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Mt Morgan Local Catchment Study

Baseline Flooding and Hazard Assessment - Volume 1

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Glossary / Abbreviations

1D	One-Dimensional
2D	Two-Dimensional
AECOM	AECOM Australia Pty Ltd
AEP	Annual Exceedance Probability (refer to Notes on Flood Frequency in Section 1.5)
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
DEM	Digital Elevation Model
DFE	Defined Flood Event
DNRM	Queensland Department of Natural Resources and Mines
ESTRY	1D component of TUFLOW
EY	Exceedances per Year
GIS	Geographical Information Systems
GSDM	Generalised Short Duration Method
IFD	Intensity Frequency Duration
LiDAR	Light Detecting and Ranging
Max:Max	Maximum flood levels across a range of storm durations within the model extent
MHWS	Mean High Water Springs
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PWSE	Peak Water Surface Elevation
RCP	Reinforced Concrete Pipe
RCBC	Reinforced Concrete Box Culvert
RRC	Rockhampton Regional Council
TUFLOW	1D / 2D hydraulic modelling software

Executive Summary

Background

In December 2016, Rockhampton Regional Council (RRC) engaged AECOM Australia Pty Ltd (AECOM) to undertake the Floodplain Management Services (FMS) program for the 2017/18 calendar years. The FMS program entails the completion of a number of individual floodplain management projects including the Mount Morgan Local Catchment Study, which is the subject of this report.

Flooding in Mount Morgan can occur as a result of two different flood mechanisms:

- Riverine flooding due to rainfall over the Dee River and Mount Morgan No. 7 Dam catchment.
- Flash flooding due to rainfall over the local catchment.

This study focuses on flash flooding due to rainfall over the local urban catchment, including flooding of the Horse Creek and Dairy Creek catchments.

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.

Catchment Characteristics

The Mount Morgan catchment covers approximately 82.3 km^2 within the suburbs of Moongan, Leydens Hill, Baree and Mount Morgan which also encompasses Mount Morgan No.7 Dam and Mount Morgan Mine.

The northern catchment boundary follows Pinnacle Mountain Range along Poison-Creek Road and Moongan-Bouldercombe Road through Moongan and continues along Creek Street through Baree to the rural catchment of Mount Morgan. The eastern boundary runs along the Dee Range, further east, the Burnett Highway runs through Leydens Hill to the rural catchment of Mount Morgan. After this, the catchment roughly follows the Burnett Highway to the Southern boundary through the urban town centre of Mount Morgan. Further south-east, Mount Morgan No. 7 Dam discharges into the Dee River extending south-west through the urban catchment. At this point, the western boundary extends to the eastern side of the Mount Morgan Mine and Pinnacle Mountain Range.

The western and northern-eastern catchment boundaries contain mountainous ranges with forest vegetation and well defined, overland flow paths. Closer to the centre of the catchment within the urban area, the slope is relatively flat and, in most instances, runoff is discharged via urban drainage infrastructure (predominantly open channels and sub-surface drainage networks). Ultimately the runoff from the urban portion of the catchment is directed to the nearest watercourse, being the Dee River.

Runoff travelling from the Northern boundary (Pinnacle Mountain Range) accumulates and flows south into Dairy Creek from the rural area of the catchment into the urban area. Runoff travelling from the Eastern boundary (Dee Range) accumulates in the Dee River and Mount Morgan No. 7 Dam flowing from the rural area of the catchment into the urban area. Dairy Creek then flows into the Dee River with the flow path traversing through the urban town centre of Mount Morgan and exiting the catchment at the Southern boundary.

Major urban flow paths run into the Dee River from both the northern and southern directions within the urban catchment. Flow from James Street and Byrnes Parade flows from North to South entering the Dee River. Flow from Central Street, East Street and Black Street flows from South to North entering the Dee River. A major concrete lined channel contributes to this flow, directing runoff from Pattison Street to Dee Esplanade, parallel with Central Street.

Hydrologic / Hydraulic Analysis

The Mt Morgan Phase 1 Local Catchment Study included the development of a TUFLOW model for the urban and rural Mt Morgan 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 with anecdotal evidence serving a key role in developing confidence in the model performance through validation to the local flood events caused by Ex-TC Oswald in January 2013, TC Marcia in February 2015 and Ex-TC Debbie in March 2017.

On completion of the validation, various design events and durations were run and results extracted. The critical duration for the catchment shows that for a 1% AEP event, the majority of steep flow paths across the catchment have a 60min critical duration. The primary channel of Dairy Creek has a 180min critical duration. Horse Creek has a 180min critical duration upstream of the Burnett Highway which transitions to a 720min duration further downstream. Similarly, the Dee River has a 720min critical duration.

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 Mt Morgan catchment. This included:

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

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

Flood Hazard

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

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

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

Figure E1 shows the adopted hazard categories along with a general description of the risk associated with each category.

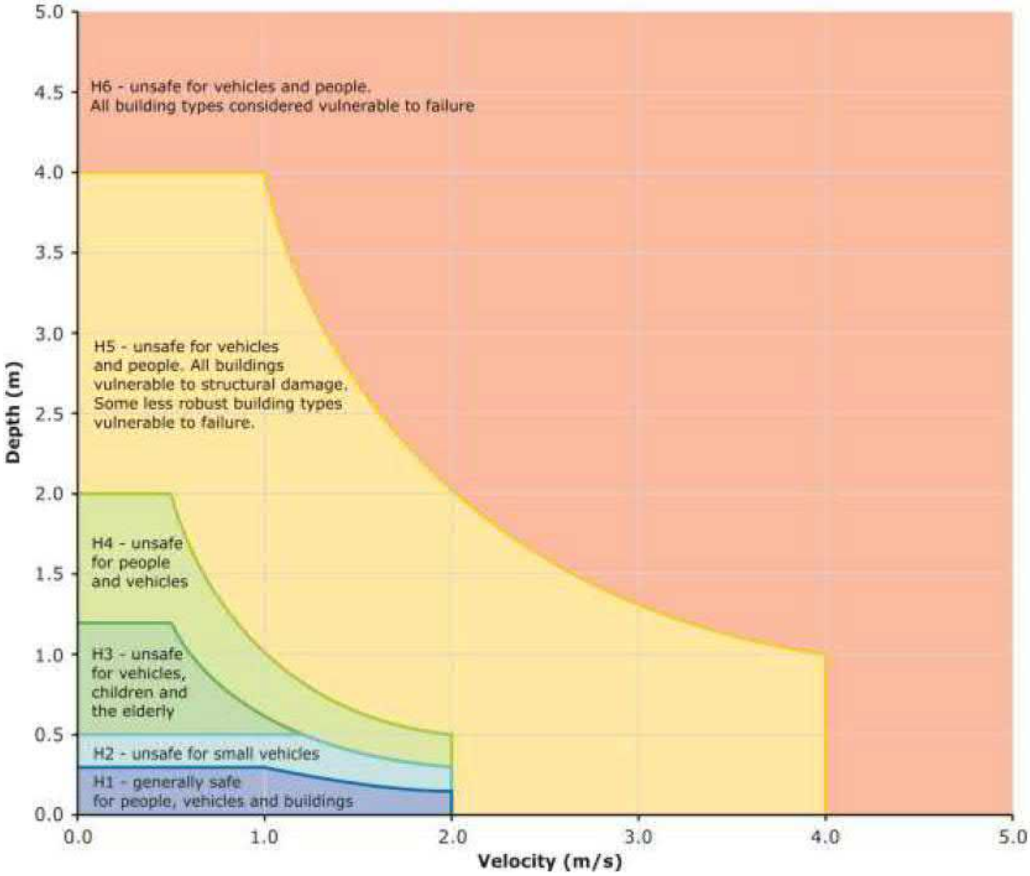

Figure E1 Hazard Vulnerability Classifications (Graphical)

Analysis of the 1% AEP baseline flood hazard within the Mt Morgan catchment generally shows:

- Low to medium hazard (H1 and H2) across the majority of ill-defined urban flow paths.
- Moderate to extreme hazard (H3 and H5) across the majority of steep gullies.
- Extreme hazard (H5 or H6) within steep, concrete-lined urban flow paths.
- Extreme hazard (H5 or H6) within the Dairy Creek, Horse Creek and Dee River channels.

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 Dee River (No. 4) sewerage pump station in James Street is predicted to be inundated by up to 0.29m in the 0.2% AEP 60min event. It is important to note that this is not the critical duration for the Dee River; longer duration storms are likely to result in higher peak flood depths and inundation frequency at this site. All other water and sewerage infrastructure have the desired 0.2% AEP flood immunity. It is recommended this information be passed onto FRW as the asset owner.

- Flood inundation is not predicted at any community infrastructure or emergency facilities.
- A number of roads are predicted to experience inundation in the 1EY event and larger. Predicted TOS generally ranges from 0.4 to 9.0 hours, with low immunity crossings across the Dee River (Piddichs Crossing, Racecourse Road and Randwick Road) predicted to be inundated between 5.6 and 9.0 hours in a 1% AEP 60min event.

Evacuation Routes

This assessment relates to isolated areas as a result of local catchment flood events and should be read in conjunction with the Mt Morgan Water Supply No 7 Dam Emergency Action Plan (FRW, 2018). Generally local catchment flooding within the Mount Morgan local catchment is due to short duration, high intensity rainfall events. The relatively steep flowpaths and urbanisation throughout catchment can result in inundation of key roads as well as residential and commercial buildings.

Due to the short critical duration of the Mount Morgan local 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:

- Horse Creek Lane, Burnett Lane and Showgrounds Road → loses evacuation to Burnett Highway during to high stage Horse Creek flood levels.
- Black Street and Campion Street → loses evacuation via Hall Street and Gordon Street to East Street.
- Baree Road and Gordon Lane → loses evacuation via Gordon Lane to James Street.
- Creek Street → loses evacuation to Creek Street (Razorback Road) due to high stage Dairy Creek flood levels.

Building Impact Assessment

Council provided a building database, containing over 2,000 buildings digitised within the modelled area.

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, Council undertook the following tasks:

- 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 surveyed information.
- Classification of buildings within the modelled area, in accordance with ANUFLOOD requirements:
  - Buildings were divided into residential and commercial based on a combination of attribute fields, depending on what fields contained data for each building.
  - Commercial buildings were assigned a size class based on floor area – small/medium/large.
  - Commercial building classifications were assigned 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.

Table E2 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Mt Morgan 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	0 (0)	0 (0)
39	2 (0)	0 (0)
18	4 (2)	1 (1)
10	7 (2)	1 (1)
5	14 (5)	1 (1)
2	17 (6)	3 (2)
1	19 (7)	3 (2)
0.2	48 (21)	7 (6)
0.05	77 (37)	8 (6)
PMF	255 (179)	36 (32)

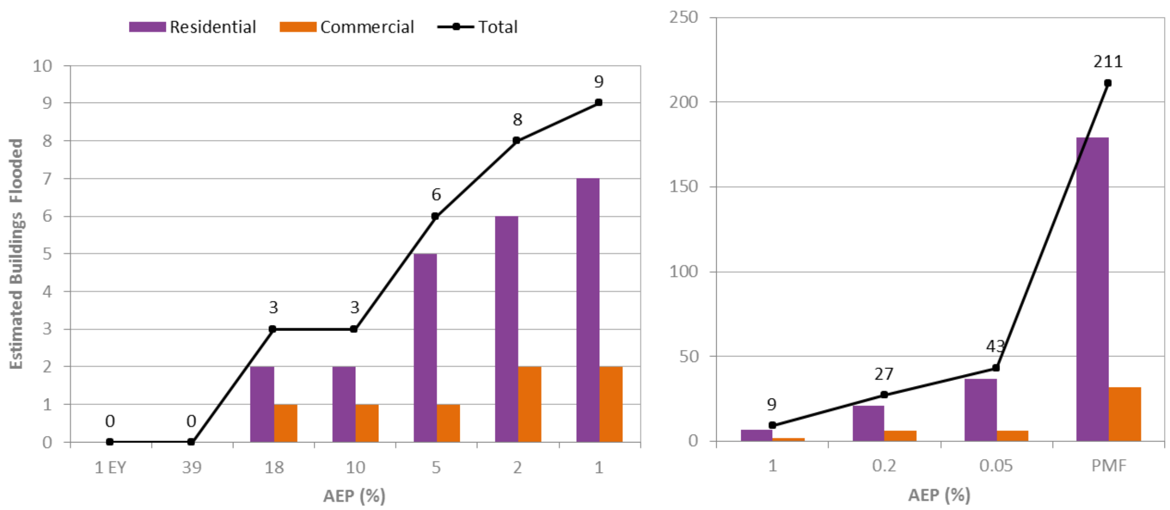

Figure E2 Estimated Buildings with Above Floor Flooding (Number of Buildings)

Figure E3 provides a breakdown of the number of buildings inundated in ‘creek’ and ‘overland flow’ areas. The graph confirms that the majority of buildings within the catchment (90%) are not inundated up to and including the PMF event. Of the 10% of buildings predicted to experience inundation, approximately 23% are impacted by overland flow and 77% are impacted by creek inundation.

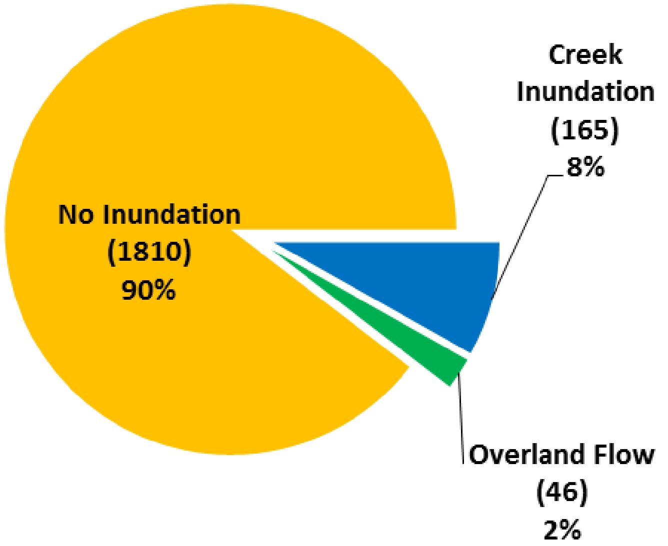

Figure E3 Inundation within Creek and Overland Flow Areas (Number of Buildings)

As shown in Figure E4, median flood depths are generally less than 0.3m for each flood event. This indicates that reductions in flood depths of 0.3m could significantly reduce overall damage. The figure also shows that a pockets of impacted buildings experience flood depths of 0.1m or less during more frequent events.

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

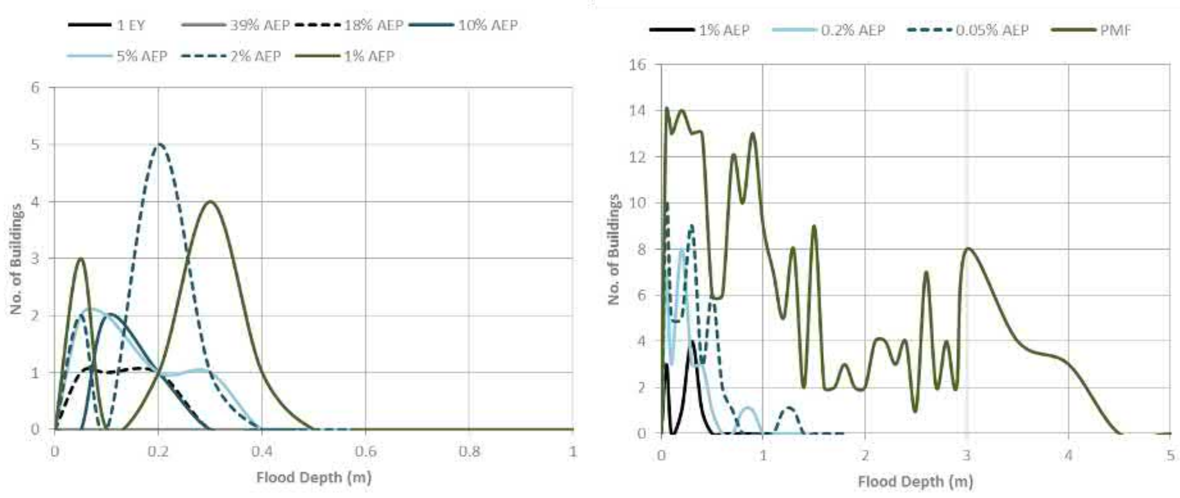

Figure E4 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

Flood Damages Assessment

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

Figure E5 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from no damage (1EY flood event) to $54M (PMF event). Figure E4 confirms that no buildings are expected to be inundated above floor in the 1EY event, whilst 211 buildings are anticipated to be inundated above floor in the PMF event.

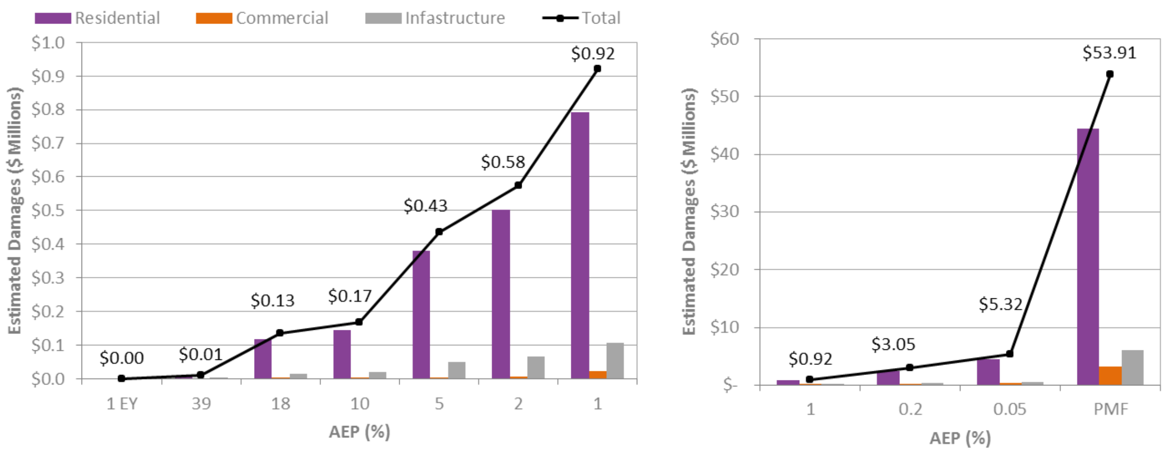

Figure E5 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

These figures also demonstrate that residential buildings make up the large majority of impacted buildings, and consequently estimated flood damages, within the Mount Morgan 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 Mount Morgan catchment is estimated to range from approximately $95,000 to $103,000 per annum.

Figure E6 provides a breakdown of the AAD and building impact assessment. The area in blue corresponds to individual building AAD (residential and non-residential combined) in brackets of $100 per annum. The orange line corresponds to the cumulative AAD for residential and non-residential buildings combined. Note that this does not include infrastructure damages.

As shown, 92% of all buildings exhibit less than $500 damage per annum and produce only 6% of the total damage.

79% of damages are associated with ten buildings. This demonstrates that a minority of buildings produce the majority of damages.

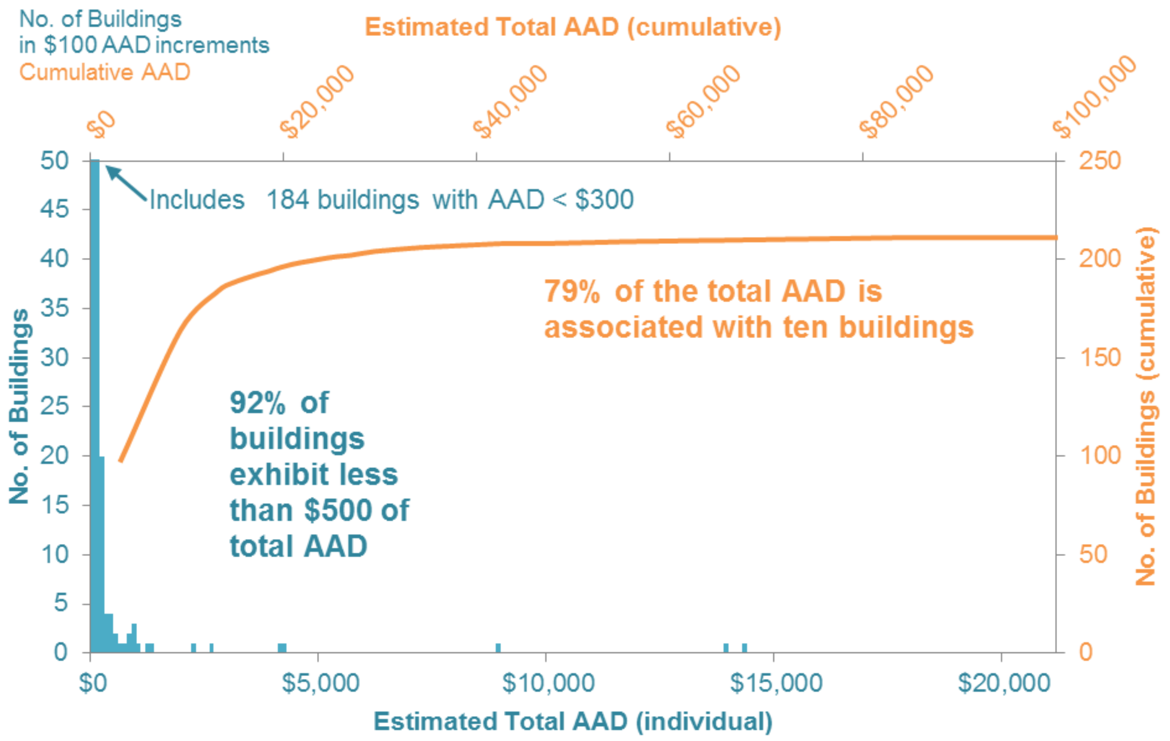

Figure E6 Individual Building vs. Cumulative Total Average Annual Damages

Rainfall Gauge, Maximum Flood Height Gauge and Flood Warning Network

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

- A suitable rainfall gauge is maintained by DNRM within the upper catchment of the Dee River. Active rainfall gauges track rainfall patterns within the Mount Morgan Township at Black Street WTP. As such, it is recommended that the pluviograph station continues to record detailed rainfall data for future events.
- A single flood height gauge is recommended for inclusion within the East Street / Campion Street concrete channel near Morgan Street to develop confidence in urban impacts within the area.

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 AR&R, 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 AR&R 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 record rainfall and flood heights associated with Mount Morgan 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 an additional gauge identified in this study is also recommended.
- Channel cross sectional survey should be undertaken after major flood events in order to assess long term geomorphic changes, and potential implications to flood behaviour.
- The results of this study should be communicated to the dam owner which will allow for a better understanding of potential flood risks and reassessment of the need for an updated failure impact assessment.
- 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 2017/18 calendar years. The FMS program entails the completion of a number of individual floodplain management projects including the Mount Morgan Local Catchment Study, which is the subject of this report.

Flooding in Mount Morgan can occur as a result of two different flood mechanisms:

- Riverine flooding due to rainfall over the Dee River and Mount Morgan No. 7 Dam catchment.
- Flash flooding due to rainfall over the local catchment.

This study focuses on flash flooding due to rainfall over the local urban catchment, including flooding of the Horse Creek and Dairy Creek catchments.

1.2 Phased Approach

The Mount Morgan Local Catchment Study has been split into two distinct phases, as outlined below.

Phase 1 - Baseline Flood Model Development → Phase 2 - Baseline Flood Hazard and Risk Assessment

Phases 1 and 2 involved the development of validated 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 Mount Morgan Local Catchment Study – Baseline Flooding and Hazard Assessment Report has been separated into 2 volumes:

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

The structure of this Volume 1 report is as follows:

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

1.5 Notes on Flood Frequency

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

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

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

1.6 Limitations and Exclusions

The following limitations apply to this study:

- With the exception of the 1% AEP design flood event, all design flood events were assessed for a single critical duration, based on an analysis of multiple storm durations for the 1% AEP event.
  - GIS mapping for the 1% AEP design flood event was prepared using a 'Max:Max' analysis of multiple storm durations, whereas all other design flood events were mapped for only the critical storm duration.
- Aerial survey data (in the form of LiDAR) used to develop the topography for the hydraulic model has a vertical accuracy of $\pm$ 0.15 m on clear, hard surfaces and a horizontal accuracy of $\pm$ 0.45 m.
- Where information gaps existed in the underground drainage network, assumptions were made to fill these gaps using desktop assessment methods.
- Assessment of the probability of coincident local rainfall and Dee River flood events has not been undertaken.
- The hydraulic model has undergone validation to a three historical events. It is recommended that as more data becomes available the model is formally calibrated.
- 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 AR&R, Data Management and Policy Review (AECOM, 2017) for details surrounding changes recommended in the 2016 revision.
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AR&R Revision Project 15 outlines several fundamental themes which are also particularly relevant:

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

2.0 Study Area Characteristics

2.1 General Description

The Mount Morgan catchment covers approximately 82.3 km^2 within the suburbs of Moongan, Leydens Hill, Baree and Mount Morgan which also encompasses Mount Morgan No.7 Dam and Mount Morgan Mine.

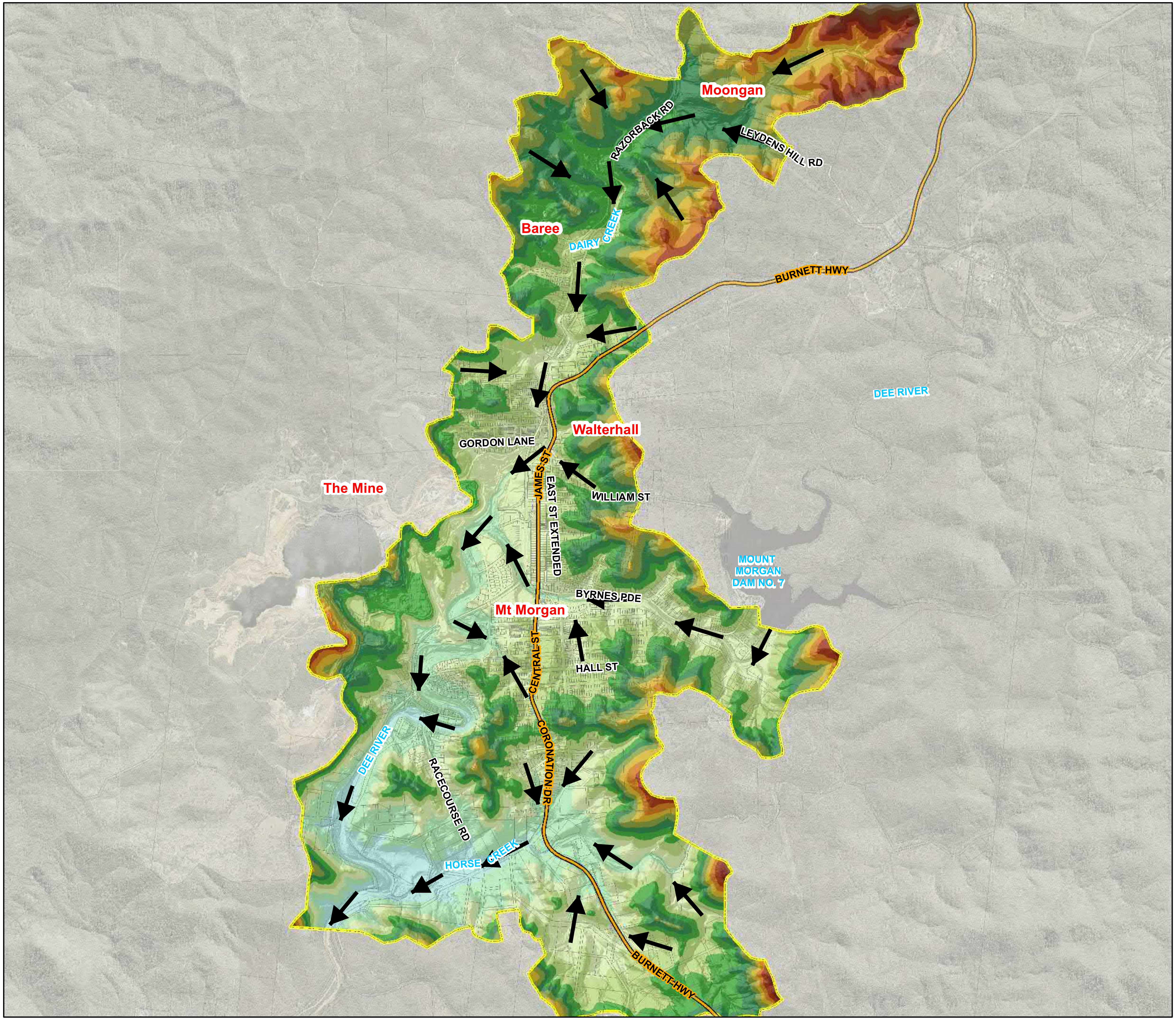
The northern catchment boundary follows Pinnacle Mountain Range along Poison-Creek Road and Moongan-Bouldercombe Road through Moongan and continues along Creek Street through Baree to the rural catchment of Mount Morgan. The eastern boundary runs along the Dee Range, further east, the Burnett Highway runs through Leydens Hill to the rural catchment of Mount Morgan. After this, the catchment roughly follows the Burnett Highway to the Southern boundary through the urban town centre of Mount Morgan. Further south-east, Mount Morgan No. 7 Dam discharges into the Dee River extending south-west through the urban catchment. At this point, the western boundary extends to the eastern side of the Mount Morgan Mine and Pinnacle Mountain Range.

The western and northern-eastern catchment boundaries contain mountainous ranges with forest vegetation and well defined, overland flow paths. Closer to the centre of the catchment within the urban area, the slope is relatively flat and, in most instances, runoff is discharged via urban drainage infrastructure (predominantly open channels and sub-surface drainage networks). Ultimately the runoff from the urban portion of the catchment is directed to the nearest watercourse, being the Dee River.

Runoff travelling from the Northern boundary (Pinnacle Mountain Range) accumulates and flows south into Dairy Creek from the rural area of the catchment into the urban area. Runoff travelling from the Eastern boundary (Dee Range) accumulates in the Dee River and Mount Morgan No. 7 Dam flowing from the rural area of the catchment into the urban area. Dairy Creek then flows into the Dee River with the flow path traversing through the urban town centre of Mount Morgan and exiting the catchment at the Southern boundary.

Major urban flow paths run into the Dee River from both the northern and southern directions within the urban catchment. Flow from James Street and Byrnes Parade flows from North to South entering the Dee River. Flow from Central Street, East Street and Black Street flows from South to North entering the Dee River. A major concrete lined channel contributes to this flow, directing runoff from Pattison Street to Dee Esplanade, parallel with Central Street.

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



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LEGEND

- Natural Flow Lines
- Highways
- Cadastre
- Hydraulic Model Extent

Topography (mAHD)

- <210
- 210 - 225
- 225 - 240
- 240 - 255
- 255 - 270
- 270 - 285
- 285 - 300
- 300 - 315
- 315 - 330
- 330 - 345
- 345 - 360
- 360 - 375
- 375 - 390
- 390. - 405
- 405 - 420
- 420 - 435
- 435 - 450
- 450 - 465

Data Sources:

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

Mount Morgan Model

Sub Catchment Delineation and Natural Flow Paths

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2018
VERSION:	1

Figure 1

2.2 Climate Characteristics

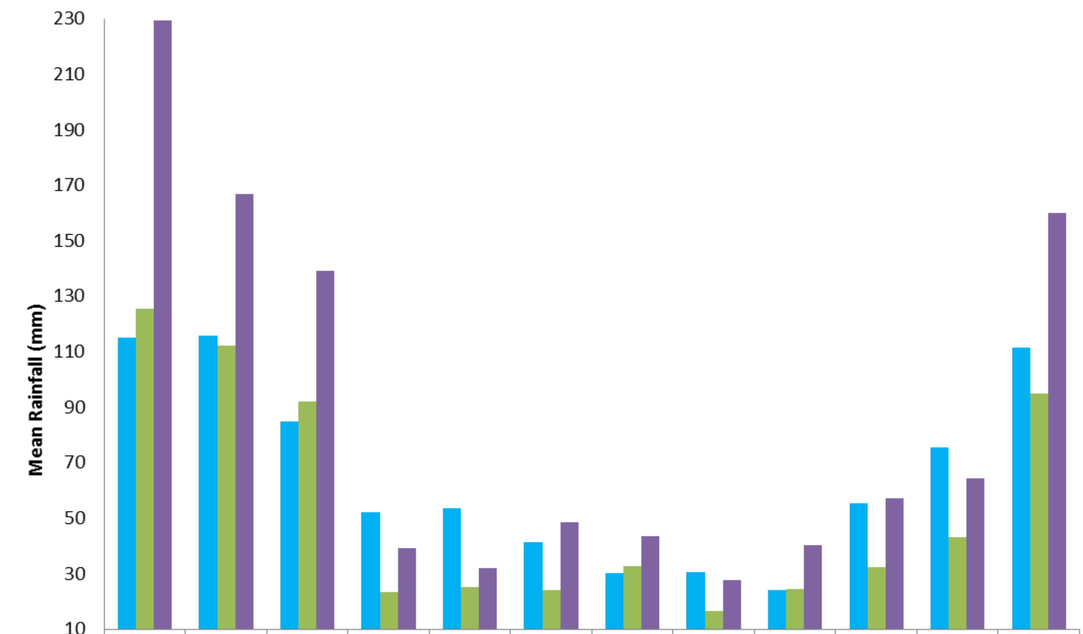
The Mount Morgan local catchment is centred on latitude 23º 38' 21.76" south and longitude 150º 24' 33.70" east. The catchment centroid is about 52km west of the Pacific Ocean at Port Alma and, as a result, the catchment experiences a humid subtropical climate. The climate is dominated by summer rainfalls with falls likely from severe thunderstorms and occasionally from tropical cyclones. Heavy rainfall is most likely to occur between the months of December to March.

2.3 Rainfall Characteristics

Daily rainfall data is available for Moonmera rainfall station through the BoM website (www.bom.gov.au) (Moonmera – Site Number 039067) and the Water Monitoring Information Portal (https://water-monitoring.information.qld.gov.au/) for the No.7 Dam and Upper Dee.

Moonmera (directly north of the Mount Morgan Catchment) has a mean annual rainfall of approximately 790mm, with the No.7 Dam gauge reporting similar annual depths of 650mm. The Upper Dee gauge reports significantly higher average rainfall totals at 1,050mm; this is likely to be skewed by significant recent events within the 16 year period, but may also be attributed to unquantified orographic effects. The highest mean monthly rainfall generally occurs in January, with roughly two-thirds of annual rainfall falling between November and March. The highest and lowest annual rainfall recorded is 1660mm (in 1956) and 270mm (in 1957) respectively which shows a significant variation in annual rainfall, year on year. The highest monthly rainfall of 860mm was recorded in January 1918 with the next highest month being January 2013 as a result of 650mm rainfall from Ex-TC Oswald.

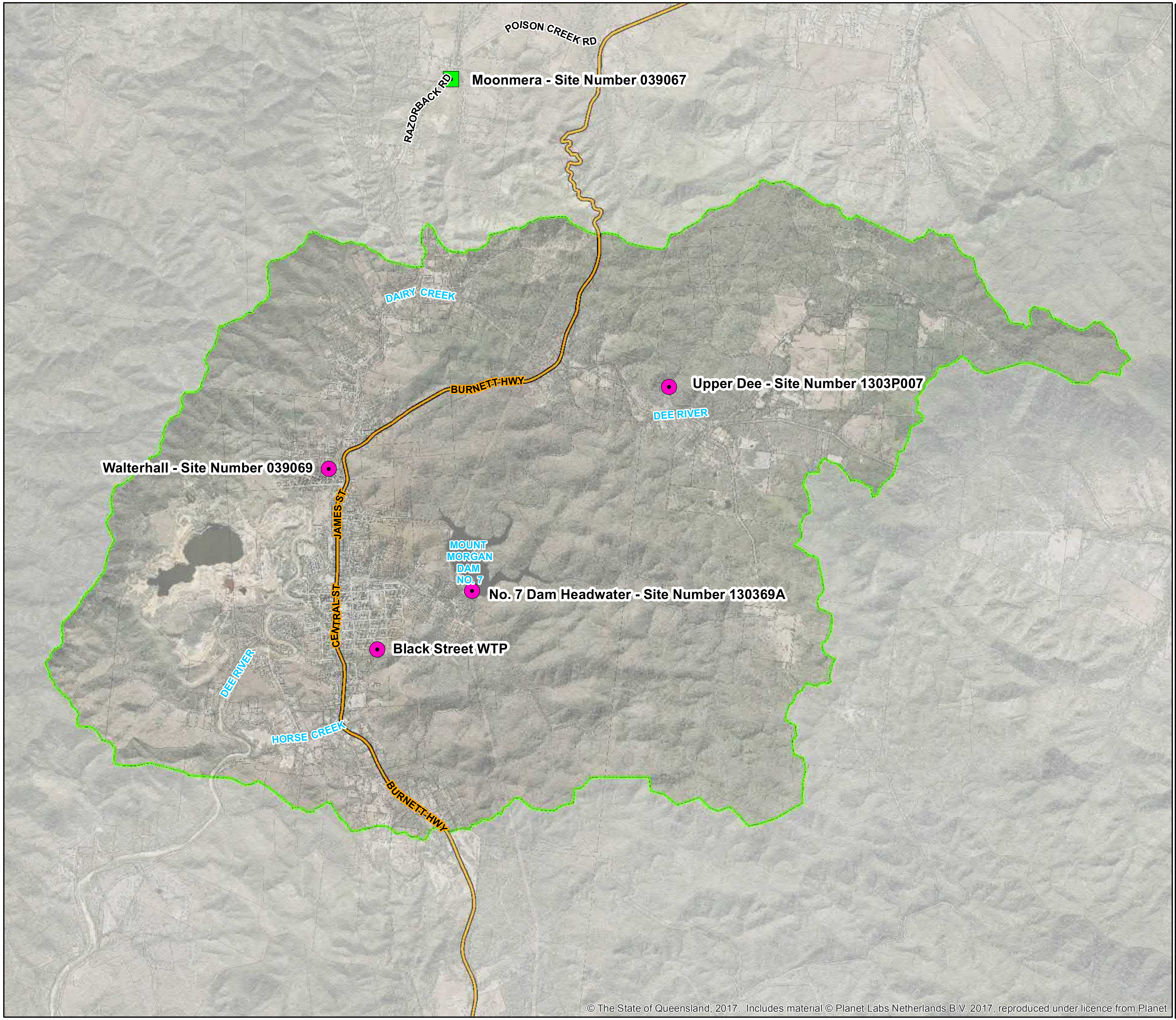
Figure 2 shows the distribution of the mean monthly rainfall depths for the period of 1972 – 2009 at the Moonmera, Dee at No 7 Dam and Upper Dee rainfall stations.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Moonmera	115	116	85	52	54	41	30	31	24	55	75	111
Dee at No 7 Dam	126	112	92	23	25	24	33	17	24	32	43	95
Upper Dee	230	167	139	39	32	49	43	28	40	57	64	160

Figure 2 Mean Monthly Rainfall at the Moonmera and Walterhall Rainfall Station

Analysis of historical rainfall records at key gauges across the catchment confirmed that the spatial variability of rainfall can vary significantly between locations. With this in mind, the compilation of historical rainfall records within the catchment will play an important role in future validation of the hydrodynamic model.



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LEGEND

- Daily Rainfall Station
- Pluviograph Station
- Highways
- Cadastre
- Hydraulic Model Extent (GPU)

Data Sources:

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

Mount Morgan Model

Rainfall Guage Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	1/11/2018
VERSION:	1

Figure 3

2.4 Historic Local Catchment Events

Similar to the Rockhampton local catchments, Mount Morgan has experienced overland flooding in recent years due to cyclonic activity and rapidly intensifying troughs. Significant recent events for which FRW, RRC and the public have provided anecdotal evidence of flood behaviour include Ex-TC Oswald (2013), TC Marcia (2015) and Ex-TC Debbie (2017) events.

This study included the simulation of 2013, 2015 and 2017 local catchment events, which served to validate model performance for the study.

2.5 River Flooding Influence

River flooding in the study area can result from rainfall over the rural, mountainous catchments of Dee River and Mount Morgan No.7 Dam east of the study area. Whilst dam outflows can (and have in historic events) reach high, sustained peaks; flood impacts along the lower Dee River are limited due to the highly modified state of the downstream channel. Though a potential deficit to the overall watercourse balance, long-term stripping, incision and widening of the primary channel has allowed for containment of high magnitude flood events along the majority of the river reach. Flood expansion is still evident across lower lying floodplains and gully lines, however these areas are generally undeveloped or used for community purposes.

To assess the impact of the Dee River on local catchment flood behaviours, dam outflows have been applied to design events. In addition, a range of dam outflow scenarios (including dam break) have been undertaken in order to assess the interaction between local catchment and riverine system flood behaviours. The results form a component of the discussion made in Section 8.0.

2.6 Flood Warning System

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

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 SunWater, 2009).
- 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 (DNRM).
- Historical flood records for the 2013, 2015 and 2017 flood events (RRC & FRW).
- No.7 Dam hydrology (SunWater).
- No.7 Dam wall hydraulic characteristics (SunWater).

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

3.2 Previous Studies

3.2.1 AR&R, Data Management and Policy Review (AECOM, 2017)

Completed by AECOM in March 2017 as part of the 2017 FMS project, the AR&R, 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 No. 7 Failure Impact Assessment (SunWater, 2009)

SunWater undertook a formal Failure Impact Assessment (FIA) for the Mount Morgan No. 7 Dam in August 2009. This assessment was carried out in accordance with the license conditions associated with the No. 7 Dam and was completed at the request of the Dam Safety Regulator.

With reference to the SunWater report, AECOM understand that the No.7 Dam is a "Category 2' referable dam under the Water Act 2000. The Guidelines for Failure Impact Assessment of Water Dams (DEWS, 2012) notes that updated FIA's are only required for 'Category 2' dams when operational works are proposed that will increase the capacity of the dam by more than 10%.

On this basis, we note that a formal FIA (in accordance with the Dam Safety Regulations) is not required for the No.7 Dam, and that an assessment of failure scenarios noted in this report is only to support an understanding of flood risk for the Mount Morgan Township.

Outputs from the SunWater URBS hydrologic model and MIKE 11 hydraulic model, developed as part of the 2009 FIA, have been used as inflows to the direct rainfall dynamically linked 1d/2d TUFLOW Hydraulic Model of the Mount Morgan urban area for coincident event and dam break scenarios. The stage-discharge curve for the dam spillway has also been utilised to transcribe stream gauge data (depth over spillway) to inflow hydrographs for historic events.

3.3 Topographic Data

The topographical information used for the Mount Morgan 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.

RRC surveyed cross sections and longitudinal invert levels for ten key urban flow paths where the LiDAR was expected to misrepresent the terrain or not provide sufficient detail. Within this dataset, cross-drainage structures such as culverts and bridges and the channel material type was also recorded, enabling accurate modelling of critical drainage channels.

3.4 Aerial Photography

Aerial photography of Mt Morgan 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.

3.5 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. In the rare instance that 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

Pit inlet dimensions were measured by RRC and used to inform the hydraulic components of the model. Inlet dimension sensitivities were not warranted for the Mount Morgan model as a result of the detailed surveyed data provided.

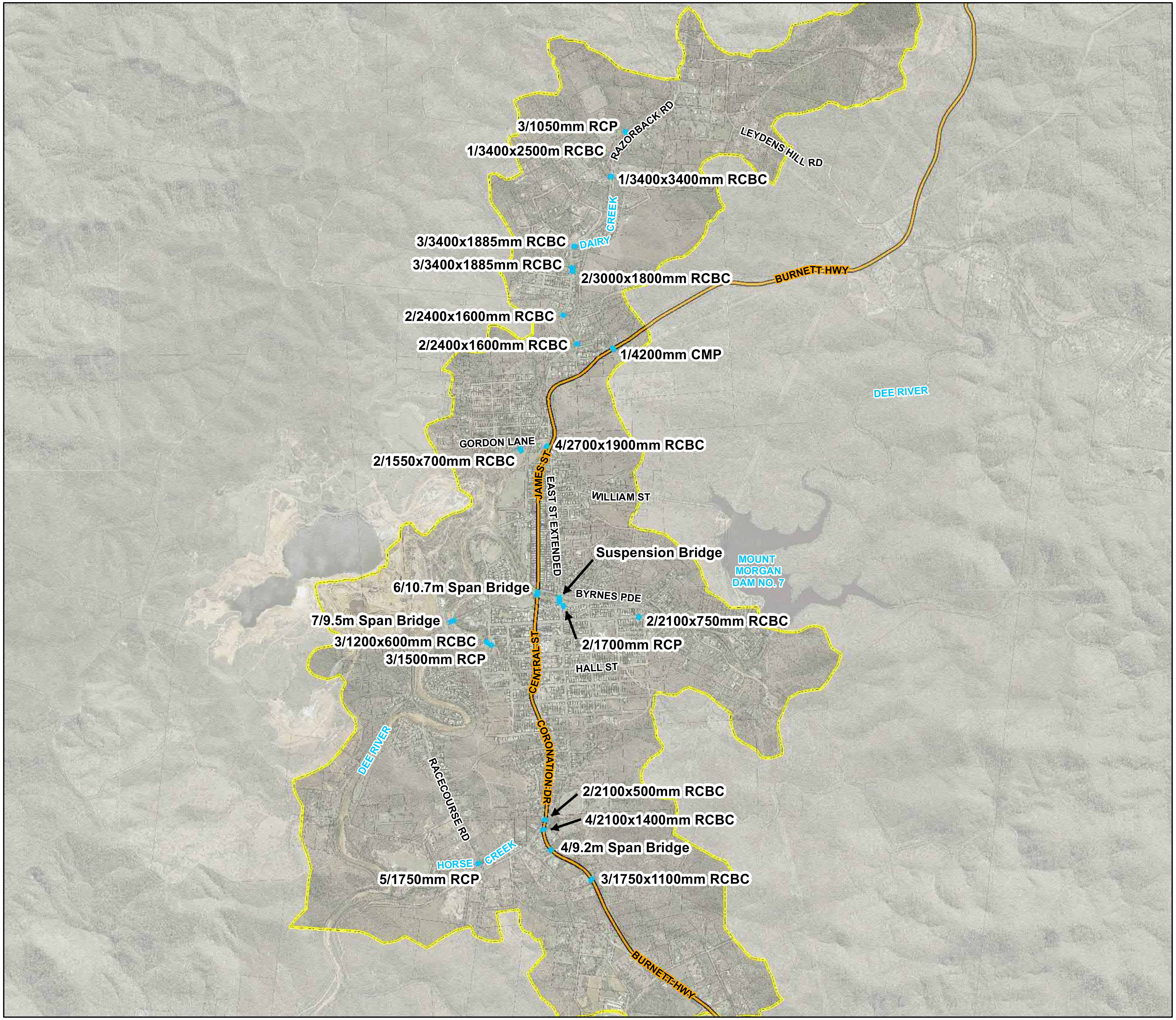
3.6 Hydraulic Structures

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 175 culverts and 4 bridge structures were identified within the hydraulic model extent. Although the majority of structures were digitized in the model, some minor structures (such as 225mm uPVC and subsoil pipes) 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		
Dee River Bridge	6/10.7m span bridge	2D
Dee River Pedestrian Bridge	80m suspension bridge	2D
Dee River Rail Bridge	7/9.5m span bridge	2D
Horse Creek Bridge	4/9.2m span bridge	2D
Major Culverts		
Racecourse Road	5/1750mm RCP	1D
Coronation Drive	2/2100x500mm RCBC	1D
Gordon Lane	4/2700x1900mm RCBC	1D
Coronation Drive	4/2100x1400mm RCBC	1D
Tipperary Road	3/1500mm RCP	1D
Mine Road	3/1200x600mm RCBC	1D
Dee Street	2/2100x750mm RCBC	1D
East Street	2/1700mm RCP	1D
Razorback Road	3/3400x1885mm RCBC	1D
Razorback Road	3/3400x1885mm RCBC	1D
Razorback Road	2/3000x1800mm RCBC	1D
Coronation Drive	3/1750x1100mm RCBC	1D
Razorback Road	2/2400x1600mm RCBC	1D
Razorback Road	2/2400x1600mm RCBC	1D
James Street	1/4200mm CMP	1D
Razorback Road	1/3400x2500m RCBC	1D
Razorback Road	1/3400x3400mm RCBC	1D
Razorback Road	3/1050mm RCP	1D
Gordon Lane	2/1550x700m RCBC	1D



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LEGEND

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

Data Sources:

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

Mount Morgan Model

Key Hydraulic Structures

PROJECT ID	60534898	Figure
CREATED BY	maultbyj	4
LAST MODIFIED	10/07/2018	
VERSION:	1	

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3.7 Historical Rainfall Data

Historical rainfall records for 2015 and 2017 events were acquired from BoM and DNRM's Water Monitoring Information Portal (WMIP) in the form of 1-minute intervals for the range of pluviograph stations shown in Figure 3. A list of rainfall gauging stations, their locations, type of data and applicable events is provided in Table 2, where:

- ✓ → reliable data;
- ⊘ → unreliable data; and
- ✗ → 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
039067	Moonmera	Daily	BoM	✓	✓	✓
1303P007	Upper Dee	1-Minute Intervals	DNRM	✓	✓	✓
130369A	Dee at No 7 Dam	1-Minute Intervals	DNRM	✓	✓	✓
-	Black St WTP	1-Minute Intervals	RRC	Not supplied.		

3.8 Historical Flood Records

Anecdotal flood level data has been collected from local residents by RRC and FRW for the 2013, 2015 and 2017 rain events. Generally speaking, observations included relative water depths, debris marks and photographs (pre-, at- and post-peak).

It is understood that the anecdotal data was collected by RRC using a Real Time Kinematic (RTK) satellite navigation device. The anecdotal evidence is summarised in Table 3. Photographs of flood behaviour from local residents have been included in Appendix C.

Table 3 Anecdotal Data

Location	Event	Description
Byrnes Parade	2013 Ex-TC Oswald	Significant erosion up to sealed pavement; erosion extents indicate peak flood extent and magnitude of velocities.
Bridge Street	2013 Ex-TC Oswald	Significant erosion at inner channel banks and sewer pump station; debris marks and saturation lines indicate peak flood extent and magnitude of velocities.
1 Gordon Lane	2015 TC Marcia	Advised water depth outside the property fence of about 2/3 at the colour bond fence; the fence consequently collapsed and flow occurred through the property; advised first two culvert barrels from 1 Gordon Lane were blocked to about 50% resulting in backing up of flow and overtopping of the road.
7 Gordon Lane	2015 TC Marcia	100mm of debris mark still visible underneath the house while debris mark was at 500mm high from surface level in the middle of this property.
89 Byrnes Parade	2015 TC Marcia	Level captured using RTK survey Easting (m) = 234,807 Northing (m) = 7,382,696 Height (mAHD) = 232.34 Data captured in March 2018.
2 Dee Esplanade	2015 TC Marcia	Water backed up approximately 400mm above the concrete drain. The owner has been living at the address over 40 years.
Piddichs Crossing	2017 Ex-TC Debbie	A photograph supplied.

3.9 No.7 Dam Gauge Data

Gauge data for the No. 7 Dam (headwater) was available via DNRM's WMIP for the period of 2002 to present day (16 years), which covers the historic events of 2013, 2015 and 2017 assessed within this study. Stream gauge data is relative to the zero gauge height of 231.599mAHD, which is 16.701m below the spillway crest level. Using this information, timeseries of depth above the spillway were generated for the 2013, 2015 and 2017 events and are presented in Figure 5.

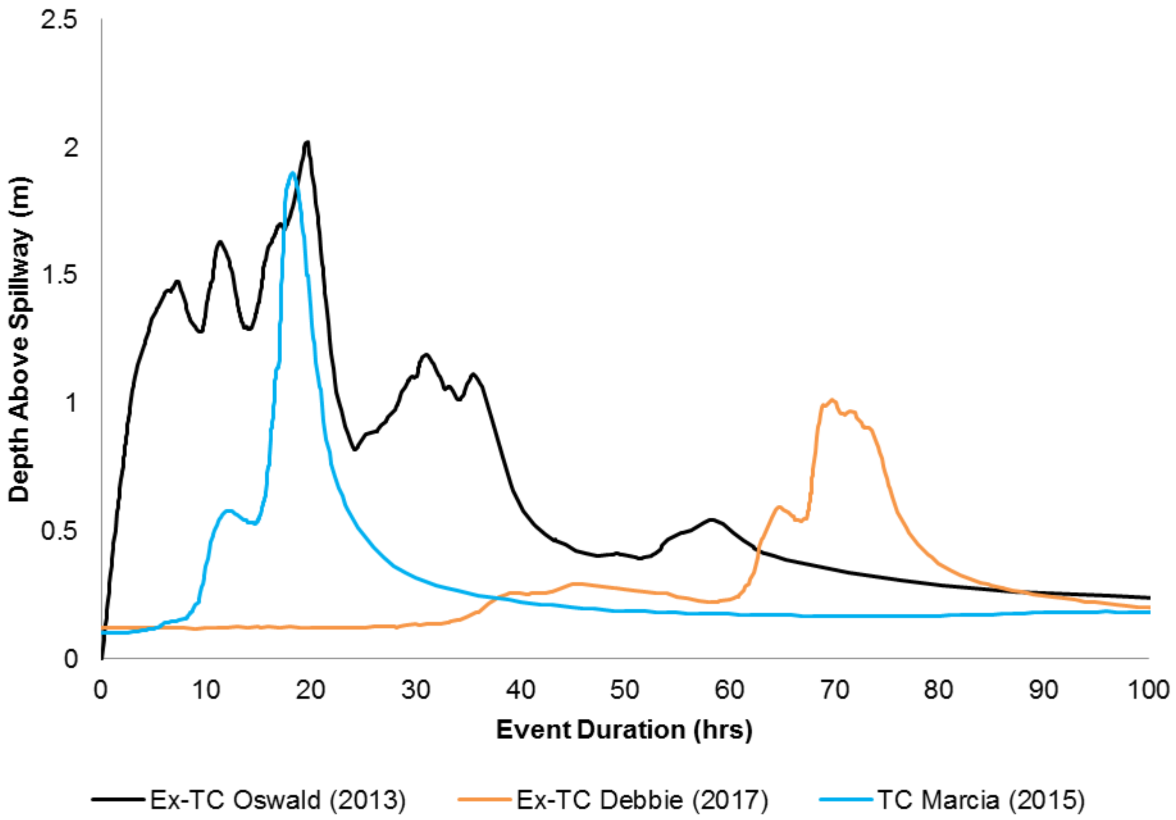


Figure 5 Historic Event Depth Above Spillway Hydrographs – No. 7 Dam (DNRM, 2018)

3.10 No.7 Dam Hydrology

A calibrated URBS hydrologic model and MIKE 11 hydraulic model was provided by SunWater to RRC for the purposes of this assessment. The URBS hydrologic model was used to inform the MIKE 11 hydraulic model which calculated discharge hydrographs from the dam following a range of dam failure/outflows scenarios. These scenarios included (peak discharges shown in brackets):

- Dam Crest Flood at Probable Maximum Flood (PMF), **no** failure of the embankment (peak flow of 1,425m^3/s); and
- Sunny Day Failure (SDF), **with** failure of the dam embankment (peak flow of 5,048m^3/s);
- Dam Crest Flood at PMF, **with** failure of the embankment (peak flow of 7,409m^3/s).

The inflow hydrograph extracted for each scenario are presented in Figure 6.

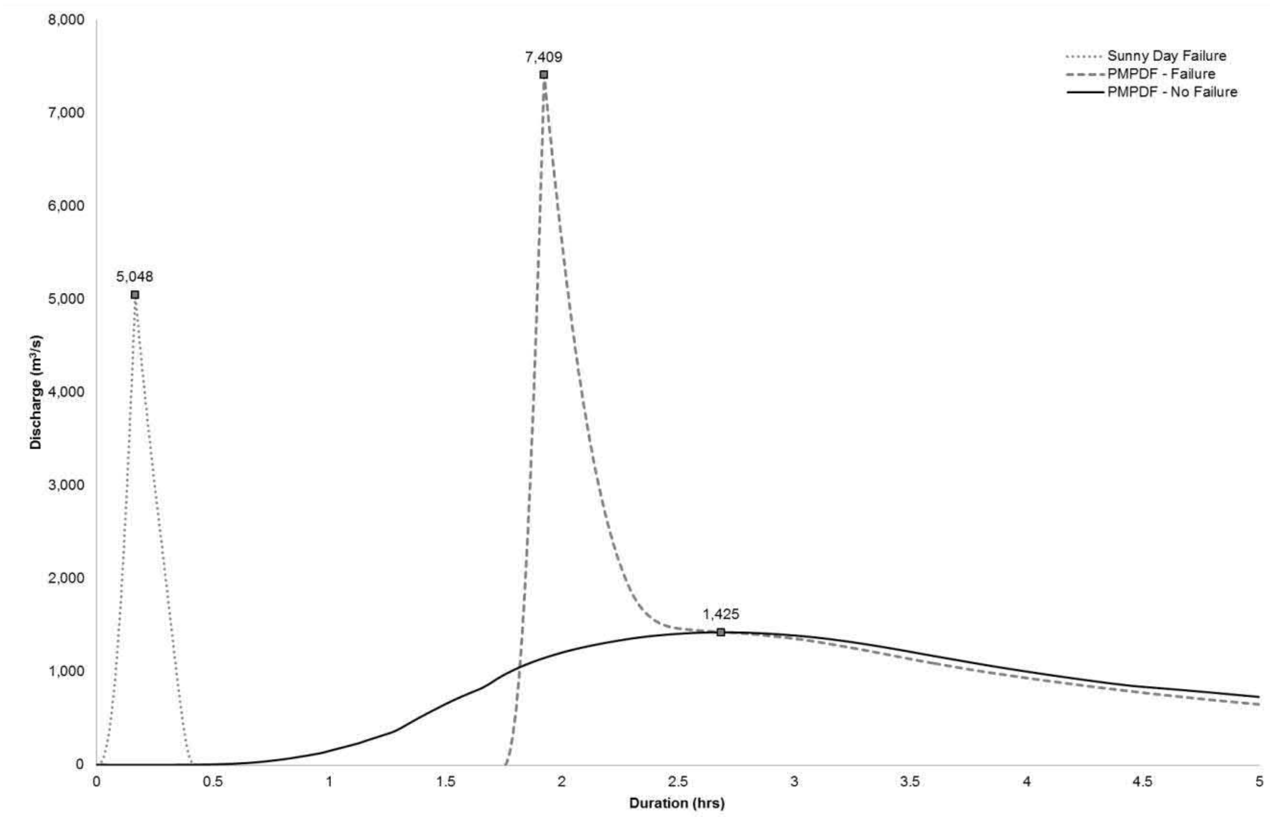


Figure 6 No. 7 Dam Inflow Scenario Hydrographs (SunWater, 2009)

3.11 No. 7 Dam Hydraulic Characteristics

In addition to the URBS and MIKE 11 models, detailed drawings of the current dam spillway arrangement were also provided by SunWater. The key information used within this study is presented in Figure 7 (RL's in mAHD).

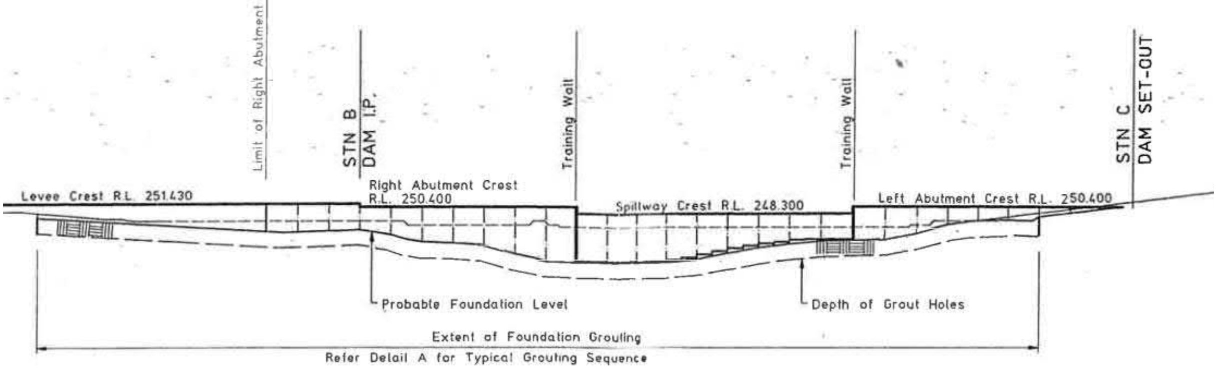


Figure 7 No. 7 Dam Spillway Section (SunWater, 2009)

The hydraulic performance of the spillway crest was determined using the stage-discharge relationship from the calibrated URBS hydrologic model. The curve is presented below in Figure 8 and was used to convert depth above spillway data to a dam outflow hydrograph (used as an inflow to the hydrodynamic model used in this study).

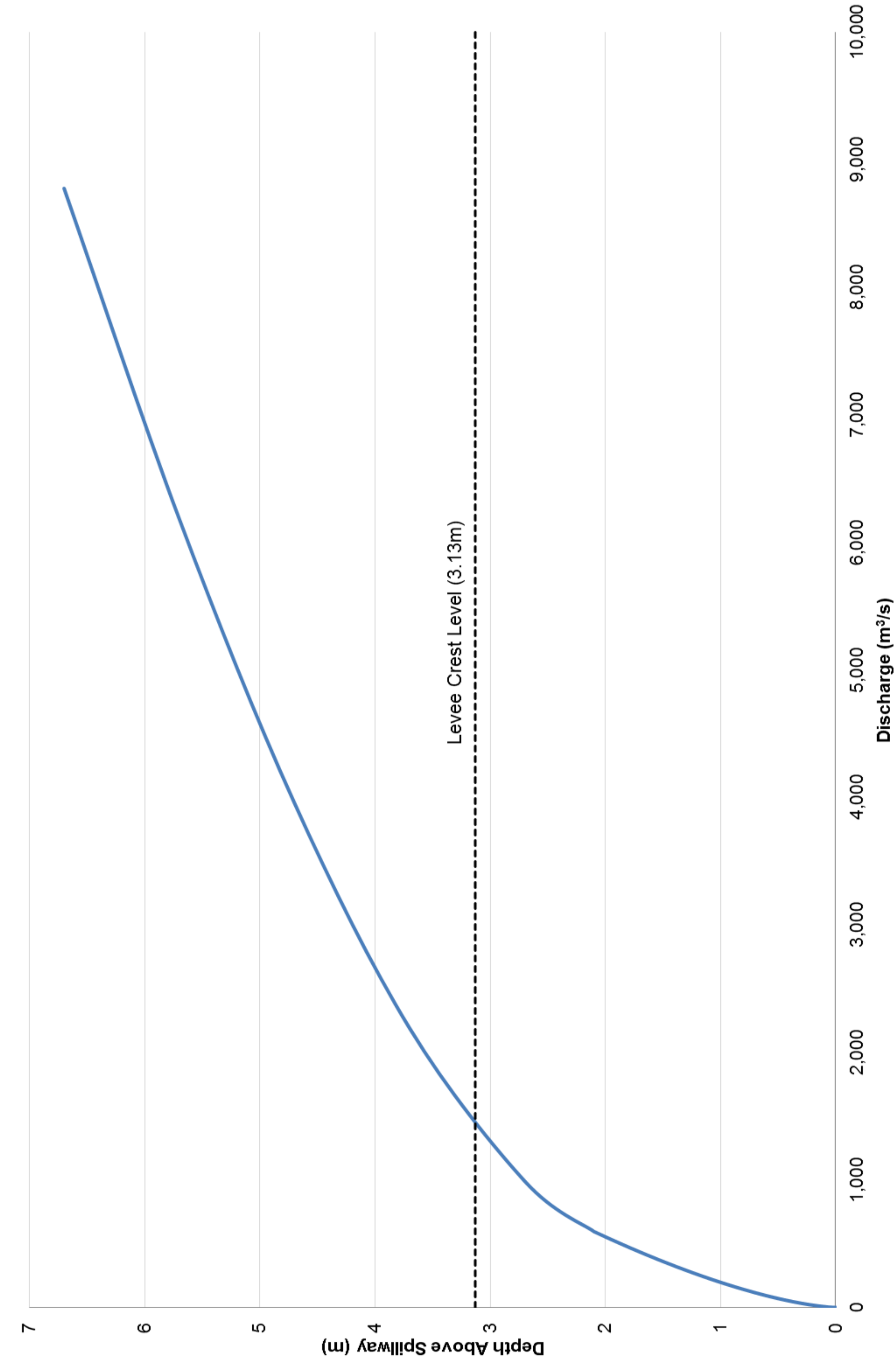


Figure 8 No. 7 Dam Spillway Stage-Discharge Curve (SunWater, 2009)

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 **Upper Dee River** catchment, a TUFLOW GPU model utilising the direct rainfall approach was developed in order to establish flow hydrographs and height-time series within these catchment. The model was designed to encapsulate the entirety of the detailed TUFLOW CPU, such that it could also be used to inform steep gully inflow hydrographs for Dairy Creek and Horse Creek. This approach allowed for optimal 2D stability and run times within the TUFLOW CPU model and reduced the simulation times.

In total, 28 flow paths (including the No. 7 Dam outflow) were estimated using the TUFLOW GPU model. Flood waters within each of these flow paths embodied high energy, allowing for a flow-time (QT) boundary to be used to apply inflows to the detailed model.

4.2 Historic Data

Historic records for the 2015 and 2017 events were obtained for the Upper Dee pluviograph station located within the study area. Records at DRNM-managed gauges were available for the 2015 and 2017 events.

4.2.1 2013 Event – Ex-TC Oswald

Tropical Cyclone Oswald passed over parts of Queensland and New South Wales at the end of January 2013, reducing in intensity to a tropical low system before reaching the Rockhampton region. Ex-TC Oswald resulted in significant precipitation over a number of days across Mount Morgan with total rainfall depths surpassing 650mm. The peak period of intensity saw 500mm of rainfall across the Upper Dee catchment in just 19 hours. The significant rainfall resulted in up to 561m^3/s overtopping the No. 7 Dam spillway (~2.0m above the spillway crest). The timeseries of rainfall data at the Upper Dee pluviograph station and inflow hydrograph at No. 7 Dam for the 2013 event is shown in Figure 9.

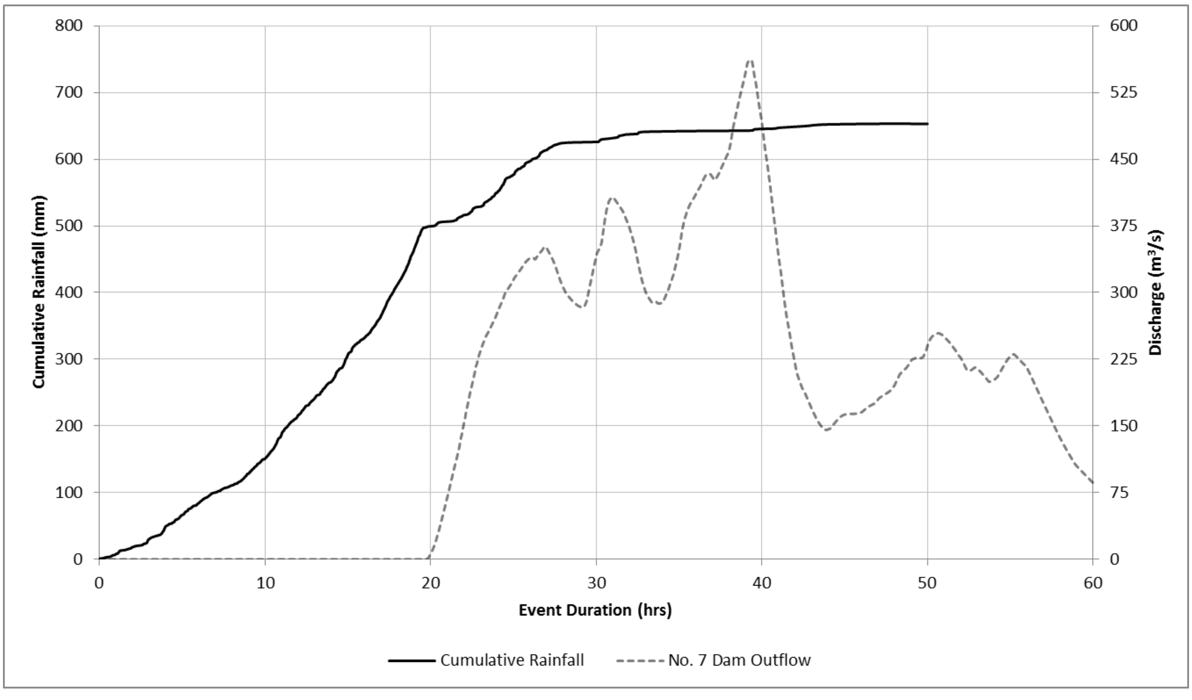


Figure 9 2013 Event Hydrologic Inputs

4.2.2 2015 Event – TC Marcia

Tropical Cyclone Marcia crossed the east coast of Queensland as a category 5 system on the 20th of February, 2015. The system weakened to a category 2 cyclone at Mount Morgan before delivering a total rainfall depth of 360.0 mm within the upper catchment, with the peak 20 hour period totalling 320.0 mm. The significant rainfall across the catchment resulted in up to 512m^3/s overtopping the No. 7 Dam spillway (~1.9m above the spillway crest). The timeseries of rainfall data at the Upper Dee pluviograph station and inflow hydrograph at No. 7 Dam for the 2015 event is shown in Figure 10.

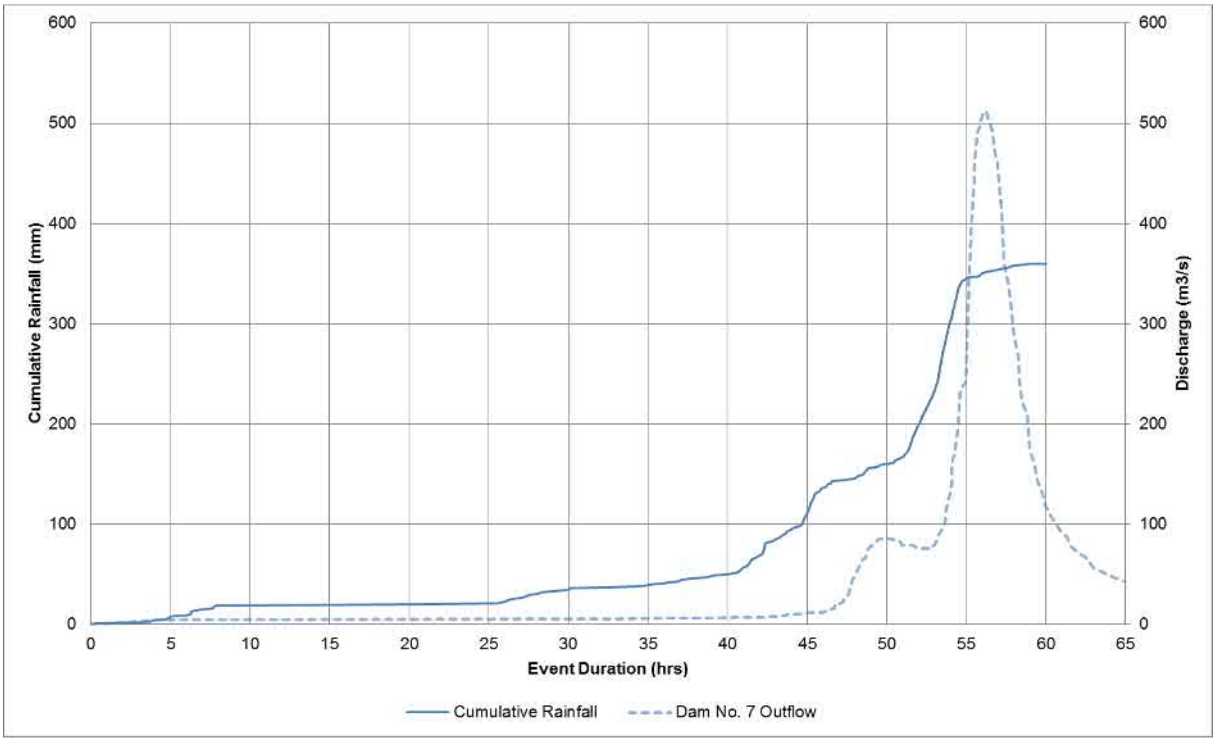


Figure 10 2015 Event Hydrologic Inputs

4.2.3 2017 Event – Ex-TC Debbie

Ex-TC Debbie moved across the Fitzroy Catchment and Mount Morgan in late March 2017. Rainfall totals of 258mm within the upper, mountainous catchment of the Dee River resulted in No. 7 Dam storage levels reaching the spillway, resulting in outflows which peaked at 200m^3/s (~1.0m above the spillway crest). The timeseries of rainfall data at the Upper Dee pluviograph station and inflow hydrograph at No. 7 Dam for the 2017 event is shown in Figure 11.

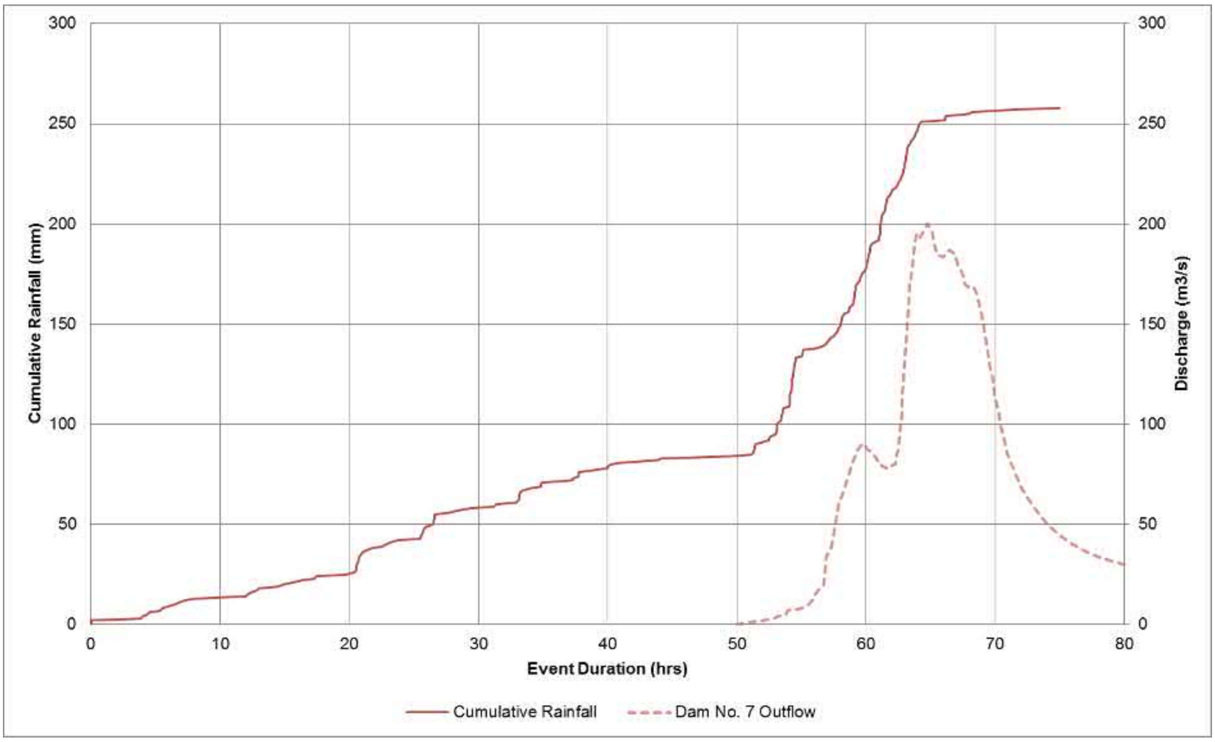


Figure 11 2017 Event Hydrologic Inputs

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-AR&R87/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 (150.425 E, 23.625 S) for Mount Morgan. The IFD input data set obtained is shown in Table 4.

Table 4 Adopted IFD Input Parameters

Parameter	Mount Morgan
1 hour, 2 year intensity (mm/hr)	44.13
12 hour, 2 year intensity (mm/hr)	7.59
72 hour, 2 year intensity (mm/hr)	2.16
1 hour, 50 year intensity (mm/hr)	78.34
12 hour, 50 year intensity (mm/hr)	16.83
72 hour, 50 year intensity (mm/hr)	5.41
Average Regional Skew ness	0.22
Geographic Factor, F2	4.22
Geographic Factor, F50	17.59

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

Table 5 Intensity Frequency Duration Data for Mount Morgan

Duration (hr)	Intensity (mm/hr)						
	1 EY	39% AEP	18% AEP	10% AEP	5% AEP	2% AEP	1% AEP
1	33.4	42.8	53.7	60.3	69.3	81.5	91
2	20.9	27	34.5	39.1	45.3	53.7	60.3
3	15.6	20.2	26.2	29.9	34.9	41.8	47.2
6	9.3	12.2	16.3	18.9	22.3	27.1	31
12	5.63	7.48	10.2	12.1	14.4	17.8	20.5

4.3.2 Temporal Pattern

Temporal patterns for Zone 3 were adopted for events up to the 0.2% AEP using the standard methodology outlined in AR&R (1987). Temporal pattern for the Probable Maximum Precipitation (PMP) event were sourced from data provided with the Generalised Short Duration Method (GSDM) guidebook (refer Section 4.3.4).

4.3.3 Areal Reduction Factors

The IFD rainfall values derived in Section 4.3.1 are applicable strictly only to one point. Reduction of the IFD rainfall was undertaken in accordance with AR&R 16 Book 2, Chapter 4 for the Mount Morgan catchment, with the resultant factors listed in Table 6.

Table 6 Areal Reduction Factors

Event AEP	Duration (mins)	Mount Morgan
1 EY	60	0.8086
39%	60	0.8016
18%	60	0.7901
10%	60	0.7814
5%	60	0.7711
2%	60	0.7576
1%	60	0.7474
	120	0.8019
	180	0.8286
	360	0.8584
	540	0.8731
	720	0.8846
0.2%	60	0.7236
0.05%	60	0.7032

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 Mount Morgan Local Catchment Study which has a catchment area of approximately 82.3 km^2 and a critical duration of 3 hours at the dam crest (as per SunWater's (2009) conclusions) and 1 hour over the steep, urban catchment.

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

- The coastal GSDM Method is applicable as the catchment lies near the Queensland coast.
- The Roughness (R), Elevation Adjustment Factor (EAF) and Moisture Adjustment Factor (MAF) were calculated as 1.0, 1.17 and 0.92 respectively.
- PMP parameters were calculated as shown in Table 7.

Table 7 Adopted PMP Parameters

Duration (hrs)	Mount Morgan	
	Rainfall Total (mm)	Rainfall Intensity (mm/hr)
1	340	340
1.5	440	293
2	500	250
3	610	203

The AEP of the PMP event was calculated as recommended in AR&R (Pilgrim, et al, 1987). For a catchment area of 82.3km^2, the PMP event is approximately a 1 in 10,000,000 AEP event.

4.3.5 Design Event Rainfall Loss Parameters

Design event losses were established based on the model configuration of the calibration and validation events. The adopted losses vary from a maximum of 15 mm initial loss and 1.0 mm continuing loss for very pervious surfaces to a minimum of 0 mm for both the initial and continuing losses on impermeable materials, depending upon the material. They are presented in Table 40 in Appendix A.

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

4.3.6 No. 7 Dam Design Event Hydrographs

Outflow hydrographs from the No. 7 Dam have been presented in Figure 12 for the range of assessed magnitudes (60min storm duration). These hydrographs have been extracted from the Mount Morgan GPU model and applied at the No. 7 Dam boundary of the Mount Morgan CPU model (refer to Figure 16). Note that the critical duration for the Dee River (and no. 7 Dam) is longer than 60 minutes and as such, these hydrographs do not represent the maximum possible spillway flows for a given event magnitude. All design events assume the storage levels within the No. 7 Dam are at the crest level (i.e. full storage).

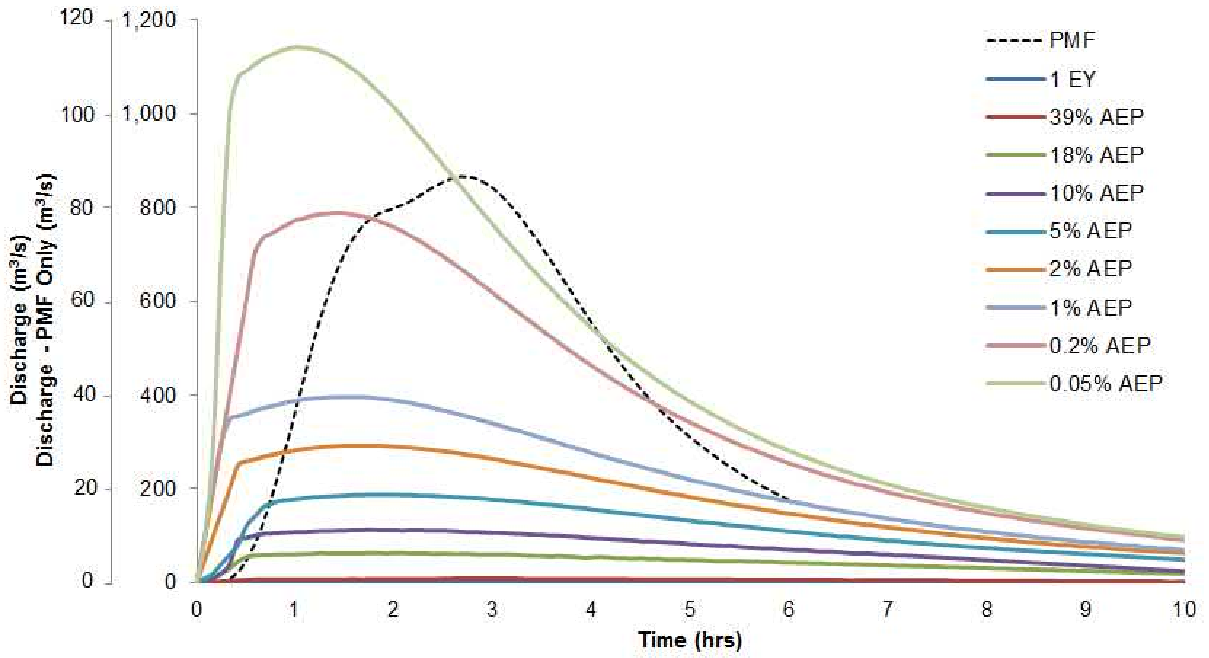


Figure 12 No. 7 Dam Inflow Hydrographs

5.0 Hydraulic Model Development

5.1 Overview

This section of the report discusses the development of a new hydraulic model for the Mount Morgan local catchment as well as the broader hydraulic model which includes the Upper Dee River catchment.

The smaller, more detailed model spanning the Mount Morgan local catchment has been used to assess key local catchment flood behaviour and deficiencies in the existing stormwater network leading to increased flood risk. In order to adequately resolve key hydraulic controls, a 4m numerical Cartesian grid resolution was adopted. A timestep of 1.5 second was adopted, giving an effective runtime of approximately 1.5 real-time hours to 1 simulation hour. TUFLOW build version 2016-03-AE (CPU) was used for this assessment.

The broader GPU hydraulic model has been used to estimate inflow hydrographs for design events 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, the No. 7 Dam spillway crest, 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 25 simulation hours. TUFLOW build version 2018-03-AB (GPU HPC) was used for this assessment.

See Appendix A for more details surrounding the development of the GPU and CPU hydraulic models.

5.2 Hydraulic Model Parameters

An overview of the model setup and key parameters for the CPU and GPU models are provided in Table 8 and Table 9, respectively.

Table 8 CPU Hydraulic Model Setup Overview

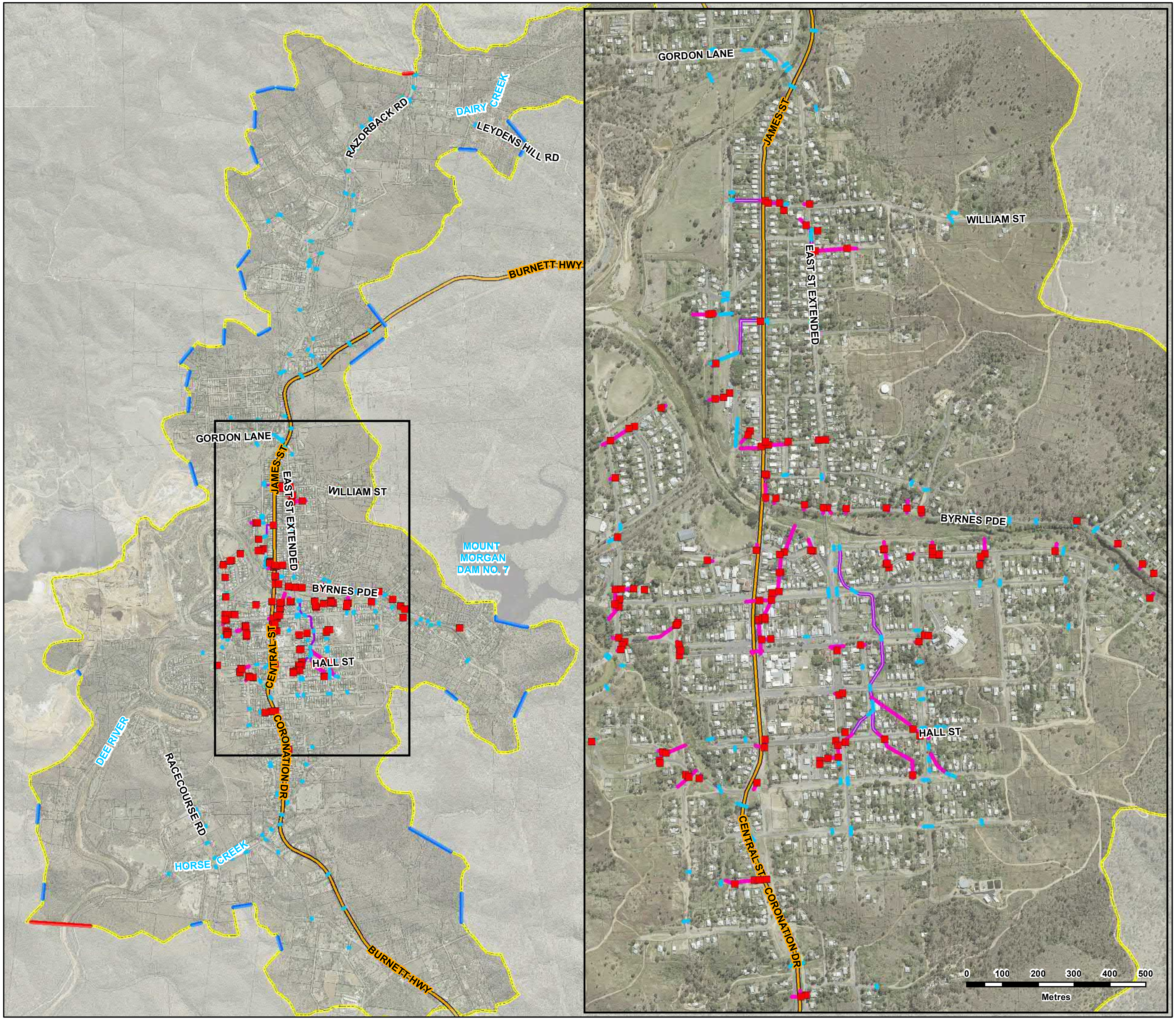
Parameter	Mount Morgan Local Catchment Model
Completion Date	July 2018
AEP's Assessed	1 EY, 39%, 18%, 10%, 5%, 2%, 1%, 0.2%, 0.05% AEP and PMF
Hydrologic Modelling	Direct Rainfall Approach
IFD Input Parameters	Refer to Section 4.3.1
Hydraulic Model Software	TUFLOW version 2016-03-AE-w64-iDP
Grid Size	4m
DEM (year flown)	2016
Roughness	Spatially varying and depth varying standard values.
Eddy Viscosity	Smagorinsky
Model Calibration	Validated to 2013, 2015 and 2017 events.
Model Boundaries	27 steep gully inflow boundaries, 1 dam crest inflow boundary, 1 rating curve boundary condition on the northern catchment extent at Razorback Road and 1 rating curve boundary condition at the southern catchment extent within the Dee River.
Timesteps	1.5 second (2D) and 0.3 second (1D)
Wetting and Drying Depths	Cell centre 0.0002 m
Sensitivity Testing	Stormwater Infrastructure Blockage, ±15% Roughness, Dam Break and Local Catchment Coincident Event and Climate Change

Table 9 GPU Hydraulic Model Setup Overview

Parameter	Mount Morgan Regional Model
Completion Date	May 2018
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 2018-03-AB -w64-iSP
Grid Size	10m
DEM (year flown)	2016
Roughness	Spatially varying and depth varying standard values – varied through partial calibration to URBS model PMF estimates at No. 7 Dam spillway.
Eddy Viscosity	Smagorinsky
Model Calibration	Not formally undertaken. Partially validated to calibrated URBS model.
Downstream Model Boundary	1 rating curve boundary condition on the northern catchment extent at Razorback Road and 1 rating curve boundary condition at the southern catchment extent within the Dee River.
Timesteps	5 second (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 13 and Figure 14 to supplement the detailed model development details outlined in Appendix A. A model setup map for the wider GPU model is also included as Figure 15. Figure 16 shows the interaction between the GPU and CPU models in order to justify the logical selection of inflow boundaries between the models.



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 500 1,000 1,500
Metres

1:30,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Pit
- Culvert
- Pipe

Boundary Conditions

- Inflow
- Outflow
- Highways
- 1D Channel Extents
- Cadastre
- Hydraulic Model Extent

Data Sources:

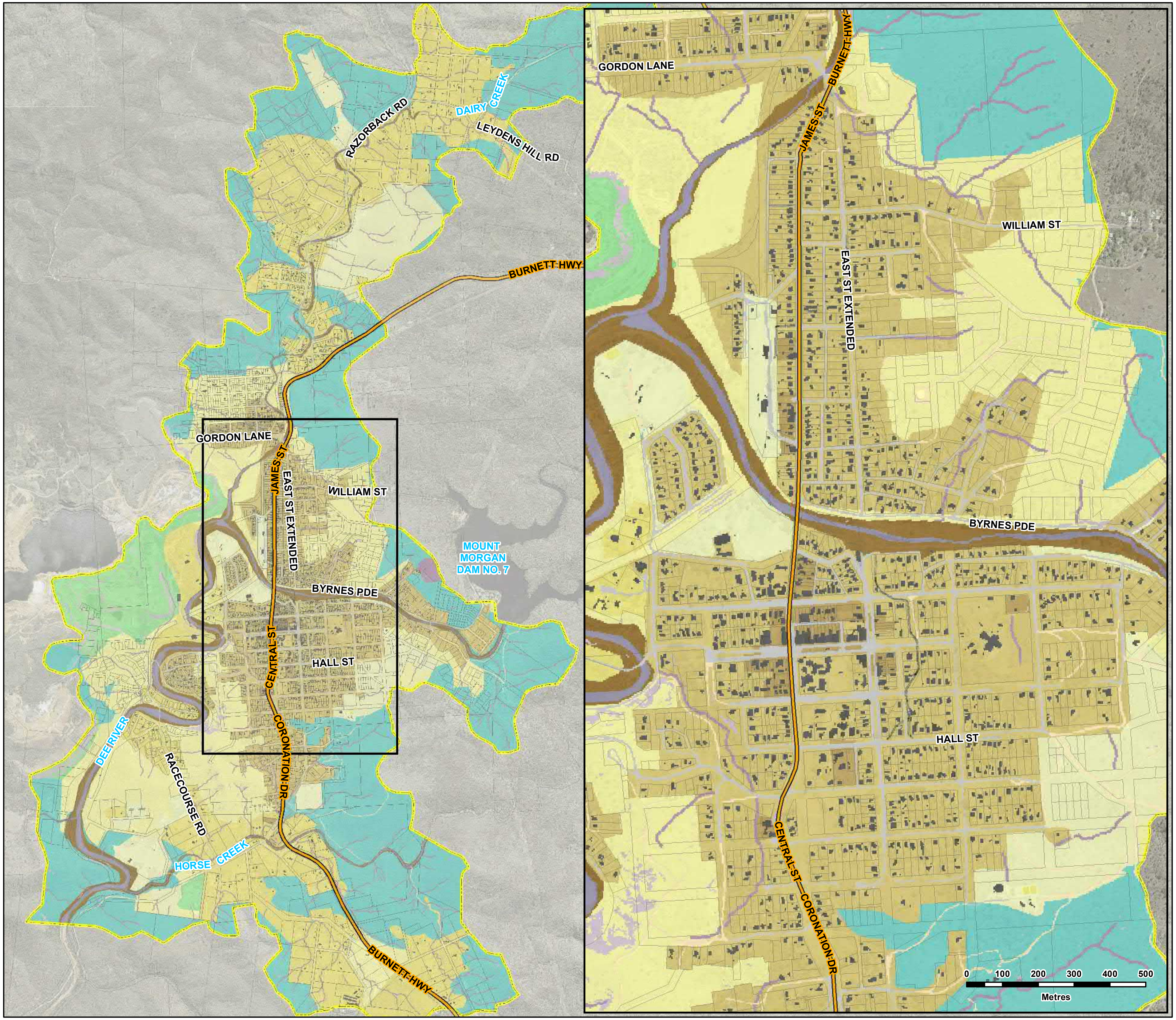
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Mount Morgan Model

CPU Model Setup and 1D Network Map

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2018
VERSION:	1

Figure 13



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Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 500 1,000 1,500

Metres

1:30,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent

Material

- Heavy Vegetation
- Mining
- Open Space / Grass / Open Channels
- Light Vegetation
- Bodies of Water
- Low Density Residential
- Medium Density Residential
- Commercial / Hardstand
- Riparian Corridor
- Unsealed Roads
- Sealed Roads
- Meandering channels
- Buildings
- Steep Gullies
- Very Steep Slopes
- Concrete

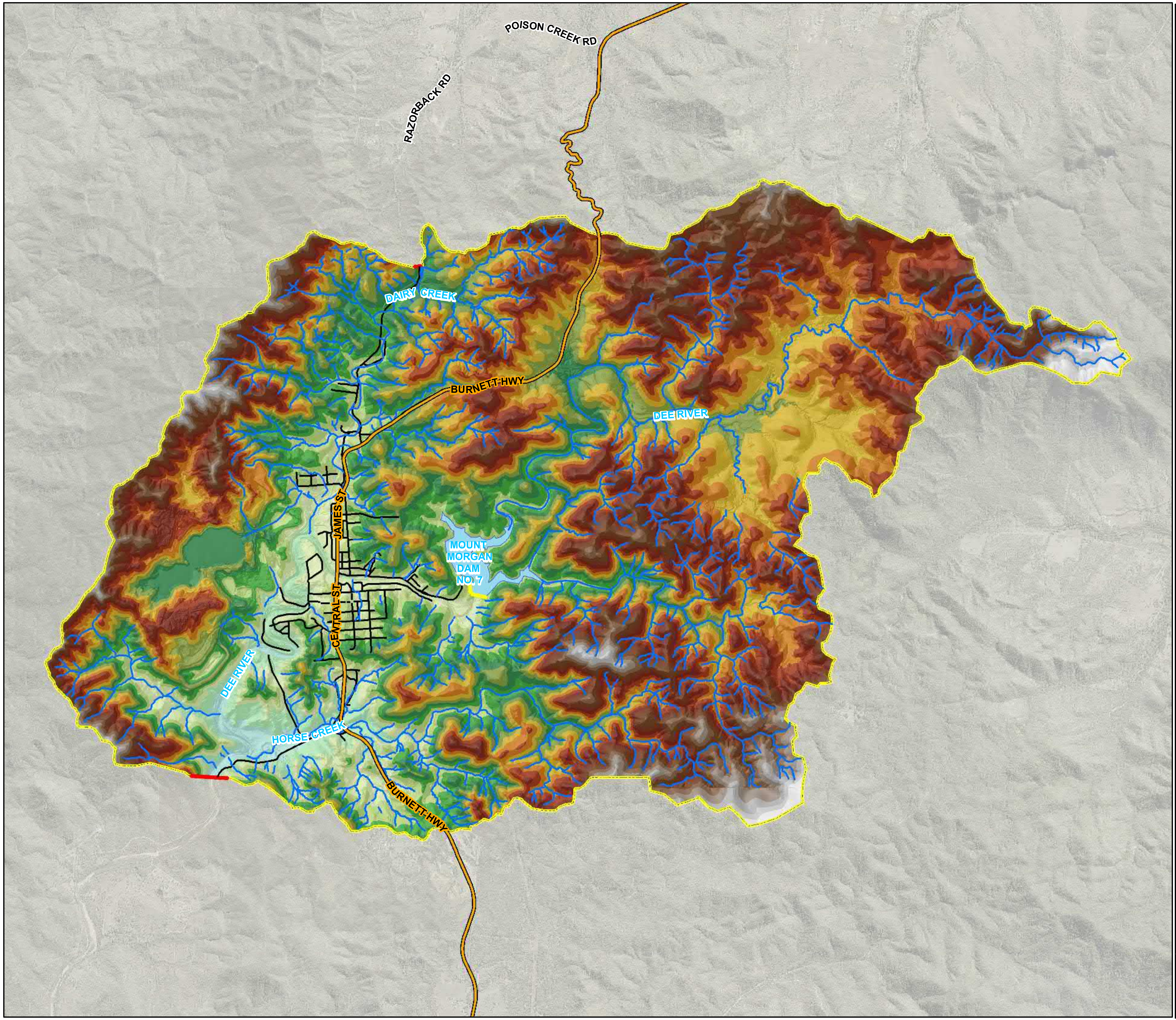
Data Sources:
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Mount Morgan Model

CPU Hydraulic Roughness Delineation Map

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	10/07/2018
VERSION:	1

Figure 14



N

DATUM GDA 1994, PROJECTION MGA ZONE 56

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

Metres

1:50,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

- Highways
- Cadastre
- Gullies
- Road Crests
- Spillway
- Outflow
- Mount Morgan Dam
- Hydraulic Model Extent (GPU)

Toporaphy (mAHD)

- <210
- 210 - 225
- 225 - 240
- 240 - 255
- 255 - 270
- 270 - 285
- 285 - 300
- 300 - 315
- 315 - 330
- 330 - 345
- 345 - 360
- 360 - 375
- 375 - 390
- 390. - 405
- 405 - 420
- 420 - 435
- 435 - 450
- 450 - 465

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

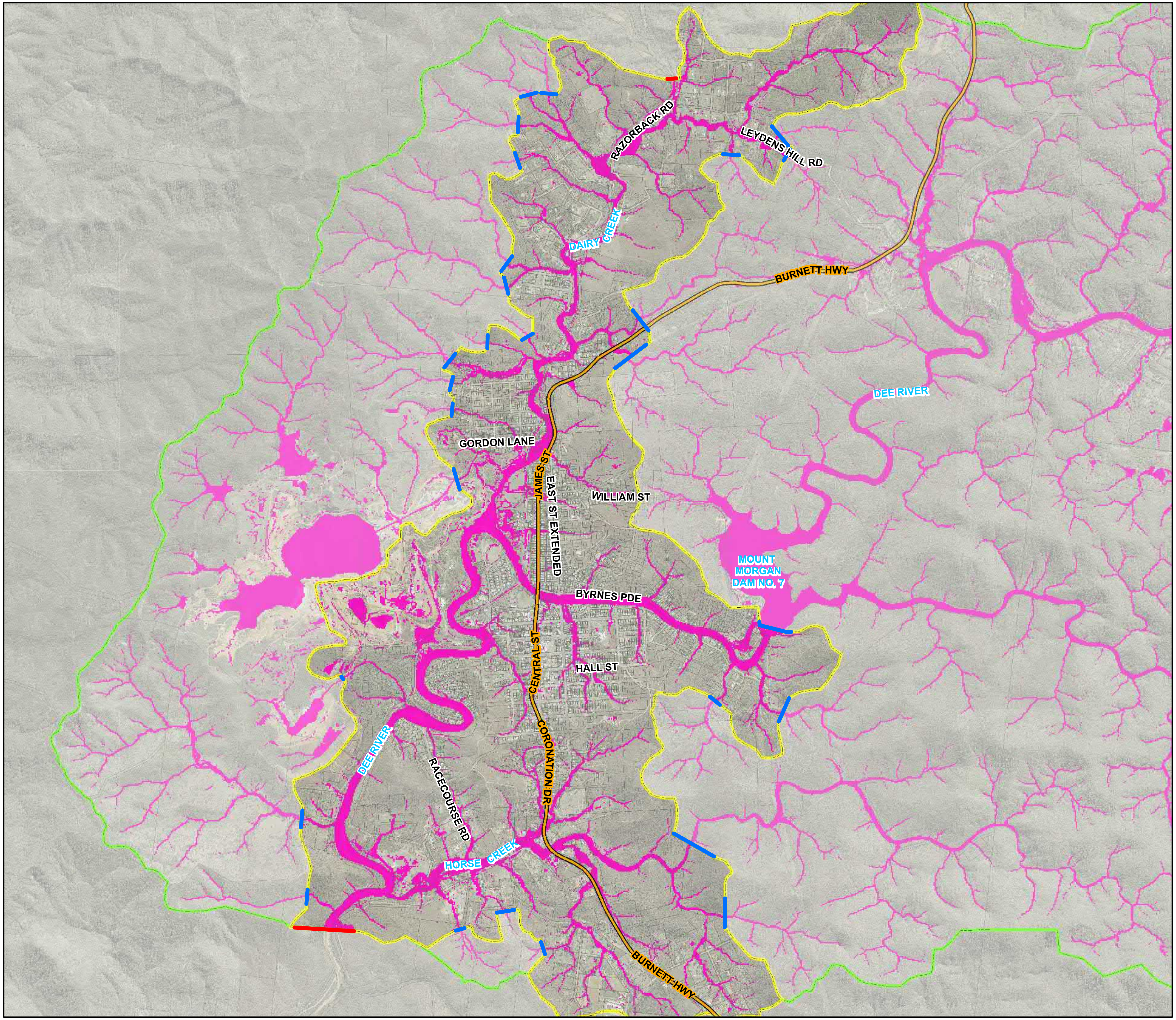
Mount Morgan Model

GPU Model Setup and 1D Network Map

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	1/08/2018
VERSION:	1

Figure 15

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure13_GPUModelSetupand1DNetworkMap.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 500 1,000 1,500
Metres

1:30,000
(when printed at A3)

AECOM
www.aecom.com

LEGEND

Boundary Conditions

- Inflow
- Outflow
- Highways
- Cadastre
- Hydraulic Model Extent (CPU)
- Hydraulic Model Extent (GPU)
- 1% AEP Flood Extent

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

Mount Morgan Model

GPU-CPU Model Interaction

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2018
VERSION:	1

Figure 16

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure14_CPU-GPU Model Interaction Map.mxd

6.0 Hydraulic Model Validation

6.1 Adopted Methodology

Validation of the TUFLOW CPU model was undertaken by simulating historical flood events and comparing the model results to anecdotal data provided by Council and FRW. Due to a lack of recorded data, the model was unable to be formally calibrated. In an effort to assess the model performance, anecdotal records (indicative levels and photographs) were compared against modelled results.

The model was validated to the 2013 and 2015 flood events. Given the preliminary nature of this performance check, model parameters have been maintained and only varied to match anecdotal data (e.g. blocked culverts). Roughness, initial losses and continuing losses have been adopted as per values consistent with other calibrated models in the Rockhampton region. The model has been partially validated to the 2017 event at Piddichs Crossing (near Possum Street). Exclusion of the pre-burst rainfall was adopted in order to make model runtimes more manageable.

Given the high level of uncertainty within the anecdotal data, adopted tolerances have been set as ±0.50m.

6.2 Validation to the 2015 Event

The 2015 rainfall gauge data at the Upper Dee pluviograph station was applied to the TUFLOW model. This gauge data was used due to it being situated within a representative location of the No. 7 Dam's catchment. The maximum water surface elevations and extents were extracted from the hydraulic model and compared to anecdotal records provided by RRC.

Useable anecdotal records were available for six locations within the Mount Morgan catchment. Each anecdotal record has been compared to modelled results and discussed below.

6.2.1 1 Gordon Lane

1 Gordon Lane is situated within the Dairy Creek corridor and includes three anecdotal records as follows:

- Property owner advised Council that water depths reached approximately 2/3 the total height of the Colourbond property fence. The fence consequently collapsed and flow continued through the property.
- Debris height at aviary behind house.
- Peak flood extent at Gorgon Lane / within property opposite the property (4 Gordon Lane).

6.2.1.1 Colourbond Fence

The Colourbond fence at 1 Gordon Lane was a standard, 6ft (1.83m) fence as shown in Plate 1. The force of floodwaters overtopping Gordon Lane destroyed all but 1 panel of the fenceline, as seen in Plate 2.

A statement from the owner suggested that the water depths reached approximately two-thirds of the fence's full height, or 1.22m. Figure 17 shows the modelled peak flood depths along the eastern boundary of 1 Gordon Lane against the observed depths. As can be seen, modelled results are within ±0.2m of the observed results.

Plate 1 1 Gordon Lane Colourbond Fence (2010)

Plate 2 1 Gordon Lane Colourbond Fence (2010)

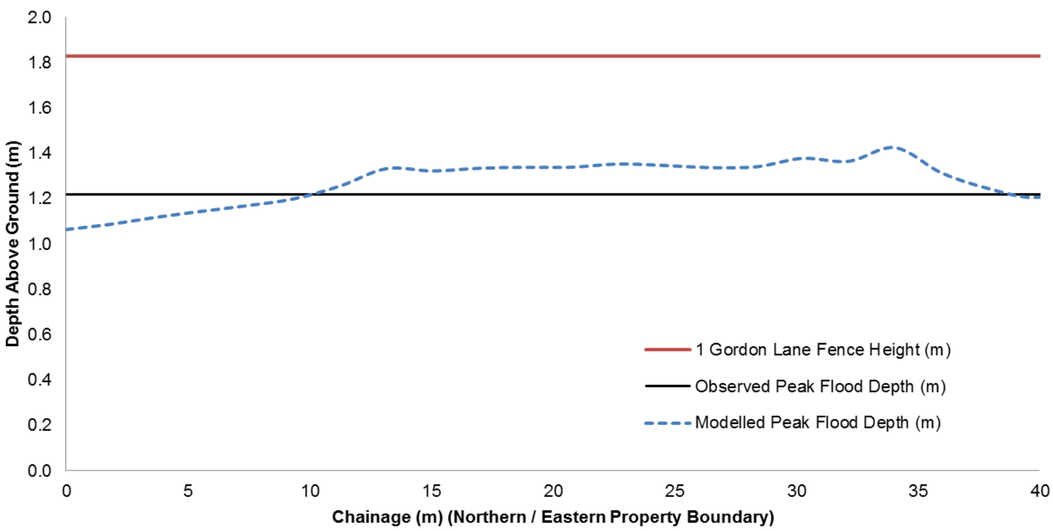


Figure 17 Observed vs Modelled Peak Flood Depths Against Fence

6.2.1.2 1 Gordon Lane Aviary

The aviary near the rear of the property is shown in Plate 3. As can be observed, the aviary is of a similar height (considering relativity) to the 1.8m house posts (refer to Appendix C for further photos). If assuming the aviary is a 1.8m tall unit, the debris line reached approximately 0.85m. The modelled peak flood depth at this location is 0.96m which is 0.11m above the recorded depth.

Plate 3 1 Gordon Lane Aviary

6.2.1.3 Gordon Lane

The photographed flood extent along Gordon Lane is shown alongside the simulated peak flood extent in Figure 18. Is it assumed that vehicles were moved against the fenceline of 4 Gordon lane, as shown by the yellow star. Comparison shows the simulated flood extent is within a reasonable proximity (slightly higher) to the expected extent.

Figure 18 Left: 4 Gordon Lane from 1 Gordon Lane | Right: Simulated peak flood depths and extents

6.2.2 7 Gordon Lane

7 Gordon Lane is situated adjacent the Dairy Creek corridor and includes two anecdotal records as follows:

- 100mm of debris mark still visible underneath the house.
- Debris mark was 500mm above surface level in the middle of this property.

A peak flood depth long section was extracted from the modelled results and plotted against the indicative debris marks within the property (shown in Figure 19). Comparison reveals the simulated peak flood depths are 100 – 140mm higher than the anecdotal records.

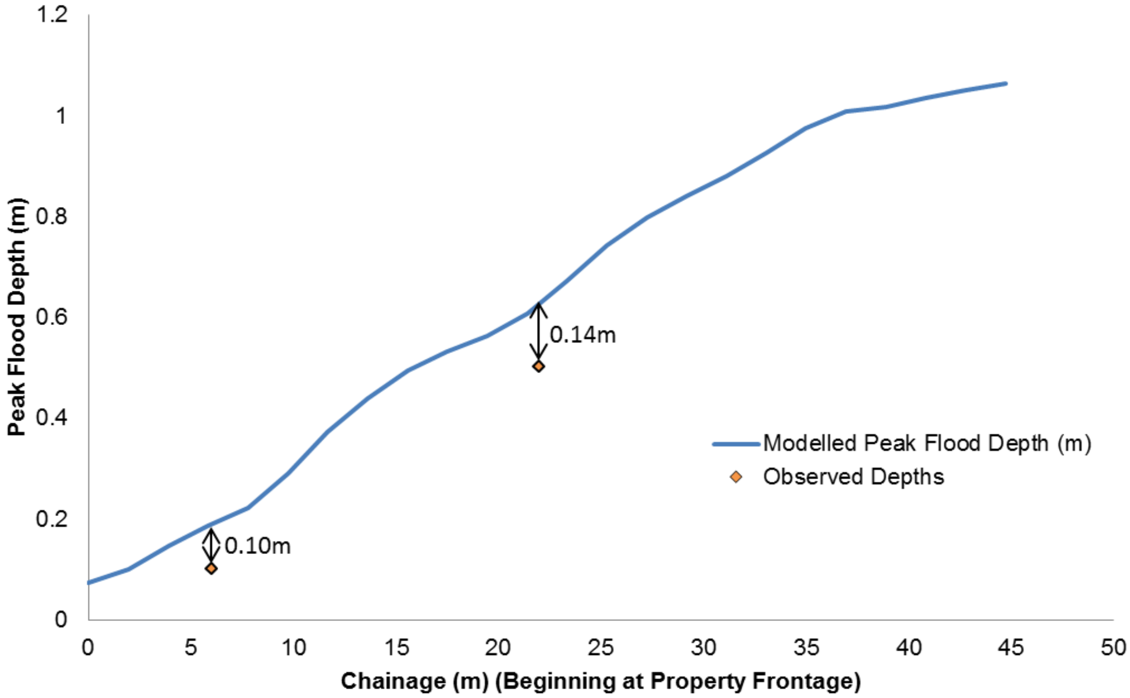


Figure 19 Peak Flood Depths at 7 Gordon Lane

6.2.3 89 Byrnes Parade

89 Byrnes Parade is situated adjacent the Dee River corridor and includes a single observed flood height/extent captured using RTK survey equipment. The recorded peak flood height has been compared to the simulated peak flood height in Table 10. When inspecting Figure 20, it becomes obvious that the recorded peak flood heights and extents compare well.

Table 10 89 Byrnes Parade PWSE Comparison

Observed PWSE (m AHD)	Simulated PWSE (m AHD)	Difference (m)
232.34	232.30	-0.04

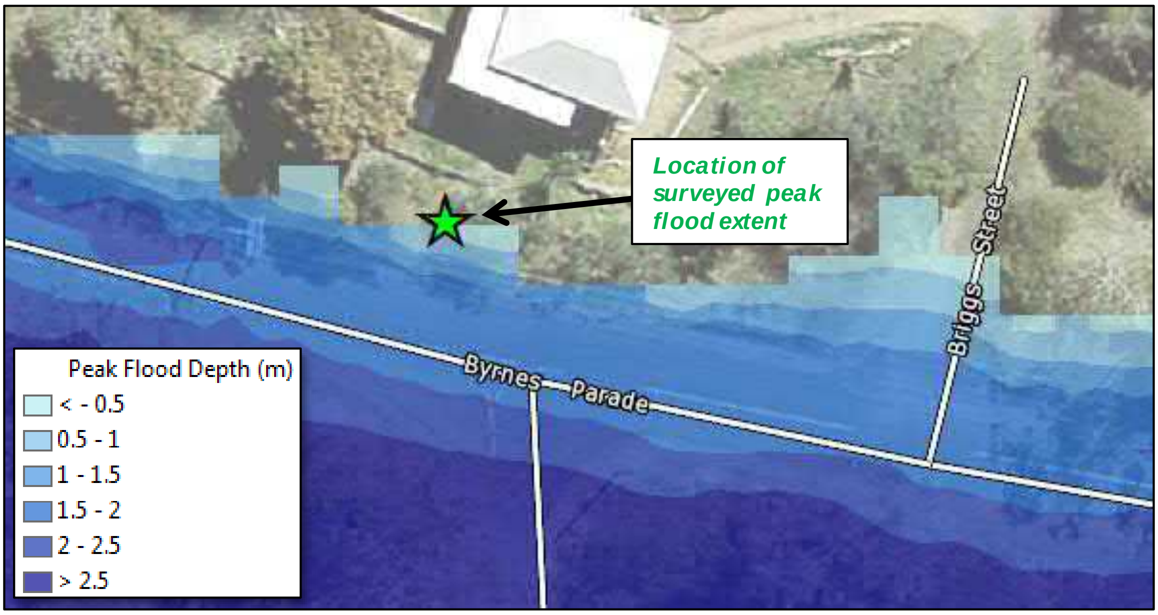


Figure 20 2015 Event Peak Flood Extent at 89 Byrne Parade (near Piddichs Crossing)

6.2.4 2 Dee Esplanade

2 Dee Esplanade is situated immediately south of Dee River and includes a single anecdotal record as follows:

- Water backed up approximately 400mm above the concrete drain.

Peak flood heights were estimated using the concrete drain obvert. Table 11 compares the peak observed and recorded flood heights.

Table 11 2 Dee Esplanade PWSE Comparison

Concrete Drain Obvert (m AHD)	Observed depth above drain (m)	Observed PWSE (m AHD)	Simulated PWSE (m AHD)	Difference (m)
227.73	0.4	228.13	228.07	-0.06

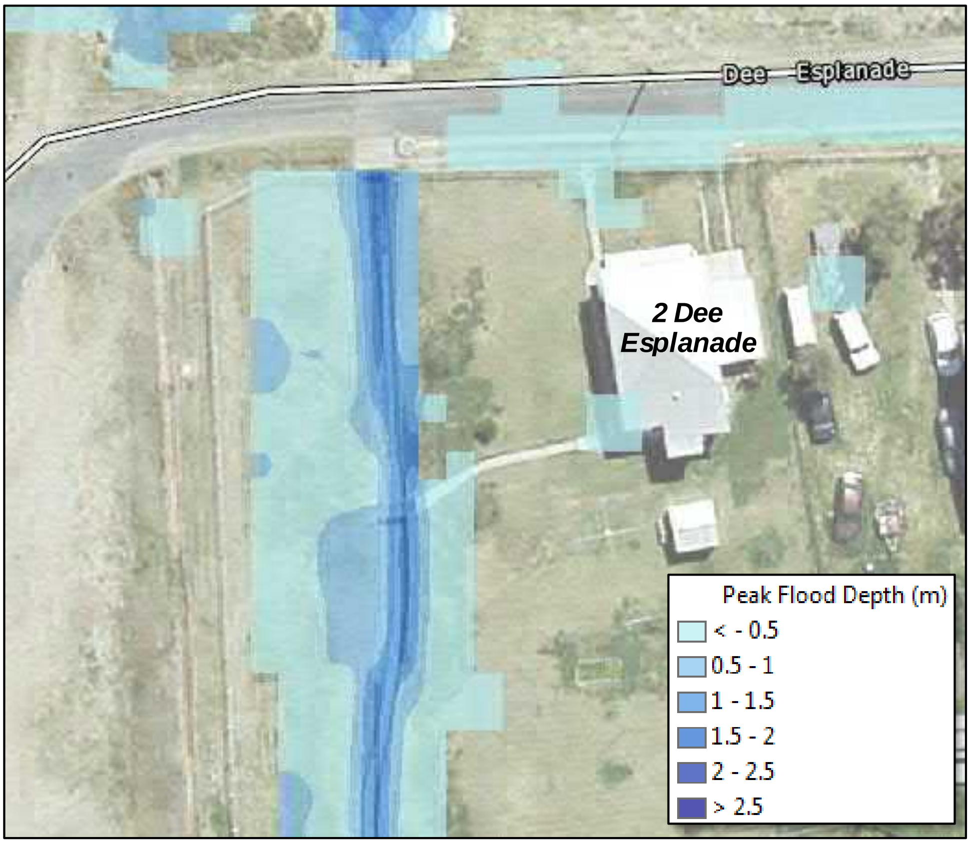


Figure 21 Peak Flood Depths at 2 Dee Esplanade

6.2.5 Summary

Given the range of anecdotal evidence presented for the 2015 flood event, a summary table has been included below. Tolerances have been assigned based on ±0.50m which has been adopted due to the high degree of uncertainty associated with the anecdotal records.

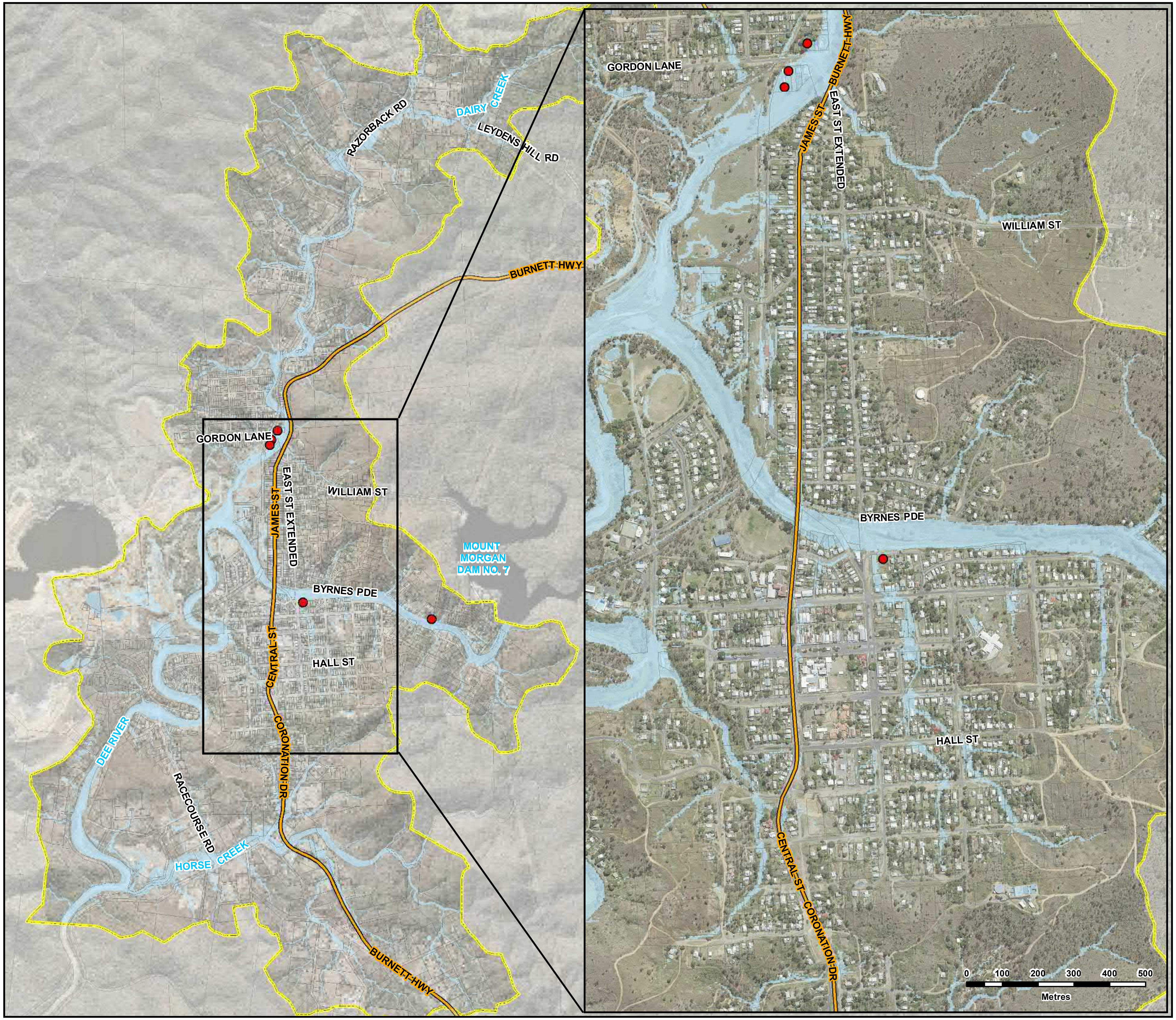
Table 12 February 2015 Validation Event Results

Point Location	Watercourse	Observed Depth (m) or Height (m AHD)	Simulated Depth (m) or Height (m AHD)	Difference (m)	Tolerance
1 Gordon Lane	Dairy Creek	1.22m	1.42m	+0.20	In tolerance
		0.85m	0.96m	+0.11	In tolerance
4 Gordon Lane		Peak flood extent is similar.			
7 Gordon Lane		0.10m	0.20m	+0.10	In tolerance
		0.50m	0.64m	+0.14	In tolerance
89 Byrnes Parade	Dee River	232.34mAHD	232.30mAHD	-0.04	In tolerance
2 Dee Esplanade	Concrete channel from Hall Street to Dee Esplanade	228.13mAHD	228.07mAHD	-0.06	In tolerance

Key outcomes from the validation are:

- Of the 7 recorded points, 6 were within the corresponding tolerances with not able to be estimated (due to it being an indicative peak flood extent).
- The average difference between modelled and recorded levels was calculated to be +0.08m with standard deviation of 0.09m.

Whilst the anecdotal records match the simulated results relatively well, it's important to reiterate that future calibration to a range of surveyed peak flood extents and/or recorded gauge heights is necessary to provide holistic confidence in the model.



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- Highways
- Cadastre
- Hydraulic Model Extent
- Februrary 2015 Validation Points
- February 2015 Modelled Extent

Data Sources:

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

Mount Morgan Model

February 2015 Validation Results

PROJECT ID	60534898
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LAST MODIFIED	26/11/2018
VERSION:	1

Figure 22

6.3 Validation to the 2013 Event

The 2013 rainfall gauge data at the Upper Dee pluviograph station was applied to the TUFLOW model. The maximum water surface elevations and extents were extracted from the hydraulic model and compared to anecdotal records provided by RRC. Each anecdotal record has been compared to modelled results and discussed below.

6.3.1 87 Byrnes Parade

87 Byrnes Parade is situated adjacent the Dee River near Piddichs Crossing. A photograph was taken immediately after the 2013 event looking from Byrnes Parade uphill to 87 Byrnes Parade near the unsealed access track. This photograph is shown below in Plate 4, above the simulated peak flood extents and depths in Figure 23.

The modelled peak flood extent matches the erosion limits in the anecdotal images well.

Plate 4 87 Byrnes Parade post-2013 Event

Figure 23 Peak Flood Depths at 87 Byrnes Parade

6.3.2 79A Byrnes Parade

79A Byrnes Parade is situated adjacent the Dee River west of Piddichs Crossing. Photographs (Plate 5 and Plate 6) were taken of the exposed 200mm water trunk main following the 2013 event, confirming the significant power of the Dee River's floodwaters. Modelled peak depth average flood velocities are shown in Figure 24.

Plate 5 79A Byrnes Road post-2013 Event

Plate 6 79A Byrnes Road post-2013 Event

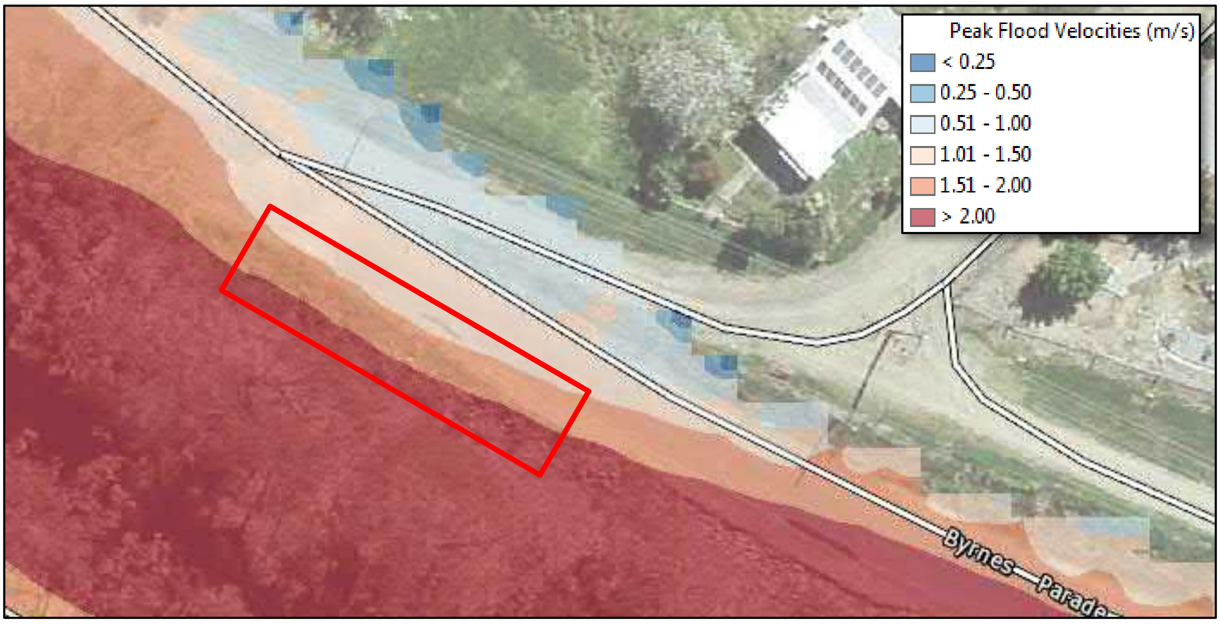


Figure 24 Peak Flood Velocities at 79A Byrnes Parade

Significant erosion occurred along the grassed road shoulder along Byrnes Parade, resulting in over a metre of scour exposing the 200mm water trunk main. Generally, well-grassed surfaces are able to withstand velocities of 1.5 to 2.0m/s. Velocities at the site vary from 1.2 – 2.6m/s, indicating that there was potential for the effective shear strength of the surface to be overcome.

Inspection of the remaining surface material reveals that the majority of finer particles (d_{50} < 100mm) were removed from the site and deposited downstream, whilst larger particles (d_{50} > 200mm) were only moved as a result of undermining as fines were removed.

Preliminary calculation of the rock size required to resist erosion at this site (in accordance with QUDM 2017) reveals that rock armour would need a d_{50} of at least 200mm to resist mobilisation. This matches with the particles remaining at the site.

6.3.3 1 Bridge Street

1 Bridge Street is situated adjacent the Dee River near James Street. Photographs (Plate 7 and Plate 8) were taken of the compromised Dee River (No. 4) Sewer Pump Station (SPS) and surrounding river channel.

Plate 7 Dee River (No. 4) SPS post-2013 Event (Looking Northeast)

Plate 8 Dee River (No. 4) SPS post-2013 Event (Looking South)

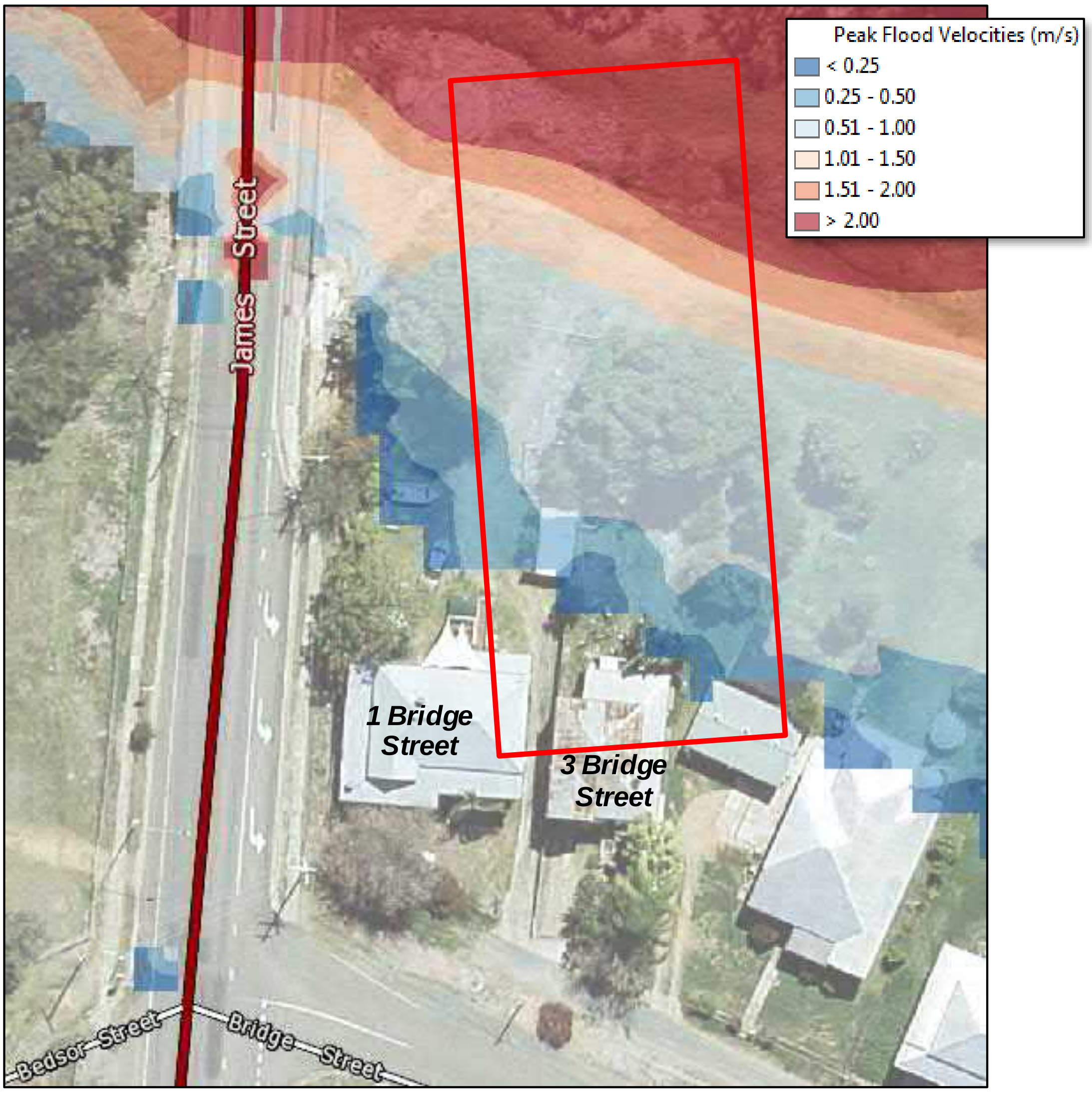


Figure 25 Peak Flood Velocities at 1 Bridge Street

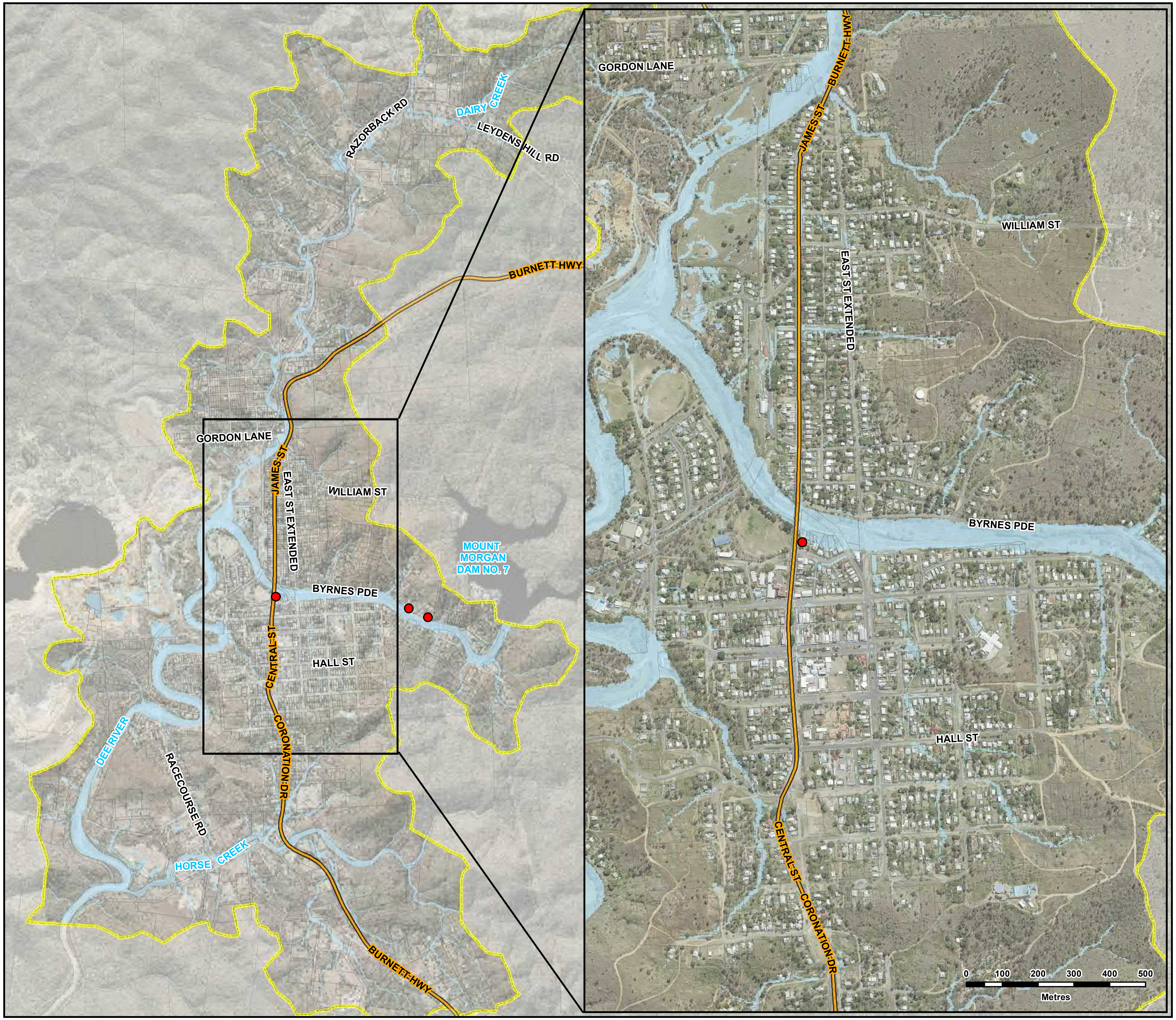
Significant erosion occurred across the inner channel banks of the Dee River where peak depth averaged flood velocities ranged from 2.0 to 3.5m/s. The final result was over 1.0m of scouring and undermining of the Dee River (No. 4) Sewer Pump Station (SPS). Above the inner channel banks, benches (within-channel floodplains) remained intact, which correlates well with the gentler velocities of 1.0 to 2.0m/s predicted within the TUFLOW model.

The finer particle fraction (d_{50} < 100mm) was easily eroded, as was the case further upstream. Preliminary calculation of the rock size required to resist erosion at this site (in accordance with QUDM 2017) reveals that rock armour would need a d_{50} of at least 300mm to resist mobilisation.

Based on saturation lines and peak debris marks shown in Plate 8, peak flood extents were expected to almost reach the shed at 3 Bridge Street. Comparison to simulated results in Figure 25 show similar extents, though slightly higher (100-200mm) than expected.

6.3.4 Summary

Anecdotal evidence for model performance checks during the 2013 flood event was limited to the Dee River upstream of James Street. Whilst physical levels were not able to be inferred, peak flood extents and velocities were able to be compared to likely erosion thresholds and peak saturation lines / debris marks. Comparisons between modelled results and anecdotal records were highly logical, with no outstanding anomalies identified. Whilst the anecdotal records match the simulated results relatively well, it's important to reiterate that future validation to a range of surveyed peak flood extents and/or recorded gauge heights is necessary to provide holistic confidence in the model.



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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent
- January 2013 Validation Points
- January 2013 Modelled Extent

Data Sources:

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

Mount Morgan Model

January 2013 Validation Results

PROJECT ID	60534898
CREATED BY	maultbyj
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VERSION:	1

Figure 26

6.4 Validation to the 2017 Event

The 2017 rainfall gauge data at the Upper Dee pluviograph station was applied to the TUFLOW model. The peak flood extents from the hydraulic model were inspected and compared to anecdotal records provided by RRC. A single anecdotal record was available for the 2017 flood event, which is investigated below.

6.4.1 Piddichs Crossing (89 Byrnes Parade)

A photograph of Piddichs Crossing during the 2017 flood event was taken from 89 Byrnes Parade and is shown in Plate 9. As can be observed, floodwaters had not overtopped Byrnes Parade (near) or River Street (afar).

Plate 9 Piddichs Crossing During 2017 Flood Event

Investigation into the likelihood that the peak flood extent overtopped Byrnes Parade began with inspection of FRW's No 7 Dam Mt Morgan Emergency Action Plan (EAP). Based on the latest spillway rating curves, Byrnes Parade is expected to be cut when dam storage levels reach 249.1mAHD (p. 22, FRW 2018). Review of gauge data at the spillway reveals that storage flood heights reached 249.3mAHD which is 0.2m above the trigger height for Byrnes Parade. Consequently, it is reasonable to assume that the anecdotal evidence is unlikely to have been taken at the peak of the event and is therefore not reliable for model validation of peak flood extents.

Considering the No. 7 Dam spillway stage-discharge curve in Figure 8, an additional 0.2m over the spillway (at an overtopping depth of 0.8m) correlates to an increase of 60m^3/s, or ~43% more flow within the Dee River channel across Piddichs Crossing. Given this information, it is reasonable to assume that the peak flood extent during the 2017 flood event did overtop Byrnes Parade as shown in Figure 27. Modelled results predict peak depths of 0.4m at Byrnes Parade near Piddichs Crossing, as well as overtopping of Byrnes Parade immediately west of Possum Street, with peak depths of almost 0.6m (Figure 28).

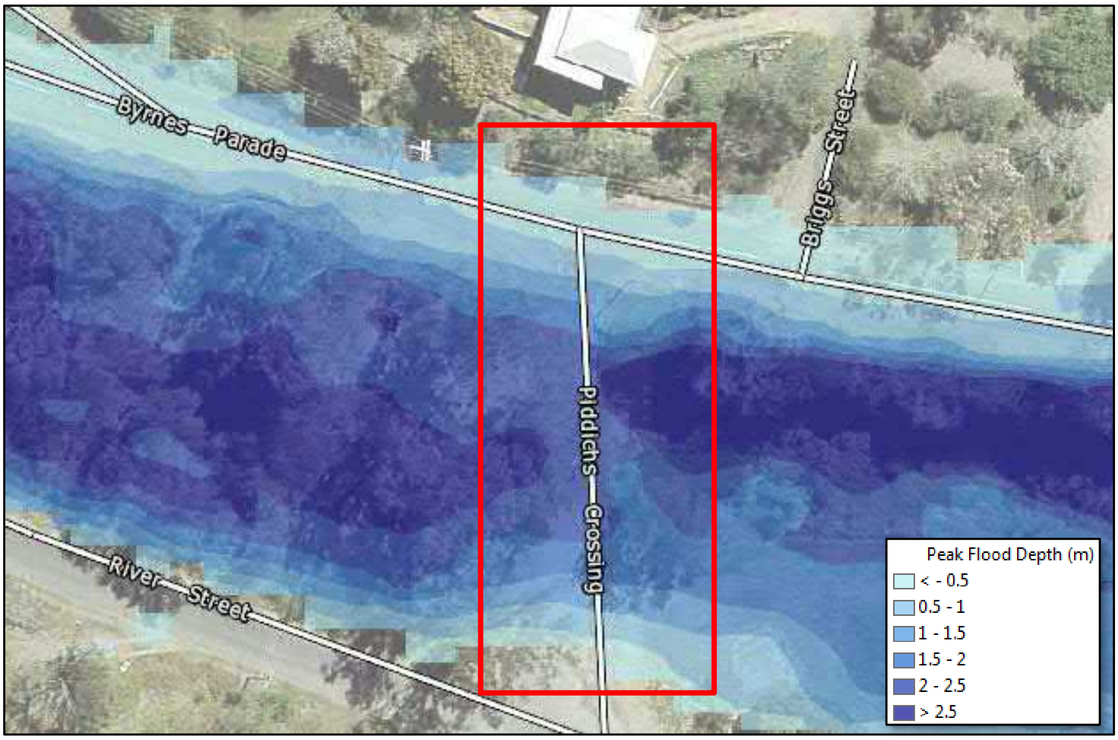


Figure 27 2017 Event Peak Flood Extent at 89 Byrne Parade (near Piddichs Crossing)

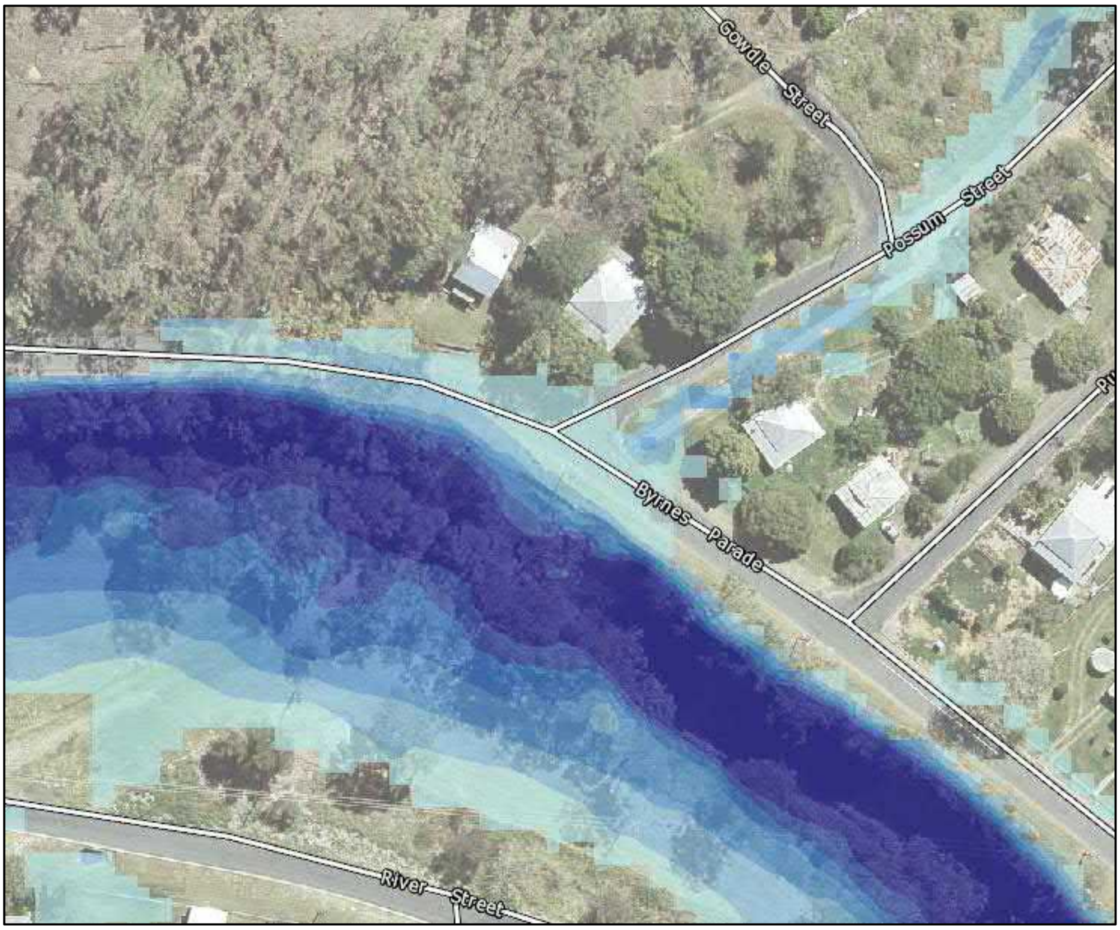
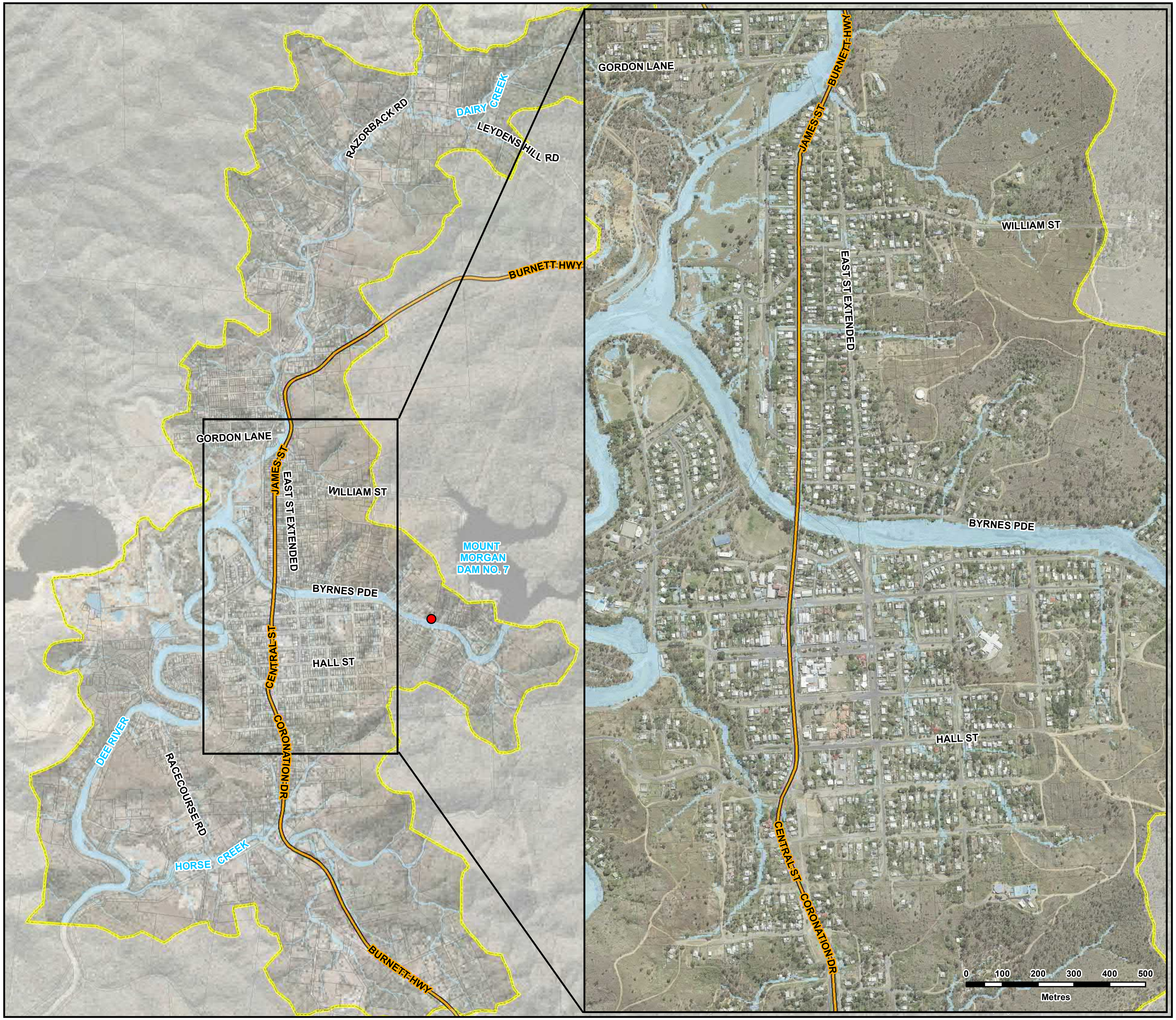


Figure 28 2017 Event Peak Flood Extent at Possum Street



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- Highways
- Cadastre
- Hydraulic Model Extent
- March 2017 Validation Point
- March 2017 Modelled Extent

Data Sources:

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

Mount Morgan Model

March 2017 Validation Results

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VERSION:	1

Figure 29

6.5 Key Findings

Summarised below are the key calibration / validation parameters for the Mount Morgan local catchment model.

6.5.1 Final Design Losses and Roughness

The final design losses adopted following the validation process are outlined in Table 40 in Appendix A. Pervious areas were modelled with an initial loss of 15 mm and continuing loss of 1 mm. Where a surface was understood to be partially pervious, the initial and continuing losses were halved.

The adopted roughness values for each of the different land uses are outlined in Table 39 in Appendix A. Roughness values are based on the calibrated values from the North Rockhampton local creek catchment models, given that insufficient calibration data disabled fine-tuning of roughness values within this study. It is recommended that losses and roughness values are re-visited in future calibration works.

6.5.2 Adopted Blockage

The adopted blockage across major bridge structures follows best-estimates of piers and abutments within the bridge cross-section. Best-estimates are based on first principles form losses and trapezoidal integration to accurately (for modelling purposes) calculate the blockage proportion of the bridge conveyance area. All major cross-river structures were included in the model, including the Dee River Pedestrian Bridge near Bridge Street.

Additional blockage was not incorporated at major culvert crossings; the sensitivity of peak flood extents and heights to culvert blockage (in accordance with AR&R 16) was investigated within Section 9.6.

6.5.3 Critical Areas

Several critical areas across riverine, creek and local flowpaths exists within the Mount Morgan catchment. These locations align with sites where frequent inundation of infrastructure (especially roads) and properties occur. Locations which have no anecdotal records (e.g. Horse Creek) have also been included, highlighting the need for future performance checks of the model as data becomes available.

Table 13 Critical Area Summary

Watercourse	Critical Area
Dee River	Byrnes Parade near Piddichs Crossing and Possum Street.
	Northern face of Bridge Street.
	Mine Road, near the western extent of Morgan Street.
Dairy Creek	Razerback Road near Wyvills Road, Porters Road, Crossley Street and Creek Street.
	Old Baree Road
	Properties adjacent Dairy Creek at Baree Road and Gordon Lane.
Horse Creek	42 Coronation Drive, between East Street South and Showgrounds Road
	2 and 42 Showgrounds Road, immediately west of Burnett Highway
Local Catchment	Eastern face of Black Street, near Hall Street
	Eastern face of Campion Street, near Gordon Street
	Southern Face of Morgan Street, east of Campion Street
	Royal Lane
	James Street near Nicholson Street and William Street

7.0 Baseline Hydraulic Modelling

7.1 Overview

The Mount Morgan 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

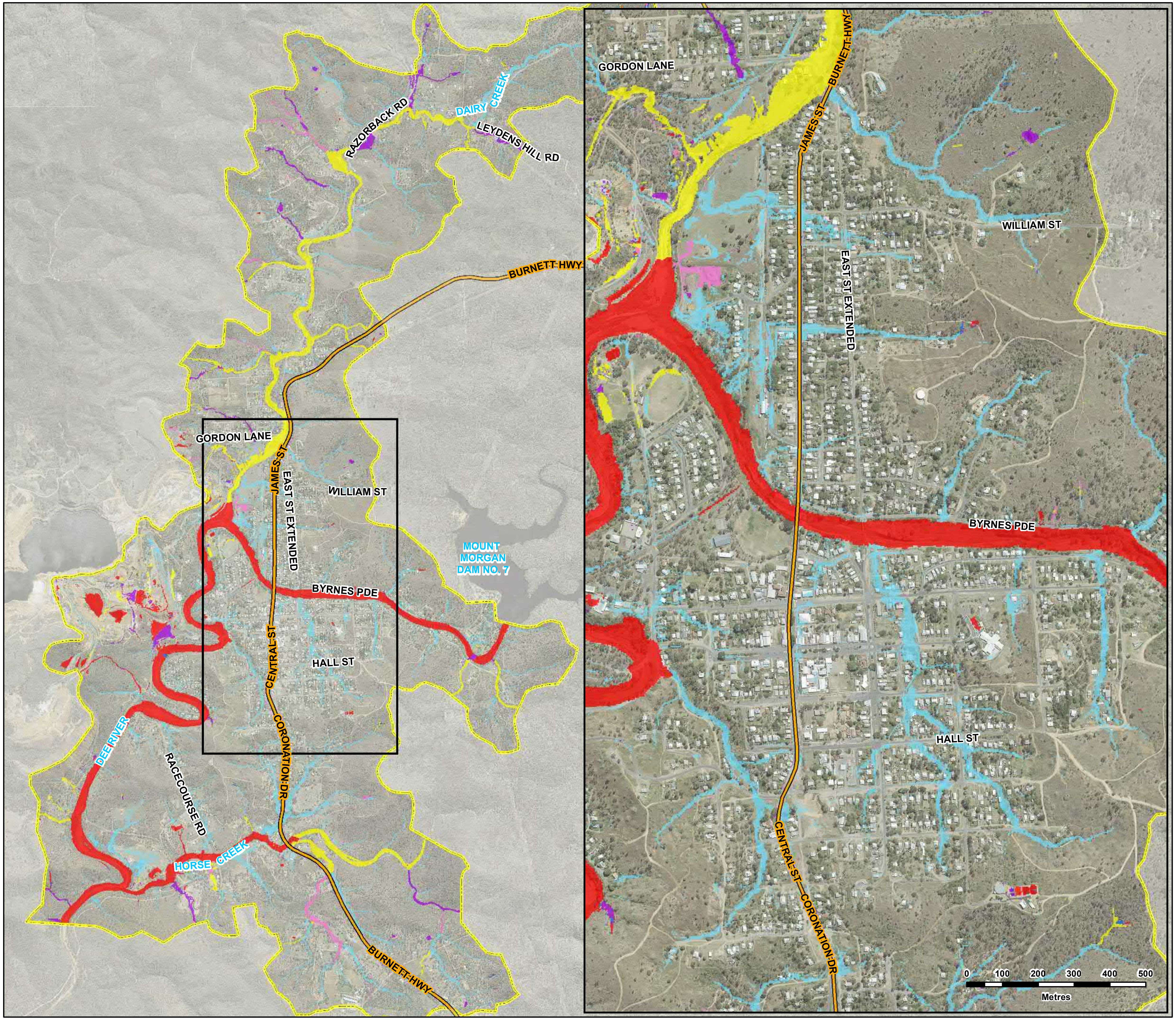
The critical storm duration for the Mount Morgan Local Catchment area was assessed by simulating the 60min, 120min, 180min, 360min, 540min and 720min storm durations for the 1% AEP event. Figure 30 shows that for a 1% AEP event, the majority of steep flow paths across the catchment have a 60min critical duration. The primary channel of Dairy Creek has a 180min critical duration. Horse Creek has a 180min critical duration upstream of the Burnett Highway which transitions to a 720min duration further downstream. Similarly, the Dee River has a 720min critical duration.

Analysis of differences between the 60min, 180min and 720min storm events (refer Figure 31 and Figure 32) in the steep, overland drainage lines of the catchment indicated peak water surface elevations are generally higher by 100mm or more in the more intense 60min duration event. In contrast, creek and riverine systems are often 300mm (or more) higher in longer duration events. A location of interest at Gordon Lane shows that the peak water surface elevation is up to 250mm higher in the 180min event.

Due to the majority of impacts and key urban, overland flow paths being within the steeper gully lines, a critical duration of 60 minutes has been selected, acknowledging that potential flood risk to infrastructure and properties within Dairy Creek, Horse Creek and the Dee River (which are anticipated to cause limited flood risk to properties) may be underestimated.

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 60min, 120min, 180min, 360min, 540min and 720min 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.



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- Highways
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- Hydraulic Model Extent

Critical Duration

- 60 min
- 120 min
- 180 min
- 360 min
- 540 min
- 720 min

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

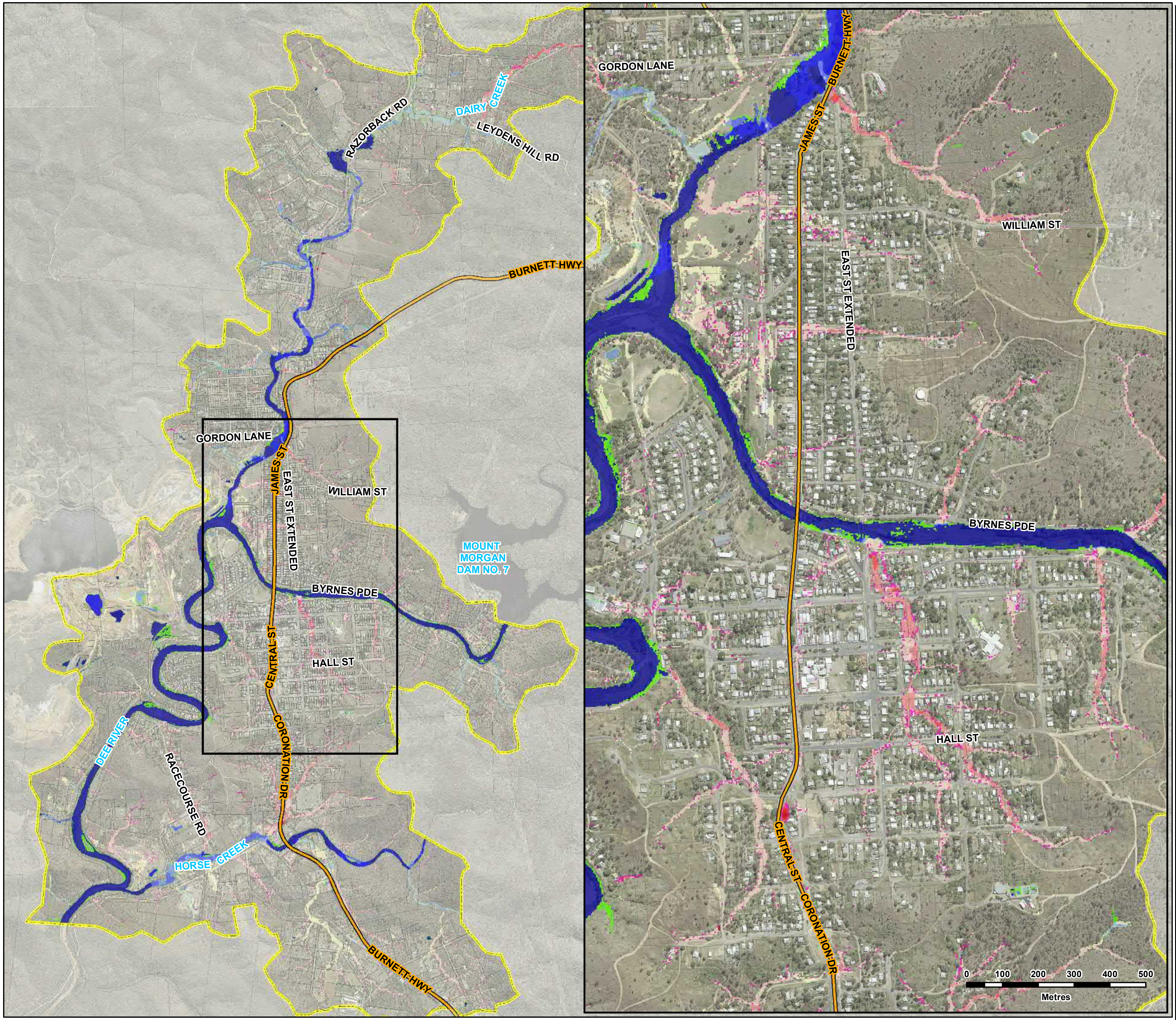
Mount Morgan Model

Critical Duration Assessment

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	1/08/2018
VERSION:	1

Figure 30



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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent

Difference (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

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

Mount Morgan Model

60min minus 180min

1% AEP Event

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CREATED BY	maultbyj
LAST MODIFIED	12/07/2018
VERSION:	1

Figure 31

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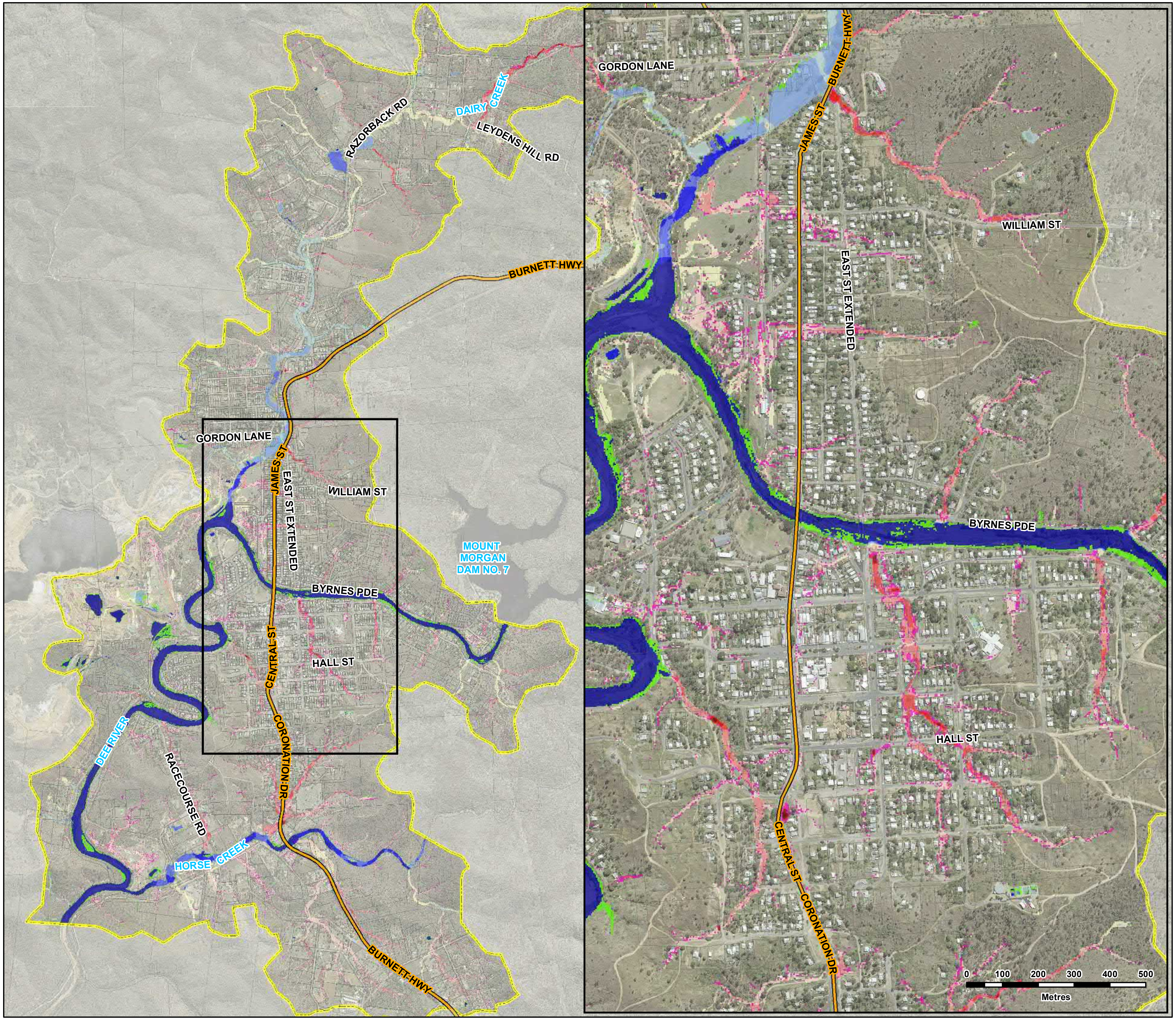

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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent

Difference (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

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

Mount Morgan Model

60min minus 720min

1% AEP Event

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	12/07/2018
VERSION:	1

Figure 32

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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 54 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 Dee River, Horse Creek and the above and underground drainage network and road / drainage reserves, with ponding occurring in some low lying areas.

Small breakout flow, with an average flood depth of 300 - 350mm, occurs along Morgan Street between Campion Street and Black Street. Peak flood depths are 3m throughout Dee River and Horse Creek; and depths within the urban town centre generally vary between 0 - 300mm however are contained within drainage networks and road / drainage reserves and natural flow paths.

Peak depth averaged flood velocities are predicted between 1.0 - 1.5m/s in both the upper reaches and low-lying terrain of the catchment.

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 along Dee River, Horse Creek and their main tributaries.

Flood depths generally remain shallow throughout urban areas, with some flow paths now predicting depths around 400mm.

The small breakout flow occurring along Morgan Street between Campion Street and Black Street has similar flood depths to the 1 EY Baseline however the flood extent has increased. Small breakout flow is also predicated between two major culverts along Razorback Road. The flood extent adjacent to Gordon Lane and Baree Road is significantly wider than the 1 EY Baseline, along the main flow path, with small breakout flow also occurring with velocities remaining relatively low.

Peak depth averaged velocities are again similar to the 1 EY Baseline event - most notable increases are along the main flow paths throughout urban areas, Dee River and Horse Creek. Velocities remain relatively low across the entire catchment.

- **Maps 7 to 21** – 18% AEP Baseline

Again, the flood extent continues to widen along the main flow paths in the 18% AEP event, especially within Dee River, Horse Creek and their main tributaries. Depths remain shallow across the majority of the catchment, although some key flow paths are beginning to show small breakout flows.

The breakout flow between two major culverts along Razorback Road has increased and begun pooling with a peak depth and peak velocity of 2.5m and 2.0m/s respectively.

Peak depth averaged velocities are increasing within main overland flow paths in the catchment. Velocities are predicted to vary between 1.0 – 3.0m/s in Dee River and Horse Creek. Velocities of 1.0 - 1.5m/s are still predicted within the urban town centre with flow mainly contained within the drainage networks and road / drainage reserves and natural flow paths.

- **Maps 22 to 24** –10% AEP Baseline

More significant breakouts are predicted in the 10% AEP event, with notable pooling between two major culverts along Razorback Road and adjacent to Gordon Lane and Baree Road. Further breakout is experienced at the Mount Morgan Showground with notable ponding of up to 100mm predicted within the main oval.

Overtopping occurs at Queens of the Valley Road, Leydens Hills Road, Porters Road, Razorback Road, Old Baree Road, Gordon Lane, Lester Street, Nicholson Street, Byrnes Parade, River Street, Morgan Street, Pattison Street, Dary Street, Millican Street, Showgrounds Road, Racecourse Road, Burnett Highway, Horse Creek Lane and East Street.

Peak depth averaged velocities are predicted to reach more than 3.0m/s in some sections of Dee River and more the 4.0m/s in some sections of the concrete channel from Hall Street to Dee Esplanade. Overland flow paths in the urban town centre are predicted to increase to 0.5m/s with flow mainly contained within the drainage networks and road / drainage reserves and natural flow paths.

- **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.

More significant breakouts are predicted in the 5% AEP event, as overland flows exceed the capacity of the road corridor and subsurface network along several natural flow paths including Dee River and Horse Creek.

- **Maps 28 to 30** – 2% AEP Baseline

The 2% AEP event is predicted to further increase flood depths and extents, with significant pooling occurring where channel capacity is exceeded. Flood depths are predicted to increase to 4.5m between two major culverts along Razorback Road and to 2.5m adjacent to Gordon Lane and Baree Road.

Flow along key urban flow paths continues to increase, with private property inundation evident along most of the notable drainage paths.

Peak depth averaged velocities continue to increase across the catchment with a peak velocity of 4.5m/s experienced in major channels and flow paths, being Dee River and concrete channel from Hall Street to Dee Esplanade.

- **Maps 31 to 45** – 1% AEP Baseline

Predicted flooding in the 1% AEP event is similar to the 2% AEP event, although peak flood depths and velocities continue to increase in key flow paths. Urban flow path channels are showing significant areas of breakout, with flows predicted to discharge across several private properties along a number of key drainage paths.

Further breakout has occurred at the Showgrounds and key underground drainage network and road / drainage reserves. Majority of the concrete channel from Hall Street to Dee Esplanade has exceeded its capacity and is predicting peak depth and peak velocity of 2.0m and 5.0m/s respectively.

Average flood depths experienced in Dee River vary from 1.0 - 3.5m.

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

Flood depths and extents are predicted to be extensive in the 0.2% AEP event, particularly in low-lying and areas. Flood depths across major road connections are increased, as is the flooding within adjacent properties.

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

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

The 0.05% AEP event shows several sections of roads within the Mount Morgan catchment to be inundated, with key connections such as Old Baree Road now predicted to have flood depths greater than 2.5m. The 0.05% AEP event shows similar flow patterns to the 0.2% AEP event, although flood extents and depths have slightly increased.

Dee River and Horse Creek flood levels continue to increase, with some areas beginning to reach bank full flows with the showgrounds also showing encroachment of shallow flooding.

- **Maps 52 to 54** – PMF Baseline

The PMF events involves significantly high peak discharges than the 0.05% AEP event, with almost 1,000m^3/s overtopping the No.7 Dam spillway and almost 1,200m^3/s traversing Gordon Lane at Dairy Creek. The result is a significantly wider and deeper flood extent than previous events and several prominent urban flowpaths.

Cross-river structures and tall road embankments significantly impede floodwaters, with all major flowpaths are predicted to see velocities continually in excess of 2.0m/s. The Dee River often reaches 4.0m/s and Dairy Creek sees almost 5.0m/s near Gordon Lane. Combined with peak flood depths in excess of 3.0m, several pockets of properties and infrastructure are exposed to extreme flood risk, namely:

- Properties near Gordon Lane and Creek Street.
- Byrnes Parade.
- Campion Street-Royal Street concrete channel and adjacent properties.
- Bridge Street and Dee Esplanade.
- Properties along Showgrounds Road.

Map 55 – Design Event Extent Comparison

The comparison between the peak flood extents demonstrates that peak floodwaters are largely contained within the Dee River and Horse Creek main channel for events more frequent than the 1% AEP. This is due to the highly incised, steep nature of existing waterways and urban channels. Events less frequent then the 1% AEP begin to reveal major breakouts, including areas near Bridge Street, Gordon Lane, Creek Street and Showgrounds Road. Steep urban flowpaths begin to see noteworthy breakouts during the 10% AEP event and greater, with the 1% AEP event showing well-connected overland flowpaths between private parcels which are exacerbated as magnitude increases.

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 flow paths of:

- Dee River, Dairy Creek and Horse Creek;
- Tributary flow paths of the above systems which intersect infrastructure or properties;
- East Street; and
- Burnett Highway.

Refer to Figure 33 for extraction cross-section locations. Table 14 below presents the results at corresponding locations.

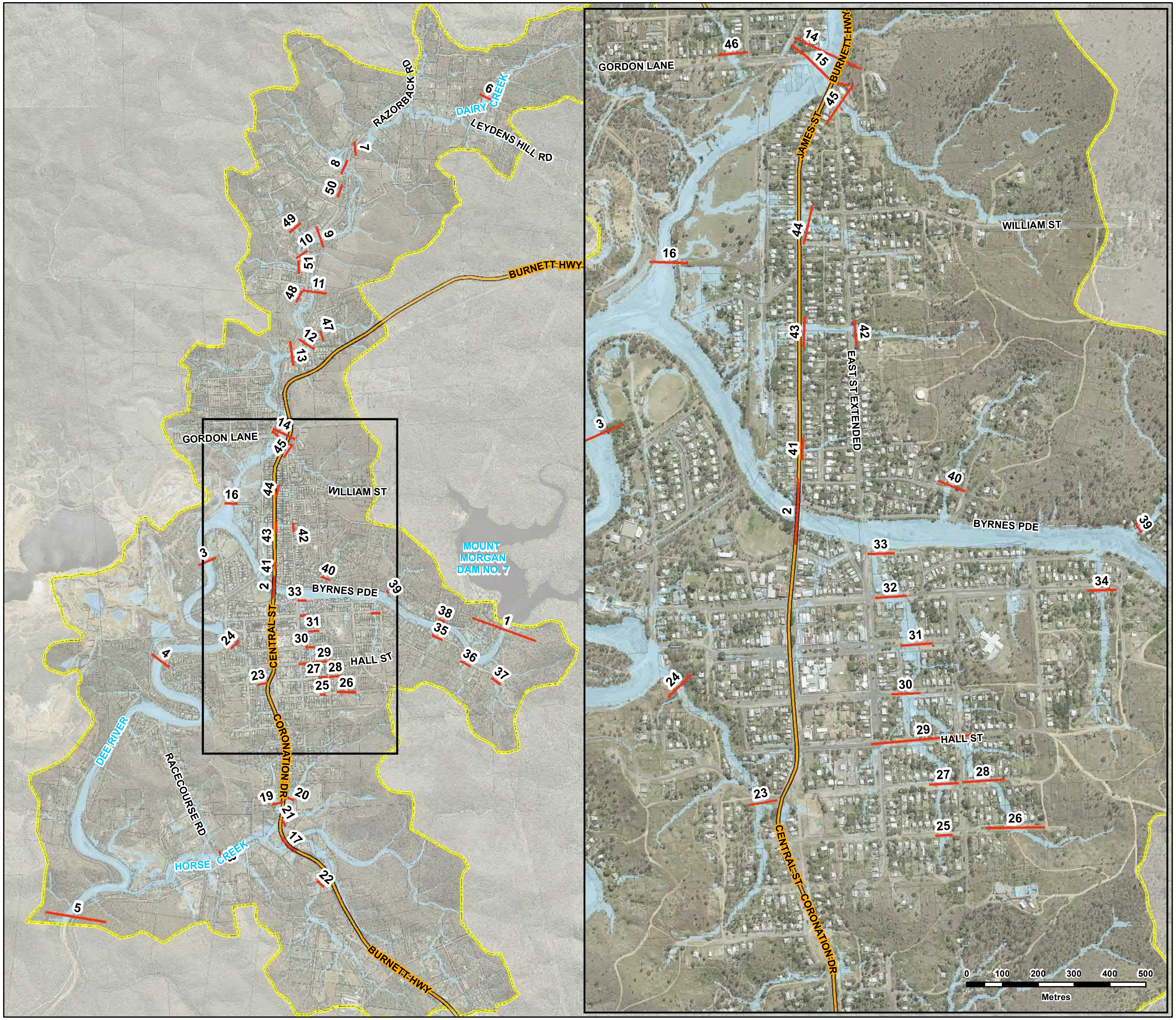
Table 14 Summary of Baseline Peak Discharges

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (60 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
Dee River	1	0.7	1.8	7.4	11.8	18.9	29.3	39.6	79.3	114.9	866.0
	2	10.0	13.5	23.2	32.2	46.0	72.8	94.6	142.5	220.2	851.0
	3	10.0	25.4	53.4	72.7	99.8	136.5	172.7	310.8	439.2	1807
	4	9.0	25.1	52.4	71.5	98.3	135.5	171.6	309.3	436.6	1812
	5	14.0	35.7	77.9	109.3	149.2	210.3	265.4	438.4	616.7	2598
Dairy Creek	6	3.9	7.8	13.0	16.1	20.4	23.9	28.4	42.0	52.4	130.1
	7	4.6	10.7	17.0	21.5	26.1	32.1	36.1	56.1	87.2	375.5
	8	5.7	12.2	20.9	28.4	36.0	44.3	50.2	80.7	119.0	509.0

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (60 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
	9	6.6	12.6	21.3	29.0	35.9	44.8	51.5	85.6	125.3	584.9
	10	7.0	12.9	21.6	29.3	36.1	44.6	50.9	84.6	123.4	541.4
	11	7.2	13.9	24.6	35.8	49.4	63.0	73.5	124.0	180.8	848.3
	12	7.9	15.4	29.7	42.0	60.0	78.9	94.6	162.6	233.0	1124
	13	7.5	15.8	30.0	42.4	60.3	79.1	95.1	162.9	232.8	1130
	14^	8.0	16.9	32.8	45.4	65.4	85.8	104.1	179.6	256.4	1275
	15^	0.0	0.1	0.4	7.3	21.1	36.4	53.9	130.6	209.4	1227
	16	8.0	18.4	33.8	47.3	67.5	88.0	108.8	188.6	265.6	1165
Horse Creek	17	7.4	14.2	25.0	30.8	39.6	49.2	59.6	101.7	138.2	698.2
	18	11.3	20.9	36.0	44.5	57.5	70.1	83.7	131.9	172.4	814.2
Coronation Drive	19	2.3	4.1	6.0	7.1	8.6	9.5	10.8	15.0	18.3	42.4
Mount Morgan Cemetery	20	2.3	4.4	6.7	8.4	10.5	12.3	14.4	21.0	25.7	61.0
	21	4.8	9.2	13.7	16.9	20.8	24.4	28.5	40.0	48.1	104.8
Burnett Hwy	22	2.4	4.5	7.3	9.4	12.4	16.1	19.5	31.5	40.6	114.9
Meinberg Gully	23	1.6	2.4	3.8	4.5	5.4	5.9	6.5	8.9	11.3	26.3
	24	2.9	4.4	6.3	7.5	9.0	10.2	11.7	16.4	20.4	49.9
East Street Concrete Channel	25	0.6	0.8	1.1	1.2	1.4	1.6	1.7	2.4	2.8	6.0
	26	0.1	0.1	0.7	1.3	1.8	2.1	2.6	4.0	5.1	12.6
	27	0.2	0.3	0.5	0.8	1.1	1.3	1.7	2.7	3.5	9.6
	28	0.1	0.3	1.2	1.9	2.7	3.0	3.6	5.3	6.8	16.8
	29	0.1	0.2	0.4	0.8	2.3	3.7	5.3	9.5	13.0	39.2
	30	0.0	0.0	0.2	0.8	1.6	2.7	4.0	7.8	10.8	49.9
	31	0.4	1.4	2.4	3.5	4.6	6.0	7.9	13.0	16.8	51.8
	32	0.0	0.0	0.0	0.4	1.4	2.5	4.3	9.5	13.5	65.6
	33	0.2	0.2	0.3	0.3	0.4	0.4	2.0	7.6	11.7	57.8
Dee Street	34	1.2	2.2	3.3	3.9	4.7	5.1	5.8	8.0	9.8	22.1
River Street	35	0.9	1.6	2.5	3.0	3.5	3.8	4.3	5.9	7.1	15.3
	36	0.5	1.1	3.0	4.1	5.7	8.5	11.1	18.9	25.1	91.5
	37	0.8	2.0	4.5	6.2	8.5	11.3	13.9	23.2	30.6	117.2
Byrnes Parade	38	0.5	0.8	1.3	1.6	2.1	2.2	2.7	3.1	3.7	7.9
Possum Street	39	1.7	3.1	4.7	6.0	7.8	8.3	9.4	13.8	15.3	32.1
Gowdie Street	40	1.2	2.0	3.2	3.9	4.6	5.1	5.7	7.8	9.4	20.5
Dalley Street	41	0.1	0.3	0.5	0.7	0.9	1.0	1.3	2.0	2.5	6.0
East Street Extended	42	0.8	1.4	2.1	2.6	3.1	3.4	3.8	5.1	6.2	13.1

Flow Path Label / ID	ID	Peak Discharge (m^3/s) for Design AEP (60 minute storm duration)									
		1 EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF
James Street	43	0.1	0.3	0.9	1.5	2.3	2.7	3.1	4.9	6.5	17.0
	44	1.1	1.5	2.1	2.4	2.7	3.1	3.4	4.6	5.6	12.4
Boundary Street	45	2.5	4.6	6.6	8.0	10.1	11.6	13.4	18.7	22.8	53.4
Gordon Lane	46	0.6	1.3	2.0	2.5	3.2	3.7	4.4	6.3	8.1	30.1
Razorback Road	47	1.0	2.0	5.6	8.1	11.7	16.8	22.0	40.8	56.9	272.4
Farris Street	48	0.5	1.0	1.5	1.8	2.2	2.5	2.8	3.9	4.8	10.2
Porters Road	49	0.4	0.7	1.1	1.4	1.7	1.8	2.2	3.5	4.7	26.0
Razorback Road	50	1.4	2.2	3.0	3.5	4.1	4.5	5.1	7.2	9.1	37.3
Crossley Street	51	0.8	1.4	5.2	8.7	14.0	20.1	25.7	45.1	61.9	233.9

^ Note: Cross section ID 14 represents the peak flow approaching Gordon Lane, whereas cross section ID 15 represents peak flow overtopping Gordon Lane.



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LEGEND

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

Data Sources:

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

Mount Morgan Model

Key Flowpath Discharge Locations

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	12/07/2018
VERSION:	1

Figure 33

7.5 Stormwater Network Capacity

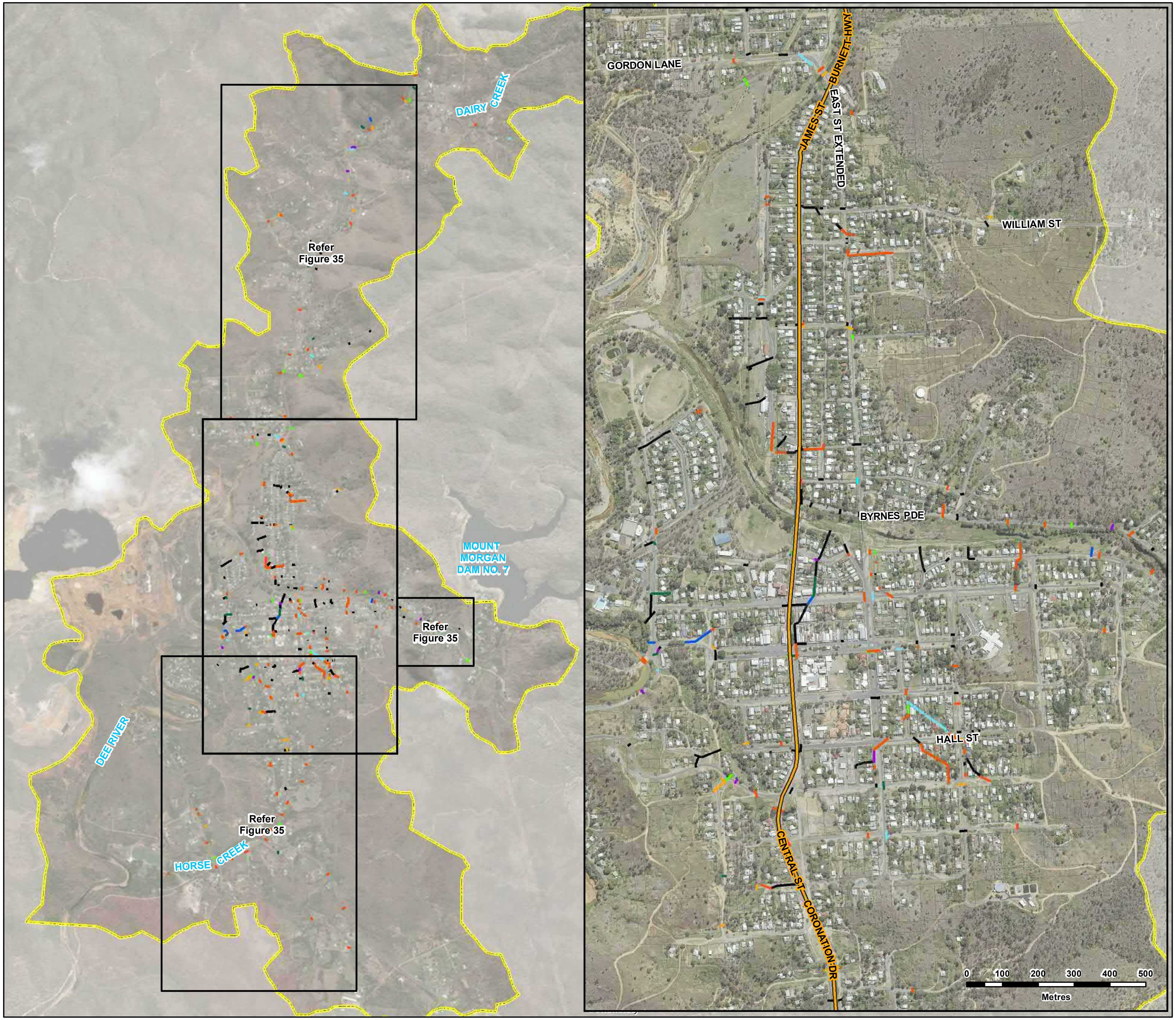
Figure 34 provides a spatial analysis of the existing underground network capacity, for the 60 minute storm duration.

It can be seen that a significant proportion of the network is performing at capacity in a 1EY event, with an estimated 35% 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.

The majority of the network flowing at capacity during a 1 EY event are located within the town centre of Mt Morgan. The pipe network across Byrnes Parade and Dee Esplanade and along East Street and Black Street are predicted to be flowing at capacity. It is also anticipated that several pipes located along Razorback Road will be flowing at or above 80% capacity.

In an 18% AEP event, 49% of the network is predicted to be at capacity. In addition to the above mentioned network, several additional mains have been identified along Razorback Road to now be performing at capacity during an 18% AEP event.

In a 1% AEP event, up to 61% of the network is at 80% or more capacity. Similar to the 1 EY and 18% AEP events, the majority of pipe networks at capacity are located within Byrnes Parade, Dee Esplanade, East Street and Black Street. Several mains along Horse Creek, Burnett Highway, Coronation Drive, and Central Street are also at capacity during the 1% AEP event.



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LEGEND

Hydraulic Model Extent

Pipe Flowing Full In

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

Data Sources:

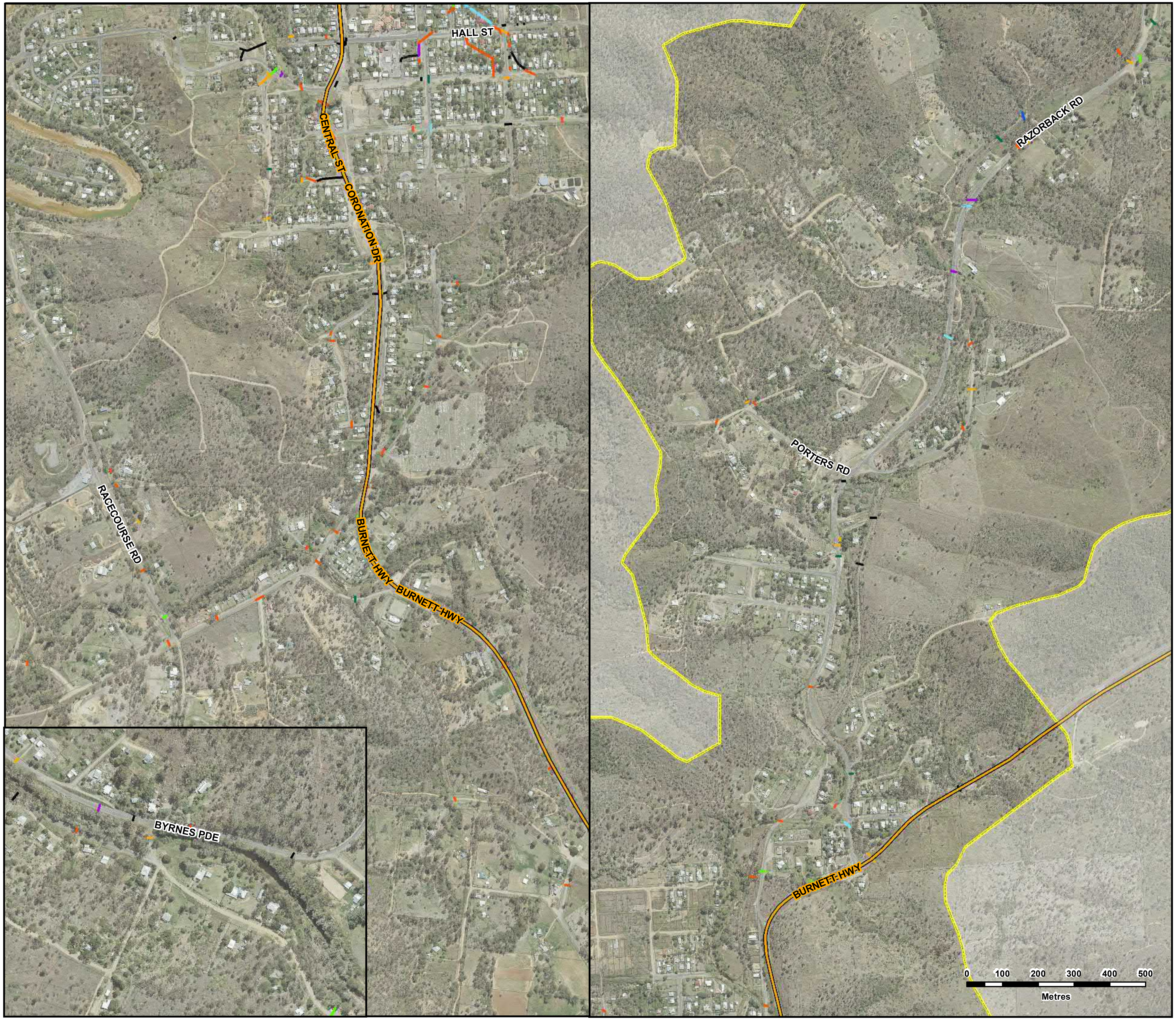
DCDB (c) 2016 QLD Government
Imagery (c) 2016 RRC

Mount Morgan Model

Network Capacity Analysis
Sheet 1 of 2

PROJECT ID	60534898
CREATED BY	staffordl
LAST MODIFIED	18/12/2018
VERSION:	1

Figure 34



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LEGEND

- Hydraulic Model Extent
- Highways
- Cadastre

Pipe Flowing Full In

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

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

Mount Morgan Model

Network Capacity Analysis
Sheet 2 of 2

PROJECT ID	60534898
CREATED BY	staffordl
LAST MODIFIED	18/12/2018
VERSION:	1

Figure 35

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8.0 Dam Failure Modelling

8.1 Overview

The Mount Morgan No. 7 Dam is a mass concrete dam (with zoned earthen embankments) located directly upstream of the Mount Morgan Township. It was constructed in 1990 by the Mount Morgan Gold Mine Company and was raised by 4.5m in 1998, facilitating a total storage volume of 2,926ML. The dam collects overland runoff from Limestone Creek and the Dee River (whose combined catchment area is 38.8km^2) and rests at their confluence. The spillway itself is an uncontrolled ogee crest concrete gravity spillway which spans 90.6m and sits roughly 16m above the base of the dam.

The most recent FIA was undertaken by SunWater in 2009 in order to 'determine the failure impact rating of the dam based on the number of population at risk downstream of the dam in the event of dam failure' (SunWater, 2009). The FIA was conducted in accordance with DNRM's "Guidelines for Failure Impact Assessment of Water Dams", using the Sunny Day Failure (SDF) scenario as the dam failure event.

Dam failure modelling scenarios within this study were undertaken with the intention to develop a better understanding of flood risk downstream of the No. 7 dam. The primary purpose is not to compare results between previous studies, but rather to investigate flood risks to the Mount Morgan Township using new technologies consistent with modelling platforms adopted for other FMS models.

The dam failure modelling undertaken in this study does not constitute a Failure Impact Assessment.

8.2 Methodology

8.2.1 Overview

This assessment maintains the previous study's methodology at and upstream of the spillway, with a combination of calibrated URBS (hydrologic) and MIKE 11 (1D hydraulic) models being utilised to estimate hydrographs immediately downstream of the dam. Downstream of the dam, methodologies differ:

- The **previous study** maintains a broad-scale 1D model which extends 26km downstream of No. 7 Dam; and
- The **current study** adopts a 4m Cartesian grid model (TUFLOW GPU HPC), extending approximately 9km downstream of the dam near the Horse Creek – Dee River confluence.

In order to maintain consistency between hydrologic components at the upper limits of the hydraulic model, hydrographs were extracted from the MIKE 11 dam breach model (SunWater, 2009) and applied as discharge timeseries via a 2d source inflow boundary condition. This allowed for stable introduction of significant volumes into the model based on the topography at the upstream boundary.

8.2.2 Breach Parameters

Breach parameters were adopted as per SunWater's FIA. As per SunWater's Failure Impact Assessment Report (2009), the following parameters were adopted:

- 30% of the total monoliths instantaneously fail. At Mount Morgan No. 7 Dam, this equates to 3 monoliths (9 total) being removed at the spillway to the dam foundation (RL 235m).
- The breach development occurs over a 10 minute period.

8.2.3 Differences and Limitations

A number of differences and limitations are noted between the adopted methodologies for the previous and current studies. These may be broadly summarised as follows:

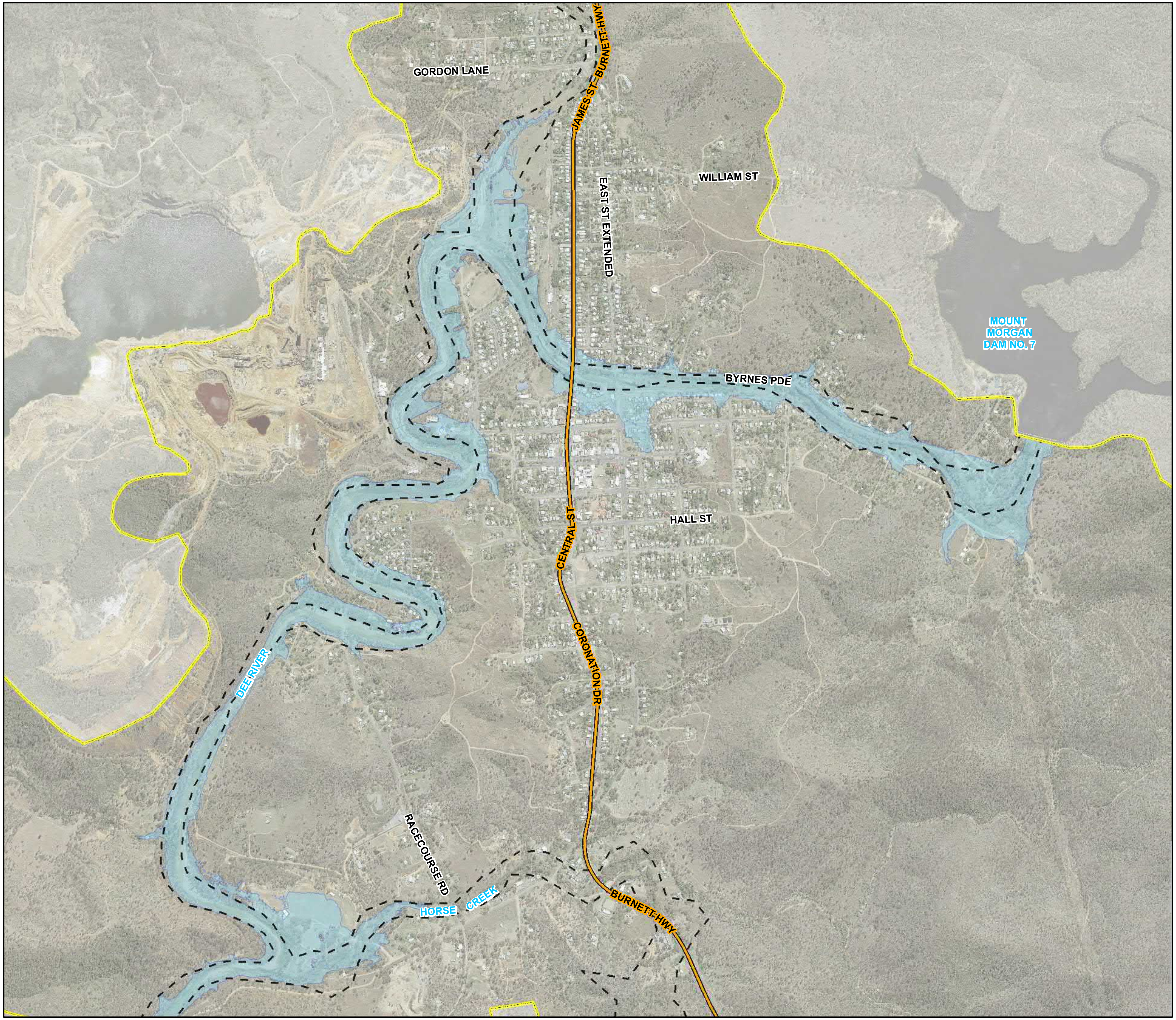
- The previous study was conducted before broad-scale aerial survey was available and therefore relied on a combination of sparse, surveyed cross sections and 20m contours (picked up in 1982 with a vertical accuracy of ±5m and horizontal accuracy of ±20m) to inform the model topography. The current study is able to utilise detailed LiDAR in the form a 1m DEM (picked up in 2016 with a vertical accuracy of ±0.15m and horizontal accuracy of ±0.40m), allowing for significantly greater detail of the landforms to be represented in the model.

- The previous study utilised a 1D model to determine peak flood surfaces throughout the impact zone. Whilst this model platform is capable of simulating open channel flow in natural streams, limitations are realised in areas where sinuosity or backwater may drive flood extents (depending on the model detail).
- Due to the large scale of the hydraulic model, minor and major road crossing's impact on the flood behaviour were assumed to be insignificant in the previous study and were therefore excluded from the hydraulic model. As such, impedance posed by bridge abutments and floodways modelled in this study may (in part) be responsible for differences between modelled results.
- Neither study takes into account the potential geomorphic or ecologic (riparian vegetation) changes within the Dee River channel. Aside from depth-varying roughness values adopted for this study, bedform and resistance are set as static parameters.
- Neither study assesses the hydraulic impact of embankment (or other major hydraulic controls) failure downstream of the dam site, such as bridges or bridge abutments.

8.3 Comparison to Previous Study

Several key differences exist between the modelled results of the previous and current study as a result of the varying purposes and end users. Figure 36 to Figure 38 present comparisons between the modelled scenarios. Differences are noted as follows:

- Southeast of Byrnes Parade → newly modelled flood extent widens across River Street as a result of higher topographic detail used in this study.
- Southern bank of Dee River between Edward Street and Central Street (highway) → newly modelled flood extent is significantly wider, especially directly upstream of the major transport corridor and East Street where break-out flows backup within low-lying areas. These differences are a result of the higher detail landforms, and hydraulic controls included in this study. Some instances are likely a result of the positioning of MIKE 11 model cross section locations.
- Showgrounds (Horse Creek) → flood extents within this study are significantly wider due to lateral expansion of floodwaters across the low-lying floodplain.
- Horse Creek upstream of Racecourse Road → predicted peak flood extents within the previous study extended a significant distance upstream of Racecourse Road, with some portions of the predicted peak flood extent exceeding the height of the No. 7 Dam spillway. It is assumed this may be as a result of post-processing triangulation issues within the previous study. This study does not predict flood risk to structures east of Racecourse Road within Horse Creek.



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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent (Dam Break Scenario)
- PMF, Without Failure Flood Extent (Previous Study)
- PMF, Without Failure Flood Extent

Data Sources:

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

Mount Morgan Model

Flood Extent Comparison
PMF, Without Failure

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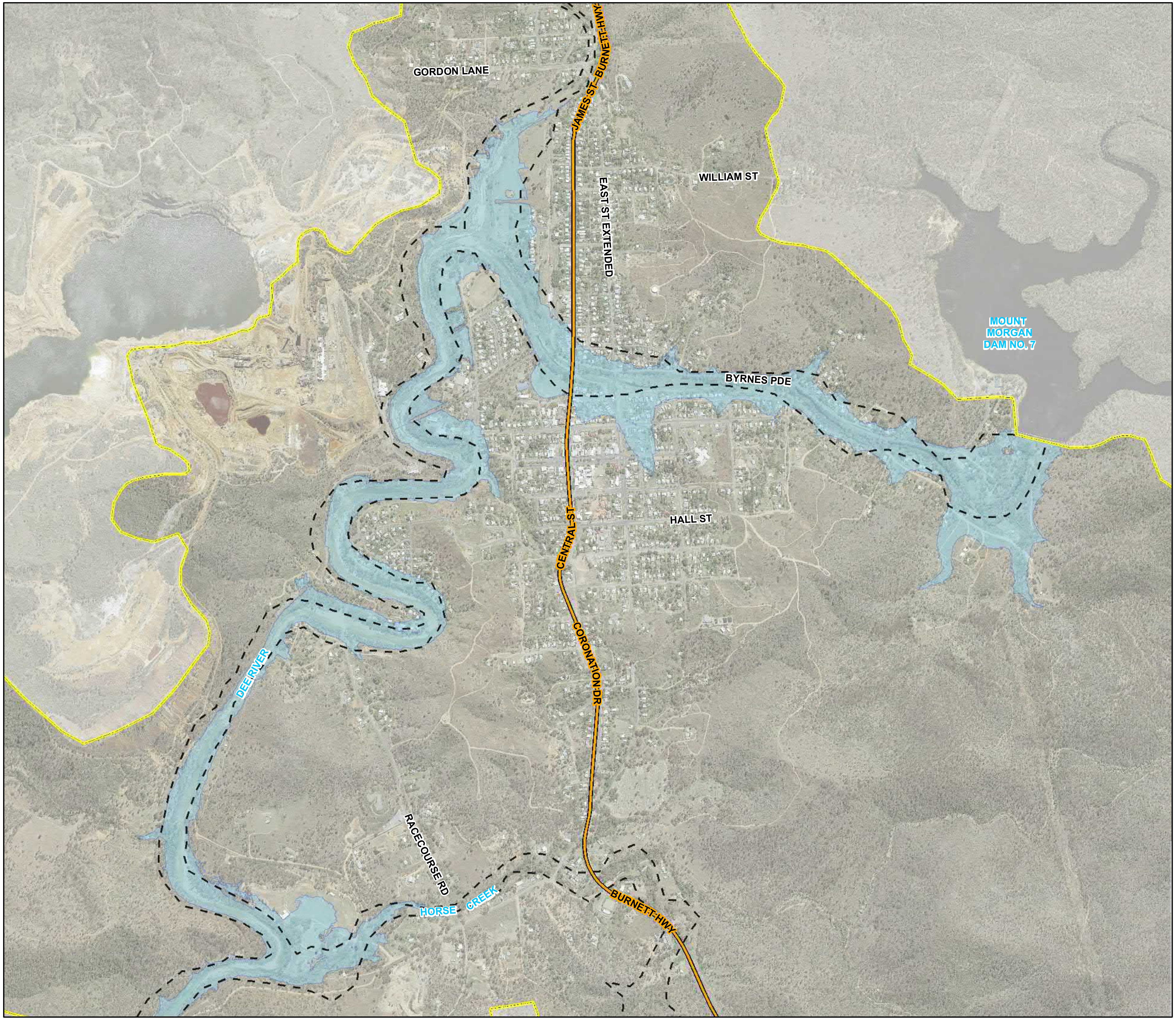
CREATED BY	staffordl
LAST MODIFIED	1/08/2018
VERSION:	1

Figure 36



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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent (Dam Break Scenario)
- Sunny Day Failure Flood Extent (Previous Study)
- Sunny Day Failure Flood Extent

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

Mount Morgan Model

Flood Extent Comparison
Sunny Day Failure

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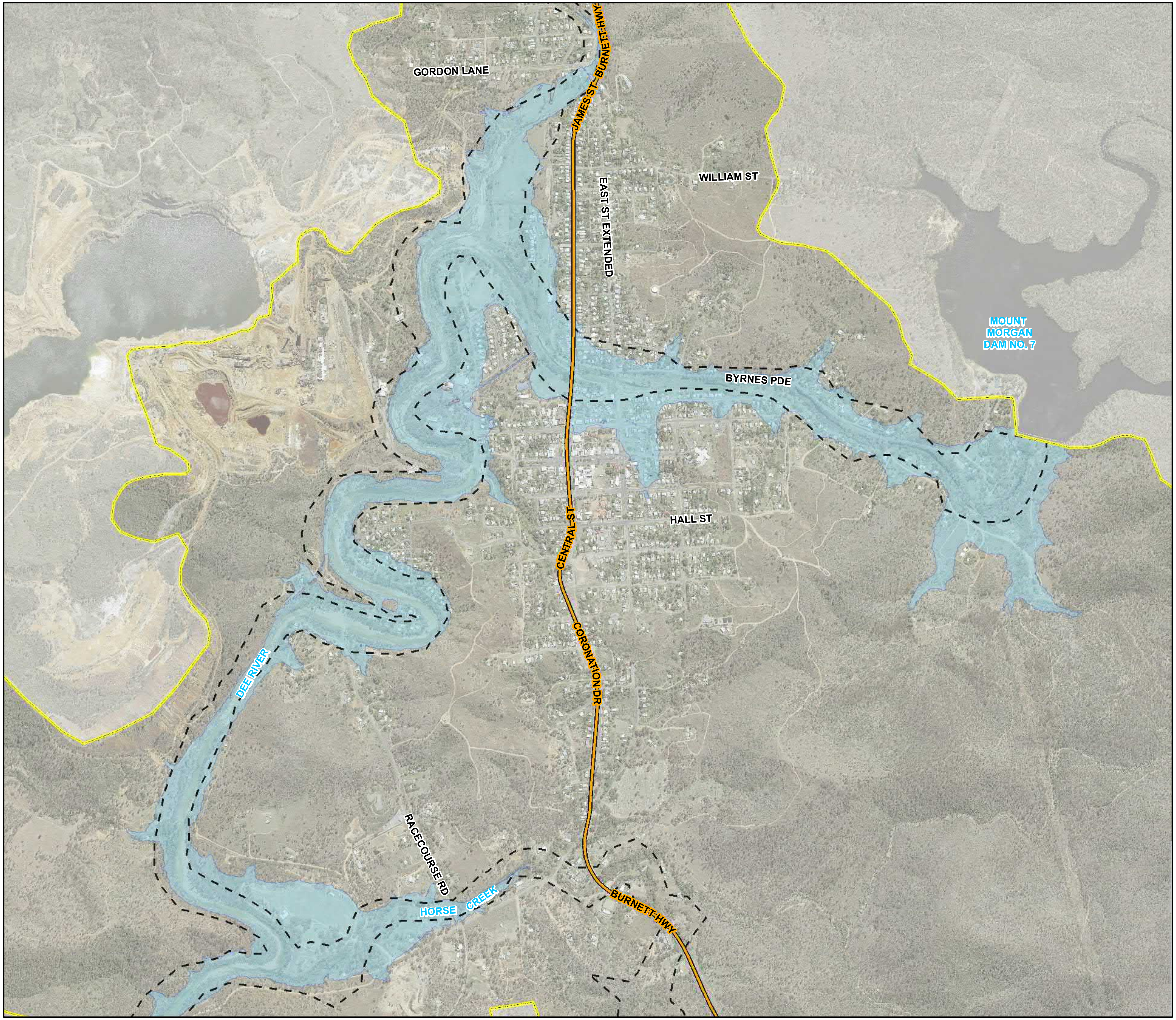
LAST MODIFIED	1/08/2018
VERSION:	1

Figure
37



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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent (Dam Break Scenario)
- PMF, With Failure Flood Extent (Previous Study)
- PMF, With Failure Flood Extent

Data Sources:

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

Mount Morgan Model

Flood Extent Comparison
PMF, With Failure

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LAST MODIFIED	1/08/2018
VERSION:	1

Figure
38

8.4 Results Analysis

8.4.1 Peak Flood Extents, Depths and Velocities

Maps 64 to 103 of the Volume 2 report show the peak flood extents, depths and velocities for the PMF (No Failure), Sunny Day Failure and PMF (With Failure) events. The modelling shows:

8.4.1.1 PMF (No Failure)

- Maps 64 to 73

Peak flood extents broaden beyond the Dee River banks approximately 150m downstream of the spillway, inundating several properties. Within this inundation extent is Byrnes Parade, which is completely inundated by 4.0 to 5.0m from Perlick Street through to its beginning at the highway. Flood extents break out at Butler Street, Mine Road, Tipperary Road, Usher Street and the Showgrounds. Flood extents also widen across localised low points in the natural topography where gully lines meet the river. Key instances where this occurs includes:

- Possum Street;
- East of Edward Street, across River Street;
- Norton Street; and
- Dee Esplanade, within the concrete-lined channel which extends along Royal Lane and Campion Street.

Peak flood depths within the Dee River channel generally range between 8.0 and 10.0m with break out depths through nearby parcels ranging between 1.0 and 3.0m. The PMF event is also predicted to overtop the highway, at which depths over the crown exceed 2.7m.

Peak depth averaged velocities within the Dee River channel range between 3.0 and 6.0m/s with break out velocities rapidly dissipating through residential lots (generally 1.0m/s or less). Higher velocities in break-out areas are noted within road corridors due to reduced impedance, reaching up to 2.0m/s.

8.4.1.2 Sunny Day Failure

- Maps 79 to 88

Peak flood extents follow similar trends to the above description, with the addition of a lateral channel break-out immediately downstream of the dam wall. The above-mentioned lower-lying gullies are inundated, with larger extents noted at the concrete-lined channel near Royal Lane and Campion Street. The peak flood extent at this location is anticipated to overtop Morgan Street and reach as far as Gordon Street. Floodwaters are again expected to overtop the main transport corridor with floodwaters now stretching across the entire oval at Bedsor Street.

Peak flood depths within the Dee River channel generally range between 8.0 and 12.0m with break out depths through nearby parcels ranging between 1.0 and 4.0m. The Sunny Day Failure event is also predicted to overtop the highway.

Peak depth averaged velocities within the Dee River channel range between 5.0 and 8.0m/s with break out velocities rapidly dissipating through residential lots (generally 1.0m/s or less). Higher velocities in break-out areas are noted within road corridors due to reduced impedance, reaching up to 2.5m/s.

8.4.1.3 PMF (With Failure)

- Maps 94 to 103

Peak flood extents again follow similar trends to the above description, extents increasing by 20m to 50m through low-lying areas in comparison to a SDF scenario. Significant increases in peak flood extents in comparison to the SDF scenario are noted at the following locations:

- Glen Gordon Street, where peak flood extents now encompass all structures along this street;
- Gordon Lane and Baree Road;
- Thompson Avenue;
- Limerick Lane (near Tipperary Road); and
- Low-lying areas west of Racecourse Road, including the full extent of the Showgrounds.

Peak flood depths within the Dee River channel mostly exceed 10.0m, with extended segments surpassing 11.0m. Properties facing onto Byrnes Parade and surrounding local roads experience over 6.0m of flood water, with similar depths anticipated for properties near Dee Street.

Peak depth averaged velocities within the Dee River channel continually exceed 5.0m/s, with some segments reaching 10.0m/s in high-flow zones. Channel break-out flows near Currin Street and Perlick Street range between 1.5 to 2.5m/s, with one structure experiencing velocities above 4m/s. Velocities within road corridors (River Street, Byrnes Parade, Bridge Street) range between 2.0 and 3.0m/s, with peak segments along Byrnes Parade in excess of 5m/s. These velocities are expected to induce shear stresses above the strength of the road surface, resulting in delamination and potentially full-depth erosion of the road pavement.

8.4.2 Peak Flood Hazard

Maps 74 to 78, 89 to 93 and 104 to 108 of the Volume 2 report show the peak flood hazard for the PMF (No Failure), Sunny Day Failure and PMF (With Failure) events. The modelling shows:

8.4.2.1 PMF (No Failure)

- Maps 74 to 78

The PMF event peak flood extents are predicted to produce various hazard classes along the Dee River channel and surrounding road corridors and private properties. Hazard class six is mainly anticipated along the Dee River channel and ridges. Directly downstream of the dam wall, Perlick Street, River Road and the adjacent dwellings are expected to experience category five flooding. Further downstream, Byrnes Parade experiences category five and six flooding, also restricting access via Possum Street and Pugh Street. Properties along Henry Street are predicted to experience a combination of categories three, four and five. On the Southern side of the river, Dee Esplanade and River Street experience hazard class four and five flooding with a significant number of adjacent properties predicted to experience class three and four flood hazards.

Further downstream, flood hazards of category four and five encroach into East Street. It is noted that the properties along Bridge Street and Cornes Street and properties along East Street and Dee Street to Morgan Street and Royal Lane have the potential to experience category four and five flood hazards during the PMF event.

Category six flooding continues to extend further downstream of the Burnett Highway Bridge however is largely contained to the main river channel. Properties along Limerick Lane and Usher Street are anticipated to be on the fringe of category three and four flooding. The PMF event peak flood breakout at the Mount Morgan showgrounds is anticipated to be within class one and four flooding.

8.4.2.2 Sunny Day Failure

- Maps 89 to 93

Similar to the PMF flood event, the SDF produces hazard class six along the main river channel however the extent of category six has broadened, in particular, directly downstream of the dam wall. Properties along Lake Road, Perlick Street and River Road are predicted to be inundated with category six flooding, with properties along Currin Street also predicted to experience class three flooding. Along the northern river bank, break out flow now encroaches as a class six hazard along the entire length of Byrnes Parade. Several properties along Byrnes Parade are now on the fringe of category six inundations. Dee Esplanade and River Street road corridors and adjacent properties are also forecast to experience category six flooding.

The SDF flood extent is anticipated produce category six floodwaters along East Street and Royal Lane from Dee Esplanade, River Street, Bridge Street and Cornes Street to Dee Street. Category five flooding extends across several properties nested within Dee Esplanade to Morgan Street and from James Street to Royal Lane.

Category four and five flooding is anticipated for properties near Byrnes Parade from Roche Street to Dalley Street. Properties near Glen Gordon Street are also anticipated to be on the fringe of category one and two flooding.

Further downstream, properties along Bulter Street are predicted to experience category five flooding and properties along Limerick Lane and Usher Street are predicted to experience a combination of category three, four and five flooding. The SDF event peak flood breakout at the Mount Morgan showgrounds is anticipated to be within class one and three flooding.

8.4.2.3 PMF (With Failure)

- Maps 104 to 108

Peak flood extents follow similar trends to the above description, with the addition of a lateral channel break-out immediately downstream of the dam wall and further downstream into the urban town centre of Mount Morgan. Within the PMF event and with dam failure, all properties adjacent to the river are estimated to experience category six flooding. Access to these properties via River Road, Perlick Street, Lake Road, Possum Street, Pugh Street, Henry Street, Brynes Parade, Dee Esplanade, Dee Street and River Street is also expected to be hazard category six flooding.

Similar to the SDF, on the northern side of the Dee River, category six flooding is evident along Byrnes Parade from Roche Street to Dalley Street however the category six flood hazard has deepened, also effecting domestic properties situated along Neil Street and Dobbs Street. A large number of properties in Glen Gordon Street are anticipated to experience category five and six flooding.

During this event, properties from Dee Esplanade to Morgan Street and from Royal Lane to James Street are predicted to experience category six flooding with several other properties now encroaching on category five flooding also.

Further downstream, Chenery Street and Thompson Avenue are now predicted to experience class four category floodwaters, whereas properties along Bulter Street experience category five. The majority of the category six flooding is still largely contained within the main channel of the Dee River.

During the PMF and dam failure event, Limerack Lane, Usher Street, Shamrock Street and Macks Esplanade and their surrounding properties experience category five and six flooding. Finally, the Showgrounds Road has been completely inundated with class five and six flood, restricting access to the Mount Morgan Showground which is now predicted to experience category five flooding across the entire property.

8.4.3 Hydraulic Controls

Several structures and crossings serve as critical controls by impeding high-stage flows found in dam break scenarios. This significant resistance to flow and impacts to flood behaviour occurs through several mechanisms, but can generally be understood as a combination of the following:

- reduced flow area (i.e. impervious abutments or bridge decks);
- increased turbulence;
- increased drag; and
- contraction and expansion, all of which reduce the efficiency of the flood water.

Locations where substantial impedance is observed within the dam break scenarios have been summarised in Table 15. It is important to appreciate the degree to which each control impacts the peak flood height as this will dictate the degree to which the flood extent will expand upstream.

Table 15 Hydraulic Control Summary

Location Within Dee River	Hydraulic Control	Indicative Head Loss (m)		
		PMF (No Failure)	Sunny Day Failure	PMF (With Failure)
East Street	Pedestrian suspension bridge	0.5	0.8	1.2
James Street / Central Street (Burnett Highway)	Bridge abutments and deck	1.6	1.8	1.9
Rail Line (north of Mine Road)	Bridge abutments and deck	0.4	0.6	1.3

8.4.4 Buildings Within Flood Extents

High-level analysis of building polygons within each of the dam break scenario flood extents was undertaken in order to understand potential impacts using the new hydraulic model. This assessment is not in accordance with any guidelines and nor does it assess the risk in relation to surveyed floor heights. As such, **it should not be used in place of a formal flood impact assessment**. Quoted numbers are based on Council's property database (which excludes small structures such as garden sheds). Table 16 summarises the results of the structure polygons within the peak flood extent for each of the assessed scenarios.

Table 16 Structures within Flood Extents Summary

Scenario	Habitable		Uninhabitable		Total	
	Residential	Commercial	Residential	Commercial	Residential	Commercial
PMF (No Failure)	110	4	19	8	**129**	**12**
Sunny Day Failure	159	9	31	12	**190**	**21**
PMF (With Failure)	253	19	48	26	**301**	**45**

8.4.5 Timings

8.4.5.1 PMF (No Failure)

Inundation timings for the PMF (no failure) are presented in **MM-61** in Volume 2 of this report in 15 minute intervals. Based on the results, Byrnes Parade is susceptible to overtopping within 1.25 hours of the storm event occurring. Flows are not anticipated to break out of the Dee River channel within the township until ~1.5hours into the simulation (close to the peak). Inundation initially occurs at Dee Esplanade and propagates further over a 1 hour period with the peak extent occurring across residential parcels between 2.5 and 3 hours into the event.

8.4.5.2 Sunny Day Failure

Inundation timings for the SDF scenario are presented in **MM-62** in Volume 2 of this report in 3 minute intervals. Based on the results it can be appreciated that the flood wave under a failure scenario propagates rapidly throughout the Dee River reach, with highly hazardous flood waters reaching urban areas within 15 minutes. This indicates the potential need for an automatic, instantaneous warning system to trigger evacuations in a dam failure event. The flood wave is predicted to peak across developed parcels upstream of the highway within 21 to 24 minutes of the breach. Impacts downstream of the mine near Tipperary Road are anticipated to occur 30 minutes after the breach, with inundation of the Showgrounds occurring after 45 minutes.

8.4.5.3 PMF (With Failure)

Inundation timings for the PMF (with failure) scenario are presented in **MM-63** in Volume 2 of this report in 3 minute intervals. The results describe a similar outcome to the SDF, with the flood wave reaching urban areas in approximately 10 minutes. Byrnes Parade and privately-owned parcels directly downstream of the dam wall are predicted to be inundated in less than 10 minutes. The flood wave is again predicted to peak across developed parcels upstream of the highway within 21 to 24 minutes of the breach. Impacts downstream of the mine near Tipperary Road are anticipated to occur 30 minutes after the breach, with inundation of the Showgrounds occurring after 40 minutes.

8.4.6 Summary and Future Work

The results of this study show that the inclusion of detailed topographic datasets and 2D modelling of the landforms and hydraulic controls downstream of the No. 7 Dam result in significantly different peak flood extents and potential flood impacts to those previously reported (SunWater, 2009). As such, it is recommended that the results of this study be communicated to the dam owner which will allow for a better understanding of potential flood risks and reassessment of the need for an updated failure impact assessment.

Future work should also consider assessment of flood risk as a result of cascading bridge or embankment failures, which may trigger larger flood waves and increase the risk to downstream properties.

9.0 Sensitivity Analyses

9.1 Overview

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

- Sensitivity 1 – Increase in manning's roughness values (15%).
- Sensitivity 2 – Decrease in manning's roughness values (15%).
- Sensitivity 3 – Increase in rainfall intensities to replicate potential climate change impacts (30% increase in rainfall intensity).
- Sensitivity 4 – Coincident event of full storage dam failure and Mount Morgan local catchment.
- Sensitivity 5 – 20% Underground Stormwater Infrastructure Blockage.
- Sensitivity 6 – 50% Underground Stormwater Infrastructure Blockage.
- Sensitivity 7 – 100% Underground Stormwater Infrastructure Blockage.
- Sensitivity 8 – Key Cross Drainage Culvert Blockage.

Further discussion on each sensitivity analysis is provided below.

9.2 Hydraulic Roughness

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

The following maps represent the results of the sensitivity testing.

- 15% Increase in Roughness → **Map MM -109**
- 15% Decrease in Roughness → **Map MM -110**

Map MM -109 indicates that with a uniformly increased roughness value across all material types, there is a corresponding overall decrease in peak flood heights and peak flood extent in Dee River and a slight increase in peak flood heights and peak flood extent in Dairy Creek and Horse Creek. The majority of the urban area within the catchment experience negligible increases in peak water surface elevation and extent. The most significant decrease in peak flood height is contained within Dee River and is anticipated to be above depths of 0.3m. Areas directly downstream of the Mount Morgan No. 7 Dam are also anticipated to experience decreases of approximately 150mm – 250mm. The most significant increases are contained within the main channels of Dairy Creek and Horse Creek, with depths between 20mm and 150mm anticipated.

The result from the sensitivity analysis which applies a 15% decrease in manning's roughness values are shown in **Map MM -110.** The decrease in roughness indicates a corresponding decrease in peak flood heights, within Dee River, Dairy Creek and Horse Creek. Similar to Map MM -109, the most significant decrease in peak flood height is contained within Dee River and is anticipated to be above depths of 0.3m. Areas directly downstream of the Mount Morgan No. 7 Dam are also anticipated to experience decreases of approximately 20mm – 75mm. Unlike Map MM -110 however Dairy Creek and Horse Creek experience decreases in peak flood height between 0mm and 75mm.

9.3 Climate Change

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

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

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

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

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

As a conservative approach, the overall rainfall in the Mt Morgan TUFLOW model was increased by 30% to represent the predicted rainfall patterns in 2100. The rainfall in the Mount Morgan GPU model simulation for the inflows was also increased by 30%, for the 1% AEP design event.

Map MM -111 indicates that the 30% increase in applied rainfall significantly increases peak flood heights and extents throughout the catchment. The peak flood height throughout the majority of Dee River and Horse Creek increased by at least 225mm, with most areas increasing >300mm. Results indicate that for smaller tributaries of the creek systems, peak flood heights will increase between 20mm and 150mm.

9.4 Full Storage Dam Failure Coincident Event

Sensitivity testing of peak flood height and extent for coincident events between Mount Morgan local catchment and full storage dam failure was undertaken with the intent of:

- Understanding the effect of dam break floodwaters on local catchment flood behaviour; and
- Quantifying the degree to which a coincident event would worsen the peak flood heights and extents within the Dee River.

Full storage dam failure has been modelled in equivalence to a sunny day failure as described in Section 3.10.

The following maps represent the results of the sensitivity testing.

- Dam Break Influence → **Maps MM -112** (18% AEP) and **MM-113** (1% AEP)
- Local Catchment Influence → **Maps MM -114** (18% AEP) and **MM-115** (1% AEP)

9.4.1 Dam Break Influence

A dam failure's effect on local catchment flood behaviour was quantified by comparing a coincident scenario (dam failure + local catchment) to a local catchment event (no dam failure). The effects of full storage dam failure floodwaters on local catchment flood behaviour are shown in Maps **MM-112** and **MM-113**.

As can be observed, dam failure floodwaters have limited impact on local catchment flood behaviour outside the Dee River corridor in both the 18% and 1% AEP flood events. This is due to the steep, energy-driven nature of flowpaths throughout the Mount Morgan Township and surrounds. Within the Dee River corridor and lower extremities of Dairy Creek, Horse Creek and Campion Street concrete channel, the flood waters as a result of dam failure dominate.

9.4.2 Local Catchment Influence

The local catchment's effects on dam failure floodwaters within the Dee River was quantified by comparing a coincident scenario (dam failure + local catchment) to a dam failure scenario (no local catchment event). The effects of a local catchment flood event on dam failure floodwaters are shown in Maps **MM-114** and **MM-115**.

As can be observed, local catchment flood events have the potential to exacerbate dam failure flood heights and extents. During more frequent flood events (i.e. 18% AEP) peak flood heights and extents show limited change upstream of the Showgrounds with increases generally within 20-30mm. Increases in peak flood heights of 200-350mm are seen downstream of Racecourse Road within Horse Creek and at the showgrounds.

Similar observations are noted during larger (1% AEP) local catchment coincident events. Upstream of the Dee River – Dairy Creek confluence, increases in peak flood heights between 20 – 40mm can be expected, which increases to 50 – 100mm downstream of Dairy Creek. Despite this increase, changes to the peak flood extents are negligible. Significant increases in peak flood extents are predicted near the confluence of Horse Creek and Dee River. Increased flood levels of up to 0.5m are expected downstream of Racecourse Road, resulting in widened flood extents within Horse Creek and the Showgrounds.

9.5 Stormwater Infrastructure Blockage

Testing of the model sensitivity to the underground stormwater infrastructure being blocked by debris, was undertaken for the 18% AEP event using an increasing percentage blockage on the underground stormwater network. This excluded cross drainage structures which was the subject of a specific sensitivity analysis (refer to Section 9.6).

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

- 20% Increase in Blockage → **Map MM -114**
- 50% Increase in Roughness → **Map MM -115**
- 100% Increase in Roughness → **Map MM -116**

9.5.1 20% Blockage of Stormwater Infrastructure

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

The results presented in Map **MM -114** indicate that across the majority of the catchment, applying a 20% blockage to the stormwater network causes negligible change in peak water surface elevation with most areas being between ± 0.02 m of the baseline peak flood height results. However, specific areas in the vicinity of Hall Street and Campion Street experience a slight increase of approximately 20mm when the stormwater network is 20% blocked.

9.5.2 50% Blockage of Stormwater Infrastructure

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

Blockage of the stormwater infrastructure by 50% results in higher peak flood heights in the vicinity of Hall Street and Campion Street. Map **MM -115** demonstrates the increase in peak water surface elevation predicted to be between 20mm and 225mm when the stormwater network is 50% blocked. Majority of the catchment demonstrates negligible change in peak water surface elevation with most areas being between ± 0.02 m of the baseline peak flood height results, similar to the 20% blockage.

9.5.3 100% Blockage of Stormwater Infrastructure

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

The results shown in Map MM -116 that majority of the catchment demonstrates negligible change in peak water surface elevation with most areas being between ± 0.02 m of the baseline peak flood height results, similar to the 20% and 50% blockages. However, several areas experience increases in peak flood heights. Areas which are predicted to experience increases are those around Campion Street, Hall Street, Black Street, Morgan Street and Byrnes Parade, with increases of up to 300mm anticipated.

9.6 Key Cross Drainage Culvert Blockage

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

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

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

9.6.1 Factors influencing blockage

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

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

9.6.2 Common Blockages

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

9.6.3 Floating Debris

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

9.6.4 Non-Floating Debris

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

9.6.5 Urban Debris

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

9.6.6 Design Blockage Level

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

9.6.6.1 Debris Available

Table 17 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 Mt Morgan has been selected as source areas generally falling between the High and Low categories.

9.6.6.2 Debris Mobility

Table 18 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 Mt Morgan has been selected as source areas generally falling between the High and Low categories.

9.6.6.3 Debris Transportability

Table 19 Debris Transportability - Ability to Transport Debris to the Structure (Table 6.6.3 ARR, 2016)

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

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

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

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

A **High** classification of debris transportability for Mt Morgan has been selected as:

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

9.6.6.4 Debris Potential

Table 20 1% AEP Debris Potential (Table 6.6.4 ARR, 2016)

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

A **High** classification of debris potential for Mt Morgan has been selected as the combination of individual factors is HMH.

9.6.6.5 AEP Adjusted Debris Potential

Table 21 AEP Adjusted Debris Potential (Table 6.6.5 ARR, 2016)

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

A **Medium** classification of AEP Adjusted Debris Potential for Mt Morgan has been selected as the Event AEP assessed is 18% AEP.

9.6.6.6 Design Blockage Level

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

Table 22 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 25.

9.6.6.7 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 23 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 25.

Table 24 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 25.

Table 25 Mt Morgan 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
1 / 900 RCP	W < L10	Medium	50%	3.315	L	15%	50%
1 / 900 x 300 RCBC	W < L10	Medium	50%	0.519	M	40%	50%
1 / 1000 x 1000 RCBC	W < L10	Medium	50%	3.716	L	15%	50%
2 / 1200 RCP	W < L10	Medium	50%	3.802	L	15%	50%
1 / 1200 x 600 RCBC	W < L10	Medium	50%	1.767	M	40%	50%
3 / 1200 x 600 RCBC	W < L10	Medium	50%	1.126	M	40%	50%
2 / 1200 x 450 RCBC	W < L10	Medium	50%	1.206	M	40%	50%
1 / 1200 RCP	W < L10	Medium	50%	2.189	M	40%	50%
1 / 1500 RCP	L10 < W < 3*L10	Medium	10%	3.815	L	15%	15%
3 / 1500 RCP	L10 < W <	Medium	10%	1.917	M	40%	40%

Culvert Specification	Control Dimension	AEP Adjusted Debris Potential	Most Likely Inlet Blockage Levels	Peak Velocity (m/s)	Sediment Likelihood	Most Likely Depositional Blockage Levels	Highest Blockage Factor
	3*L10						
1 / 1500 x 750 RCBC	L10 < W < 3*L10	Medium	10%	3.309	L	15%	15%
1 / 1500 x 750 RCBC	L10 < W < 3*L10	Medium	10%	2.224	M	40%	40%
2 / 1700 RCPC	L10 < W < 3*L10	Medium	10%	2.217	M	40%	40%
5 / 1750 RCP	L10 < W < 3*L10	Medium	10%	1.628	M	40%	40%
1 / 1800 x 750 RCBC	L10 < W < 3*L10	Medium	10%	2.225	M	40%	40%
1 / 200 x 1420 RCBC	L10 < W < 3*L10	Medium	10%	3.106	L	15%	15%
2 / 2100 x 750 RCBC	L10 < W < 3*L10	Medium	10%	2.042	M	40%	40%
4 / 2100 x 1400 RCBC	L10 < W < 3*L10	Medium	10%	1.563	M	40%	40%
2 / 2100 x 500 RCBC	L10 < W < 3*L10	Medium	10%	2.068	M	40%	40%
1 / 2150 x 2150 RCBC	L10 < W < 3*L10	Medium	10%	2.222	M	40%	40%
4 / 2700 x 1900 RCBC	L10 < W < 3*L10	Medium	10%	1.576	M	40%	40%
2 / 900 RCP	W < L10	Medium	50%	1.787	M	40%	50%
1 / 900 RCP	W < L10	Medium	50%	1.545	M	40%	50%
2 / 900 RCP	W < L10	Medium	50%	3.305	L	15%	50%
3 / 1050 RCP	W < L10	Medium	50%	1.761	M	40%	50%
1 / 1050 RCP	W < L10	Medium	50%	1.806	M	40%	50%
1 / 1050 RCP	W < L10	Medium	50%	1.731	M	40%	50%
1 / 1050 RCP	W < L10	Medium	50%	2.401	M	40%	50%
1 / 1200 RCP	W < L10	Medium	50%	2.388	M	40%	50%
1 / 1200 x 1300 RCBC	W < L10	Medium	50%	3.175	L	15%	50%
2 / 1200 RCP	W < L10	Medium	50%	1.88	M	40%	50%
1 / 1200 RCP	W < L10	Medium	50%	2.119	M	40%	50%
1 / 1200 RCP	W < L10	Medium	50%	2.537	M	40%	50%
1 / 1350 RCP	W < L10	Medium	50%	1.74	M	40%	50%
2 / 1500 x 700 RCBC	L10 < W < 3*L10	Medium	10%	2.074	M	40%	40%
1 / 1650 RCP	L10 < W < 3*L10	Medium	10%	2.179	M	40%	40%
3 / 1750 x 1100 RCBC	L10 < W < 3*L10	Medium	10%	1.219	M	40%	40%

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 / 1800 x 600 RCBC	L10 < W < 3*L10	Medium	10%	2.164	M	40%	40%
2 / 2400 x 1600 RCBC	L10 < W < 3*L10	Medium	10%	1.489	M	40%	40%
2 / 2400 x 1600 RCBC	L10 < W < 3*L10	Medium	10%	2.782	M	40%	40%
2 / 3000 x 1800 RCBC	L10 < W < 3*L10	Medium	10%	2.117	M	40%	40%
3 / 3400 x 1885 RCBC	L10 < W < 3*L10	Medium	10%	1.552	M	40%	40%
1 / 3400 x 1885 RCBC	L10 < W < 3*L10	Medium	10%	2.834	M	40%	40%
1 / 3400 x 2500 RCBC	L10 < W < 3*L10	Medium	10%	3.322	L	15%	15%
1 / 4200 RCP	L10 < W < 3*L10	Medium	10%	1.845	M	40%	40%

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 Mt Morgan is 50%.

9.6.7 Results of Sensitivity Analysis

The results which are presented on **Map MM-117** show that there is negligible change to the flood extent and the change in peak flood height is minimal throughout majority of the catchment. However, there are a few specific areas where flood heights have increased due to the blockage of culverts. The specific areas and the corresponding increase in peak flood heights are:

- Culvert under James Street (near Gordon Lane) – up to 350mm increase in peak flood height.
- Culvert under Razorback Road (near Wyvills Road) – an increase of 650mm in peak flood height.
- Culvert under Razorback Road (near Porters Road) – an increase of 400mm in peak flood height.
- Culverts along Campion Street – up to 290mm increase in peak flood height.
- Culverts at Dee Street – up to 330mm increase in peak flood height.
- Culvert under Coronation Drive (near Showgrounds Road) - up to 500mm increase in peak flood height.

9.7 Summary of Sensitivity Analysis Results

Table 26 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 from the sensitivity analyses which were undertaken indicate that the most influential parameters are the applied rainfall and No. 7 Dam inflow. Whilst changes in ±15% roughness caused widespread change, the degree of difference was minor.

As can be seen in Table 26, an increase to the rainfall or inclusion of dam failure results in a large portion of the catchment experiencing increases to peak flood heights of >300mm. The 20%, 50% and 100% blockage analysis indicate that only minor pockets of urban overland flowpaths are sensitive, with very limited areas (<1% of the total flood footprint) expected to see differences greater than ±75mm. Whilst a similar case is true for the 50% culvert blockage scenario, critical areas prone to increased flood extents and damages have been identified, meaning the catchment is more sensitive to cross drainage structure blockage than subsurface network blockage.

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. Special consideration should also be given to areas within the dam failure influence zone as this scenario involves considerable uncertainty and variability.

Table 26 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	Dam Failure – Effect on 18% AEP Local Storm Event	Dam Failure – Effect on 1% AEP Local Storm Event	Coincident Event – 18% AEP Effect on Dam Failure	Coincident Event – 1% AEP Effect on Dam Failure	20% Blockage of Stormwater Infrastructure	50% Blockage of Stormwater Infrastructure	100% Blockage of Stormwater Infrastructure	Blockage of Key Cross Drainage Structures
< -0.3	0%	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%
-0.225 to -0.150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-0.150 to -0.075	2%	3%	0%	0%	0%	0%	0%	0%	0%	0%	2%
-0.075 to -0.02	4%	28%	0%	0%	0%	0%	0%	0%	0%	1%	6%
-0.02 to 0.02	71%	63%	14%	83%	78%	38%	13%	100%	99%	98%	87%
0.02 to 0.074	23%	4%	23%	1%	1%	32%	30%	0%	1%	1%	2%
0.075 to 0.150	0%	2%	13%	0%	0%	14%	24%	0%	0%	0%	1%
0.150 to 0.225	0%	0%	6%	0%	0%	10%	17%	0%	0%	0%	1%
0.225 to 0.299	0%	0%	5%	0%	0%	5%	1%	0%	0%	0%	0%
>0.3	0%	0%	39%	16%	21%	1%	15%	0%	0%	0%	1%

10.0 Flood Hazard and Risk Assessment

10.1 Overview

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

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

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

10.2 Baseline Flood Hazard Analysis

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

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

Identifying hazards associated with flood water depth and velocity help focus management efforts on minimizing the risk to life and property. As such, a series of Flood Hazard Zones have been developed according to AR&R 2016, in alignment with recommendations made in the AR&R, 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 AR&R 2016 are identical to those of which shown in the Guide for Flood Studies and Mapping in Queensland document (DNRM, 2016). However, the AR&R guidelines provide additional definition as to the classification levels for the hazard classes. This information is summarised in the Table 27 and Table 28.

Table 27 AR&R 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 28 AR&R 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 AR&R 2016 flood hazard classification limits are also shown graphically in Figure 39.

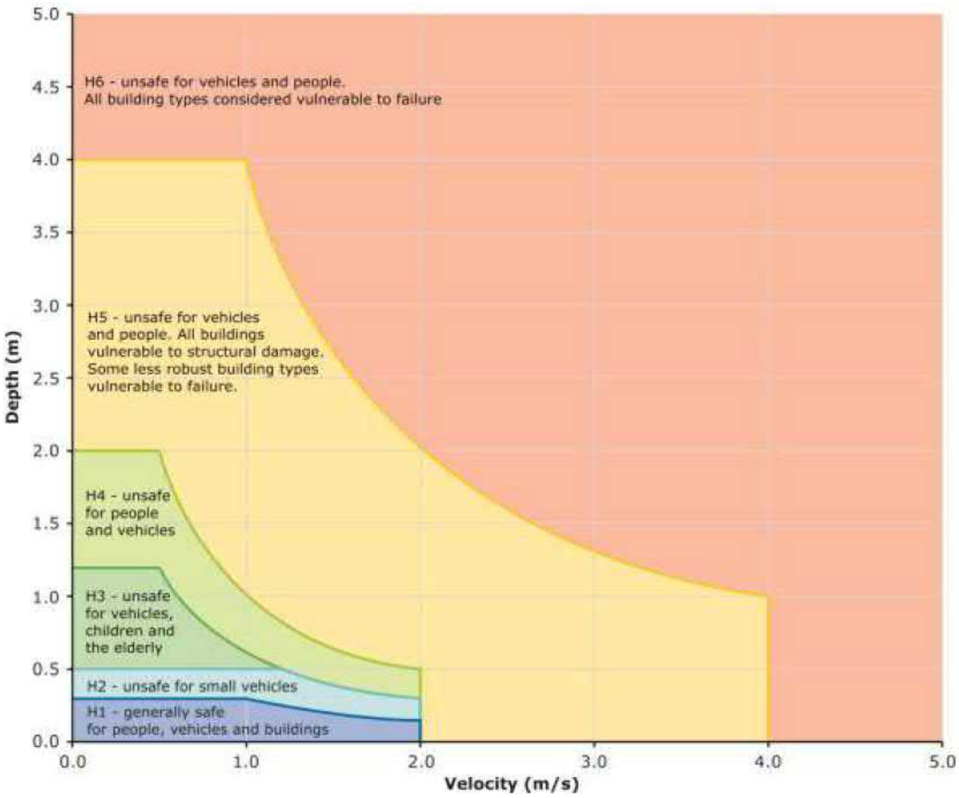


Figure 39 Hazard Vulnerability Classifications (Graphical)

Flood hazard mapping for the 18% and 1% AEP event has been included as maps **MM-120** to **MM-129** in the Volume 2 report. The 1% AEP hazard analysis generally shows:

- Low to medium hazard (H1 and H2) across the majority of ill-defined urban flow paths.
- Moderate to extreme hazard (H3 and H5) across the majority of steep gullies.
- Extreme hazard (H5 or H6) within steep, concrete-lined urban flow paths.
- Extreme hazard (H5 or H6) within the Dairy Creek, Horse Creek and Dee River channels.

10.3 Baseline Sewerage Infrastructure Flood Risk

Map **MM-130** shows active sewerage infrastructure (gravity mains, rising mains, access chambers and pump stations) overlain on the 18% AEP and 1% AEP Baseline Flood Extents. The intent of these maps is to identify sewerage infrastructure at increased risk of flooding, and therefore potential locations for stormwater ingress (inflow).

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

10.4 Baseline Vulnerability Assessment

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

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

Table 29 summarises the criterion used for each category, along with the corresponding reference to the specific table of results and locality figure.

Table 29 Vulnerability Assessment Criterion

Category	Criterion	Table	Figure
Water and Sewerage Infrastructure	Any electrified water or sewerage assets within the Mount Morgan catchment, experiencing flooding up to the baseline PMF event.	Table 30	Figure 40
Emergency Services	Any emergency services facilities within the Mount Morgan catchment, experiencing flooding up to the baseline PMF event.	Table 31	Figure 40
Community Infrastructure	Any community and critical infrastructure within the Mount Morgan catchment, experiencing flooding up to the baseline PMF event.	Table 31	Figure 40
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 32	Figure 41
Bridge Assets	All bridge crossings within the catchment were assessed.	Table 33	Figure 41
Rail Assets	Active rail segments were not present within the Mount Morgan 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 10.5.

Table 30 Water and sewage infrastructure - inundation depths for all modelled events

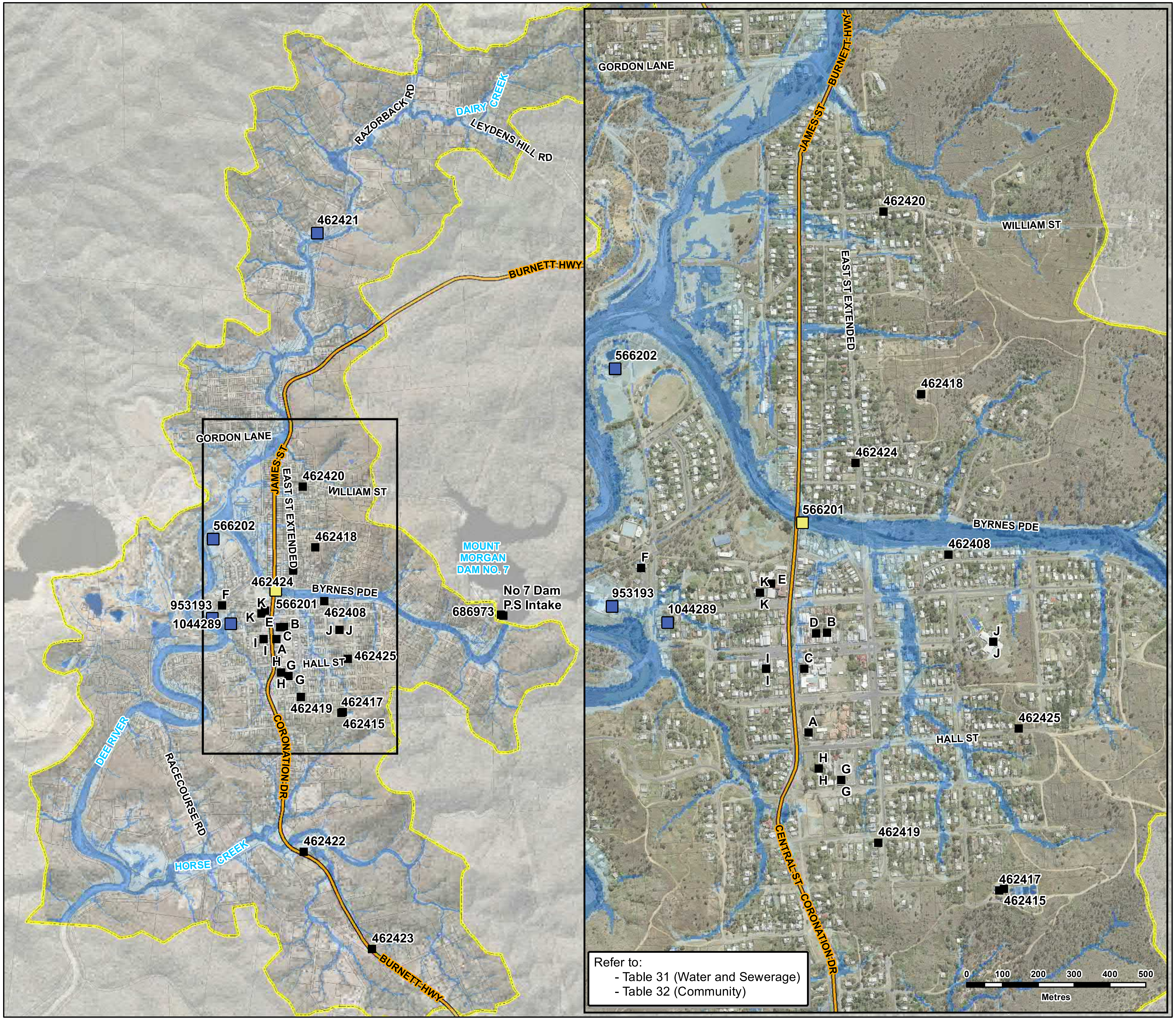
Infrastructure Type (Asset ID)	Suburb	Location	Inundation Depths at Design AEP Events (m) – 60 minute storm										1% AEP Hazard Category*
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
Sewerage Treatment Plant (566202)	Mount Morgan	Thompson Ave	-	-	-	-	-	-	-	-	-	1.55	-
Sewerage Pump Station (566201)	Mount Morgan	Dee River (No. 4) James Street	-	-	-	-	-	-	-	0.29	0.88	4.49	-
Sewerage Pump Station (953193)	Mount Morgan	Swimming Pool Thompson Ave	-	-	-	-	-	-	-	-	-	2.33	-
Sewerage Pump Station (1044289)	Mount Morgan	Dee Street	-	-	-	-	-	-	-	-	-	-	-
Water Treatment Plant (462415)	Mount Morgan	Jeannie Street	-	-	-	-	-	-	-	-	-	-	-
Water Intake Pump Station (-)	Mount Morgan	No. 7 Dam Intake	Within No. 7 Dam										
Water Reservoir (462418)	Mount Morgan	North Street Reservoir No. 2	-	-	-	-	-	-	-	-	-	-	-
Water Reservoir (462417)	Mount Morgan	Southside Reservoir No. 1	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (462425)	Mount Morgan	Hall Street	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (462422)	Horse Creek	Horse Creek Booster PS	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (462420)	Mount Morgan	William Street	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (462408)	Mount Morgan	Black Street	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (686973)	Mount Morgan	No. 7 Dam PS	Within No. 7 Dam										
Water Pump Station (462424)	Mount Morgan	East Street Ext	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (462423)	Horse Creek	Hamilton Creek Booster PS	-	-	-	-	-	-	-	-	-	-	-
Water Pump Station (462421)	Baree	Baree Booster PS Razorback Road	-	-	-	-	-	-	-	-	-	0.83	-
Water Pump Station (462419)	Mount Morgan	Darcy Street	-	-	-	-	-	-	-	-	-	-	-

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

Table 31 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) – 60 minute storm										1% AEP Hazard Category*
				1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
A	Kindy Care Mount Morgan	Mount Morgan	17 Central Street	-	-	-	-	-	-	-	-	-	-	-
B	Mount Morgan Aboriginal Vacation Care	Mount Morgan	63 Morgan Street	-	-	-	-	-	-	-	-	-	-	-
C	Mount Morgan Central State School	Mount Morgan	42 Morgan Street	-	-	-	-	-	-	-	-	-	-	-
D	Mount Morgan Family Support Hub	Mount Morgan	55 Morgan Street	-	-	-	-	-	-	-	-	-	-	-
E	Mount Morgan State High School	Mount Morgan	4 Central Street	-	-	-	-	-	-	-	-	-	-	-
F	Mount Morgan Child Care Centre	Mount Morgan	32 Thompson Avenue	-	-	-	-	-	-	-	-	-	-	-
G	SES Mount Morgan	Mount Morgan	30 Hall Street	-	-	-	-	-	-	-	-	-	-	-
H	Mount Morgan Police Station	Mount Morgan	30 Hall Street	-	-	-	-	-	-	-	-	-	-	-
I	Mount Morgan Fire Station	Mount Morgan	32 Morgan Street	-	-	-	-	-	-	-	-	-	-	-
J	Mount Morgan General Hospital	Mount Morgan	72 Morgan Street	-	-	-	-	-	-	-	-	-	-	-
K	Mount Morgan Ambulance Centre	Mount Morgan	21 Dee Street	-	-	-	-	-	-	-	-	-	-	-

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



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 500 1,000 1,500
Metres

1:30,000
(when printed at A3)

AECOM
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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
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extent
- PMF Flood Extent

Flood results are based on local catchment events

Data Sources:

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

Mount Morgan Model

Critical Infastruncture Inundation

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	30/10/2018
VERSION:	1

Figure 40

Table 32 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) – 60 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
1	Boundary Street	Mount Morgan	40	1.2	0.21	0.27	0.30	0.32	0.35	0.36	0.40	0.53	0.65	2.16	H5
2	Burnett Highway	Horse Creek	110	1.0	0.14	0.17	0.26	0.32	0.38	0.43	0.46	0.53	0.57	0.63	H5
3	Burnett Highway	Horse Creek	40	0.4	-	-	0.12	0.16	0.20	0.22	0.25	0.35	0.41	0.58	H5
4	Byrnes Parade	Mount Morgan	40	0.4	-	0.11	0.15	0.18	0.21	0.22	0.24	0.30	0.34	2.80	H5
5	Creek Street	Moongan	45	2.4	0.26	0.43	0.58	0.67	0.76	0.85	0.91	1.16	1.44	3.81	H4
6	Creek Street	Baree	70	2.2	0.21	0.32	0.49	0.61	0.71	0.84	0.92	1.30	1.63	3.90	H6
7	Cunningham Lane	Mount Morgan	45	1.6	0.27	0.36	0.44	0.49	0.54	0.59	0.64	0.77	0.86	1.33	H6
8	East Street Ext.	Mount Morgan	35	2.4	0.40	0.50	0.55	0.59	0.66	0.77	0.96	1.35	1.65	4.45	H6
9	East Street South	Mount Morgan	150	1.4	0.18	0.24	0.28	0.31	0.33	0.36	0.40	0.54	0.63	1.10	H5
10	East Street South	Mount Morgan	40	0.6	0.08	0.17	0.23	0.26	0.30	0.33	0.37	0.44	0.49	0.62	H5
11	Gilmore Street	Mount Morgan	50	0.8	0.26	0.40	0.51	0.56	0.61	0.63	0.66	0.77	0.84	1.12	H4
12	Gordon Lane	Walterhall	20	1.1	0.02	0.08	0.11	0.14	0.17	0.19	0.21	0.26	0.29	0.95	H4
13	Gordon Lane	Mount Morgan	80	1.5	-	-	-	0.17	0.28	0.38	0.47	0.73	0.99	3.30	H2
14	Gordon Street	Mount Morgan	20	1.2	0.32	0.39	0.48	0.51	0.54	0.56	0.59	0.67	0.72	0.94	H2
15	Lester Street	Mount Morgan	65	0.6	-	0.13	0.17	0.19	0.20	0.21	0.23	0.28	0.32	0.52	H1
16	Leydens Hill Road	Moongan	50	1.6	0.20	0.29	0.37	0.42	0.48	0.53	0.57	0.66	0.70	1.71	H2
17	Morgan Street	Mount Morgan	30	0.8	0.11	0.17	0.21	0.24	0.26	0.29	0.31	0.38	0.42	0.77	H5
18	Morgan Street / Mine Road	Mount Morgan	85	9.0	0.25	0.50	0.92	1.14	1.44	1.79	2.07	2.89	3.49	7.56	H2
19	Nicholson Street	Mount Morgan	15	0.5	-	0.14	0.18	0.21	0.24	0.25	0.27	0.31	0.35	0.51	H6
20	Old Baree Road	Baree	70	5.2	0.65	0.84	1.10	1.27	1.53	1.77	1.97	2.64	3.12	6.10	H2
21	Old Baree Road	Baree	85	3.6	0.35	0.72	1.12	1.37	1.60	1.83	1.99	2.55	2.99	5.98	H6

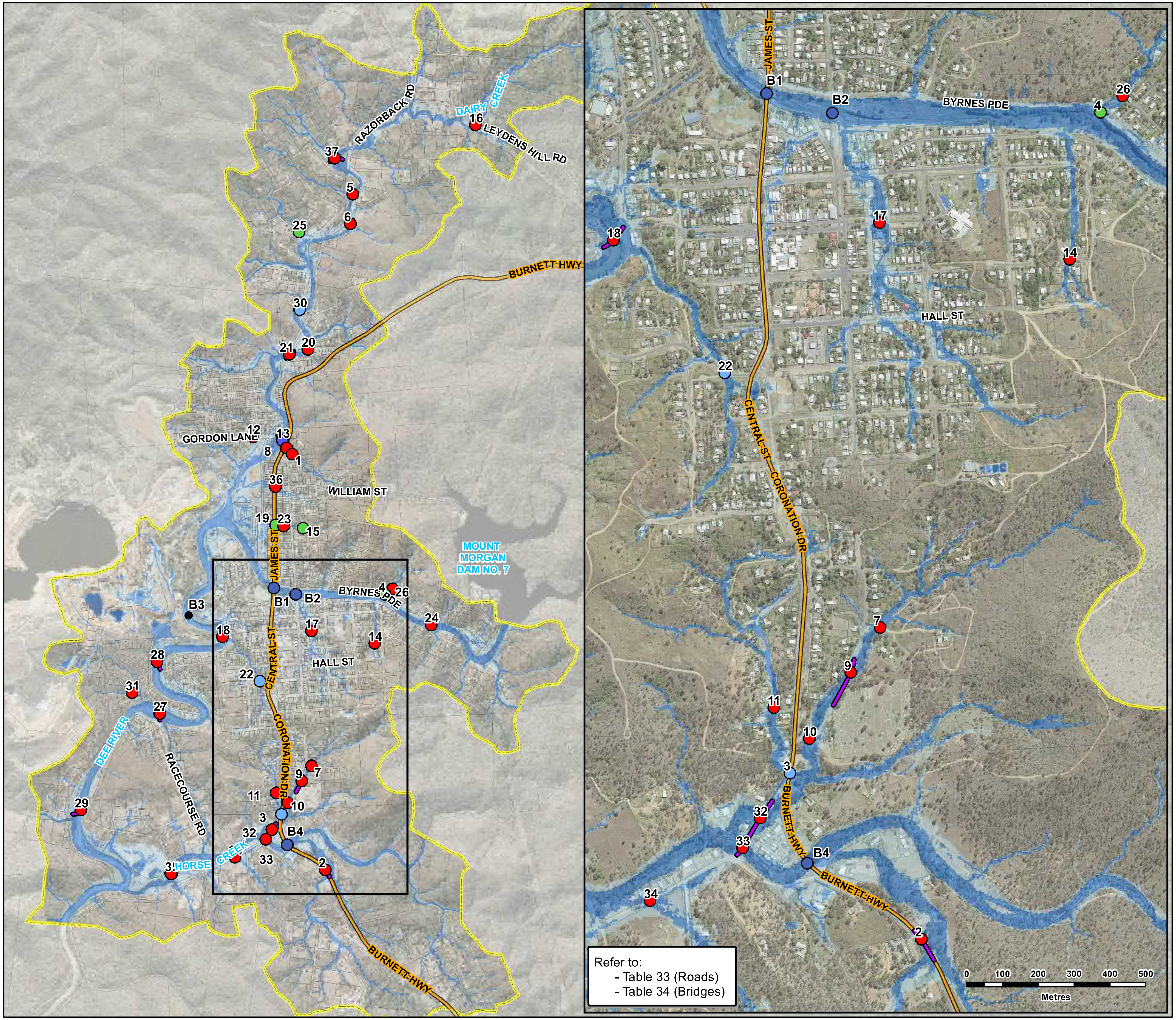
ID	Road | Street Name	Suburb	1% AEP Inundation Length (m)^	1% AEP TOS (hrs)^	Inundation Depths at Design AEP Events (m) – 60 minute storm *										1% AEP Hazard Category
					1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
22	Pattison Street	Mount Morgan	20	0.4	-	-	0.20	0.23	0.25	0.26	0.28	0.32	0.36	0.60	H3
23	Pepperina Avenue	Mount Morgan	15	0.8	0.19	0.26	0.31	0.35	0.38	0.39	0.41	0.47	0.51	0.65	H6
24	Piddichs Crossing	Mount Morgan	35	5.6	0.153	0.36	0.6	0.74	0.89	1.1	1.26	1.78	2.19	5.16	H3
25	Porters Road	Baree	35	1.0	-	0.15	0.19	0.21	0.24	0.25	0.28	0.39	0.46	1.80	H4
26	Possum Street	Mount Morgan	50	1.2	0.28	0.36	0.44	0.50	0.58	0.61	0.64	0.76	0.82	1.10	H6
27	Racecourse Road	Mount Morgan	100	8.5	0.25	0.39	0.52	0.59	0.69	0.80	0.92	1.23	1.36	5.93	H4
28	Racecourse Road	Mount Morgan	105	7.8	0.22	0.36	0.55	0.63	0.76	0.91	1.00	1.32	1.56	5.34	H5
29	Randwick Road	Mount Morgan	115	9.0	0.44	0.73	1.07	1.28	1.52	1.82	2.05	2.64	3.09	6.62	H3
30	Razorback Road	Baree	70	1.5	-	-	0.12	0.21	0.31	0.36	0.38	0.54	0.68	3.87	H3
31	Shamrock Street	The Mine	35	1.7	0.36	0.42	0.48	0.52	0.55	0.57	0.60	0.68	0.73	1.00	H6
32	Showgrounds Road	Horse Creek	180	2.0	0.30	0.39	0.48	0.53	0.58	0.63	0.68	0.81	0.92	2.75	H2
33	Showgrounds Road	Horse Creek	180	5.6	0.28	0.40	0.66	0.79	0.96	1.10	1.23	1.62	1.88	4.25	H5
34	Showgrounds Road	Horse Creek	40	0.8	0.15	0.18	0.21	0.24	0.27	0.29	0.31	0.37	0.41	2.03	H6
35	Showgrounds Road	Horse Creek	80	5.4	0.50	0.66	0.84	0.93	1.06	1.18	1.31	1.70	1.98	5.28	H2
36	William Street	Mount Morgan	10	2.8	0.32	0.33	0.35	0.35	0.36	0.37	0.38	0.40	0.41	0.49	H2
37	Wyvills Road	Moongan	120	3.6	0.34	0.60	0.94	1.20	1.64	2.19	2.64	3.29	3.62	5.45	H5

^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 33 Bridge Assets - Inundation depths for all modelled events

ID	Bridge Name	Deck Height (m AHD) #	Inundation Depths Above Deck at Design AEP Events (m) – 60 minute storm *										1% AEP Hazard Category **
			1EY	39%	18%	10%	5%	2%	1%	0.2%	0.05%	PMF	
B1	Dee River Bridge	228.25	-	-	-	-	-	-	-	-	-	0.93	-
B2	Dee River Pedestrian Bridge	229.20	-	-	-	-	-	-	-	-	-	0.80	-
B3	Dee River Rail Bridge	224.80	-	-	-	-	-	-	-	-	-	-	-
B4	Horse Creek Bridge	213.14	-	-	-	-	-	-	-	-	-	1.83	-

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.



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 500 1,000 1,500
Metres

1:30,000
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LEGEND

Road, Rail and Bridge Infrastructure (Lowest Immunity)

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

Flood results are based on local catchment events

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

Mount Morgan Model

Road, Bridges and Rail Inundation

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 30/10/2018
VERSION: 1

Figure 41

10.4.1 Vulnerability Assessment Summary

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

- The Dee River (No. 4) sewerage pump station in James Street is predicted to be inundated by up to 0.29m in the 0.2% AEP 60min event. It is important to note that this is not the critical duration for the Dee River; longer duration storms are likely to result in higher peak flood depths and inundation frequency at this site. All other water and sewerage infrastructure have the desired 0.2% AEP flood immunity. It is recommended this information be passed onto FRW as the asset owner.
- Flood inundation is not predicted at any community infrastructure or emergency facilities.
- A number of roads are predicted to experience inundation in the 1EY event and larger. Predicted TOS generally ranges from 0.4 to 9.0 hours, with low immunity crossings across the Dee River (Piddichs Crossing, Racecourse Road and Randwick Road) predicted to be inundated between 5.6 and 9.0 hours in a 1% AEP 60min event.

10.5 Evacuation Routes

This assessment relates to isolated areas as a result of local catchment flood events and should be read in conjunction with the Mt Morgan Water Supply No 7 Dam Emergency Action Plan (FRW, 2018). Generally local catchment flooding within the Mount Morgan local catchment is due to short duration, high intensity rainfall events. The relatively steep flowpaths and urbanisation throughout catchment can result in inundation of key roads as well as residential and commercial buildings.

Due to the short critical duration of the Mount Morgan local catchment, the warning time between the commencement of the rain event and subsequent flood inundation can be short (refer Figure 48 to Figure 52). 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 34 provides a summary of the isolated areas and key evacuation routes, assessed up to the PMF event.

Table 34 Isolated Areas Summary

Isolated Area	Key Evacuation Route/s	Accessed Via	Warning Time Until Evac. Route Cut	Figure Reference
Horse Creek Lane, Burnett Lane and Showgrounds Road	Burnett Highway	-	Up to 0.25 hour	Figure 42 and Figure 43
Black Street and Campion Street	East Street	Hall Street and Gordon Street	Up to 0.25 hour	Figure 44
Baree Road and Gordon Lane	James Street	Gordon Lane	Up to 0.25 hour	Figure 45
Creek Street	Creek Street	-	Up to 0.25 hour	Figure 46 and Figure 47

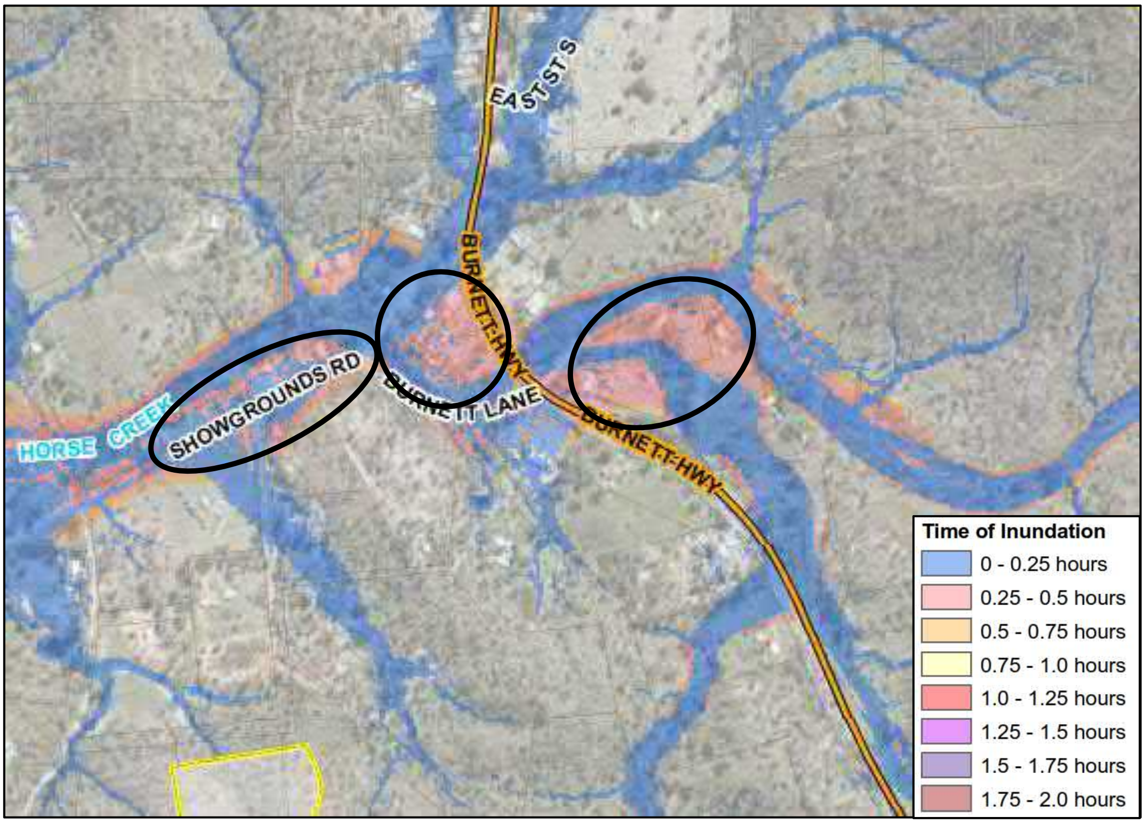


Figure 42 Isolated Area - Bounded by Horse Creek Ln and Showgrounds Rd (Note: PMF flood extents shown)

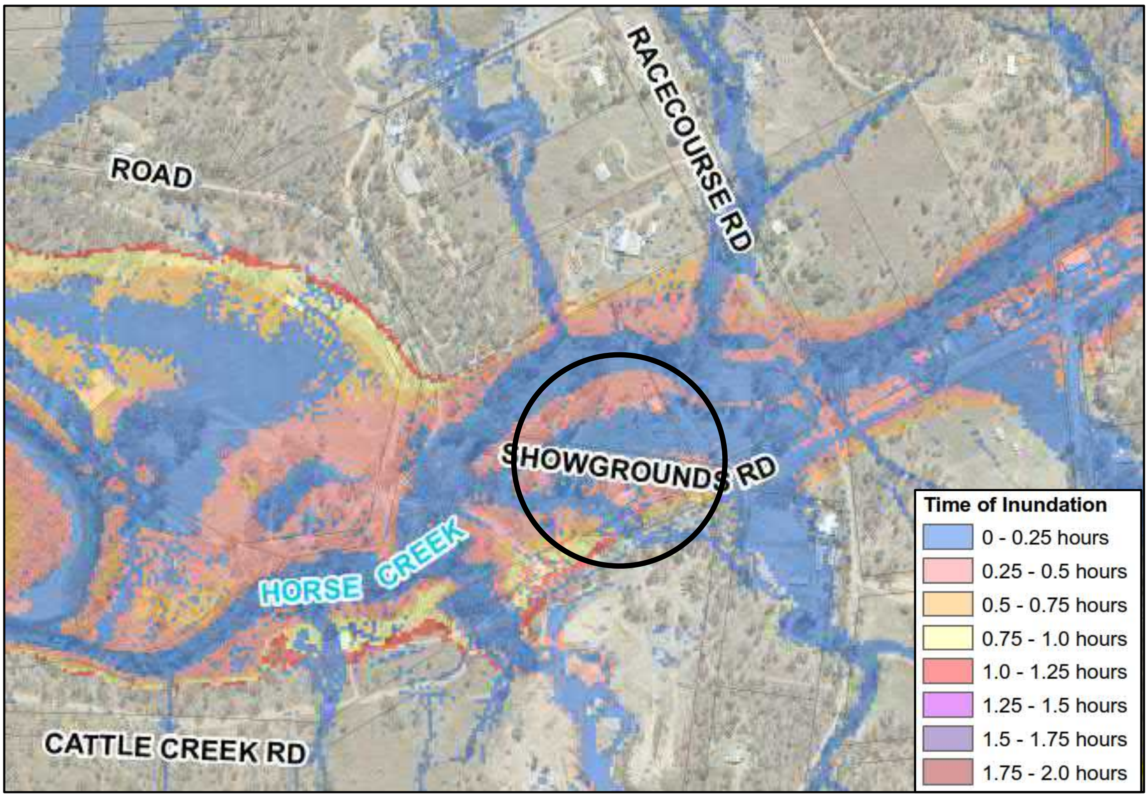


Figure 43 Isolated Area - Bounded by Showgrounds Rd and Horse Creek (Note: PMF flood extents shown)

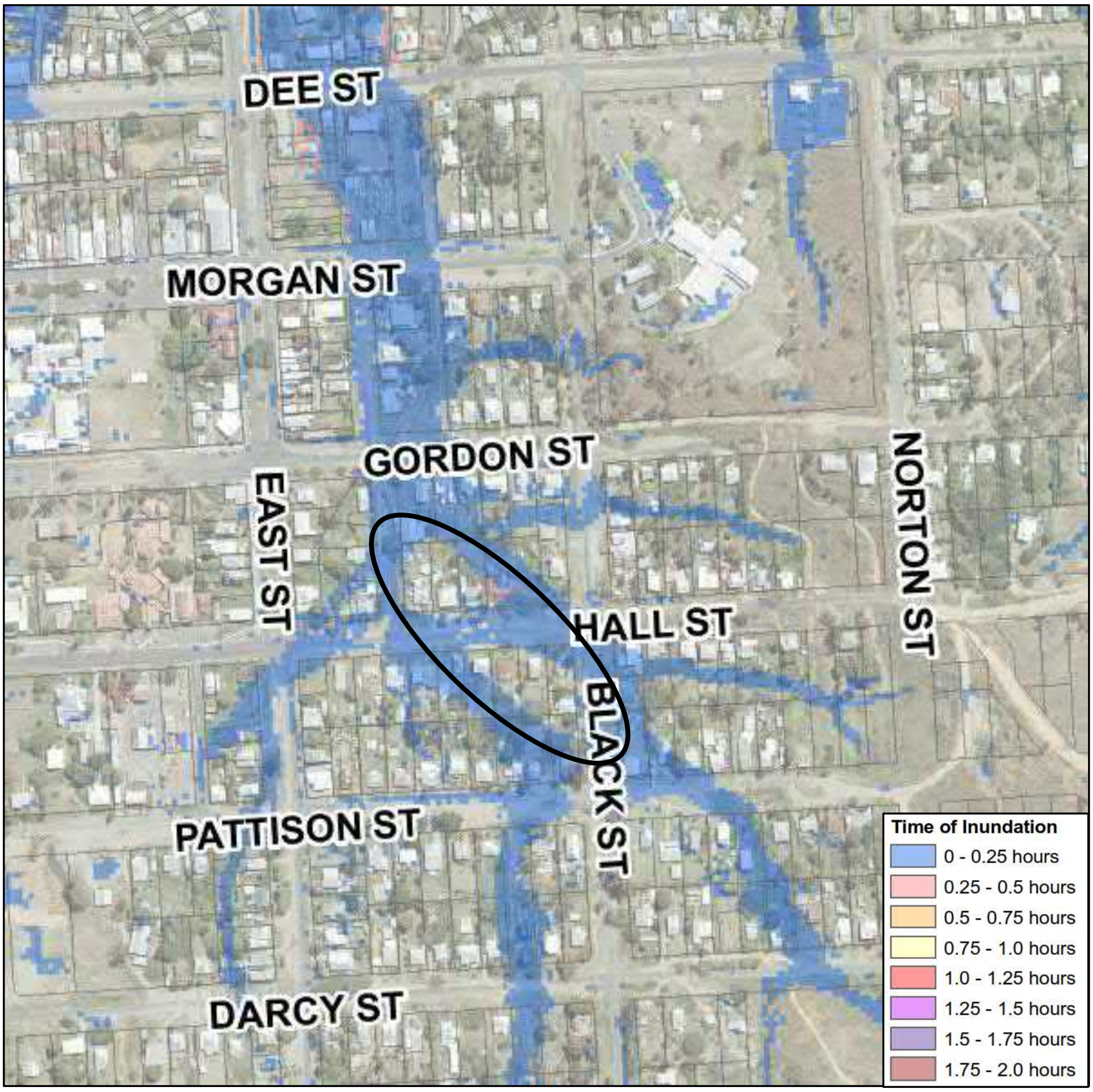


Figure 44 Isolated Area - Bounded by Gordon St and Black St (Note: PMF flood extents shown)

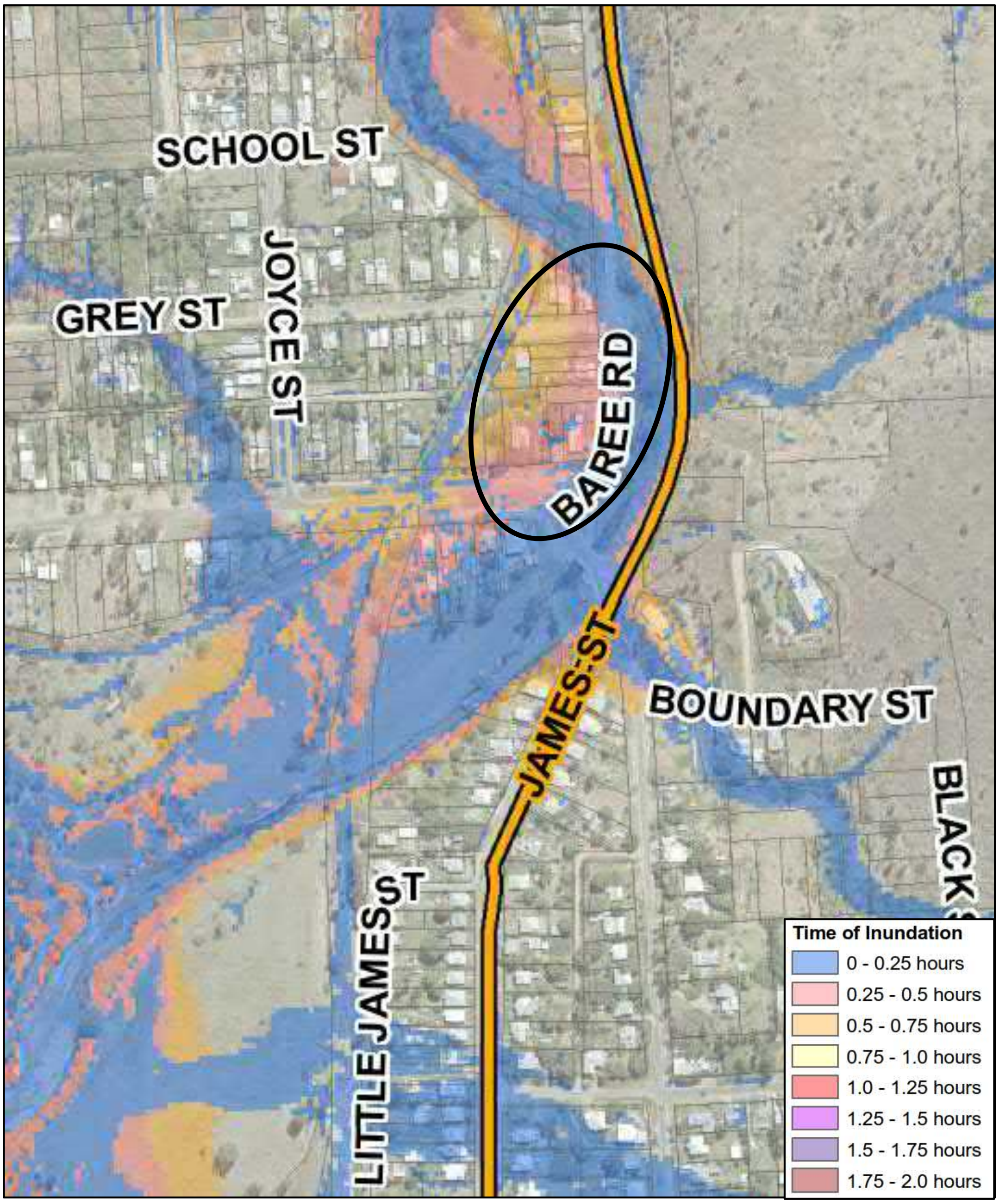


Figure 45 Isolated Area - Bounded by Baree Rd and Gordon Ln (Note: PMF flood extents shown)

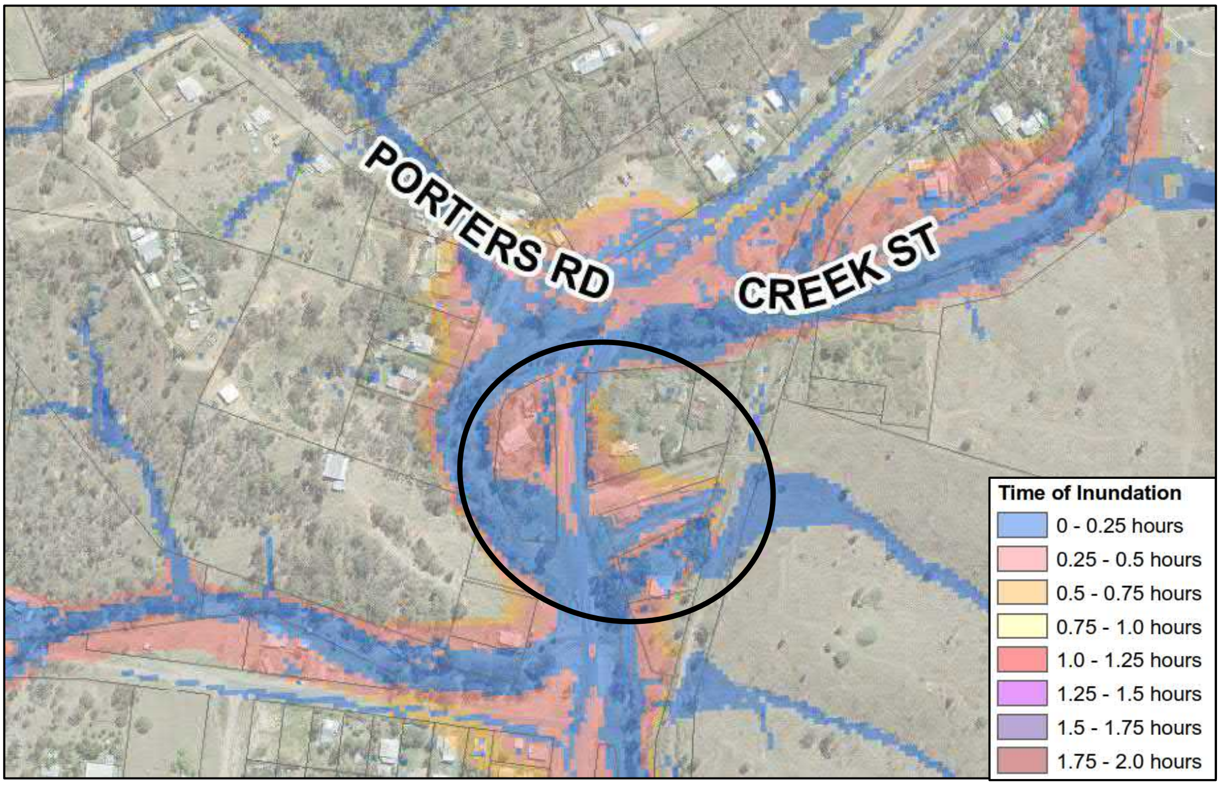


Figure 46 Isolated Area - Bounded by Creek St and Unnamed Access Rd (Note: PMF flood extents shown)

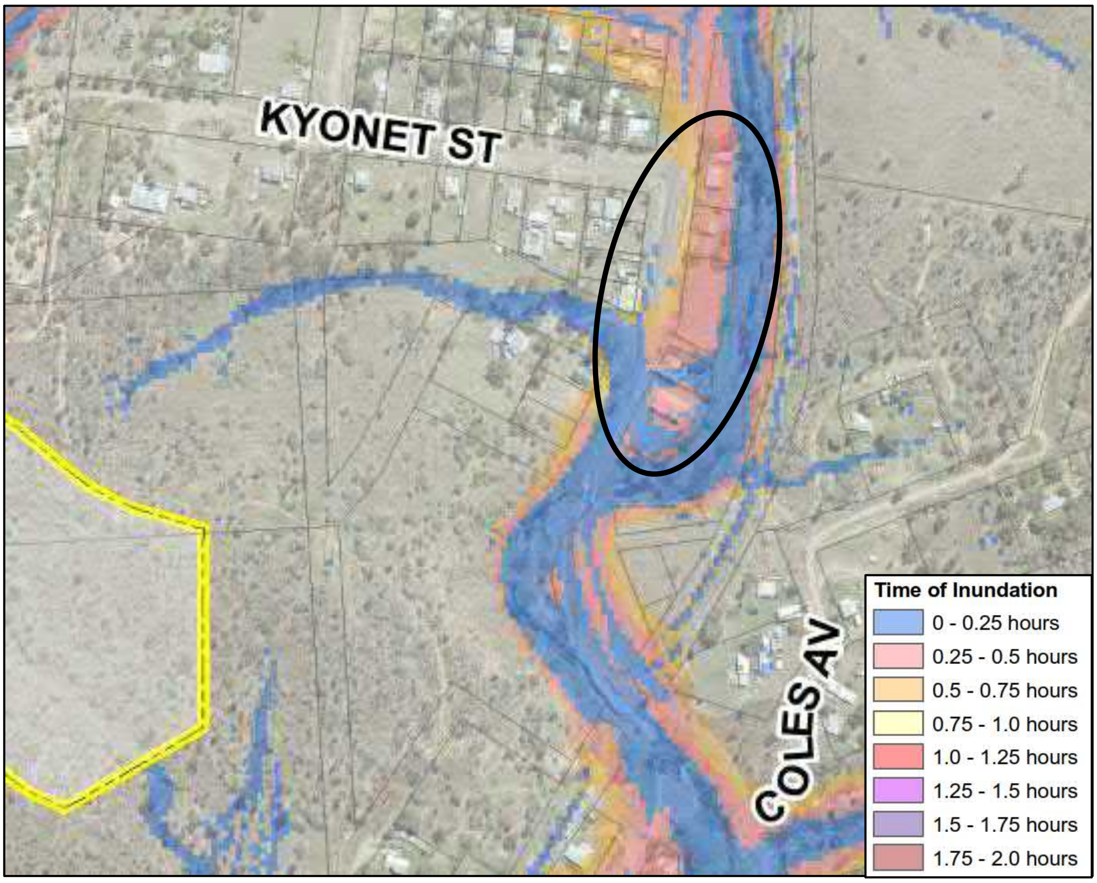
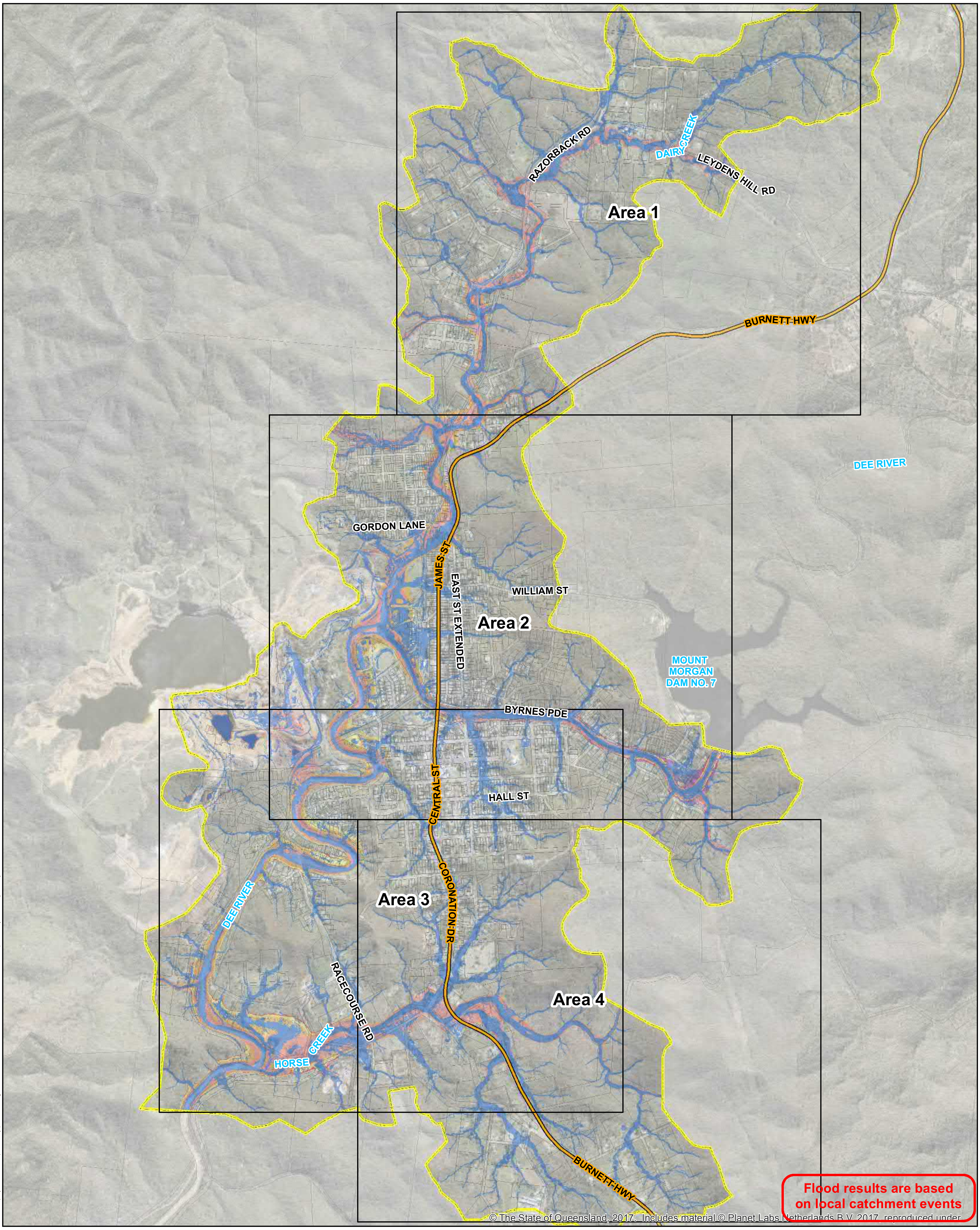


Figure 47 Isolated Area - Bounded by Razorback Rd and Dairy Creek (Note: PMF flood extents shown)



Rockhampton Regional Council

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0 250 500 750 1,000 metres

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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.25 hours
- 0.25 - 0.5 hours
- 0.5 - 0.75 hours
- 0.75 - 1.0 hours
- 1.0 - 1.25 hours
- 1.25 - 1.5 hours
- 1.5 - 1.75 hours
- 1.75 - 2.0 hours

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

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

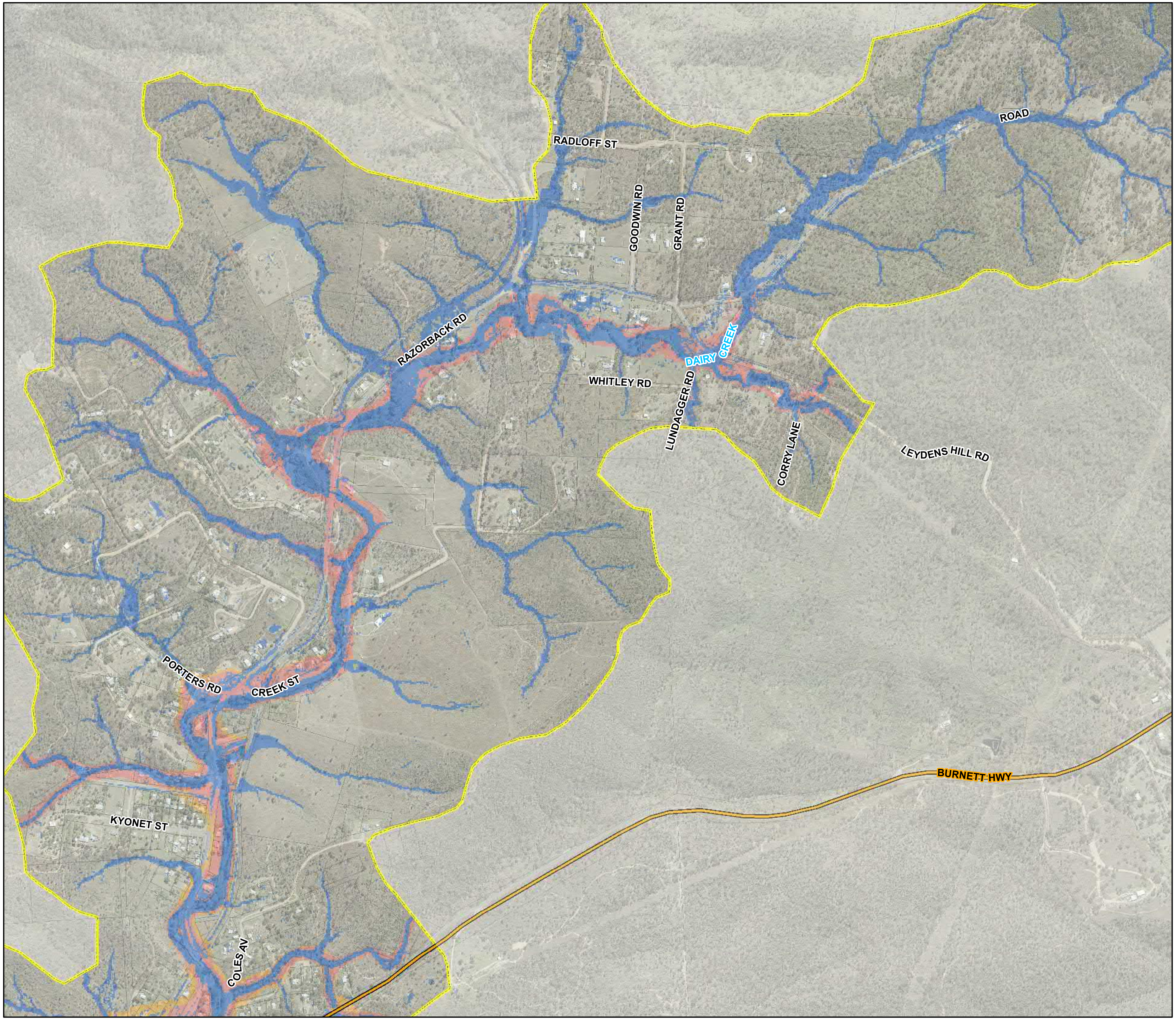
Mount Morgan Model
Time of Inundation

PMF 60min Storm Event
Catchment Overview

PROJECT ID	60534898
CREATED BY	huffm
LAST MODIFIED	25 Oct 2018
VERSION:	1

Figure
48

A3 size



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0 100 200 300 400 500
Metres

1:10,000
(when printed at A3)

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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.25 hours
- 0.25 - 0.5 hours
- 0.5 - 0.75 hours
- 0.75 - 1.0 hours
- 1.0 - 1.25 hours
- 1.25 - 1.5 hours
- 1.5 - 1.75 hours
- 1.75 - 2.0 hours

Flood results are based on local catchment events

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

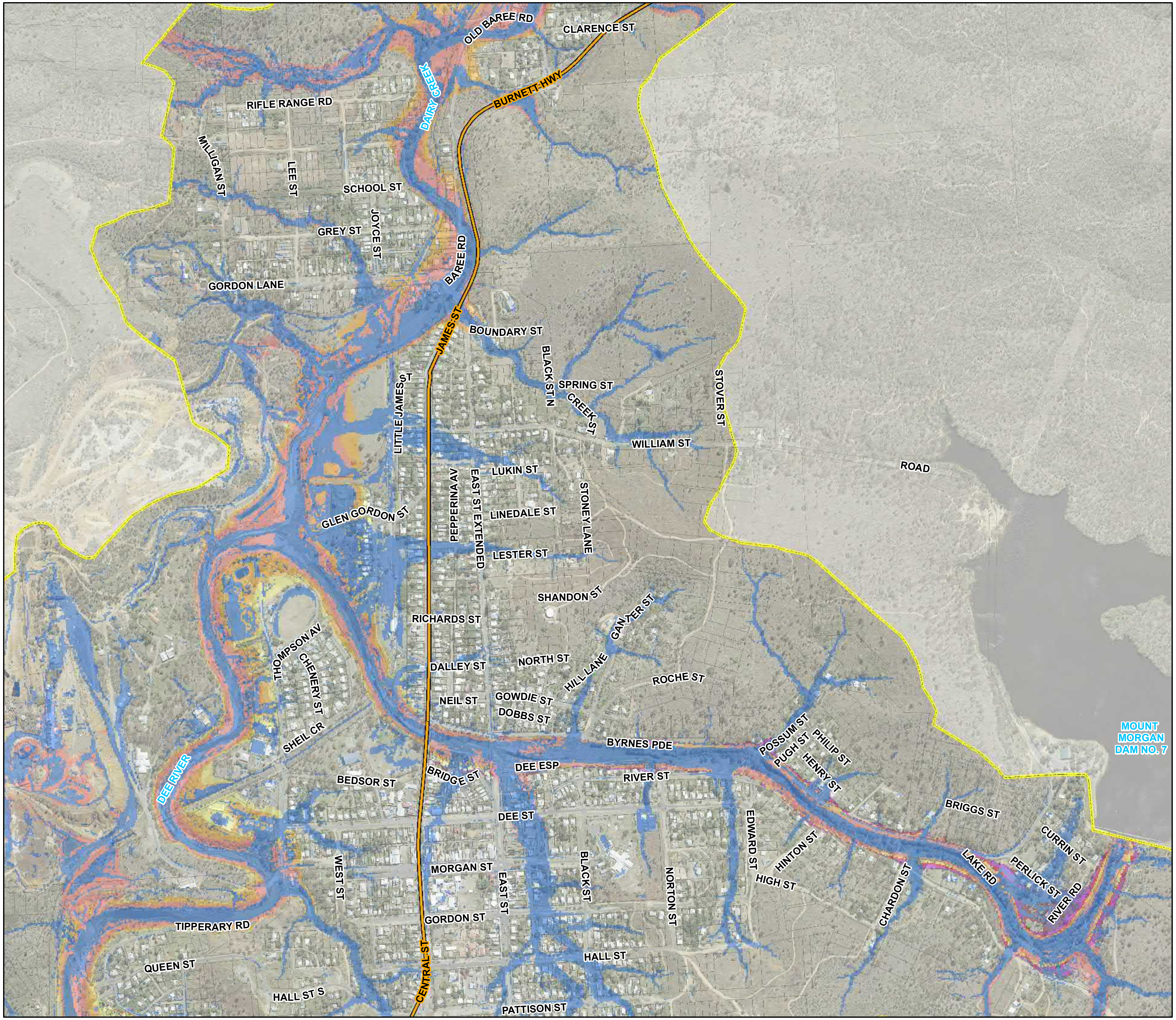
Results Filtering:
75mm Min. Depth
$100m^2$ Min. Area

Mount Morgan Model
Time of Inundation

PMF 60min Storm Event
Area 1

PROJECT ID 60534898
CREATED BY huffm
LAST MODIFIED 25/10/2018
VERSION: 1

Figure 49



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Metres

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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.25 hours
- 0.25 - 0.5 hours
- 0.5 - 0.75 hours
- 0.75 - 1.0 hours
- 1.0 - 1.25 hours
- 1.25 - 1.5 hours
- 1.5 - 1.75 hours
- 1.75 - 2.0 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

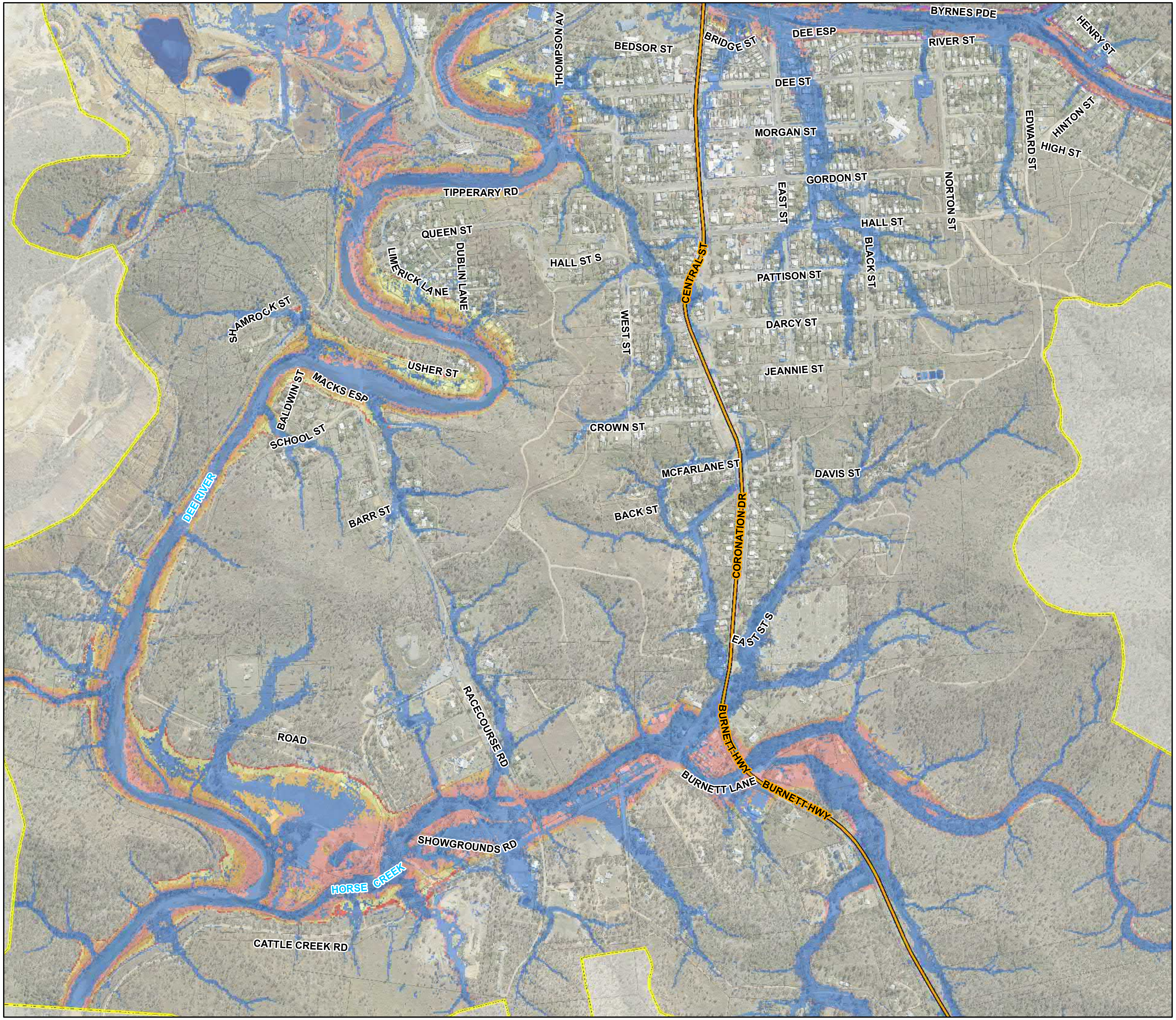
Mount Morgan Model
Time of Inundation

PMF 60min Storm Event
Area 2

PROJECT ID	60534898
CREATED BY	huffm
LAST MODIFIED	25/10/2018
VERSION:	1

Figure 50

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure36_Inundation_Timings_Area2.mxd



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Metres

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(when printed at A3)

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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent

Time of Inundation

- 0 - 0.25 hours
- 0.25 - 0.5 hours
- 0.5 - 0.75 hours
- 0.75 - 1.0 hours
- 1.0 - 1.25 hours
- 1.25 - 1.5 hours
- 1.5 - 1.75 hours
- 1.75 - 2.0 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

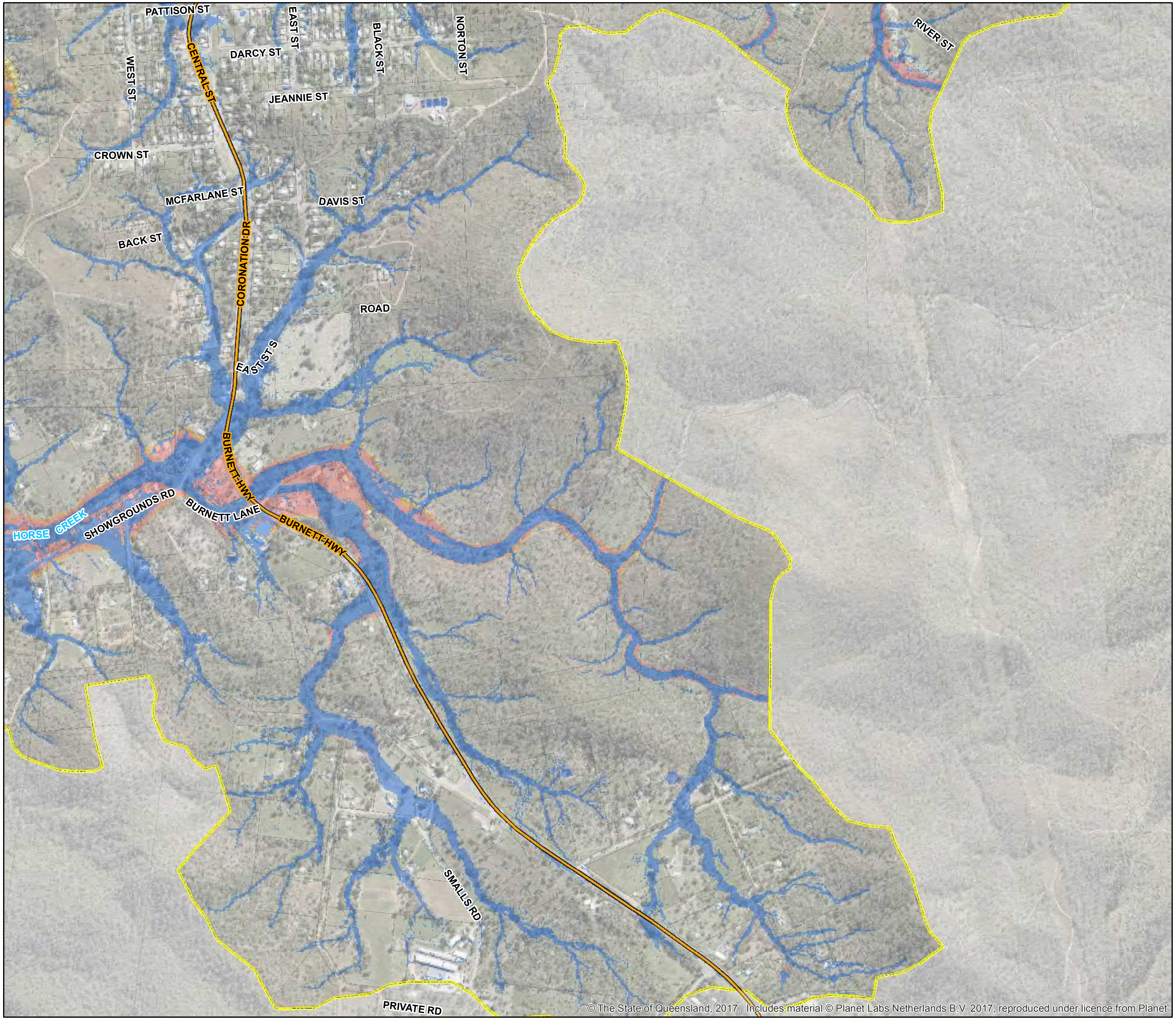
Mount Morgan Model
Time of Inundation

PMF 60min Storm Event
Area 3

PROJECT ID	60534898
CREATED BY	huffm
LAST MODIFIED	25/10/2018
VERSION:	1

Figure 51

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure37_Inundation_Timings_Area3.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
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LEGEND

Highways
Cadastre
Hydraulic Model Extent

Time of Inundation

0 - 0.25 hours
0.25 - 0.5 hours
0.5 - 0.75 hours
0.75 - 1.0 hours
1.0 - 1.25 hours
1.25 - 1.5 hours
1.5 - 1.75 hours
1.75 - 2.0 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

Mount Morgan Model
Time of Inundation

PMF 60min Storm Event
Area 4

PROJECT ID 60534898
CREATED BY huffm
LAST MODIFIED 25/10/2018
VERSION: 1

Figure 52

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure38_Inundation_Timings_Area4.mxd

10.6 Building Impact Assessment and Flood Damages Assessment

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

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

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

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

10.6.1 Baseline Building Impact Assessment

Council provided a building database, containing over 2,000 buildings digitised within the modelled area. As a result of recent building survey in Mount Morgan, the majority of key structures contained surveyed floor height data. Gaps existed for structures in more rural settings, or where structures are not directly visible from the road.

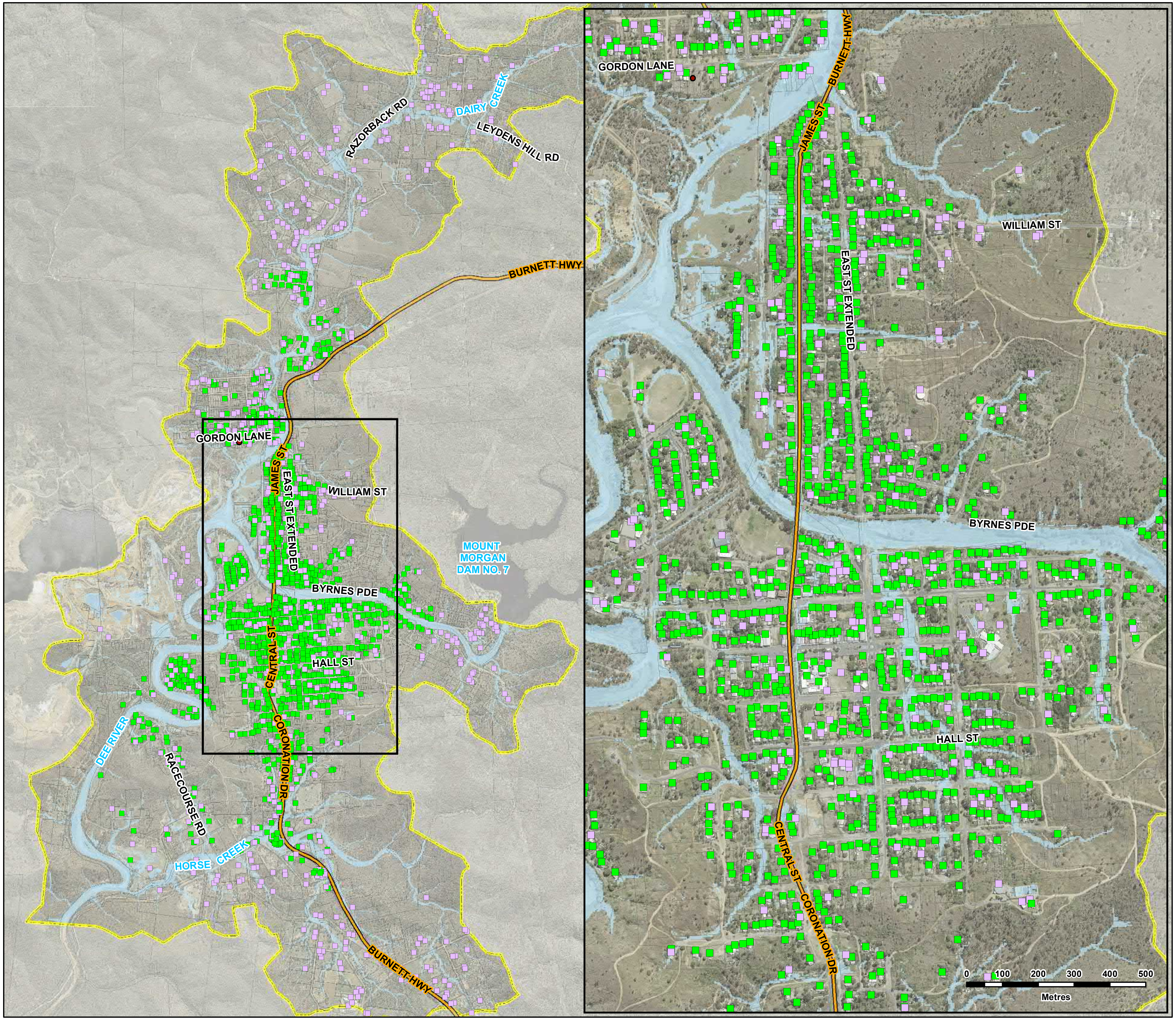
Figure 53 shows the spatial distribution of properties with surveyed floor levels.

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, Council undertook the following tasks:

- 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 surveyed information.
- Classification of buildings within the modelled area, in accordance with ANUFLOOD requirements:
  - Buildings were divided into residential and commercial based on a combination of attribute fields, depending on what fields contained data for each building.
  - Commercial buildings were assigned a size class based on floor area – small/medium/large.
  - Commercial building classifications were assigned 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

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0 500 1,000 1,500

Metres

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LEGEND

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

FLOOR LEVEL SUMMARY

Surveyed Floor Levels = 1,320
GIS-Derived Floor Levels = 701

Data Sources:

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

Mount Morgan Model

Building Database Summary

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	13/07/2018
VERSION:	1

Figure
53

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure39_surveyed.mxd

Table 35 provides a summary of the number of residential and commercial buildings anticipated to be inundated for various flood events within the Mount Morgan local catchment. These results are also shown graphically in Figure 54.

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 35 № 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	0 (0)	0 (0)
39	2 (0)	0 (0)
18	4 (2)	1 (1)
10	7 (2)	1 (1)
5	14 (5)	1 (1)
2	17 (6)	3 (2)
1	19 (7)	3 (2)
0.2	48 (21)	7 (6)
0.05	77 (37)	8 (6)
PMF	255 (179)	36 (32)

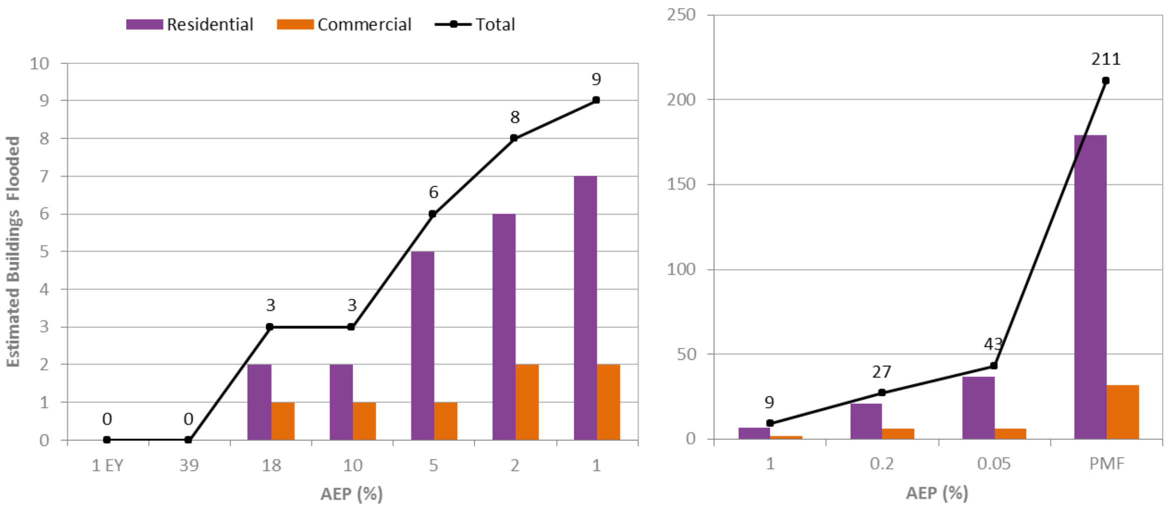


Figure 54 Estimated Buildings with Above Floor Flooding (Number of Buildings)

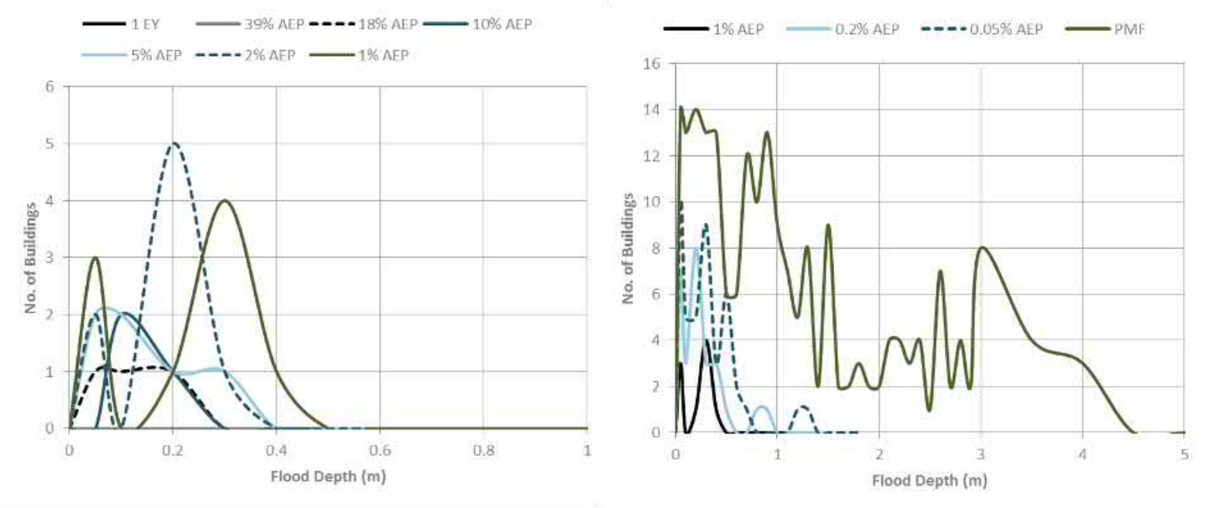


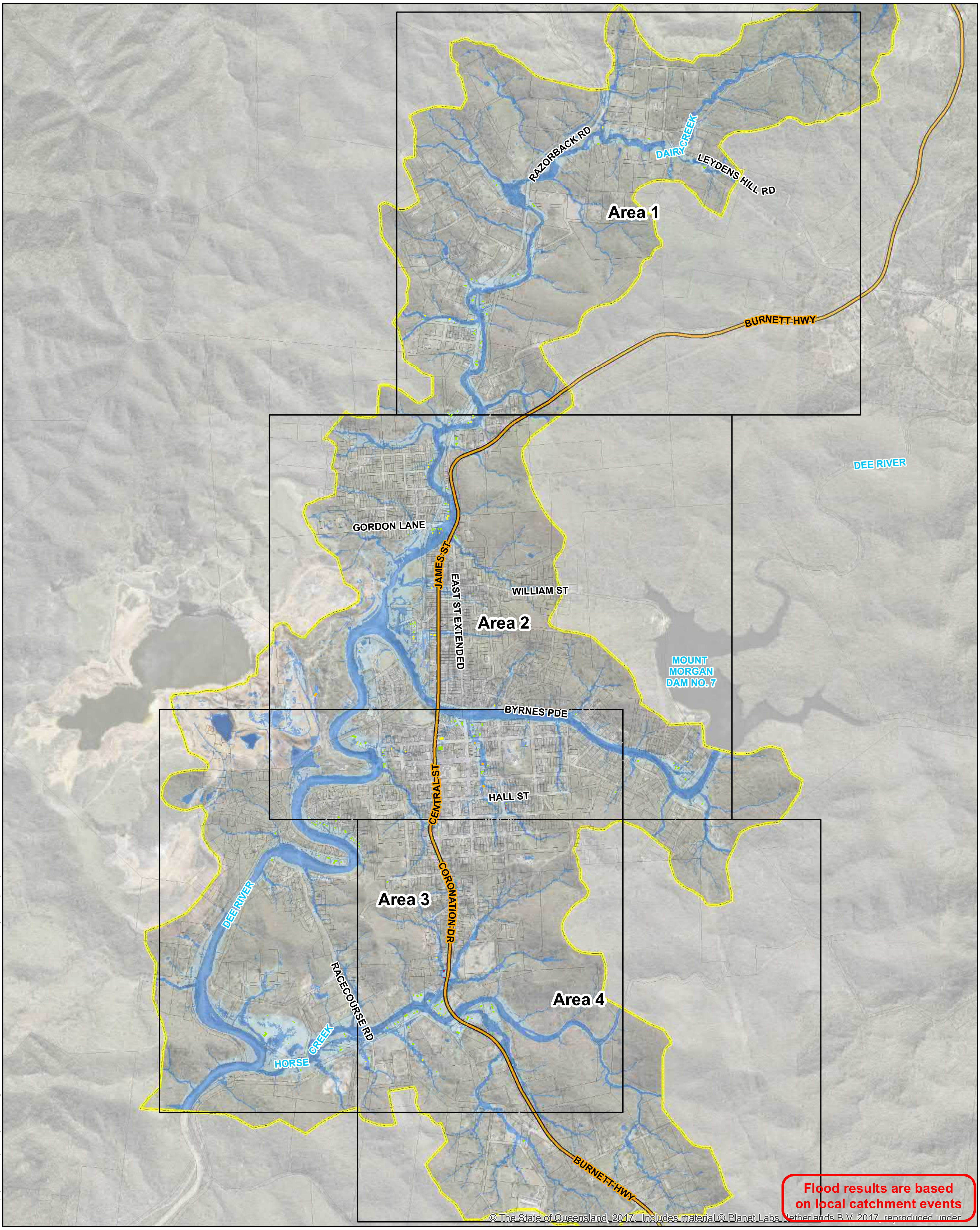
Figure 55 Estimated Flood Depths Above Floor Level by % AEP (Number of Buildings)

As shown in Figure 55, median flood depths are generally less than 0.3m for each flood event. This indicates that reductions in flood depths of 0.3m could significantly reduce overall damage.

The figure also shows that a pockets of impacted buildings experience flood depths of 0.1m or less during more frequent events.

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 region, however may result in a higher estimate of inundated buildings and consequential flood damages due to the increased incidence of above floor flooding.

Figure 56 to Figure 60 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
metres

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(when printed at A3)

AECOM
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LEGEND

- Highways
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Inundation of Buildings with Above Floor Flooding

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

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

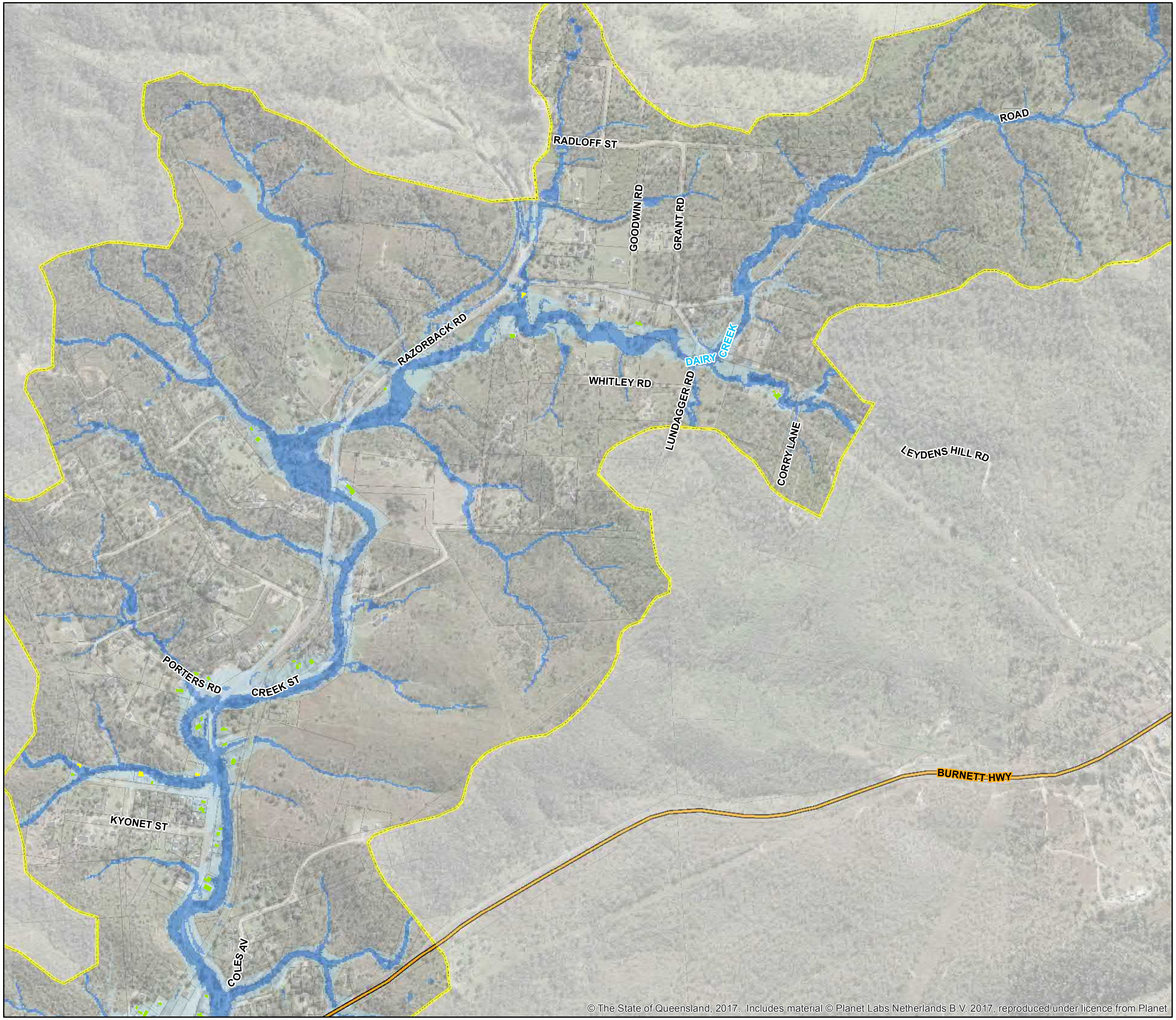
Results Filtering:
75mm Min. Depth
100m^2 Min. Area

Mount Morgan Model

Inundation of Buildings with Above Floor Level Flooding - Catchment Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	25 Oct 2018
VERSION:	1

Figure 56



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500
Metres

1:10,000
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AECOM
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LEGEND

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
- Highways
- 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

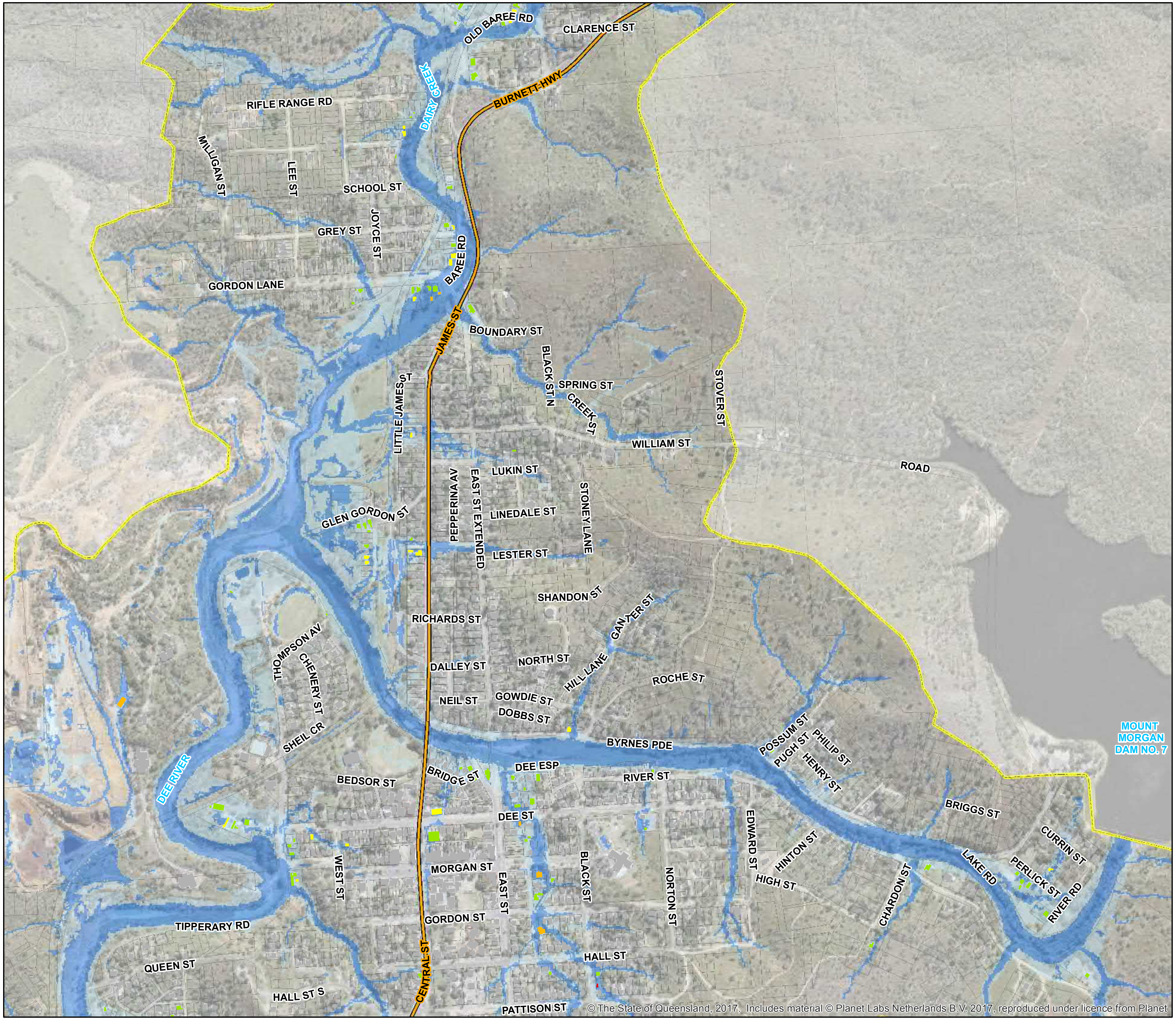
Mount Morgan Model

Inundation of Buildings with Above Floor Level Flooding - Area 1

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	25/10/2018
VERSION:	1

Figure 57

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure43_Buildings_Area1.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)

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LEGEND

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
- Highways
- 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

Mount Morgan Model

Inundation of Buildings with Above Floor Level Flooding - Area 2

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	25/10/2018
VERSION:	1

Figure 58

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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

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
- Highways
- Cadastre
- Hydraulic Model Extent
- 1% AEP Flood Extents
- PMF Flood Extents

Flood results are based on local catchment events

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

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

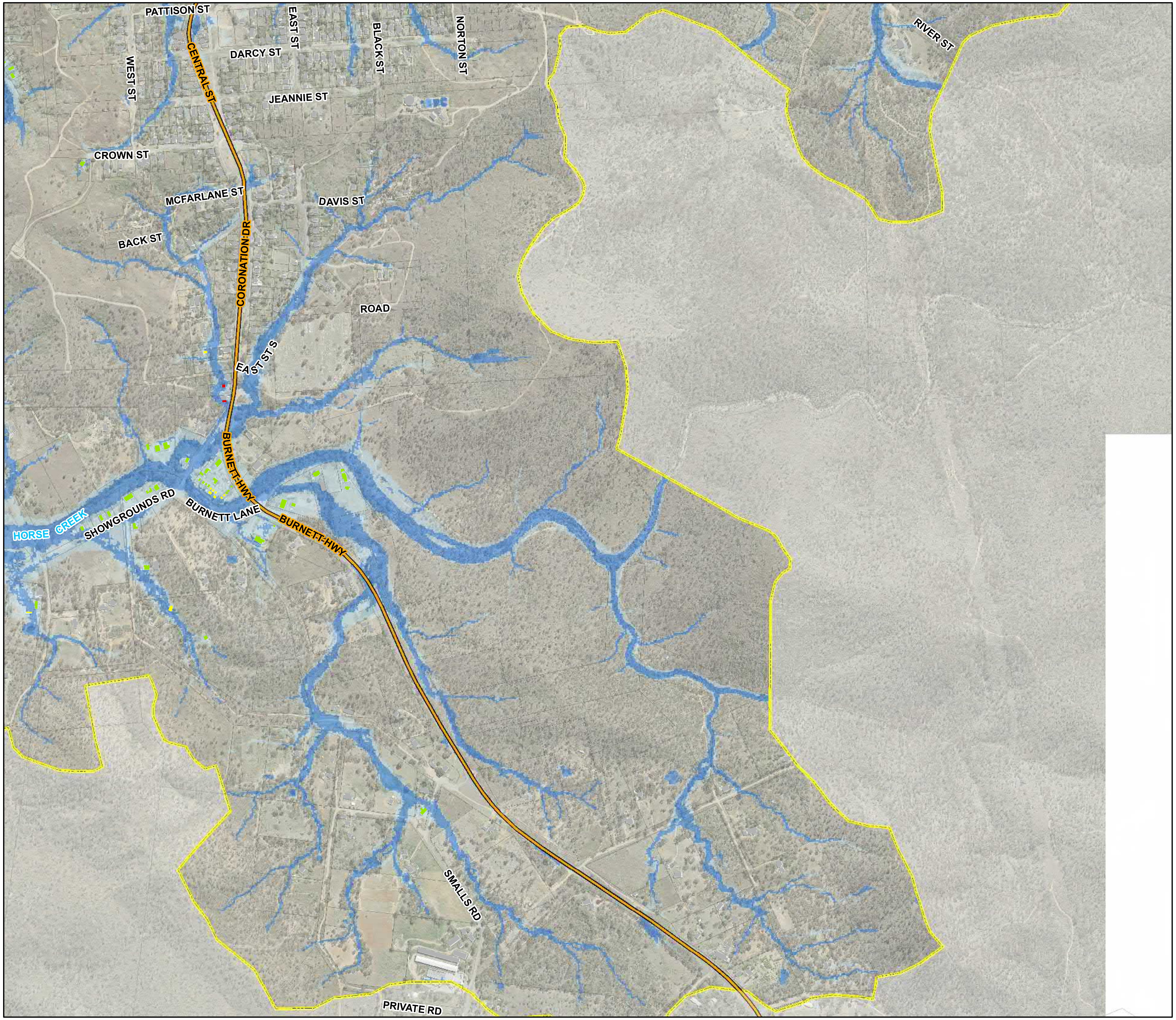
Mount Morgan Model

Inundation of Buildings with Above Floor Level Flooding - Area 3

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 25/10/2018
VERSION: 1

Figure 59

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure45_Buildings_Area3.mxd



N

Rockhampton Regional Council

DATUM GDA 1994, PROJECTION MGA ZONE 56

0 100 200 300 400 500
Metres

1:10,000
(when printed at A3)

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LEGEND

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
- Highways
- 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

Mount Morgan Model

Inundation of Buildings with Above Floor Level Flooding - Area 4

PROJECT ID 60534898
CREATED BY maultbyj
LAST MODIFIED 25/10/2018
VERSION: 1

Figure 60

Filename: P:\605x\60534898\4. Tech Work Area\4.99 GIS\3. MXDs\Mt Morgan\Report Figures\MtMorgan_Figure46_Buildings_Area4.mxd.mxd

10.6.2 Baseline Flood Damages Assessment

Table 36 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 37 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 36 Summary of flood damages using WRM stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$ -	$ -	$ -	**$ -**
39	$ 8	$ -	$ 1	**$ 9**
18	$ 128	$ 2	$ 17	**$ 146**
10	$ 147	$ 3	$ 19	**$ 169**
5	$ 368	$ 4	$ 48	**$ 420**
2	$ 460	$ 7	$ 61	**$ 527**
1	$ 734	$ 24	$ 98	**$ 855**
0.2	$ 2,129	$ 221	$ 299	**$ 2,650**
0.05	$ 3,426	$ 308	$ 477	**$ 4,211**
PMF	$ 27,504	$ 3,264	$ 3,903	**$ 34,672**

Table 37 Summary of flood damages using O2 Environmental stage-damage curves

Event	Flood Damages (,000s of March 2017 $)			
AEP (%)	Residential	Commercial	Infrastructure	Total
63	$ -	$ -	$ -	**$ -**
39	$ 8	$ -	$ 1	**$ 9**
18	$ 118	$ 2	$ 16	**$ 135**
10	$ 145	$ 3	$ 19	**$ 167**
5	$ 381	$ 4	$ 50	**$ 435**
2	$ 502	$ 7	$ 66	**$ 575**
1	$ 791	$ 24	$ 105	**$ 920**
0.2	$ 2,486	$ 221	$ 346	**$ 3,053**
0.05	$ 4,411	$ 308	$ 605	**$ 5,323**
PMF	$ 44,519	$ 3,264	$ 6,123	**$ 53,906**

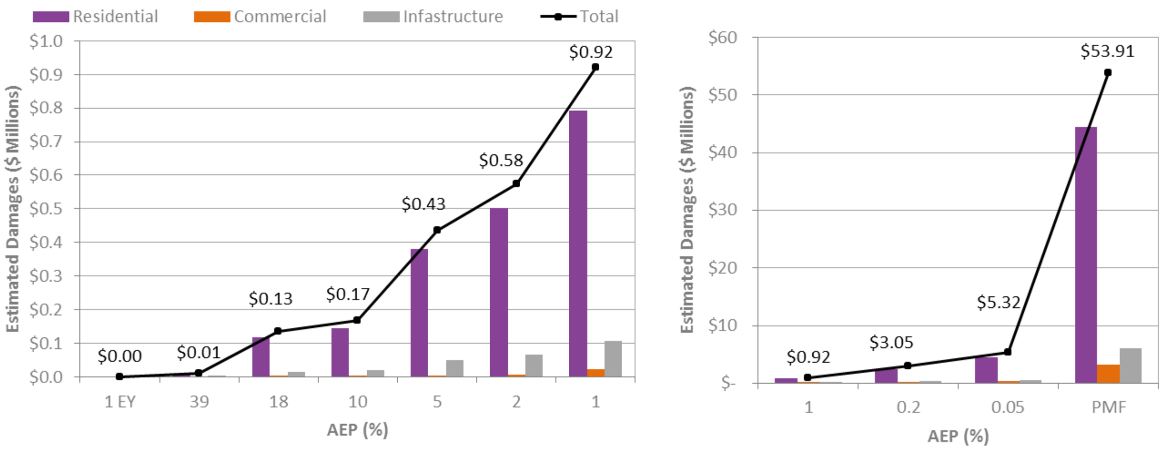


Figure 61 Estimated Flood Damages – O2 Environmental Damage Curves ($ Million)

Figure 61 summarises the estimated total flood damages for various flood events according to their AEP. As shown, total damages range from no damage (1EY flood event) to $54M (PMF event). Figure 54 shows that no buildings are expected to be inundated above floor in the 1EY event, whilst 211 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 Mount Morgan catchment across the full range of design events assessed.

10.6.3 Average Annual Damages

While the above provides an estimate of potential damages during specific flood events, understanding what damages may be expected on an annual basis is often an easier way to relate risk to residents and businesses. As such, the above damages were converted to Average Annual Damages (AAD) based on the likelihood of the flood event and the total estimated damage during that event. The AAD is determined by taking the estimated damage for each AEP event and multiplying it by the likelihood of the event. The process is repeated and AAD values are summed for the total AAD. For instance, the AAD for a 10% AEP event is based on the estimated $3.08M damages and 10% or 0.1 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 **$95,000** and using those from O2 Environmental gives an AAD of approximately **$103,000**. The difference of approximately 8% provides a narrow range for the estimated AAD.

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

Figure 62 provides a breakdown of the number of buildings inundated in 'creek' and 'overland flow' areas. The graph confirms that the majority of buildings within the catchment (90%) are not inundated up to and including the PMF event. Of the 10% of buildings predicted to experience inundation, approximately 23% are impacted by overland flow and 77% are impacted by creek inundation.

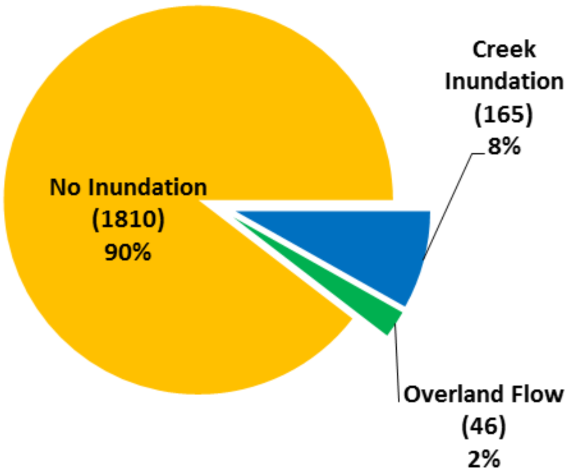


Figure 62 Inundation within Creek and Overland Flow Areas (Number of Buildings)

Figure 63 shows the total AAD split between flooding caused by Dairy Creek / Horse Creek and flooding which occurs due to overland runoff through urbanised areas of the catchment. It can be seen that approximately 73% of AAD within the Mount Morgan catchment is attributed to overland flooding.

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

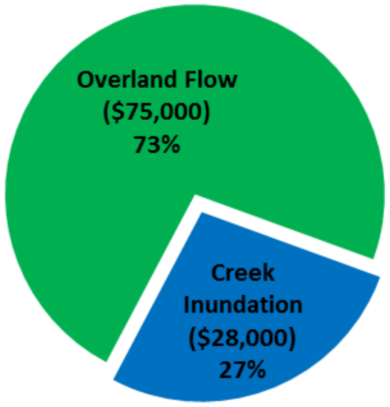


Figure 63 Total AAD within Creek and Overland Flow Areas

Figure 64 shows the breakdown of residential, non-residential and infrastructure AAD over the entire catchment. As shown, a total AAD cost of $103,000 is estimated, with the vast majority (85%) being attributed to residential buildings.

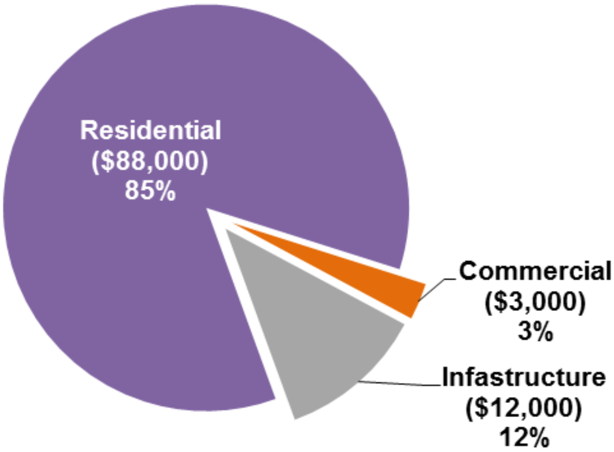


Figure 64 Total AAD by Building Type

Figure 65 and Figure 66 breakdown the AAD for residential and non-residential properties. It can be seen that 92% of residential and 91% of non-residential properties experience a damage cost of less than $500 per annum. As a result, 79% of the total AAD is associated with only 10 buildings, demonstrating that a minority of buildings produce the majority of damages within the catchment.

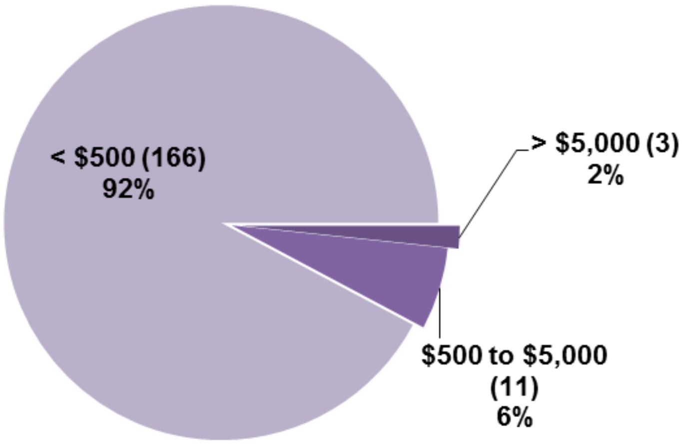


Figure 65 Residential AAD (Number of Buildings)

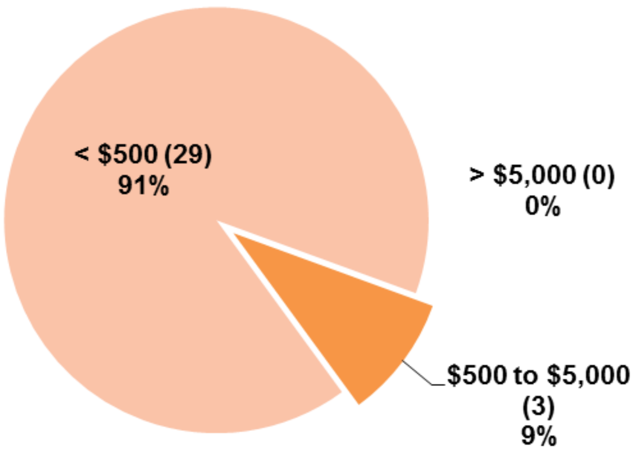


Figure 66 Non-Residential AAD (Number of Buildings)

10.6.4 AAD Summary

Figure 67 summarizes the same information as above in a different manner. The area in blue corresponds to individual building AAD (residential and non-residential combined). 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, 92% of all buildings exhibit less than $500 damage per annum and produce only 6% of the total damage. In addition 79% of damages are associated with 10 buildings. Again, this demonstrates that a minority of buildings produce a significant proportion of damages.

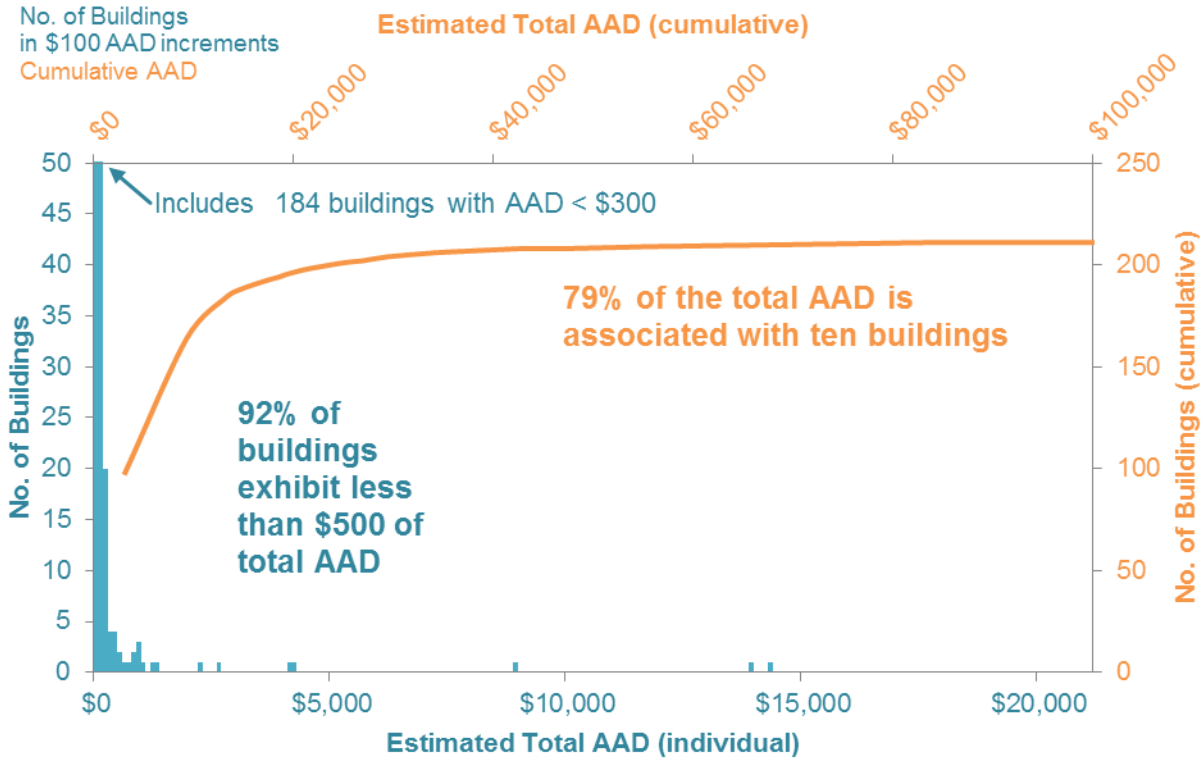


Figure 67 Individual Building vs. Cumulative Total Average Annual Damages

10.7 Rainfall Gauge and Maximum Flood Height Gauge Network Coverage

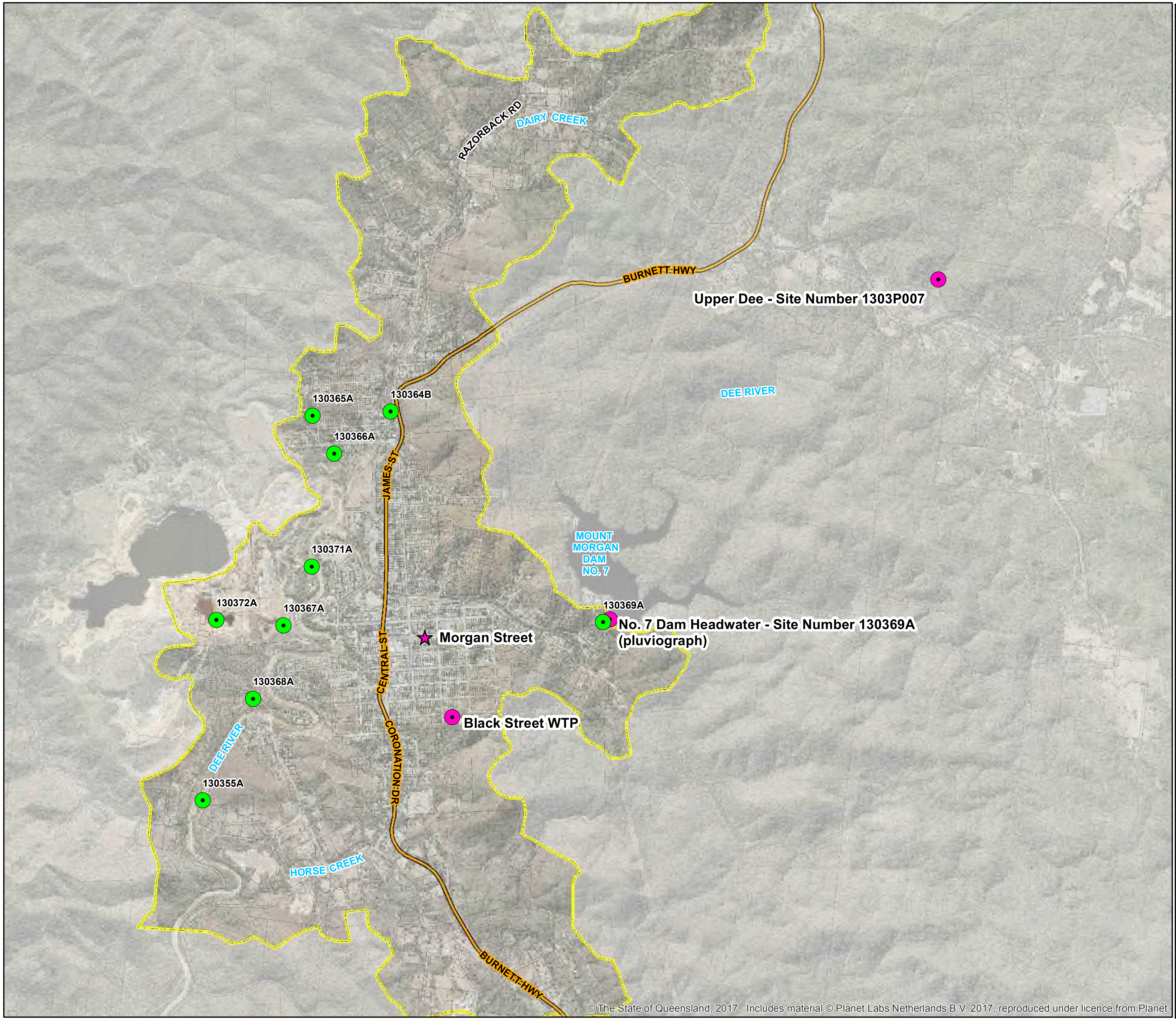
Figure 68 shows the location of existing rainfall gauges within the Mount Morgan region.

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 suitable rainfall gauge is maintained by DNRM within the upper catchment of the Dee River. Active rainfall gauges track rainfall patterns within the Mount Morgan Township at Black Street WTP. As such, it is recommended that the pluviograph station continues to record detailed rainfall data for future events.
- A single flood height gauge is recommended for inclusion within the East Street / Campion Street concrete channel near Morgan Street to develop confidence in urban impacts within the area.

10.8 Flood Warning Network Coverage

As noted in Section 2.6, there is currently no flood warning network for the Mount Morgan local catchment.



N

Rockhampton Regional Council

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Metres

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LEGEND

- DNRM Stream Gauges
- Daily Rainfall Station
- Pluviograph Station

Proposed Flood Gauges

- RRC
- Highways
- Cadastre
- Hydraulic Model Extent

Data Sources:

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

Mount Morgan Model

Rainfall Gauge and Flood Height Gauge Network Overview

PROJECT ID	60534898
CREATED BY	maultbyj
LAST MODIFIED	1/11/2018
VERSION:	1

Figure 68

11.0 Conclusion

11.1 Baseline Model Development

The Mount Morgan Phase 1 Local Catchment Study included the development of a 1D/2D dynamically linked TUFLOW model for the local creek and 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.

11.1.1 Validation

Anecdotal data was received and used to validate the model to flood events caused by Ex-TC Oswald (2013), TC Marcia (2015) and Ex-TC Debbie (2017). The model validated well (average difference of +0.08m) to the 2015 event considering the degree of uncertainty. The validation to the 2013 event also resulted in a reasonable comparison between modelled results and peak flood extents / erosion. The validation to the 2017 event was limited due to the single piece of evidence being captured prior to the flood peak. Nevertheless, evacuation route inundation trigger levels were compared to the flood stage over the spillway, revealing Byrnes Parade was very likely to be inundated which the model also predicted.

Despite the limited data, the model validates well with modelled behaviours anticipated to appropriately predict flood patterns at the time of this study. Future calibration and validation to recorded gauge heights or surveyed peak flood levels is recommended as data becomes available.

11.1.2 Design Event Modelling

On completion of the calibration / validation process, various design flood events and durations were simulated and results extracted. The critical duration for the urban catchment with areas of interest was determined to be the 60 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 the majority of 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 land and infrastructure throughout the catchment. This is often a result of natural or man-made channels being constricted at road crossings, driveways or minor bridges (such as pedestrian bridges).

The larger systems of Dee River, Horse Creek and Dairy Creek were found to be largely confined to their channels in large magnitude events, with the exception of vulnerabilities noted near Gordon Lane.

11.1.3 Sensitivity Analysis

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

11.2 Baseline Flood Hazard and Vulnerability Assessment

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

11.2.1 Flood Hazard

As can be seen in maps **MM-120** to **MM-129** in the Volume 2 report, the 1% AEP hazard analysis generally shows:

- Low to medium hazard (H1 and H2) across the majority of ill-defined urban flow paths.
- Moderate to extreme hazard (H3 and H5) across the majority of steep gullies.
- Extreme hazard (H5 or H6) within steep, concrete-lined urban flow paths.
- Extreme hazard (H5 or H6) within the Dairy Creek, Horse Creek and Dee River channels.

11.2.2 Vulnerability Assessment

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

- The Dee River (No. 4) sewerage pump station in James Street is predicted to be inundated by up to 0.29m in the 0.2% AEP 60min event. It is important to note that this is not the critical duration for the Dee River; longer duration storms are likely to result in higher peak flood depths and inundation frequency at this site. All other water and sewerage infrastructure have the desired 0.2% AEP flood immunity. It is recommended this information be passed onto FRW as the asset owner.
- Flood inundation is not predicted at any community infrastructure or emergency facilities.
- A number of roads are predicted to experience inundation in the 1EY event and larger. Predicted TOS generally ranges from 0.4 to 9.0 hours, with low immunity crossings across the Dee River (Piddichs Crossing, Racecourse Road and Randwick Road) predicted to be inundated between 5.6 and 9.0 hours in a 1% AEP 60min event.

11.2.3 Evacuation Routes

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

- Horse Creek Lane, Burnett Lane and Showgrounds Road → loses evacuation to Burnett Highway during to high stage Horse Creek flood levels.
- Black Street and Campion Street → loses evacuation via Hall Street and Gordon Street to East Street.
- Baree Road and Gordon Lane → loses evacuation via Gordon Lane to James Street.
- Creek Street → loses evacuation to Creek Street (Razorback Road) due to high stage Dairy Creek flood levels.

11.2.4 Building Impact Assessment

The building impact assessment shows the following:

- No buildings predicted to be impacted in the 1EY event.
- 5 buildings (3 with above floor flooding) predicted to be impacted in the 18% AEP event.
- 22 buildings (9 with above floor flooding) predicted to be impacted in the 1% AEP event.
- 291 buildings (221 with above floor flooding) predicted to be impacted in the PMF event.
- Many of impacted buildings are understood to experience flood depths of less than 0.3m flood depth in frequent events.
- Of the 10% of the buildings impacted by flooding, 23% are associated with overland flow.

11.2.5 Flood Damages Assessment

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

- WRM and O2 curves used to establish upper and lower bounds for tangible flood damages:
    - No damage estimated in 1EY event.
    - \$146,000 to \$167,000 damage estimated in 18% AEP event.
    - \$855,000 to \$920,000 damage estimated in 1% AEP event.
    - \$35M to \$54M damage estimated in PMF event.
- AAD ranging from **\$95,000 to \$103,000** for WRM and O2 damage curves respectively.
- 85% of the total AAD is associated with residential buildings.
- 73% of the total AAD is attributed to overland flooding.

- 92% of residential buildings and 91% of commercial buildings exhibit less than $500 damage per annum.
- 79% of the total AAD is attributed to just ten impacted buildings.

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

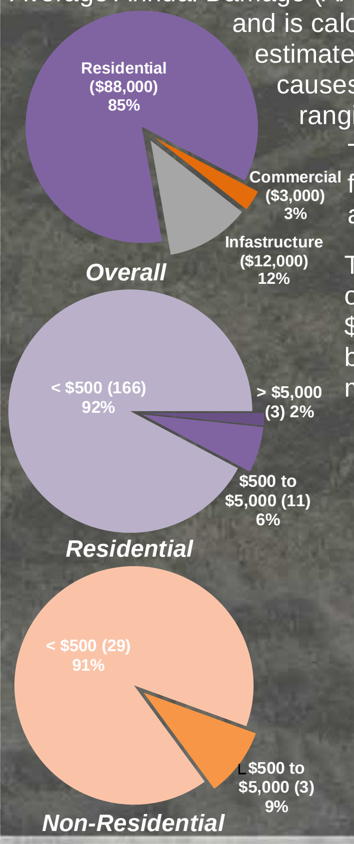
A high level desktop review of the coverage provided by the existing gauges has been undertaken, with the following recommendations provided for future upgrades to the system:

- A suitable rainfall gauge is maintained by DNRM within the upper catchment of the Dee River. Active rainfall gauges track rainfall patterns within the Mount Morgan Township at Black Street WTP. As such, it is recommended that the pluviograph station continues to record detailed rainfall data for future events.
- A single flood height gauge is recommended for inclusion within the East Street / Campion Street concrete channel near Morgan Street to develop confidence in urban impacts within the area.

Mount Morgan Catchment Overview

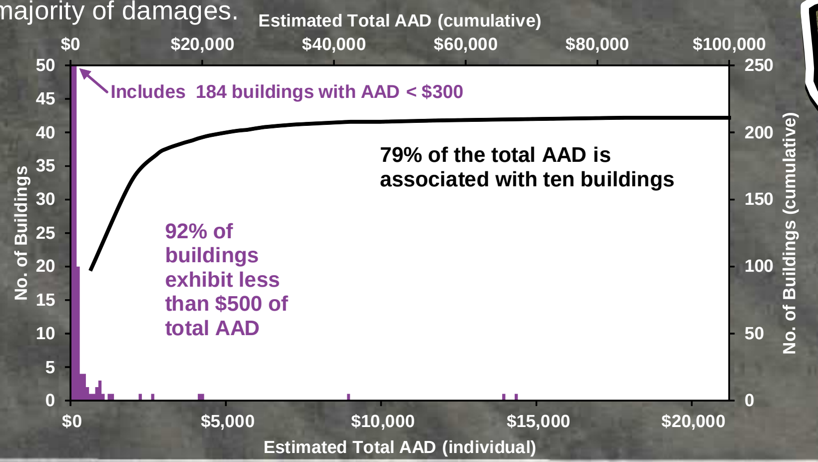
Average Annual Damages

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



The calculated AAD for the Mount Morgan catchment is estimated to range from approximately $95,000 to $103,000 per annum. The difference of approximately 8% provides a relatively narrow range for the estimated AAD.

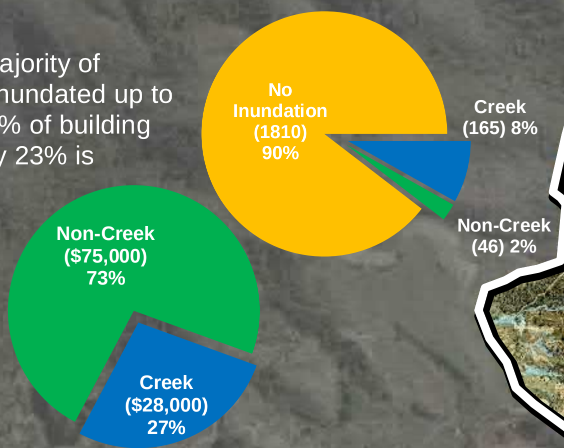
The vast majority (85%) of AAD is attributed to residential buildings. 92% of residential and 91% of non-residential properties experience less than $500 of AAD. As a result, 79% of the total AAD is associated with just 10 buildings, revealing that a minority of buildings are responsible for the majority of damages.



Inundation Breakdown

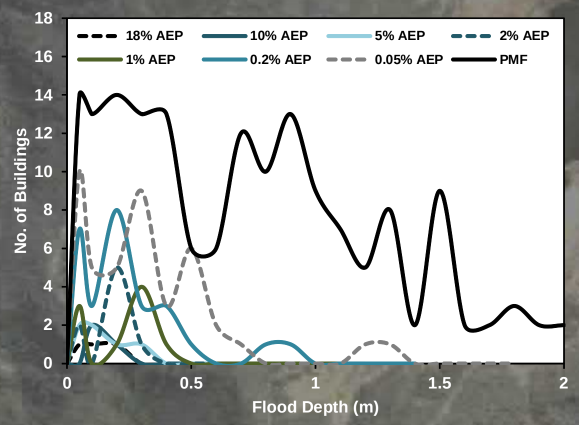
The adjacent graph confirms that the majority of buildings within the catchment are not inundated up to and including the PMF event. Of the 10% of building predicted to experience inundation, only 23% is associated with overland flow.

It can also be seen that 73% of AAD within the Mount Morgan catchment is attributed to overland flooding. As such, mitigation efforts to reduce AAD within the catchment should be focused on overland flooding areas.



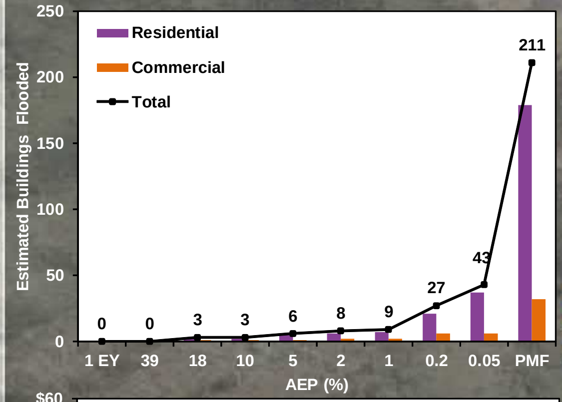
Depth of Inundation

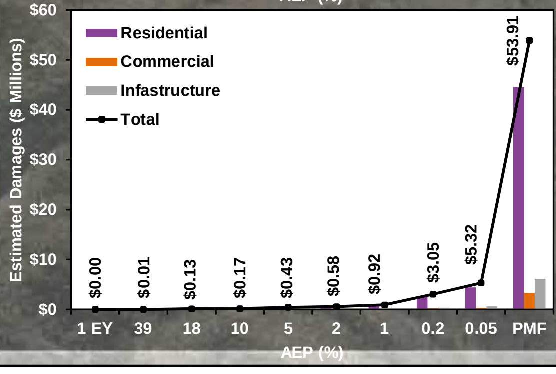
As seen in the figure below, median flood depths are less than 0.3 m for each flood event. This indicates that reductions in flood depths of 0.3 m could significantly reduce overall damage. The figure also shows that a significant number of buildings experience flood depths of 0.3 m or less during frequent events such as the1 EY flood event, generally corresponding to higher flood damages. Note that above floor flooding is not predicted during local catchment events more frequent than the 18% AEP event.

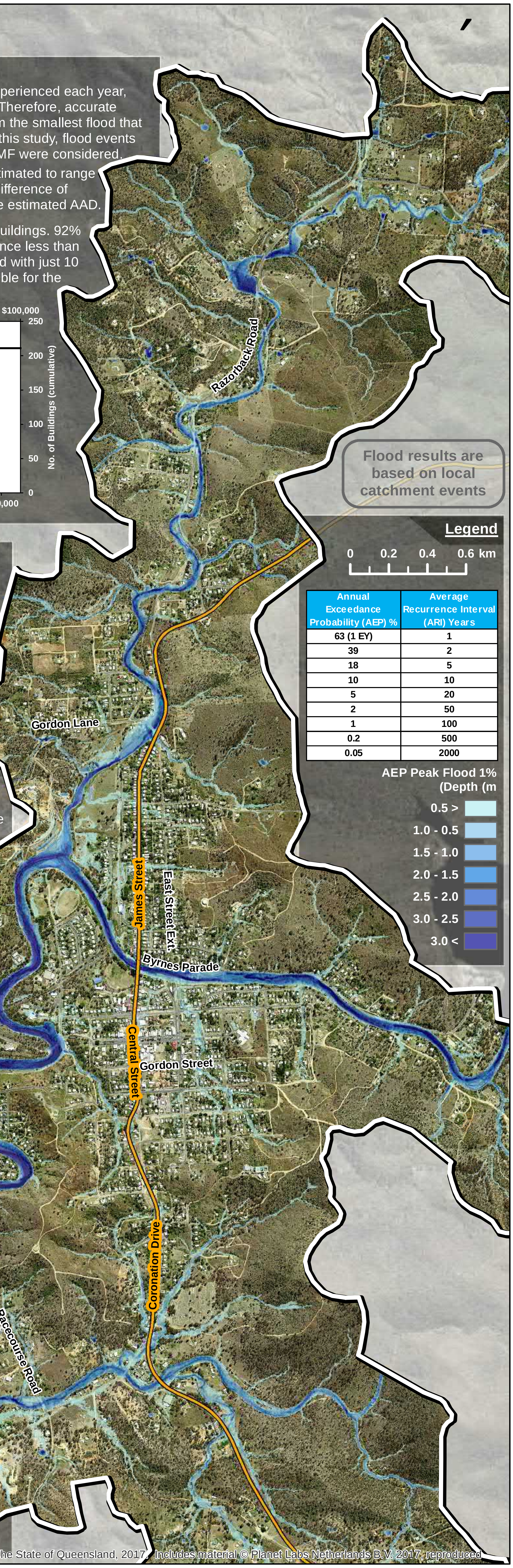


Flood Damages

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







Legend

0 0.2 0.4 0.6 km

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

AEP Peak Flood 1% (Depth (m

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

12.0 Recommendations

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

- Baseline flood mapping (i.e. peak depths, velocities and water surface elevations) provided in this study should be used to update Council's current Planning Scheme layers, at the next available opportunity.
    - Final post-processing of the GIS flood layers is recommended in accordance with the procedures outlined in the AR&R, 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 AR&R 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 record rainfall and flood heights associated with Mount Morgan 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 an additional gauge identified in this study is also recommended.
- Channel cross sectional survey should be undertaken after major flood events in order to assess long term geomorphic changes, and potential implications to flood behaviour.
- The results of this study should be communicated to the dam owner which will allow for a better understanding of potential flood risks and reassessment of the need for an updated failure impact assessment.
- 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).

13.0 References

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

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

Fitzroy River Water (2018), Mt Morgan Water Supply No 7 Dam Emergency Action Plan, prepared by FRW, 2018.

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

SunWater (2009), Mt Morgan No. 7 Dam – Failure Impact Assessment, prepared by SunWater, 2009.

Appendix A

Hydraulic Model Development

Appendix A Hydraulic Model Development

GPU Model Development

Model Setup Parameters

The time step for the 2D model domain has been set to 2.5 seconds. 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. A cutoff depth of 75mm has been adopted, consistent with the Mount Morgan CPU model.

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). Where the catchment extent surpassed the available LiDAR, the Shuttle Radar Topographic Mission (SRTM) 30m topography DEM was used. This was required at the extremities of upper catchments and is not expected to noticeably influence the downstream hydrograph.

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 model were initially developed based on aerial imagery, land use zoning information and other TUFLOW models within the region.

Comparison to URBS Model

A calibrated and validated URBS model exists for the No. 7 Dam. The Mount Morgan GPU model was compared to the URBS model and roughness parameters were modified in order to correlate with the URBS outputs. Reasonable correlation to the URBS model was achieved through variation of Manning's 'n' values, with the primary control being heavy vegetation within the upper catchment. This exercise was based on the PMF 180min event as this was the only design event hydrograph available for the URBS model. The heavy vegetation roughness 'n' was tested across a range from 0.080 to 0.300, with the resultant change in the hydrograph shown in Figure 70.

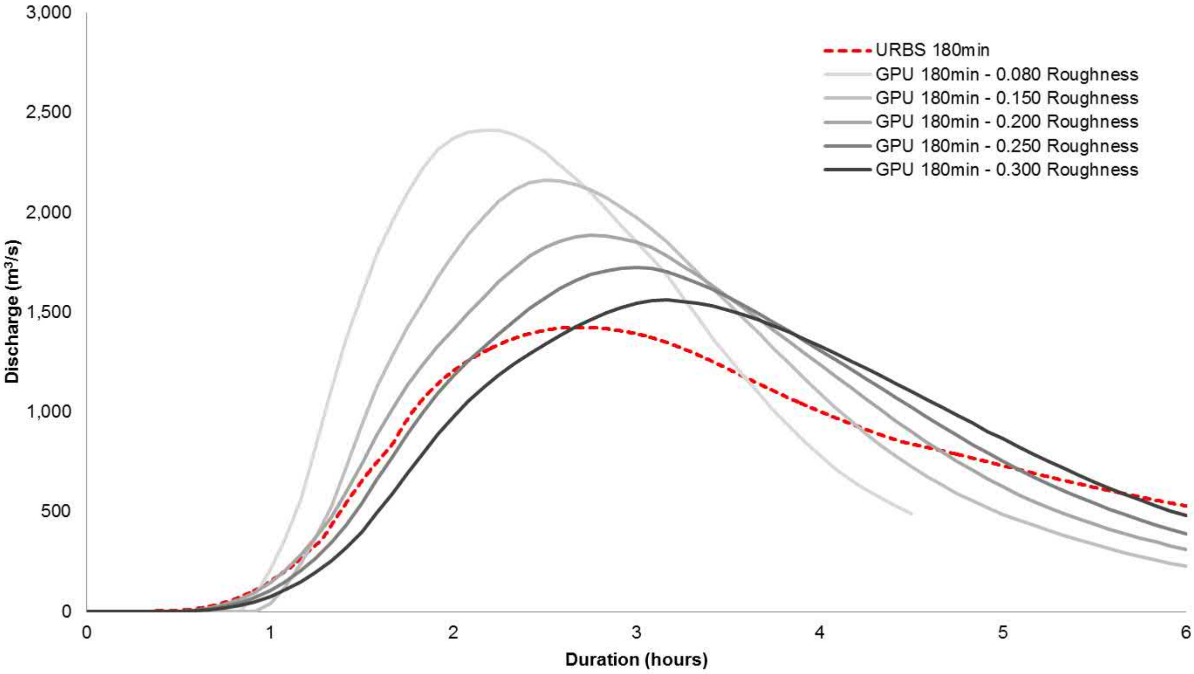


Figure 70 GPU Model versus URBS Model – PMF 180min Event

The only scenario which peaked within 10% of the URBS model was the 0.300 scenario which was then adopted as the baseline settings for design events within the TUFLOW GPU model. The effect this had on the 60 minute PMF (which is the selected critical duration for the Mount Morgan urban catchment) is shown in Figure 71.

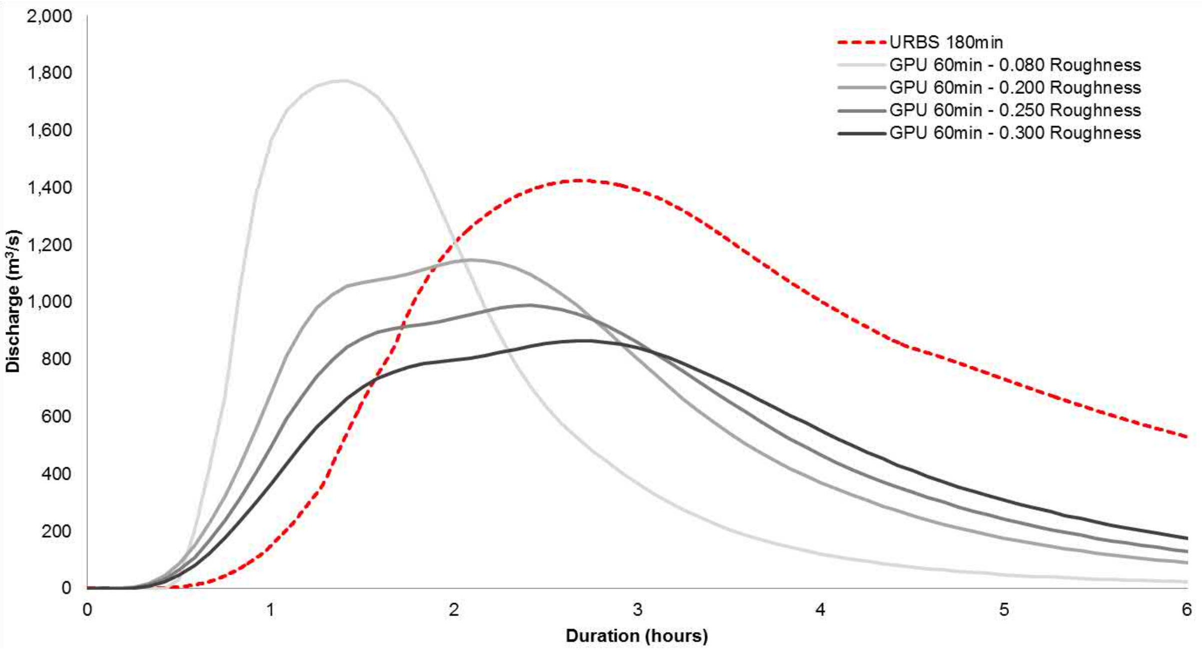


Figure 71 GPU Model versus URBS Model – PMF 60min Event

The final roughness values for each category as applied in the GPU model are outlined in Table 39.

Table 38 Adopted Roughness Values – TUFLOW GPU Model

Material Description	Manning's 'n'			
	Depth 1 (m)	Manning's 'n' 1	Depth 2 (m)	Manning's 'n' 2
Heavy Vegetation	0.300			
Mining	0.1	0.030	0.3	0.020
Open Space / Grass	0.1	0.040	0.3	0.030
Light Vegetation	0.1	0.060	0.3	0.045
Mount Morgan No. 7 Dam (deep water)	0.200			
Low Density Residential	0.1	0.050	0.3	0.090
Medium Density Residential	0.1	0.060	0.3	0.120
Sparse Commercial / Hardstands	0.1	0.020	0.3	0.040
Riparian Corridor	0.1	0.070	0.5	0.050
Unsealed Roads	0.030			
Sealed Roads	0.022			
Meandering Channels	0.1	0.050	0.3	0.040
Buildings	0.1	0.018	0.3	0.500

CPU 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 0.30 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 cell centre.

One-Dimensional Network Development

As detailed in Section 3.5, 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. 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.

Four 1D channels were digitized between stormwater network openings to ensure the overland conveyance was sufficiently represented. 1D channels were modelled at the following locations:

- East Street Concrete Channel (near Campion Street and Royal Lane);
- Downstream of Nicholson Street;
- East Street Extended; and
- East of Little James Street.

Channel captured surveyed cross-sections and variable roughness throughout the channel, however was not able to be stabilised for all design events. As such, the channels at East Street and Nicholson Street were removed for the PMF design event. The invert levels of the channels were stamped into the 2D model surface for the PMF event to ensure conveyance was captured. Review of the results between the 1D and 2D channels revealed minor differences in flood behaviour.

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). A number of surveyed longitudinal invert profiles and cross sections were also enforced within the model based on data provided by RRC. These inverts and cross sections generally informed 1D channels, but were also used to ensure the 2D domain was suitably representing overland conveyance.

Due to limitations surrounding large-scale hydraulic modelling, the adopted grid cell size (4 m) may not always adopt the peak crest level of roads or invert level of channels. Given the hydraulic significance of road crests and minor flow paths in urban catchments, heights were extracted from the 1 m LiDAR DEM at 4 m intervals using centreline alignments. These point elevations were read into the model after the 1 m DEM in order to enforce the road crowns and drainage paths along all surfaces not previously surveyed.

Hydraulic Roughness and Losses

The specified hydraulic roughness reflects the different types of development and ground cover that exists within the hydraulic model extent. The roughness categories adopted for this study were developed based on aerial imagery 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 39.

Table 39 Adopted Roughness Values – TUFLOW CPU Model

Material Description	Manning's 'n'			
	Depth 1 (m)	Manning's 'n' 1	Depth 2 (m)	Manning's 'n' 2
Heavy Vegetation	0.1	0.090	0.3	0.075
Mining	0.1	0.040	0.3	0.035
Open Space / Grass	0.1	0.050	0.3	0.035
Light Vegetation	0.1	0.060	0.3	0.045
Bodies of Water	0.030			
Low Density Residential	0.1	0.050	0.3	0.090
Medium Density Residential	0.1	0.060	0.3	0.120
Sparse Commercial / Hardstands	0.1	0.020	0.3	0.040
Riparian Corridor	0.1	0.070	0.5	0.050
Unsealed Roads	0.030			
Sealed Roads	0.022			
Meandering Channels	0.1	0.050	0.3	0.040
Buildings	0.1	0.018	0.3	0.500
Steep Gullies	0.1	0.100	0.5	0.075
Very Steep Slopes	0.1	0.120	0.8	0.075
Concrete	0.020			

It is noted that the majority of roughness values within the TUFLOW CPU model are the same as those adopted within the TUFLOW GPU model, with the following exceptions:

- Heavy Vegetation, varying from 0.090 to 0.075 in the CPU model compared to 0.300 in the GPU model → the upper catchment within the GPU model includes very dense vegetation when compared to the areas within the CPU model which are less dense. The GPU model was also increased in roughness to correlate with the URBS model.
- Mining, varying from 0.040 to 0.035 in the CPU model compared to varying from 0.030 to 0.020 in the GPU model → the finer grid within the CPU model provides a better representation of ground levels within the mining areas, requiring an increase in roughness to represent modelled features.
- Open Space / Grass, varying from 0.050 to 0.035 in the CPU model compared to varying from 0.040 to 0.030 in the GPU model → again improved resolution within the CPU model required an increase in roughness to represent open space areas.
- Bodies of Water, simulated as 0.030 in the CPU model compared to 0.200 in the GPU model → bodies of water within the GPU model includes No. 7 Dam which incorporates very deep water. Increased roughness represents additional time for inflows to traverse the deeper water areas.

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 validation process if events contained a pre-burst rainfall that was excluded from the simulation the initial losses applied were reduced to 0 mm. This simulates the catchment being saturated by the pre-burst rainfall. Continuing losses 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 in Table 40.

Table 40 Adopted Initial and Continuing Loss Values

Material Description	Initial Loss (mm)	Continuing Loss (mm/h)
Heavy Vegetation	15.0	1.0
Mining	15.0	1.0
Open Space / Grass	15.0	1.0
Light Vegetation	15.0	1.0
Bodies of Water	0.0	0.0
Low Density Residential	7.5	0.5
Medium Density Residential	7.5	0.5
Sparse Commercial / Hardstands	7.5	0.5
Riparian Corridor	0.0	0.0
Unsealed Roads	15	1.0
Sealed Roads	0.0	0.0
Meandering Channels	0.0	0.0
Buildings	0.0	0.0
Steep Gullies	15.0	1.0
Very Steep Slopes	15.0	1.0
Concrete	0.0	0.0

Boundary Conditions

A range of different boundary conditions have been applied within the Mount Morgan 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.

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 regional GPU model or transcribed gauge data at No.7 Dam. 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 summary of the boundary conditions applied to the three models are summarised in Table 41.

Table 41 Summary of Boundary Conditions

Boundary Type	Details
Direct rainfall	Applied across entire 2D domain
QT	Inflows for the upstream Dee River catchment (No. 7 Dam) and 27 steep drainage gullies.
HQ	2 outflow boundaries applied along the northern and southern model boundaries

Appendix B

Tangible Flood Damages Assessment Methodology

Appendix B Tangible Flood Damages Assessment Methodology

1.0 Introduction

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

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

2.0 Estimating Flood Damages

2.1 Overview

Flooding can result in significant financial and social impacts on a community. A breakdown of the various types of flood damages is displayed in Figure 72. As intangible flood damages are difficult to quantify as a monetary value, they have not been included in this flood damages assessment. Therefore, reference to flood damages within this report refers to tangible flood damages only.

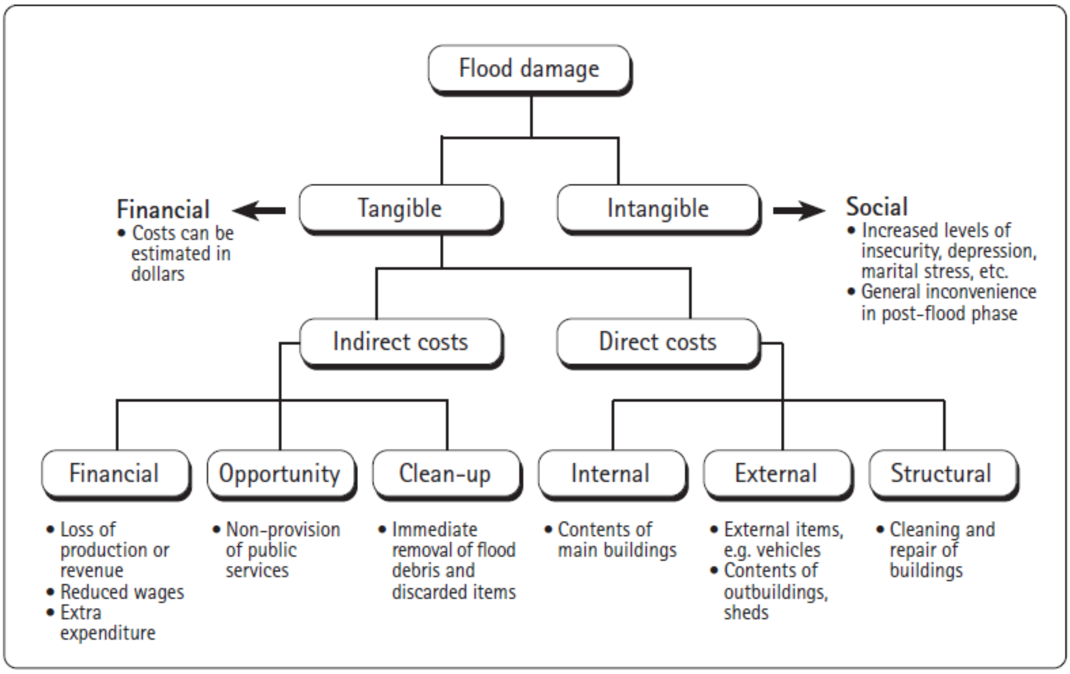


Figure 72 Breakdown of flood damage categories (source: DNRM, 2002)

2.2 General Methodology

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

Alternative Approaches

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

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

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

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

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

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

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

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

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

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

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

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

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

Actual and Potential Damages

The stage-damage curves used during this study provide estimates of the potential flood damages which would occur during a flood event if no actions were taken to reduce the amount of damage. During actual flood events, residents will usually take measures to reduce the amount of damage incurred, such as moving possessions to higher ground.

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

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

2.3 Residential Damages

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

O2 Environmental Stage Damage Curves

Direct residential damages were estimated using the O2 Environmental (2012) stage-damage curves based on rebuilding costs, which are presented in Table 42 to Table 44. Individual curves are given for external, contents and structural damages. Figure 73 presents stage damage curves representing total flood damages (sum of external, contents and structural damages).The external and damage component is based on the WRM (2006a) curves adjusted to present day dollars (refer Section 2.6, Table 49), 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 42 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 43 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 44 O2 Environmental Stage-Damage curves for residential structural damage (March 2017 $)

Depth Over Floor (m)	Detached Single Storey (200m²)	Detached Single Storey (150m²)	Detached Double Storey (2 x 150m²)	High Set Queenslander (200m²)	Multi-unit Single Storey	Multi-unit Double Storey
0	$0	$0	$0	$0	$0	$0
0.025	$10,796	$7,936	$10,796	$7,936	$7,337	$5,393
0.15	$19,694	$14,358	$20,429	$14,889	$13,397	$10,129
0.5	$85,060	$66,271	$87,480	$78,831	$57,838	$53,609
1	$141,259	$112,984	$112,860	$116,670	$96,060	$79,340
1.5	$141,259	$112,984	$117,540	$116,670	$96,060	$80,052
2	$141,259	$112,984	$122,232	$116,670	$96,060	$80,052
2.3	$141,259	$112,984	$122,232	$116,670	$96,060	$80,052
2.8	$154,927	$123,227	$135,889	$136,431	$105,353	$92,771
3	$176,701	$141,485	$157,900	$159,494	$120,152	$108,451
4	$176,701	$141,485	$157,900	$162,761	$120,152	$110,678
5	$176,701	$141,485	$157,900	$169,286	$120,152	$115,110
5.2	$176,701	$141,485	$157,900	$180,579	$120,152	$122,797
6	$176,701	$141,485	$157,900	$198,837	$120,152	$135,210

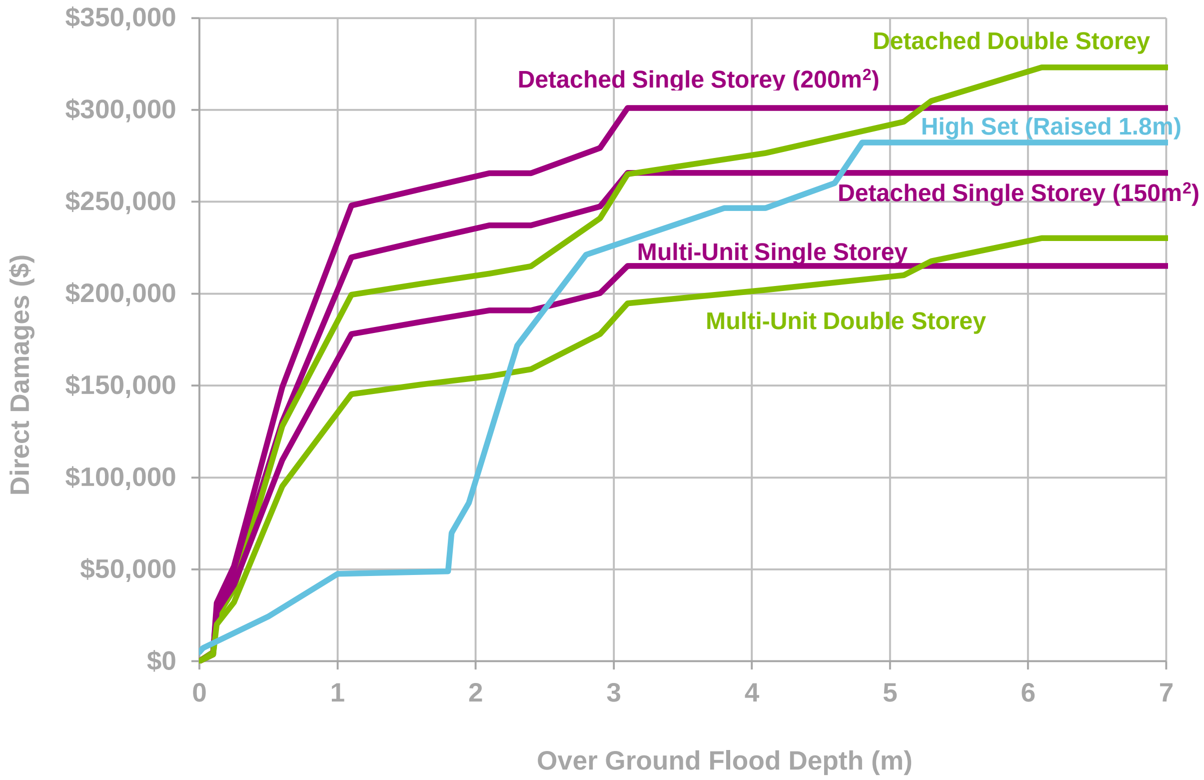


Figure 73 Total residential stage-damage curves based on O2 Environmental curves (March 2017 $)

WRM Stage Damage Curves

Direct residential damages were estimated using the WRM (2006a) stage-damage curves presented in Table 45 to Table 47. Individual curves are given for external, contents and structural damages, which were derived from stage-damage surveys conducted in Maroochy Shire on the Sunshine Coast. Figure 74 presents stage damage curves representing total flood damages (sum of external, contents and structural damages).

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

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

Table 45 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 46 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 47 WRM Stage-Damage curves for residential structural damage (March 2017 $)

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

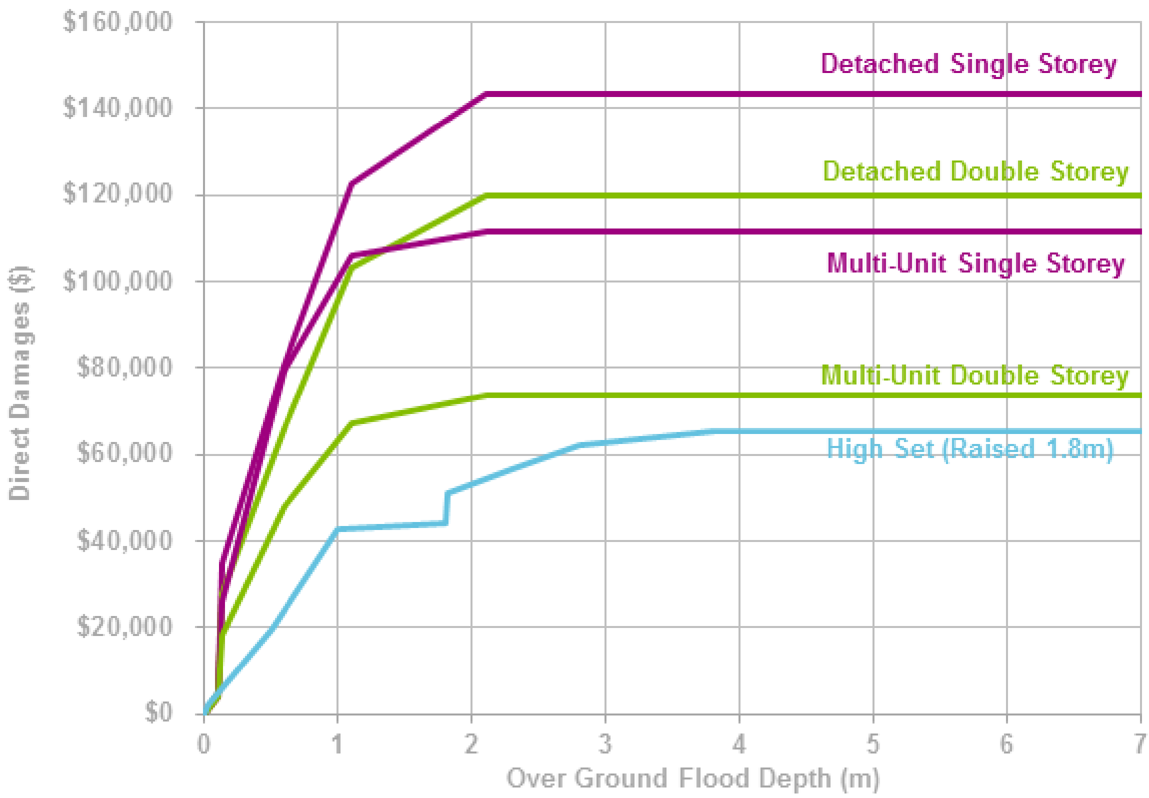


Figure 74 Total residential stage-damage curves based on WRM curves (March 2017 $)

Indirect Damages

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

2.4 Commercial Damages

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

ANUFLOOD Stage-Damage Curves

Commercial, industrial and public building damages were estimated using the ANUFLOOD commercial stage-damage curves summarized in Table 48 and Figure 75. Commercial buildings were assigned a value class based on their use. Details on building classification are presented in Section 3.3. It should be noted that large-classed building damages were estimated using area directly (i.e. the large-class building damage curves are in units of $/m2 vs. $).

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

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

Table 48 ANUFLOOD Stage-Damage curves for commercial properties (March 2017 $)

Depth Over Floor (m)	Small – Damages in $ (< 186 m^2)					Medium – Damages in $ (186 - 650 m^2)					Large – Damages in $/m^2 (> 650 m^2)				
	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 m^2' rate, whereas damage costs for Small and Medium Commercial Properties are based on a pure 'dollar' rate.

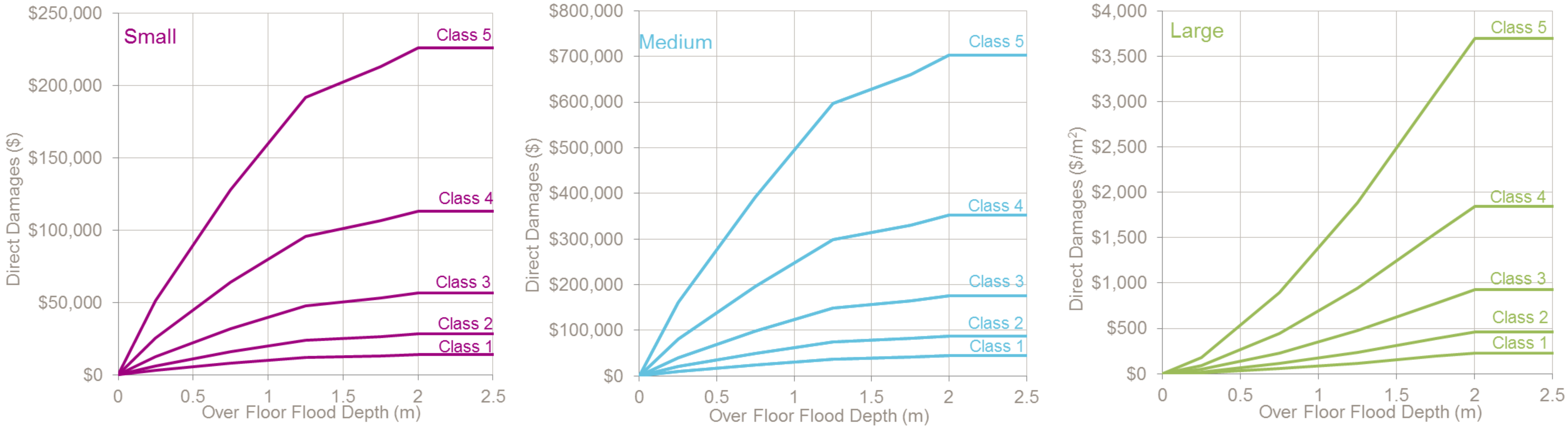


Figure 75 ANUFLOOD Stage-Damage curves for commercial properties (March 2017 $)

Indirect Damages

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

2.5 Infrastructure Damages

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

2.6 Consumer Price Index Adjustment

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

The commercial ANUFLOOD damage curves were adjusted using the CPI for All Groups, as the allotment of ANUFLOOD damages to structure damages and contents damages is unknown. The external and structural components of O2 Environmental damages were adjusted separately using the relevant CPI's. The contents component of the O2 Environmental damages were not indexed, as the maximum value of $80,000 for residential contents damages is considered reasonable for the study area. Table 49 presents an overview of the CPI adjustments.

Table 49 CPI adjustment summary

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

3.0 Building Classification

3.1 Introduction

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

3.2 Footprints

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

3.3 Class

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

Residential Buildings

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

Commercial Buildings

Commercial buildings were further classified based on size and value of the building contents to align with the classes presented in Section 2.4. The ANUFLOOD damage value classes for commercial buildings are shown in Figure 76.

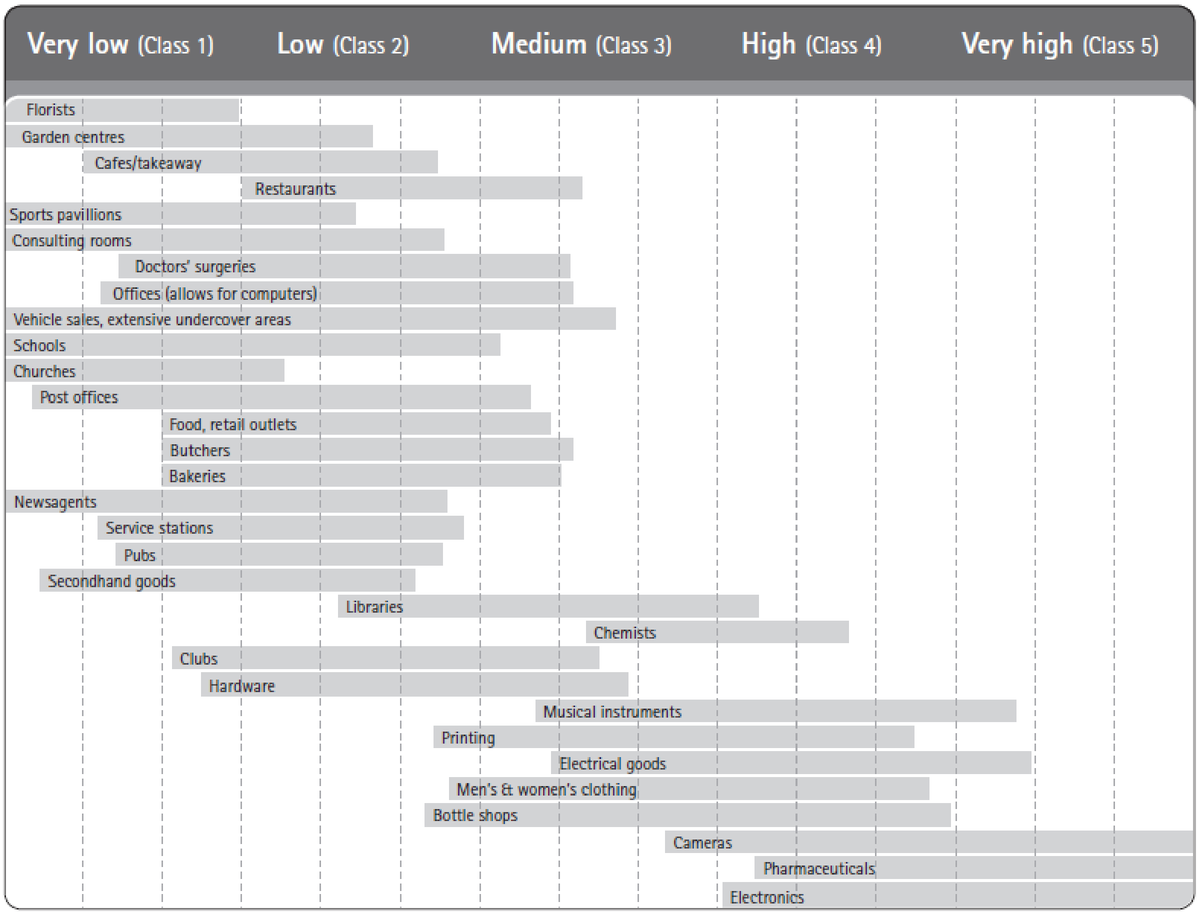


Figure 76 ANUFLOOD commercial damage value classes (source: DNRM, 2002)

As ANUFLOOD provides a range of property classes for each property type, a single value class has been assigned based on the land use field of the building footprints dataset. Where the land use did not correspond directly to an ANUFLOOD damage value class, a reasonable value class was assigned. Areas labelled as footpaths were assumed not to be buildings and were not classified. Sheds and Garages were given a classification based on land use data. Table 50 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 50 Assignment of commercial damage class values based on Council land use dataset

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

3.4 Levels

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

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

4.0 Bibliography

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Appendix C

Flood Behaviour Photographs

Appendix C – January 2013


Ford
ALWAYS SAFE
895·MDP


CRANE HIRE


NE HIRE


C.Q. CRANE HIRE


SUBARU GL
02ESE


9
8
7
6
5
4
3
2
1
18
9
8
7
6
5
4
3
2
1


CASE
BELL'S PLANT HIRE

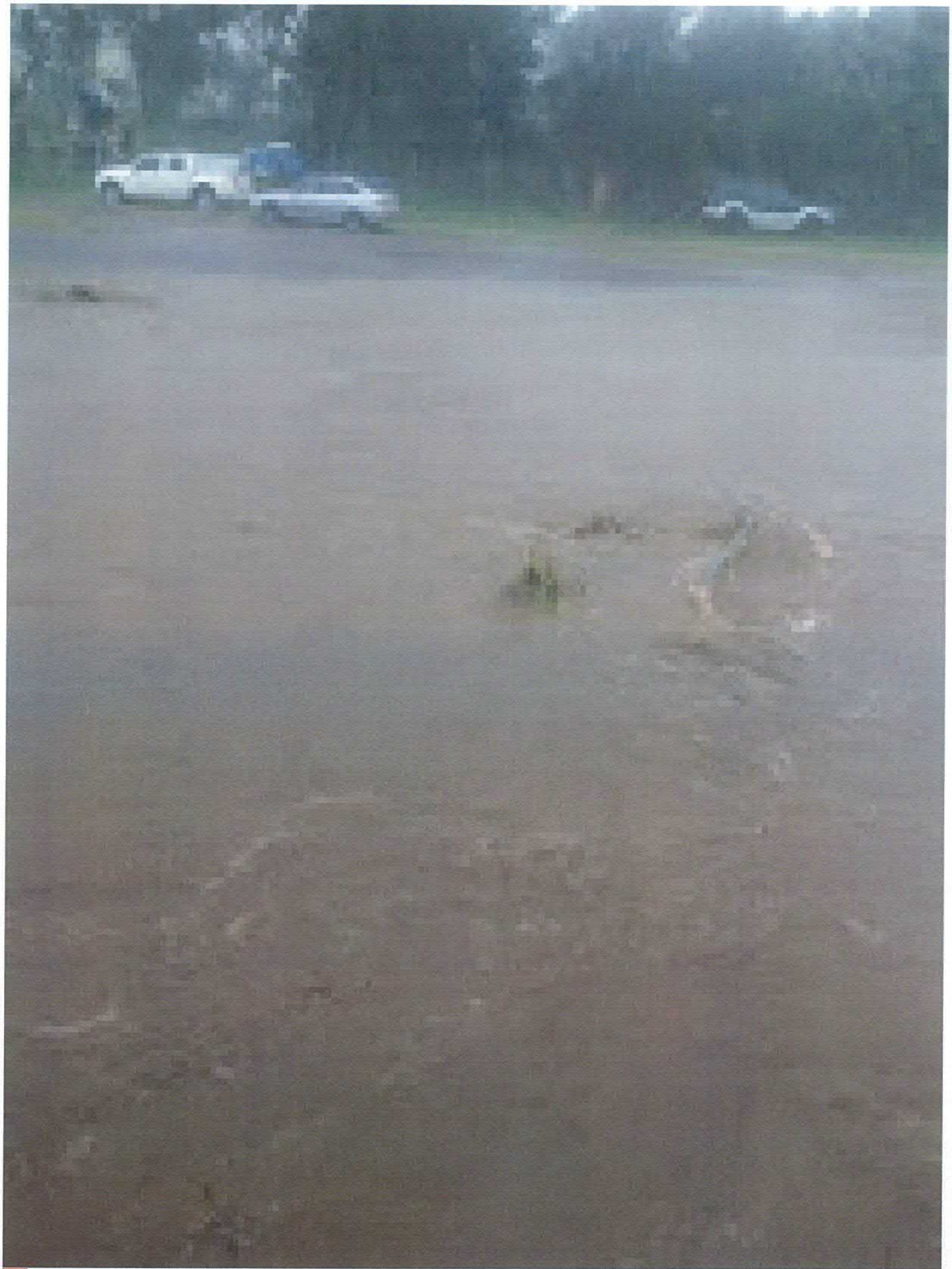
Appendix C – February 2015

IMG_0791.JPG

The only standing Colourbond fence
in North-east of 1 Gordon Ln.

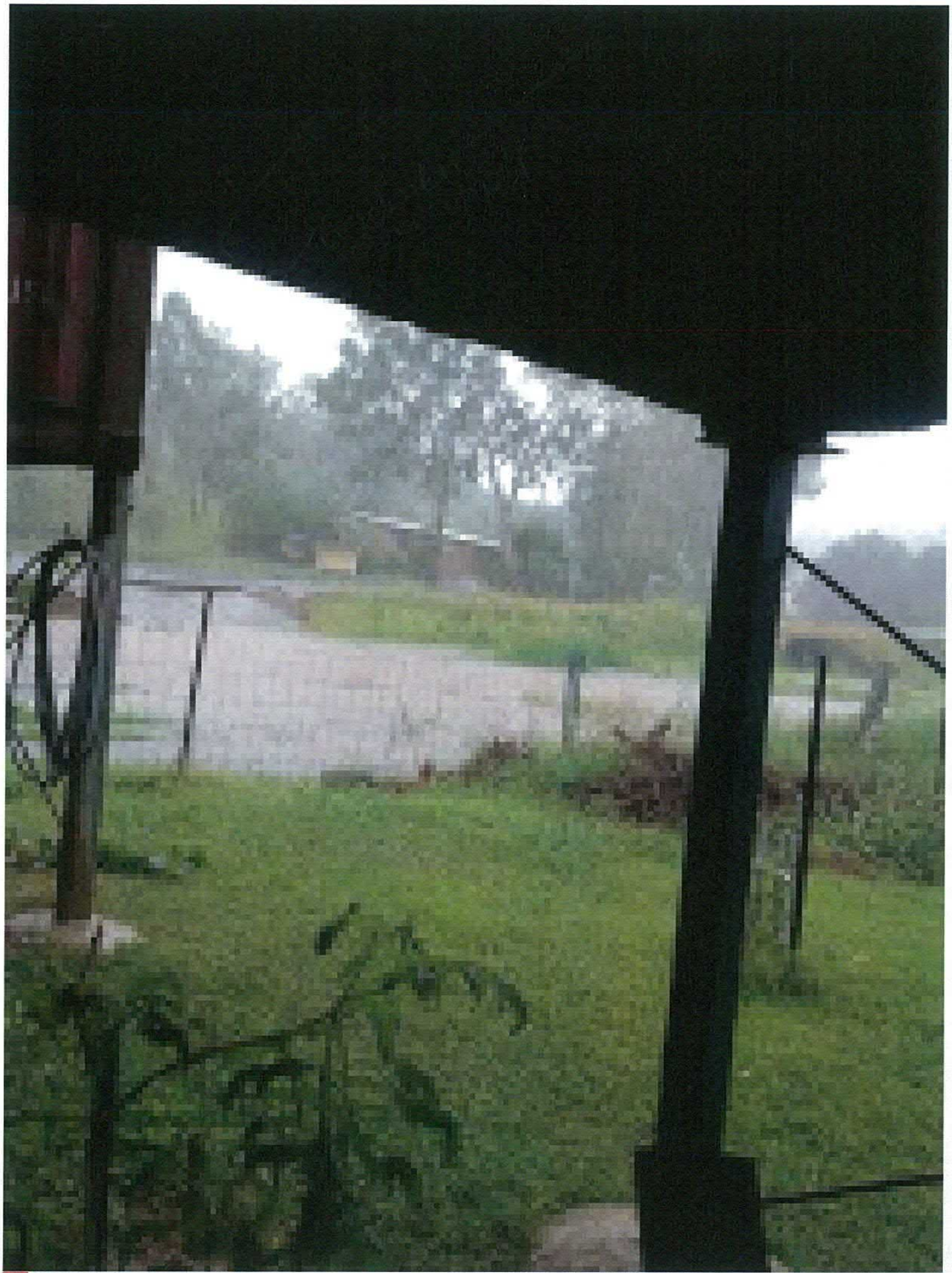
IMG_0793.JPG

1 Gordon Ln - flow through the property.
House on stumps - ≈ 1.8m High.

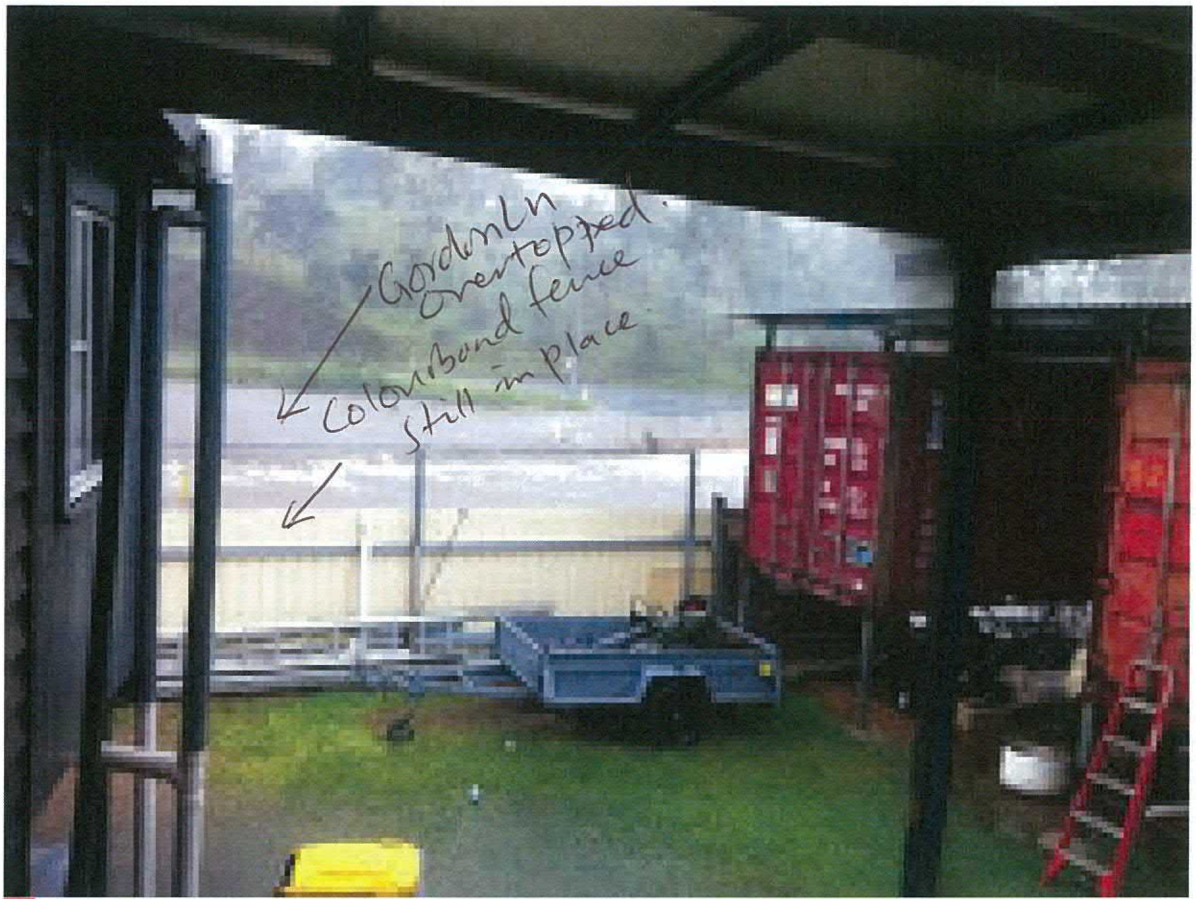


IMG_0779.JPG

From 1 Gordon Ln across to 4 Gordon Ln.



IMG_0781.JPG



IMG_0795.JPG

Aftermath of flooding

culvert across the highway.

IMG_0827.JPG from 1 Gordon Ln across to highway.

IMG_0825.JPG

IMG_0801.JPG

IMG_0797.JPG

Aftermath of flooding 1 Gordon Ln looking d/s of culvert & highway.

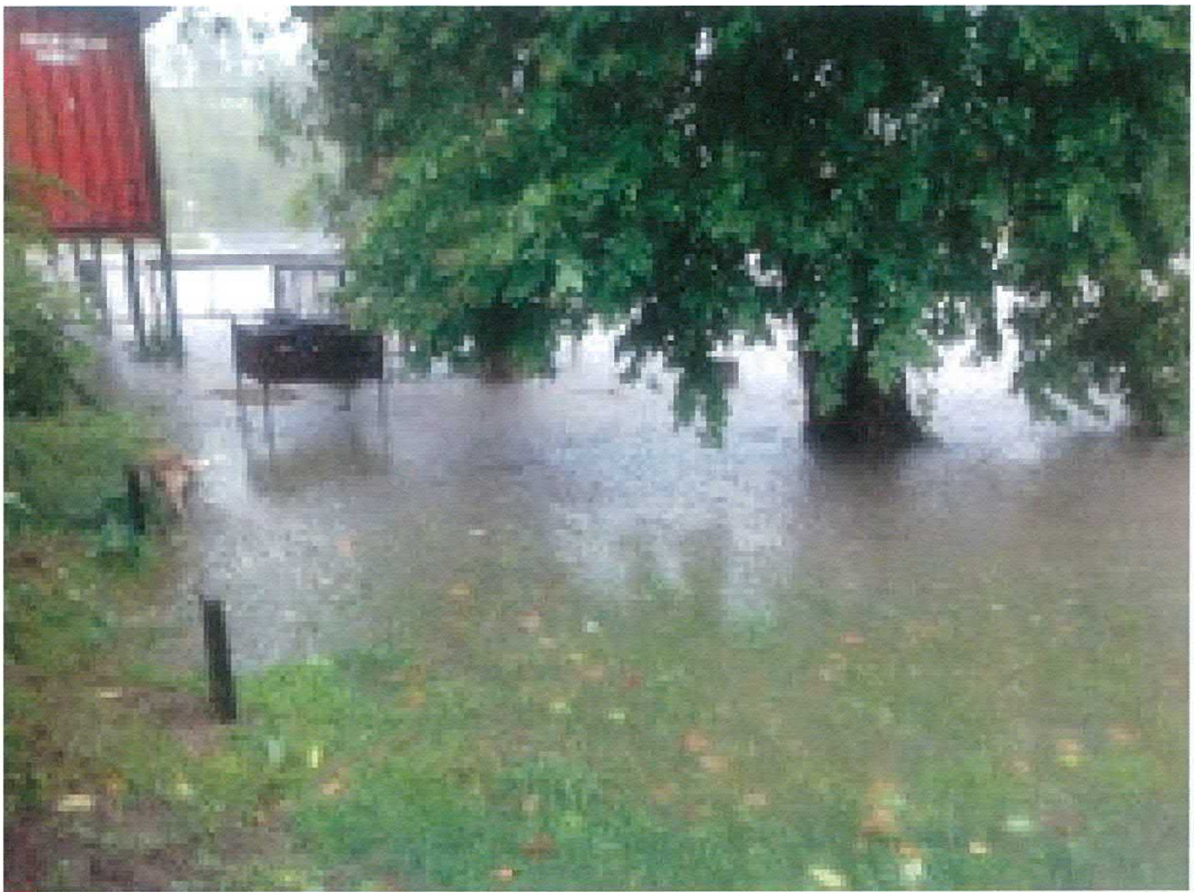
IMG_0821.JPG

IMG_0822.JPG Looking across to 1 Gordon Ln from Highway.

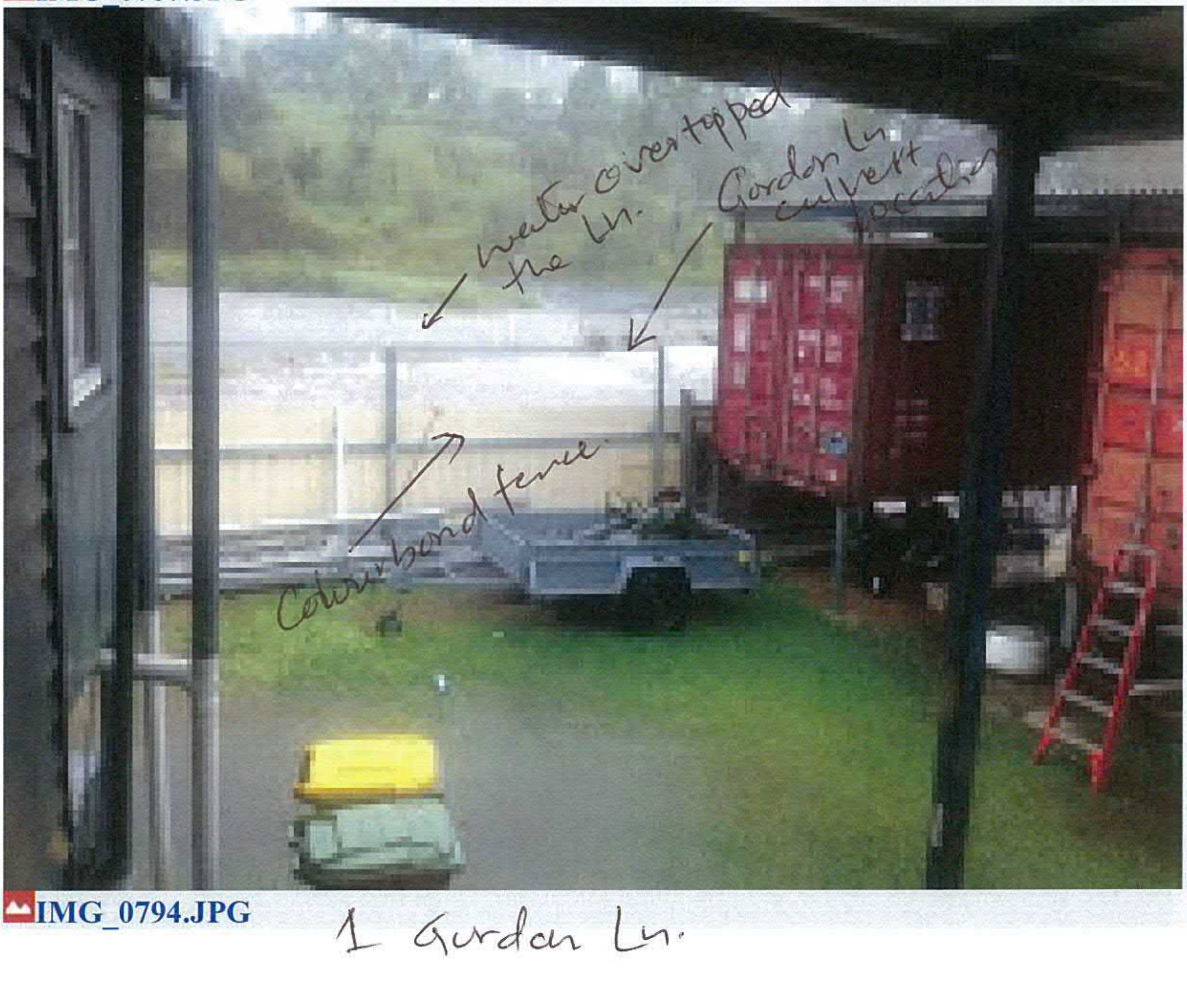
1 Gordon Ln.

culvert location (outlet)

looking d/s from culvert (Gordon Ln).



IMG_0787.JPG



IMG_0794.JPG

1 Gordon Ln.

Appendix C – March 2017

March 2017 - Pidichs Crossing (Byrnes Parade)