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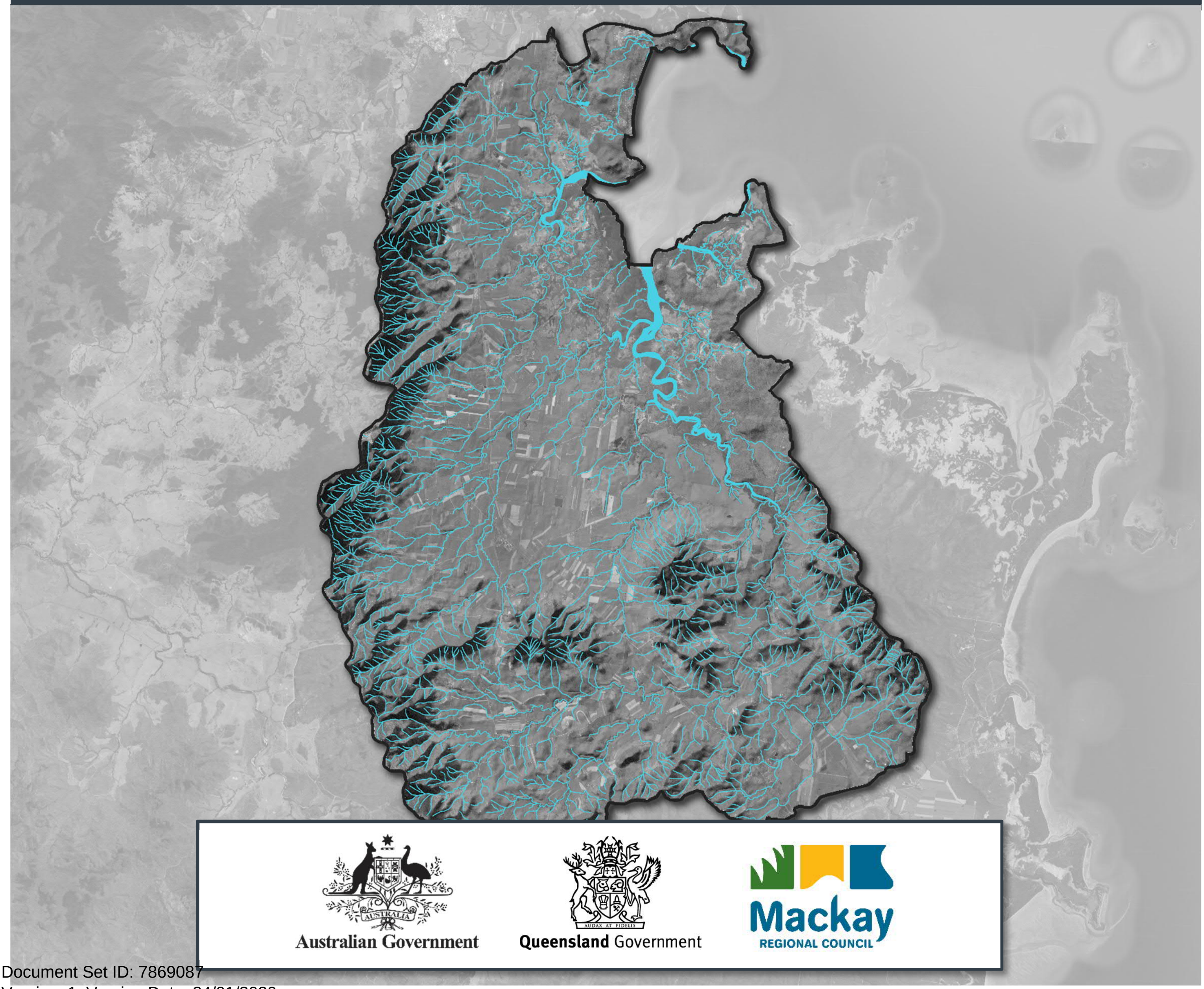
AECOM

ROCKY DAM CREEK CATCHMENT

VOLUME 1 REPORT
TROPICAL CYCLONE DEBBIE FLOOD STUDIES

Prepared for Mackay Regional Council as part of the Tropical Cyclone Debbie Flood Studies with funding assistance from the Australian and Queensland Governments through the 2017-2018 Natural Disaster Resilience Program.



Australian Government

Queensland Government

Mackay Regional Council

Rocky Dam Creek Catchment

Volume 1 Tropical Cyclone Debbie Flood Studies

Client: Mackay Regional Council

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Quality Information

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Explanatory Notes and Disclaimer

This report is to be viewed in conjunction with the mapping in the Rocky Dam Creek Catchment – Tropical Cyclone Debbie Flood Study Volume 2 Report (AECOM, 2019).

Maps in this report have been developed to represent local catchment flood behaviour in the Rocky Dam Creek area, particularly around the residential areas.

Information presented in this mapping may vary, depending upon development within the floodplain over time. It is suggested that the TUFLOW model and these associated maps be updated by Mackay Regional Council as development occurs.

The development of the TUFLOW hydraulic model is detailed in this report outlining input data, modelling assumptions and schematisation parameters adopted.

All information presented in tables and mapping is expressed in meters Australian Height Datum (AHD).

Hydraulic model results used in this this report and associated mapping have been based on an 5-metre fixed Cartesian grid hydraulic model. Use of the mapping to determine hydraulic parameters in sub-grid scale applications is not recommended.

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Executive Summary

AECOM Australia Pty Ltd (AECOM) has been commissioned by the Mackay Regional Council (MRC) to conduct a flood study for the Rocky Dam Creek – Koumala catchment affected by Tropical Cyclone Debbie in March 2017.

Rocky Dam Creek study area encompasses a 15-kilometre section of the Bruce Highway, the North Coast Rail line and Wilmar's southern cane rail. The catchment headwaters are in the Connors Range with the general discharge patterns eastwards to the coastal plains and then the Coral Sea. The road and rail corridors are generally north-south across the catchments. The Goonyella-Hay Point Rail line traverses some of the upper catchment areas.

The main objectives of the Rocky Dam Creek – Koumala Catchment Flood Study are:

- To assess the flood flows and water elevations in the catchment for a range of events including the Tropical Cyclone (TC) Debbie event;
- Estimation of the probability of the TC Debbie compared with design rainfall events using AR&R methodology;
- Provide recommendations regarding non-structural flood mitigation options, to improve resilience within the study area;
- Liaison with community recovery officers and residents regarding 2017 TC Debbie flood elevations and use the information to assist in model calibration.

Rocky Dam Creek is the main stream of interest with other minor creeks entering the watercourse including Cameron Creek, Station Creek, Little Station Creek, Devil Flat Creek Waterfall Creek and their tributaries. Rocky Dam Creek and all upstream tributaries within the catchment have a total catchment area of approximately 388 km^2. The upper catchments contain dense vegetation before transitioning to sugar cane land which encompasses a large percentage of the catchment.

Hydrologic inputs to hydraulic models have been applied using inflow hydrographs extracted from XP-Rafts and direct rain on grid approach utilised in TUFLOW. The model has been developed primarily using CatchmentSIM, XPRAFTS and Storm Injector software utilising data from Australian Rainfall and Runoff (AR&R) that was used for the estimation of design flood characteristics in Australia.

The closest rainfall gauges which contained sub-daily data for TC Debbie are located within Sarina at the Sucrogen Weir Alert (MRC Station Number 533143) and Murray Creek at Undercliff (Queensland Government Station Number 130416A) located approximately 25 km southwest of Koumala. Both rainfall gauges were modelled to compare the results from anecdotal information and surveyed supplied by the community and MRC. The Undercliff rainfall TUFLOW model flood elevations provided the best representation of the flooding that occurred during the TC Debbie event based on anecdotal and survey information provided. Peak rainfall intensities that occurred during the Cyclone Debbie event was identified to be greater than a 0.2% AEP rainfall event when compared with BOM design rainfall data.

TC Debbie was modelled from 27th March 2017 12:00pm to 30 March 12:01am and found an intense storm occurred after 1:00pm on 29/03/2017, with approximately 430mm of rain falling over a 5-hour period between 1:00pm and 6:00pm on 29th March 2017.

Community consultation was held on the 25th of May 2019 in Koumala to discuss resident accounts of what occurred during the Cyclone Debbie Event. The community identified flooding within the township of Koumala outside the hotel, photographs of flooding within Koumala were taken on the 29th March 2017 between 3pm and 5pm. The times shown on the photos align with the intense rainfall period that occurred on the Undercliff rainfall station.

While flooding observations were provided by the community, they were relatively limited in terms of quantity and elevations or water depths. Key Cyclone Debbie flooding observation provided by the community included flooding up to the step of the Koumala hotel; with no water entering the building. The flooding observations were able to be replicated at the Koumala hotel within the TC Debbie hydraulic model.

Three points were surveyed by MRC within the TUFLOW model boundary. This included the bottom of the rail sign southwest of Koumala (Survey Point A) approximately 600 metres west of the Bruce Highway, Rocky Dam Creek flooding extent seen by property owner (Survey Point B) and flooding to the side of a house located on the bank of Rocky Dam Creek (Survey Point C).

In general, the hydrological and hydraulic simulation of the TC Debbie event in the Rocky Dam Creek catchment was within 300mm of two survey points (B and C) and was approximately 1 metre at survey Point A. Significant modelling of possible floodplain behaviour was undertaken by simulating:

- Changes to stream behaviour by increasing blockage factors to exceptional percentages (approximately 60% for bridges and culverts) which are considered outside normal values;
- Changes to floodplain behaviour by increasing hydraulic roughness factors above accepted values;
- Changes to hydraulic factors to simulate the possibility of cane being blown down thus allowing increased flows at higher elevations than would be if the cane was standing;
- Increasing the rain intensities are certain locations to potentially mimic the recorded flood elevations.

None of the above simulations either individually or collectively generated flood behaviour that approximately matched the recorded flood elevations. It is to be noted that the areas where there are significant differences in modelled and recorded flood elevation there are no rain gauging stations.

An hypothesis is that in the areas where the hydraulic simulation is significantly different to the recorded elevations, there was a very localised and intense rain burst that was significantly in excess of the recorded rainfalls.

The critical storm duration for the study area was assessed by simulating 180 (3 hrs), 270 (4.5 hrs), 360 (6 hrs), 540 (9 hrs), 720 (12 hrs), 1080 (18 hrs), 1440 (24 hrs), 1800 (30 hrs), 2160 (36 hrs), 2880 (48 hrs) and 4320 (72 hrs) minute durations for the 1% AEP event (1 in 100) in the baseline hydraulic model. The 540-minute storm was found to result in the highest mean peak flow for the majority of the subcatchment and was selected as the critical design storm duration.

A summary of non-structural mitigation measures identified to improve resilience within the study area includes:

- Community engagement to inform the community on the Rocky Dam Creek flood risk and protective actions they can make in the event of flooding;
- Emergency management planning such as flood forecasting (prediction of flood severity), flood preparedness and flood response guidelines should be provided to the community;
- Increase in community connectivity after the flood event by having a communication device (such as satellite phone) available at community centres to assist in informing Council of community requirements.

The main limitations that apply to the Rocky Dam Creek catchment is the availability of reliable data such as flood elevations and Cyclone Debbie rainfall information. The following information is recommended to be completed prior to executing future calibration flood studies within the Rocky Dam Creek catchment:

- Survey of railway hydraulic structures such as bridges and culverts;
- Installation of point rainfall gauges located throughout the catchment for future rainfall events to assist in calibration;
- More current topographic data;
- Surveyed flood elevations and the collation of anecdotal information of all major rainfall events that can be utilised for calibration of the model.

1.0 Introduction

1.1 Study Location

AECOM Australia Pty Ltd (AECOM) has been commissioned by the Mackay Regional Council (MRC) to conduct a flood study for the Rocky Dam Creek – Koumala catchment affected by Tropical Cyclone Debbie in March 2017.

The study area encompasses a 15-kilometre section of the Bruce Highway, the North Coast Rail line and Wilmar's southern cane rail. The catchment headwaters are in the Connors Range with the general discharge patterns eastwards to the coastal plains and then the Coral Sea. The road and rail corridors are generally north-south across the catchments. The Goonyella-Hay Point Rail line traverses some of the upper catchment areas.

The study area catchments are broadly described as:

- Steep forested upper sections;
- Generally well-defined watercourse systems;
- Flatter coastal plain areas of predominately cane farming interspersed with local road network;
- Farming activities giving way to tidal flats and mangroves towards the coast.

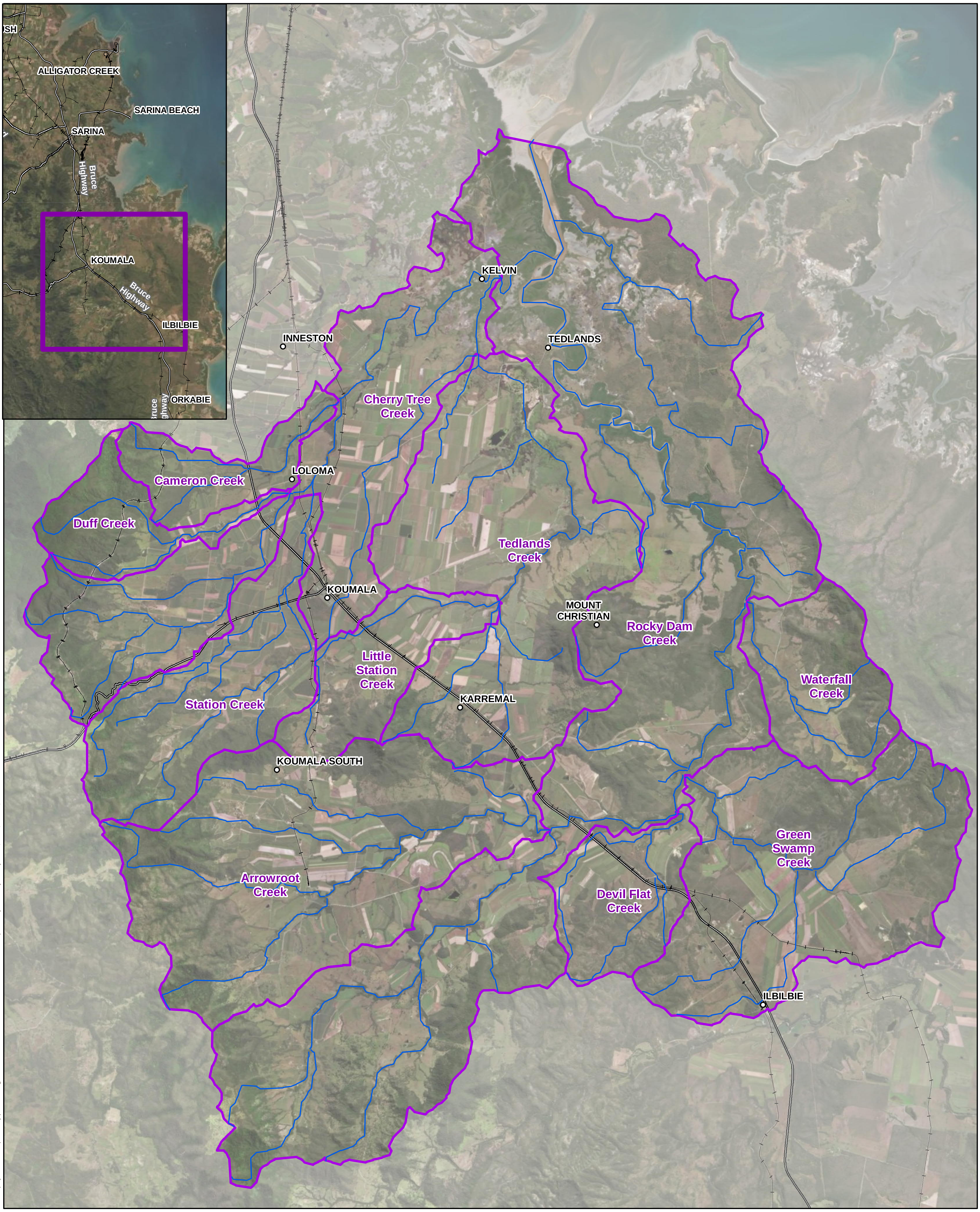
The study area includes the watercourses of Cameron Creek, Duff Creek, Cherry Tree Creek, Station Creek, Little Station Creek, Leichardt Creek, Tedlands Creek, Rocky Dam Creek, Bull Creek, Devil Flat Creek and Marion Creek.

The study area is approximately 28600 ha (286 km^2). The TUFLOW model extents were agreed with council to cover from approximately 2 km upstream to 2 km downstream of the Bruce Highway. Upstream catchments outside of the TUFLOW model boundary were modelled as inflow boundaries and were outside the area of interest for the hydraulic model results.

The hydraulic study area consists of forested areas on the steeper slopes with the lower slopes and creek flats mainly for pastoral, agricultural use or small rural holdings.

The road network in the study area and adjacent precincts experienced disruption from weather events such as Cyclone Debbie event which resulted in the closure of Bruce Highway.

Figure 1 shows the Rocky Dam Creek – Koumala Catchment Map and Locality Plan.



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0 1 2 3 4 5
Kilometers
1:90,000 (when printed at A3)

LEGEND
- Watercourse Line
- Study Catchment Boundary
- Rail Line
- State Controlled Road

Data sources:
Base Data: (c) 2017 Qld Gov

MACKAY REGIONAL COUNCIL
Rocky Dam Creek - Koumala

Catchment Map and Locality Plan

PROJECT ID	60598460
CREATED BY	reitanod
LAST MODIFIED	18/09/2019
VERSION:	v01

Figure
02

A3 size

1.2 Study Objectives

The main objectives of the Rocky Dam Creek - Koumala Catchment Flood Study are:

- To assess the flood flows and water elevations in the catchment for a range of events including calibration to the Tropical Cyclone (TC) Debbie event;
- Estimation of the probability of the TC Debbie rainfall compared with design rainfall events using AR&R methodology;
- Liaison with community recovery officers and residents regarding 2017 TC Debbie flood elevations and use flood information to assist in model calibration.
- Undertake hydrologic and hydraulic modelling of the Rocky Dam Creek catchment using the latest hydrologic / hydraulic methodologies and data inputs that have been revised through the 2016 release of Australian Rainfall and Runoff;
- Development of XPRAFTS models and updated hydrologic analysis to establish the hydrographs for the 39%, 18%, 2%, 1% (1 in 100), 0.5% (1 in 200), 0.2% (1 in 500) Annual Exceedance Probability (AEP), Probable Maximum Flood (PMF) and 1% & 0.2% AEP events with year 2100 climate change scenario in accordance with Australian Rainfall and Runoff;
- Development of a new hydraulic model for the Rocky Dam Creek catchments using the TUFLOW modelling platform (GPU HPC);
- Inform potential flood impacts within the broader community to enhance community understanding and therefore empowerment to enable a more resilient community;
- Provide recommendations to improve planning, emergency management and disaster preparedness in the catchment.
- Prepare reporting and mapping.

1.3 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 of once in 5 years on average.

The correspondence between the two systems is shown in Table 1 below.

Table 1 Flood Frequency Classification

Annual Exceedance Probability (AEP) %	Average Recurrence Interval (ARI) Years
63 (1EY)	1
39	2
18	5
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 as recommended in AR&R.

1.4 Limitations and Exclusions

The following limitations and exclusions apply to the Rocky Dam Creek Catchment hydrologic and hydraulic modelling updates.

- The 1% AEP critical duration was adopted for all events from 1EY up to and including the 1% AEP event. Critical duration for events rarer than the 1% AEP event were nominated individually.
- Aerial survey data was captured in 2009/2014 in the form of Light Detection and Ranging (LiDAR) used to develop the topography for the hydraulic model has a vertical accuracy of ± 0.15 m on clear, hard surfaces and a horizontal accuracy of ± 0.3 m.
- Bathymetry of stream inverts was not available for the study. The invert of streams has been represented as enforced gully lines within the TUFLOW hydraulic model. Culvert inverts have been modified where required to align with the available topographical information.
- The hydrologic model has been compared to anecdotal information from Cyclone Debbie flood event occurred in March 2017, based on current available data at the time of this study.
- The hydrologic and hydraulic modelling undertaken as part of the study has been based on methods and data outlined in Australian Rainfall and Runoff (AR&R). The 2016 revision has been adopted as per MRC's request.
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- Where information has been supplied by the Client or other external sources, the information has been assumed correct and accurate unless stated otherwise. No responsibility is accepted by AECOM for incorrect or inaccurate information supplied by others.
- While every effort has been made to simulate the provided flood elevations with only two sub-daily gauges located at the northern and southern extremities of the study area, the likelihood of not capturing a localised intense rain burst is relatively high.

Australian Rainfall and Runoff (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 requires 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.
- Recognition that no two flood events behave in exactly the same manner.
- Design floods are a best estimate of an "average" flood for their probability of occurrence.

1.4.1 Interpretation of Results

The interpretation of results and other presentations in this report requires an appreciation of the limitations in accuracy, as noted above.

Unless otherwise stated, presentations in this report are based on peak values of water surface elevations, flow, depth and velocity. Using flood elevations as an example, the peak elevation does not occur everywhere at the same time and, therefore, the values presented are based on taking the maximum value which occurred at each computational point in the model during the entire flood.

Hence, a presentation of peak elevations does not represent an instantaneous point in time, but rather an envelope of the maximum values that occurred at each computational point over the duration of the flood event.

1.5 Report Structure

The Rocky Dam Creek – Koumala Flood Study Report has been split into 2 volumes:

- Volume 1 → Study methodology, results, findings and recommendations;
- Volume 2 → A3 GIS results 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 catchments including typical land use, rainfall characteristics and a summary of historical flood events;
- Section 3.0 describes the data available for the development of the hydrologic and hydraulic models;
- Section 4.0 outlines the hydrologic assessment approach;
- Section 5.0 outlines the hydraulic modelling approach and presents the results of the modelling;
- Section 6.0 presents Tropical Cyclone Debbie Information;
- Section 7.0 presents the design flood depths, elevations and extents for the study area;
- Section 8.0 presents the results of the investigation with the effects of climate change on discharges and planning scheme flood mapping;
- Section 10.0 provides summary of non-structural flood mitigation measures;
- Section 11.0 provides a summary of the high-level structural mitigation options;
- Section 12.0 summarises the key finding and recommendations of the study.

2.0 Catchment Characteristics

2.1 General

The catchments of the Rocky Dam Creek, Cherry Tree Creek, Tedlands Creek, Waterfall Creek and Green Swamp Creek are identified as the contributing catchments for this study area. (refer Figure 1). Rocky Dam Creek is the main catchment of interest and drains an area of 387.86 km^2.

It includes the sub-catchments of Cameron Creek, Station Creek, Little Station Creek, Devil Flat Creek Waterfall Creek and their tributaries. Sub-catchments and boundaries are shown on Figure 1.

2.2 Rocky Dam Creek

Rocky Dam Creek main stream originates from the southern area of the catchment and flows north towards the coastline. The main stream originates to the west of the Bruce Highway adjacent to Cone Creek Road with a stream length of approximately 52 km before its confluence with the coastline. The upper catchment is steep and well vegetated. The stream meanders to the northeast and flattens out as it approaches the Bruce Highway. Land surrounding this area is mainly used for pastoral and sugar cane purposes.

Rocky Dam Creek collects the minor watercourse of Arrowroot Creek prior to crossing the Bruce Highway approximately 7.8 km south of Koumala at Rocky Dam Creek bridge. Rocky Dam Creek crosses the highway from west to east. The eastern catchment contains sugar cane cultivation near the highway and transitions to pastoral and mangrove areas further downstream.

Green Swamp Creek is a large tributary of approximately 41.85 km^2, which enters Rocky Dam Creek approximately 10km downstream from the Bruce Highway. The southern portion of the Green Swamp Creek catchment consists of flat pastoral and sugar cane land while northern portion consists of hilly forested land.

2.2.1 Cherry Tree Creek

Cherry Tree Creek is the northern most major watercourse that drains to Rocky Dam Creek approximately 3 km from the coastline. The stream length is approximately 21 km from the top of the catchment to the Rocky Dam Creek confluence. Minor watercourses that enter Cherry Tree Creek include Cameron Creek, Station Creek and Duff Creek which are all north of Koumala. The catchments comprise cane farming land and with vegetation along the creek banks.

2.2.2 Tedlands Creek

Tedlands Creek is a major watercourse that contributes 43.56 km^2 to Rocky Dam Creek approximately 9 km from the coastline. Stream length is approximately 14 km from the top of the catchment to Rocky Dam Creek. The catchment comprises cane farming land in the upper reaches, with pastoral land in the lower reaches.

Minor watercourses that enter Tedlands Creek includes Little Station Creek, Coalters Creek and Leichhardt Creek. Koumala is located within Little Station Creek catchment. Little Station and Coalters Creeks cross the Bruce Highway approximately 1.3 km and 1.7 km south of Koumala before converging and then joining to Tedlands Creek, 3.6 km downstream of the Bruce Highway.

2.3 Rainfall Regime

Rainfall alert stations closest to the study area are:

- Koumala Hatfields Road (BOM Station Number 33038) contains an incomplete rainfall data set from 1914 to current. The station is within the catchment and is approximately 2.5 kilometres south-west from the township of Koumala. The data available consists of daily total rainfall.
- Sucrogen Weir Alert (MRC Station Number 533143) rainfall was provided by MRC with rainfall recorded from 2013 to 2017. The station is located 20 km to the north of the township of Koumala within Sarina outside of model boundary. This alert station contains tipping bucket rainfall data during the Cyclone Debbie Event.

- Murray Creek at Undercliff (Queensland Government Station Number 130416A), the site is located approximately 25 km south of Koumala. The Queensland Government Water Monitoring Information Portal website indicates that this site has been active since 2011 and has tipping bucket rainfall data available.
- Members of the community record daily totals within Koumala which were limited to the year 2016/17 and during the Cyclone Debbie Rainfall Event;

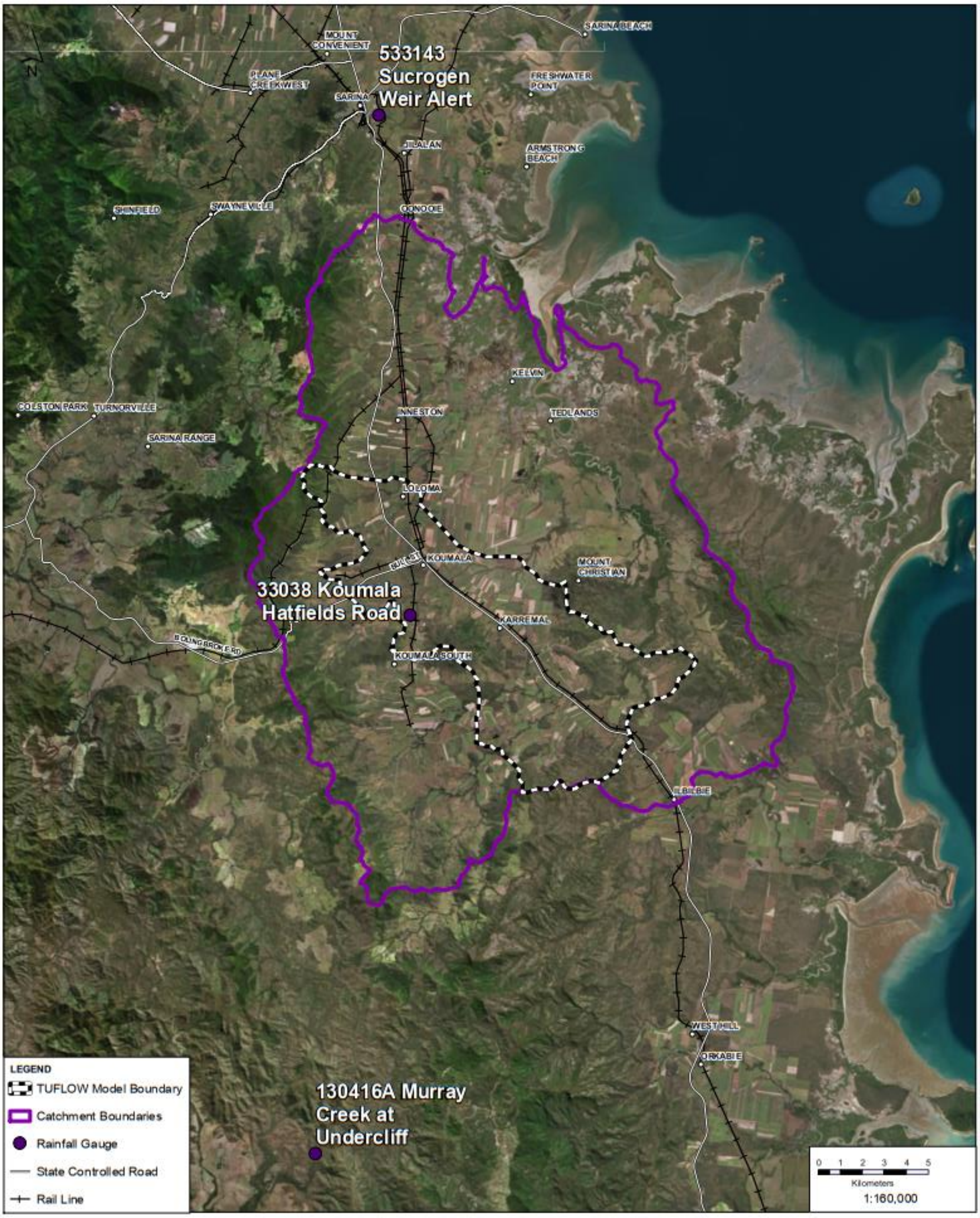


Figure 2 Rainfall Gauge Locations

Koumala Hatfields station contained the longest period of rainfall on record within the study area with data recorded from October 1914. The rainfall station has an average annual rainfall total of 1521mm per year (January to December). The highest mean monthly rainfall of 321.7mm occurs in February. The highest and lowest annual rainfalls recorded at the alert station are 3138mm (1918) and 672mm (1923) which shows significant variation in annual rainfall from year to year.

The highest monthly rainfall of 2217mm was recorded in January 1918 and 1570mm in January 1951. The highest daily rainfall of 567mm was recorded on the 23rd January 1918. Figure 3 shows the distribution of the mean monthly rainfall through the year at the Koumala Hatfields station compared to 2017 (Cyclone Debbie) records.

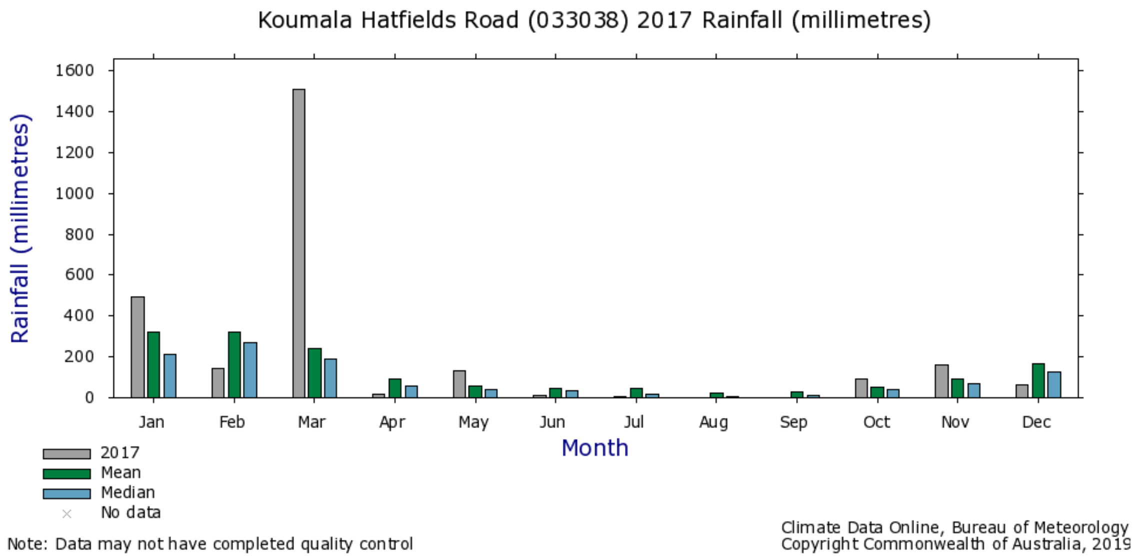


Figure 3 Koumala Hatfields Road (033038) Rainfall Statistics 2017

2.4 Sugar Cane

Sugar Cane cultivation is a dominant feature of the floodplains in the area. The growth patterns and response of sugar cane to flooding presents a challenge for flood modelling. It is difficult to apply a single suitable roughness parameter to represent sugar cane due to the variability in potential plant maturity throughout the wet season.

To ensure a consistent approach, a representative varying roughness was applied uniformly across all Sugar Cane while sensitivity analysis was undertaken to account for potential variability in roughness throughout the growing season. Adopted hydraulic roughness is shown in Table 17.

3.0 Available Data

3.1 General

Comprehensive data collation was undertaken to ensure that all parameters contributing to the hydrologic and hydraulic characteristics of the project area could be fully accounted for and to ensure that modelled baseline conditions match observations of historical flood events.

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

- Collections of rainfall data for the validation of the hydrological and hydraulic models;
- Topographical data for the digital representation of the model area;
- Bruce Highway (10G) 2017 road centreline elevations;
- Bridge and culvert drawings.

A summary of the available data reviewed and applied to the study is provided below.

3.2 Previous Reports

There are a number of historical studies that have been closely reviewed to help inform various aspects of the hydrologic and hydraulic model updates. The key reports used for this study include:

- The Cyclone Debbie Review – Inspector-General Emergency Management (Qld Government, October 2017);
- Tropical Cyclone Debbie Technical Report (Bureau of Meteorology, 2018).
- Koumala Flood Study – Modelling Summary Memorandum (Water Modelling Solutions, August 2018)

A brief synopsis of these historical reports, and the relevant information gained from them is given in the following subsections.

3.2.1 The Cyclone Debbie Review – Inspector-General Emergency Management (Qld Government, October 2017)

The report was prepared by the Inspector General of Emergency Management (IGEM) Queensland regarding the effectiveness of the disaster management system in response to the event across the state of Queensland. Issues that arose during the event were examined and analysed to consider improvement strategies for the future. The views of the community were sought to inform future strategies that could improve the integration of government services and deliver safer and inclusive communities.

The report uncovered a series of lessons for the disaster management sector, which, if acted on, will deliver greater public value and confidence through trust and empowerment. The findings include timely public messaging, continued need of information sharing, fatigue management for sustained events, coordinated exercises to prepare for disaster events and improved business continuity planning across state agencies including tourism and communities.

The above-mentioned report investigated overall disaster management system for Cyclone Debbie.; This study prepared for MRC investigates the local risk areas associated with the Rocky Dam Creek catchment to support MRC in addressing the recommendations of the IGEM review.

3.2.2 Tropical Cyclone Debbie Technical Report (Bureau of Meteorology, 2018)

The report prepared by the Bureau of Meteorology (BoM) collated information related to Cyclone Debbie. This information includes cyclone tracking, rainfall, peak river elevations and tide elevations.

This information was utilised in Section 6.0 and was taken in consideration when developing the XP-RAFTS and TUFLOW models.

3.2.3 Koumala Flood Study – Modelling Summary Memorandum (Water Modelling Solutions, August 2018)

The report prepared by Water Modelling Solutions for Queensland Rail compared the Cyclone Debbie rainfall with ARR87 rainfall for an area south of the Koumala township (approximately 64.7km^2). Analysis of the rainfall confirms the March 2017 event was in excess of the 100-year ARI event. The modelling shows that the flooding within the township was primarily governed by the significant size of the event, the event was in excess of the Bruce Highway cross-drainage and lowering the northern coast line embankment in the sensitivity scenarios showed no change to flood levels within the township.

This was used as background information when comparing ARR16 design rainfall intensities with Cyclone Debbie rainfall in Section 6.2

3.3 TUFLOW Model Extent

The catchment extent and TUFLOW extent were discussed with Council at the beginning of the project. Council required the TUFLOW model extents to include key areas that are to be included within the model. Catchment extent is shown on Figure 1 and TUFLOW model extent in Figure 6 below.

3.4 Topographic Data

Topographic data available within the Rocky Dam Creek study area is Digital Elevation Model (DEM) of Australia extracted from Department of Natural Resources and Mines (DNRM). The data covering the site is in the form of LiDAR and is a combination of data captured in 2009 and 2014.

The 2009 LiDAR information covered the entire catchment, with more recent 2014 LiDAR captured at the southern portion of the catchment, as shown in Figure 4. 2009 LiDAR and 2014 LiDAR was provided in 2 kilometre tiles and 1 kilometre tiles respectively.

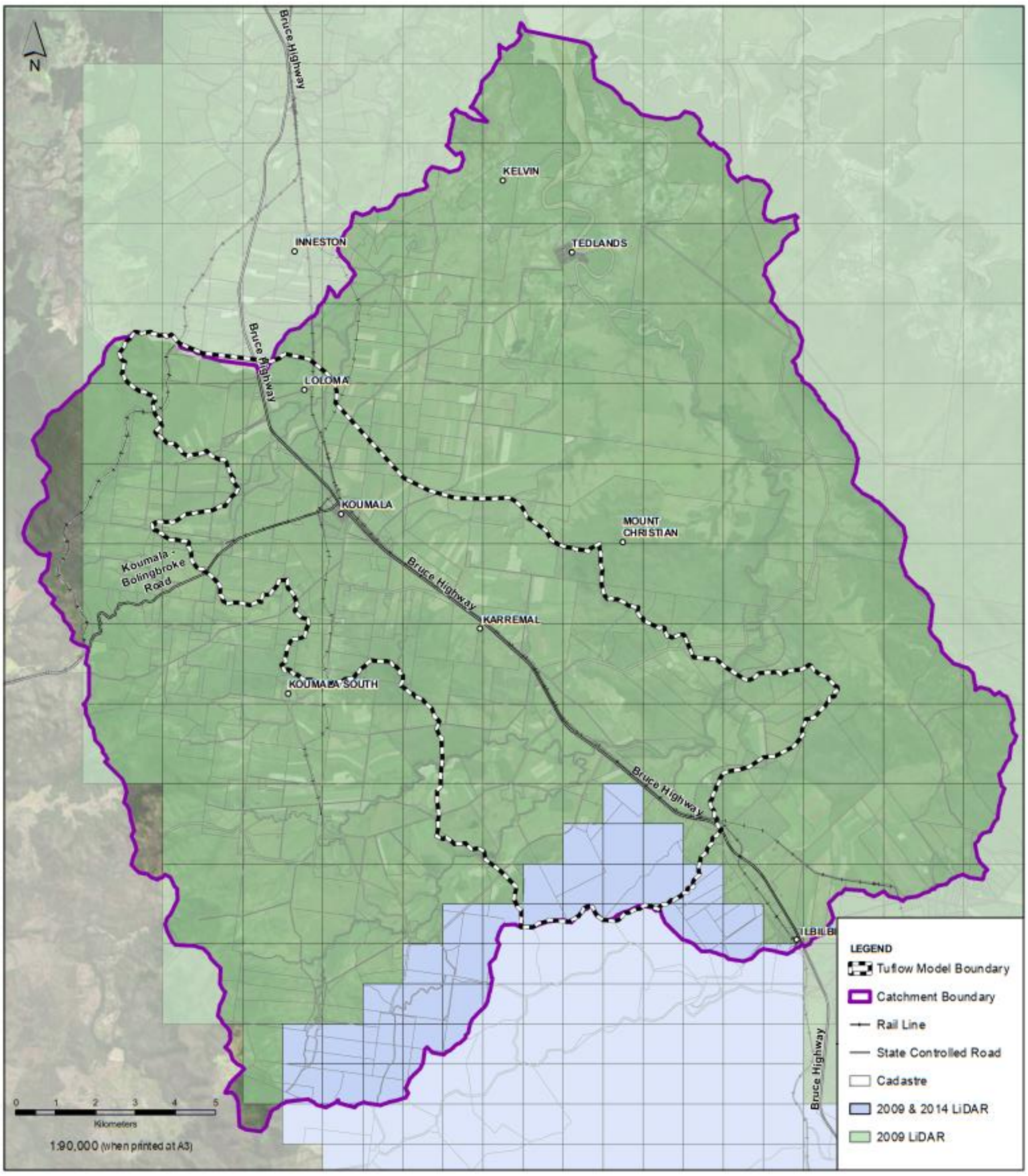


Figure 4 Available LiDAR data

The 2009 LiDAR was utilised for the entire catchment to ensure uniformity. Figure 5 shows the inconsistency when using LiDAR captured at different times, which can cause sudden terrain changes across the merge line, that could impact water flow direction.

The LiDAR points were used to generate a base Digital Elevation Model (DEM) with a grid spacing of 1 m. It is stated in the metadata provided by DNRM that the vertical accuracy is ±0.15 m on clear, hard surfaces and the horizontal accuracy of ±0.3.

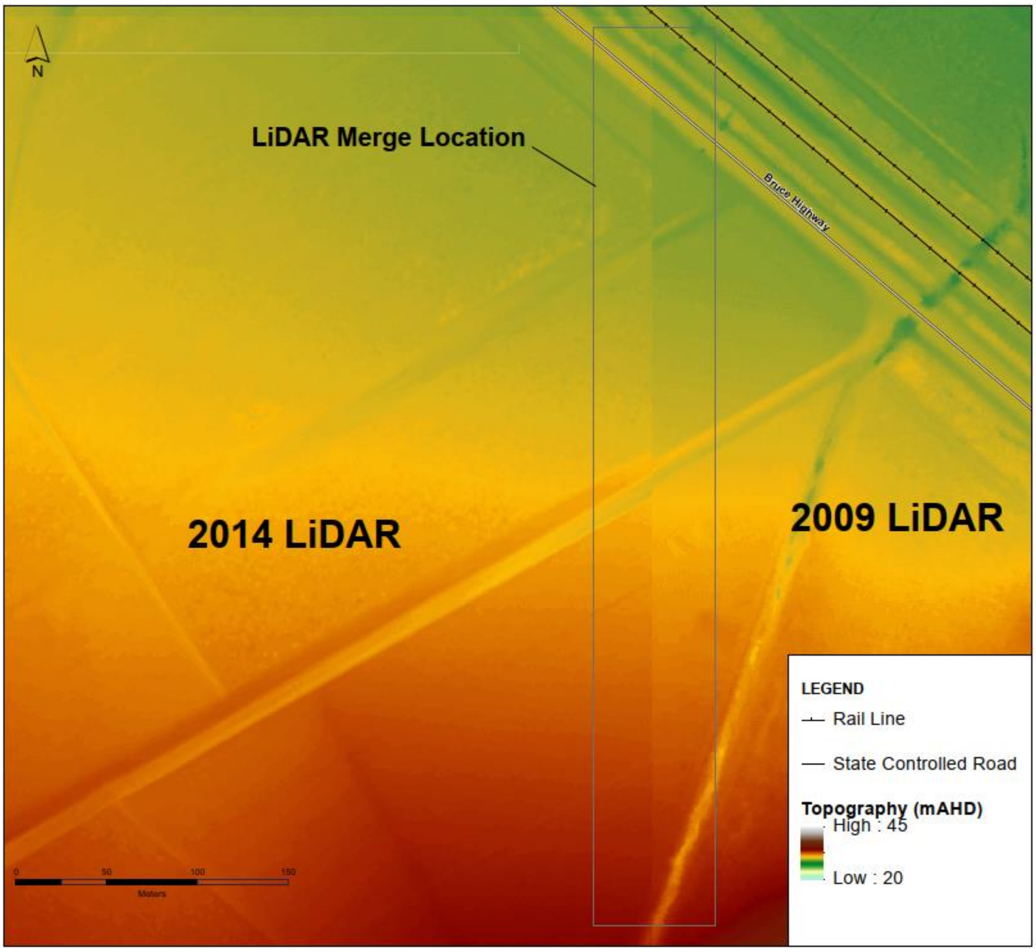


Figure 5 2014 and 2009 LiDAR Merge lines

3.5 Design Rainfall Data

Design rainfall data was acquired from the Bureau of Meteorology (BOM) on 23rd July 2019.

3.6 Rainfall Gauges

Rainfall data was available within the Rocky Dam Creek catchment from the Bureau of Meteorology (BOM) and Queensland Government Water Monitoring Portal (WMP)

Available Daily rainfall depth for the area around Koumala are listed in Table 2 below. The daily rainfalls are measured from 9.00am to the following day at 9.00am, with numbers contained within the brackets showing 24-hour totals between 12.00am and 12.00am.

Table 2 Daily Rainfall Depth

Location	TC Debbie Daily Rain Depth (mm)			
	27/03/2017	28/03/2017	29/03/2017	Total
Sarina	226	191	355	772
Sucrogen Weir	(136)	(478)	(4)	(614)
Orkabie West	105	452	409	966
Koumala Hatfields Road	138	287	500	925
Murray Creek at Undercliff	118 (483)	569 (728)	590 (24)	1277
Carmila Beach	84	350	164	598
Carmila	66	277	300	643
Koumala (Community Rainfall Information)	179	270	415+[1]	864

[1] – Amount of rainfall above 415mm is not known

There are no sub-daily rain fall gauges within the study area. The nearest sub daily rain gauges to the study area are listed in Table 3 and Figure 2.

Table 3 Closest Rainfall Sub-daily rainfall gauges to Koumala

Rainfall Gauge (Station)	Distance to study from Koumala (km)
Sucrogen Weir (533143)	20
Undercliff (130416A)	25

Application of the TC Debbie hydrology is discussed in Section 6.2.

3.7 Community Consultation

The floods associated with Cyclone Debbie (28-29 March 2017) were some of the most devastating on record at several locations through the Mackay Region. Some residents reported the flooding as being the worst flooding experienced in residents' living memory.

The local communities were consulted at the data collection phase using an on-line survey on the community engagement website “Connecting Mackay” and at workshops held at locations throughout the catchments in May 2019. At Koumala, the consultation was held on 25th May at the Community Hall with a smaller listening post near the Hotel a week later. The workshops were attended by Council officers from Strategic Planning, Emergency Management, Community Lifestyle, and Community Engagement, AECOM and a representative from the Queensland Health Disaster Recovery team.

The engagement involved discussions with residents about where they witnessed flooding, the timing and length of the inundation and flooding depth. A large map (3.6m by 5m) of the Koumala and Rocky Dam Creek catchments was provided for an overview of the catchment and streams and to identify points of interest where they identified flooding. Notes were written on the map identifying flow direction and key flood elevations observed by the community to assist in the validation of the TC Debbie flood model.

Surveyed elevations, photos and anecdotal information was provided by MRC and how the information provided aligns with the TC Debbie model in discussed in Section 6.4.

Flood studies were prepared for the communities to assess the flood flows and water levels in the catchments for a range of events including the TC Debbie event. The flood study will make recommendations to improve planning, emergency management and disaster preparedness in the catchments.

3.7.1 Community Feedback on Draft Study

Council undertook a community engagement event on the 1 December 2019 with a stall at the Koumala Christmas Fair to provide the opportunity to discuss with residents the draft report on the study focusing on the TC Debbie event that occurred over the Koumala and Rocky Dam catchments in March 2017. The opportunity to discuss the study was part of Council's broader emergency management engagement with the community at this event.

While there was a general interest in Council's community engagement, there was only a small number of residents who were interested in the study outcomes. There were no negative responses to the study from the interested parties.

3.8 Hydraulic Structures

Transport and Main Roads (TMR) culvert and bridge data and was made available for use in the hydraulic analysis. The following data was provided:

- Culvert and Bridge chainages along the Bruce Highway in the form of a csv;
- Culvert and bridge drawings.

3.8.1 Culverts

Culvert information along the Bruce Highway was digitised using ArcGIS for application to the TUFLOW hydraulic model. Information was unable to be obtained for local council roads.

Where invert level, slope, pipe diameter or inlet and outlet information was missing, the following assumptions were made:

- Inlet and outlet levels and locations based on LiDAR information;
- Minimum cover of 600mm, where practical;
- Culvert sizes based on surrounding culverts of similar open channel size;

It is recommended that survey be completed of all missing culvert data.

3.8.2 Bridges

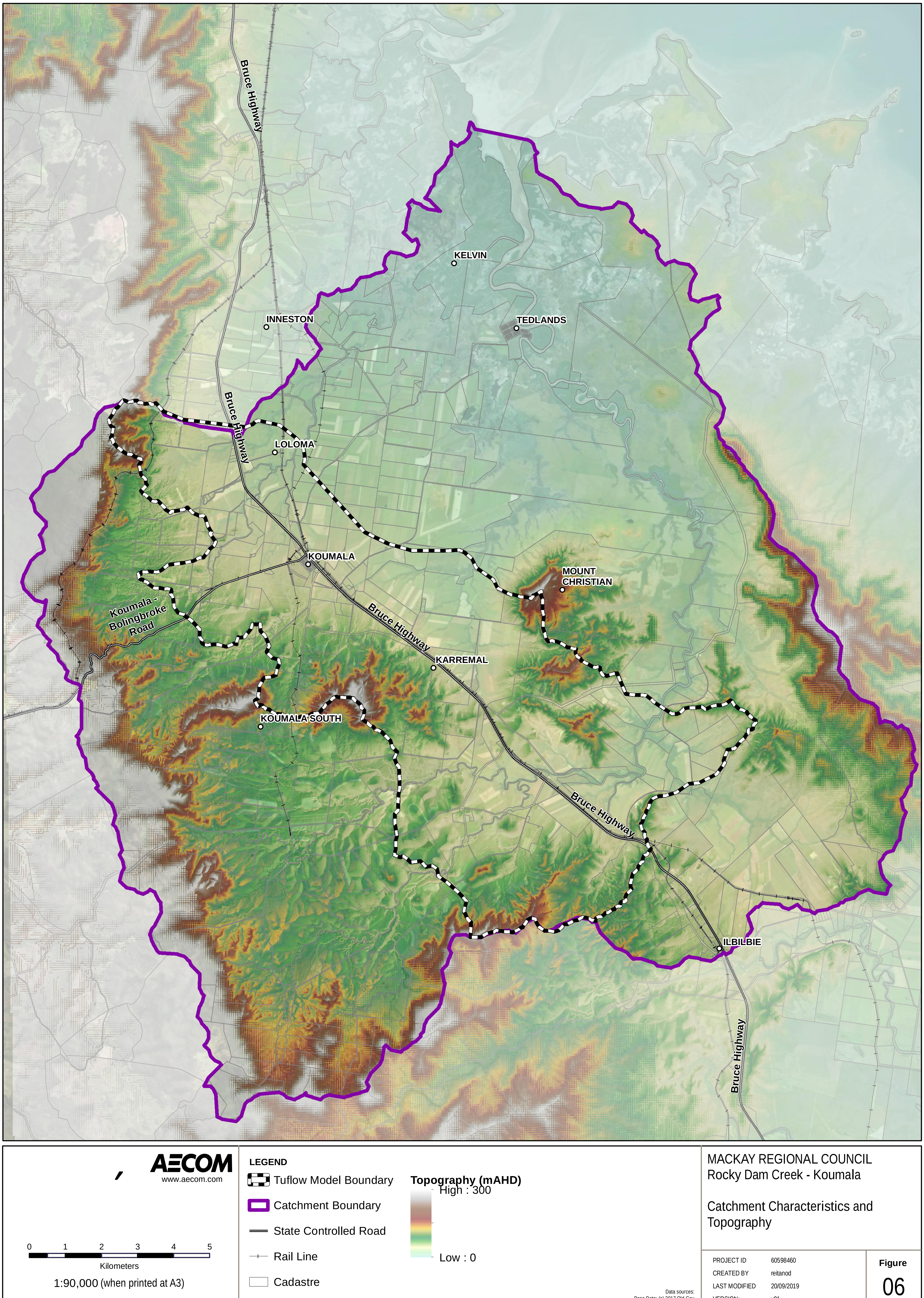
Where no information was obtained the following the utilised to determine bridge requirements;

- Aerial imagery;
- Channel invert level, depth and width;
- Height of the road or rail;
- Surrounding known bridges of similar size.

It is recommended that survey or drawings be obtained of all missing bridge data to determine the size and blockage that may impact flow through the bridge.

3.8.3 Rail Structures

Rail culverts and bridges were unable to obtained by the relevant departments and assumptions outlined in Sections 3.8.1 and 3.8.2 were made for missing information.



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Data sources:
Base Data: (c) 2017 Qld Gov

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Rocky Dam Creek - Koumala

Catchment Characteristics and Topography

PROJECT ID	60598460
CREATED BY	reitanod
LAST MODIFIED	20/09/2019
VERSION:	v01

Figure 06

A3 size

4.0 Hydrologic Assessment

4.1 Overview

In order to estimate peak flood elevations, flood extents and flood risk across the study area, a hydrologic assessment was undertaken to estimate flood flows resulting from catchment rainfall events.

4.2 Adopted Methodology

Hydrologic inputs to hydraulic models have been applied using a combined approach of runoff-routing modelling upstream of the TUFLOW model with a direct rain on grid approach, within the bounds of the TUFLOW model. The direct rainfall method involves the application of rainfall directly to the 2D model domain with TUFLOW. The rainfall depth in each timestep is applied to each individual hydraulic model grid cell, and the 2D model calculates the runoff for each cell.

Australian Rainfall and Runoff (AR&R) is a national guideline document, data and software suite that can be used for the estimation of design flood characteristics in Australia. AR&R is pivotal to the safety and sustainability of Australian infrastructure, communities and the environment. It is an important component in the provision of reliable and robust estimates of flood risk. Consistent use of AR&R ensures that development does not occur in high risk areas and that infrastructure is appropriately designed.

The new release of the AR&R guidelines presented several changes to the previous 'best practice' modelling advice. Key changes that are relevant to the revised modelling of the Rocky Dam Creek catchments are listed below:

- Updates to design rainfall Intensity Frequency Duration (IFD) values based on the inclusion of nearly 30 years additional rainfall data since the estimation of the AR&R 1987 IFDs;
- Changes to design hydrograph simulation approaches including the addition of the ensemble event approach where the magnitude of the design flood is estimated from the weighted average of a group (or ensemble) of design hydrographs. By using a set of design rainfall patterns to produce the estimates rather than a single pattern of variability, a reasonably unbiased estimate of the design flood is produced;
- Updates to catchment initial/continuing loss values based on regionalisation methods as well as the incorporation of pre-burst rainfall to simulate rainfall before the beginning of the design storm;
- Updates to Areal Reduction Factors (ARF) and the calculation process based on a more regionalised approach. ARFs convert the design point rainfall depth into a rainfall depth over the entire catchment;
- Climate change factors and calculations have also been updated based on the current industry best practise and knowledge.

4.3 Hydrologic Modelling

Hydrologic models were developed over the study area as shown in Figure 1. The model has been developed primarily using CatchmentSIM, XPRAFTS and Storm Injector software. The hydrologic assessment utilises the ensemble approach.

4.3.1 CatchmentSIM

CatchmentSIM was utilised for analysis of terrain based on SRTM data to delineate the Rocky Dam Creek catchment into subcatchments. Individual sub-catchment values for area and slope parameters were defined using SRTM data. The catchment delineation of sub-catchments within the study area is shown in Figure 8.

4.3.2 XP-RAFTS Modelling

Hydrological modelling was undertaken to determine the design flood hydrographs for various design events. XP-RAFTS software was used to model the rainfall-runoff processes of the catchments.

The XP-RAFTS software is an event type rainfall-runoff hydrological model that calculates catchment flows based on rainfall data for application to flood simulation. Within the hydrological model, catchments are represented by nodes that are inter-connected by links. Each node in the model represents the characteristics of a sub-catchment and each link represents flow path routing between sub-catchments.

The model parameters required for each catchment are:

- Sub-catchment area;
- Sub-catchment slope;
- Sub-catchment surface roughness;
- Sub-catchment fraction impervious.

The XP-RAFTS model network is shown in Figure 8. Impervious fraction parameters were determined based on aerial imagery. Appendix A summarises the parameters applied to the nodes in XP-RAFTS to define sub-catchments.

Initial and continuing storm losses are specified in AR&R data hub as 54.0mm and 3.2mm/hr. Many other Mackay Regional Council local catchment studies utilise lower initial / continuing loss models due to the tropics having high saturation of soils before intense rainfall events occur. For consistency, similar losses have been adopted in this study, continuing losses are specified as 2.5mm/hr. Losses are further discussed in Appendix A.

4.3.3 Storm Injector

The ensemble temporal patterns and rainfall from the AR&R Data Hub for the Wet Tropics region were simulated through XP-RAFTS. Storm Injector software serves as the interface to efficiently employ the range of magnitude-duration-temporal pattern combinations required for the ensemble approach. The Storm Injector platform was also used to prepare hydrologic outputs for inflow files to the TUFLOW hydraulic models. Separate 2016 BoM rainfall depths was utilised for each sub-catchment to represent the spatial variance of rainfall.

Once the hydrological models were simulated for all ensemble temporal patterns, the design event hydrograph for each catchment will be selected though statistical analysis of the results. AR&R does not provide definitive guidance regarding rationale behind selecting the representative design event hydrograph from an ensemble of storms. Based on current industry 'best practice' and MRC's preference, the design hydrograph for this project was selected as the result of the temporal pattern that delivers **a peak flow rate that is closest to the mean flow rate with a bias of 2 to those exceeding the mean** from the critical duration flood. The critical duration is determined based on the ensemble of storms with the highest mean flow from all storm durations across the durations for the given storm probability.

Figure 7 shows a flow chart of the process described detailing how the design flow hydrograph was selected through the ensemble approach.

The design flow hydrograph for each event at key sites will then be prepared for input into the TUFLOW hydraulic models following completion of formal checking and verification processes.

Climate change hydrological investigations were undertaken using the methodology stated in Section 8.0.

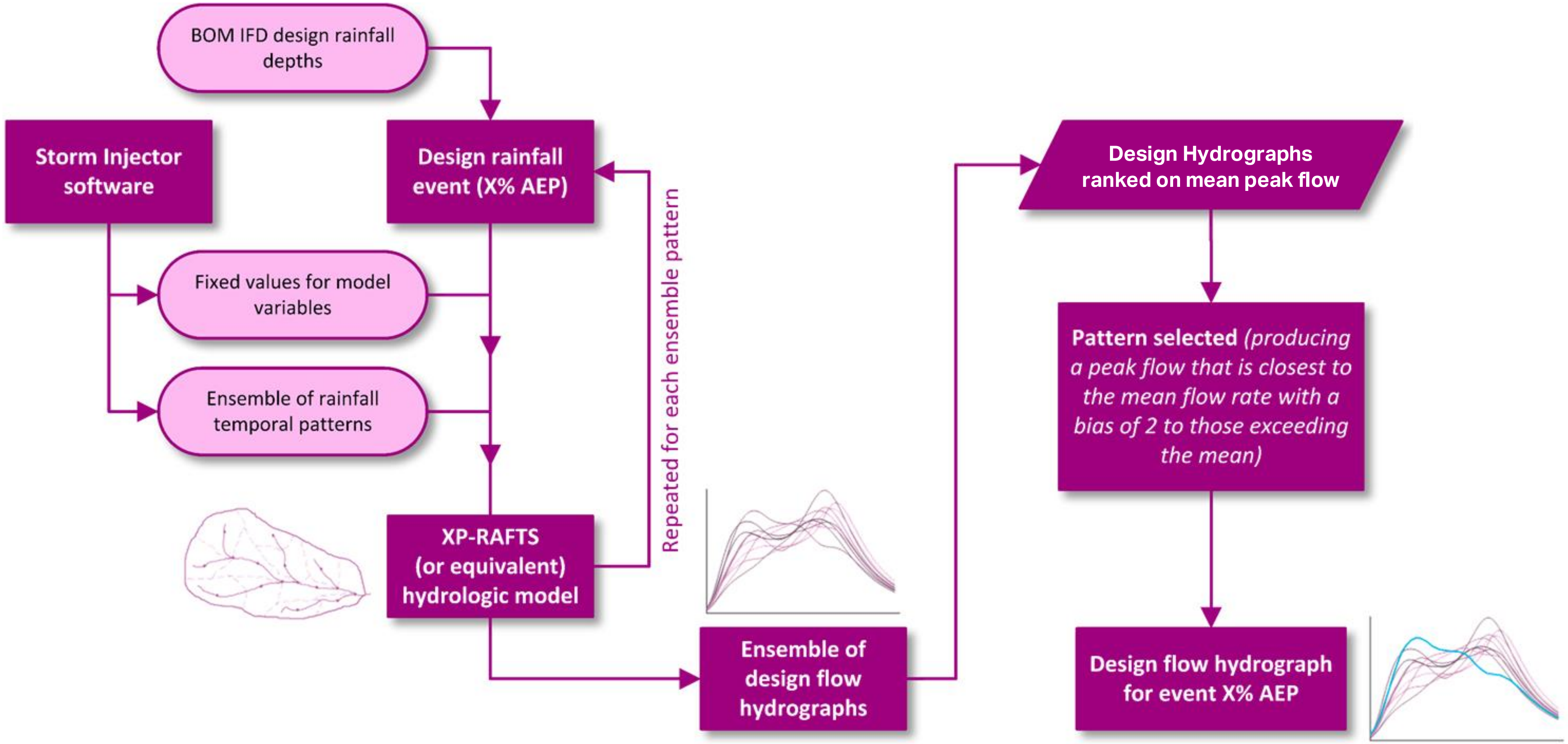
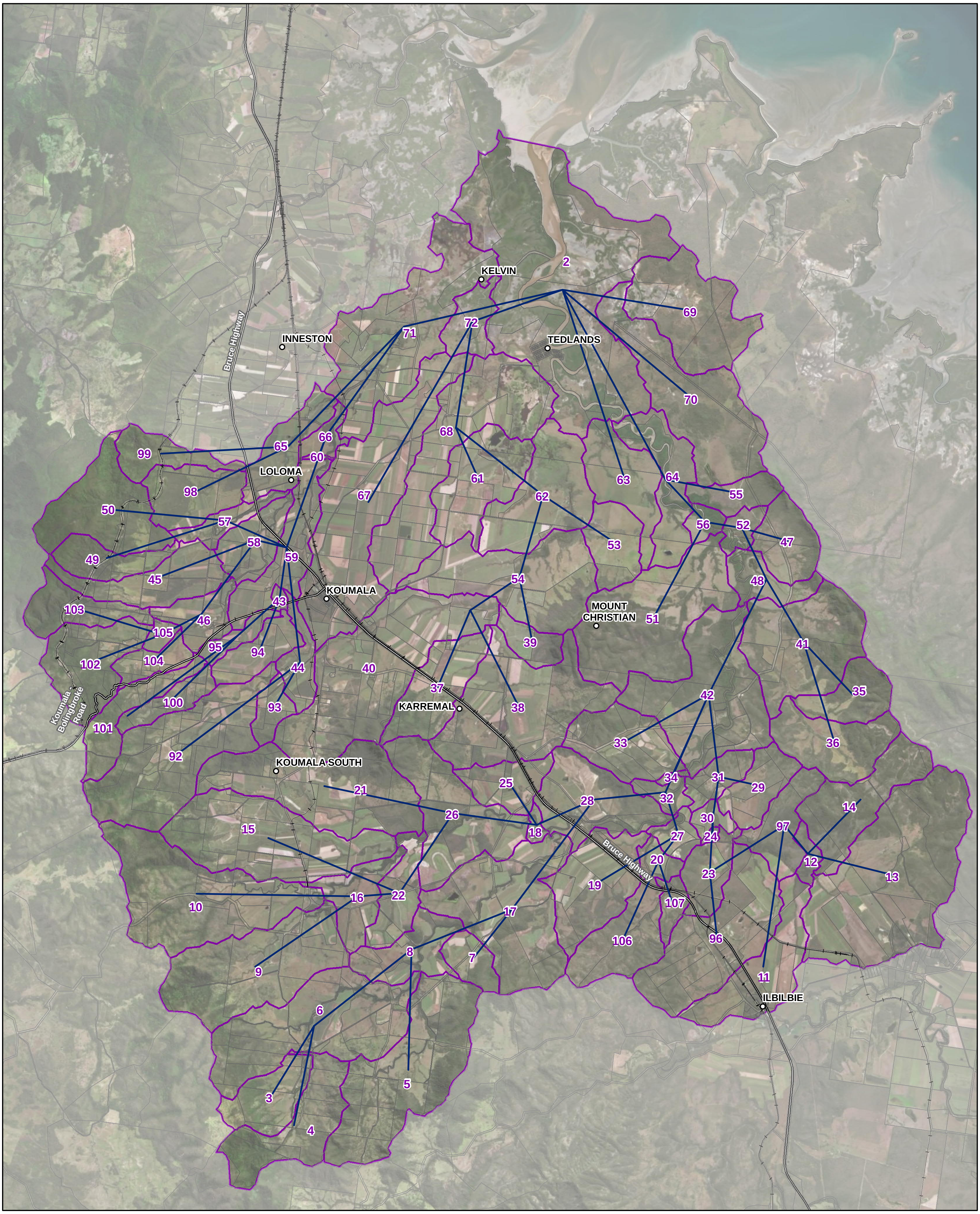


Figure 7 Ensemble approach to design flow hydrograph selection



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LEGEND
- Subcatchment Node Links
- Rail Line
- State Controlled Road
- Cadastre
- Subcatchment

Data sources:
Base Data: (c) 2017 Qld Gov

MACKAY REGIONAL COUNCIL
Rocky Dam Creek - Koumala

Subcatchment Delineation

PROJECT ID	60598460
CREATED BY	reitanod
LAST MODIFIED	20/09/2019
VERSION:	v01

Figure
08

A3 size

4.3.4 Direct Rainfall Modelling

Rainfall total hyetograph time series for each design storm were created to represent the local rainfall for the study area from 2016 BOM IFD data. Design rainfall losses parameters are discussed further in Section 4.3.9.

The time series rainfall hyetographs were developed for a range of design events for magnitudes of 63% AEP, 39% AEP, 18% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.2% AEP (total of seven events).

4.3.5 Intensity Frequency Duration (IFD) Parameters

Site specific Intensity Frequency Duration (IFD) data was determined using the design rainfall database from the Bureau of Meteorology (BoM) (accessed 26th June 2019). The relevant Design Rainfall IFD values are as shown in Table 4.

Table 4 IFD Koumala Design Rainfall Intensities (mm/hr) (BoM, 2016)

Duration	Design Rainfall Depth (mm)				
	63.2% AEP	50% AEP	20% AEP	2% AEP	1% AEP
1 hr	43.2	48.4	64.0	95.7	105
3 hr	22.3	25.4	34.8	55.0	60.9
4.5 hr	17.3	19.8	27.7	45.0	50.2
6 hr	14.5	16.7	23.6	39.1	43.9
9 hr	11.2	13.0	18.8	32.3	36.6
12 hr	9.35	10.9	16.0	28.2	32.3
18 hr	7.25	8.52	12.7	23.4	27.1
24 hr	6.04	7.13	10.8	20.5	24.0
30 hr	5.24	6.2	9.5	18.5	21.7

4.3.6 Ensemble Temporal Patterns

The revision of the AR&R guidelines introduced an ensemble approach to peak flow estimation which aims provide a more robust assessment than traditional methods (refer Section 4.3). The ensemble approach requires hydrological simulation of 10 separate temporal patterns for each combination of storm duration and probability, rather than the single temporal pattern approach from AR&R 1987.

A common difference between the old and new temporal patterns is how rainfall is distributed across a storm event. Almost three-quarters of each storm's rainfall falls in the first half of the previous AR&R 1987 temporal patterns. Temporal patterns for AR&R2016 have been determined based on updated analysis with a range of rainfall distributions, however rainfall is more often consistent throughout each storm duration compared with AR&R 1987 temporal patterns. Figure 9 illustrates the distribution of new temporal patterns against the AR&R 1987 temporal pattern for a 9-hour storm.

Comparison of the temporal patterns for each storm was extracted from Storm Injector for a single subcatchment and is located in Appendix B.

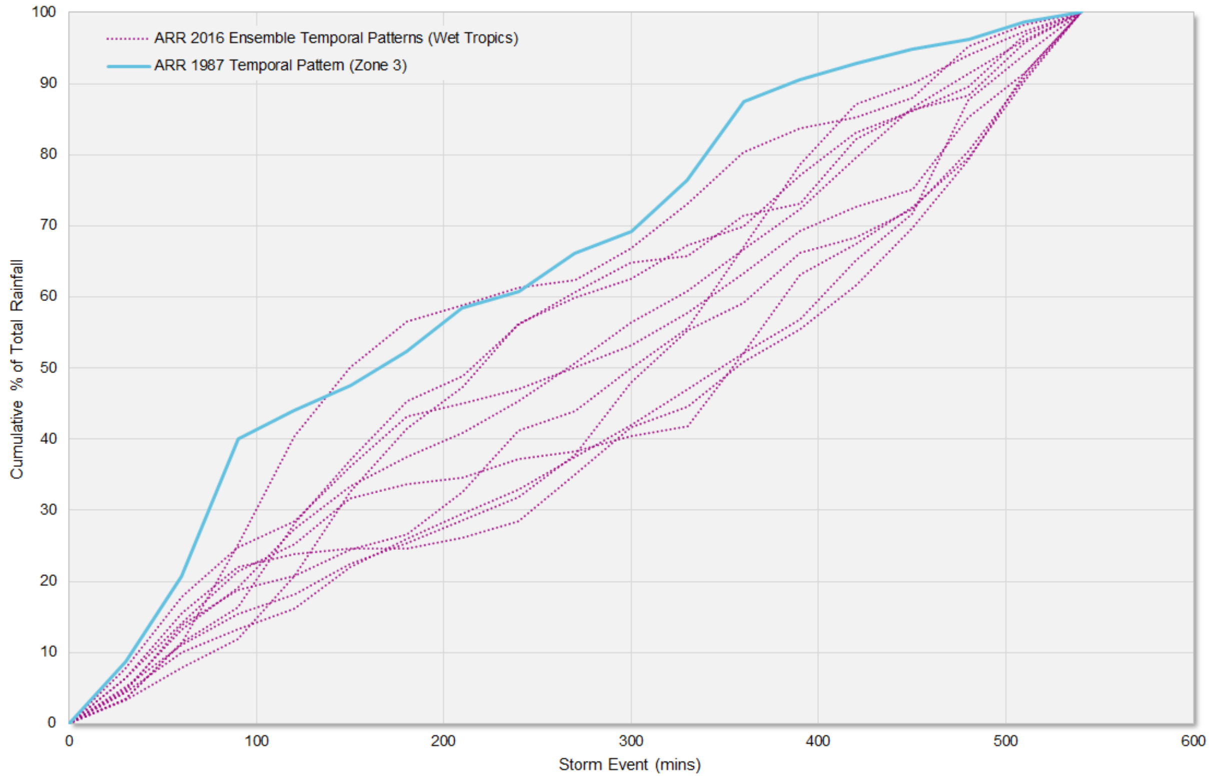


Figure 9 Comparison of Temporal Patterns – 1% AEP 9 Hour Storm

4.3.7 Areal Reduction Factors (ARF)

As the catchments within the study area are large, design rainfall intensities at a point are not representative of the areal average rainfall intensity across the catchment. The ratio between the design values of areal average rainfall and point rainfall, computed for the same duration and Annual Exceedance Probability (AEP), is called the Areal Reduction Factor (ARF). This allows for the fact that larger catchments are less likely than smaller catchments to experience high intensity storms simultaneously over the whole of the catchment area.

ARF values were calculated as per the AR&R guidelines. As the critical duration was found to be short (less than 12 hours), the short duration ARF equation was used.

$$ARF = \min\left\{1, \left[1 - 0.287(Area^{0.265} - 0.439\log_{10}(Duration)).Duration^{-0.36} + 2.26\times 10^{-3}\times Area^{0.226}.Duration^{0.125}(0.3+\log_{10}(AEP)) + 0.0141\times Area^{0.213}\times 10^{-0.021\frac{(Duration-180)^2}{1440}}(0.3+\log_{10}(AEP))\right]\right\}$$

Where Area is in km^2, Duration is in minutes and AEP is a fraction (between 0.5 and 0.0005).

4.3.8 Embedded Bursts

Embedded bursts occur when the rainfall accumulated over a subset (the “burst”) of a storm’s temporal pattern has a depth (mm) that exceeds the IFD value for the burst’s duration for the same AEP. Consideration of ARFs (which vary by duration) also exacerbates problems with embedded bursts since ARFs tend to be lower (more reduction) for shorter durations which reduces the amount of rainfall that can occur in embedded bursts and, as such, increases the amount and severity of embedded bursts.

AR&R states that consideration should be given to filtering out (or excluding) embedded bursts of lower AEP by re-distributing rainfalls of high intensity to other time increments proportionally to their magnitudes. Embedded bursts smoothing was applied for all bursts that exceeded 2% of specified IFD depth value (mm).

4.3.9 Design Event Rainfall Loss Parameters

Both TUFLOW and XP-RAFTS calculate a design rainfall excess time series for each storm probability (AEP) and duration to represent the local net precipitation for the study area. This rainfall excess was calculated by applying initial and continuing losses to the design rainfall to represent infiltration and storage of runoff in surface depressions.

The AR&R data hub provides a mean initial loss for the catchments (from the East Coast North region) of 54.0 mm (refer Table 5).

Table 5 Initial / Continuing Loss Values – AR&R Data Hub

Catchment	Storm Initial Loss (mm)	Continuing Loss (mm/hr)
Rocky Dam Creek	54.0	3.2

This is to be considered in conjunction with the preburst depth, which AR&R provides values for various percentiles of occurrence. For this project the median preburst depth has been adopted for consideration of initial loss.

Where the initial storm loss exceeds the preburst depth, the difference is taken as the initial burst loss parameter. Where the preburst depth exceeds the initial loss the excess preburst rainfall was reduced to 0.

The median preburst depth for the catchment are shown in Table 6.

Table 6 Median Preburst Depth – Rocky Dam Creek Catchment

Storm Duration (hrs)	Design Event (AEP) Median Preburst Depth (mm)					
	50%	20%	10%	5%	2%	1%
1	13.3	11.8	10.9	9.9	11.4	12.5
1.5	4.5	10.3	14.1	17.8	23.3	27.5
2	6.4	13.1	17.6	21.9	31.7	39.1
3	14.1	16.4	17.9	19.4	37.2	50.5
6	31.8	40.2	45.7	51.1	79.1	100.1
12	21.5	40.9	53.7	65.9	83.2	96.1
18	7.1	31.2	47.2	62.5	88.2	107.4
24	4.3	30.1	47.1	63.5	71.7	77.8
36	0.3	19.1	31.6	43.6	71.0	91.5
48	0.9	16.4	26.7	36.5	87.3	125.4
72	0.0	6.1	10.1	13.9	40.9	61.2

The continuing loss values for each external sub-catchment were set to 2.5 mm/hr. This was consistent with previously modelling undertaken in Sarina approximately 20 kilometres north of the study area. Vegetation surrounding Sarina comprises of sparse vegetation, rural holdings and agricultural land such as cane and grazing fields, which is consistent with the land within the model boundary. The AR&R data hub suggested a continuing loss value in excess of 4 mm/hr, this was deemed inappropriate based on previous models developed within the region.

4.3.10 Critical Duration Assessment

A critical duration assessment was undertaken reviewing the results of the hydrologic modelling for the 1% AEP event. This assessment was undertaken using methodologies outlined in the AR&R guidelines. A box and whisker plot was produced at each subcatchment to assess the statistical variation of the ensemble peak flows for each event.

The critical storm duration for the study area was assessed by simulating 180 (3 hrs), 270 (4.5 hrs), 360 (6 hrs), 540 (9 hrs), 720 (12 hrs), 1080 (18 hrs), 1440 (24 hrs), 1800 (30 hrs), 2160 (36 hrs), 2880 (48 hrs) and 4320 (72 hrs) minute durations for the 1% AEP event in the baseline hydraulic model.

The 180, 270, 360, 540, 720, 1080-minute storm durations were found to be critical across different areas of Rocky Dam Creek.

The 540-minute (9 hrs) storm was found to result in the highest mean peak flow for the majority of the subcatchment. The results of the critical duration assessment at Koumala, which is the township within the catchment and experienced flooding (Subcatchment_67). The 540-minute storm was selected for simulation through the TUFLOW hydraulic model.

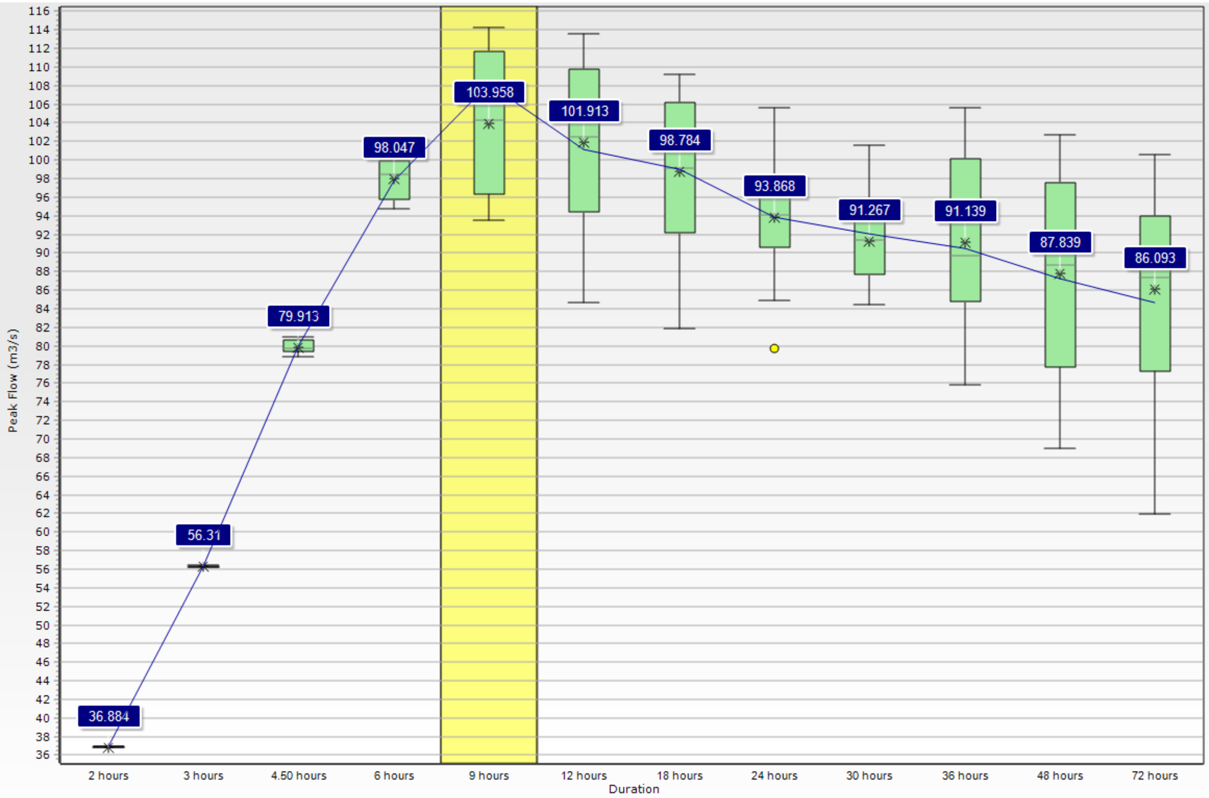
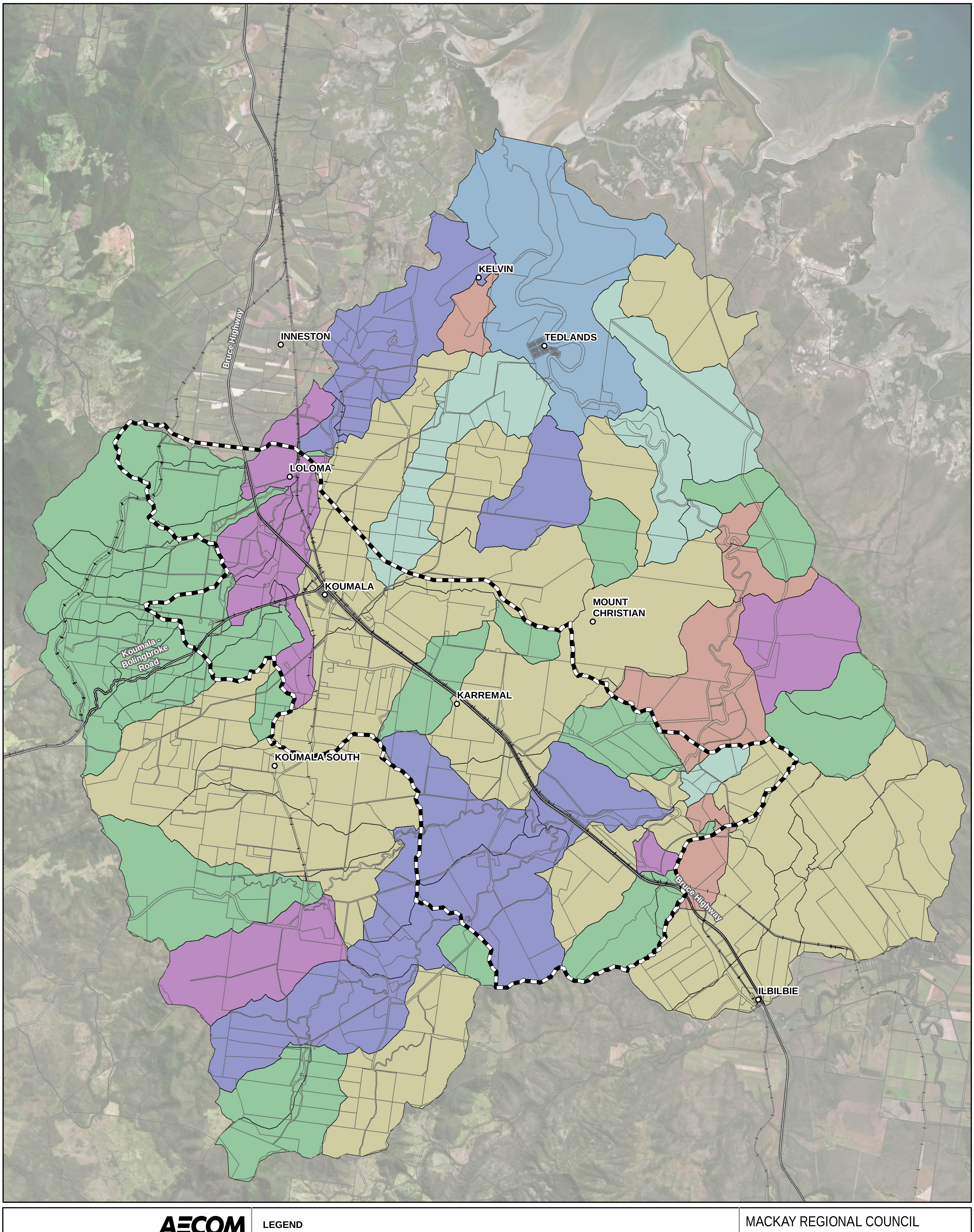


Figure 10 Critical Duration Assessment – Rocky Dam Creek - Koumala (Subcatchment_67)

The critical duration was applied to the 63.2%, 39%, 18%, 2% and 1% (1 in 100) AEP events. Separate critical duration storm durations were completed for the 0.5% (1 in 200) and 0.2% (1 in 500) AEP events, which were also found to be 540 minute storm duration.



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LEGEND

- TUFLOW Model Boundary
- Rail Line
- State Controlled Road
- Cadastre

Critical Duration

- 180 minute Storm
- 270 minute Storm
- 360 minute Storm
- 540 minute Storm
- 720 minute Storm
- 1080 minute Storm
- 1800 minute Storm

Data sources:
Base Data: (c) 2017 Qld Gov

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Rocky Dam Creek - Koumala

1% AEP Rainfall Event
Critical Duration Map

PROJECT ID	60598460
CREATED BY	reitanod
LAST MODIFIED	20/09/2019
VERSION:	v01

Figure
11

4.4 Adopted Discharges

Design flood hydrographs were generated from the output of the hydrological model for boundary conditions and source flow inputs to the TUFLOW hydraulic model. A summary of the peak flows generated by the hydrological Storm Injector model at key locations are presented in Table 7.

Table 7 Peak Design Discharges at Key Locations (9 Hour Storm Event)

Catchment ID	Design Event (AEP and Temporal Pattern)					
	63% AEP	39% AEP	18% AEP	2% AEP	1% AEP	TC Debbie
	TP 8891	TP 8891	TP 8891	TP 8713	TP 8835	
Sub100	4.83	6.90	9.88	17.88	18.09	50.76
Sub101	8.21	11.72	17.13	30.63	31.01	88.45
Sub104	4.27	6.16	8.85	16.19	16.58	47.76
Sub105	23.84	33.95	48.18	86.29	86.43	244.97
Sub21	18.32	27.59	40.54	77.82	84.67	258.02
Sub22	63.35	93.72	136.66	279.56	274.23	919.01
Sub23	64.54	98.16	153.89	275.25	324.95	895.19
Sub45	10.54	15.13	21.66	39.89	41.23	121.21
Sub49	7.69	10.74	15.14	26.25	26.19	73.53
Sub50	18.41	25.99	37.29	66.02	66.51	185.98
Sub7	4.82	6.82	9.82	17.61	17.81	47.19
Sub8	57.07	83.10	119.76	279.93	260.60	488.12
Sub92	20.70	29.99	43.40	86.51	89.13	278.39
Sub93	4.19	5.84	8.30	14.24	14.32	39.01

4.5 Sensitivity Analysis

A sensitivity analysis was undertaken on catchment parameters that are subject to the greatest uncertainty including:

- Stream roughness;
- Catchment roughness;

Increasing the catchment roughness by 20% within the model increased the water elevations within Rocky Creek of approximately 200-500mm during a 1% AEP rainfall event. This increase does not significantly change the flooding extents within the creeks, seen on Maps 31 and 32 in Volume 2 of the report.

5.0 Hydraulic Model

5.1 Overview

A two-dimensional TUFLOW hydraulic model based on LiDAR topographic data has been developed to simulate flood hydraulics in the study area. The purpose of the assessment was to define the flooding within the Rocky Dam Creek floodplain, with calibration of the model to Cyclone Debbie event

The hydraulic model extent is shown in Figure 12 and extends from Cameron Creek to the north to Marion Creek to the south.

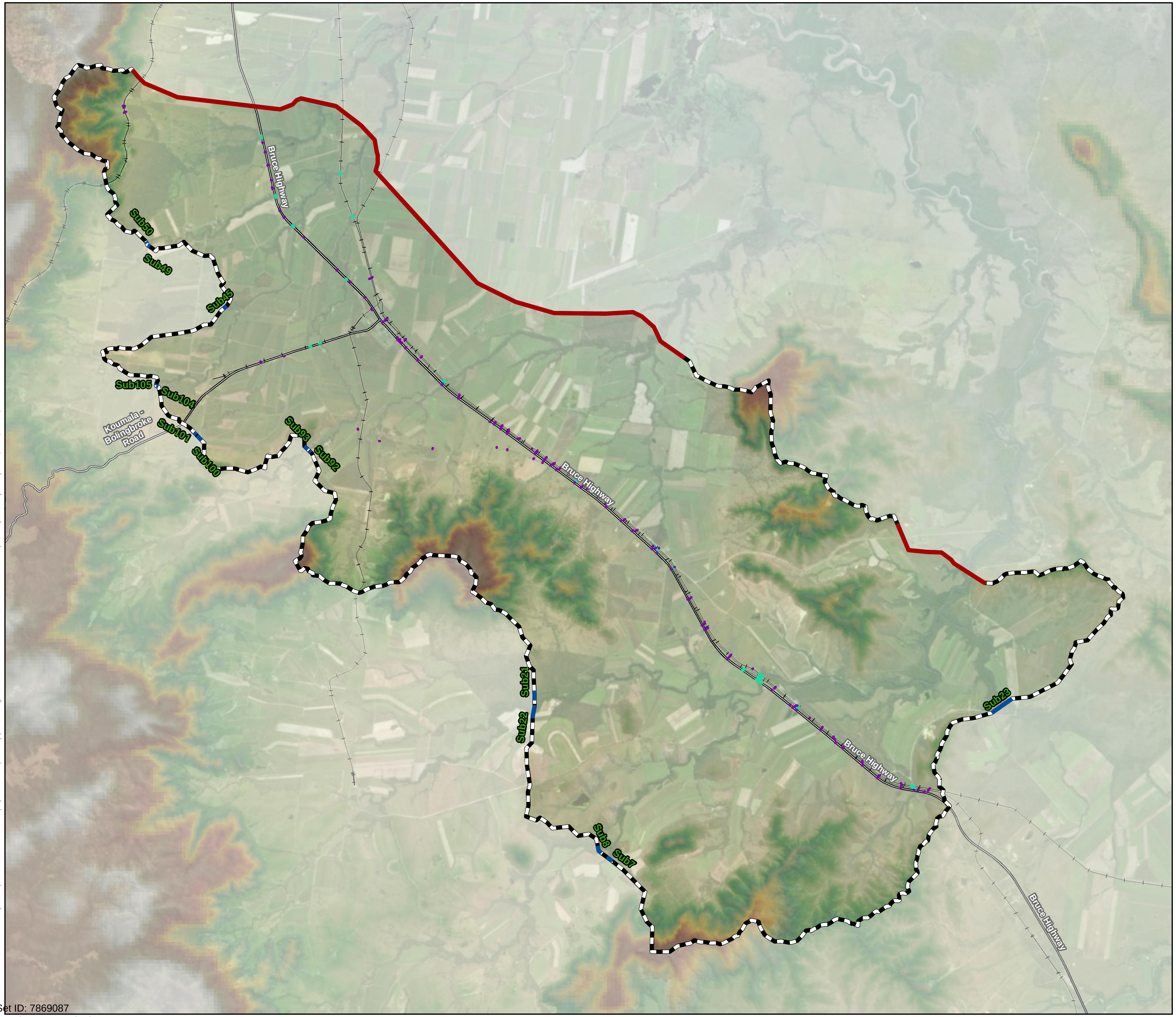
5.2 Adopted Methodology

This section of the report documents the development of the hydraulic model used to simulate piped drainage and overland flows within the catchment. A TUFLOW hydraulic model was produced with parameters as per Table 8.

Table 8 TUFLOW model Parameters

Parameter	Rocky Dam Creek TUFLOW Hydraulic Model
Completion Date	August 2019
AEP's Assessed	63.2% 39%, 18%, 2%, 1%, 0.5%, 0.2% AEP
Hydrologic Modelling	XP-RAFTS runoff routed inflows and direct rainfall on 2D grid
IFD Input Parameters	AR&R, Refer Section 4.3.4
Hydraulic Model Software	TUFLOW Version 2018-03-AD-iSP-w64
Grid Size	5m
DEM (year captured)	LiDAR (2009)
Roughness	Spatially varying and depth varying standard values (Refer to Figure 13)
Eddy Viscosity	Smagorinsky
Model Calibration	Anecdotal flooding information from Council used to confirm model accuracy from Tropical Cyclone Debbie rainfall event. Refer to Section 6.4.
Downstream Model Boundary	Rocky Dam Creek Catchment downstream boundary conditions were height varying discharge (HQ) based on catchment slope (Manning's equation-based rating curves), each creek utilises its own boundary. Refer to Section 5.3.5.
Inflow Model Boundary	Time-varying discharge (QT) inflow boundaries for all external catchments.
Timesteps	1 second (2D)
Wetting and Drying Depth	Cell centre 0.0002 m
Sensitivity Testing	Manning's Roughness ± 20% (Refer Section 5.4) Climate Change to year 2100 (Refer Section 8.0)

A visual representation of the model setup including the 2D model extent, inflow and downstream model boundaries is shown in Figure 12. Direct rainfall was applied over the entire model boundary of the 2D model domain.



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LEGEND

- TUFLOW Model Boundary
- 1D Pipe
- Rail Line
- 1D Bridge
- State Controlled Road

TUFLOW Boundary Condition

- QT
- HQ

Topography (mAHD)

High : 447.027

Low : -2.06841

Data sources:

Base Data: (c) 20XX (data source)
(additional data)

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Rocky Dam Creek - Koumala

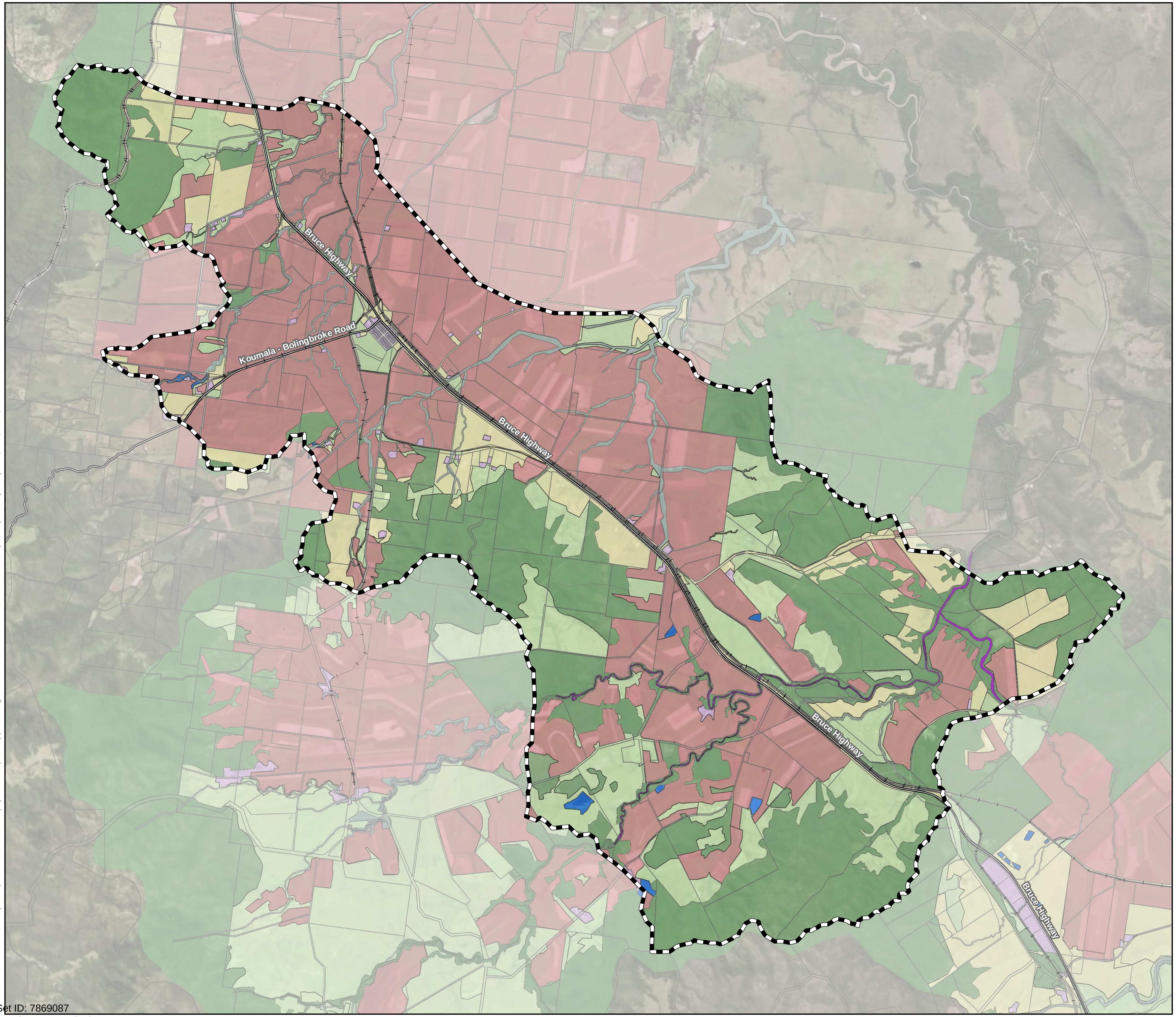
Model Setup and 1D Network Map

PROJECT ID	60598460
CREATED BY	DR
LAST MODIFIED	20/09/2019
VERSION:	v01

Figure
12

A3 size

S\02_MXDs\Figures\KOU\Figure 12 - TUFLOW Model Extent.mxd



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GDA 1994 MGA Zone 55

0 700 1,400 2,800
Metres

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LEGEND

- TUFLOW Model Boundary
- Rail Line
- State Controlled Road
- Cadastre

Material

- Minimal Vegetation
- Moderate Vegetation
- Dense Vegetation
- Creek
- Creek - Reedy Vegetation
- Agricultural (Sugar Cane)
- Rail Corridor
- Road Corridor
- Rural Residential
- Rocky Dam Creek

Data sources:

Base Data: (c) 20XX (data source)
(additional data)

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Rocky Dam Creek - Koumala

Hydraulic Roughness Delineation

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LAST MODIFIED	20/09/2019
VERSION:	v01

Figure
13

A3 size

Filename: ...S\02_MXDs\Figures\KOU\Figure 13 - Roughness Delineation.mxd

5.3 Two-Dimensional Model Development

5.3.1 Model Setup Parameters

The grid cell size selected for the model was 5m.

The minimum time step for the 2D model domain was set to 1.0 seconds, the TUFLOW HPC Solver utilises an adaptive time step and can adjust the time step to ensure model stability.

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 rainfall below the wetting depth will not be applied. The wetting and drying depth has been set to the default of 0.0002m for the centre of a cell.

5.3.2 Model Topography

Base model topography was derived from 2009 and 2014 LiDAR and was downloaded from Geoscience Australia. The data is a 1m resolution Digital Elevation Model (DEM).

5.3.3 Adopted Blockage

Assessment of culvert blockage was undertaken in accordance with Queensland Urban Drainage Manual 4th Edition 2017 (Table 10.4.1). QUDM suggests a design blockage of 20% for culverts less than 3 metres high, or 5 metres wide and 10% blockages for larger culverts.

5.3.4 2D Modelling Roughness

Roughness Delineation within the TUFLOW model boundary is shown on Figure 13 and roughness values shown in Table 17.

5.3.5 Boundary Conditions

Upstream boundary conditions were specified as time varying discharge hydrographs (QT Boundaries) to represent the flows from catchments upstream of the hydraulic model boundary.

Inflow discharge hydrographs were applied at the boundaries shown in Figure 12. These discharge hydrographs were extracted from the Storm Injector hydrologic models.

The downstream model boundaries was modelled as a height-varying discharge (HQ boundary) outflow boundary based on surface slope for flows leaving the model. HQ type boundaries allow flood waters to discharge from the model relative to the water surface elevation.

5.3.6 Bridge Form Loss Coefficient

Bridge drawings were obtained for Cherry Creek Bridge, Rocky Dam Creek Bridge and Duff Creek bridge. Form Loss Coefficient (FLC) was completed in accordance with Hydraulics of Bridge and Waterways – Figure 4 Incremental Backwater Coefficient for Piers.

5.4 Sensitivity Analysis

5.4.1 Design Model

A series of sensitivity analyses were undertaken as part of the modelling work to assess the impact of changes to basic model set up parameters. The following sensitivity analyses were modelled for a 1% AEP event:

- Manning's Roughness increase by 20%;
- Manning's Roughness decrease by 20%.

The results of the sensitivity analysis are presented in Volume 2 of the report as Maps 31 and 32 for the 20% increase and decrease respectively.

As shown, it was found that the model is quite sensitive to changes in hydraulic roughness, mainly due to the dominant grazing and agricultural land. Changes of 20% to the hydraulic roughness values saw an increase/decrease peak water levels by up to 250mm at some locations. Table 9 identifies the changes in Peak Water Surface Levels due to the increase/decrease in hydraulic roughness, key locations are shown in Figure 20.

It was found that adjusting the roughness values by 20% had negligible flood extent increase with no additional breakouts occurred within the creeks and no additional houses affected by the increase in roughness for the 1% AEP flood. It was found that reducing the hydraulic roughness causing an increase in Peak Water Surface Elevation at Little Station Creek (PT_LIT_us) due to water reaching the road crossing faster with reduced roughness values.

It is recommended that these roughness values be further investigated through calibration of future flooding events within the catchment when they occur.

Table 9 Increase/Decrease in Peak Water Surface Elevation (±20% Hydraulic Roughness)

Location	Change in Peak Water Surface Elevations (mAHD)	
	1% AEP -20% Roughness	1% AEP +20% Roughness
PT_BUL_ds	-0.03	0.03
PT_BUL_us	0.01	0.00
PT_CAM_ds	-0.08	0.12
PT_CAM_us	0.03	0.06
PT_CHE_ds	-0.22	0.24
PT_CHE_us	-0.03	0.14
PT_COA_ds	-0.12	0.02
PT_COA_us	-0.02	0.05
PT_COA2_ds	-0.01	0.02
PT_COA2_us	-0.02	0.02
PT_COA3_ds	-0.04	0.04
PT_COA3_us	-0.02	0.02
PT_DUF_ds	-0.13	0.17
PT_DUF_us	-0.05	0.08
PT_hwy	-0.04	0.05
PT_LEI_ds	-0.02	0.03
PT_LEI_us	0.00	0.01
PT_LEI2_ds	0.00	0.03

Location	Change in Peak Water Surface Elevations (mAHD)	
	1% AEP -20% Roughness	1% AEP +20% Roughness
PT_LEI2_us	0.04	0.03
PT_LIT_ds	-0.01	0.08
PT_LIT_us	0.20	-0.01
PT_LOL_ds	-0.02	0.03
PT_LOL_us	0.01	0.02
PT_PRI_ds	0.03	0.04
PT_PRI_us	-0.02	0.04
PT_RIL_ds	-0.03	0.11
PT_RIL_us	0.00	0.04
PT_ROC_ds	-0.14	0.16
PT_ROC_us	-0.11	0.13
PT_STA_ds	-0.07	0.20
PT_STA_us	0.00	0.03
PT_STA2_ds	-0.18	0.20
PT_STA2_us	-0.02	0.06
PT_STA4_ds	-0.04	0.06
PT_STA4_us	-0.02	0.04
PT_TED_ds	-0.03	0.03
PT_TED_us	-0.01	0.03
PT_TED2_ds	-0.01	0.03
PT_TED2_us	0.04	0.04
PT_TED3_ds	-0.06	0.04
PT_TED3_us	0.01	0.03
PT_TUR_ds	-0.02	0.01
PT_TUR_us	0.00	0.02

6.0 Tropical Cyclone Debbie

6.1 General

Tropical Cyclone (TC) Debbie first reached cyclonic strength on 25 March 2017, before developing over the next two days into a Category 2 cyclone. TC Debbie was forecast to increase rapidly in intensity before making landfall on the Queensland coast; this prediction was borne out as TC Debbie made landfall as a Category 4 Severe Tropical Cyclone near Airlie Beach on 28 March 2017.

From Airlie Beach, TC Debbie tracked inland on a south-westerly track, losing tropical cyclone intensity at about 3.00am on 29 June. Ex-TC Debbie continued south, turning onto a south-easterly track and passing over the coast of northern New South Wales and out to sea on the 31 March. Figure 14 shows the movement of TC Debbie through MRC boundary.

Figure 14 North Queensland – cyclone and flooding event (The Cyclone Debbie Review – Inspector-General Emergency Management)

After TC Debbie made landfall and moved across the central interior of Queensland, a band of slow-moving thunderstorms developed inland of the Mackay coast and produced heavy rainfall on the 29 March. Figure 15 shows the line of thunderstorms that become orientated north-south along the terrain inland from the coast.

Figure 15 29th March 2017 Radar, Major Thunderstorm occurred over Mackay (Tropical Cyclone Debbie Technical Report, Bureau of Meteorology, 2018)

6.2 TC Debbie Rainfall Gauges

6.2.1 Sucrogen Weir Alert and Koumala Hatfields Road

Closest rainfall data available is approximately 3 km south-west of Koumala at the Koumala Hatfields Road (33038) which contains daily rainfall amounts. The closest working rainfall gauge which contained sub-daily data was provided by MRC and is located within Sarina at the Sucrogen Weir Alert (533143) to the north.

The rainfall distribution was extracted from the Sucrogen Weir Alert and the daily rainfall at Koumala Hatfields Road station was applied to allow for the best representation from the Cyclone Debbie Event. Reviewing the rainfall data at the station found that no TC Debbie rainfall occurred from the 31st March 2017. Rainfall that occurred during the days of 27th – 29th March 2017 (925mm) was utilised in the model and applied to the rainfall distribution from Sucrogen Weir Alert station between 12:13am on 27/03/2017 to 12:13am on 30/03/2017 (72 hours), cumulative rainfall distribution shown below on Figure 16.

6.2.2 Murray Creek at Undercliff Station

Undercliff station (130416A) is the next closest rainfall gauge after Sucrogen Weir which contained sub-daily rainfall totals. Undercliff Station TC Debbie rainfall was utilised as a sensitivity run as it contained the maximum rainfall depths over the three daily totals as indicated in Table 2.

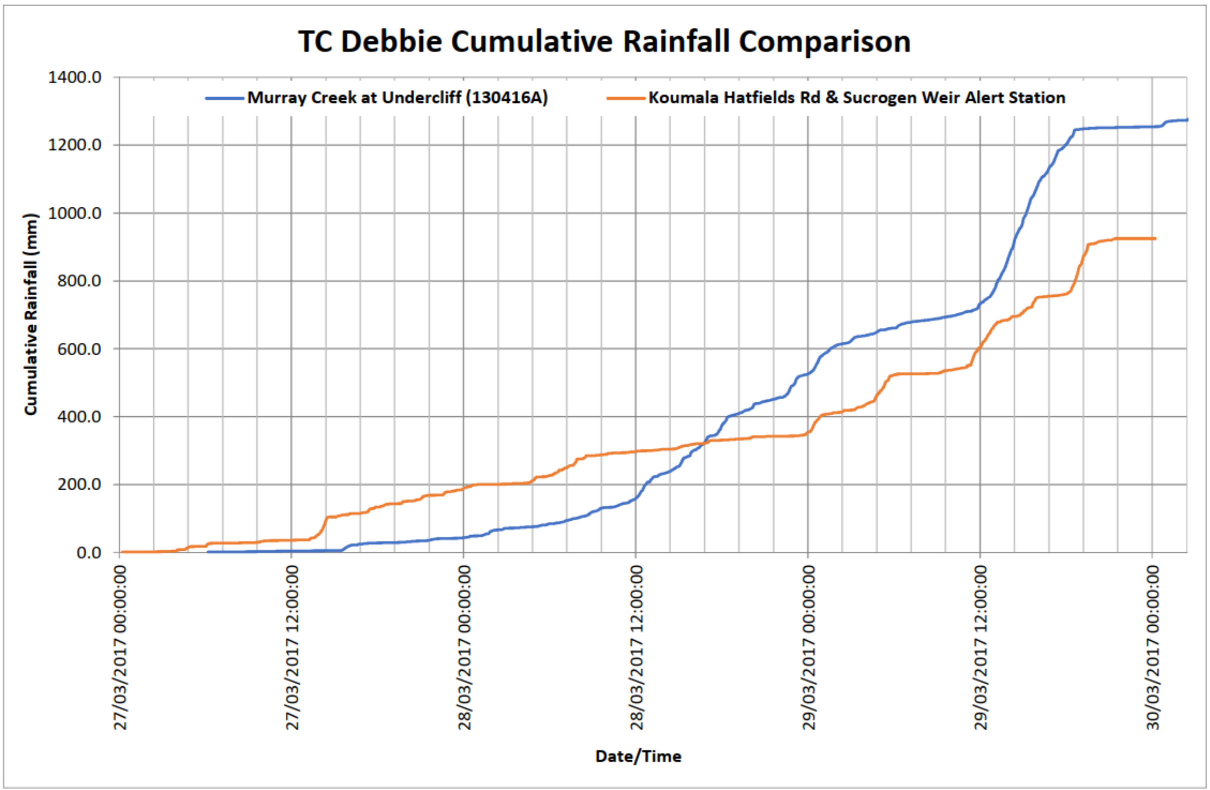


Figure 16 Cyclone Debbie – Undercliff Cumulative Rainfall

Comparison between the rainfall gauges is shown on Figure 16 shows the Undercliff has a more intense peak after 29/03/2017 1:00pm, with approximately 430mm of rain falling over a 5-hour period between 1:00pm and 6:00pm on 29/03/2017.

6.2.3 TC Debbie Rainfall Intensity Comparison

Figure 17 indicates that the peak rainfall intensity that occurred during the Cyclone Debbie event based on the rainfall data available, the Sucrogen Weir Alert and Koumala Hatfields Road was greater than a 1% AEP rainfall event and Undercliff rainfall data greater than a 0.2% AEP rainfall event, based on BoM 2016 Rainfall data at Koumala (Latitude -21.6094, Longitude 149.2457).

6.3 TC Debbie Initial and Continuing storm losses

Initial and continuing losses were discussed with MRC for the TC Debbie rainfall event. Due to the duration of the event (3 days), initial and continuing losses were both set to 0, due to the constant wetting of the catchment across the 2-day period leading up to the peak which occurred towards the end of day 3 after 12:00pm.

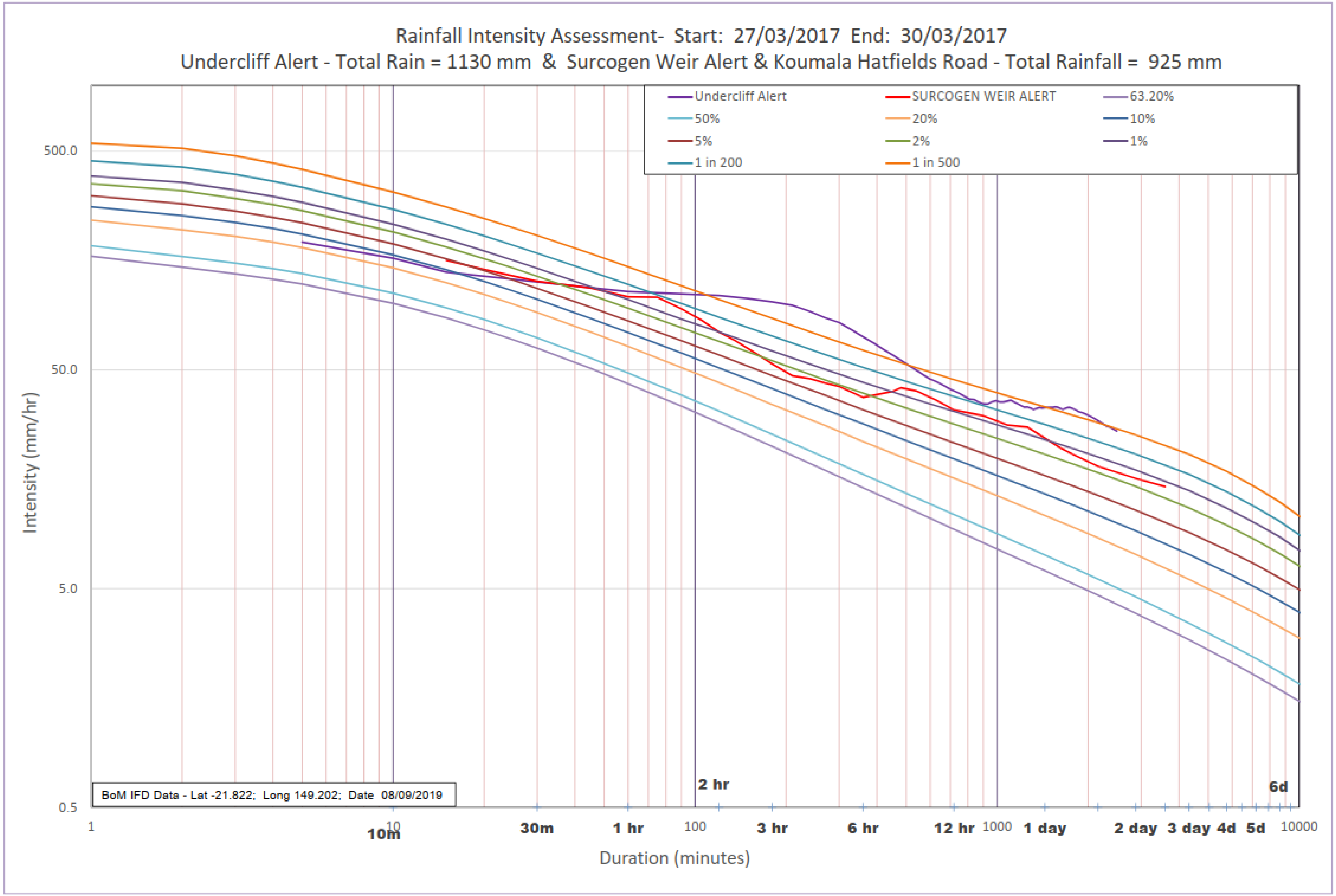


Figure 17 Comparison of BoM Peak Rainfall Intensities with Cyclone Debbie Rainfall

6.4 Community Consultation

6.4.1 Surveyed Elevations

In August 2019, MRC surveyed flood surface elevations identified by the community. Three points were surveyed within the TUFLOW model boundary. This included the bottom of the rail sign southwest of Koumala (Survey Point A), Rocky Dam Creek flooding extent seen by property owner (Survey Point B) and flooding to the side of a house located on the bank of Rocky Dam Creek (Survey Point C). The locations of these survey points are shown in Figure 18.

Figure 18 TC Debbie Community identified flooding – Survey Points

Upon conducting the survey, MRC identified that the rail sign (Survey Point A) was located within a drain and was bent at the time of survey. Surveyed levels may not reflect actual TC Debbie flood level due to the changes that may have occurred since the cyclone event.

Surveyed elevations provided were compared to the constructed TUFLOW model. Both the Sucrogen Weir Alert Station (with Koumala rainfall) and Undercliff Station models utilising separate rainfalls (as discussed in Section 6.2) were compared in Table 10.

Table 10 Surveyed and Modelled Water Elevations Comparison

Surveyed Point	Surveyed Elevation	Sucrogen Weir Rainfall	Undercliff Station Rainfall
	Water Elevation (mAHD)		
A	32	30.92	31.08
B	34.5	33.33	34.19
C	32.7	32.16	32.98

Based on the surveyed points provided by MRC and the rainfall data available, Undercliff Station rainfall data provided the best representation of what occurred within the Rocky Dam Creek Catchment. The difference between the surveyed point A and the modelled storm (920mm), indicates an isolated storm near Koumala may have occurred that was not identified on the rainfall gauges, or the terrain flow conditions have been altered since the capture of the 2009 LiDAR.

6.4.2 Photography

Photos were provided by the community with timestamps of when they were taken. Photos of flooding within Koumala were taken on the 29th March 2017 between 3pm and 5pm. The times shown on the photos align with the intensity rainfall as shown in Figure 16. Photos provided could not be provided within the report due privacy concerns.

6.4.3 Rainfall Information

Cyclone Debbie rainfall information was provided by the community at the community consultation. Records show that approximately 865mm of rainfall of recorded over the 3 days, with 4 inches (approximately 381mm) of rain falling in 4 hours, no time was provided for this amount. It is assumed that this period was between 2:00pm and 6:00pm on 29/03/2017 where a majority of the flooding occurred based on the photographs provided. This matches what occurred at the Undercliff station (130416A) which had approximately 430mm of rain falling over a 5-hour period between 1:00pm and 6:00pm on 29/03/2017.

6.4.4 Community Identified Risks

Community members provided key observations from the Cyclone Debbie flooding event numerous responses identifying issues at Koumala. Residents evacuated to the Koumala community centre and the Koumala hotel within the Rocky Dam Creek catchment where flooding was observed by the evacuees along the Bruce Highway adjacent to the hotel.

The following observations included:

- Flooded properties;
- Road inundation.

While some observations were provided, they were relatively limited to terms of quantity and flood levels or water depths were unable to be provided from the community. Key observations provided by the community is indicated below:

Water rose up to the step of the Koumala hotel; no water entered the hotel.

As indicated by Figure 19 the LiDAR of the model indicates that the road crown is higher than the hotel. The community identified that the water did not enter the hotel, however water was located up to the steps, no survey levels of this location were provided.

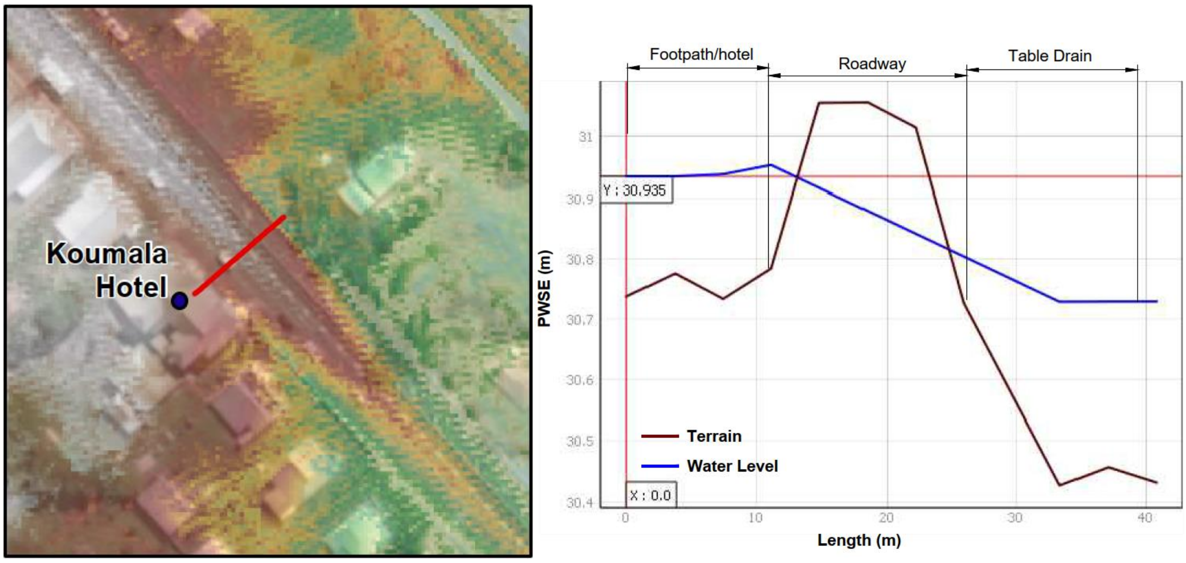


Figure 19 Koumala hotel Terrain Elevations

6.5 Model Validation

The model was compared to anecdotal observations and surveyed flood elevations obtained from community consultation to ensure modelled flood patterns generally matched observed flood patterns and behaviour.

It is recommended that further model development and calibration of the model is undertaken for future studies using recorded flood elevations of future events. TC Debbie flood extents are seen on Maps 27-29 in Volume 2 of the report.

6.6 TC Debbie Sensitivity Analysis

A series of sensitivity analyses were undertaken for the TC Debbie model to determine whether changing selected parameters will change how the water performs, in terms of creek breakout points and cause the model to align with anecdotal and surveyed results. The parameters adjusted included:

- Manning roughness (increase/decrease);
- Bridge and culvert blockage (increase);
- Rainfall (increase);

It was found that increasing the rainfall had the greatest impact to the model. The increase in rainfall was unable to align with Surveyed Point A discussed in Section 6.4.

6.7 TC Debbie Modelling Limitations

A number of limitations were presented when modelling the Cyclone Debbie rainfall event, these are summarised below:

- Availability of rainfall data within the extents of the Rocky Dam Creek catchment. With the two closest hyetograph data being approximately 20km north and 25km southwest of Koumala. Due location of the rainfall gauges, they are unable to represent rainfall bursts during the event and provide no information regarding the rainfall distribution within the TUFLOW model boundary.
- Topography data that was available for the Rocky Dam Creek was 2009 LiDAR information. Any changes in terrain due to scouring, deposition or filling by land owners in the 8 years leading up to the TC Debbie event are not captured providing potential for discrepancy between modelled results and observed flooding;
- Survey flood levels were obtained at three points across the catchment by MRC. The sparsity of available flood survey levels or anecdotal information limits the comparison of the model to actual events.

7.0 Baseline Assessment

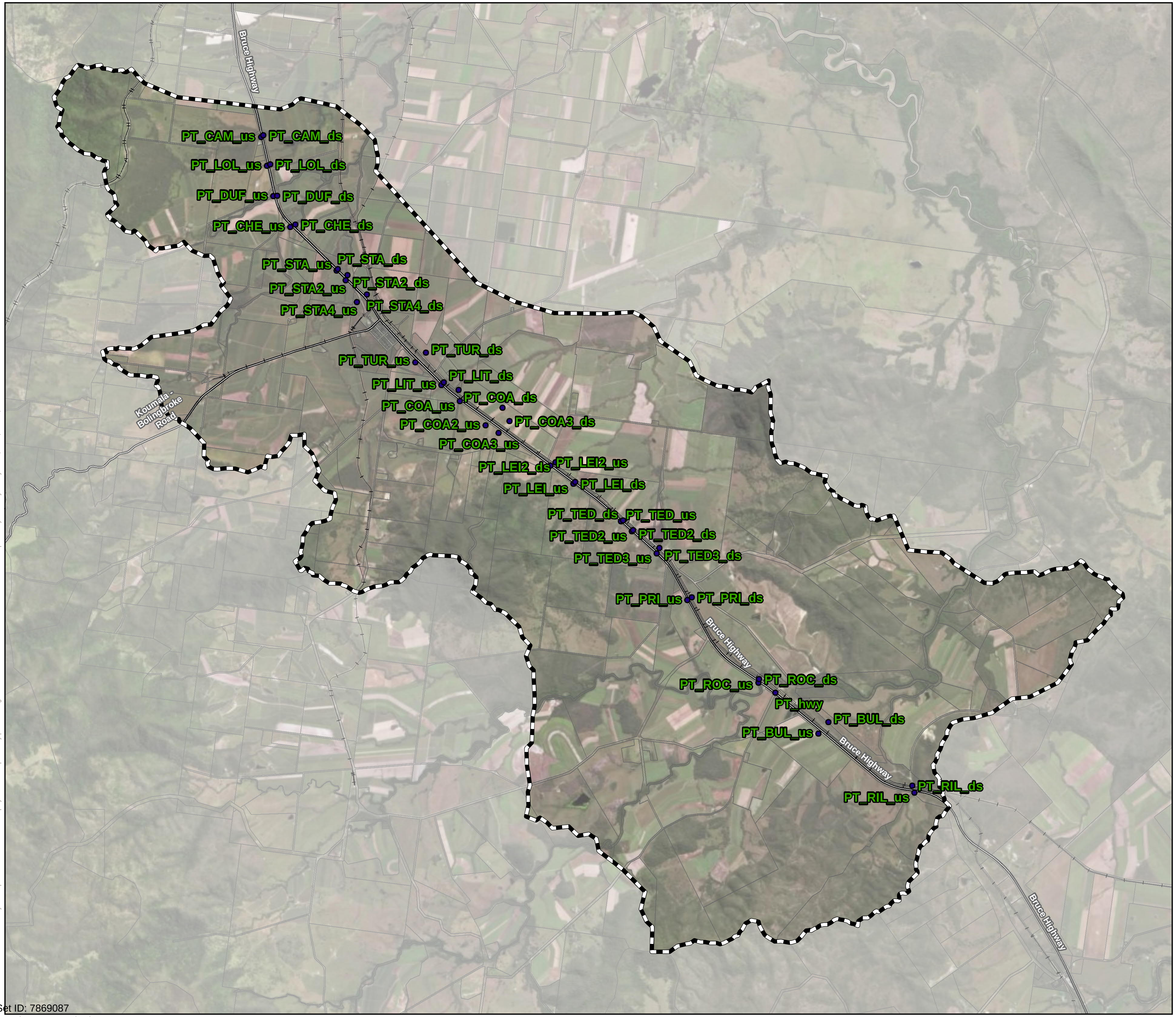
7.1 Overview

Mapping of direct rainfall results requires adoption of flooding threshold criteria to ensure meaningful flood maps. In this study, areas where the flow depth is less than 100 mm were removed from the mapping and are considered free of flooding. It should be noted that these depths are not excluded in the computational model and tabulated results.

GIS results mapping includes peak flood elevations, depths and velocities and can be found in the Rocky Dam Creek – Hydraulic Analysis Report (Volume 2).

The following sections present PWSE and peak flows at key points of interest. Key points of interested are identified in Figure 20 and Figure 21 as follows:

- Figure 20 – Points for PWSE;
- Figure 21 – Cross sections for flow locations.



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Metres

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LEGEND

- TUFLOW Model Boundary
- Cadastre
- State Controlled Road
- Rail Line
- Key Points

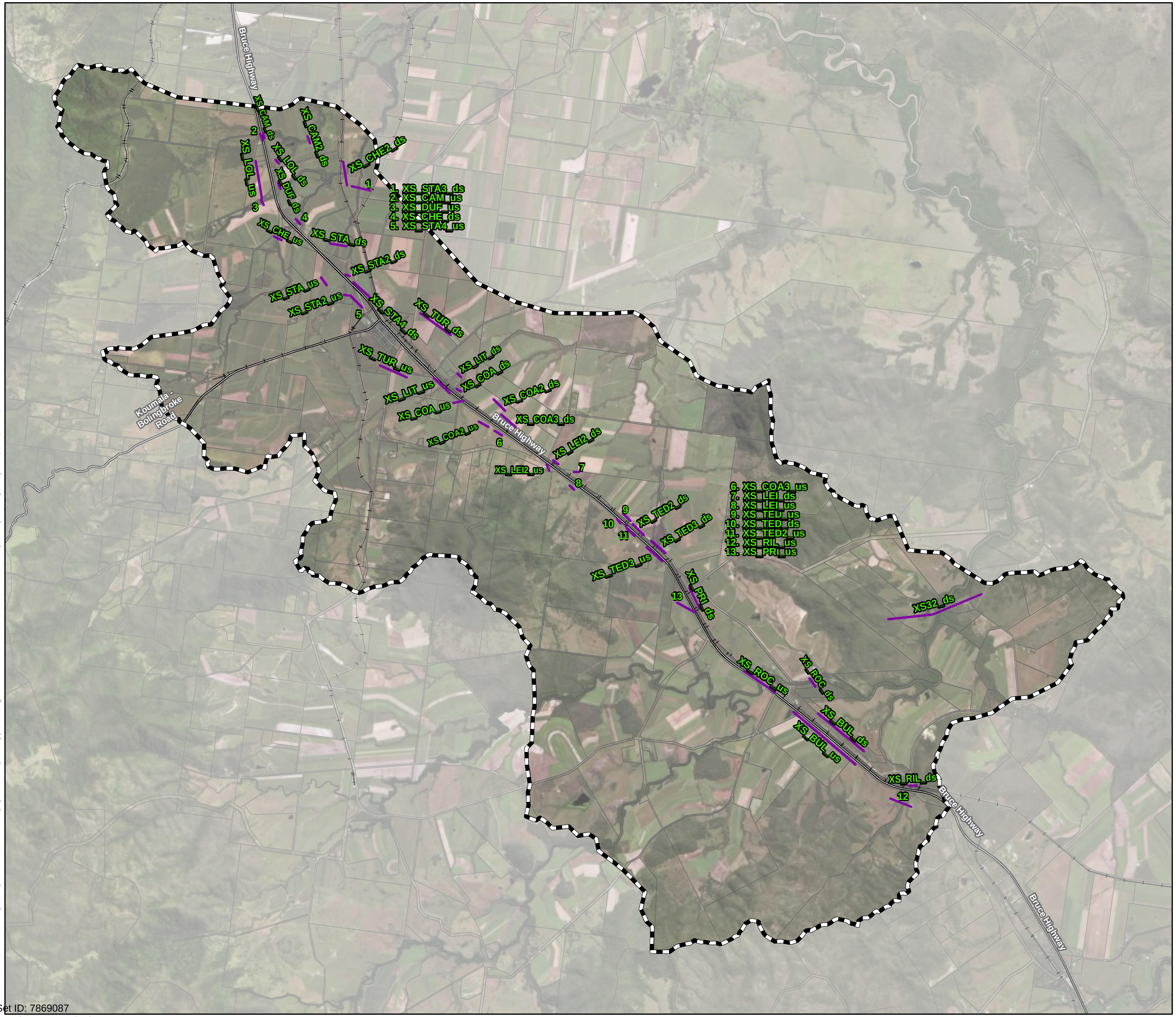
Data sources:

Base Data: (c) 20XX (data source)
(additional data)

MACKAY REGIONAL COUNCIL
Rocky Dam Creek - Koumala

Model Key Points of Interest
Water Surface Levels

PROJECT ID	60598460	**Figure**
CREATED BY	DR	20
LAST MODIFIED	20/09/2019	
VERSION:	v01	



AECOM
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GDA 1994 MGA Zone 55

0 700 1,400 2,800

Metres

1:60,000 (when printed at A3)

LEGEND

- TUFLOW Model Boundary
- Cadastre
- State Controlled Road
- Flow Lines
- Rail Line

Data sources:

Base Data: (c) 20XX (data source)
(additional data)

MACKAY REGIONAL COUNCIL
Rocky Dam Creek - Koumala

Model Key Points of Interest
Flow Cross-Sections

PROJECT ID	60598460	Figure
CREATED BY	DR	21
LAST MODIFIED	20/09/2019	
VERSION:	v01	A3 size

7.2 Modelled Flood Depths and Elevations

The peak flow rates for the flow paths at key locations within the study area were extracted for each of the events modelled, with the results summarised in Table 11.

Table 11 Summary of Modelled Peak Water Surface Elevations

Location	Natural Surface	Peak Water Surface Elevation (mAHD)					
		1EY	39% AEP	18% AEP	2% AEP	1% AEP	TC Debbie
PT_BUL_ds	26.51	27.59	27.65	27.73	27.94	28.05	28.43
PT_BUL_us	28.65	28.94	29.04	29.33	29.75	29.81	29.93
PT_CAM_ds	16.89	19.79	20.09	20.45	20.87	21.02	21.83
PT_CAM_us	17.29	20.68	20.88	21.22	21.75	21.91	23.29
PT_CHE_ds	16.77	20.36	20.68	21.16	22.31	22.24	24.19
PT_CHE_us	17.72	21.04	21.49	22.11	23.79	23.69	25.66
PT_COA_ds	28.85	29.46	29.57	29.59	29.66	29.76	29.86
PT_COA_us	31.05	32.53	32.99	33.24	33.42	33.43	33.78
PT_COA2_ds	30.82	30.85	30.86	30.87	30.89	30.90	31.06
PT_COA2_us	35.14	35.22	35.24	35.26	35.29	35.30	35.38
PT_COA3_ds	30.72	31.52	31.55	31.58	31.64	31.64	31.75
PT_COA3_us	34.81	34.85	34.87	34.89	34.93	34.93	35.18
PT_DUF_ds	20.18	22.28	22.59	22.96	23.68	23.68	25.36
PT_DUF_us	21.05	23.40	23.75	24.17	24.96	24.95	27.41
PT_hwy	31.08	31.36	31.36	31.36	31.40	31.50	31.83
PT_LEI_ds	35.88	36.87	36.97	37.13	37.28	37.29	37.35
PT_LEI_us	35.90	37.47	37.66	37.89	38.16	38.16	38.41
PT_LEI2_ds	34.40	35.09	35.12	35.28	35.36	35.36	35.53
PT_LEI2_us	35.81	37.06	37.20	37.41	37.86	37.88	38.38
PT_LIT_ds	24.42	27.28	27.59	27.79	28.23	28.33	29.10
PT_LIT_us	25.27	27.85	28.21	28.60	29.72	29.95	32.00
PT_LOL_ds	21.18	22.37	22.46	22.56	22.68	22.68	22.78
PT_LOL_us	21.75	22.86	23.08	23.67	24.63	24.69	25.19
PT_PRI_ds	36.26	36.86	37.03	37.21	37.65	37.78	38.04
PT_PRI_us	35.76	36.05	36.08	36.12	36.18	36.21	36.44
PT_RIL_ds	29.96	32.60	32.76	33.03	33.35	33.44	33.89
PT_RIL_us	30.23	33.17	33.51	33.97	34.38	34.42	34.74
PT_ROC_ds	23.15	28.09	28.76	29.59	31.12	31.31	32.79
PT_ROC_us	22.26	28.21	28.92	29.82	31.54	31.79	33.03
PT_STA_ds	21.39	23.64	23.83	24.07	24.84	24.95	27.04
PT_STA_us	23.06	23.79	24.16	24.79	27.24	27.28	28.03
PT_STA2_ds	20.80	24.38	24.69	25.09	25.72	25.75	26.61

Location	Natural Surface	Peak Water Surface Elevation (mAHD)					
		1EY	39% AEP	18% AEP	2% AEP	1% AEP	TC Debbie
PT_STA2_us	21.21	25.20	25.84	26.49	27.90	27.95	28.52
PT_STA4_ds	26.46	27.07	27.10	27.15	27.25	27.26	27.54
PT_STA4_us	27.76	27.96	28.02	28.09	28.25	28.28	28.79
PT_TED_ds	31.11	33.00	33.06	33.14	33.22	33.22	33.33
PT_TED_us	32.72	33.56	33.68	33.81	33.93	33.94	34.19
PT_TED2_ds	29.14	30.45	30.56	30.94	31.06	31.08	31.24
PT_TED2_us	29.73	30.66	30.74	31.19	31.68	31.73	32.90
PT_TED3_ds	28.60	29.37	29.54	29.59	29.66	29.68	29.76
PT_TED3_us	29.69	31.19	31.35	31.56	31.94	31.99	32.21
PT_TUR_ds	28.94	29.33	29.37	29.40	29.47	29.50	29.63
PT_TUR_us	30.42	30.71	30.75	30.79	30.90	30.95	31.42

7.3 Modelled Peak Discharges

The peak flow rates for the flow paths at key locations within the study area were extracted for each of the events modelled, with the results summarised in Table 12.

Table 12 Peak Discharges at Select Locations for Modelled Events

Location	Peak Discharges (m^3/s)					
	1EY	39% AEP	18% AEP	2% AEP	1% AEP	TC Debbie
XS_BUL_ds	11.3	15.8	20.5	44.5	69.2	177.5
XS_BUL_us	10.5	14.5	20.8	37.7	45.2	153.4
XS_CAM_ds	25.8	34.3	48.0	72.7	82.3	172.3
XS_CAM_us	25.5	34.3	47.8	72.4	82.1	170.9
XS_CAM2_ds	30.1	40.8	57.7	89.6	100.3	213.9
XS_CHE_ds	44.7	63.7	91.1	174.1	180.0	396.1
XS_CHE_us	43.6	61.9	88.7	165.7	173.6	383.3
XS_CHE2_ds	71.6	100.3	141.8	273.5	274.4	702.9
XS_COA_ds	12.8	16.0	17.7	24.3	24.4	33.3
XS_COA_us	13.0	16.8	22.3	29.7	30.3	59.4
XS_COA2_ds	0.3	0.4	0.6	1.1	1.3	6.9
XS_COA2_us	1.2	1.7	2.5	3.8	3.9	9.1
XS_COA3_ds	4.8	6.2	8.0	12.8	13.3	25.0
XS_COA3_us	2.7	3.7	4.8	6.6	6.7	14.8
XS_DUF_ds	26.6	37.9	55.0	98.0	97.2	244.0
XS_DUF_us	26.8	38.1	55.6	98.1	98.5	266.8
XS_LEI_ds	7.1	8.6	10.5	12.2	12.4	18.7
XS_LEI_us	7.2	9.5	13.0	17.6	17.9	38.2

Location	Peak Discharges (m³/s)					
	1EY	39% AEP	18% AEP	2% AEP	1% AEP	TC Debbie
XS_LEI2_ds	4.0	5.4	7.1	10.8	11.1	19.8
XS_LEI2_us	4.0	5.3	7.2	10.3	10.4	24.3
XS_LIT_ds	20.2	26.9	38.4	62.2	66.7	113.2
XS_LIT_us	20.3	26.5	34.6	54.6	58.7	100.7
XS_LOL_ds	4.7	6.7	8.7	12.3	12.8	18.8
XS_LOL_us	4.0	5.6	7.9	13.6	15.2	31.4
XS_PRI_ds	1.3	1.7	2.2	3.1	3.8	9.5
XS_PRI_us	1.6	2.2	2.9	4.2	4.9	11.9
XS_RIL_ds	24.6	32.2	41.5	60.5	63.9	103.0
XS_RIL_us	23.0	30.4	41.6	63.9	66.1	130.0
XS_ROC_ds	156.3	235.2	355.2	611.8	686.2	1457.4
XS_ROC_us	155.4	233.7	352.4	587.6	641.1	1274.4
XS_STA_ds	5.1	7.2	10.7	45.3	51.8	360.9
XS_STA_us	4.2	6.1	9.2	21.7	22.7	218.2
XS_STA2_ds	48.6	68.9	99.6	166.7	169.7	231.8
XS_STA2_us	48.5	68.1	98.2	179.0	188.6	330.3
XS_STA3_ds	52.8	76.2	110.8	218.6	226.1	514.9
XS_STA4_ds	2.9	3.8	5.3	9.3	9.8	78.4
XS_STA4_us	3.0	4.4	6.4	11.7	12.9	68.4
XS_TED_ds	2.2	2.3	2.5	2.7	2.9	3.9
XS_TED_us	3.4	4.2	5.2	6.9	7.0	10.9
XS_TED2_ds	4.7	6.8	8.9	15.1	15.6	33.9
XS_TED2_us	2.8	4.0	6.0	9.4	9.6	26.4
XS_TED3_ds	4.4	5.8	7.3	12.4	12.8	29.8
XS_TED3_us	4.5	6.0	7.8	11.4	11.9	29.6
XS_TUR_ds	3.2	4.7	7.2	12.0	16.8	83.1
XS_TUR_us	1.3	2.0	2.8	5.7	6.2	40.1
XS32_ds	238.5	361.4	569.1	1122.2	1338.8	3498.7

7.4 Flood Risk Areas

7.4.1 Modelled Flooding Risk

Key risk areas identified based on the 1% AEP baseline mapping includes road crossings and inundated properties within the TUFLOW model boundary. Risk areas that occurred during the 1% AEP rainfall event includes flooded properties within Koumala and flooded the Bruce Highway south of Rocky Dam Creek are shown in Figure 22 below.

Figure 22 Modelled Flooding Risk

8.0 Effects of Climate Change

8.1 General

Mackay Regional Council has used the Local Government Association of Queensland (LGAQ) and the Queensland Government's (Qld Govt, 2010) advice on how to account for climate change in assessing flood risk since 2011. The study recommends a 'climate change factor' be included into flood studies in the form of a 5% increase in rainfall 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.

These increases in temperature equate to a 10% increase in rainfall depth by 2050, and 15% increase in rainfall depth by 2070 and a 20% increase in rainfall depth by 2100 (Qld Govt, 2010). ARR 2019 provides an interim climate change guideline in Book 1 Chapter 6 of ARR 2019 (Ball et al., 2019). The maximum consensus case for the high concentration pathway RCP8.5 predicts that by 2090, there will be an increase in temperature of 2.9°C, leading to a 15.4% increase in rainfall.

The increase in rainfall depth using ARR 2019 interim climate change guidelines is slightly lower but generally consistent with the Qld Govt (2010) findings. A conservative approach was used and a 20% increase in rainfall was applied as requested by MRC.

8.2 Adopted Approach

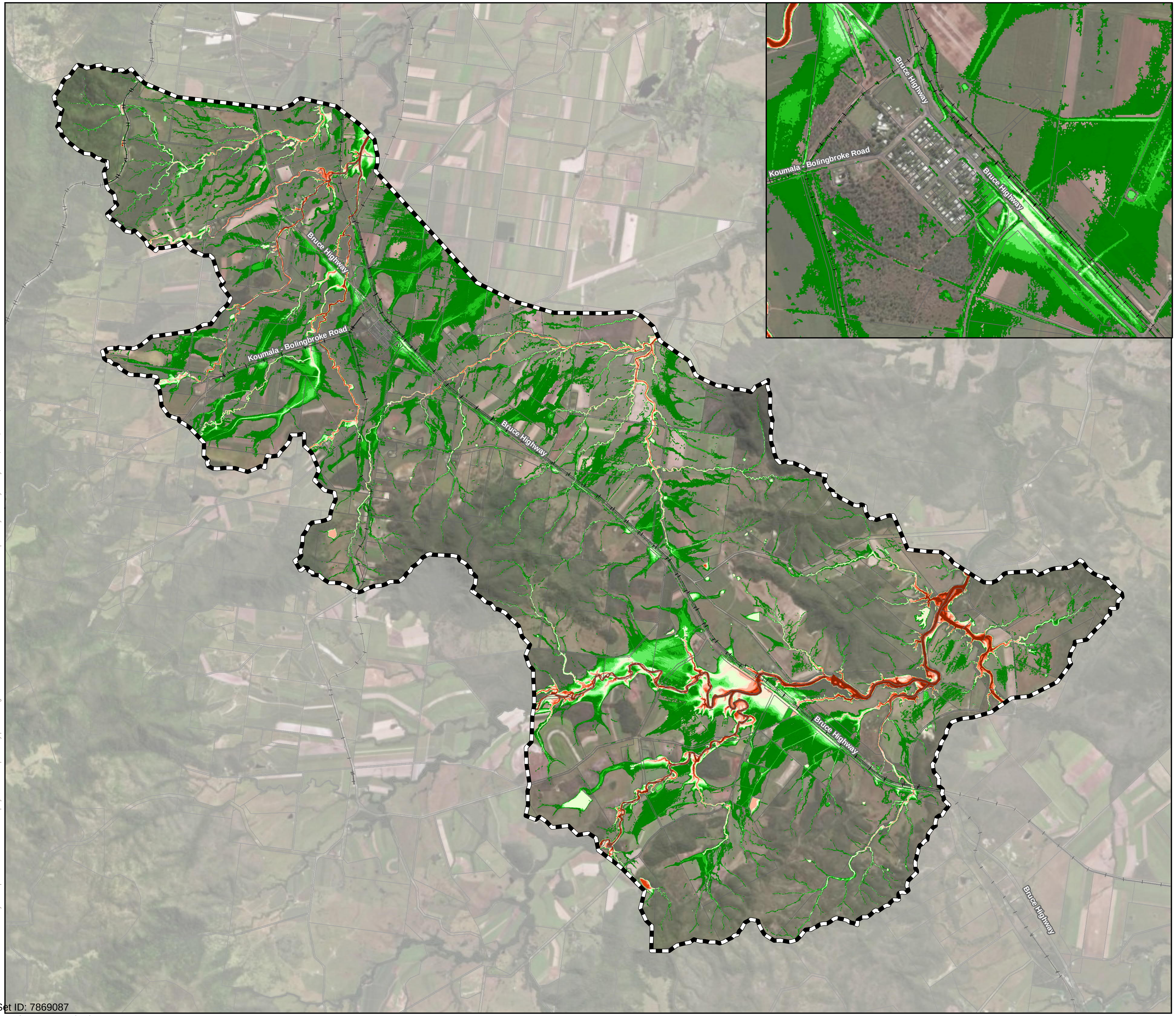
Given the uncertainty in climate change, particularly with respect to changes in rainfall intensity, climate change sensitivity has been undertaken as part of this study. The hydrologic and hydraulic models have been used to assess the impact of climate change that would be expected to occur in 2100 for the 1% and 0.2% AEP design event.

8.3 Hydraulic Model Results

The sensitivity result maps (20% increase in rainfall) are available in the Rocky Dam Creek – Hydraulic Analysis Report (Volume 2). However, the increase in rainfall due to climate change causes an increase in peak water surface levels, maximum of 0.5m PWSE increase for 1% AEP within the main stream of Rocky Dam Creek. A minimal increase of less than 0.05 m was seen around the township of Koumala, additional flooding of the area was minimal.

8.4 Planning Scheme Flood Mapping

To inform the current planning scheme the adopted approach was completed in accordance with Sections 8.1, which includes a 20% increase in rainfall. Maps 36 – 37 contain the Flood Hazard mapping results for the 1% and 0.2% AEP rainfall event with climate change.



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GDA 1994 MGA Zone 55
0 700 1,400 2,800
Metres
1:60,000 (when printed at A3)

LEGEND

- TUFLOW Model Boundary
- Rail Line
- Cadastre

Peak Flood Depth (m)

- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0
- >5.0

Data sources:
Base Data: (c) 2017 Qld Gov

MACKAY REGIONAL COUNCIL
Rocky Dam Creek - Koumala
Basecase Climate Change
Peak Flood Depth
1% AEP (100 yr ARI) 540 min Storm

PROJECT ID	60589930
CREATED BY	Reitanod
LAST MODIFIED	15/10/2019
VERSION:	v01

Figure
23

A3 size

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9.0 Flood Hazard Mapping

9.1 Flood Hazard Curves

When dealing with specific floodplain management or emergency management analysis there may be a clear need to use specific thresholds. However, particularly in a preliminary assessment of risks or as part of a constraints analysis such as might be applied as part of a strategic floodplain management assessment, there is also an acknowledged need for a combined set of hazard vulnerability curves, which can be used as a general classification of flood hazard on a floodplain. A suggested set of curves based on the referenced thresholds presented above is provided in Figure 24.

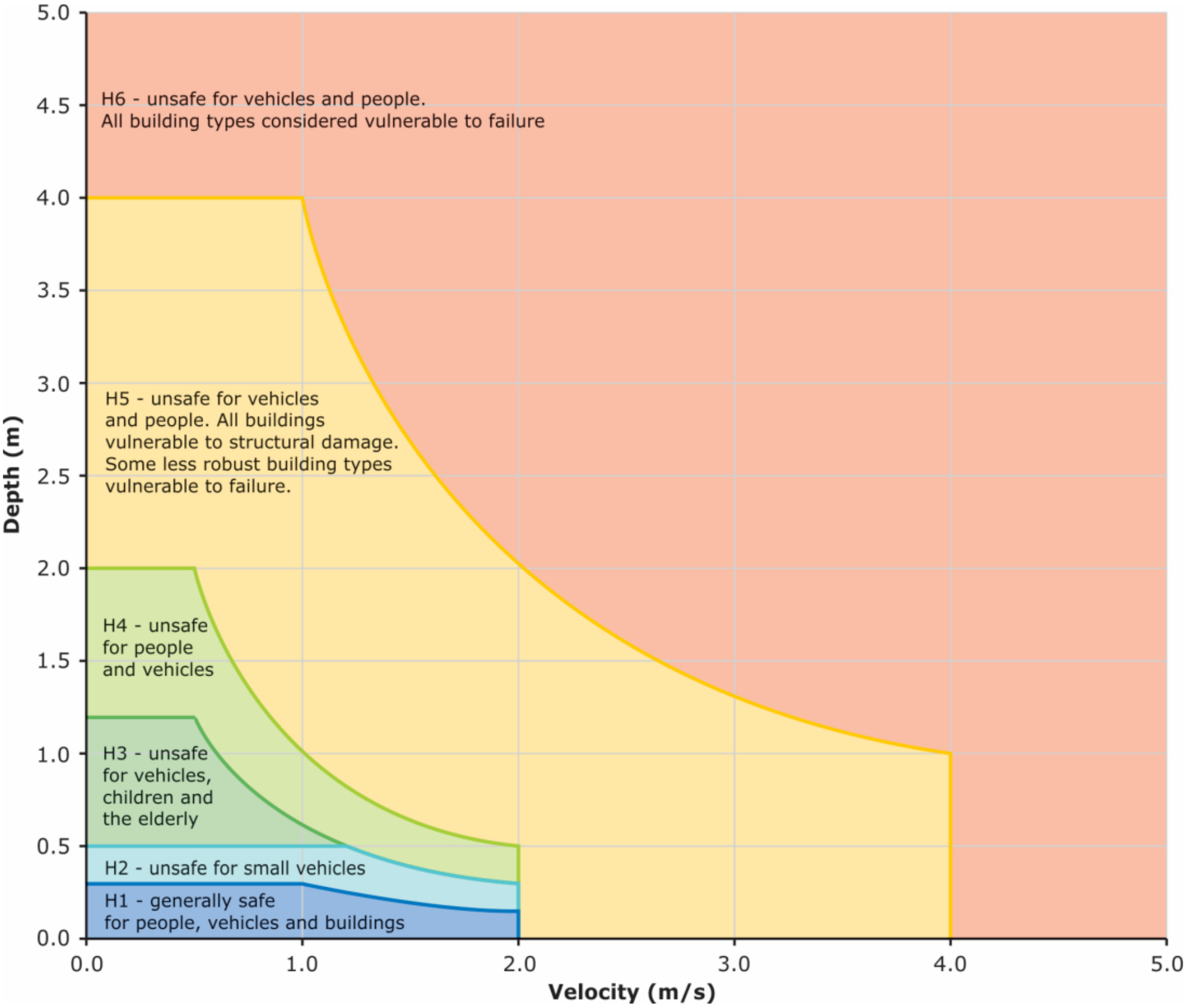


Figure 24 Combined Flood Hazard Curves (Smith et al, 2014)

The combined flood hazard curves presented in Figure 24 set hazard thresholds that relate to the vulnerability of the community when interacting with floodwaters. The combined curves are divided into hazard classifications that relate to specific vulnerability thresholds as described in Table 13. Table 14 provides the limits for the classifications in Table 13.

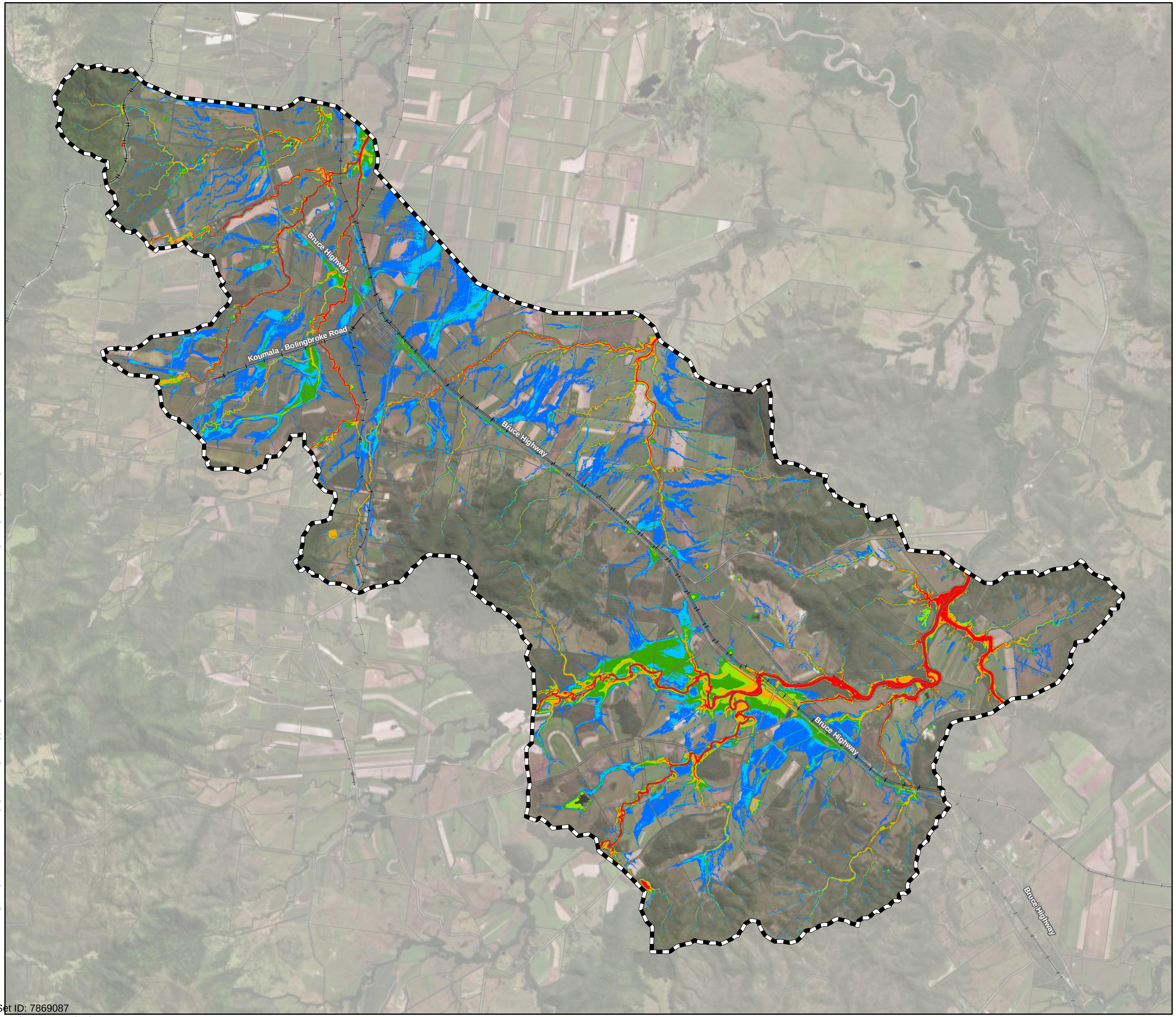
Table 13 Combined Hazard Curves - Vulnerability Thresholds (Smith et al, 2014)

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 14 Combined Hazard Curves - Vulnerability Thresholds Classification Limits (Smith et al, 2014)

Hazard Vulnerability Classification	Classification Limit (D and V in combination)	Limiting Still Water Depth (D)	Limiting Velocity (V)
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	-	-

Importantly, the vulnerability thresholds identified in the flood hazard curves described above can be applied to the best description of flood behaviour available for a subject site. In this regard, the hazard curves can be applied equally to flood behaviour estimates from measured data, simpler 1D numerical modelling approaches, through to complex 2D model estimates with the level of accuracy and uncertainty of the flood hazard estimate linked to the method used to derive the flood behaviour estimate.



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Metres
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LEGEND

- TUFLOW Model Boundary
- Rail Line
- Cadastre

Peak Flood Hazard

- Category 1
- Category 2
- Category 3
- Category 4
- Category 5
- Category 6

Data sources:
Base Data: (c) 2017 Qld Gov

MACKAY REGIONAL COUNCIL
Rocky Dam Creek - Koumala
Basecase Climate Change
Peak Flood Hazard Mapping
1% AEP (100 yr ARI) 540 min Storm

PROJECT ID	60589930	Figure
CREATED BY	Reitanod	25
LAST MODIFIED	21/08/2019	
VERSION:	v01	

A3 size

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10.0 Non-Structural Mitigation Options

10.1 Overview

Non-structural flood mitigation measures are outlined below for Council's consideration.

10.2 Community Awareness

It is critical that community living in the flood-prone areas of Rocky Dam Creek catchment be made aware – and remains aware – of their role in the overall floodplain management strategy for the region, including defence of their communities and their personal evacuation. Sustaining an appropriate level of flood awareness involves continuous effort by Council and the emergency services which can significantly increase the community's resilience to future flood events.

Irrespective of flood warnings, there can be widespread variation in flood awareness in a community which can result in a high degree of variation in flood damages. Within the Rocky Dam Creek catchment area, more recent flood events (i.e. 2017 Cyclone Debbie event) have raised flood awareness in the community. However, as time passes, this awareness will reduce.

Council can enhance flood awareness through, for example, regular public education programs via newspaper, videos, mobile applications, pamphlets, meetings, community events and other media outlets. Community awareness brochures have been widely adopted and many followed the successful implementation of NSW SES's 'Flood Safe' brochures.

These brochures can include material specific to the local region and provide the following information:

- What floods are and the history on flooding at Rocky Dam Creek.
- Flood behaviour in Rocky Dam Creek.
- Flood warnings.
- What to do before, during and after a flood.
- Preparation of a household emergency plan.

It is recommended that Council develop a communications plan to explain existing flood risk to the Rocky Dam Creek community using outputs from this report. This should be incorporated into Council's current Storm Smart Strategy community awareness campaign.

10.3 Land Use Planning Development Control

Through suitable land use planning, the likelihood and consequence of flooding can be managed by guiding appropriate future development, removing existing inappropriate development and selecting land use zoning which is flood compatible.

Appropriate development and building controls can significantly reduce flood risk and the amount of damage to flood prone properties when a flood occurs. The level of protection provided by the Planning Scheme should be a consequence of an analysis of the risks and consequences of flooding and the opportunities provided by sustainable land uses.

An underlying factor of community vulnerability is the degree of exposure to flooding. Where people have chosen to live is their own decision however, they may not be aware of the flood risk and hazard to which they are exposed.

Planning schemes are a key element to prevent increasing the number of people, business and assets exposed to flooding from events less than the Defined Flood Event (DFE). It is therefore fundamental that future development is guided so that people and their property have limited exposure to flood hazard and/or the development uses flood resilient building material and practices and adopts/accepts a flood impact philosophy of shelter in place.

Several broad recommendations are provided below for further consideration by Council's Planning and Development officers:

- Council needs to have regard to the cumulative impacts of developments, i.e. the consideration of the impacts of a development in combination with other developments.
- A key component of land use planning is the adoption of a DFE. This has traditionally been adopted as the 1% AEP flood however there is considerable evidence that rainfall intensity will increase during current planning horizons.
    - In application, a DFE being the 1% AEP flood with an allowance for the adverse impacts of climate change as represented by an increase in design rainfall intensities of 20% (being a 5% per degree Celsius rise in mean global temperature of 4°C to the year 2100) is recommended.
- In consideration of the results of the sensitivity tests, and minimal data on which to base model calibration, it is recommended that a freeboard of 0.3m be applied to the model results from this report, when using them for development control purposes.
- Council should ensure the key overland flow paths identified are considered as part of future capital works to promote preferred overland conveyance routes.
- A comprehensive suite of development assessment measures is recommended, that not only includes the direct impact of development, but also the indirect impacts regarding flood warning and evacuation.
- Relevant Council staff should be appropriately trained in assessing flood study reports with respect to the development control measures selected.

There are a range of methods that can also be considered for future development and or future planning scheme controls. Methods include:

- Internal Council Policy to guide development assessments including draft conditions for stormwater flooding prevention and control.
- Preparing more up to date *Flood Hazard Overlay Mapping*, using the flood maps prepared for this study.
- Planning maps easily accessible by the public to find out if Council has planning controls for flooding on the subject property.
- Ensuring in development control provisions that any portion of a structure below flood planning levels will be built from materials that minimise potential damage due to inundation and impact from flood velocities.

Planning scheme controls can also provide Performance Criteria & Acceptable Solutions that seek to achieve the following objectives:

- Habitable floor areas for residential developments to be above the defined flood event plus freeboard.
- Commercial buildings all habitable flooring to be above the ground floor for multi-story buildings.
- Increase housing density that makes use of prefabricated or tilt up concrete panels.
- Basement carparks prohibited in areas where the 1% (or lower) AEP event extends above to top of existing kerb and channel flood areas.
- Major electrical equipment (switchboard, lift controls, etc.) for the buildings to be above the defined flood event.
- Major plumbing and house drainage equipment (switchboard, pump controls, etc.) for the buildings to be above the defined flood event.
- Maximum site discharge to be no greater than 39% AEP - to be triggered by development application.

- Avoid filling to minimise cumulative impacts on flood plains.
- Maximise use of non-stud frame dwellings to reduce contents damage.
- Place electrical outlets above flood elevations.
- Build all external wall and load bearing internal walls below the DFE plus freeboard of masonry construction e.g. double brick, concrete block, concrete panel rather than brick veneer or framed walls.
- Use timber framed walls with sheet cladding only for non-load-bearing internal partitions.
- Building foundations to be flood impact and inundation resilient.
- For structural purposes use materials that are dimensional stable and not weakened by immersion.
- Use of water resistant bracing materials – e.g. steel straps, fibre cement or waterproof plywood sheets.
- Ignore bracing contribution from plasterboard wall lining.
- Use medium of heavy-duty side fixed brick ties.
- Use insulation with minimal absorption that dries- e.g. polystyrene panels.
- Ensure adequate ventilation to cavities.
- Staircases should be designed to facilitate the relocation of contents from the ground floor to the upper floor.

10.3.1 Habitable Floor Level

MRC currently set habitable floor levels based on the highest of:

- 300mm above the 1% AEP (annual likelihood) flood level or defined storm tide event;
- 225mm above natural ground level;
- 300mm above the greater of top of the kerb level or the crown of the adjacent bitumen road.

It is recommended MRC considers utilising the 1% AEP with climate change to set habitable floor levels instead of the 1% AEP rainfall event.

10.4 Emergency Management Planning

Council's Local Disaster Management Group (LDMG) is responsible for coordinating local planning and response for flood events. A lack of available data can be a limiting factor for a LDMG's ability to plan for the event and to communicate the expected impacts to local residents / media.

10.4.1 Flood Emergency Plan

It is recommended that Council further develop or amend their existing Flood Emergency Plan (FEP) following the completion of this study. The FEP should be a detailed document containing an agreed set of roles, responsibilities, functions, actions and management arrangements to deal with flood events of all sizes.

The primary aim of the FEP is to reduce hazard during an actual flood. Essential issues addressed in the plan are flood forecasting, flood warning, location of vulnerable people/communities and evacuation and initial recovery. A local FEP forms an essential component of a floodplain management plan and requires close liaison between emergency management staff.

Typically, a FEP has several trigger points that result in the activation and implementation of the plan as the actual flood event develops. The flood emergency plan should include activities to protect and reinstate essential infrastructure services required during clean-up and in the recovery phase.

10.4.2 Assessment of Critical Infrastructure

The flood immunity of critical infrastructure should be determined based on outputs of this study. This could include infrastructure such as:

- Emergency services facilities (e.g. ambulance, police, fire, hospital);
- Facilities for evacuation of vulnerable groups (e.g. child care, education, retirement, nursing care, caravan parks);
- Communication infrastructure;
- Key evacuation routes;
- Key water and sewerage infrastructure;
- Roads / bridges.

10.5 Summary of Non-Structural Flood Mitigation Measures

A summary of non-structural flood mitigation measures is shown in Table 15, with a brief discussion on the various types of mitigation measures also provided in Section 11.0.

Table 15 Summary of Non-Structural Mitigation Options

Measure	Mitigation Option	Description	Advantages / Disadvantages
Community awareness	Community and Stakeholder consultation	Engagement throughout the floodplain management process, to inform the community on flood risk and develop flood resilience within the community.	<u>Advantages</u> - Creates a flood resilient community. - Gives the community a sense of ‘buy in’ related to flood risk. - Allows for informed debate regarding flood mitigation strategies. - Consequence of flooding may be reduced. <u>Disadvantages</u> - May result in negative community feelings towards flood prone areas. - Likelihood of flooding remains the same.
Land use planning	Zoning	Appropriate land use zoning to guide future development away from flood prone areas. Re-zoning of existing developments within flood prone areas, to flood compatible land uses (e.g. parks and open spaces).	<u>Advantages</u> - Eliminates future development in areas affected by flooding. - Reduces future flood risk. <u>Disadvantages</u> - Re-zoning of existing developed areas may take time to have an effect on flood risk, as existing residents may not move on for some time. - May reduce land values, particularly on the flood fringe areas.
	Buyback / Purchase	Voluntary or forced purchase of existing buildings within high hazard flood areas, to eliminate the flood risk.	<u>Advantages</u> - Eliminates flood risk. - Links with re-zoning. <u>Disadvantages</u> - Costly. - May cause distress if residents resist the purchase. - Could take a long time, particularly if there is isolated resistance within a larger group of buybacks.
Development planning and building controls	Planning Scheme	An overarching plan for the region to guide areas of development outside flood prone areas.	<u>Advantages</u> - Provides a clear picture of areas where development should not take place, due to flood risk. <u>Disadvantages</u> - Could sterilise areas on the flood fringe.

Measure	Mitigation Option	Description	Advantages / Disadvantages
Development planning and building controls	Minimum floor levels	Habitable floor levels are set based on a minimum height (freeboard) above the DFE.	Advantages - Provides a level of flood resilience, up to the DFE. Disadvantages - Residual risk remains for flooding in events larger the DFE. - There may be issues with flood free access / egress to buildings. -
	Raising of dwellings	Lifting of the habitable floor level of an existing dwelling, based on a minimum height (freeboard) above the DFE.	Advantages - Provides a level of flood resilience, up to the DFE. - May prove to be cost effective, when compared to other building controls. Disadvantages - Not possible for all types of buildings. - Residual risk remains for flooding in events larger the DFE. - There may remain issues with flood free access to the building.
	Flood proofing of dwellings	Improving the flood resistance of a building to inundation and velocities, through the use of appropriate materials. This is done by retrofitting to existing buildings or designing into new buildings.	Advantages - Structural damage is reduced during flooding. Disadvantages - Other detrimental effects of flooding remain, including access, clean up, etc.
	Raising of services – electrical and plumbing	Improved flood resilience of building to loss of services if major electrical equipment (lifts and switchboards) and major plumbing items (pumps) are above the DFE	Advantages - Loss of service is reduced during flooding. Disadvantages - Other detrimental effects of flooding remain, including access, clean up, etc.
Emergency management planning	Response planning	Planning associated with managing flood forecasting, flood preparedness, emergency response and flood recovery.	Advantages - Provides clear details on the responsibilities and actions to be taken prior to, during and after a flood event. - Identifies areas that require improvement, in relation to flood response. Disadvantages - Flood risk remains.

Measure	Mitigation Option	Description	Advantages / Disadvantages
	Forecasting and warning	Relates to the prediction of flood severity, flood extent and flood timing for a specific area, and the methods by which affected persons are informed.	Advantages - Provides advanced warning of a flood event, which allows for flood preparedness and flood response. Disadvantages - Flood risk remains.
	Flood preparedness	Refers to the awareness of affected parties (community and agency alike) of what they need to do prior to the arrival of a flood. This will include items such as agency staff training and individual resident's actions taken to prevent loss.	Advantages - Reduces incidental flood damage. - Reduces social impacts. - Allows for effective flood response. Disadvantages - Flood risk remains.
	Community connectivity	Relates to community connectivity after the flood event where the all networks (phone/internet) are unable to be used. Council is unable to quickly determine the damage caused by the flooding and the community is unable to ask for assistance. Evacuation points will require a point of contact and a device to easily allow contact when other sources are down.	Advantages - Provides a point of contact with the community during and after a flood event; - Members of the community can contact family and other agencies to confirm whether they are safe Disadvantages - A trusted member of the community to control the device and be present at the evacuation point.
	Flood Response	Refers to the response by agencies and individuals affected by the flood, to reduce the hazard. This could include road closures, evacuations and rescue.	Advantages - May reduce the consequences of flooding. Disadvantages - Flood risk remains.
	Recovery	Once flood waters recede, the recovery process includes clean-up, services restoration, financial assistance and other activities to ensure safe access is available to flood affected areas.	Advantages - Good planning will accelerate the recovery process. - Clearly defines the roles and responsibilities related to flood recovery. Disadvantages - Flood risk remains.

11.0 Structural Mitigation Options

11.1 Overview

The following broad principles should be applied when developing preliminary structural mitigation options.

- Improvements to existing open channels, including regarding and widening;
- Incorporation of additional stormwater pipework, where possible.

As outlined in Section 6.4.4 and Section 7.4 risk areas have been identified by the communities and baseline mapping. It is proposed that further investigation is required in the area around Koumala, where several properties were flooded and bought to Council's attention by the community.

The following proposed high-level structural mitigation scenarios shown in Table 16 are to be further investigated and discussed with the relevant stakeholders by MRC.

Table 16 High-Level Structural Mitigation Options

Option	Location	Mitigation Scenario
A	East of Koumala	Formulise and widen downstream open channels passing through cane fields
B	South-East of Koumala Bruce Highway and Rail	Duplication of culverts under the Bruce Highway and rail line to increase conveyance to the open channel mentioned in Option A.
C	Bruce Highway south-east of Rocky Dam Creek	Raise the Bruce Highway to ensure 1% AEP immunity.
D	Bruce Highway south-east of Rocky Dam Creek	Install/duplicate culverts under the Bruce Highway and rail line and construct open channels downstream of the Bruce Highway to convey flows away from the road

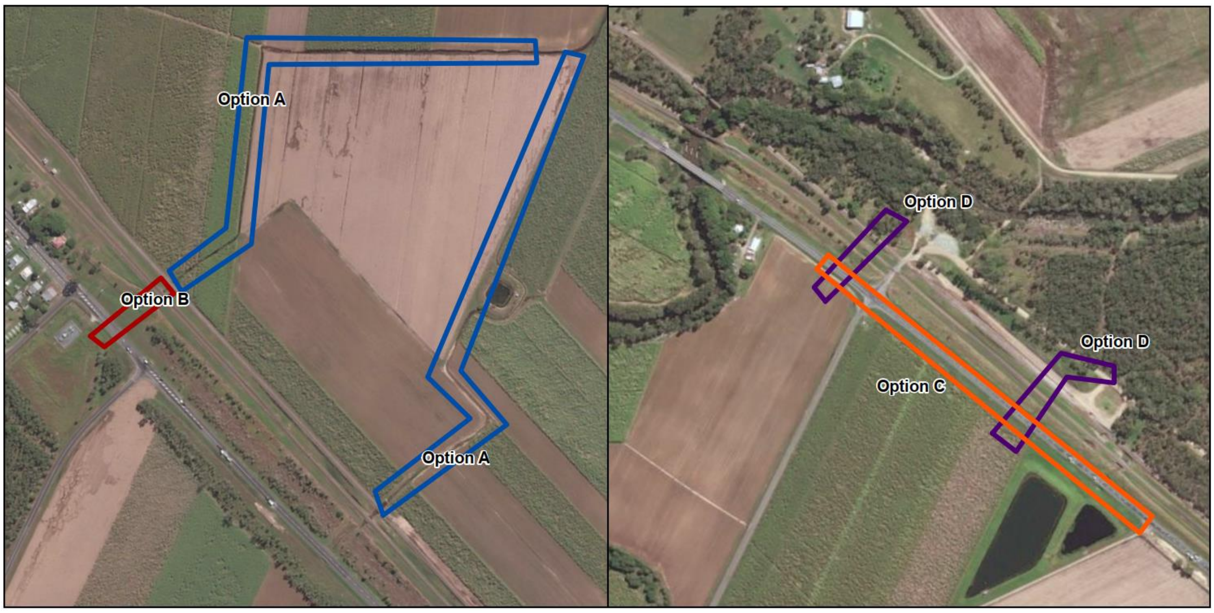


Figure 26 High-Level Structural Mitigation Options

12.0 Conclusion

12.1 Key Findings

The key findings from the TUFLOW hydraulic modelling and associated analysis undertaken for the Rocky Dam Creek - Koumala Flood Study project is summarised below:

- 540-minute storm was found to result in the highest mean peak flow for the majority of the sub-catchment and was utilised by the critical duration for 63.2%, 39%, 18%, 2%,1%, 0.5% and 0.2% AEP events;
- Cyclone Debbie rainfall within the catchment was found to be greater than a 0.2% AEP design rainfall event based on AR&R methodology;
- The community identified flooding within the township of Koumala during Tropical Cyclone Debbie, up to the first step of the Koumala Hotel, which was replicated;
- TC Debbie peak rainfall intensity at the Murray Creek at Undercliff Rainfall station (130416A) after 29/03/2017 1:00pm, with approximately 430mm of rain falling over a 5-hour period between 1:00pm and 6:00pm on 29/03/2017, which aligned with what the community experienced;
- The hydraulic simulation infers that an intense localised rain event occurred over the catchment west of Koumala was not captured in a sub-daily rain gauge;
- Lidar data quality with respect to the processing of cane fields and heavy vegetation is of concern in that flow patterns may be influenced by lidar data quality;
- The impacts of cane on the hydraulic roughness is of concern in that it is not fully known the extent of cane laying over and thus reducing the impedance of floodplain flows;
- Surveyed points (B and C) provided within Rocky Dam Creek was within 300mm of modelled results;
- Structural mitigation options adjacent to Koumala and Rocky Dam Creek have been identified for further investigation to reduce property flooding. These include:
  - Culvert duplication/installation;
  - Highway raising;
  - Widening and formulising open channels.
- Adjusting the roughness values by ±20% had negligible flooding extent increase with no additional breakouts occurred within the creeks and no additional houses were affected;

The following information is recommended to be completed prior to executing future calibration flood studies within the Rocky Dam Creek catchment:

- Survey of railway hydraulic structures such as bridges and culverts;
- Survey of pit and pipes, specifically within the township of Koumala;
- Current Lidar flown at a time when the cane is at a relatively low height;
- Installation of point rainfall gauges located throughout the catchment for future rainfall events to assist in calibration;

13.0 References

- Australian Rainfall and Runoff: A Guide to Flood Estimation 2016 [Geoscience Australia, 2016];
- Tropical Cyclone Debbie Technical Report (Bureau of Meteorology, 2018);
- Koumala Flood Study – Modelling Summary Memorandum (Water Modelling Solutions, August 2018)
- The Cyclone Debbie Review – Inspector-General Emergency Management [Qld Government, October 2017];
- Tropical Cyclone Debbie Technical Report [Bureau of Meteorology, 2018].

Appendix A

Hydraulic Model Development

Appendix A Hydraulic Model Development

Model Setup Parameters

The time step for the 1D and 2D model domains has been set to 0.1 seconds and 0.5 seconds respectively. These time steps are within the feasible time step range given the grid cell size.

The wetting and drying depth represents the depth of water on a cell which is the criteria for whether the cell is “wet” or “dry”. Direct rainfall modelling applies rainfall to each cell in small increments, so the wetting and drying values must also be very small or the calculation will not take place. The wetting and drying depth has been set to the default of 0.0002 m for the centre of a cell and 0.001 m for the side of a cell.

Model Topography

Base model topography was derived from 2009 and 2014 LiDAR and was downloaded from Geoscience Australia. The data is a 1m resolution Digital Elevation Model (DEM).

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 roughness maps developed in previous studies, aerial imagery, building footprints, site visits and land use zoning information.

Variable Manning’s ‘n’ values based on depth can be utilised within TUFLOW. Manning’s ‘n’ 1 is applied for all flow depths up to depth 1, between depths 1 and 2 the Manning’s ‘n’ 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 and open water a single roughness has been applied.

Specific roughness values for each category as applied in the model are outlined in Table 17.

Table 17 Adopted Roughness Values

Material Description	Manning’s ‘n’			
	Depth 1 (m)	Manning’s ‘n’ 1	Depth 2 (m)	Manning’s ‘n’ 2
Open Space Minimal vegetation	0.1	0.050	0.3	0.040
Open Space moderate vegetation	0.1	0.070	0.3	0.060
Open Space dense vegetation	0.1	0.090	0.3	0.080
Creek	0.035			
Open Water – Reedy Vegetation	0.1	0.120	0.5	0.080
SugarCane	0.5	0.150	0.7	0.080
Rail Corridor	0.1	0.130	0.5	0.050
Road Corridor	0.1	0.025	0.3	0.025
Rural Residential	0.1	0.070	0.3	0.040
Rocky Dam Creek	0.9	0.045	1.0	0.060

Rainfall losses allow TUFLOW to model situations in which water is prevented from reaching the ground or is infiltrated into the soil system before surface ponding and/or runoff occurs. When using a direct rainfall approach initial losses and continuing losses are specified for soils file. Soils file shares identical roughness definitions to define soil boundaries.

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 soil is considered saturated and any additional rainfall will become surface water.

Many other Council local catchment studies utilise initial / continuing loss models. For consistency, similar losses have been adopted in this study in absence of model calibration and validation. The initial losses and continuing losses applied to this model are indicated below in.

Table 18 Adopted Initial and Continuing Loss Values

Material Description	Initial Loss (mm)	Continuing Loss (mm/hr)
Open Space Minimal vegetation	15	1
Open Space moderate vegetation	15	1
Open Space dense vegetation	15	2
Creek	0	0
Open Water – Reedy Vegetation	0	0
SugarCane	20	2
Rail Corridor	20	2
Road Corridor	0	0
Rural Residential	15	2
Rocky Dam Creek	0	2

Boundary Conditions

A range of different boundary conditions have been applied within the Rocky Dam Creek hydraulic model. The types of boundaries are as follows:

- Direct rainfall over 2D model terrain;
- Time-varying discharge (QT) inflow boundaries for external catchments;
- Height-varying discharge (HQ) outflow boundaries based on surface slope for flows leaving the model internal model boundaries.

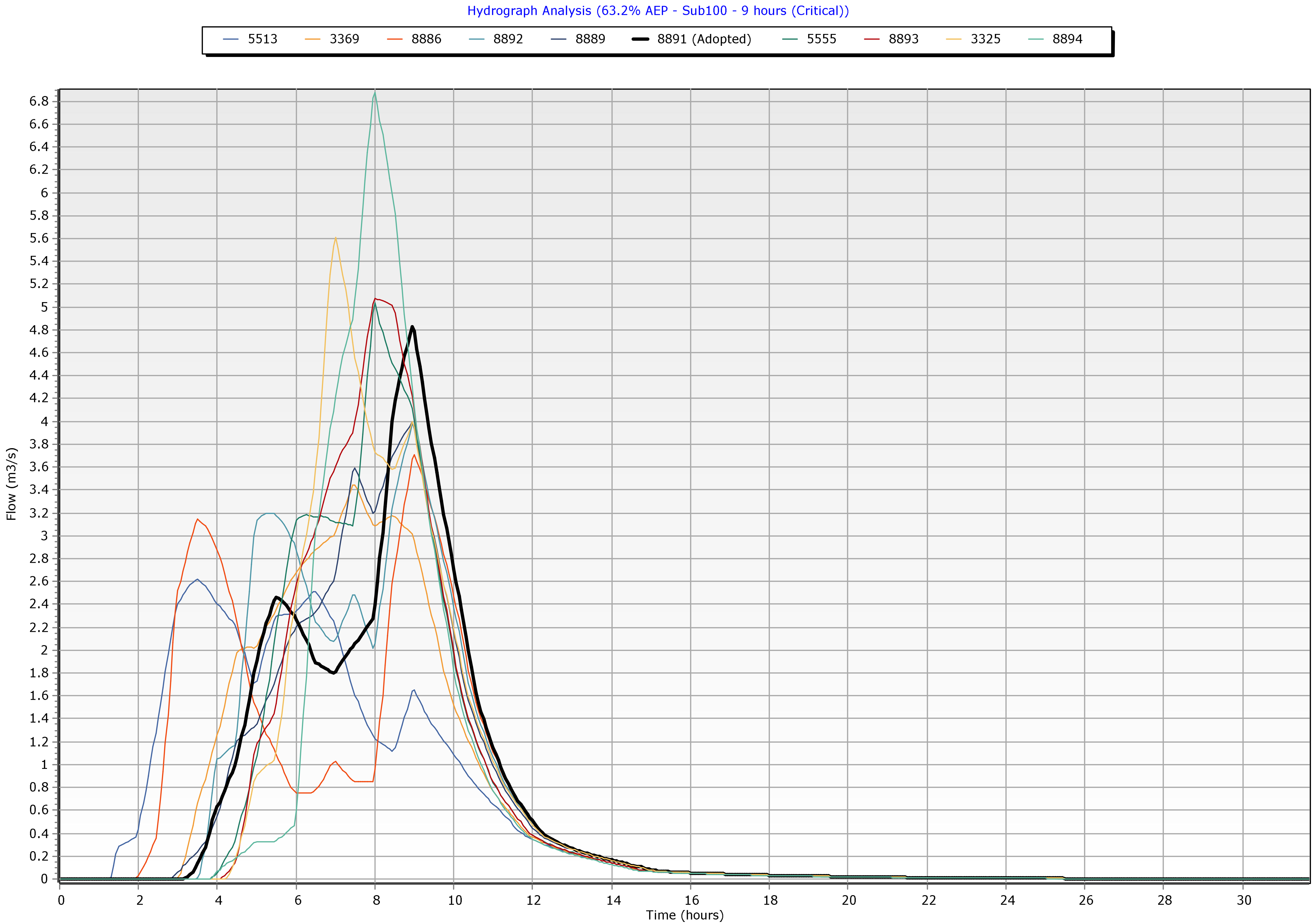
Direct rainfall has been applied to the 2D domain; background to this approach is described in Section 4.3.4. The inflow and outflow boundaries are identified on Figure 12.

The QT inflow boundaries apply the predicted inflow over time as generated by the XPRAFTS hydrologic model for the catchment area external to the 2D domain. HQ type boundaries allow flood waters to discharge from the model relative to the water surface elevation.

Appendix B

Storm Adopted Temporal Patterns

Appendix B Storm Adopted Temporal Patterns


Hydrograph Analysis (63.2% AEP - Sub100 - 9 hours (Critical))
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3369
8886
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8891 (Adopted)
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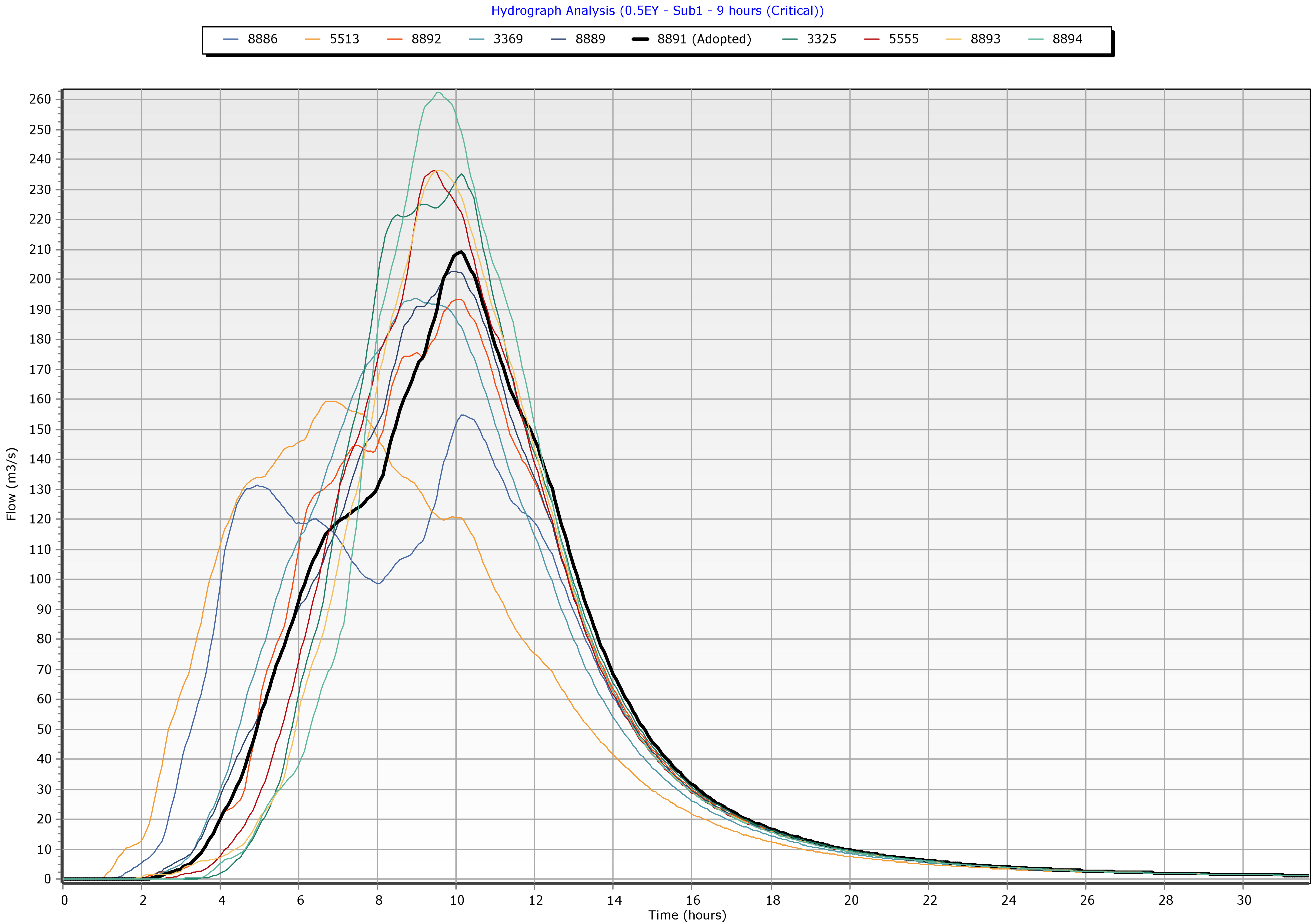
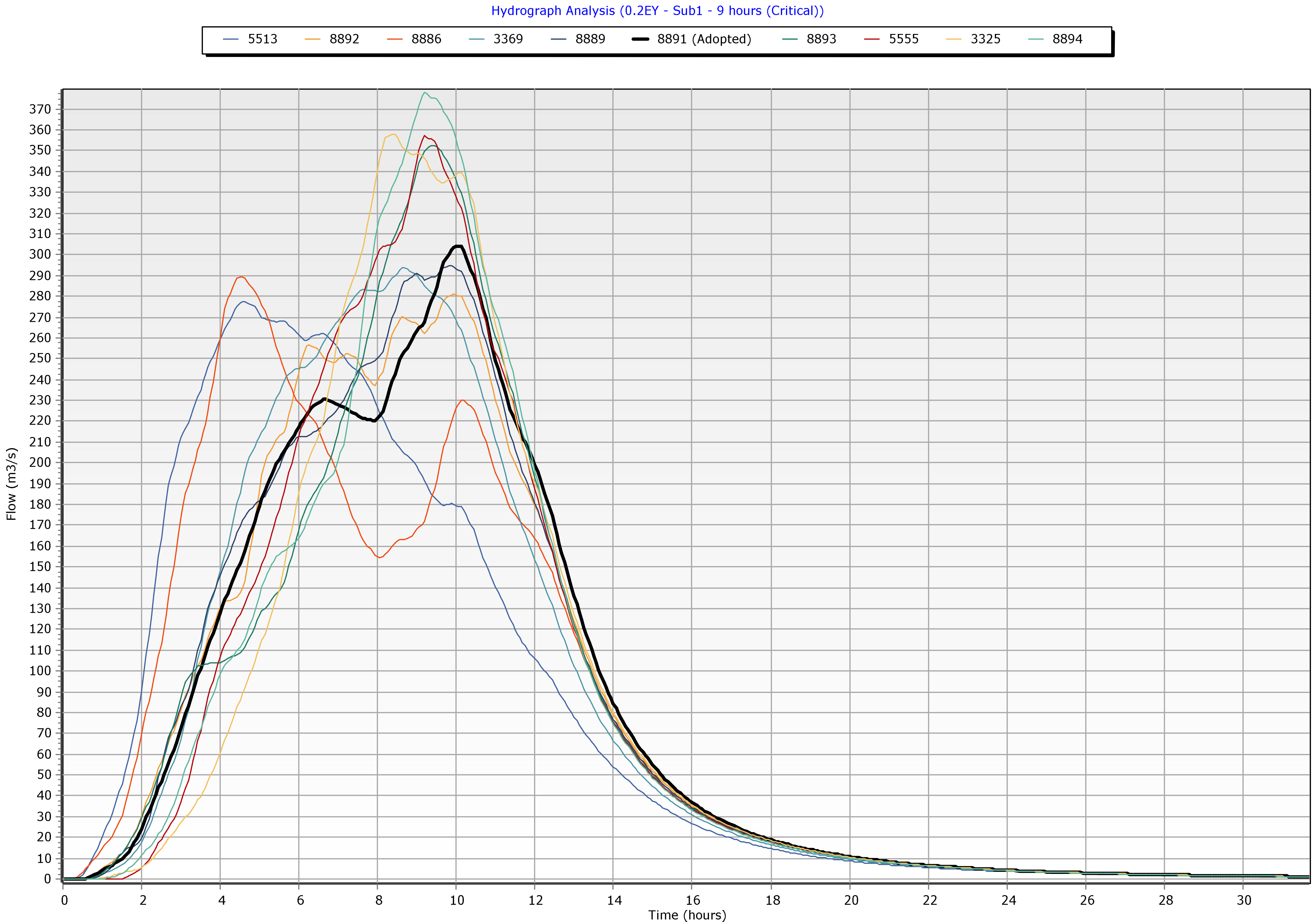
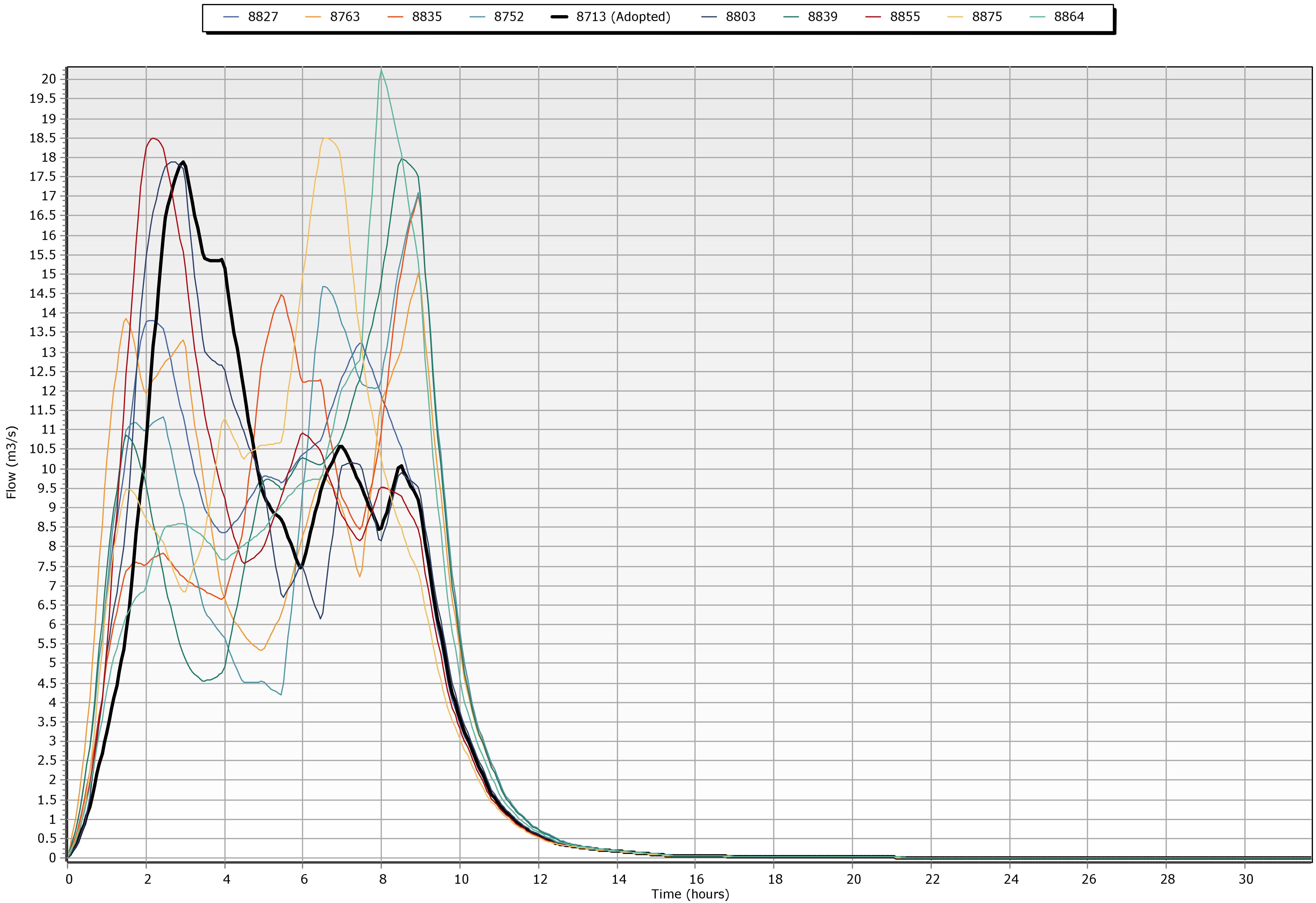
8893
3325
8894
Flow (m3/s)
Time (hours)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4
6.6
6.8

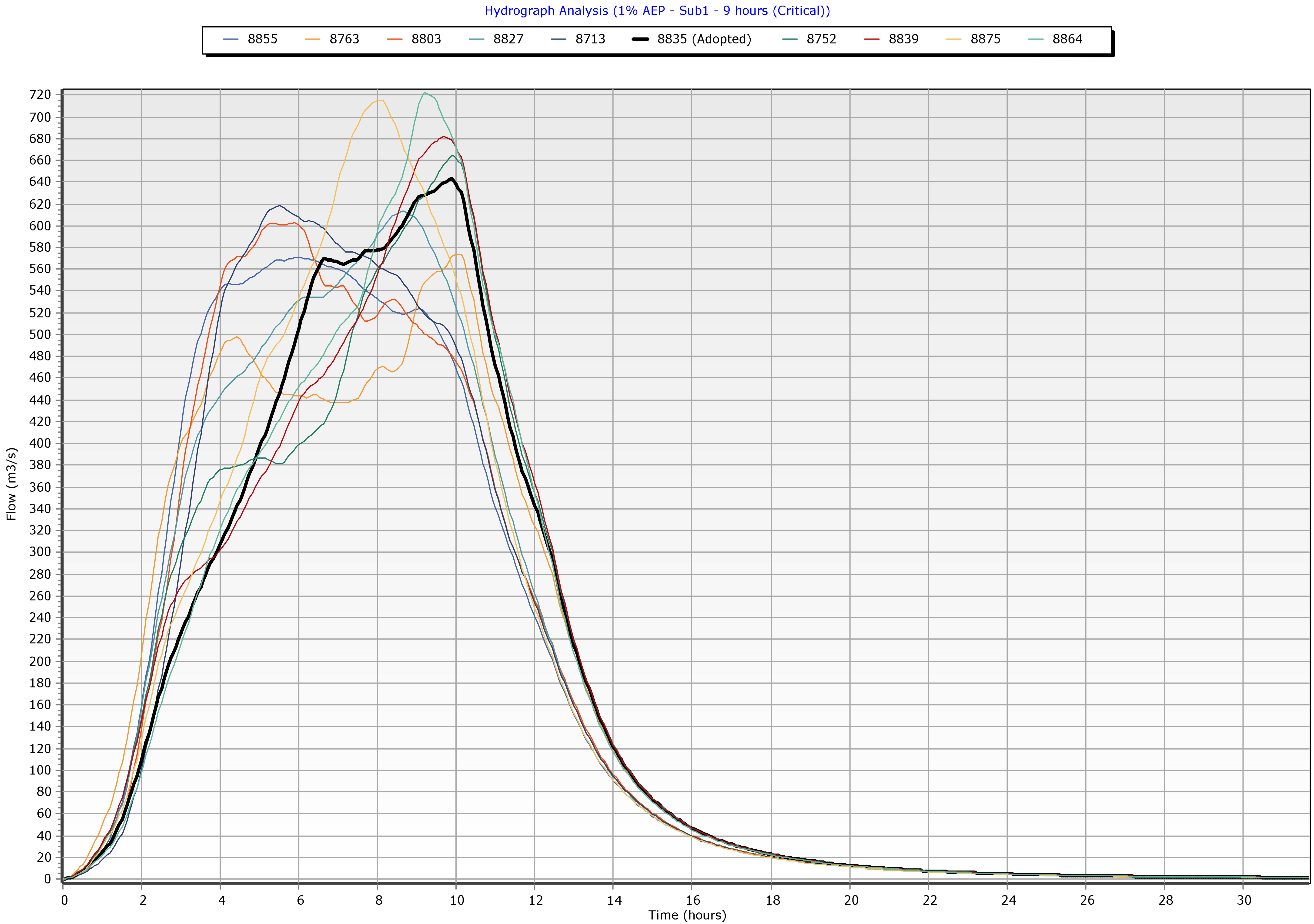


Hydrograph Analysis (0.5EY - Sub1 - 9 hours (Critical))
8886
5513
8892
3369
8889
8891 (Adopted)
3325
5555
8893
8894
Flow (m3/s)
Time (hours)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30


Hydrograph Analysis (0.2EY - Sub1 - 9 hours (Critical))
5513
8892
8886
3369
8889
8891 (Adopted)
8893
5555
3325
8894
Flow (m3/s)
Time (hours)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Hydrograph Analysis (2% AEP - Sub100 - 9 hours (Critical))





Hydrograph Analysis (1% AEP - Sub1 - 9 hours (Critical))
8855
8763
8803
8827
8713
8835 (Adopted)
8752
8839
8875
8864
Flow (m3/s)
Time (hours)