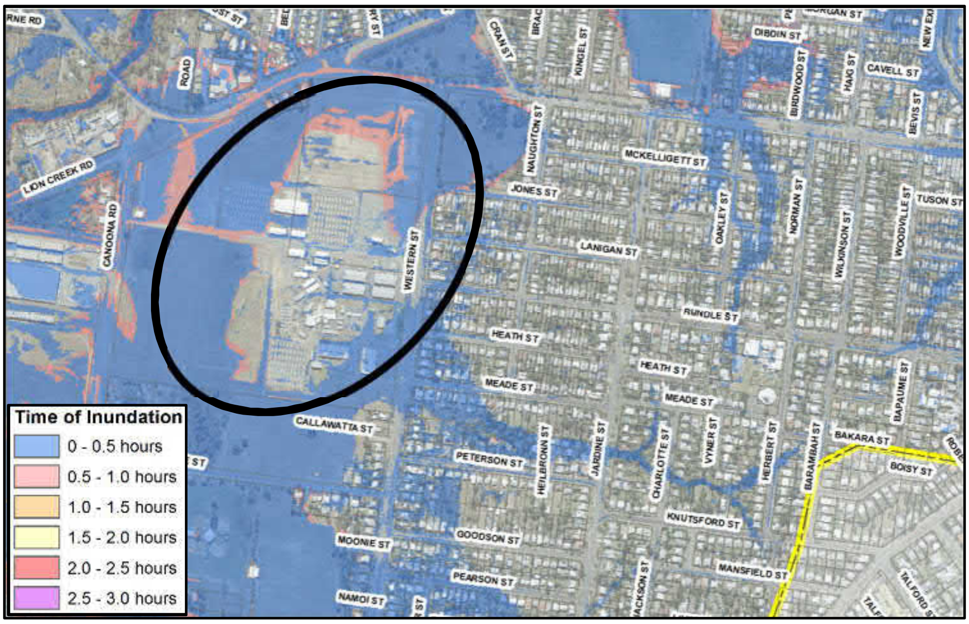


Figure 28 Isolated Area - Bounded by Canoona Rd and Western St (Note: PMF flood extents shown)

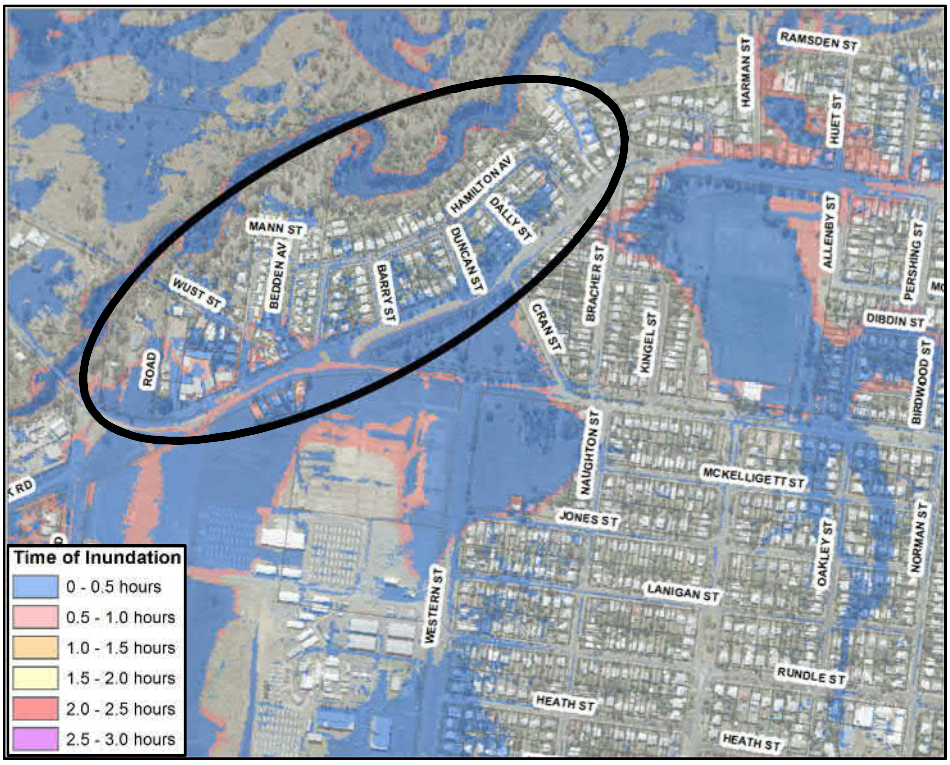


Figure 29 Isolated Area - Bounded by Lion Creek Rd and Dally St (Note: PMF flood extents shown)

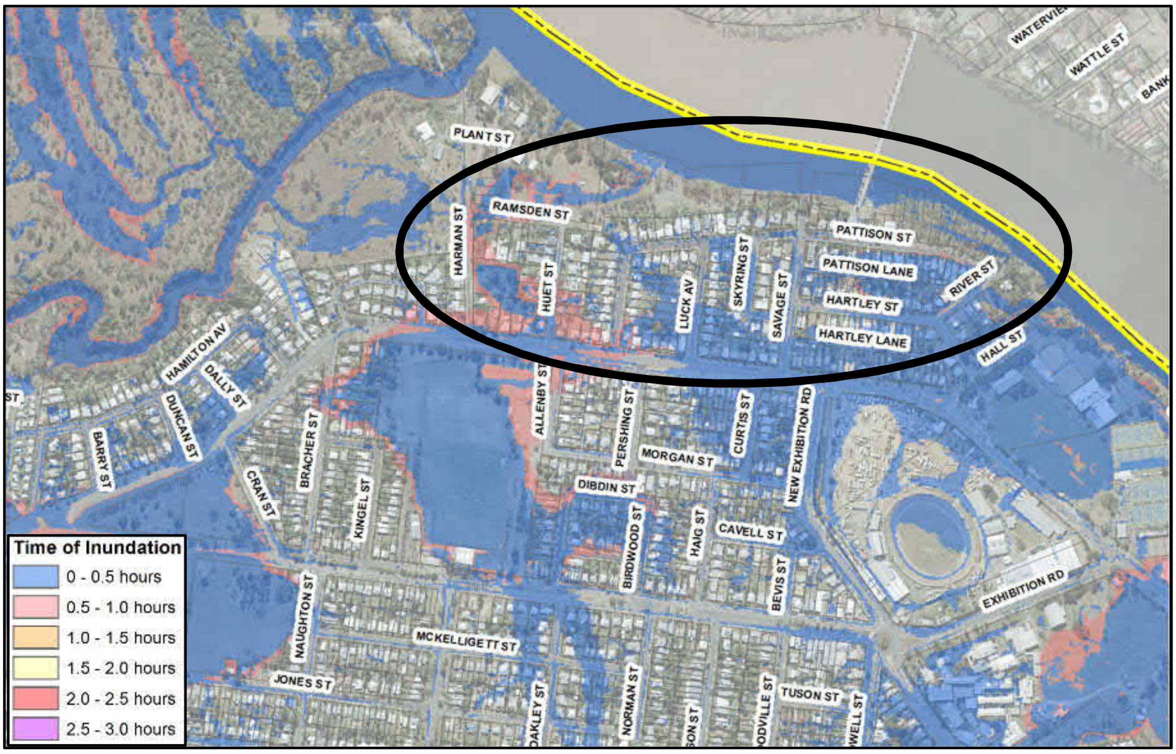
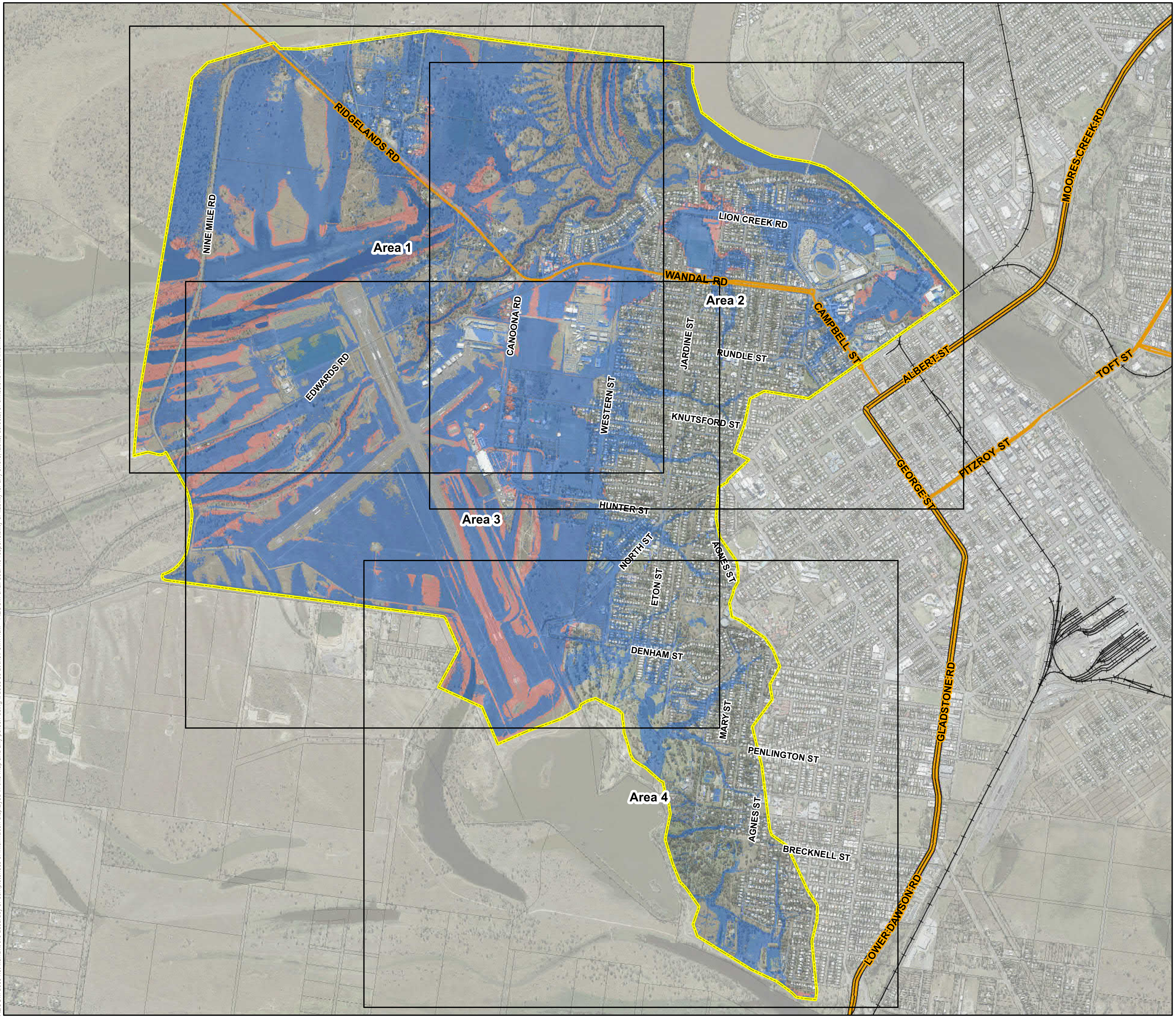


Figure 30 Isolated Area - Bounded by Lion Creek Rd, Harman St and Hall St (Note: PMF flood extents shown)



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 250 500 750 1,000 1,250

Metres

1:22,500
(when printed at A3)

AECOM
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LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

Data Sources:

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

Results Filtering:

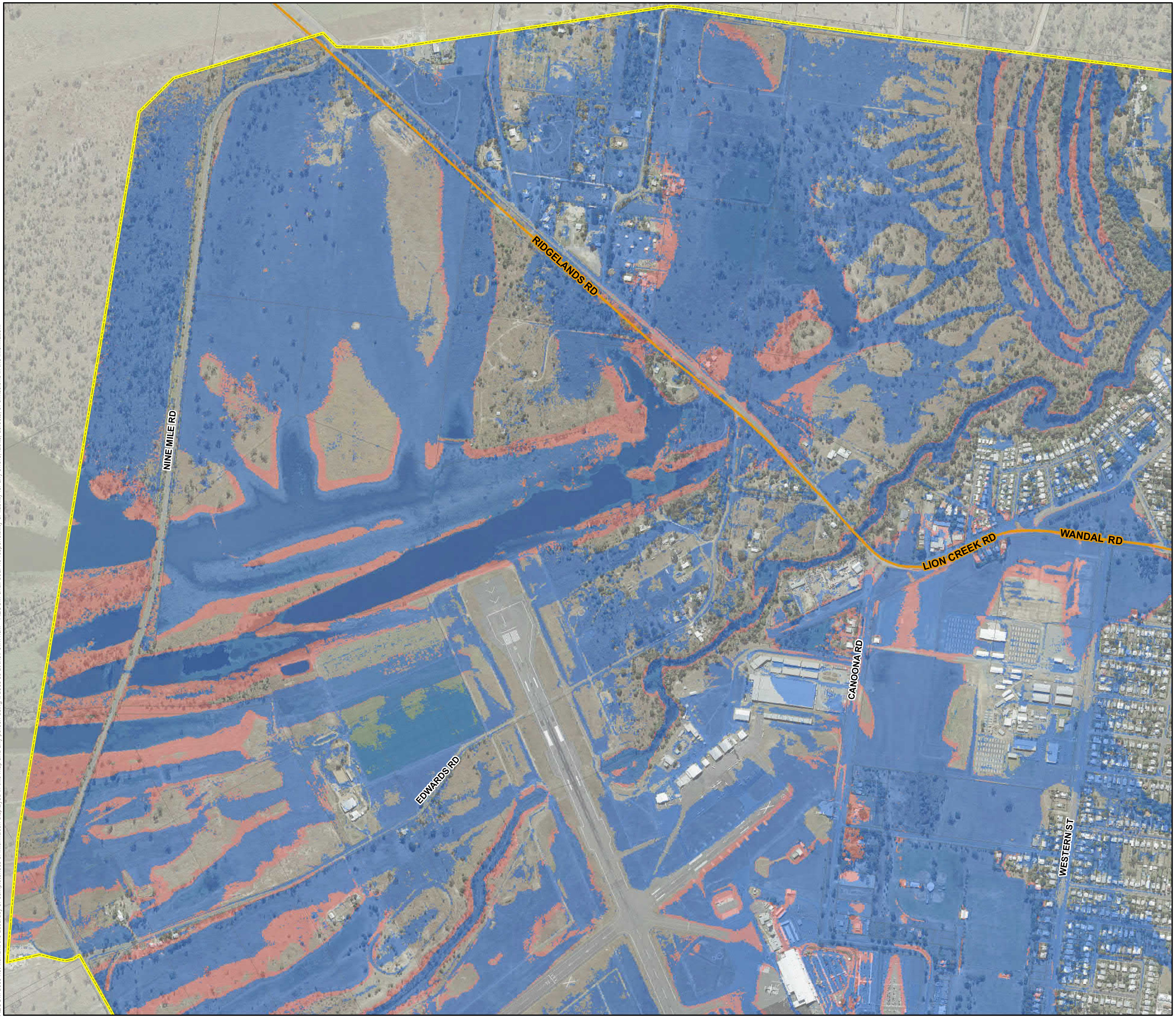
75mm Min. Depth
$100m^2$ Min. Area

West Rockhampton Model
Time of Inundation - Catchment Overview

PMF 90min Storm event

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 17/01/2018
VERSION: 2

Figure 31



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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

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

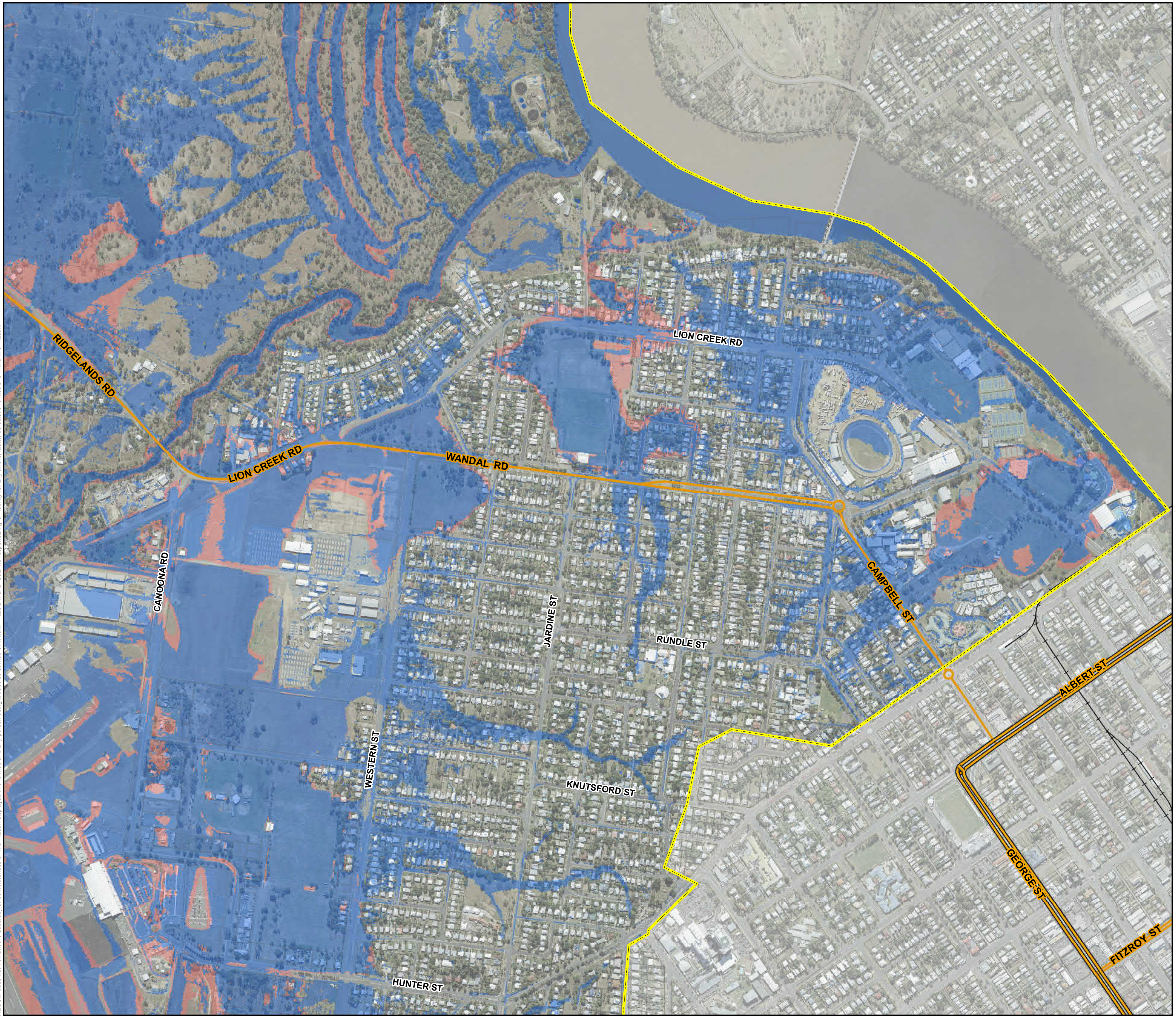
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

West Rockhampton Model
Time of Inundation - Area 1

PMF 90min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	17/01/2018
VERSION:	2

Figure 32



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500
Metres

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(when printed at A3)

AECOM
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LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

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

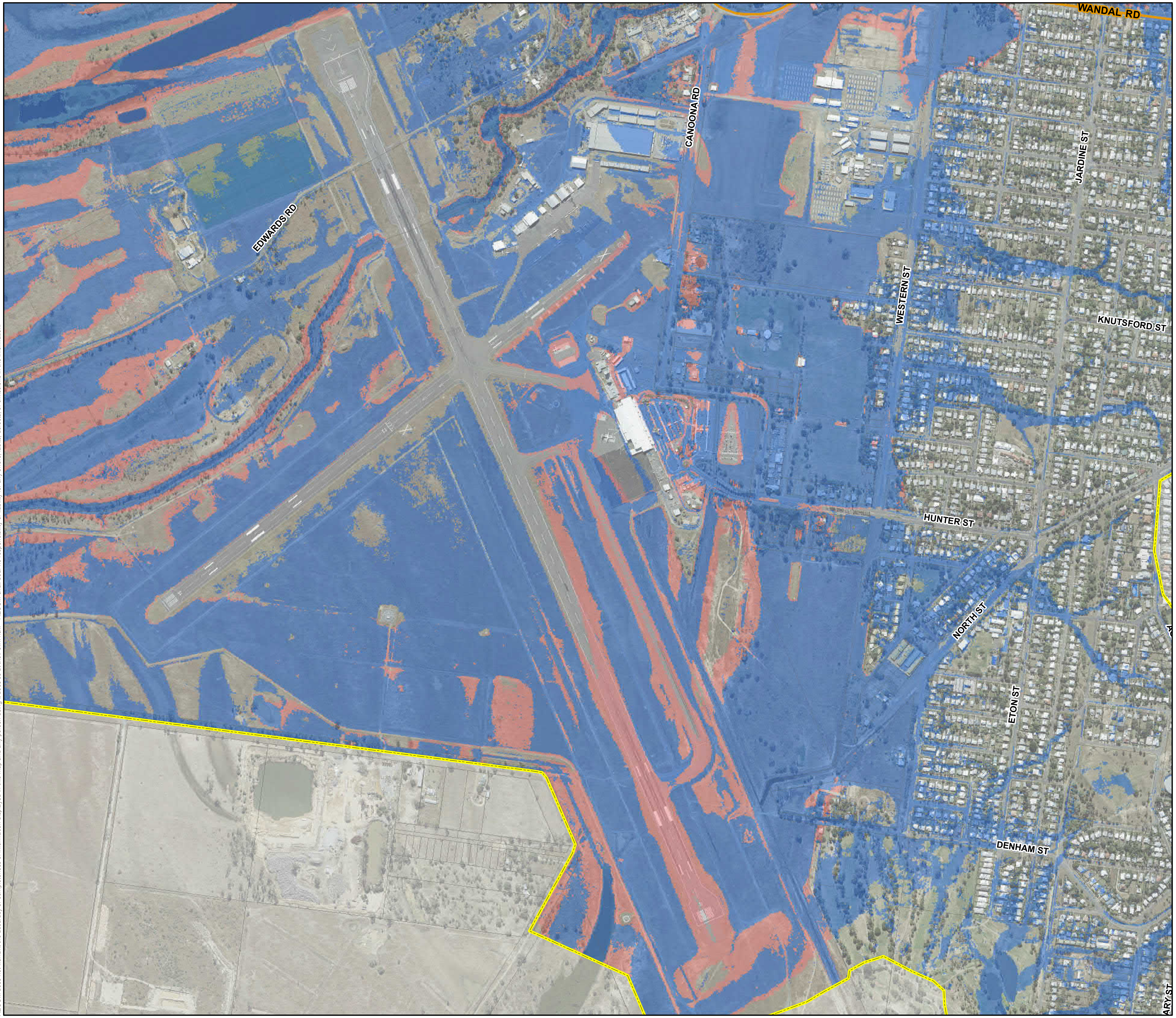
West Rockhampton Model
Time of Inundation - Area 2

PMF 90min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	17/01/2018
VERSION:	2

Figure
33

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 28_Phase_2_Inundation_Time - Area 2.mxd



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

1:10,000
(when printed at A3)

AECOM
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LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

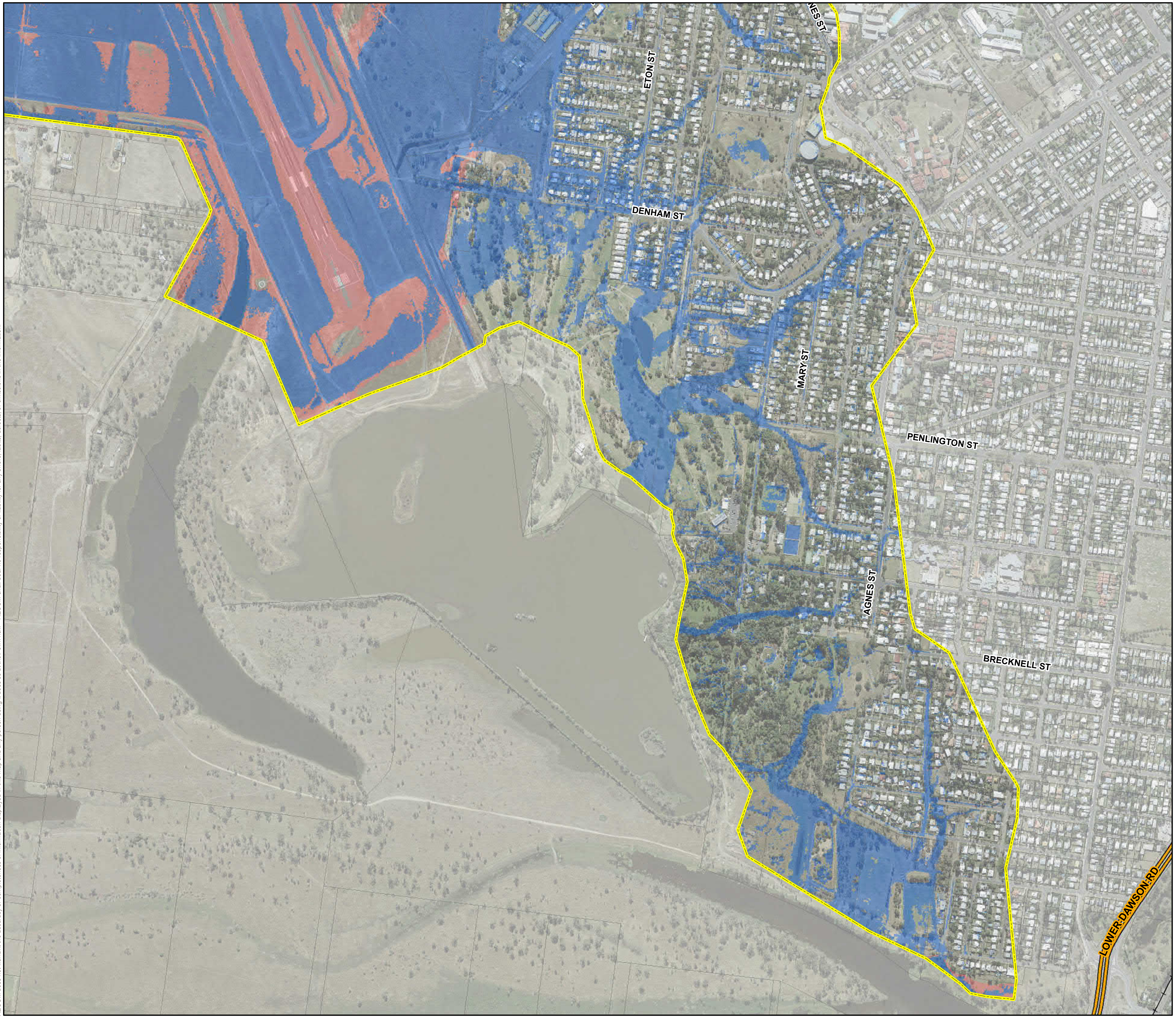
Results Filtering:
75mm Min. Depth
100m² Min. Area

West Rockhampton Model
Time of Inundation - Area 3

PMF 90min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	17/01/2018
VERSION:	2

Figure 34



Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500
Metres

1:10,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Time of Inundation

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

Flood results are based on local catchment events

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

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

West Rockhampton Model
Time of Inundation - Area 4

PMF 90min Storm event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	17/01/2018
VERSION:	2

Figure
35

9.6 Building Impact Assessment and Flood Damages Assessment

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

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

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

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

9.6.1 Baseline Building Impact Assessment

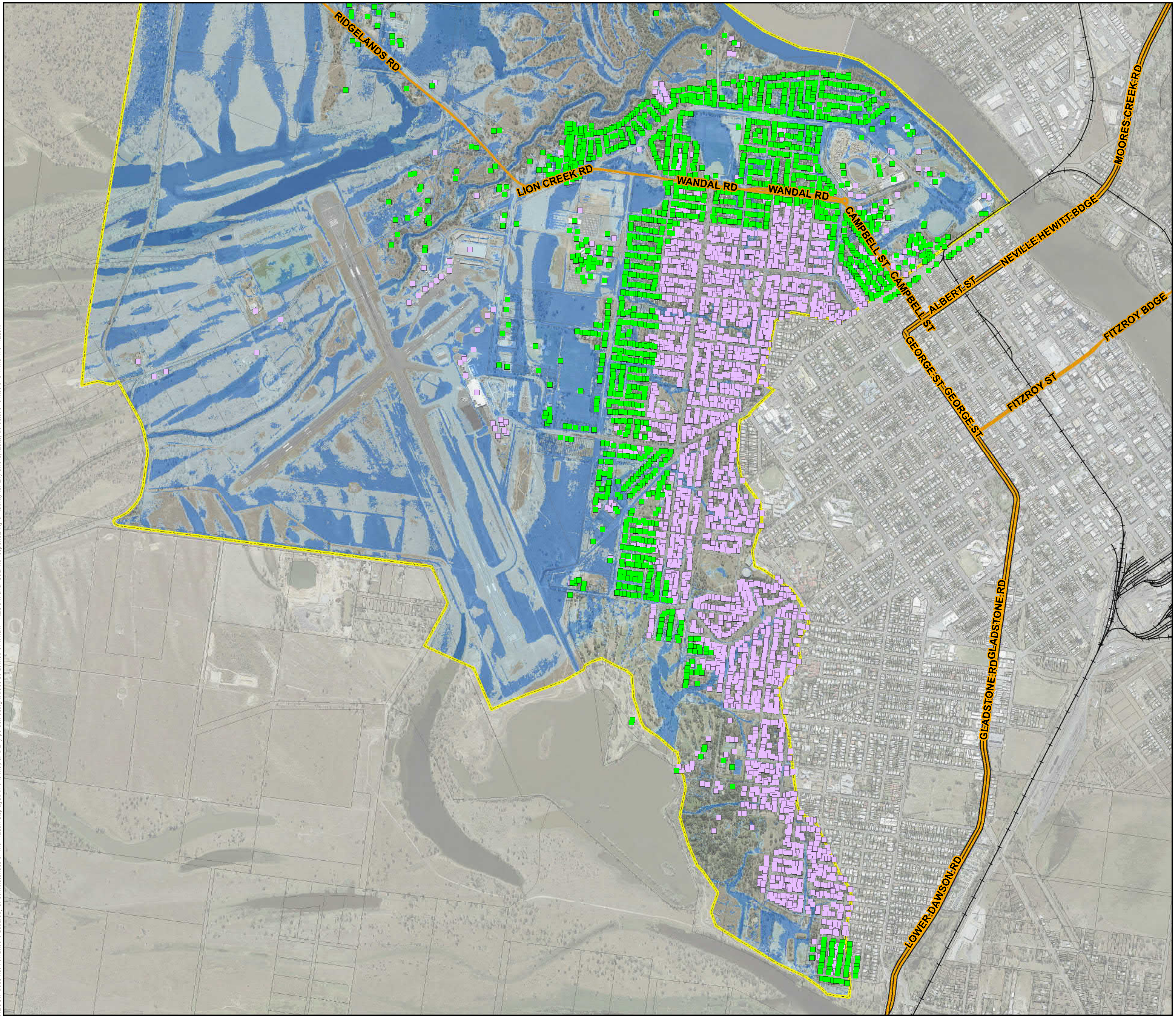
Council provided a building database, containing ~4,300 buildings digitised within the modelled area. Of these, ~1,800 buildings contained surveyed data, focussed on Fitzroy River flooding extents in Wandal, West Rockhampton and The Range (refer Figure 36).

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 ~2,500 within Wandal and West Rockhampton catchment).
  - The height above ground level was assumed based on information in the "*Floor_type*" field.
- Classification of buildings within the modelled area, in accordance with ANUFLOOD requirements (~28,000 buildings in total, with ~4,300 within Wandal and West Rockhampton catchment):
  - Buildings were divided into residential and commercial based on a combination of attribute fields, depending on what fields contained data for each building.
  - Residential buildings were assigned a class based on the "*Struc_type*" & "*Floor_type*" fields. Detached single storey buildings were also classified by floor area.
  - Commercial buildings were assigned a size class based on floor area – small/medium/large.
  - Commercial building classifications were assigned based on the "*Land_use_d*" field, with a value class of 3 (on a scale from 1 to 5) assigned to buildings lacking data.

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

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



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 200 400 600 800 1,000
Metres

1:20,000
(when printed at A3)

AECOM
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LEGEND

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

FLOOR LEVEL SUMMARY

Surveyed Floor Levels = 1,823
GIS-Derived Floor Levels = 2,510

Flood results are based on local catchment events

Data Sources:

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

Wandal & West Rockhampton Model

Building Database Summary

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	10/01/2018
VERSION:	1

Figure 36

Table 32 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Wandal and West Rockhampton catchment. These results are also shown graphically in Figure 37.

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 32 № 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	11 (3)	0 (0)
39.4	25 (7)	2 (2)
18.1	45 (13)	3 (3)
10	70 (22)	5 (5)
5	92 (29)	8 (8)
2	107 (36)	12 (11)
1	129 (40)	18 (15)
0.2	194 (67)	23 (20)
0.05	273 (99)	33 (30)
PMF	593 (232)	65 (61)

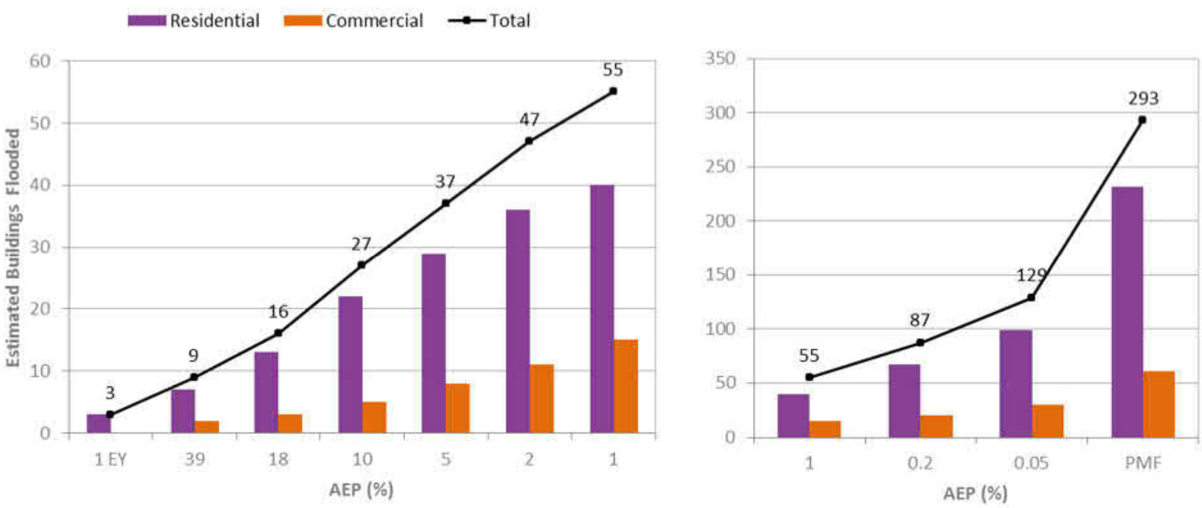


Figure 37 Estimated Buildings with Above Floor Flooding (Number of Buildings)

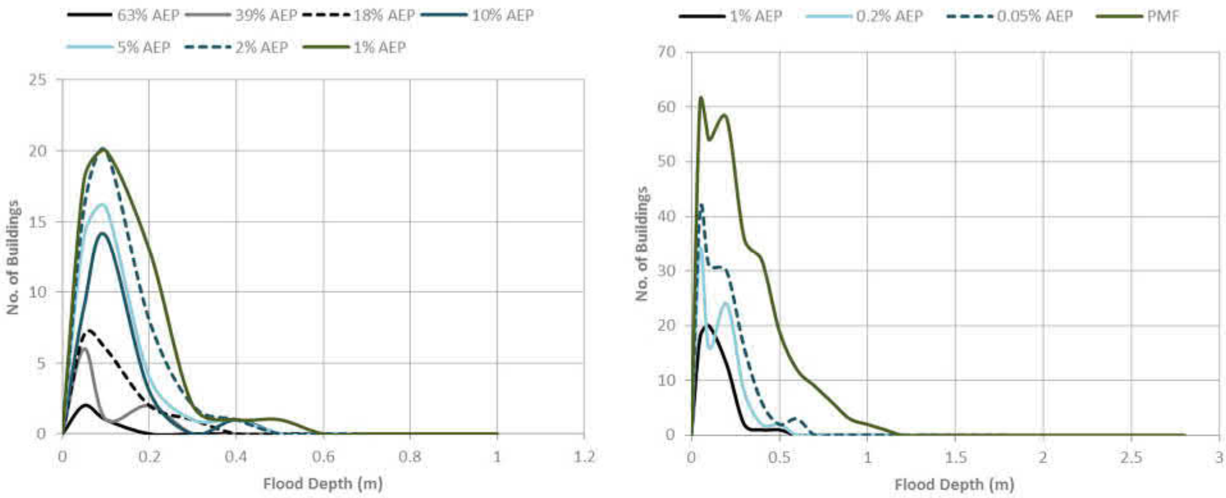


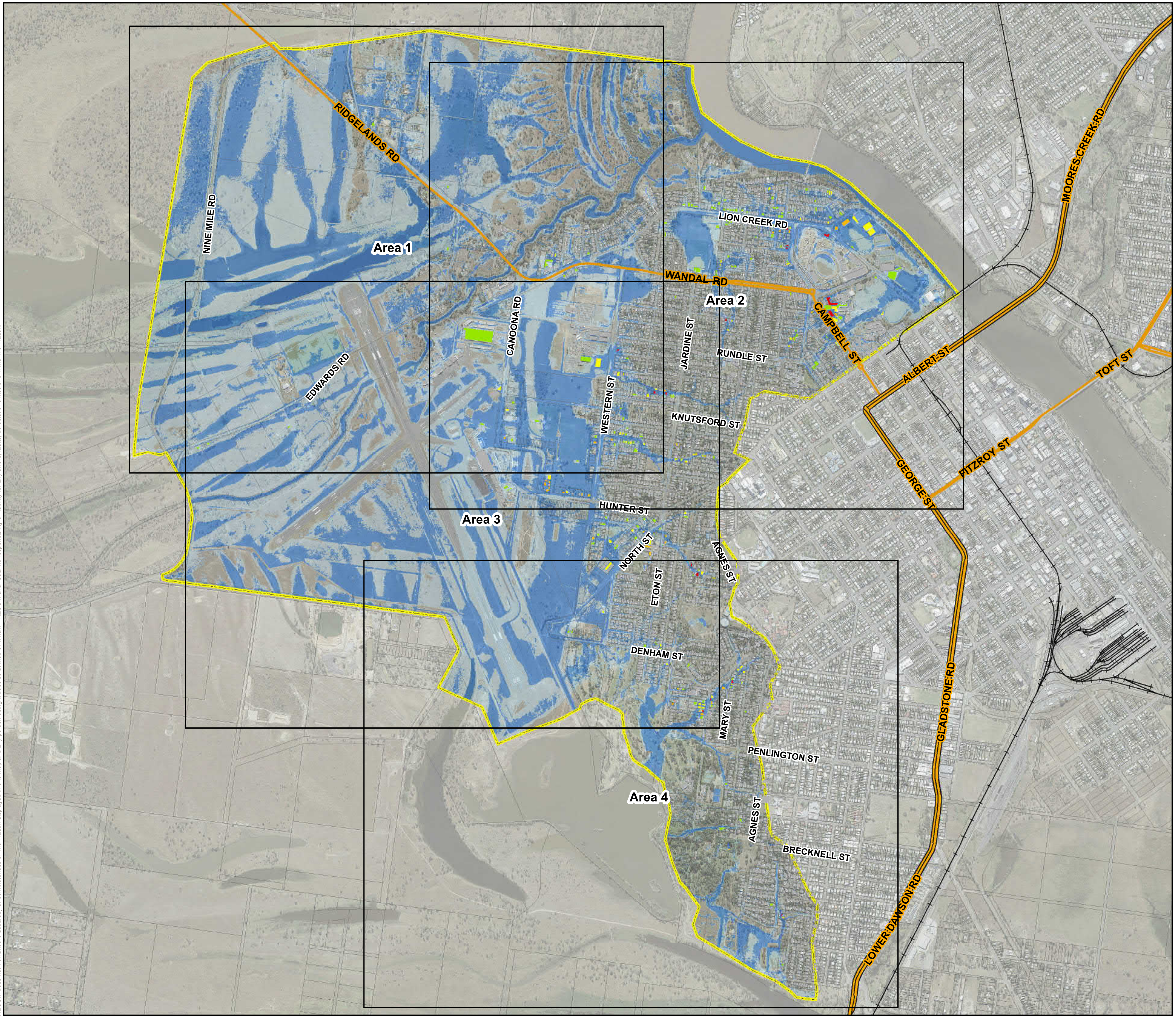
Figure 38 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

As shown in Figure 38, median flood depths are generally less than 0.3 metre for each flood event. This indicates that reductions in flood depths of 0.3 metre could significantly reduce overall damage.

The figure also shows that a significant number of buildings experience flood depths of 0.1 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 39 to Figure 43 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

0 250 500 750 1,000 1,250
Metres

1:22,500
(when printed at A3)

AECOM
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LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

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

Flood results are based on local catchment events

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

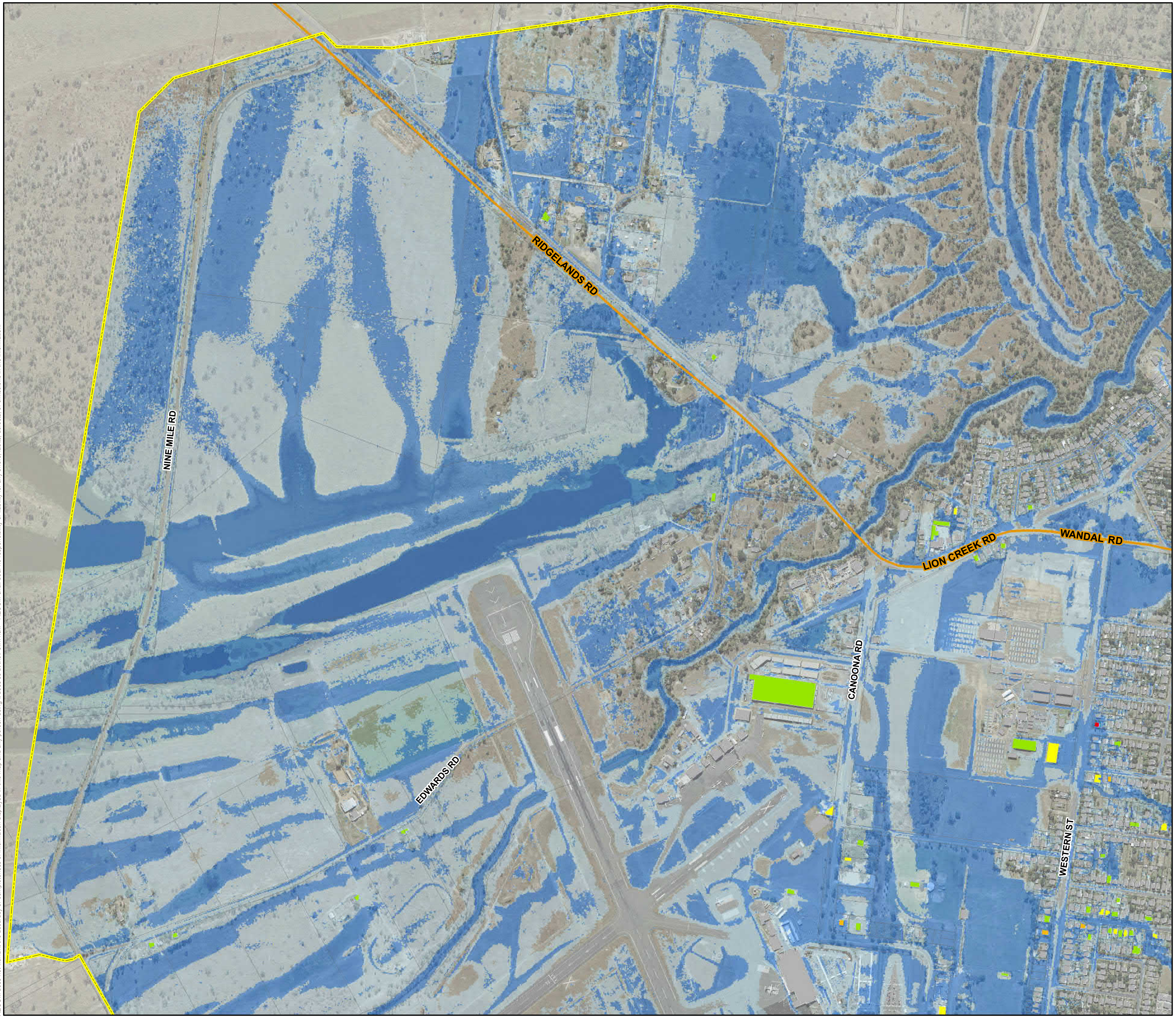
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Wandal & West Rockhampton Model Inundation of Buildings with Above Floor Level Flooding - Catchment Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	10/01/2018
VERSION:	1

Figure 39

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 32_Phase_2_Property_Inundation - Catchment Overview.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
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LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

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

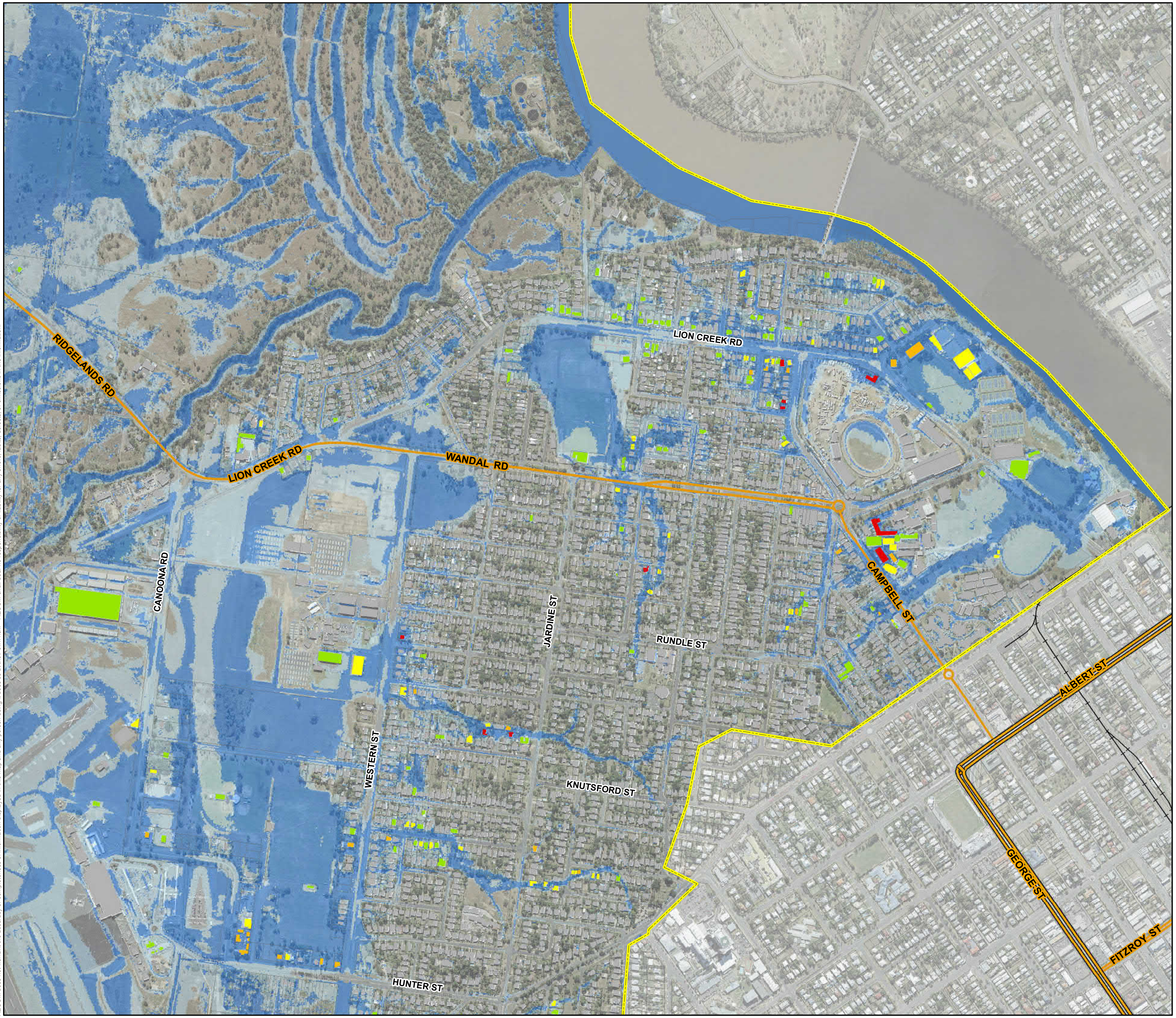
Results Filtering:
75mm Min. Depth
100m² Min. Area

Wandal & West Rockhampton Model Inundation of Buildings with Above Floor Level Flooding - Area 1

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	10/01/2018
VERSION:	1

Figure 40

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 33_Phase_2_Property_Inundation - Area 1.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

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

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

Flood results are based on local catchment events

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

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

Wandal & West Rockhampton Model Inundation of Buildings with Above Floor Level Flooding - Area 2

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	10/01/2018
VERSION:	1

Figure 41

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\West&Wandal Publishing\Figure 34_Phase_2_Property_Inundation - Area 2.mxd

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DATUM GDA 1994, PROJECTION MGA ZONE 56

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Metres

1:10,000
(when printed at A3)

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LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

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

Wandal & West Rockhampton Model Inundation of Buildings with Above Floor Level Flooding - Area 3

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	10/01/2018
VERSION:	1

Figure 42

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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
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LEGEND

- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Inundation of Buildings with Above Floor Flooding

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

Wandal & West Rockhampton Model Inundation of Buildings with Above Floor Level Flooding - Area 4

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	10/01/2018
VERSION:	1

Figure 43

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9.6.2 Baseline Flood Damages Assessment

Table 33 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 34 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 33 Summary of flood damages using WRM stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$ 244	$ -	$ 32	**$ 276**
39	$ 581	$ 68	$ 82	**$ 731**
18	$ 1,167	$ 81	$ 160	**$ 1,409**
10	$ 1,941	$ 110	$ 264	**$ 2,315**
5	$ 2,539	$ 156	$ 346	**$ 3,040**
2	$ 3,230	$ 264	$ 447	**$ 3,941**
1	$ 3,849	$ 361	$ 537	**$ 4,747**
0.2	$ 6,423	$ 686	$ 904	**$ 8,013**
0.05	$ 9,937	$ 1,219	$ 1,414	**$ 12,570**
PMF	$ 29,764	$ 4,139	$ 4,283	**$ 38,186**

Table 34 Summary of flood damages using O2 Environmental stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$ 234	$ -	$ 31	**$ 265**
39	$ 548	$ 68	$ 78	**$ 694**
18	$ 1,141	$ 81	$ 157	**$ 1,380**
10	$ 1,912	$ 110	$ 260	**$ 2,282**
5	$ 2,519	$ 156	$ 344	**$ 3,018**
2	$ 3,258	$ 264	$ 451	**$ 3,973**
1	$ 3,931	$ 361	$ 548	**$ 4,839**
0.2	$ 6,875	$ 686	$ 963	**$ 8,524**
0.05	$ 11,010	$ 1,219	$ 1,554	**$ 13,783**
PMF	$ 37,979	$ 4,139	$ 4,954	**$ 47,472**

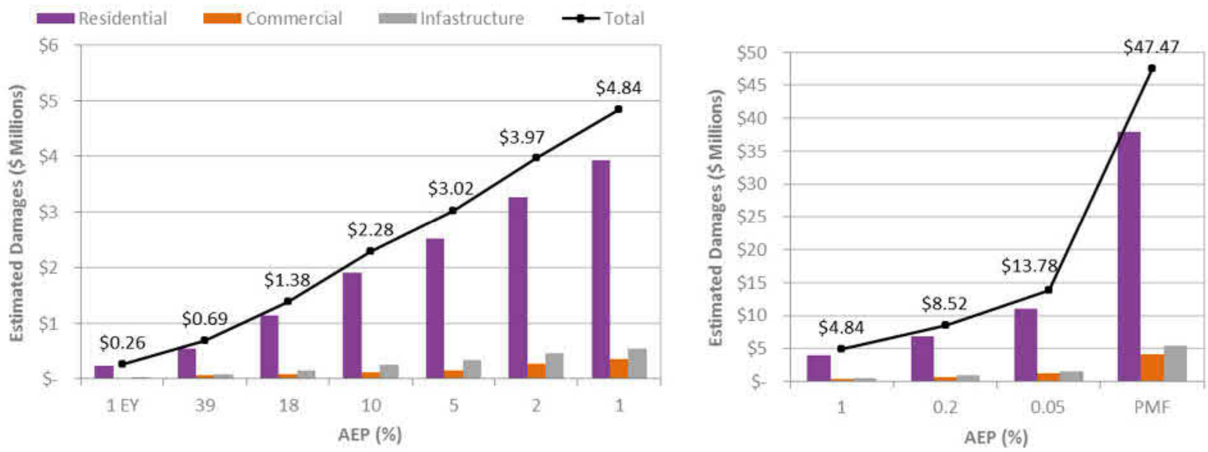


Figure 44 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

Figure 44 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from $276,000 (1EY flood event) to $47M (PMF event). Figure 37 shows that 3 buildings are expected to be inundated above floor in the 1EY event, whilst 293 buildings are anticipated to be inundated above floor in the PMF event.

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

9.6.3 Average Annual Damages

While the above provides an estimate of potential damages during specific flood events, understanding what damages may be expected on an annual basis is often an easier way to relate risk to residents and businesses. As such, the above damages were converted to Average Annual Damages (AAD) based on the likelihood of the flood event and the total estimated damage during that event. The AAD is determined by taking the estimated damage for each AEP event and multiplying it by the likelihood of the event. The process is repeated and AAD values are summed for the total AAD. For instance, the AAD for a 10% AEP event is based on the estimated $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 B. Using the WRM damage curves results in an AAD of approximately **$860,000** and using those from O2 Environmental gives an AAD of approximately **$850,000**. The difference of approximately 1% provides a very narrow range for the estimated AAD.

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

Figure 45 shows the breakdown of residential, non-residential and infrastructure AAD over the entire catchment. As shown, a total AAD cost of $0.85M is estimated, with the vast majority (82%) being attributed to residential buildings.

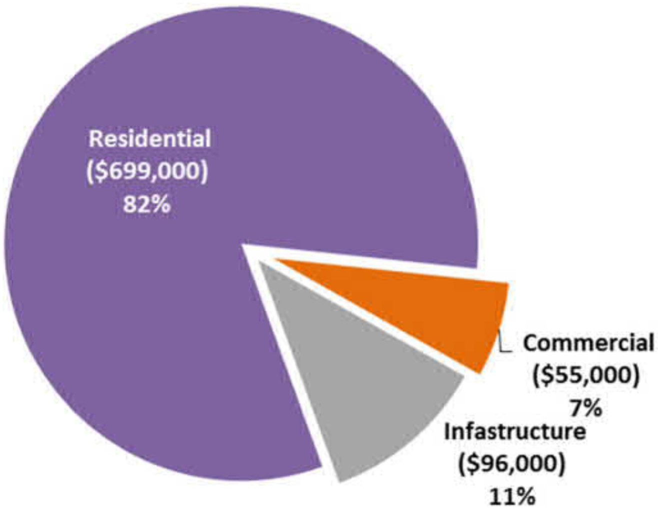


Figure 45 Total AAD by Building Type

Figure 46 and Figure 47 breakdown the AAD for residential and non-residential properties. It can be seen that 79% of residential and 89% of non-residential properties experience a damage cost of less than $500 per annum. As a result, 58% of the total AAD is associated with only 5% of all buildings, or approximately 14 buildings, demonstrating that a minority of buildings produce the majority of damages within the catchment.

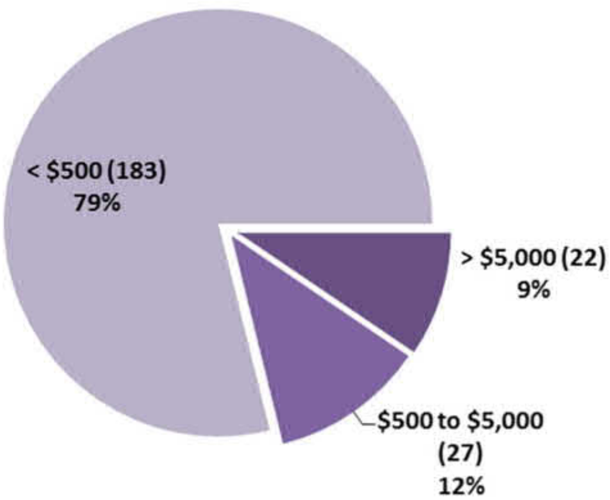


Figure 46 Residential AAD (Number of Buildings)

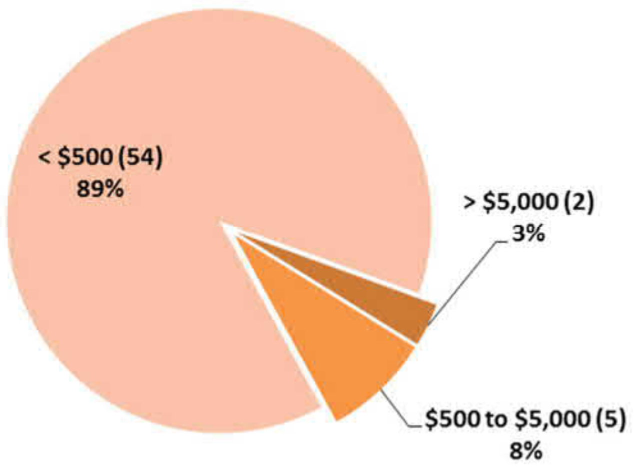


Figure 47 Non-Residential AAD (Number of Buildings)

9.6.4 AAD Summary

Figure 48 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, 81% of all buildings exhibit less than $500 damage per annum and produce only 3% of the total damage. In addition 58% of damages are associated with less than 5% of all buildings. Again, this demonstrates that a minority of buildings produce a significant proportion of damages.

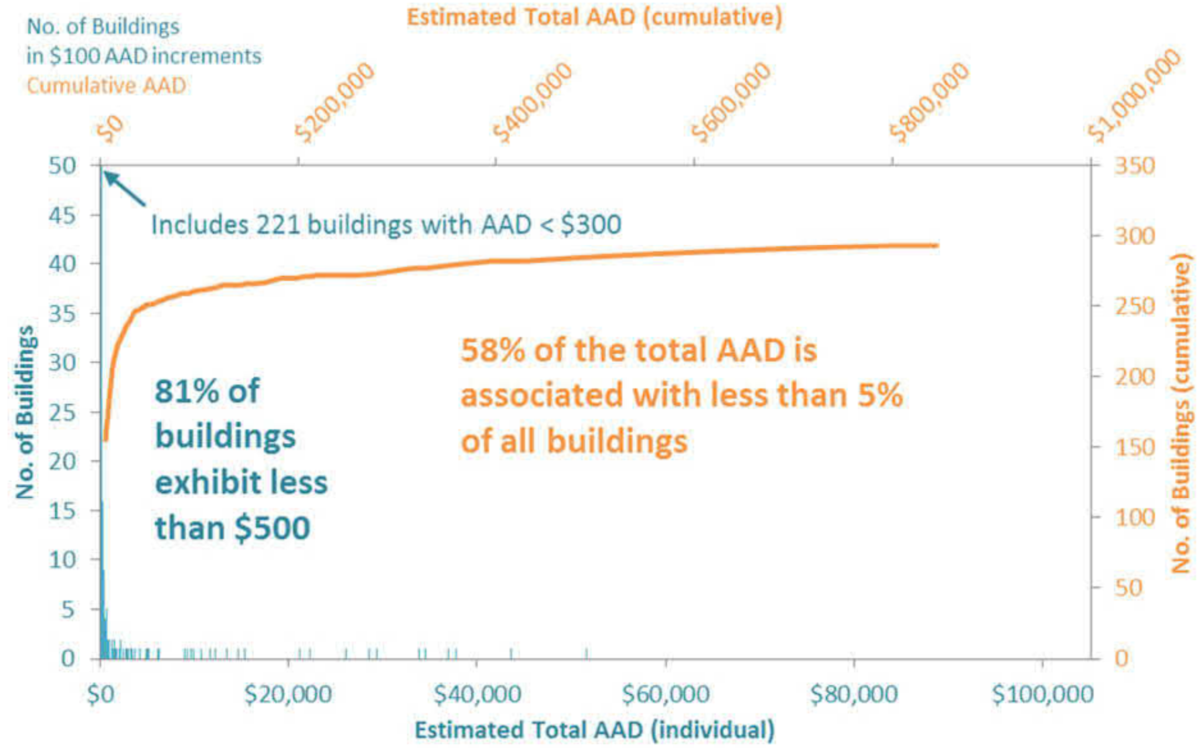


Figure 48 Individual Building vs. Cumulative Total Average Annual Damages

9.7 Rainfall Gauge and Maximum Flood Height Gauge Network Coverage

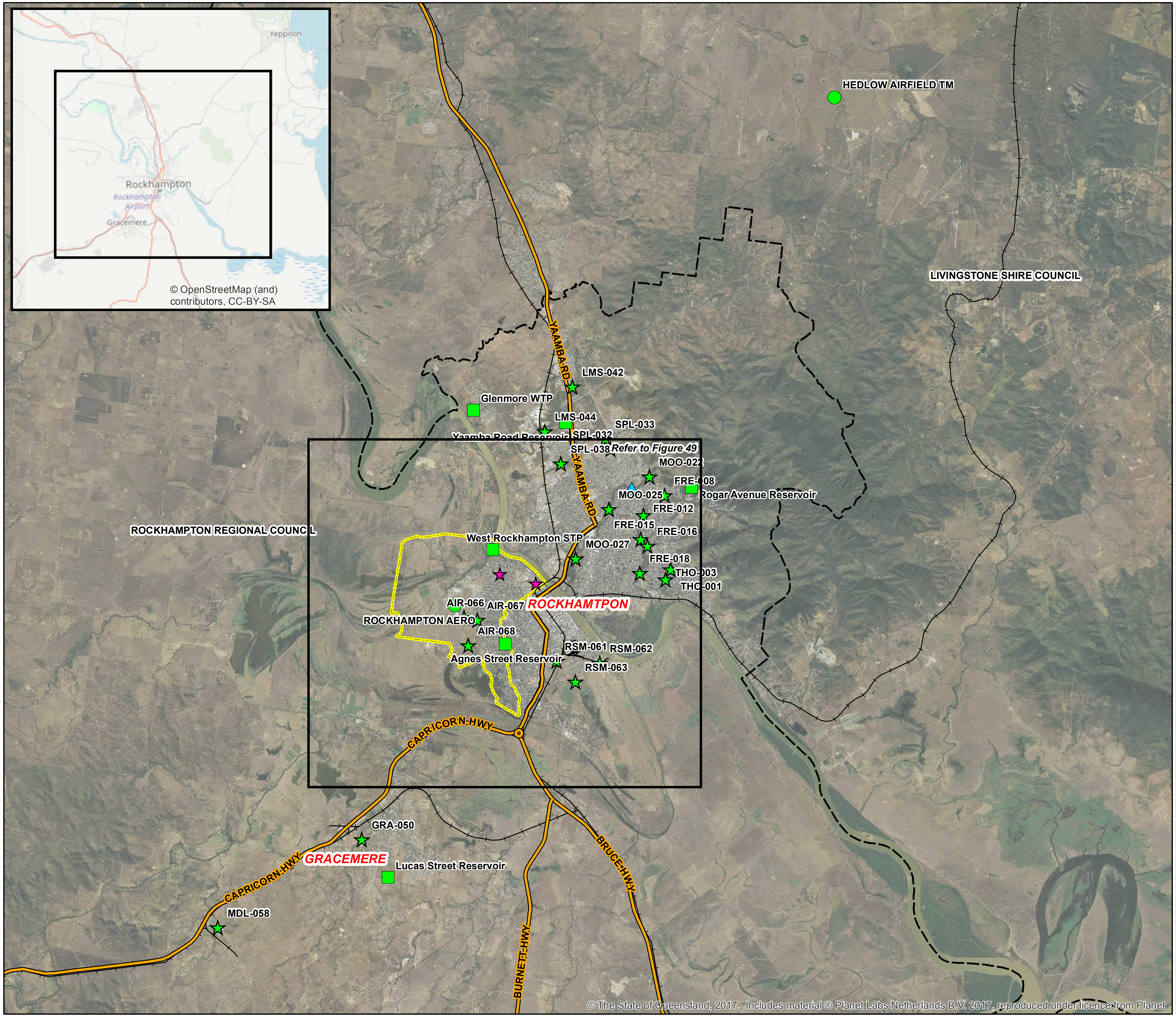
Figure 49 and Figure 50 show the location of existing rainfall gauges within the Rockhampton region, plus Council's maximum flood height gauges.

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:

- A sufficient spread of rainfall gauges are installed within the catchment to provide a confident record of rainfall depths and patterns across Wandal and West Rockhampton.
- In addition to the three existing maximum flood height gauges within the Wandal and West Rockhampton catchment, it is recommended that gauges be installed at the following locations (as shown on Figure 50):
    - South-western face of Lion Creek Road (at the low point) between Sir Raymond Huish Drive and South Rockhampton SHS Access Road.
    - Eastern side of the concrete inverted spoon drain running into Jardine Park, accessible via Morgan Street. Gauge should be placed just prior to the end of the upper soccer fields, south of the netball courts on Allenby Street.

9.8 Flood Warning Network Coverage

As noted in Section 2.8, there is currently no flood warning network for the Wandal and West Rockhampton catchment.



Rockhampton Regional Council

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DATUM GDA 1994, PROJECTION MGA ZONE 56

0 1 2 3 4 5 6
Kilometers

1:120,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

Maximum Height Gauges
- RRC

Active Rainfall Gauges
- BOM
- RRC

Inactive Rainfall Gauges
- Private

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

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

Wandal & West Rockhampton Model
Rainfall Gauge and Flood Record Network

Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	2

Figure
49

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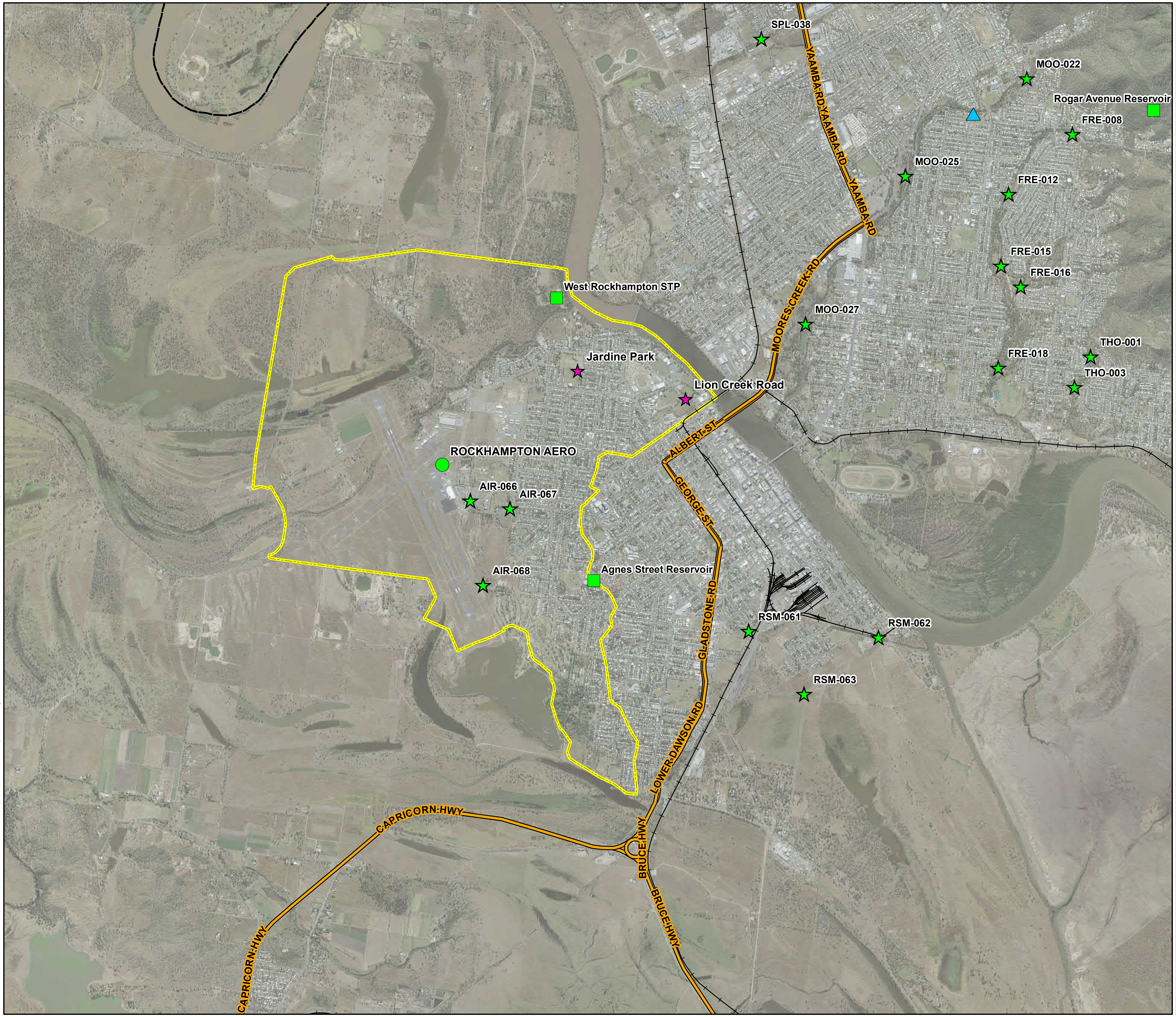

Rockhampton Regional Council

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Kilometers

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AECOM
www.aecom.com

LEGEND

Maximum Height Gauges
- RRC

Active Rainfall Gauges
- BOM
- RRC

Inactive Rainfall Gauges
- Private

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

Data Sources:

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

Wandal & West Rockhampton Model Rainfall Gauge and Flood Record Network

Figure 48 Inset - Rockhampton

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	15/01/2018
VERSION:	2

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50

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10.0 Conclusion

10.1 Baseline Model Development

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

10.1.1 Model Calibration

Anecdotal and recorded data was received and used to calibrate the model to a local flood event caused by Ex-TC Debbie in March 2017. The model calibrated well to the 2017 event.

At this stage, it is recommended that additional verification events are assessed in the future to gain further confidence in the modelling outputs

10.1.2 Design Event Modelling

On completion of the calibration / validation process, various design flood events and durations were simulated and results extracted. The critical duration for the catchment was determined to be the 90 minute event.

A comparison of the design events found that for events up to the 39% AEP event, the road and subsurface drainage infrastructure was able to prevent runoff from entering private property. For larger flood events, the overland flow paths continue to develop and are predicted to impact public and privately owned infrastructure throughout the catchment.

10.1.3 Sensitivity Analysis

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

10.2 Baseline Flood Hazard and Vulnerability Assessment

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

10.2.1 Flood Hazard

As can be seen in maps **WW-66** to **WW-75** 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 and open areas such as Jardine Park and Alf Kele Memorial Rotary Park.
- Extreme hazard (H4 and H5) within major natural and man-made flowpaths between Heilbronn Street and Western Street, along Pearson Street, along North Street and along the flowpath traversing Ann Street.
- Extreme hazard (H5 or H6) within the Lion Creek channel.

10.2.2 Vulnerability Assessment

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

- The sewerage pump stations at Jardine Park and Kele Park are predicted to have less than 39% AEP flood immunity, with the Melbourne Street Sewerage Pump Station having less than 18% AEP flood immunity. It is noted that in a 1% AEP event, the pump station at Jardine Park is predicted to reach hazard class 4 which is unsafe for both people and vehicles. It is recommended this information be passed onto FRW as the asset owner.

- Flood inundation is predicted at Rockhampton State High School in the 39% AEP event, however the low depth and velocity of flooding is expected to present a low risk until larger events where the hazard reaches Class 2.
- A number of roads are predicted to experience inundation in the 1EY event and larger. Predicted TOS generally ranges from 1 to 2 hours, with Canoona Road predicted to be inundated for almost 1 day in a 1% AEP 90min event.

10.2.3 Evacuation Routes

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

- Ann Street / Pennycuick Street à lose evacuation to Denham Street.
- Western Street / Melbourne Street à lose evacuation via Melbourne Street to Hunter Street.
- Pearson Street / Kalare Street / Peterson Street à lose access to Western Street.
- Cannona Road / Western Street à lose access to Lion Creek Road.
- Lion Creek Road / Dally Street à lose access to Lion Creek Road via Duncan Street, Barry Street and Bedden Avenue.
- Lion Creek Road / Harman Street / Hall Street à lose access to Lion Creek Road via Luck Avenue and Savage Street.

10.2.4 Building Impact Assessment

The building impact assessment shows the following:

- 11 buildings (3 with above floor flooding) predicted to be impacted in the 1EY event.
- 48 buildings (16 with above floor flooding) predicted to be impacted in the 18% AEP event.
- 147 buildings (55 with above floor flooding) predicted to be impacted in the 1% AEP event.
- 658 buildings (293 with above floor flooding) predicted to be impacted in the PMF event.
- Significant number of buildings to be impacted with less than 0.3m flood depth in frequent events, such as 1EY.

10.2.5 Flood Damages Assessment

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

- WRM and O2 curves used to establish upper and lower bounds for tangible flood damages:
  - $265,000 to $276,000 damages estimated in 1EY event.
  - $1,380,000 to $1,409,000 damages estimated in 18% AEP event.
  - $4,747,000 to $4,839,000 damages estimated in 1% AEP event.
  - $38,186,000 to $47,472,000 damages estimated in PMF event.
- AAD ranging from **$850,000 to $860,000** for O2 and WRM damage curves respectively.
- 82% of the total AAD is associated with residential buildings.
- 79% of residential buildings and 89% of commercial buildings exhibit less than $500 damage per annum.
- 58% of the total AAD is attributed to less than 5% of all buildings.

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

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

- A sufficient spread of rainfall gauges are installed within the catchment to provide a confident record of rainfall depths and patterns across Wandal and West Rockhampton.
- In addition to the three existing maximum flood height gauges within the Wandal and West Rockhampton catchment, it is recommended that gauges be installed at the following locations (as shown on Figure 50):
  - South-western face of Lion Creek Road (at the low point) between Sir Raymond Huish Drive and South Rockhampton SHS Access Road.
  - Eastern side of the concrete inverted spoon drain running into Jardine Park, accessible via Morgan Street. Gauge should be placed just prior to the end of the upper soccer fields, south of the netball courts on Allenby Street.

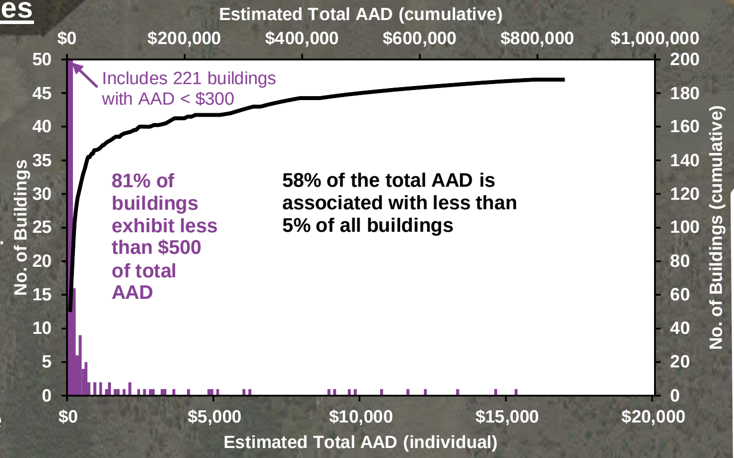
An overview of building impacts and flood damages is provided in Figure 52.

Wandal and West Rockhampton Catchment Overview

Flood results are based on local catchment events

Average Annual Damages

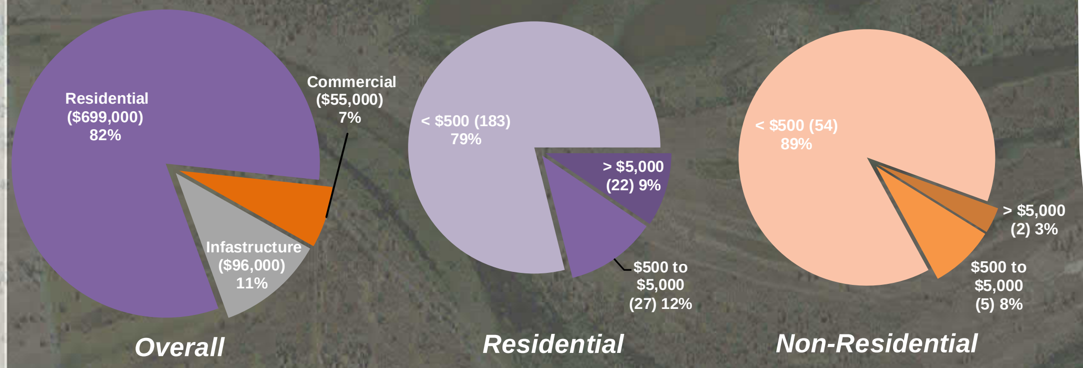
Average Annual Damage (AAD) is a measure of the average tangible flood damages experienced each year, and is calculated as the area under the Probability Damages Curve. Therefore, accurate estimates of AAD require consideration of flood events ranging from the smallest flood that causes damage, up to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



The calculated AAD for the Wandal and West Rockhampton catchment is estimated to range from approximately $850,000 to $860,000 per annum. The difference of 1% provides a very narrow range for the estimated AAD.

The majority (82%) of AAD is attributed to residential buildings. Commercial buildings make up 7% of the damages with the remaining 11% attributed to Infrastructure. 79% of residential and 89% of non-residential properties experience < $500 of AAD.

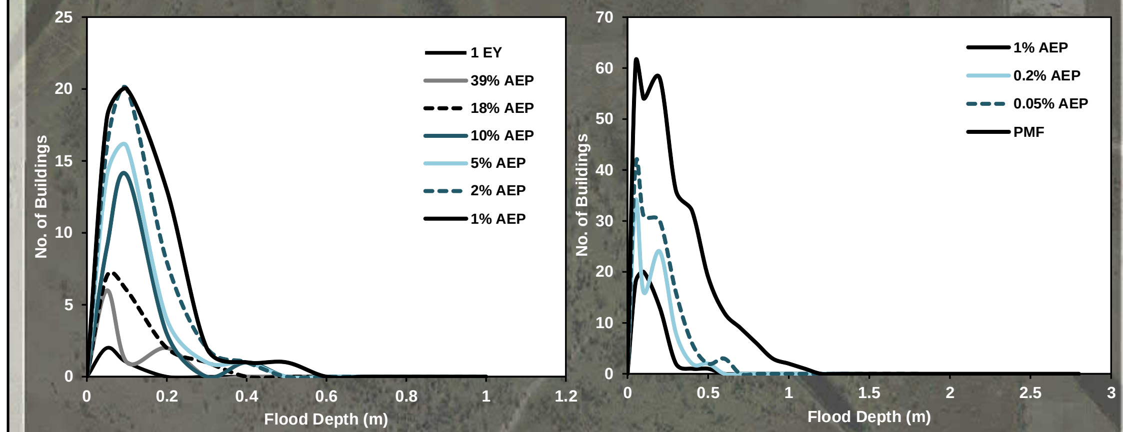
As a result, 58% of the total AAD is associated with only 5% of all buildings, revealing that a minority of buildings are responsible for the majority of damages.



Depth of Inundation

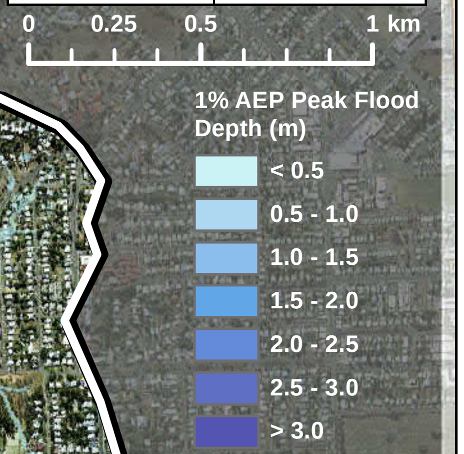
Median flood depths are generally less than 0.3 metres for each flood event. This indicates that reductions in flood depths of 0.3 metres could significantly reduce overall damage. The figures also show that a significant number of buildings experience flood depths of 0.1 metre or less during frequent events such as the 1EY flood event, generally corresponding to higher flood damages.

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



Legend

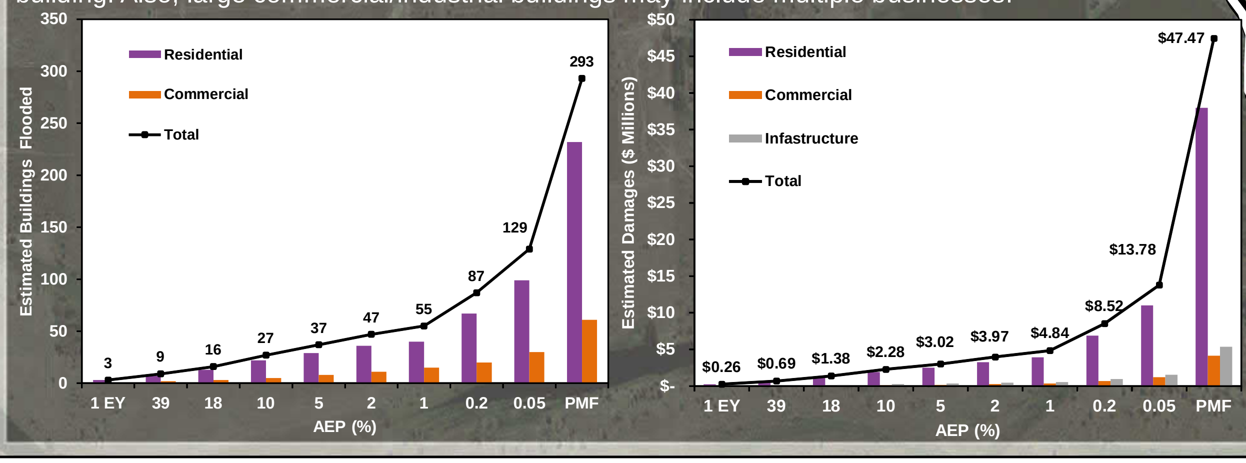
Annual Exceedance Probability (AEP) %	Average Recurrence Interval (ARI) Years
63 (1 EY)	1
39	2
18	5
10	10
5	20
2	50
1	100
0.2	500
0.05	2000



Flood Damages

The figures below provide a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Wandal and West Rockhampton catchment. Note that the indicated number of buildings is for entire buildings.

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



11.0 Recommendations

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

- Baseline flood mapping (i.e. peak depths, velocities and water surface elevations) provided in this study should be used to update Council's current Planning Scheme layers, at the next available opportunity.
  - Final post-processing of the GIS flood layers is recommended in accordance with the procedures outlined in the ARR, Data Management and Policy Review (AECOM, 2017).
  - Appropriate freeboard provisions should be included, based on the findings of the sensitivity analyses outlined in this study.
- 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 Wandal and West Rockhampton catchment to supplement the existing building database. An updated FDA should be undertaken when additional building survey data has been obtained.
- It is recommended that Council continue to record rainfall and flood heights associated with future Wandal and West Rockhampton catchment flood events. This data will support ongoing model calibration / validation works that should be undertaken in future updates to this study. The implementation of additional gauges identified in this study is also recommended.
- The baseline vulnerability and flood hazard assessment outputs from this report should be used to support a future Phase 3 of the Study (Flood Mitigation Options Development and Assessment).

12.0 References

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

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

TUFLOW 2016 Manual

Maritime Safety Queensland (2014) QLD Tide Tables book.

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

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

Appendix A

Hydraulic Model Development

Appendix A Hydraulic Model Development

Model Setup Parameters

The time step for the 2D model domain has been set to 1.5 seconds. The corresponding 1D time step has been set at 0.20 seconds to allow for suitable courant number in a steep, concrete channel digitized in the 1D domain.

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

One-Dimensional Network Development

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

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

A 1D channel was digitized between stormwater network openings downstream of Pennycuick Street to ensure the downstream pipe captured a logical proportion of the flow before overtopping the channel. 1D channels were also implemented in the confined sections of the Peterson Street flow path. This channel captured the surveyed cross-sections and variable roughness throughout the channel, however was not able to be stabilised for all design events. As such, the channel was digitized in the 2D domain with a high detail of roughness delineation. The invert levels of the channel were also stamped in to ensure conveyance was captured. Review of the results between the 1D and 2D channels revealed minor differences in peak flood heights and similar breakout locations.

Model Topography

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

- Overland flow path at Eton Street.
- Lion Creek channel.
- Knutsford Street / Peterson Street channel.
- Pennycuick Street concrete channel
- Ann Street units
- RACQ Capricorn Helicopter Rescue Service extension

Due to limitations surrounding large-scale hydraulic modelling, the adopted grid cell size (3 m) may not always adopt the peak crest level of roads. Given the hydraulic significance of road crests regarding urban catchment flow paths, heights were extracted from the 1 m LiDAR DEM at 1.5 m intervals (half the grid cell size) using centreline alignments provided by RRC. These point elevations were read into the model after the 1 m DEM in order to enforce the road crowns along all surfaces not previously surveyed. In a similar fashion, open channel inverts throughout the catchment were extracted and applied to the model to ensure open channels reflected the actual conveyance appropriately.

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 35.

Table 35 Adopted Roughness Values

Material Description	Manning's 'n'			
	Depth 1 (m)	Manning's 'n' 1	Depth 2 (m)	Manning's 'n' 2
Open Space / Medium Grass / Open Channels	0.1	0.040	0.3	0.030
Buildings	0.1	0.018	0.3	0.500
High Density Residential / Heavy Industrial	0.1	0.070	0.3	0.150
Medium Density Residential	0.1	0.060	0.3	0.120
Sparse Commercial / Hardstands	0.1	0.020	0.3	0.040
Low Density Residential	0.1	0.050	0.3	0.090
Riparian Corridor - watercourses	0.1	0.070	0.5	0.050
Light Vegetation	0.1	0.060	0.3	0.045
Medium Vegetation	0.1	0.075	0.3	0.050
Heavy Vegetation	0.1	0.090	0.3	0.060
Bodies of water - lagoons	0.030			
Road Reserve	0.025			
Airport Runway / Rough or irregular concrete	0.020			
Meandering Channels with some vegetation, rubble and rocks	0.1	0.050	0.3	0.040

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

During the calibration process if events contained a pre-burst rainfall (March 2017) that was excluded from the simulation the initial losses applied were reduced to 0 mm. This simulates the catchment being saturated by the pre-burst rainfall. Continuing losses were not adjusted. This initial loss of 0mm was also applied to the PMF event, as it is conservative to consider the catchment saturated.

The initial losses and continuing losses applied to this model are indicated below in Table 36.

Table 36 Adopted Initial and Continuing Loss Values

Material Description	Initial Loss (mm)	Continuing Loss (mm/h)
Open Space / Medium Grass / Open Channels	15	1.0
Buildings	0	0
High Density Residential / Heavy Industrial	7.5	0.5
Medium Density Residential	7.5	0.5
Sparse Commercial / Hardstands	7.5	0.5
Low Density Residential	7.5	0.5
Riparian Corridor - watercourses	0	0
Light Vegetation	15	1.0
Medium Vegetation	15	1.0
Heavy Vegetation	15	1.0
Bodies of water - lagoons	0	0
Road Reserve	0	0
Airport Runway / Rough or irregular concrete	0	0
Meandering Channels with some vegetation, rubble and rocks	15	1.0

Initial Conditions

Initial water levels were applied to the 1D pipe network and 2D domain. The MHWS water level of 2.66 mAHD was specified for the model area downstream of the barrage and a static storage level of 3.65 mAHD upstream of the barrage 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 events and tailwater sensitivities 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 Wandal and West Rockhampton 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 downstream of the barrage.

A summary of the boundary conditions applied to the three models are summarised in Table 37.

Table 37 Summary of Boundary Conditions

Boundary Type	Details
Direct rainfall	Applied across entire 2D domain
QT	Inflows for the external catchment of Lion Creek (west)
HT	· Barrage peak storage level (eastern boundary) · Fitzroy River outflow boundary (eastern boundary) · Lion Creek / Neerkol Creek / PMF lagoon storage levels (northern, western and southern boundaries)
HQ	· 6 outflow boundaries applied along the eastern model boundary

Appendix B

Tangible Flood Damages Assessment Methodology

Appendix B Tangible Flood Damages Assessment Methodology

1.0 Introduction

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

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

2.0 Estimating Flood Damages

2.1 Overview

Flooding can result in significant financial and social impacts on a community. A breakdown of the various types of flood damages is displayed in Figure 52. 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.

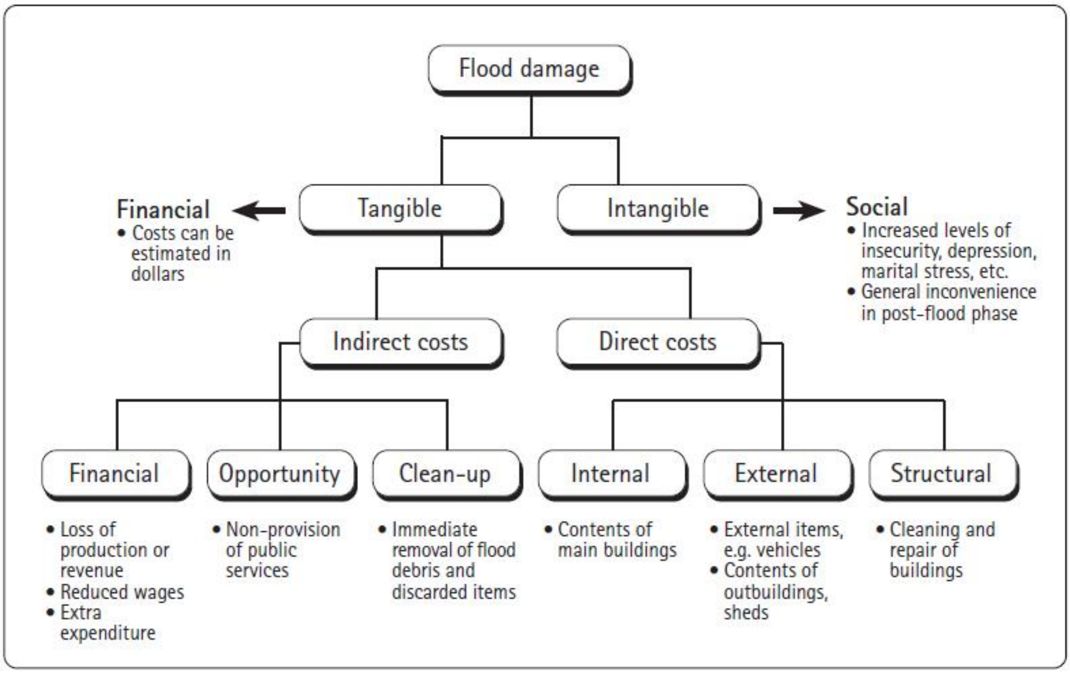


Figure 52 Breakdown of flood damage categories (source: DNRM, 2002)

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 38 to Table 40. Individual curves are given for external, contents and structural damages. Figure 53 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 45), 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 38 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 39 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 40 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 Queensland er ($200m^2$)	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

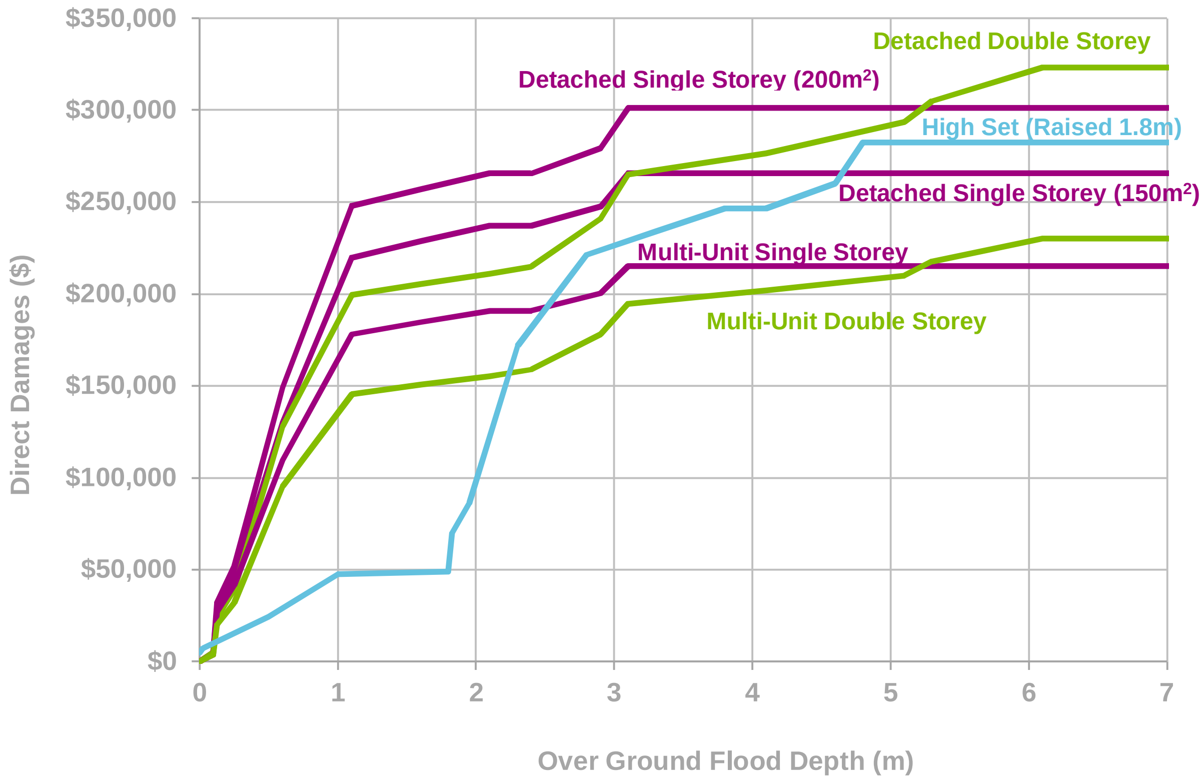


Figure 53 Total residential stage-damage curves based on O2 Environmental curves (March 2017 $)

WRM Stage Damage Curves

Direct residential damages were estimated using the WRM (2006a) stage-damage curves presented in Table 41 to Table 43. 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 54 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 41 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 42 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 43 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

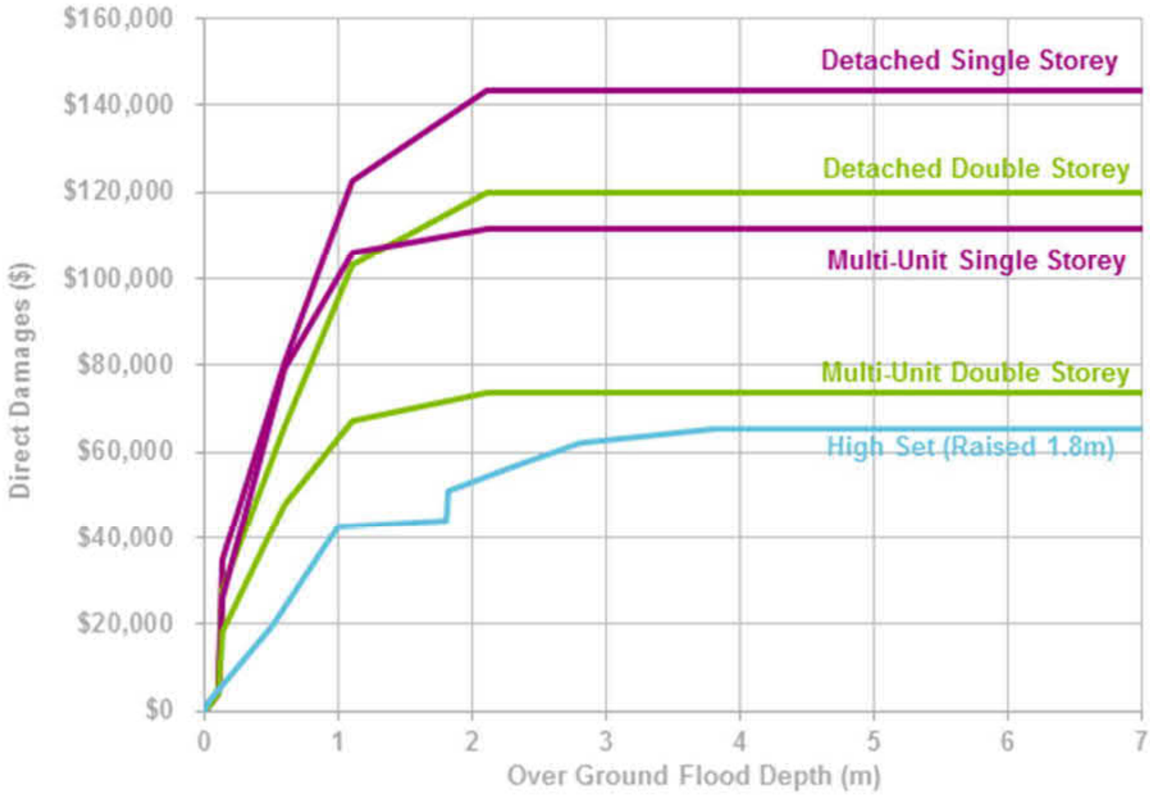


Figure 54 Total residential stage-damage curves based on WRM curves (March 2017 $)

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 44 and Figure 55. 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 44 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.

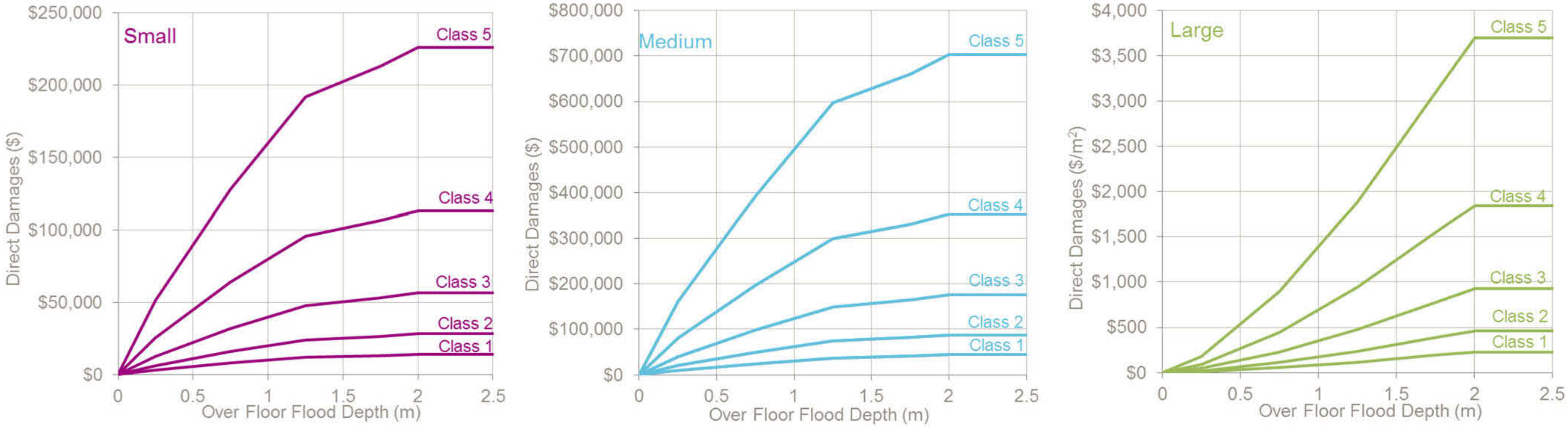


Figure 55 ANUFLOOD Stage-Damage curves for commercial properties (March 2017 $)

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 45 presents an overview of the CPI adjustments.

Table 45 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 56.

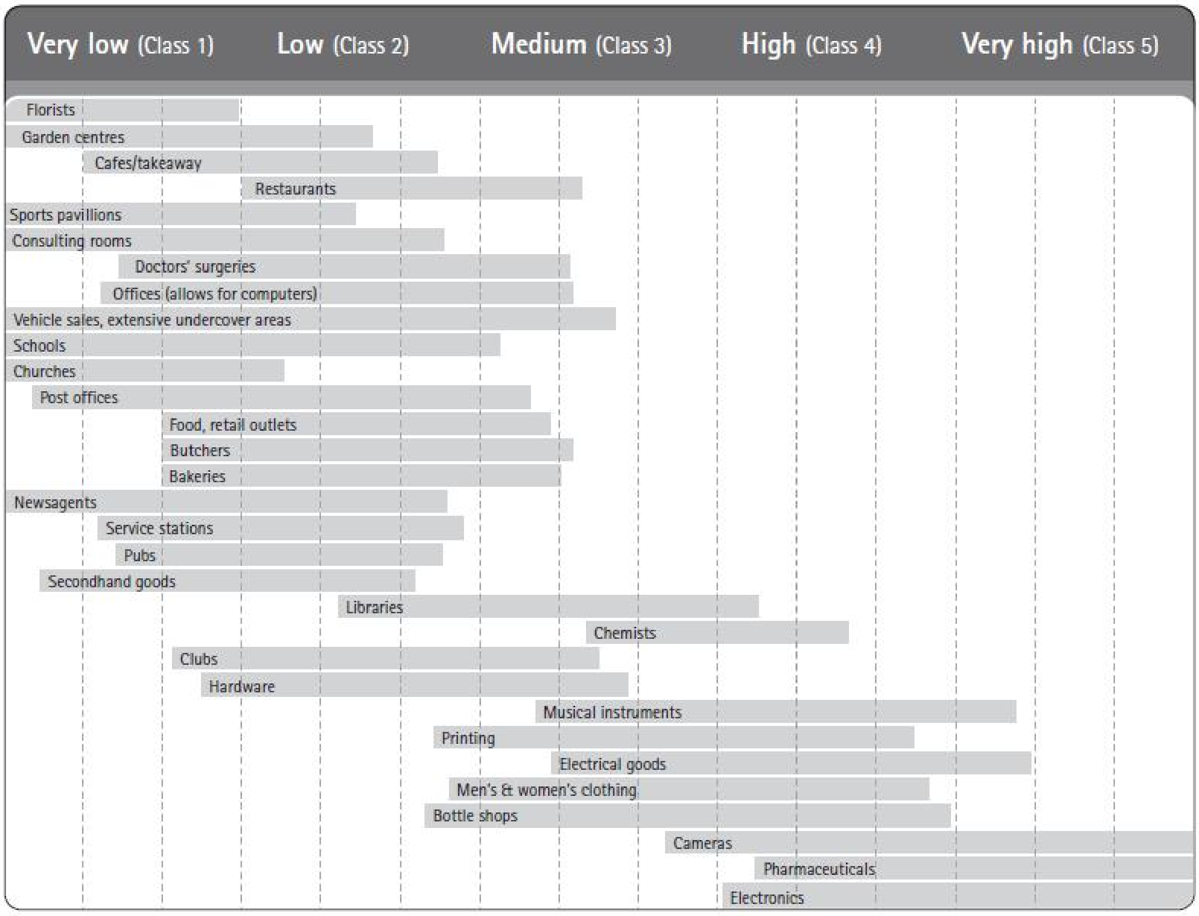


Figure 56 ANUFLOOD commercial damage value classes (source: DNRM, 2002)

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 46 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 46 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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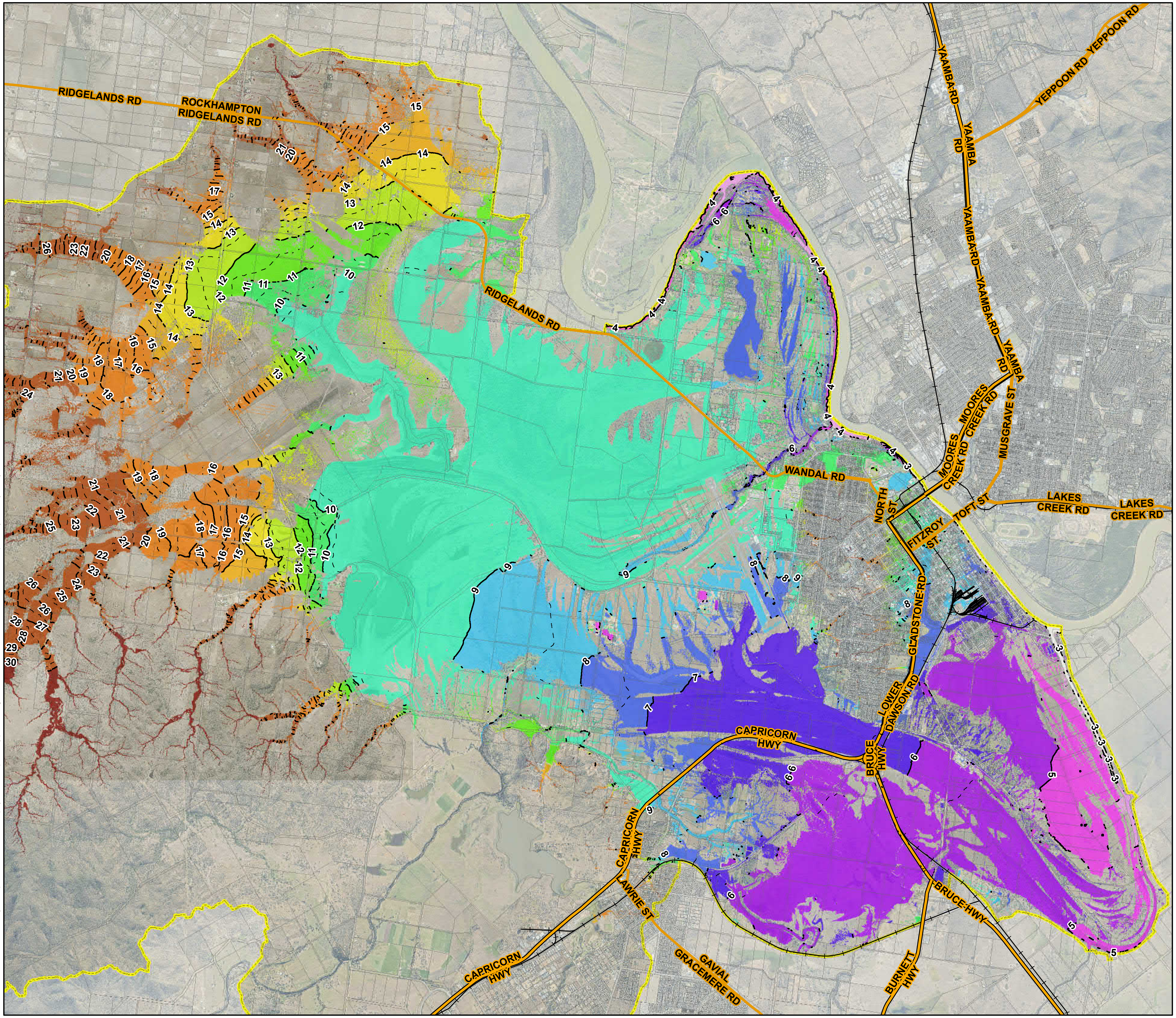
Appendix C

External Catchment 1% AEP PWSE Maps



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

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Kilometers

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AECOM
www.aecom.com

LEGEND

- 0.5m Contour
- 1m Contour
- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Peak Flood Height (mAHD)

- < 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
- 14 - 15
- 15 - 20
- 20 - 30
- > 30

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

Wandal & West Rockhampton Model
Peak Flood Height

Lion Creek Catchment
1% AEP 1440min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/02/2018
VERSION:	1

Figure
57

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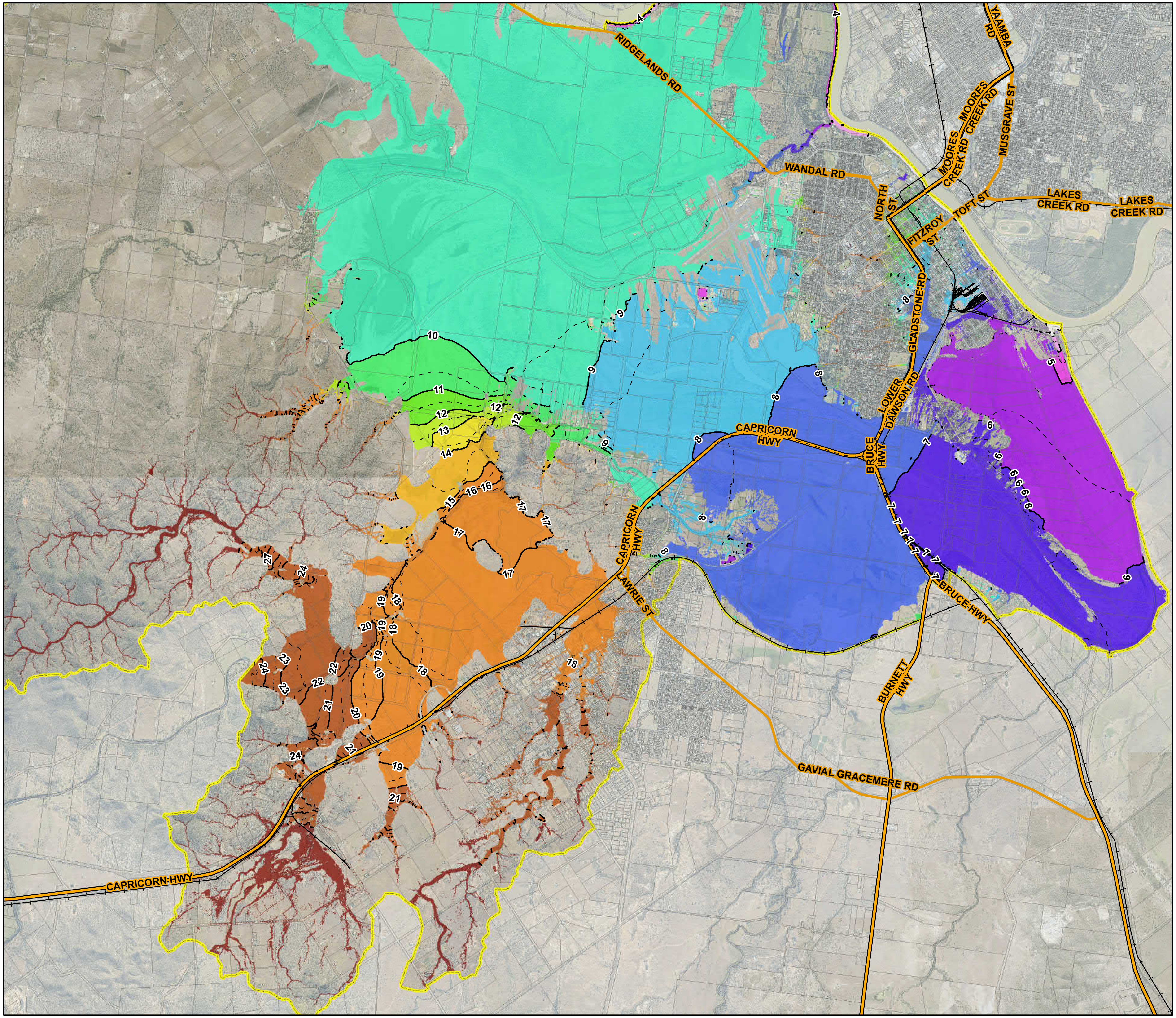

Rockhampton Regional Council

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DATUM GDA 1994, PROJECTION MGA ZONE 56

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Kilometers

1:65,000
(when printed at A3)

AECOM
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LEGEND

- 0.5m Contour
- 1m Contour
- Highways
- Main Roads
- Railway Lines
- Cadastre
- Hydraulic Model Extent

Peak Flood Height (mAHD)

- < 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
- 14 - 15
- 15 - 20
- 20 - 30
- > 30

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

Wandal & West Rockhampton Model
Peak Flood Height

Neerkol Creek Catchment
1% AEP 2160min Storm Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	8/02/2018
VERSION:	1

Figure 58

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