Independent Review of Ross River Flooding, February 2019

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Abbreviations

Abbreviation	Meaning
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AMTD	Adopted Mean Thread Distance
ANCOLD	Australian National Committee on Large Dams
AOC	Area Operations Centre MA Media Advisor (SunWater)
AOM	Area Operations Manager (SunWater)
BoM	Bureau of Meteorology
CCE	Chief Civil Engineer (SunWater)
CEO	Chief Executive Officer
CRM	Corporate Relations Manager (SunWater)
DCF	Dam Crest Flood
DCL	Dam Crest Level
DCS	Department of Community Safety
DDC	District Disaster Coordinator
DDMG	District Disaster Management Group
DDO	Dam Duty Officer (SunWater)
DDS	Director Dam Safety (SunWater)
DEWS	Department of Energy and Water Supply
DMA	Disaster Management Arrangements
DNRME	Department of Natural Resources, Mines and Energy
DS	Dam Safety Standards
DSG	Dam Safety Group
DSR	Dam Safety Regulator
EAP	Emergency Action Plan
EEC	Emergency Event Coordinator (SunWater)
EER	Emergency Event Report
EL	Elevation Level
EMA	Emergency Management Australia
EMQ	Emergency Management Queensland
FOC	Flood Operations Centre
FOCC	Flood Operations Centre Coordinator (SunWater)
FOO	Flood Operations Officer (SunWater)

FSL	Full Supply Level
LDMG	Local Disaster Management Group
LDMP	Local Disaster Management Plan
MAM	Manager Asset Management (SunWater)
O&M	Operation & Maintenance
PAR	Population At Risk
PEDS	Principal Engineer Dam Safety
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RDMG	Relevant Disaster Management Group
SDF	Sunny Day Failure
SDMG	State Disaster Management Group
SES	State Emergency Service
SHD	State Height Datum
SMS	Special Message Service
SOP	Standing Operating Procedure
TCC	Townsville City Council
WHS	Workplace Health & Safety

1 Introduction

1.1 Introduction

During late January and into early February 2019 a monsoon trough and slow-moving low-pressure system was located over the Townsville Region, causing heavy and prolonged rainfall. A series of high intensity rainfall events occurred throughout the period from 27 January to 6 February 2019 causing saturation of the ground, water level rises within watercourses and inundation across several parts of Townsville.

Water levels in the Ross River Dam rose from 36.95m AHD (65% of full supply volume) at the start of the event to the full supply level of 38.55m AHD by 12:35pm on Wednesday 30 January 2019. Once full supply level had been reached, the dam gates started to open in automatic mode as per the operational rules for the dam.

The dam gates progressively opened in response the further water level rises until the gates were fully open at 8:32pm on Sunday 3 February. The water level in the dam peaked at 43.03m AHD at 11:50pm on Sunday 3 February, releasing 1,888m^3/s of water into the Ross River. Major flooding occurred along the Ross River throughout Saturday, Sunday and Monday, with water levels in the Ross River easing by Tuesday 5 February.

Throughout the event, the dam gate operation was switched from automatic to manual operation four times following direction from Townsville City Council to reduce the risk to the downstream community.

The Inspector-General Emergency Management (IGEM) has committed to delivering a report to Minister Craig Crawford, Minister for Fire and Emergency Services, identifying lessons that will inform continuous improvement in Queensland Disaster Management Arrangements.

IGEM has commissioned BMT to assess the performance of the Ross River Dam in the lead-up to, and during, the late January/early February 2019 flood event and the impact the dam's operations had on flooding downstream of the Dam.

1.2 Scope of Works

The scope of works associated with this technical review includes:

- ***An assessment of the inflows and outflows from Ross River Dam for the event and an assessment of the Annual Exceedance Probability (AEP) of the event. An assessment of tributary inflows downstream of Ross River Dam.***

  Data and models have been collected from the Bureau of Meteorology (BoM), SunWater and Townsville City Council to estimate the inflows and outflows from the Ross River Dam. The AEP of the rainfall, dam release and subsequent flooding has been assessed using intensity-frequency-duration data published by the BoM, documentation on dam releases from SunWater and Council, and flood mapping prepared by Council. All data sources have been reviewed for consistency and applicability.

  Tributary inflows have been estimated downstream from the Ross River Dam using hydrologic and hydraulic models developed for this assessment.

- ***An assessment of the possible flooding impacts on communities downstream of the dam:***
  - ***If the Dam was not in existence***
  - ***If Dam was operated in accordance with standard operating procedures and specifications and the relevant aspects of the Ross River Dam Emergency Action Plan (EAP)***
  - ***As operated during the flood event***
  - ***If dam release had occurred earlier***

  Event timelines are presented covering the period from the first warning of a potential event, through to the receding of flood waters. The following timelines are provided:

  - timing of rainfall and flooding; and
  - timing of gate operations.

  The timelines have been analysed to determine:

  - whether operation of the dam was compliant with the specifications;
  - any actions (within the existing operating procedures) that could have been taken to reduce the impact of flooding; and
  - any actions (outside of the existing operating procedures) that could have been taken to reduce the impact of flooding.

  The above scenarios have been assessed to identify the impact that the Ross River Dam release had on flooding downstream, and how that flooding may have been different under different hypothetical scenarios.

- ***A report on the outcomes of the assessments which includes details of the:***
  - ***Methodologies applied in undertaking the assessment***
  - ***Data which was incorporated into the assessment***
  - ***Results and conclusions of the assessment and the facts and evidence on which these conclusions were based.***

  This report addresses all listed requirements including data collation and review, hydrologic and hydraulic analysis, flood mapping, review of operations, and recommendations. Options have been considered where potential changes to the dam operation would have resulted in reduced flooding or improved response during the February 2019 event.

1.3 Description of Area

1.3.1 Catchment

The Ross River drains a catchment of approximately 905km^2, flowing through the City of Townsville and discharging into the ocean. Approximately 761km^2 of the upper catchment area drains into the Ross River Dam. Refer to Figure 1-1 for locality and Figure 1-2 for catchment extents.

From the dam, the Ross River follows a northerly path for 10km. After passing the Ring Road bridge at the suburbs of Condon and Douglas, the river turns in an easterly direction, reaching Black Weir a further 1km downstream. Black Weir is the first of three weirs constructed to maintain permanent water levels along the river. A further 1km downstream is Gleesons Weir.

The Nathan Street (Bruce Highway) Bridge is located between Gleesons Weir and Aplin's Weir, 11.5km upstream from the river mouth. Aplin's Weir represents the tidal limit along the Ross River. From Aplin's Weir, there are a further three bridges; Bowen Road Bridge, Rooney's Bridge and Southern Port Road Bridge.

Downstream from the dam, the catchment is narrow, with natural and manmade banks along the left bank (looking downstream). In large flood events, upstream from Black Weir floodwaters are expected to overtop the banks and flow into the adjacent Bohle River catchment. Downstream from the Nathan Street (Bruce Highway) Bridge, floodwaters spill from the Ross River into Louisa Creek, and Ross Creek via the left bank. On the right bank, floodwaters spill from the Ross River into Gordon Creek, although return to the Ross River downstream from Rooney's Bridge. Flow behaviour is discussed in Section 5.

Tributaries of the Ross River, downstream from the dam are:

- **Gordon Creek -** draining into the Ross River between Rooney's Bridge and Southern Port Road Bridge, near the river mouth. The total catchment area is 19km^2, draining the suburbs of Idalia and Wulguru, and parts of Oonoomba, Cluden, Murray, Annandale and Stuart. The Stuart Creek catchment receives water from the Ross River as water spills from the Ross River upstream from Bowen Road Bridge.
- **Stuart Creek -** draining into the Ross River downstream from the Gordon Creek confluence. The total catchment area is 63.9km^2, draining the suburbs of Julago, Brookhill, Oak Valley, Roseneath, Stuart and Cluden.

Adjacent catchments that are affected by large flood events in the Ross River are:

- **Bohle River** – the Bohle River drains most of the western suburbs of Townsville, flowing in a northerly direction.
- **Louisa Creek** – draining into the Bohle River near the river mouth, the upper reaches of Louisa Creek drain the suburb of Heathley and parts of Vincent and Garbutt.
- **Ross Creek** – located immediately to the north of the lower Ross River, Ross Creek flows through the Townsville CBD. In extreme events, water breaks out of the Ross River and flows into the Ross Creek catchment in several locations.

Figure 1-1 Locality map

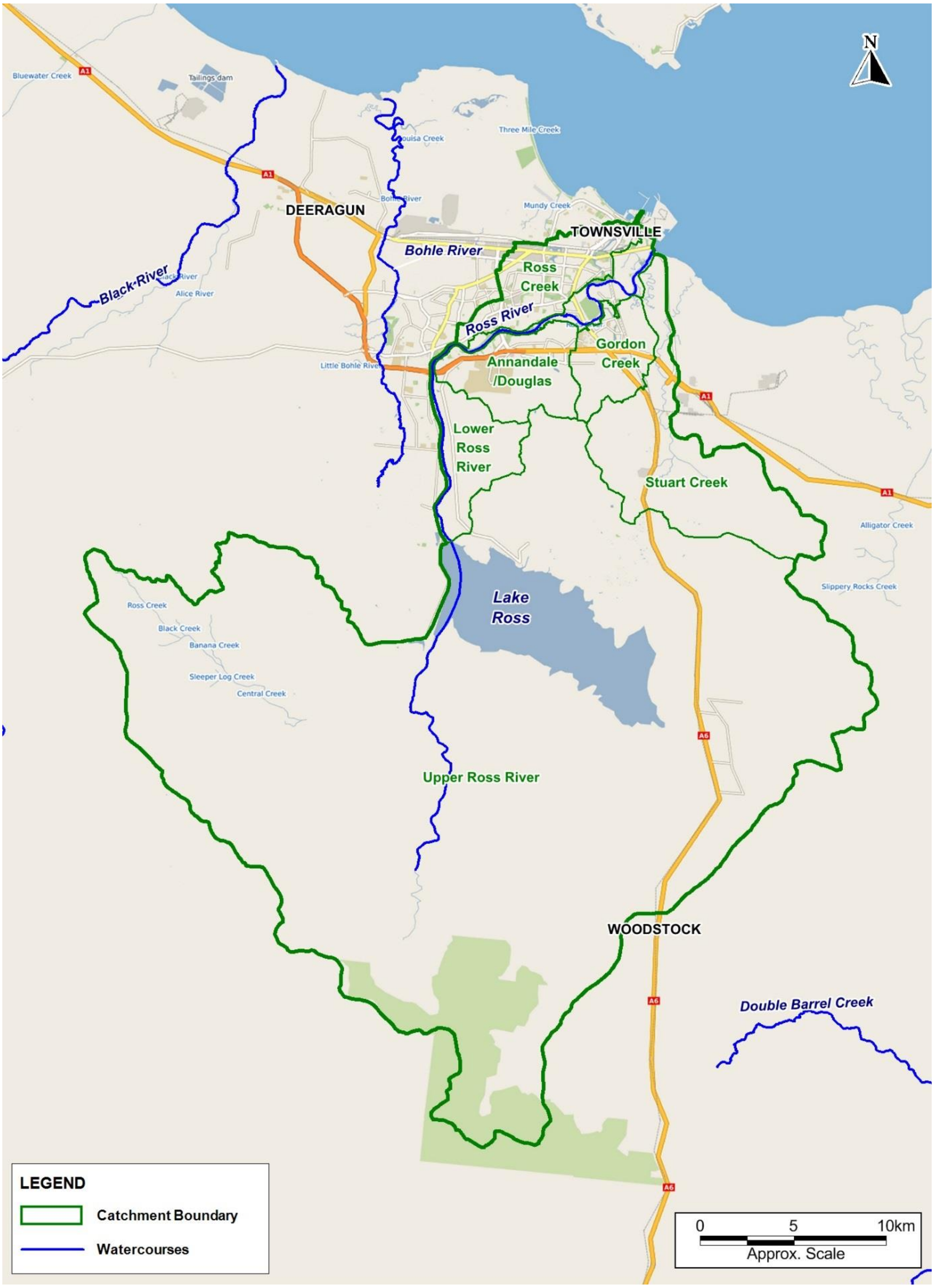

Figure 1-2 Catchment plan

1.3.2 Ross River Dam

Ross River Dam is located on the Ross River 26.4km upstream from the mouth, approximately 19km to the southwest of the Townsville CBD. The dam's primary function is a water supply facility for Townsville, with secondary function as flood mitigation. Ross River Dam is not prescribed as a flood mitigation dam under the Water Supply (Safety and Reliability) Act 2008.

The Dam has a catchment area of 761km^2 and a storage of 233,187 megalitres (ML) at the full supply level of 38.55m AHD. The catchment area accounts for 84% of the total Ross River catchment.

Refer to Section 3 for description of the dam and gate operation.

1.4 Roles and Responsibilities

The roles and responsibilities associated with dam operation prior to, during and following a flood event are listed in the *Emergency Action Plan* (SunWater, 2018). The roles and responsibilities of key personnel within SunWater and external agencies are listed in the tables below (extract from EAP, 2018).

Table 1-1 Roles and responsibilities

Role and Responsibilities	Position Holder[1]
Operator's (SunWater) Head Office Representative • Authorise the issuing of EAPs, SOPs and O&M Manuals and Amendments • Facilitate Dam Safety Training Courses for Service Managers, Operations Supervisor, Dam Operators and other staff as appropriate and ensure that all staff required to undertake Dam Safety work are trained and accredited • Ensure that risks identified in CRAs or other technical reports undertaken in relation to Dam Safety are Included in the EAP • Ensure visual inspections and instrumentation monitoring frequencies conform to ANCOLD Guidelines • Ensure all Dam Safety work orders, work instructions and lesson learned outcomes are fully implemented • Ensure requirements of the Dam Condition Schedule are met • Ensure the work instructions are correct and the Log Books, SOPs, Data Books, and EAPs are reviewed annually as per the Condition Schedule • Undertake and prepare the 5 yearly Comprehensive Inspection Reports with suitably qualified personnel within the time specified in the Condition Schedule and that work orders are created for recommendations and work is undertaken as required • Undertake Annual Inspections and prepare reports within the time frames specified in the Condition Schedule and that work orders are created for recommendations and work is undertaken as required • Review the Dam Safety Instrumentation Database and evaluate data to verify the structural integrity of the dams on a regular basis and maintain a spread sheet for verification for audit and quality control • Record communications, notifications and observations as required	Dam Safety Program Engineer (DSPE) Senior Dam Safety Engineer (SDSE) Chief Dams Engineer (CDE) General Manager Water Resources & Dam Safety (GMWR&DS)

[1] May be undertaken by one person, or jointly between the following personnel, depending on availability and/or dam hazard

Role and Responsibilities	Position Holder[1]
Operator's (SunWater) Regional Representative (SRR) • Liaise with the Storage Supervisor/Operator Maintainer • Arrange dam specific training and accreditation for relevant staff • Ensure competent, trained and accredited personnel operate the storages • Undertake the role of LEC as required • Record communications, notifications and observations as required • Ensure all work orders, work instructions and lesson learned outcomes are fully implemented.	General Manager North Queensland (GMNQ) Operator Maintainer (OM)
Technical Advisor • Analyse the situation and provide expert technical advice • Discuss issue with peers and other technical experts and make sound decisions to mitigate the risk • Determine response to incidents and emerging issues • Record communications, notifications and observations as required	Manager Environment & Water Planning (MEWP)
Water Operations Engineer (Dam Owners representative) • Approve the suite of Dam Safety Management Standards after review and recommendation by the Operator's Head Office Representative • Approve funding for the Regional Operations Centre's (ROC) 'Dam Safety Management Programs' • Approve the EAP • Liaise with the Dam Safety Regulator, and Minister • Ensure necessary responses are available to fully implement the Dam Safety program	Manager Environment & Water Planning (MEWP)
Dam Safety Technical Decision Maker (DSTDM) • Analyse the situation and provide expert technical advice in relation to Dam Safety • Discuss Dam Hazard with peers and other technical experts and make sound decisions to mitigate the risk • Determine response to incidents and emerging issues • Issue warning on dam failure and advise on protective measures • Ensure the EAP is implemented appropriately and carry out the DSTDM role as required • Maintain current RPEQ accreditation • Liaise with Regulator as required • Record communications, notifications and observations as required	Various personnel as per DSTDM roster
Flood Operations Decision Maker (FODM) • Provide hydrological advice in relation to predicted and actual dam outflows • Ensure model outputs are checked and approved • Ensure the EAP is implemented appropriately and carry out the FODM role as required • Record communications, notifications and observations as required	Various personnel as per FODM roster

Role and Responsibilities	Position Holder[1]
Operations Centre (OC) – data collector • Decide if a flood is imminent and record modes of operation • Extract data relative to the event from available sources • Utilise this data in predictive flood models and determine results from these models for approval by FODM • Liaise with the FODM or IC to update current flood situation and routing data • Record communications, notifications and observations as required	Various personnel as per OC roster
Incident Coordinator (IC) • Notify council of intent to use the Emergency Alert (EA) • Activate the EAP • Ensure the EAP is implemented appropriately and carry out the IC role as required • Arrange Situation Reports and determine frequency, as required • Record communications, notifications and observations as required	Various personnel as per IC roster
Local Event Coordinator (LEC) • Liaise with the Local Disaster Coordinator or proxy • Activate the EAP, when necessary • Ensure the EAP is implemented appropriately and carry out the LEC role as required • Record communications, notifications and observations as required	Various personnel as per LEC roster
Dam Duty Officer (DDO) • Complete accreditation to operate and maintain relevant storage • Ensure the EAP is implemented appropriately and carry out the DDO role as required • Take direction from the DSTDM and IC as requested • Arrange immediate site inspection and make informed assessment of the situation • Escalate any issue not covered in the EAP or where actions are not clear • Record communications, notifications and observations as required	Senior Operator Maintainer (SOM) Storage Supervisor (SS) Operator Maintainer (OM)

Table 1-2 Roles and responsibilities of external agencies

Role and Responsibilities	Position Holder[2]
Townsville City Council Technical Decision Maker (TDM) • Liaise with SunWater DSTDM and make any necessary decisions relating to dam operational matters during times when this document is triggered, including during the period in the lead up to events • Provide a 24/7 contact	TDM
Townsville City Council	

[2] May be undertaken by one person, or jointly between the following personnel, depending on availability and/or dam hazard

Role and Responsibilities	Position Holder[2]
Council has legislated local government functions, as per Section 80 of the Qld Disaster Management Act (2003). These include: • Ensure it has a disaster response capability • Approve its local disaster management plan • Ensure information about an event or a disaster in its area is promptly given to the district disaster coordinator for the disaster district in which area it is situated • Perform other functions given to the local government under the Act • Must assess (in consultation with its LDMG) the EAP for consistency with the Local Disaster Management Plan	
Disaster Management Groups/Personnel - (In addition to requirements outlined in the Qld. Disaster Mgmt. Act 2003). The agreement of the below is sought through the review and approval of this document. LDMG • Assist SunWater and the Townsville City Council to ensure community education around messaging and impacts of EAP related events is undertaken and continually improves • Work with Townsville City Council and SunWater to ensure the EAP is regularly exercised • Identify and coordinate the use of manpower and resources that may be required for an EAP event • Identify and provide advice to DDMG about support services required by the LDMG to manage an EAP event • Provide reports and make recommendations to the relevant DDMG about matters relating to EAP events and any support required QFES • Work with Dam Owner and LDMG to ensure Emergency Alerts polygons are prepared, stored and tested DDMG • DDMG may review plan with consistency with the District Disaster Management Plan • Ensure the communication provided under this EAP is consistent with the District Disaster Management Plan	Local Disaster Management Group (LDMG) District Disaster Management Group (DDMG) Queensland Fire & Emergency Services (QFES)
Dam Safety Regulator (DSR) • Liaise with relevant Minister on necessary actions. • Approve this document as required under legislation • Liaise with chief executive as required in administering (regulating) the Water Supply (Safety and Reliability) Act 2008	Director Dam Safety (DDS)

2 Review of Documents and Data

2.1 Documents

Documents are presented in chronological order of their publication. Much of the text provided in this Section has been directly extracted from the relevant document. Copied text is presented in italics.

2.1.1 Ross River Flood Study Base-line Flooding Assessment (Townsville City Council, 2013)

This study assesses flows within the Ross River catchment, upstream and downstream from the dam, and presents flood mapping along the Ross River downstream from the dam, for a range of design flood events.

The following models were developed, based on models produced for previous studies:

- Hydrology:
  - RORB model upstream of the dam, calibrated to the December 2010, January 2009, February 2007 and January 1998 flood events.
  - XP-RAFTS model downstream of the dam, verified against hand calculations.
- Hydraulic:
  - MIKE FLOOD coupled one and two-dimensional model, calibrated to the December 2010, January 2009 and February 2007 flood events.

Design flood mapping was prepared for the 2, 5, 10, 20, 50, 100, 200, 500, 1000 and 2000 year average recurrence interval (ARI) events and the Probable Maximum Flood (PMF).

Peak flood level grids have been provided by Council for this assessment and are mapped in the following figures for design floods that are relevant to this review of the February 2019 event:

- Figure 2-1 – 1% Annual Exceedance Probability (AEP) / 100 year ARI
- Figure 2-2 – 0.5% AEP / 200 year ARI
- Figure 2-3 – 0.2% AEP / 500 year ARI
- Figure 2-4 - -0.1% AEP / 1,000 year ARI

The study references the *Ross River Dam Upgrade Stage 2 to 5 – Hydrology Study* (SKM, 2005), tabulating peak water levels and outflows from the dam for a range of design events. Peak water levels and outflows are listed here in Table 2-1.

Table 2-1 Ross River Dam peak water levels and outflows (extract from Table 2-5 from the Ross River Flood Study Base-line Flooding Assessment)

AEP	ARI (years)	Peak water level (m AHD)	Peak outflow (m3/s)
20%	5	39.8	260
10%	10	40.2	370
5%	20	40.7	490
2%	50	41.3	820
1%	100	41.6	1,280
0.5%	200	42.0	1,540
0.2%	500	42.7	1,790
0.1%	1,000	43.2	1,960
0.05%	2,000	43.8	2,180
0.02%	5,000	44.5	2,440
0.01%	10,000	45.1	2,670
0.005%	50,000	46.4	3,220
0.001%	100,000	46.9	3,580
	500,000	47.8	4,550
	1,000,000	48.1	5,020
	1,300,000	48.3	5,230

The report also references the *Ross River Dam Upgrade Stages 2 to 5 – Design Validation* (GHD & MWH, 2005), where peak water levels for different design events are presented against different initial dam water levels. Refer to Table 2-2 for tabulated water levels.

Table 2-2 Ross River Dam peak water levels (extract from Table 2-6 from the Ross River Flood Study Base-line Flooding Assessment)

AEP (%)	ARI (years)	Initial dam level (m AHD)					
		25.0m	30.0m	32.0m	34.7m	37.0m	38.55m
20%	5	36.1	37.3	38.1	38.8	39.6	40.3
10%	10	38.5	38.7	38.8	39.3	40.0	40.6
5%	20	39.3	39.4	39.5	39.9	40.5	40.6
2%	50	40.0	40.1	40.3	40.6	41.1	41.5
1%	100	40.7	40.7	40.9	41.2	41.5	41.7
0.5%	200	41.4	41.4	41.5	41.6	41.8	42.1
0.2%	500	41.8	41.9	42.0	42.2	42.4	42.7
0.1%	1,000	42.4	42.4	42.5	42.7	42.9	43.3
0.05%	2,000	43.0	43.0	43.0	43.2	43.5	43.8
0.02%	5,000	43.8	43.8	43.8	44.0	44.2	44.5
0.01%	10,000	44.4	44.5	44.4	44.6	44.8	45.1
0.005%	50,000	45.8	45.9	45.9	46.1	46.2	46.4
0.001%	100,000	46.3	46.4	46.4	46.6	46.7	46.9
	500,000	47.4	47.4	47.5	47.5	47.6	47.8
	1,000,000	47.8	47.8	47.8	47.9	48.0	48.1
	1,300,000	47.9	47.9	47.9	48.0	48.1	48.3

The adopted peak outflows from the dam are listed in Table 2-3.The outflows presented are based on revised gate operations. Peak water levels do not differ from those presented in Table 2-2.

Table 2-3 Ross River Dam adopted peak outflows (extract from Table 3-11 from the Ross River Flood Study Base-line Flooding Assessment)

AEP (%)	ARI (years)	Peak outflow (m3/s)
50%	2	238
20%	5	367
10%	10	435
5%	20	571
2%	50	656
1%	100	745
0.5%	200	960
0.2%	500	1,777
0.1%	1,000	1,985
0.05%	2,000	2,146
PMF	PMF	4,268

The number of affected properties for different design events are listed in Table 2-4.

Table 2-4 Ross River affected properties (extract from Table 5-4 from the Ross River Flood Study Base-line Flooding Assessment)

AEP (%)	ARI (years)	Affected properties
50%	2	0
20%	5	0
10%	10	0
5%	20	27
2%	50	28
1%	100	90
0.5%	200	105
0.2%	500	2,260
0.1%	1,000	3,210
0.05%	2,000	4,280
PMF	PMF	13,250

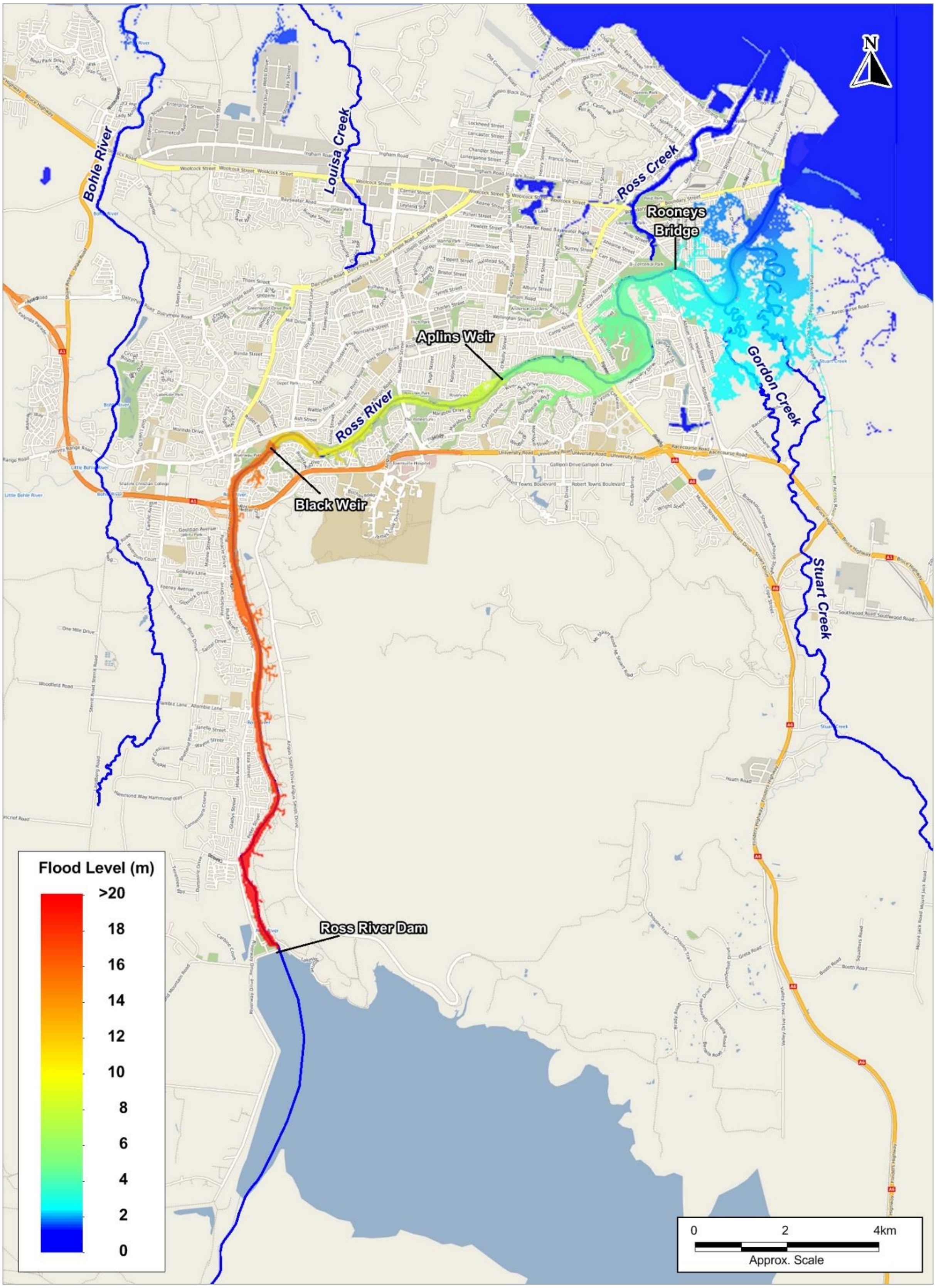

Figure 2-1 Ross River 1% AEP peak flood levels (source: Ross River Flood Study, 2013)

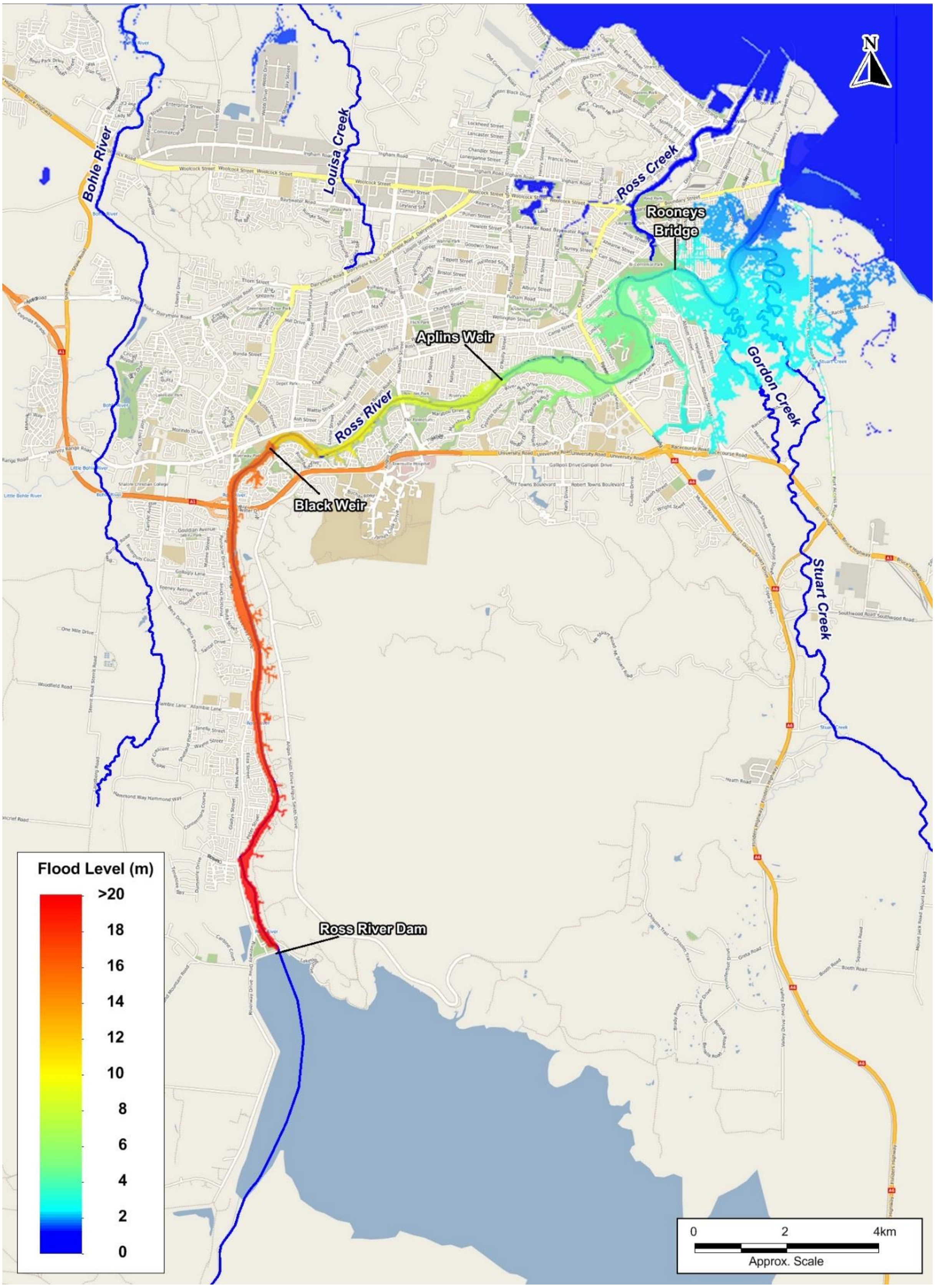

Figure 2-2 Ross River 0.5% AEP peak flood levels (source: Ross River Flood Study, 2013)

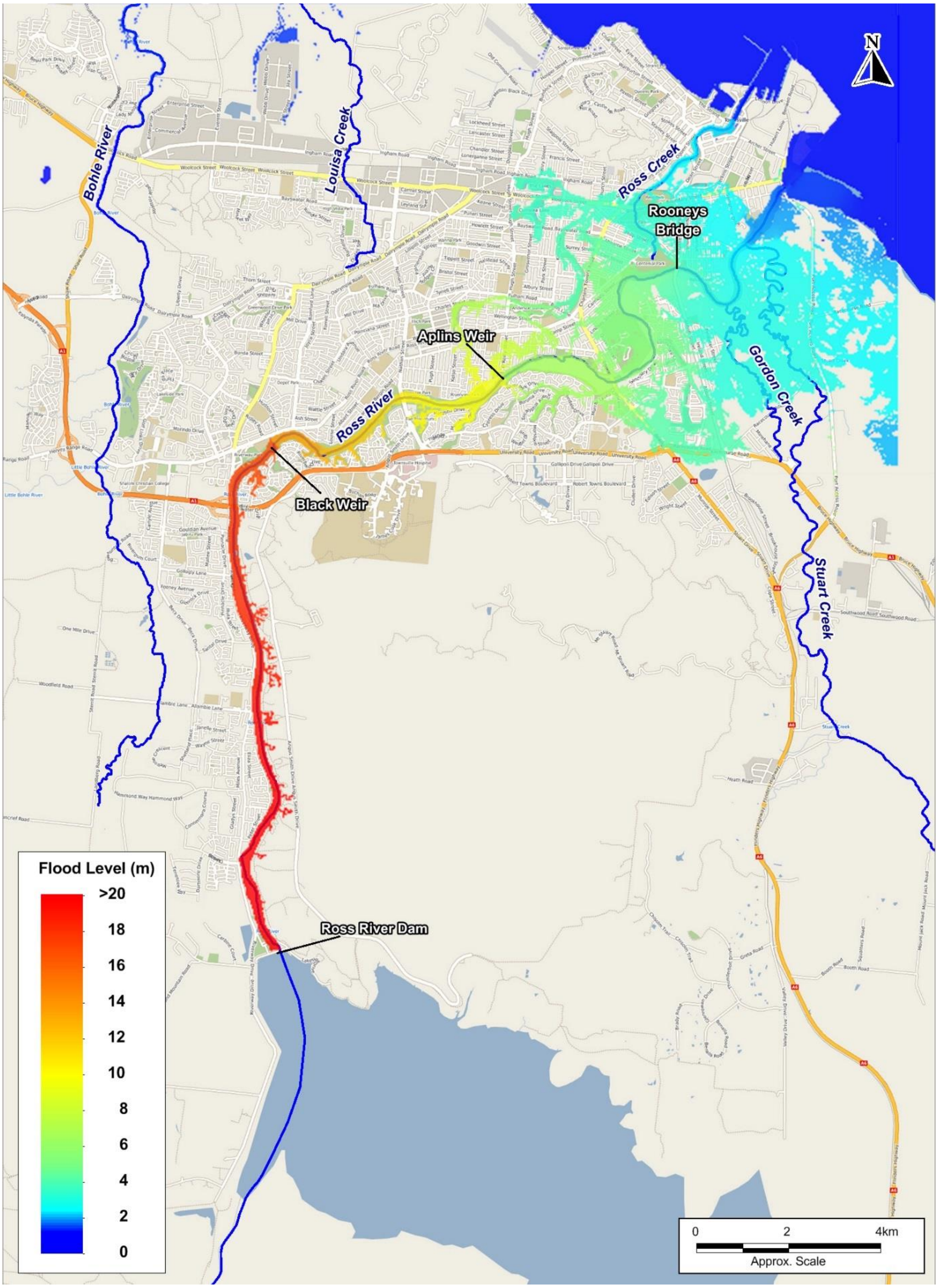

Figure 2-3 Ross River 0.2% AEP peak flood levels (source: Ross River Flood Study, 2013)

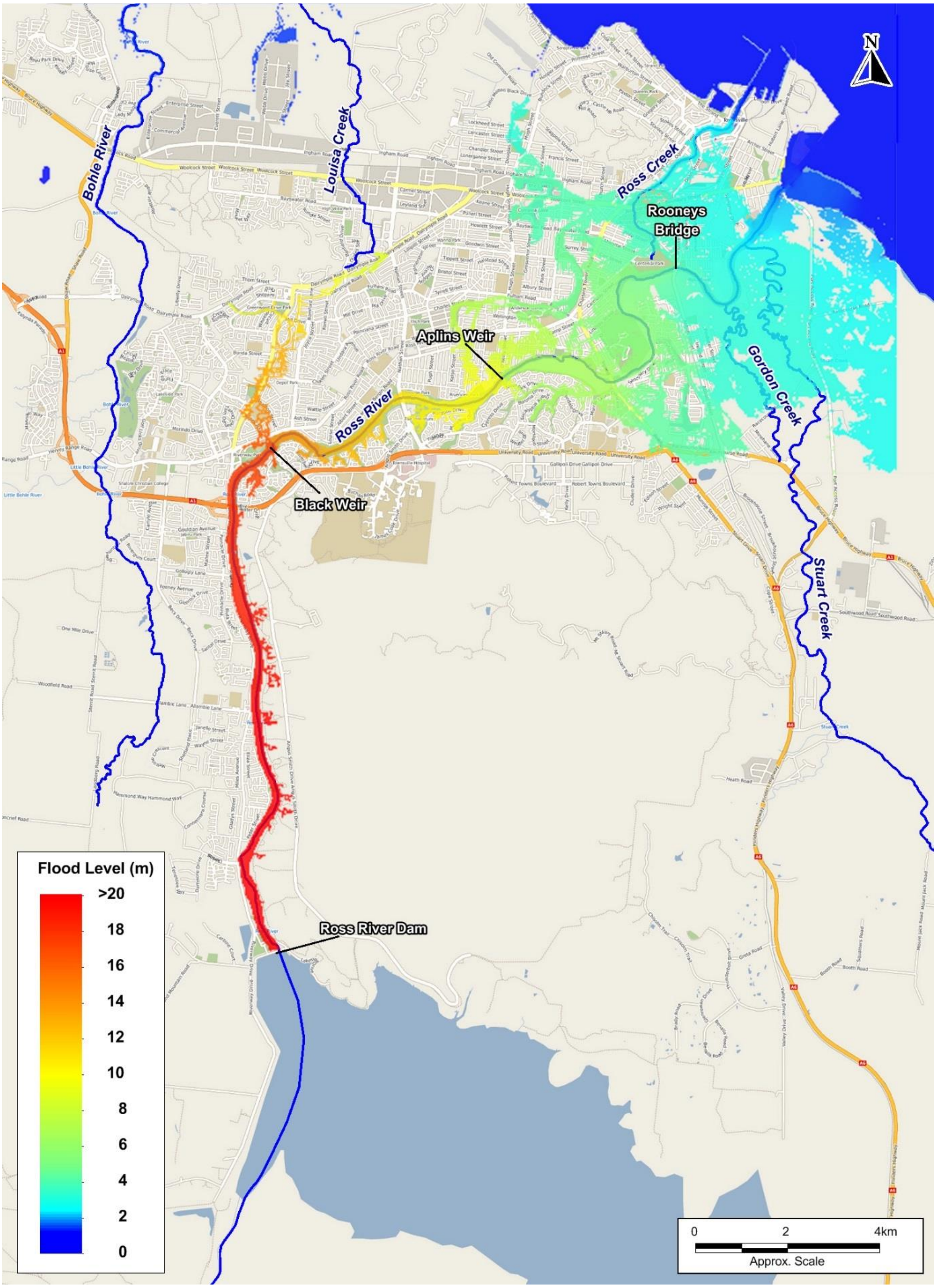

Figure 2-4 Ross River 0.1% AEP peak flood levels (source: Ross River Flood Study, 2013)

2.1.2 Gordon Creek Flood Study – Baseline Flooding Assessment (Townsville City Council, 2014)

This study assesses the flooding in Gordon Creek focussing on rainfall in the local catchment (i.e. not due to breakout of flows from the Ross River). The study used the latest LiDAR topographic survey for modelling on a higher resolution (10m grid size) than the broader Ross River model. A MIKE FLOOD coupled one and two-dimensional model was developed, calibrated to the January 1998 and February 2002 flood events.

Design flood mapping was prepared for the 2, 5, 10, 20, 50, 100, 200 and 500 year average recurrence interval (ARI) events and the Probable Maximum Flood (PMF).

2.1.3 Emergency Action Plan – Ross River Dam (SunWater, March 2018)

The purpose of the Emergency Action Plan (EAP) is to:

- *minimise the risk of harm to persons or property if a dam hazard event or emergency event for the dam happens;*
- *identify dam hazards that could occur at Ross River Dam and the area likely to be affected for each hazard; and*
- *prescribe emergency actions taken by the dam owners and operating personnel in identifying and responding to dam hazards and notifying relevant entities.*

The Incident Coordinator (IC) is responsible for the decision to activate the EAP. Should the IC be unavailable, the Local Event Coordinator (LEC) is responsible for the decision.

The following levels of EAP activation are consistent with the Queensland Disaster Management Arrangements. The four levels of activation are:

- **Alert –** A heightened level of vigilance due to the possibility of an event occurring. No further action may be required, however the situation should be monitored by someone capable of assessing the potential of the threat. Moving to an Alert level indicates the dam owner is getting ready to activate the Lean Forward level of the EAP if the situation deteriorates.
- **Lean forward** - An operational state characterised by a heightened level of situational awareness of an impending disaster event and a state of operational readiness. Disaster coordination centres are on stand-by and prepared but not activated.
- **Stand up** – The operational state where resources are mobilised, personnel are activated and operational activities commenced. Disaster coordination centres are activated. The dam owner needs to provide an ‘Emergency Event Report’ in accordance with the provision of the Act.
- **Stand down** - Transition from responding to an event back to normal core business and/or continuance of recovery operations. There is no longer a requirement to respond to the event and the threat is no longer present.

The movement of dam owners through these levels of activation is not necessarily sequential. It should be applied with flexibility and adaptability and be tailored to the location and event.

The triggering of one of these levels of activation may not necessarily mean a similar activation of relevant disaster management groups. However, the provision of information to relevant group members regarding the risks associated with a pending hazard impact should still occur.

Table 2-5 Flood event emergency activation trigger summary

Activation Level	Trigger
Alert	EL 38.45m and rising (0.1 m below FSL)
Lean Forward	Storage EL 38.65m (gate opening trigger level)
Stand-up – greater than flood of record	Storage above EL 40.73m (flood of record 2012)
Stand Up—2	Storage EL 41.00m and rising (accelerated gate opening sequence)
Stand Up—3	Storage EL 42.50m PLL for no failure flow rate or 900m^3/s (all gates fully open at EL 43.00m)
Stand Up—4	Storage EL 43.60 or flow rate 2100m^3/s
Stand Up—5	Dam failure extremely likely
Stand-down	Storage level FSL 38.55m and falling

2.1.4 2019 Monsoon Trough Rainfall and Flood Review – SunWater Submission to Inspector-General Emergency Management (SunWater, 2019)

If the dam activation level enters Stand-up mode during an event, an Emergency Event Report (EER) is required to be prepared and submitted following the event. This EER was prepared by SunWater following the February 2019 event. The EER contains the following:

- Overview of the dam;
- Dam owner and operator;
- Regulatory framework;
- Summary of responsibilities;
- Flood mitigation vs attenuation;
- Gate studies;
- Monsoon flood event summary;
- Timeline of event and actions;
- Preparedness;
- Modelled scenarios; and
- Lessons learnt and future opportunities.

The relevant content of the SunWater review is referenced throughout this independent review.

Some minor inconsistencies are evident in the timeline presented in Appendix C of the review. The times presented in tabular form in Appendix D of the review are expected to be the correct times. The inconsistencies are only considered to be minor typographical mistakes.

2.1.5 2019 Monsoon Trough Rainfall and Flood Review – Preliminary Topline Results (MCR, 2019)

Following the event, IGEM commissioned Market and Communications Research (MCR) to conduct a survey of flood affected residents. The report summarises responses to 21 questions asked to 400 Townsville residents. A summary of the outcomes is not presented here as the report only represents preliminary findings. Relevant findings will be referenced throughout this independent review.

2.2 February 2019 Event Data

2.2.1 Observations and Forecasts

2.2.1.1 Rainfall Observations

Rainfall observations have been sourced from the BoM for all gauges throughout the Ross River catchment and surrounding areas. Real-time data representing each millimetre of rainfall and the corresponding time is available. This is the highest temporal resolution data available.

Refer to Section 4.2.1 for analysis of rainfall observations.

2.2.1.2 Radar Rainfall Observations

Due to the good spatial distribution of real-time rain gauges around the Ross River catchment, a good spatial representation of rainfall is available for hydrologic modelling. Therefore, radar rainfall estimates have not been sourced for use in this review.

2.2.1.3 Dam and River Level Observations

Dam and river level observations have been sourced from SunWater and the BoM for all gauges throughout the Ross River catchment and surrounding areas.

Refer to Section 4.2 for analysis of dam and river level observations.

2.2.1.4 Rainfall Forecasts

Rainfall forecasts have not been used for this review.

2.2.2 Warnings

2.2.2.1 BoM

The following list summaries the warnings issued by the BoM in relation to flood events:

- Weather Warnings
  - Severe Weather Warning

    'The Bureau of Meteorology issues Severe Weather Warnings whenever severe weather is occurring in an area or is expected to develop or move into an area. The warnings describe

the area under threat and the expected hazards. Warnings are issued with varying lead-times, depending on the weather situation, and range from just an hour or two up to about 24 hours.' (www.bom.gov.au).

- Severe Thunderstorm Warning

  'A Severe Thunderstorm Warning is issued when a severe thunderstorm is reported, or there is strong evidence of a severe thunderstorm, and it is expected to persist.

  Also, Severe Thunderstorm Warning is issued when existing thunderstorms are likely to develop into a severe thunderstorm.

  Severe thunderstorms can be quite localised and develop quite quickly. The exact location of severe thunderstorms can be hard to predict. The warnings are usually issued without much lead-time before the event.' (www.bom.gov.au).

- Flood Warnings
  - Flood Alert, Watch or Advice

    'An Alert, Watch or Advice of possible flooding is issued if flood producing rain is expected to happen in the near future. The general weather forecasts can also refer to flood producing rain.' (www.bom.gov.au)

  - Generalised Flood Warning

    'A Generalised Flood Warning that flooding is occurring or is expected to occur in a particular region. No information on the severity of flooding or the particular location of the flooding is provided.' (www.bom.gov.au).

The BoM provided all flood watches and flood warnings for the February 2019 event.

2.2.2.2 SunWater

Under the EAP, SunWater is not required to notify downstream residents of releases or flooding. This is the responsibility of Townsville City Council.

2.2.2.3 Townsville City Council

Throughout the event, Council notified residents of potential flooding. Communication was undertaken via:

- Social media;
- Council website;
- Media broadcasts;
- Face-to-face (using Council staff, SES and the Army) for issuing evacuation orders.

2.2.3 Telecommunications

The mobile phone network remained operational throughout the event. Some land lines were affected by flood water, although this is not understood to have affected disaster management activities.

2.2.4 Flood Survey

Following the event, Townsville City Council and the Department of Natural Resources, Mines and Energy (DNRME) undertook a flood mark survey, identifying high water marks, ground levels and flood extents. The coverage of the survey is shown on Figure 2-6. The flood level survey is used for model calibration.

2.2.5 Submissions

IGEM received several submissions from the community following the event. All submissions have been reviewed in detail, and relevant content has been used to inform this review.

Figure 2-5 Rain and river gauges

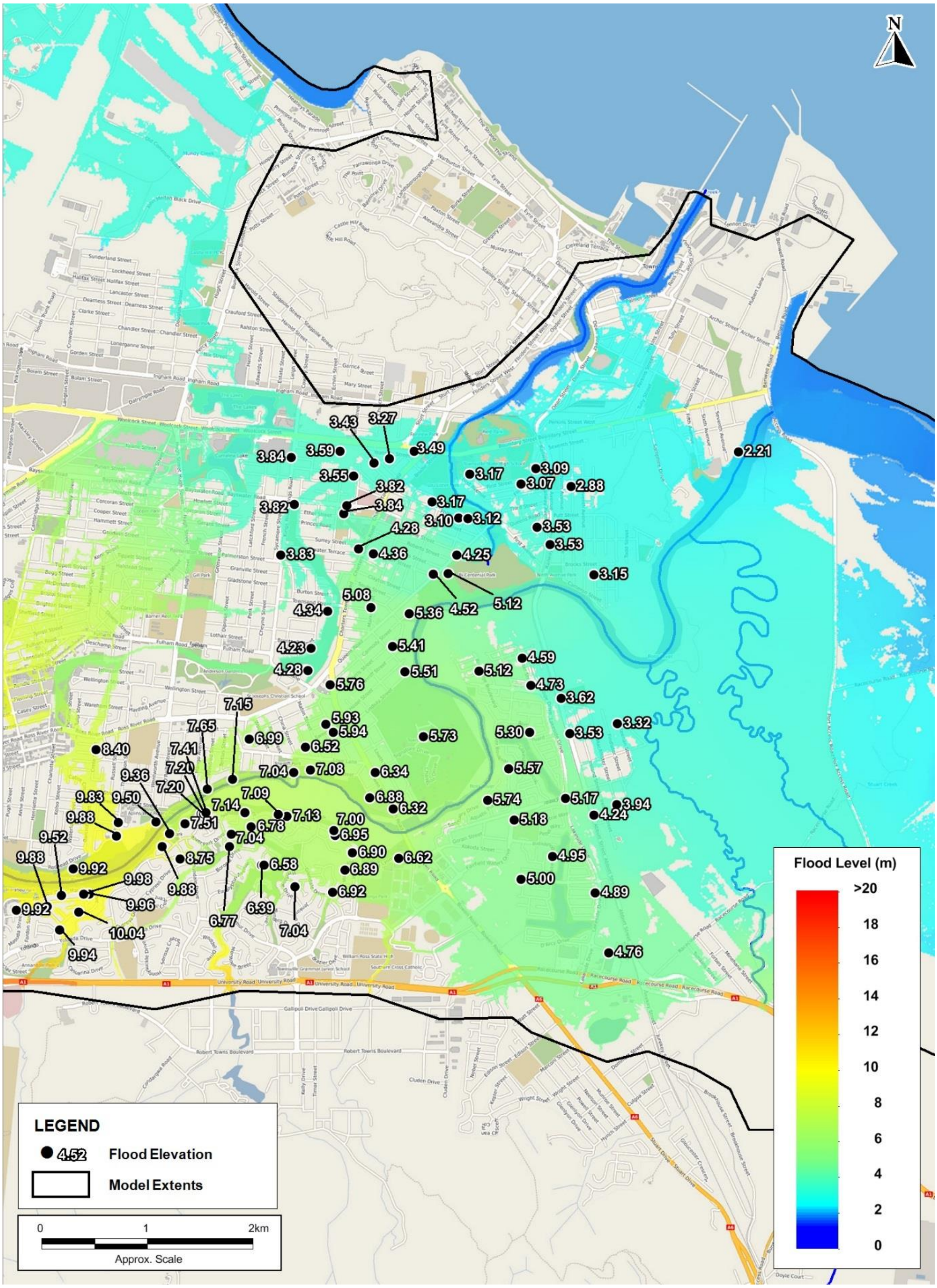

Figure 2-6 Flood mark survey (including indicative flood mapping for the February 2019 event)

3 Dam Description and Operation

3.1 Dam Description

Some statistics regarding the dam are listed below:

- Main Dam Type – Earth core rock-fill
- Full Supply Level (FSL) – 38.55m AHD
- Normal Operating Range – 23.70m - 38.55m
- Storage Capacity at FSL – 233,187 ML
- Storage Area at FSL – 5,690 hectares
- Catchment area – 761km^2
- Embankment Length – 8,400m
- Dam Crest Level – 48.00m AHD
- Height of Dam above downstream toe level – 34.4m (approx.)
- Spillway Crest Level – 34.65m AHD
- Spillway Crest Length – 36.6m
- Gate Trigger Level – 38.65m AHD
- Max. Spillway Capacity – 3,655 m^3/s
- PMF Inflow – 15,800 m^3/s
- PMF Outflow – 3,880 m^3/s.

Figure 3-1 Ross River Dam and spillway gates in operation (source: SunWater, 2019)

3.2 Spillway and Gates

The Ross River Dam was constructed between 1970 and 1974, with an upgrade in 1987 to increase the storage capacity. The dam consisted of a fixed spillway with crest level at 34.656m AHD. When dam water levels rose above the spillway crest, water would have freely flowed over the spillway.

Three radial gates were installed in 2007 allowing the full supply level of the dam to be increased from 38.21m AHD to 38.55m AHD. The two side gates are 11.8m wide and the centre gate is 13.0m wide.

Figure 3-2 Ross River Dam and spillway gates in operation (source: SunWater 2019)

The spillway is assessed to have a capacity of 3,655m^3/s, slightly lower than the PMF discharge of 3,880m^3/s.

3.3 Gate Operation

The gates are operated in one of two ways:

- Automatic operation – the dam gates are automatically operated by hydraulic rams in response the water levels recorded in the dam. The control system is programmed to operate in accordance with the operational rules.
- Manual operation – the gates can be operated manually by overriding the automatic control. Manual control can only be used if directed by Townsville City Council.

The relationship between water level and outflow for rising dam levels and falling dam levels are shown in Figure 3-3 and Figure 3-4. The rapid increase in flow as the water level reaches 43.0m AHD is indicative of the gates being fully open at this water level.

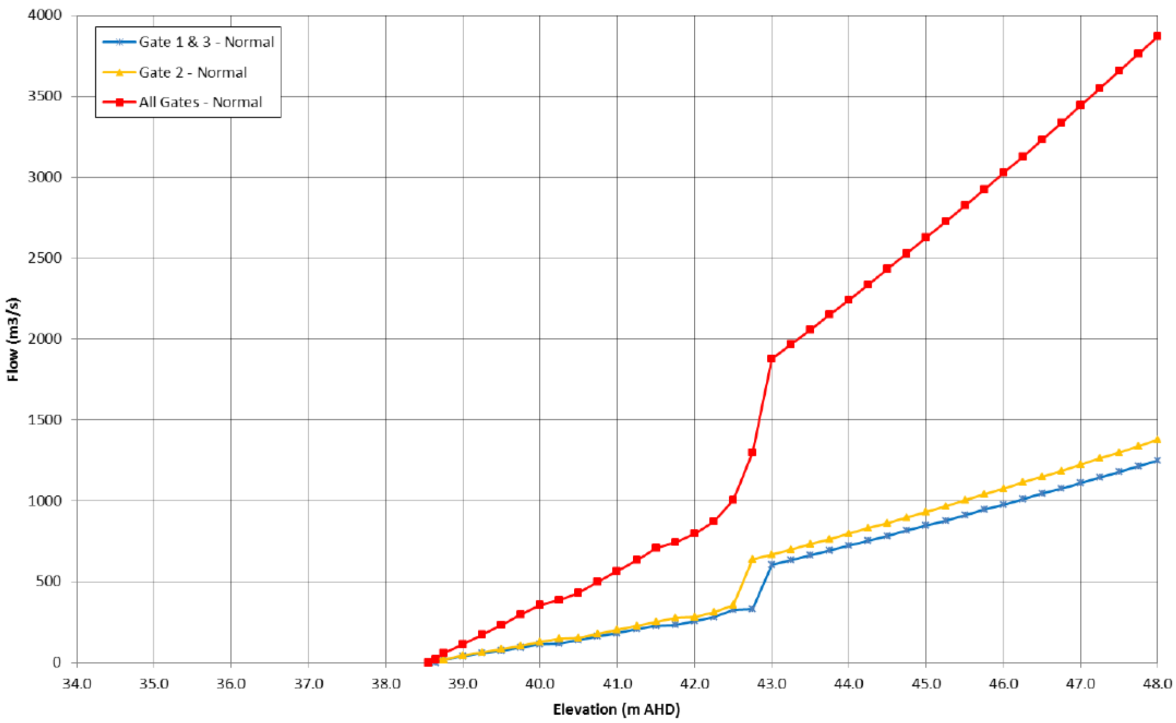

Figure 3-3 Spillway discharge vs water level – rising water level

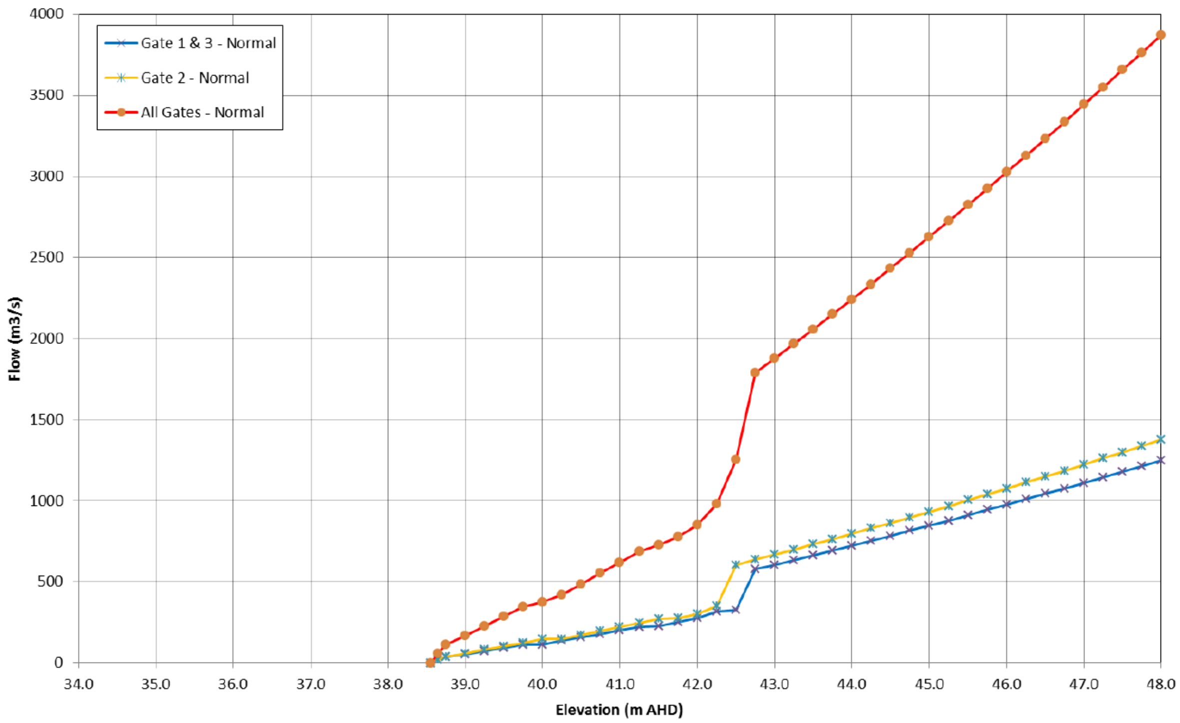

Figure 3-4 Spillway discharge vs water level – falling water level

4 Event Description

4.1 Event Timeline

The event timeline has been split into two groups for ease of interpretation:

- Rainfall, water levels, and discharge timeline; and
- Gate opening timeline.

4.1.1 Rainfall, water levels and gate opening timeline

This section should be read in conjunction with the rainfall listed in Table 4-1 and rainfall, water level and discharge timeline shown on Figure 4-1.

Figure 4-1 shows the dam level in blue, and cumulative rainfall in green. Discharges from the dam are shown in red. Note the right-hand axis represents discharge (m^3/s) and cumulative rainfall (mm) on the same scale.

Table 4-1 Daily and cumulative rainfall at the Ross River Dam ALERT gauge

Day	Daily rainfall (mm)	Cumulative rainfall (mm)
Sunday 27 January	33	33
Monday 28 January	52	85
Tuesday 29 January	109	194
Wednesday 30 January	158	352
Thursday 31 January	171	523
Friday 1 February	175	698
Saturday 2 February	198	896
Sunday 3 February	264	1,160
Monday 4 February	30	1,190
Tuesday 5 February	22	1,212
Townsville average annual rainfall		**1,143**

Rainfall across the Ross River catchment commenced on Sunday 27 January with 85mm recorded at the Ross River Dam ALERT gauge by the end of Monday 28 January. The water level in the Ross River Dam on Sunday 27 January was 36.95m AHD which is approximately 65% of the full supply volume of the dam.

A further 109mm of rainfall was recorded at the Ross River Dam on Tuesday 29 January with water levels in the dam starting to rise slowly. On Wednesday 30 January, 158mm of rainfall was recorded, with the dam reaching the EAP ALERT trigger level of 38.45m AHD by 11:40am. At this time the EAP was activated in ALERT status. Less than an hour later, at approximately 12:35pm, the water level in the dam reached the full supply level of 38.55m AHD. A further 0.1m rise in water levels had occurred by 1:26pm causing the middle gate to commence opening in automatic mode. The outer gates commenced opening shortly afterwards. By 1:33pm, SunWater escalated the EAP to LEAN

FORWARD status. By midnight on Wednesday 30 January, the water level in the dam had reached 39.40m AHD (121% of full supply volume).

On Thursday 31 January, 171m of rainfall was recorded at the dam, causing the dam level to rise to 40.7m AHD (161% of full supply volume).

By 4:16am on Friday 1 February, the water level in the dam exceeded the ‘Flood of Record’ level of 40.73m AHD, which triggers EAP escalation to STAND-UP status. At 5:30am, SunWater escalated the EAP directly to STAND UP-2, 3 hours ahead of the dam reaching the STAND UP-2 trigger level of 41.0m AHD. Note that the actions for STAND UP and STAND UP 2 are the same in the EAP.

Throughout Friday 1 February, 175mm of rainfall was recorded at the dam, causing a further rise in dam water levels to 41.55m AHD (190% of full supply volume) by the end of the day.

A hiatus in rainfall from the afternoon on Friday, allowed dam levels to fall slightly, before further rainfall on Saturday morning led to renewed water levels rises. Throughout Saturday 2 February, 198mm of rainfall was recorded at the dam, causing dam levels to rise to 42.3m AHD (220% of full supply volume) by the end of the day.

A second rainfall hiatus Saturday afternoon resulted in a second minor lowering of dam water levels. However, on Sunday 3 February, the highest event daily total rainfall of 264mm was recorded at the dam. Water levels reached the STAND UP-3 trigger level of 42.5m AHD by midday, at a similar time to the estimated[3] peak inflow rate of 4,900m^3/s. The EAP was escalated to STAND UP-3 at this time.

By 7:20pm on Sunday 3 February, the water level in the dam had reached 43.0m AHD (248% of full supply volume). By 8:30pm all gates were fully open, with a peak discharge of 1,888m^3/s.

The dam level peaked at 43.03m AHD (251% of full supply volume) at 11:50pm[4] on Sunday 3 February. From the time of peak, dam levels receded over the subsequent 12 days, returning to full supply level by 15 February. The EAP was STOOD DOWN on 16 February.

Major flooding occurred along the Ross River throughout Saturday 2, Sunday 3 and Monday 4 February, with water levels in the Ross River easing by Tuesday 5 February.

[3] 4,900m3/s inflow was estimated by SunWater. BMT estimates are lower, although the timing is similar. Refer to Section **Error! Reference source not found.**.

[4] Note times are extracted from the data provided by SunWater. Times differ slightly from those presented in the SunWater event review, although are generally within 1 hour. Differences are likely due to interpolation between recordings and/or rounding errors.

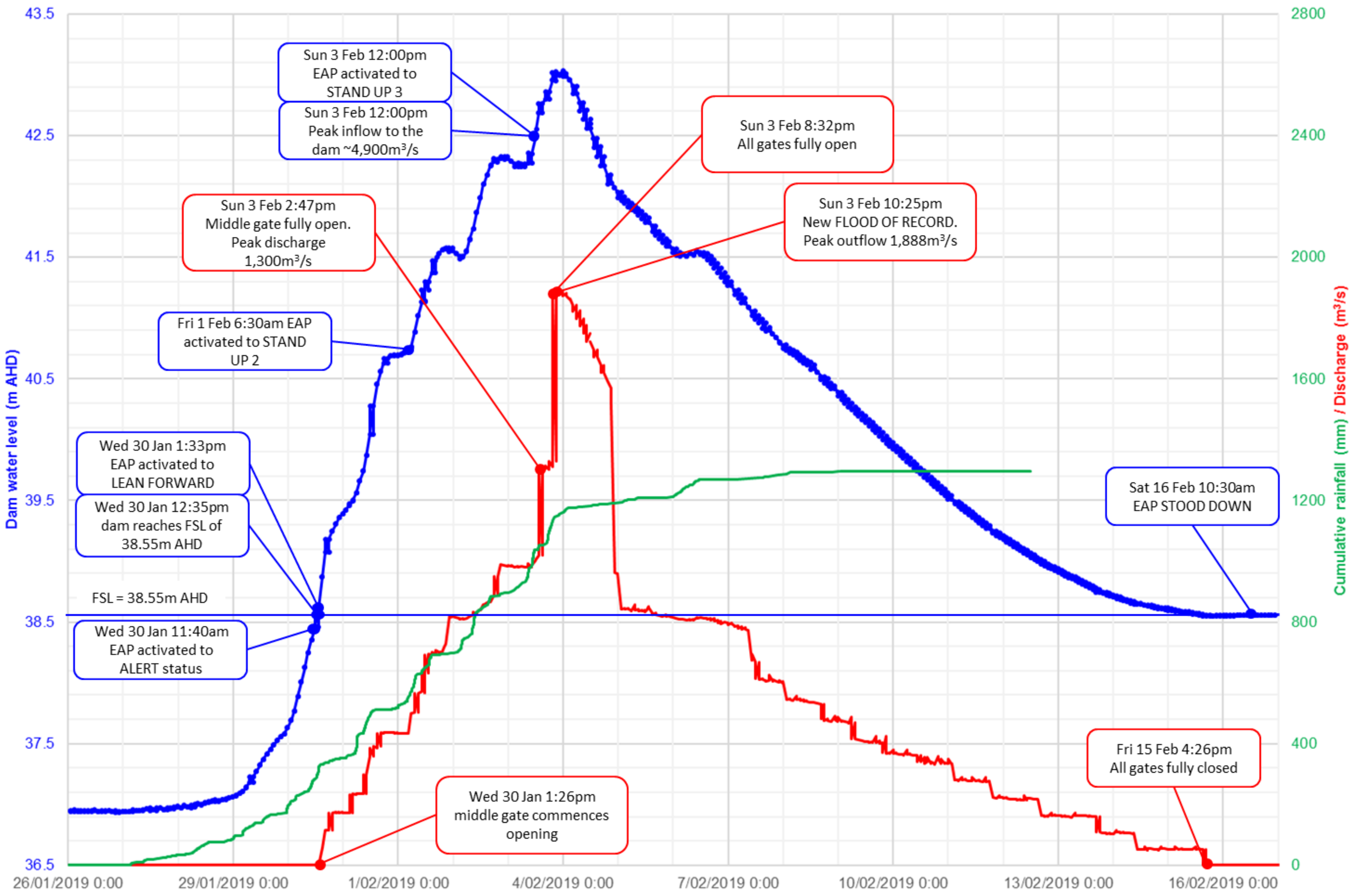

Figure 4-1 Rainfall, water level and dam release timeline

4.1.2 Gate control timeline

To assist with understanding the impact that manual control of the dam gates had on discharges and subsequent flooding along the Ross River, a gate control timeline has been prepared. This section should be read in conjunction with the gate control timeline presented on Figure 4-2.

Figure 4-2 shows the dam level in blue, and cumulative rainfall in green. Discharge is shown in red for automatic control, and light blue for periods where gates were operated manually. Note the right-hand axis represents discharge (m^3/s) and cumulative rainfall (mm) on the same scale.

The dam gates were operated manually four times throughout the event:

- 11:40am on Friday 1 February to 5:07pm on Friday 1 February (approx. 5.5 hours)
- 8:20pm on Friday 1 February to 12:24pm on Sunday 3 February (approx. 40 hours)
- 11:52am on Monday 4 February to 9:00pm on Monday 4 February (approx. 9 hours)
- 12:25pm on Tuesday 5 February to 10:52am on Thursday 7 February (approx. 46.5 hours).

As shown on Figure 4-2, two of the periods of manual control occurred prior to the peak, and two after the peak. Further discussion is provided in Section 6.4.

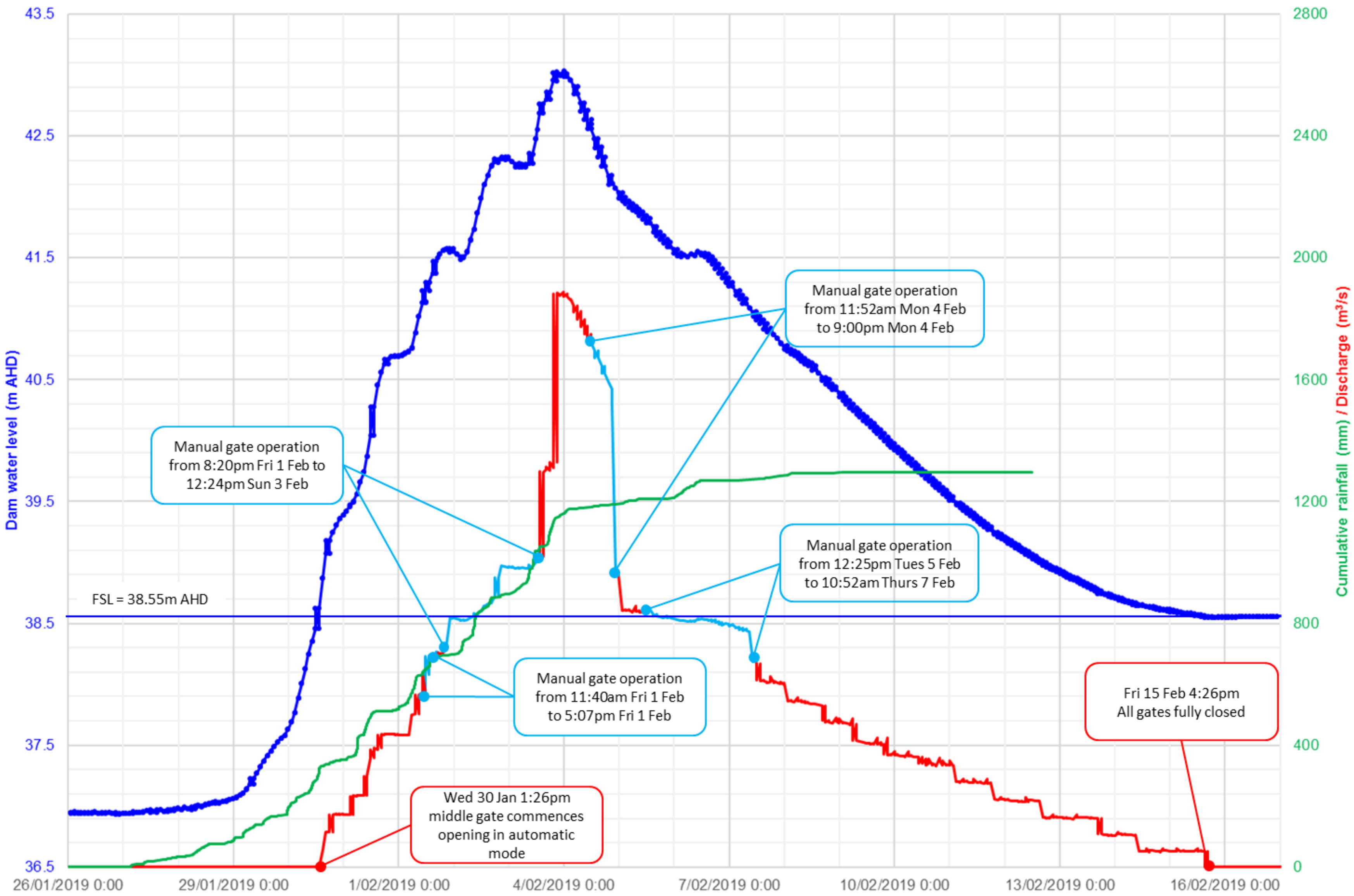

Figure 4-2 Gate control timeline

4.2 Rainfall and river levels

4.2.1 Rainfall

Within and immediately surrounding the Ross River catchment, 48 sub-daily reporting rain gauges have been identified. Gauges are owned and operated by Townsville City Council. All gauges are event reporting radio telemetry (ERRTS or ALERT), which report every 1mm of rainfall as it occurs. ALERT is near real-time, offering the fastest access to data. Refer to Figure 2-5 for distribution of rain gauges.

Shown on Figure 4-3 are the cumulative rainfall totals for 18 gauges located throughout the catchment for the period from 0:00 on 26 January until 0:00 on 5 February 2019. The pattern is similar between these and the remaining gauges in the catchment, with total rainfall varying from 1,050mm to nearly 1,400mm for the period. Note the Ross River dam gauge, referred to in Section 4.1.1 is an average representation of catchment wide rainfall.

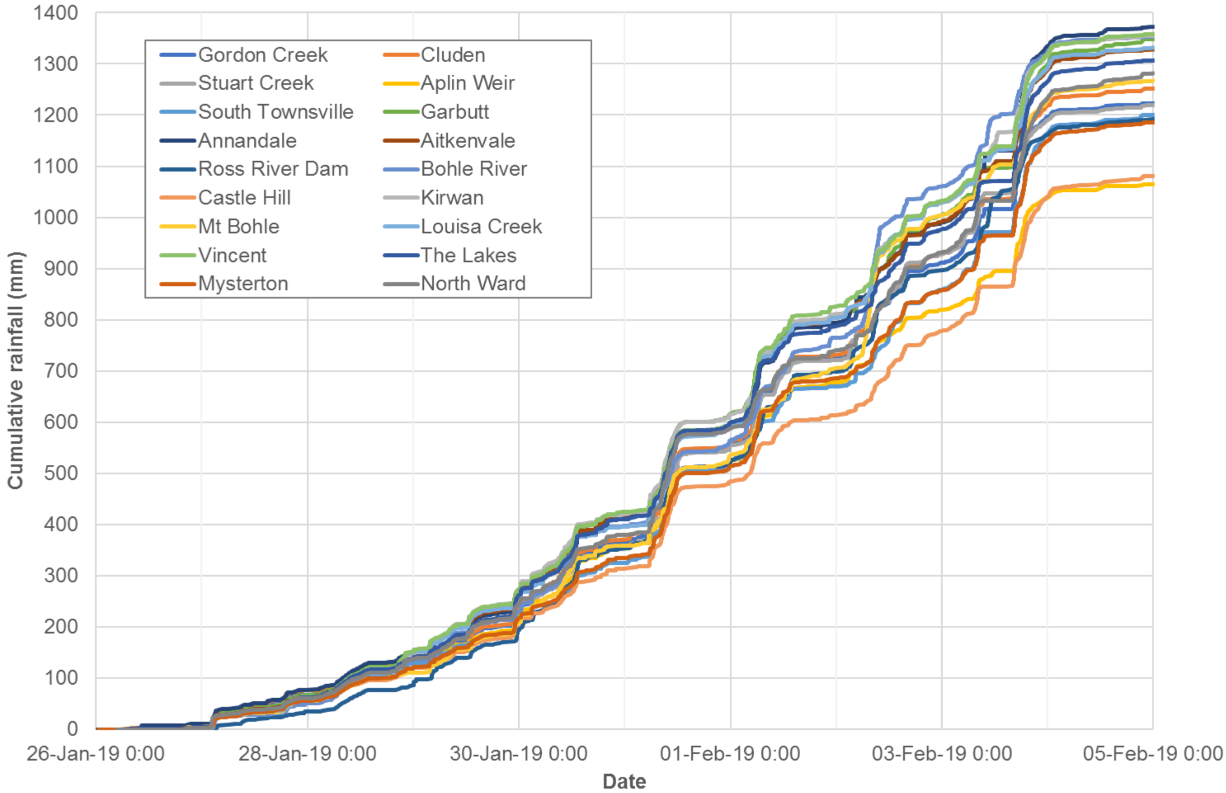

Figure 4-3 Cumulative rainfall chart (0:00 26 Jan to 0:00 5-Feb)

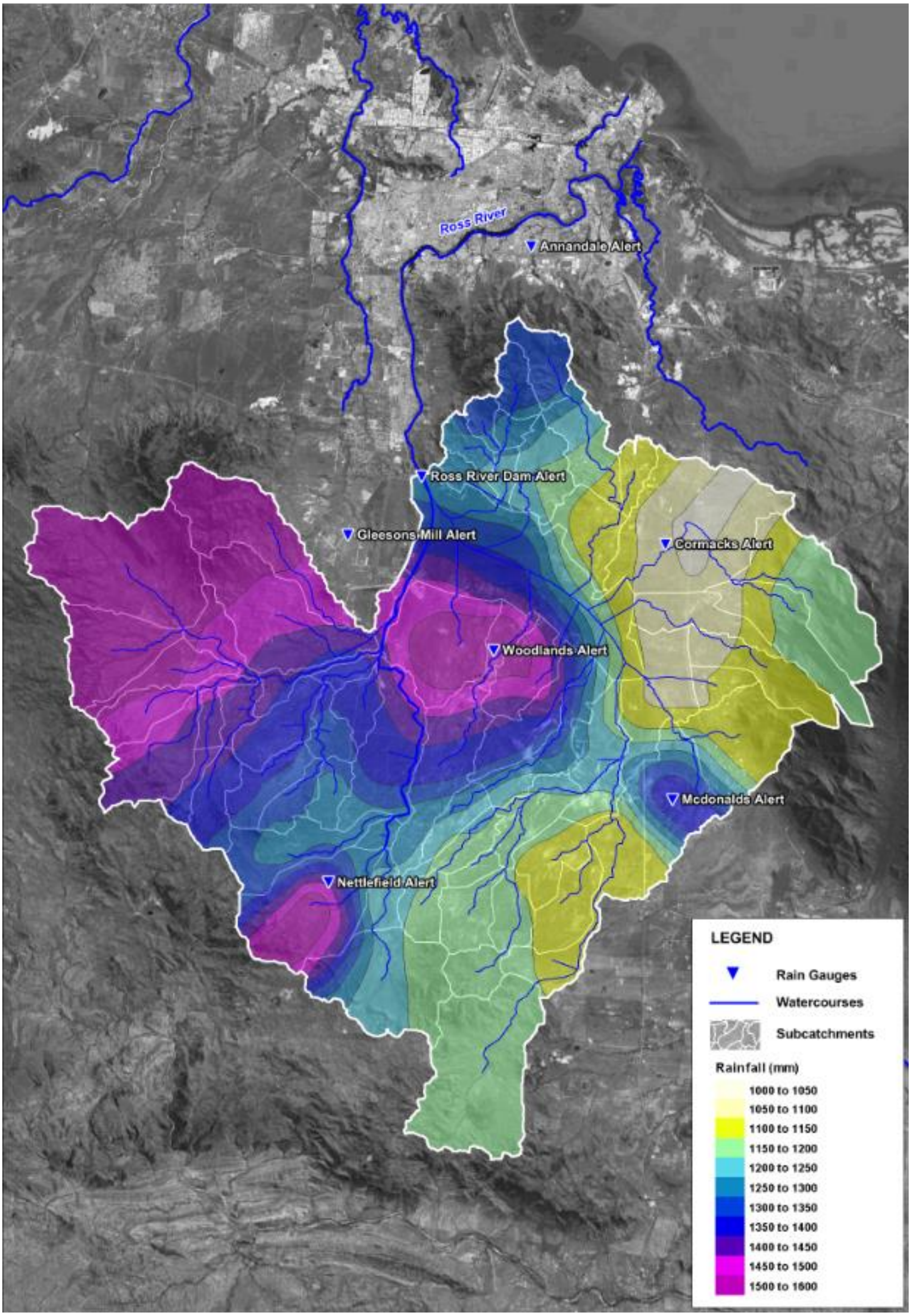

Figure 4-4 Cumulative rainfall map (0:00 26 Jan to 0:00 5-Feb)

4.2.2 Dam and River Levels

Refer to Figure 2-5 for location of water level gauges throughout the Ross River catchment. There are no river gauges upstream from the dam, which leads to uncertainty calculating inflows to the dam.

Dam levels are recorded near the spillway by SunWater and have been provided to BMT for this review. Water level records fluctuate by up to 0.15m throughout the event, which is not expected to be an accurate representation of actual water levels. Refer to Figure 4-5 for extract of water level time series. This fluctuation leads to uncertainty in calculation of dam inflows and outflows due to small changes in water levels causing large changes in discharge as different trigger levels are reached.

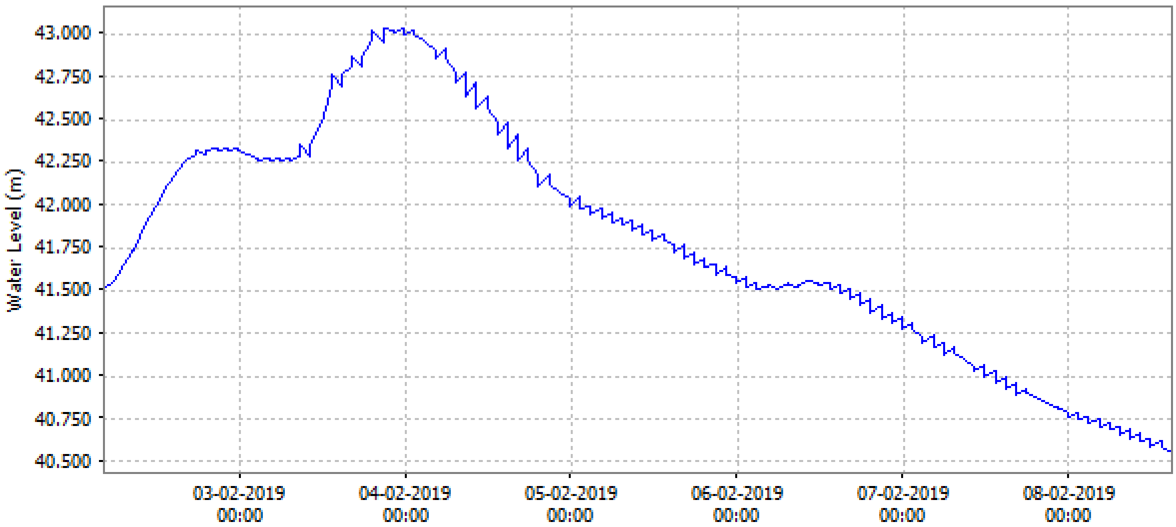

Figure 4-5 Extract of dam levels

Downstream from the dam, water levels were recorded along the Ross River at Black Weir, Aplin's Weir and Rooney's Bridge. Water level gauges in Gordon and Stuart Creeks were also recorded. The two gauges in the Mindham Park Drain in the Ross Creek catchment failed during the event.

4.3 Impacts of Flooding

The 2019 event was an unusual event with multiple bursts of heavy rainfall during each day from Tuesday to Sunday. The heavy rainfall caused localised inundation across various parts of the city. In some areas, inundation of properties and infrastructure was solely due to heavy rainfall leading to localised stormwater accumulation. In other low-lying areas, typically along the main watercourses, inundation was due to flows within the Ross River. In an atypical number of cases, inundation was initially a result of stormwater accumulation, later followed by flooding from the Ross River and its tributaries.

The total number of properties affected by each mechanism is currently unknown, however, based on the *Ross River Flood Study Base-line Flooding Assessment* (TCC, 2013), it is expected that around 2,000 to 3,000 properties would have been flooded from an event of this magnitude.

4.4 Magnitude

4.4.1 Rainfall

Intensity frequency duration (IFD) analysis has been undertaken on all gauges in the Ross River catchment. AEPs for six representative gauges from the Upper Ross River catchment and six gauges from the Lower Ross River catchment are listed in Table 4-2. IFD plots for all listed gauges are presented in Figure 4-6 to Figure 4-17.

The analysis shows that at some locations the intensity of the rainfall over certain durations exceeded the 0.05% annual exceedance probability (AEP), or 2,000 year average recurrence interval (ARI) event. The more extreme AEPs are generally associated with the longer durations (i.e. 72 - 96 hours). At Woodlands ALERT on the southern side of the Ross River Dam, the 24 and 48 hour events had 0.5% and 0.2% AEPs (200 year and 500 year ARI).

The rainfall intensity was generally higher in the catchment upstream from the dam.

Table 4-2 Rainfall AEP for gauges across the catchment

Rainfall Gauge	Station ID	24 hour rain	48 hour rain	72 hour rain	96 hour rain
Upper Ross River					
Cormacks ALERT		~20%	20%-10%	10%-5%	5%-2%
Gleesons Mill ALERT	532040	10%-5%	~1%	~0.2%	~0.05%
McDonalds ALERT	533044	50%-20%	20%-10%	10%-5%	~2%
Nettlefield ALERT	533043	5%	1%	0.2%-0.1%	>0.05%
Ross River Dam ALERT	532020	10%-5%	2%	1%-0.5%	0.2%-0.1%
Woodlands ALERT	533022	0.5%	0.2%	0.1%-0.05%	>0.05%
Lower Ross River					
Aplin Weir ALERT	532029	~20%	~10%	5%-2%	~1%
Castle Hill ALERT	532075	20%-10%	5%	5%-2%	~1%
Cluden ALERT	532076	10%-5%	5%-2%	1%-0.5%	~0.2%
Kirwan ALERT	532039	50%	50%-20%	20%-10%	20%-10%
Mysterton ALERT	532037	10%-5%	5%-2%	~1%	0.5%-0.2%
South Townsville ALERT	532077	10%-5%	5%-2%	2%-1%	0.5%-0.2%

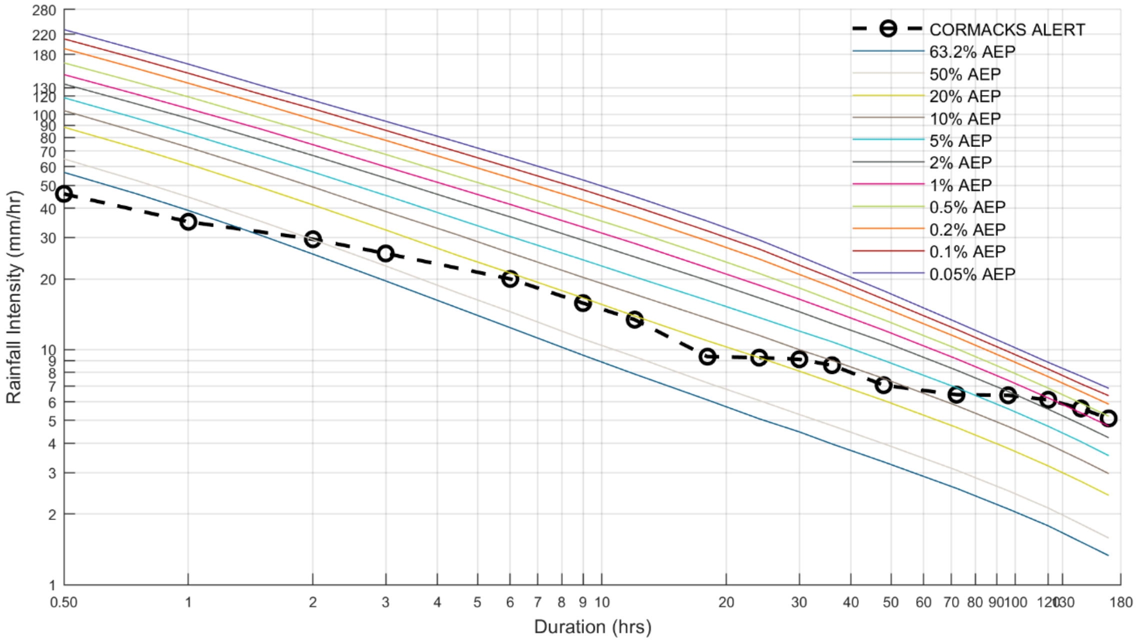

Figure 4-6 Cormacks ALERT IFD curve

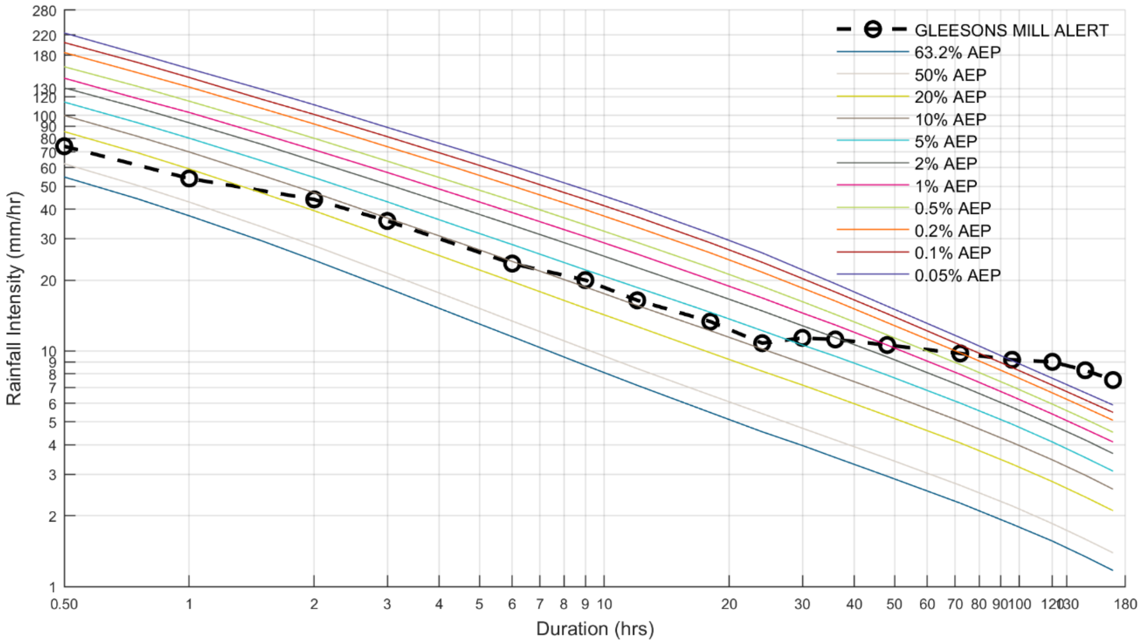

Figure 4-7 Gleesons Mill ALERT IFD curve

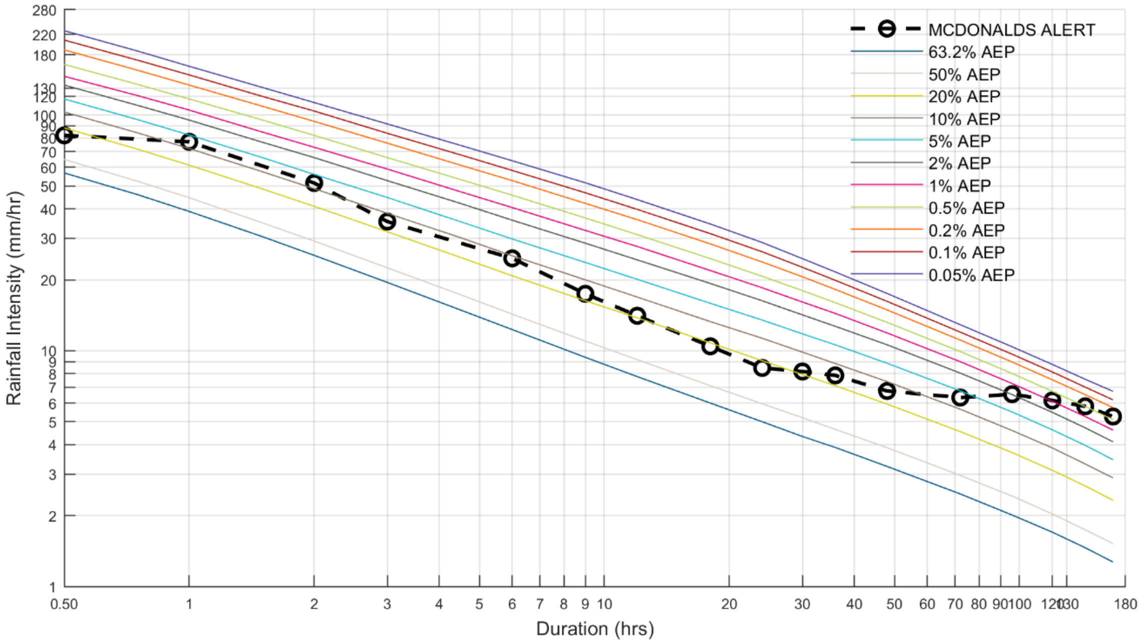

Figure 4-8 McDonalds ALERT IFD curve

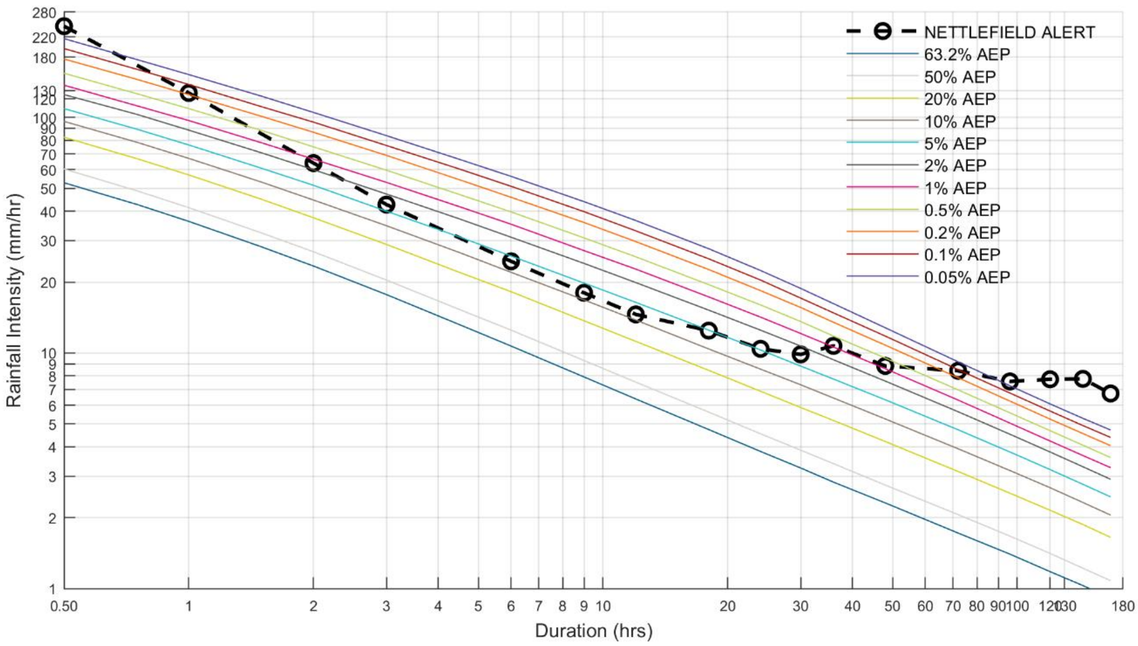

Figure 4-9 Nettlefield ALERT IFD curve

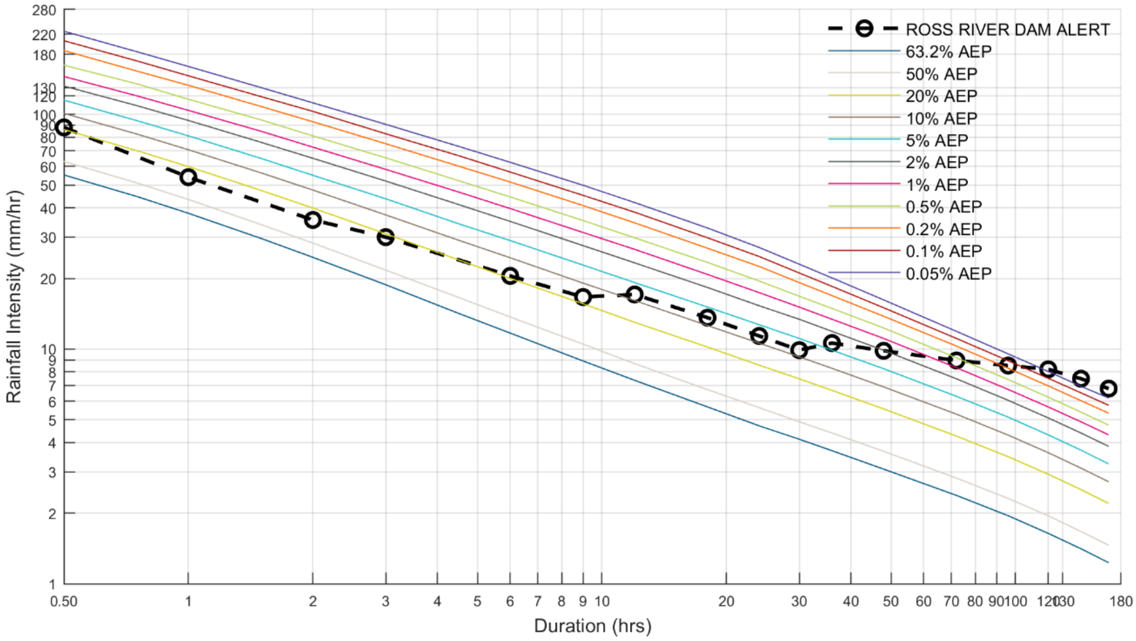

Figure 4-10 Ross River Dam ALERT rainfall IFD analysis

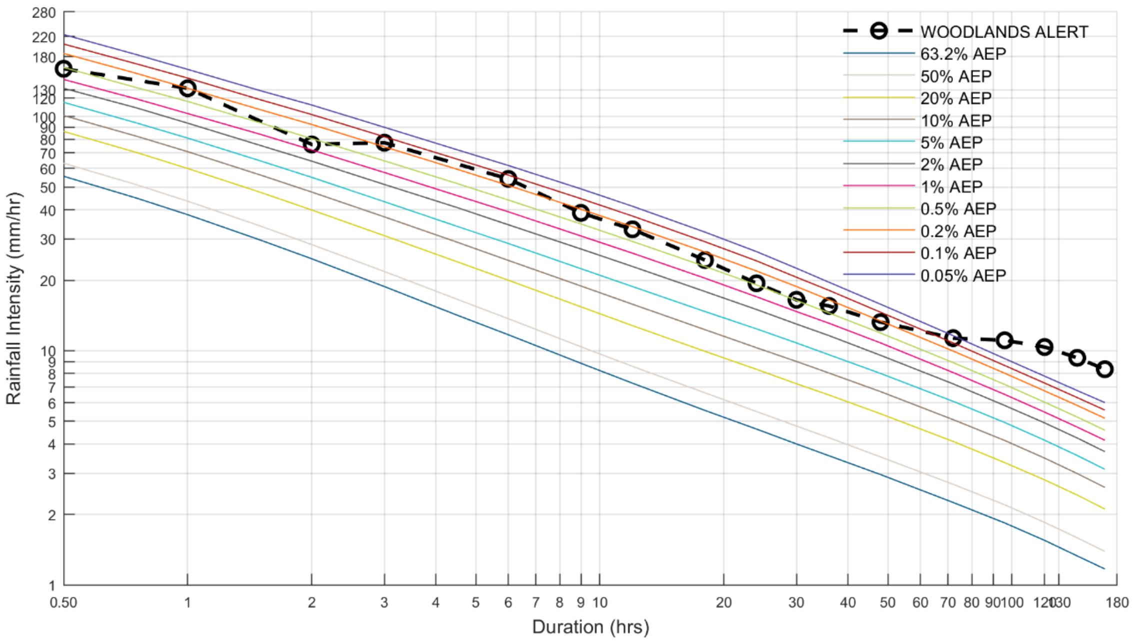

Figure 4-11 Woodlands ALERT IFD curve

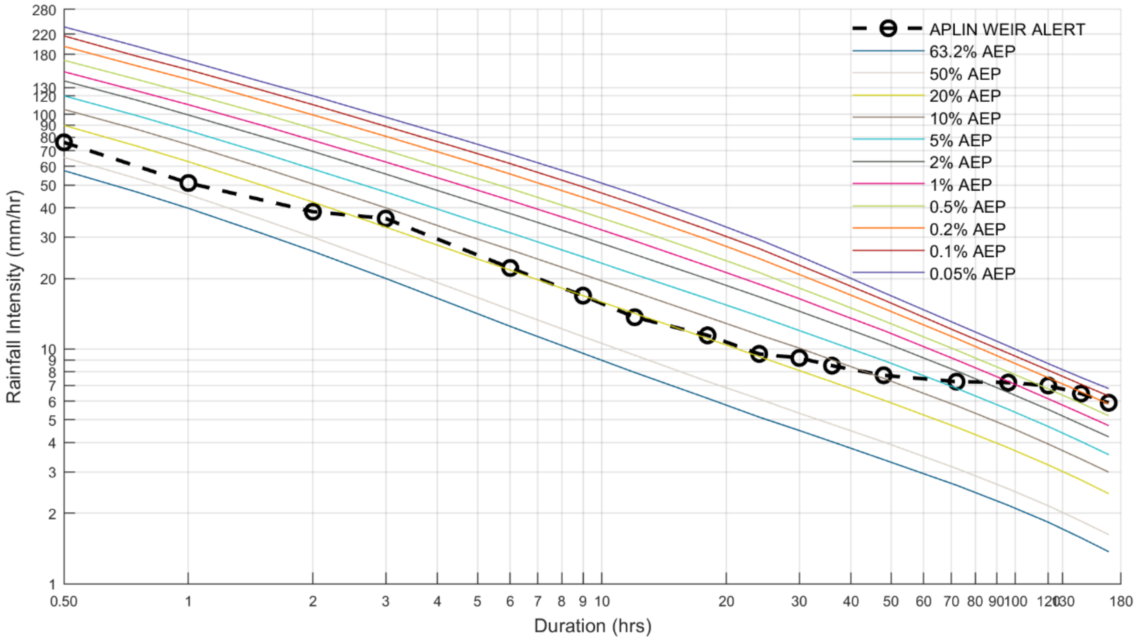

Figure 4-12 Aplin Weir ALERT IFD curve

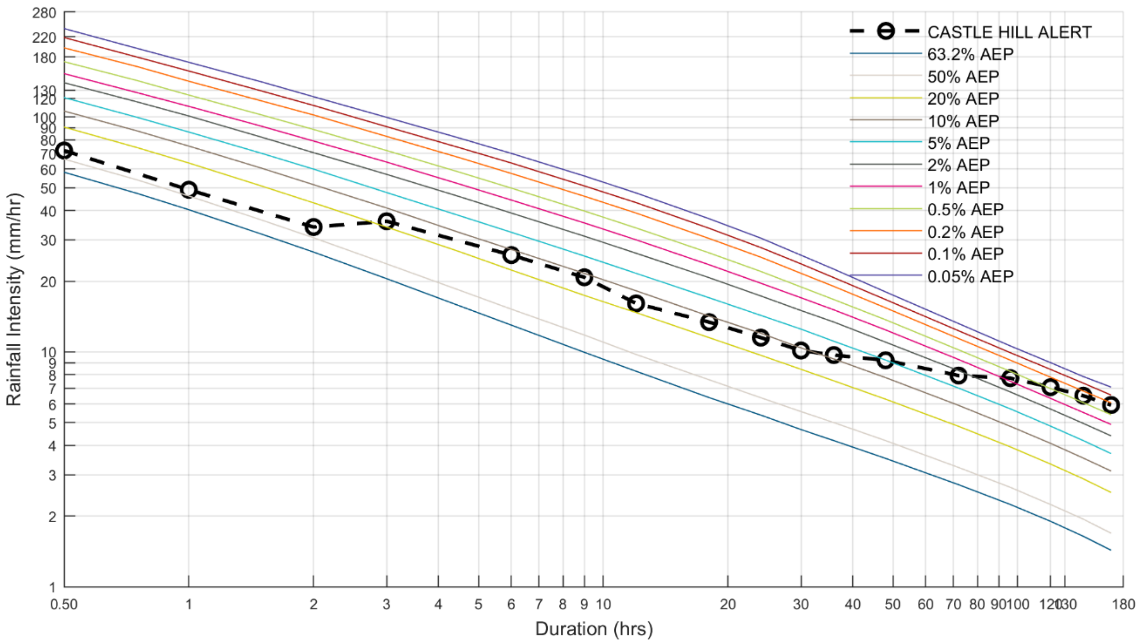

Figure 4-13 Castle Hill ALERT IFD curve

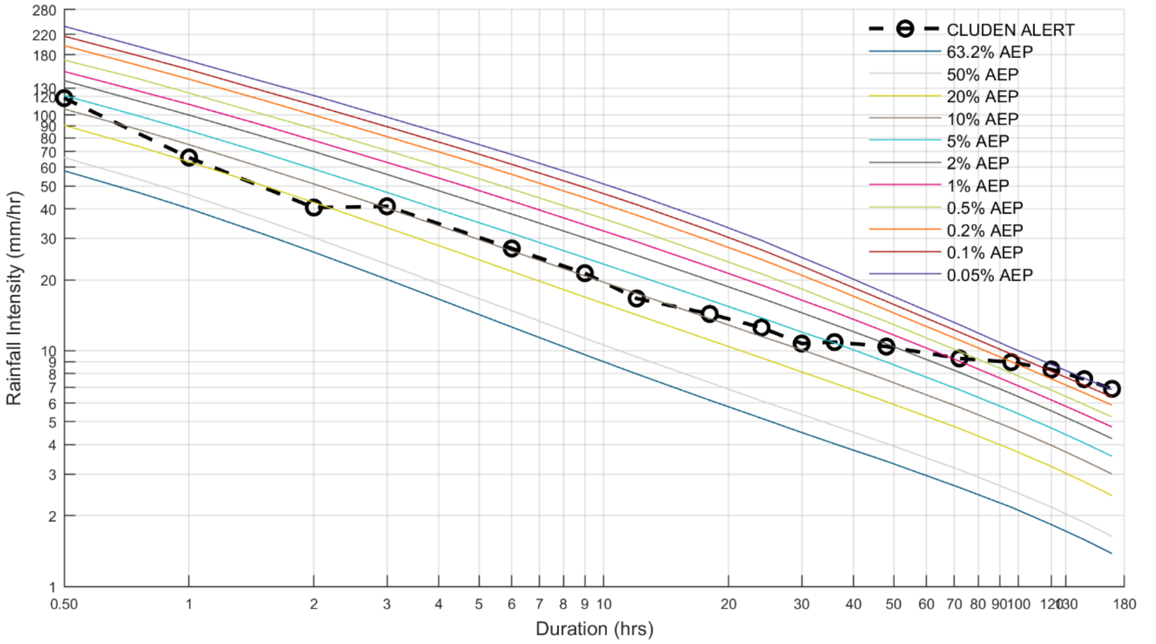

Figure 4-14 Cluden ALERT IFD curve

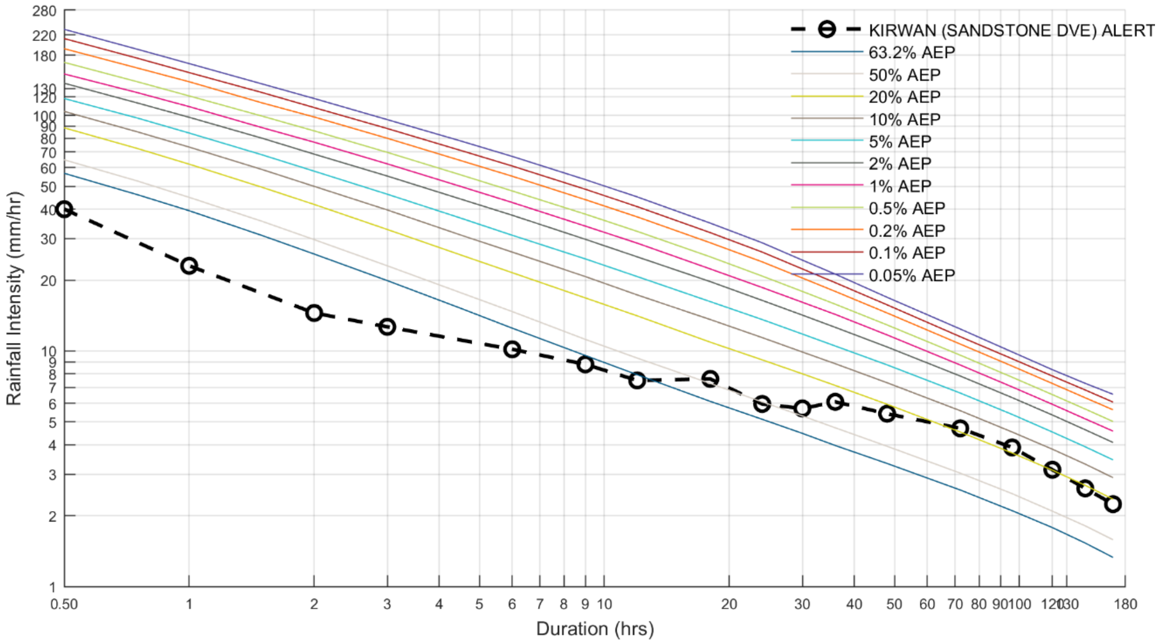

Figure 4-15 Kirwan ALERT IFD curve

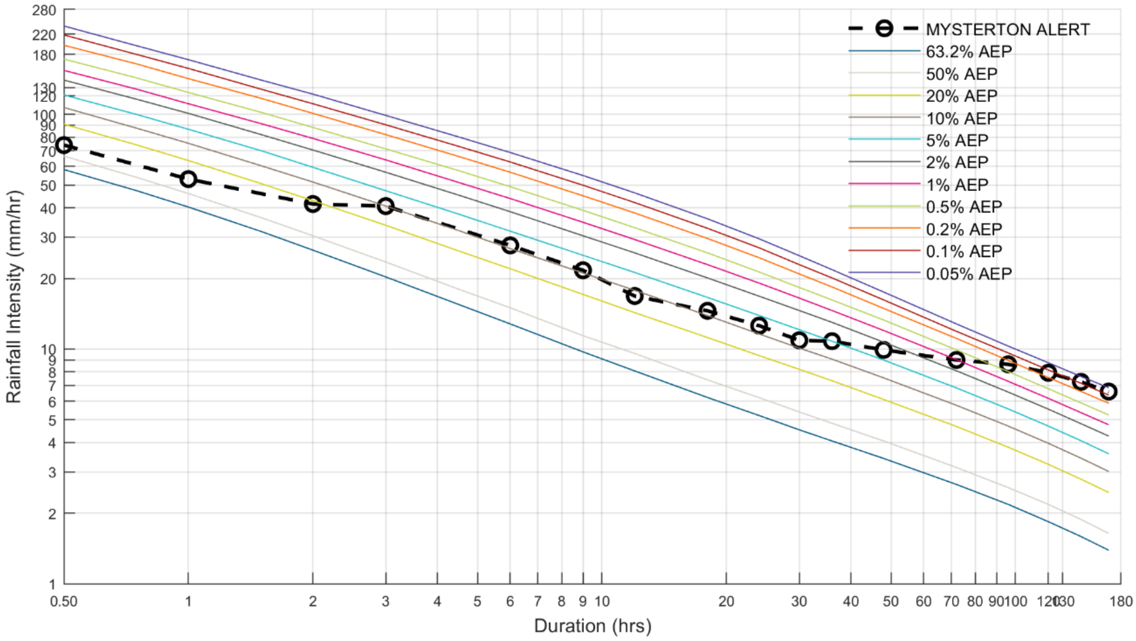

Figure 4-16 Mysterton ALERT IFD curve

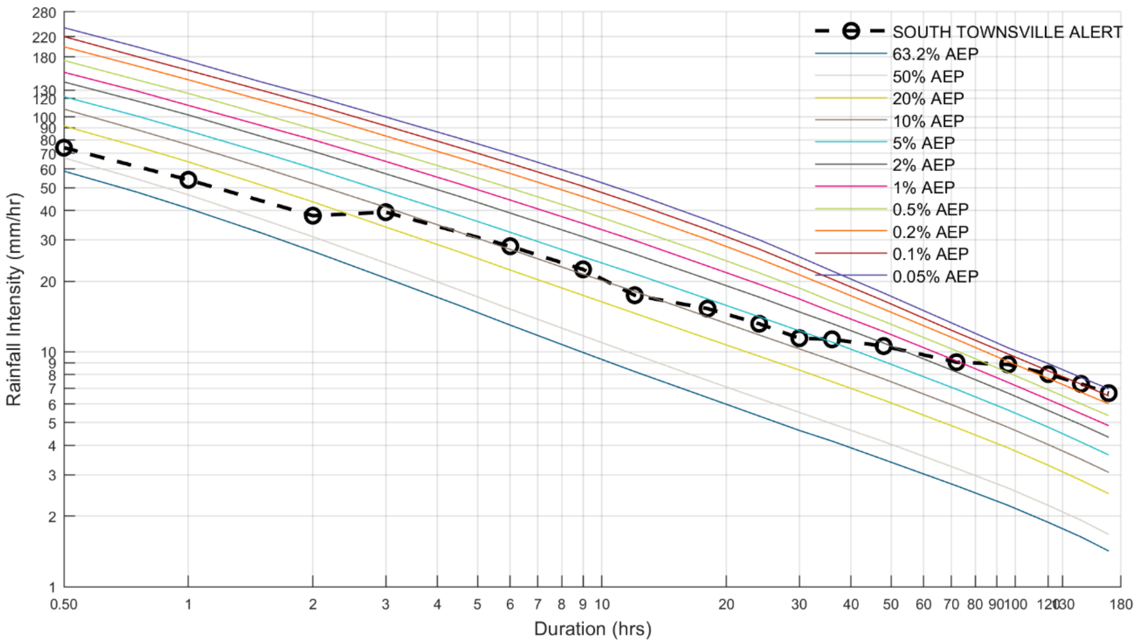

Figure 4-17 South Townsville ALERT IFD curve

4.4.2 Water levels

Design event water levels along the Ross River have been extracted from the *Ross River Flood Study Base-line Flooding Assessment* (Townsville City Council, 2013), and are presented in Table 4-3. Recorded flood levels for the February 2019 event are also shown.

Table 4-3 Design flood and February 2019 event flood levels along the Ross River

AEP	Average recurrence interval	Black Weir ALERT	Aplin Weir ALERT	Rooney's Bridge ALERT
50%	2 year	14.54	7.31	2.50
20%	5 year	14.84	7.62	3.10
10%	10 year	14.94	7.72	3.31
5%	20 year	15.13	7.91	3.57
2%	50 year	15.26	7.99	3.61
1%	100 year	15.39	8.13	3.78
0.5%	200 year	15.67	8.39	3.94
0.2%	500 year	16.60	9.38	4.30
0.1%	1,000 year	16.94	9.56	4.41
0.05%	2,000 year	17.13	9.69	4.49
PMF	PMF	18.04	10.03	4.80
Feb 2019	Feb 2019	16.30	9.75	4.40

Assigning an AEP to the event based on the design flood mapping is sensitive to the following:

- Position of gauge vs reporting location - The design flood levels presented in Table 4-3 for the 0.2%, 0.1% and 0.05% are very similar. At the gauge locations, the water surface varies significantly along the path of the river. Depending on the exact location that design flood levels have been extracted from the mapping, versus the exact location that the water level is recoded, the AEP can vary.
- Accuracy of the gauge – River gauges often experience an error with the measurement. It is expected that the Aplin Weir gauge is inaccurate, based on the following:
  - An AEP of greater than 0.05% (2,000 year ARI) (based on recorded level of 9.75m AHD) is inconsistent with upstream and downstream gauges;
  - The peak recorded level of 9.75m AHD is higher than the surveyed peak flood levels by Council and DNRME in the same area (refer to Figure 2-6); and
  - The water level observations show some noise (rapid variations in level) throughout the event.

Based on surveyed water levels, the following AEPs are suggested:

- Black Weir – 0.5% to 0.2% AEP (200 – 500 year ARI)
- Aplin Weir (assumed peak flood level about 9.5m AHD) - 0.2% to 0.1% AEP (500 – 1,000 year ARI)

- Rooney's Bridge – 0.1% AEP (1,000 year ARI).

4.4.3 Discharge

The peak discharge from the Ross River Dam during the February 2019 event is calculated to be 1,888m^3/s. In accordance with the *Ross River Flood Study – Base-line Flooding Assessment* (Townsville City Council, 2013), a 0.1% AEP event has a discharge of 1,960m^3/s. It is therefore, reasonable to suggest the release was equivalent to a 0.1% AEP (1,000 year ARI).

4.4.4 Event Magnitude Summary

The magnitude of the event can be quoted based on rainfall, water levels and/or dam releases. In the context of rainfall and water levels, these vary across the catchment, according to where the respective parameters are measured. This provides uncertainty around assigning a single AEP to the event for the entire catchment.

Based on the assessment of magnitude of rainfall, water levels and dam releases, the February 2019 event is considered to have an AEP between 0.5% and 0.1% (500 – 1,000 year ARI), most likely to be closer to a 0.1% AEP (1,000 year ARI).

5 Flood Modelling and Mapping

5.1 Types of Model

Flood modelling typically involves two key components. Firstly, a hydrologic model is used to estimate the rate of runoff from a given storm event. Historical or design rainfall are applied to the hydrologic model and algorithms used to convert the rainfall to runoff. These runoff-routing models are often simplistic representations of the catchment, generally requiring minimal geographical input data.

Secondly, a hydraulic model is used to simulate the passage of water through the catchment. Inflow hydrographs, estimated using the hydrologic modelling, are applied at the upstream ends of waterways and floodplains. Hydraulic models are generally more complex and data intensive.

5.2 Hydrologic Modelling

5.2.1 Hydrologic Model Development

URBS was used as the hydrologic model to determine the inflows to the hydraulic model.

The catchment was divided up into three model areas:

- The Upper Ross River model covers the 760km^2 Upper Ross River catchment, upstream from the dam. The catchment was sub-divided into 71 sub-catchments. This model is only used for the ‘no dam’ scenario since other scenarios use the actual or calculated discharges from the dam as inputs to the hydraulic model.
- The Lower Ross River model covers the remaining 180km^2 area of the catchment, sub-divided into 77 sub-catchments; and
- Bohle River, including Ross Creek.

A variant of the Upper Ross River model was developed that removes the dam for running the ‘no dam’ scenario. All models are simulated from a period starting on 26 January 2019 to capture all rainfall.

For the Upper Ross River model, the storage-elevation and elevation-discharge relationships for the dam have been taken from the supplied Sunwater URBS model. It is understood that the elevation discharge relationship is based on typical gate operations.

5.2.2 Hydrologic Model Calibration

Joint calibration has been undertaken between the hydrology models and the hydraulic model. There were a total of 32 rainfall gauges that were used to provide spatial representation of the rainfall that occurred during the February 2019 event.

Calibration of the URBS model was undertaken through the manipulation of model parameters to mimic observe water levels. The Upper Ross River model has been calibrated to both the level in the dam and the dam outflow. Note that due to gate operations made during the event, which deviate from the elevation-discharge relationship in the model, there are slight differences in outflow and dam water levels between modelled and recorded. The model demonstrates a reasonable match and it is considered suitable for use in deriving a 'no-dam' outflow.

For the Bohle River model calibration, the Hervey Range Road gauge, operated by DNRME, has been used. A localised hydraulic TUFLOW model was developed to check DNRME's rating curve for this gauge, which was found to be reasonable. The rating curve has been updated based on model results for flows greater than 600m^3/s. The revised rating has been used to convert the recorded levels at Hervey Range Road to flows. The hydrologic model has been calibrated to this gauge and a reasonable match in modelled versus recorded (rated) flows has been achieved.

For the lower Ross River hydrologic model, there is no reliable rating curve due to the perched nature of the river and/or tidal influences. For this model, routing parameter values and rainfall loss assumptions were taken from the calibrated Bohle River model. This model is used to provide local catchment / tributary inflows to the TUFLOW model.

The following quality assurance checks were undertaken:

- Average upstream catchment rainfall depth to the dam is 1,118mm (dam outflow + change in dam storage and a catchment area of 760km^2).
- Effective upstream catchment rainfall applied in URBS is 1,076mm based on IDW of rain gauge data and application of IL and CL.
- Cumulative rainfall totals at rain gauges were plotted and suspect gauges removed from the analysis.

5.2.2.1 Parameters

The URBS model has the following parameters that can be adjusted to achieve calibration of the model the catchment/channel routing:

- Alpha – channel lag parameter;
- Beta – catchment lag parameter; and
- Exponent m – catchment non-linearity exponent.

Various combinations of alpha and beta were tested, keeping the exponent m constant at 0.8 in accordance with the industry tested and accepted approach. The best fit to recorded data was achieved using an alpha of 0.05 and beta of 2.5.

5.2.2.2 Losses

Initial and continuing losses for the February 2019 event have been calculated to be 120mm and 1.3mm/hour respectively. The high initial loss is a reflection of the dry nature of the catchment prior to the event.

5.3 Hydraulic Modelling

5.3.1 Existing Models

The following hydraulic models have previously been developed for various parts of the Ross River and neighbouring catchments:

- Ross River;
- Gordon Creek;
- Louisa Creek;
- Townsville CBD; and
- Several Bohle River models.

The software used for all previous models would not have allowed model calibration and scenarios to have been simulated in a timeframe suitable for this review.

5.3.2 Modelling Approach

A new hydraulic model has been developed for this investigation. To meet the tight timeframe of the project, the TUFLOW HPC software has been used. The model extent has been determined to assess flood behaviour:

- Along the Ross River from Ross River Dam to the ocean;
- Across Gordon and Stuart Creeks; and
- Across Ross Creek, Louisa Creek and the Bohle River.

The creek channel and floodplain areas are represented by a 2D grid of 10m by 10m grid cells. The size of grid cell is selected based on modelling objectives and computer simulation time. During the model verification process, a 15m grid cell size was used to reduce simulation times. To accurately represent the narrow channels of some of the minor watercourses, the 10m grid was used for the final model simulations. The resolution defined by the 10m grid cell size is considered sufficient to meet the objectives of this review.

5.3.3 Topography

Topography across the 2D model domain is represented in the following manner.

- Each 2D grid cell is assigned a single elevation initially interrogated from the DEM at the cell centre;
- The sides of each grid cell are also assigned an elevation initially interrogated from the DEM at the mid-point of the cell side; and
- Cell centre or cell side elevations can then be adjusted to represent topographic features, such as road embankments, which were not initially accurately defined by the DEM.

The elevation assigned to a cell centre affects the storage applied to the cell. The elevation applied to the cell sides controls the flow of water from one cell to another.

Refer to Figure 5-1 and Figure 5-2 for the digital elevation model from the 2016 LiDAR survey for the Lower Ross River and Townsville City areas.

5.3.4 Surface Roughness

Ground surface roughness can have a significant influence on the flow of water. Ground roughness is represented in the model by assigning Manning's 'n' values for different land uses. Land use is determined from aerial photography along with on-site ground truthing.

Values of Manning's 'n' for different land uses are selected based on industry accepted values, which are subsequently refined during the model verification phase. Refer to Section 5.4 for model verification Manning's 'n' values.

5.3.5 Boundary Conditions

The term 'boundary conditions' relates to the application of hydraulic boundaries to the model. Two types of boundary conditions have been used for this model:

- Discharge over time boundaries at the upstream ends of major tributaries and at the downstream end of Ross River Dam; and
- Rainfall depth over time across the main model area.

Locations of boundary conditions are shown on Figure 5-3.

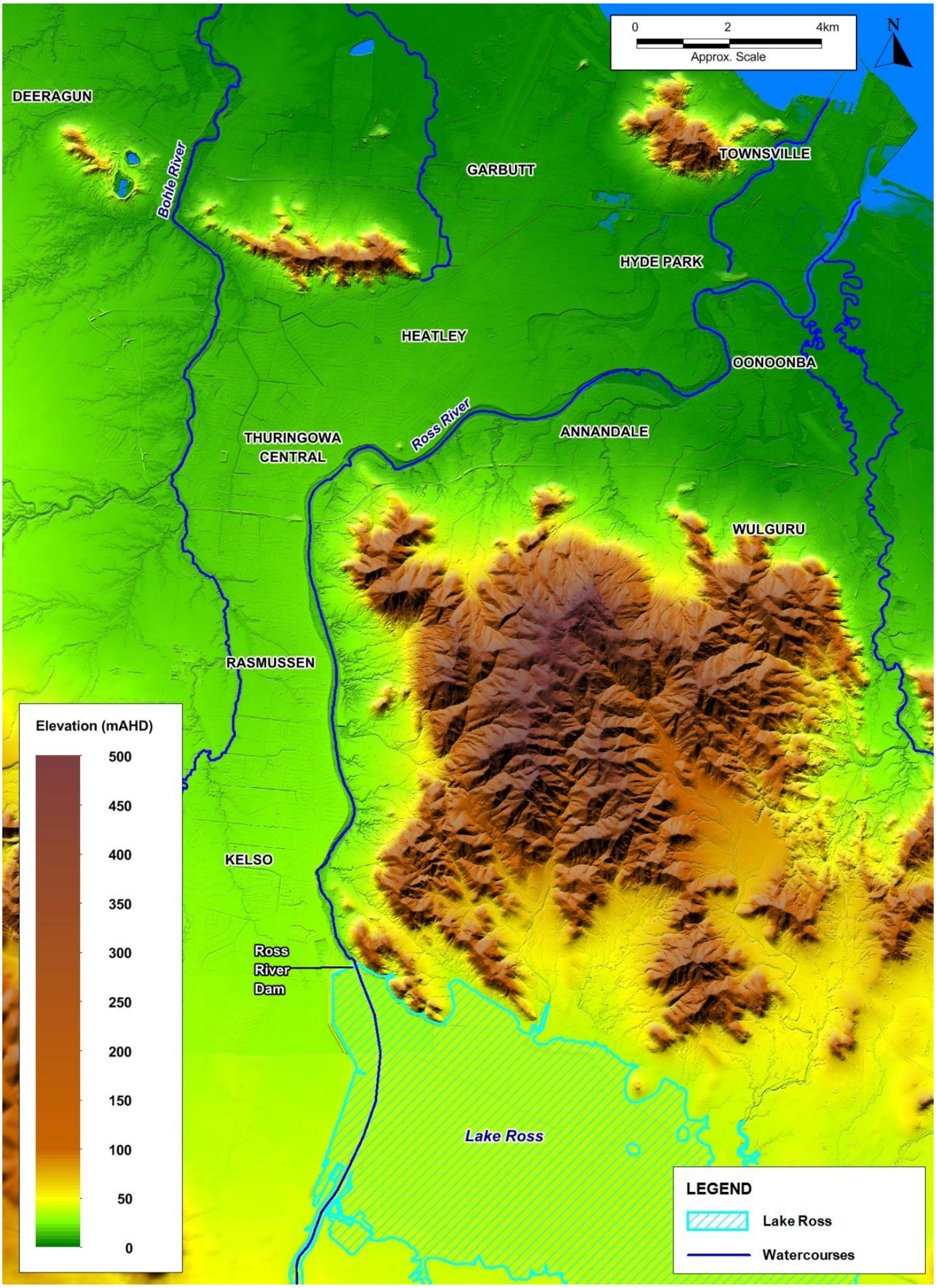

Figure 5-1 Digital elevation model of the Lower Ross River (2016 LiDAR survey)

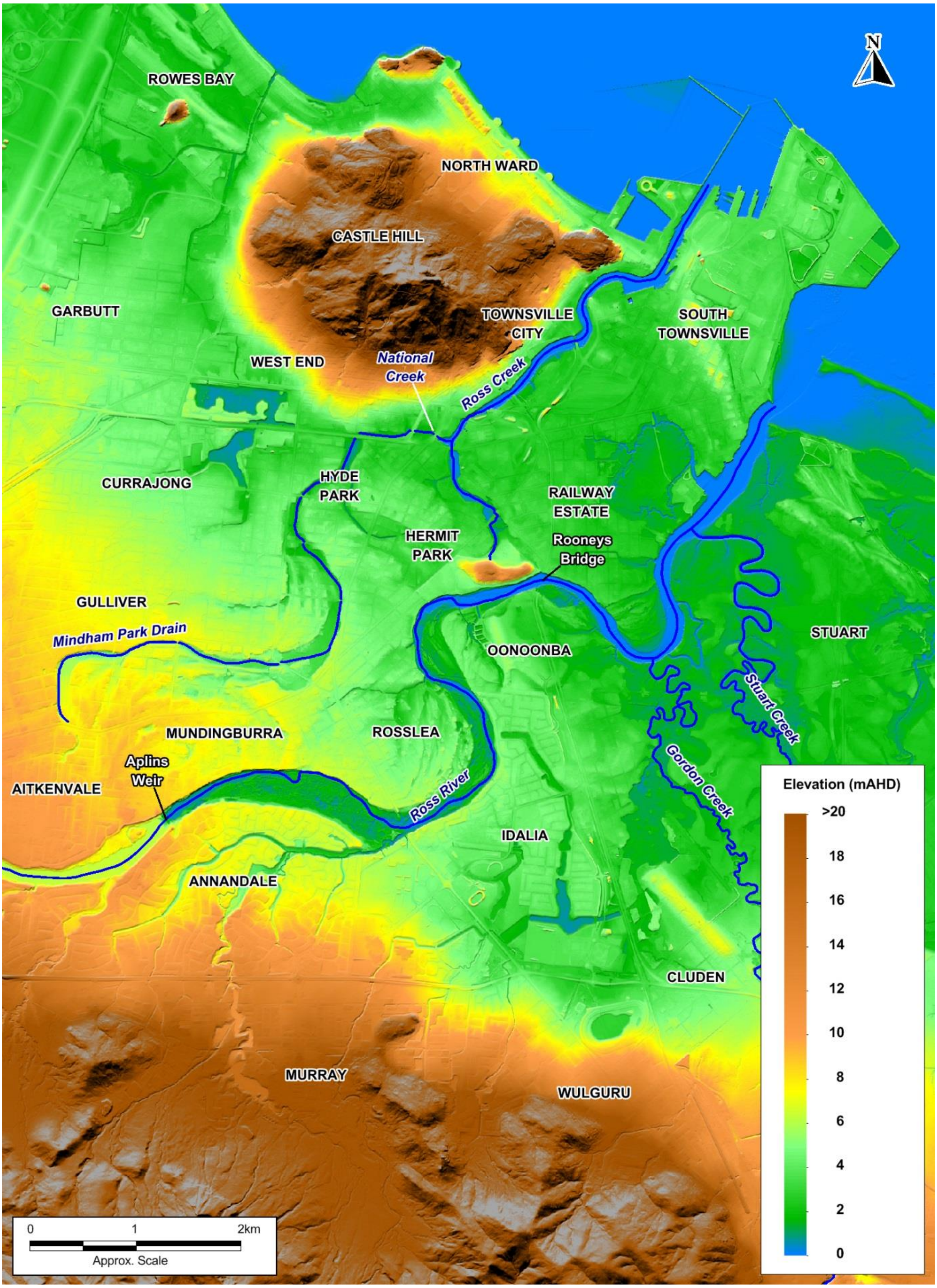

Figure 5-2 Digital elevation model of the Townsville area (2016 LiDAR survey)

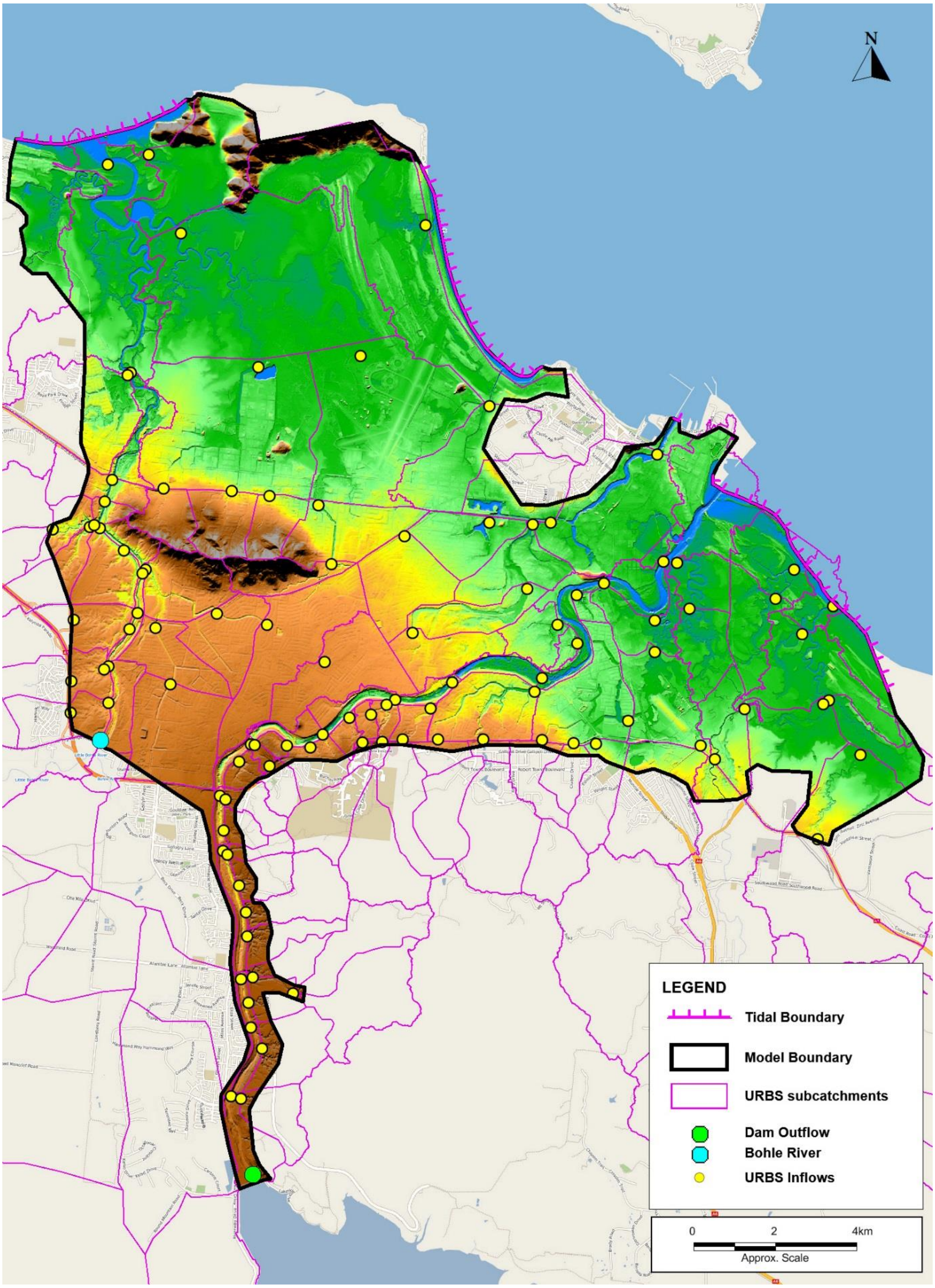

Figure 5-3 Model boundary conditions

5.4 Model Calibration and Verification

To establish a degree of confidence that the models are suitably representing actual site conditions, the model has been verified against observed and anecdotal evidence. Model calibration involves adjusting model parameters and inputs using industry acceptable values, until the model suitably replicates recorded flood behaviour. The performance of the model has been assessed against the following information:

- River gauges (Black Weir, Aplin Weir, Rooney's Bridge, Gordon Creek and the Bohle River TM); and
- Peak flood level marks collected by Council and DNRM.

Refer to Figure 5-9, Figure 5-10 and Figure 5-11 for peak flood level mapping, showing differences between modelled and surveyed peak flood levels.

Figure 5-4, Figure 5-5 and Figure 5-6 show hydrographs at Black Weir ALERT, Aplin Weir ALERT and Rooney's Bridge ALERT comparing simulated to recorded water levels. Simulated water levels at Black Weir and Aplin's Weir are consistently lower than recorded levels. At Aplin's Weir, it is expected the recorded water levels are too high. This assumption is based on the peak flood level survey upstream from Aplin's Weir, typically having levels of 9.4m – 9.5m AHD (more than 0.25m lower than recorded at the gauge). The overall shape and timing match well with recorded data.

Hydrographs at Gordon Creek ALERT and the Bohle River TM gauges are shown in Figure 5-7 and Figure 5-8. The peak of the event is well matched at Gordon Creek, although the lead up to the dam release indicates lower water levels than recorded. The Bohle River site matches recorded data well.

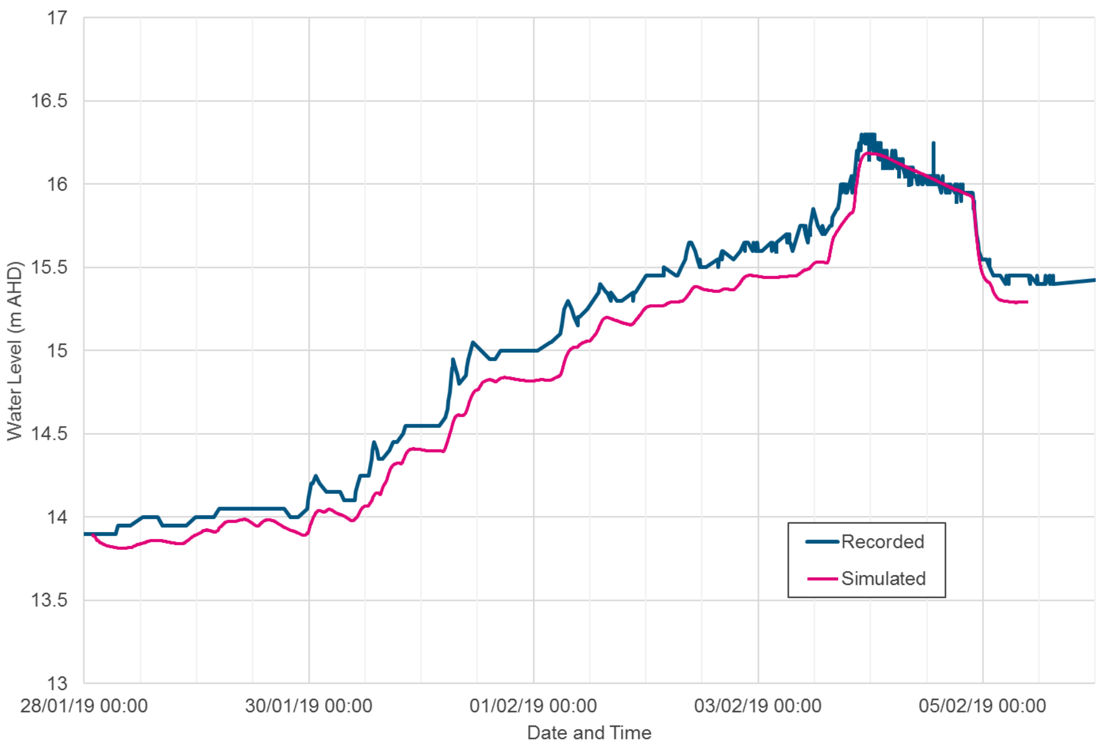

Figure 5-4 February 2019 event calibration at Black Weir ALERT

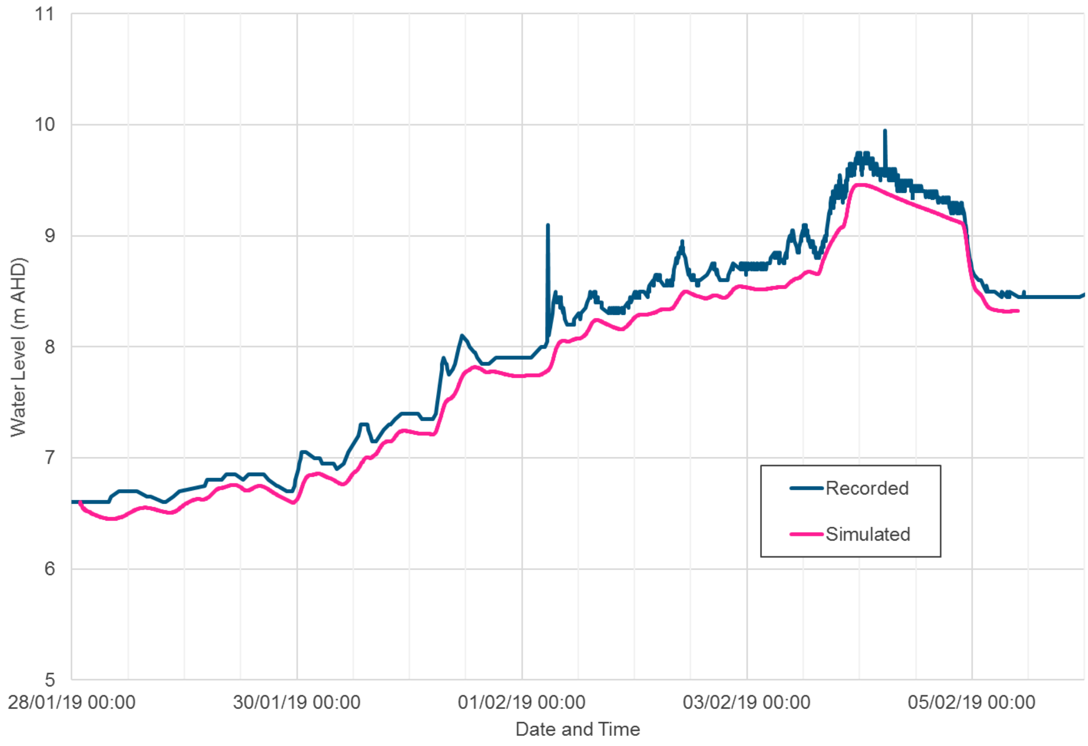

Figure 5-5 February 2019 event calibration at Aplin Weir ALERT

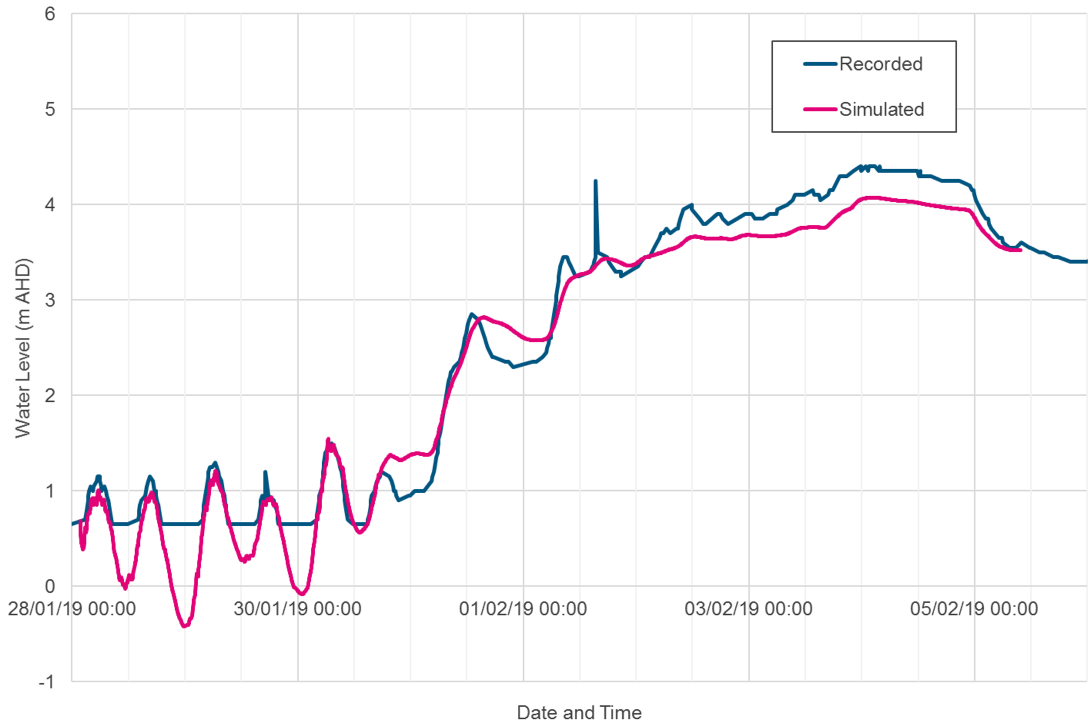

Figure 5-6 February 2019 event calibration at Rooney's Bridge ALERT

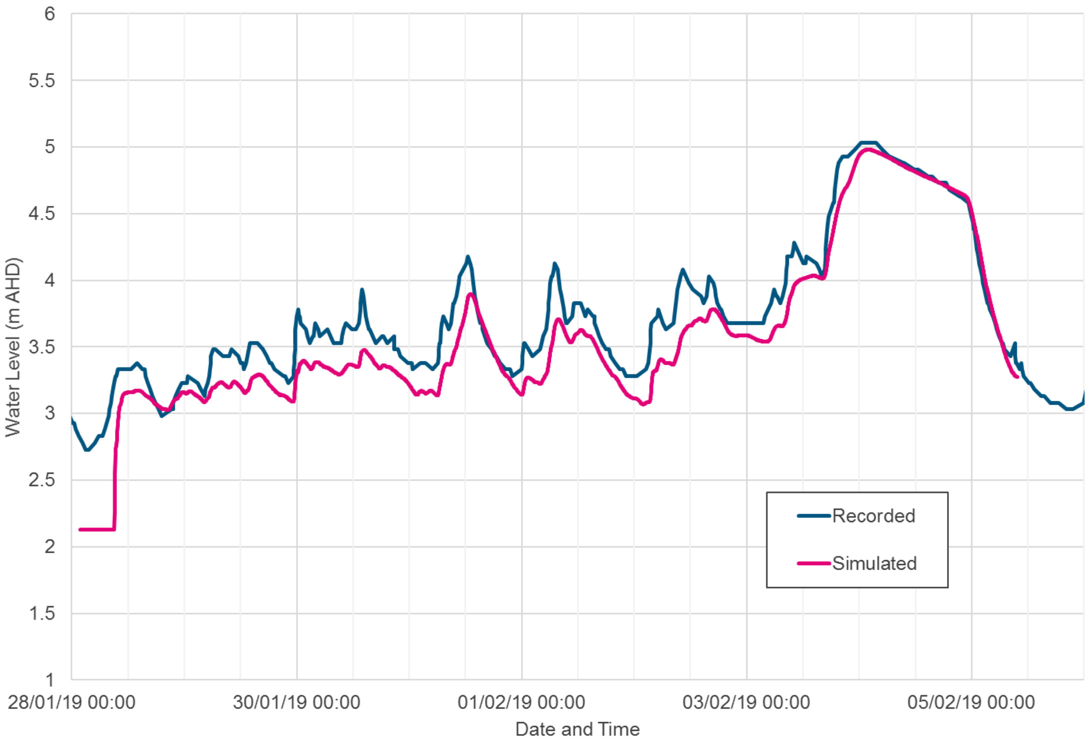

Figure 5-7 February 2019 event calibration at Gordon Creek ALERT

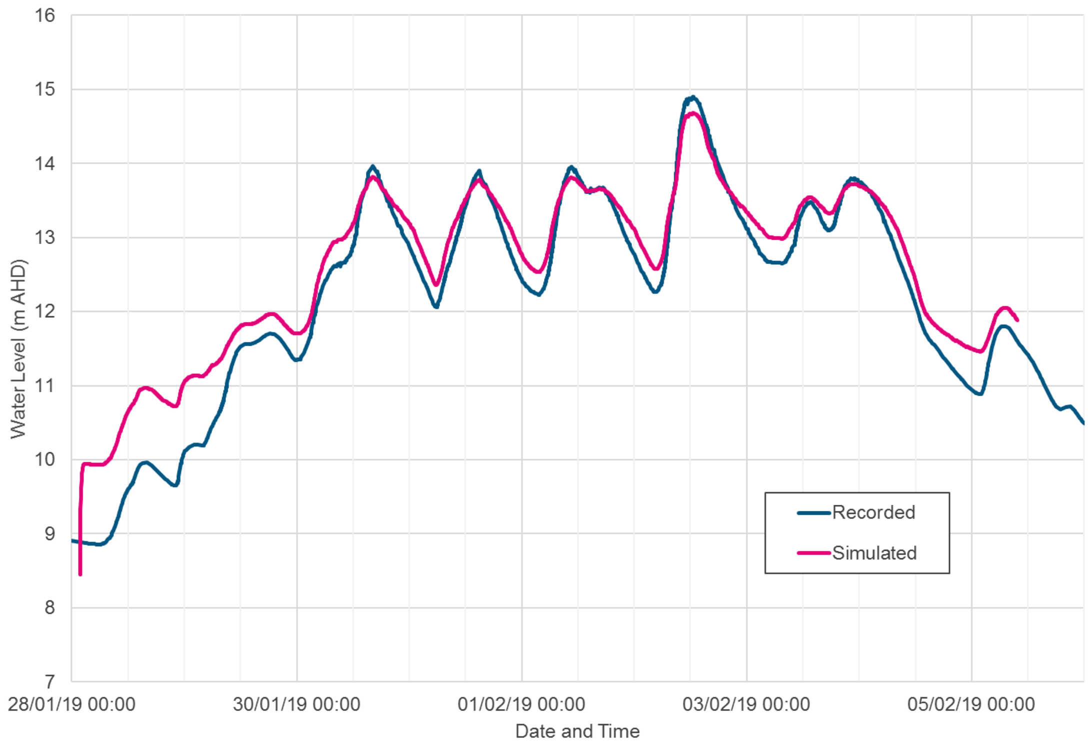

Figure 5-8 February 2019 event calibration at Bohle River ALERT

Sensitivity analysis has been undertaken on bathymetry and surface roughness, without any improvement to the match between observed and simulated water levels. Due to time constraints associated with this review, further analysis on the accuracy of gauges (influencing water level records) or accuracy of the rating curve at the dam (influencing discharge) has not been conducted.

Hydraulic modelling surface roughness coefficients adopted in the final simulations are presented in Table 5-1.

Table 5-1 Mannings 'n' surface roughness adopted during model calibration

Land Use	Mannings 'n'
Pasture / Agriculture	0.070
Light Vegetation	0.080
Medium Vegetation	0.100
Dense Vegetation	1.500
Roads	0.025
Urban Block	1.000
Water Bodies	0.040

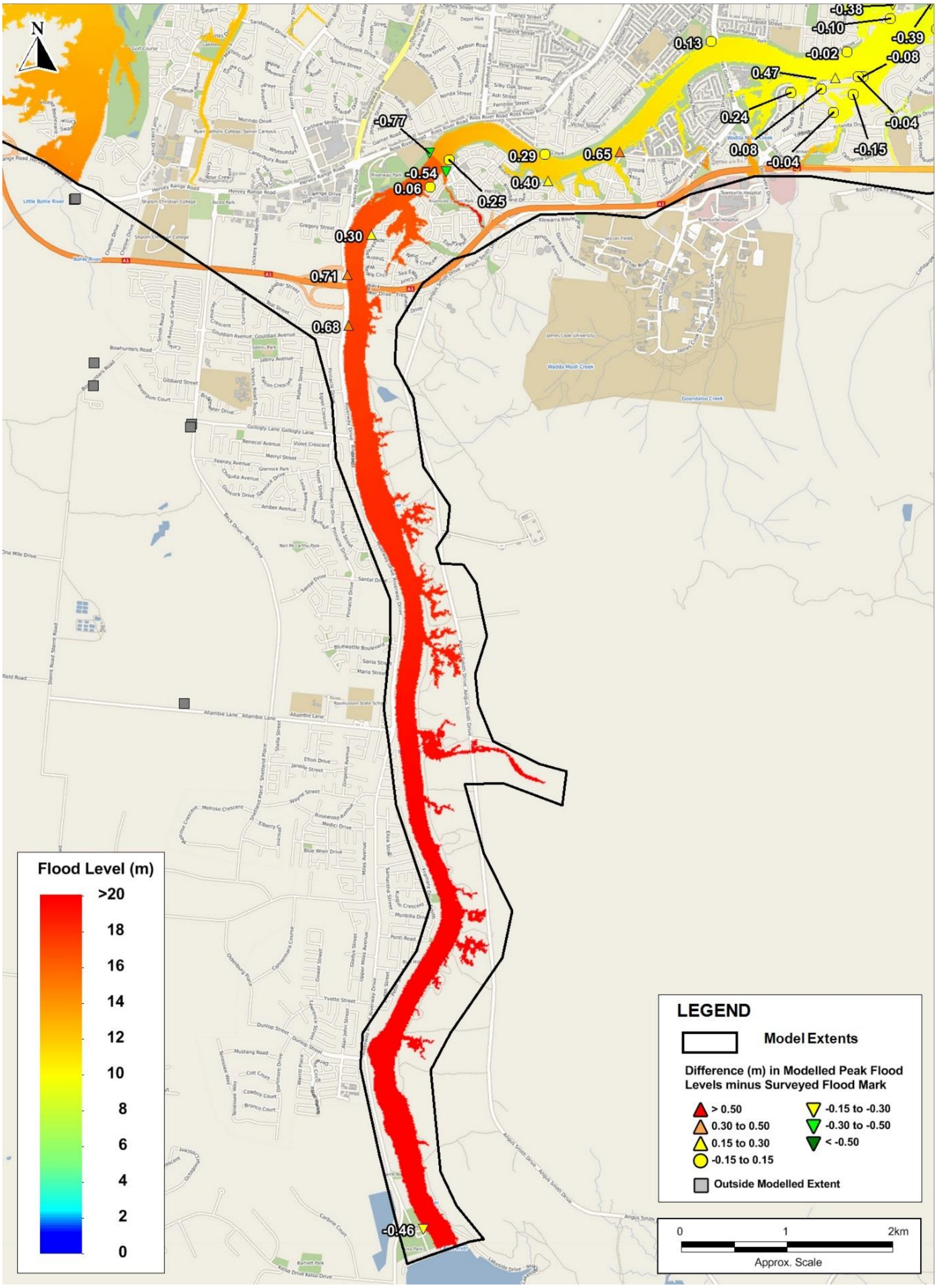

Figure 5-9 Peak flood levels and calibration summary

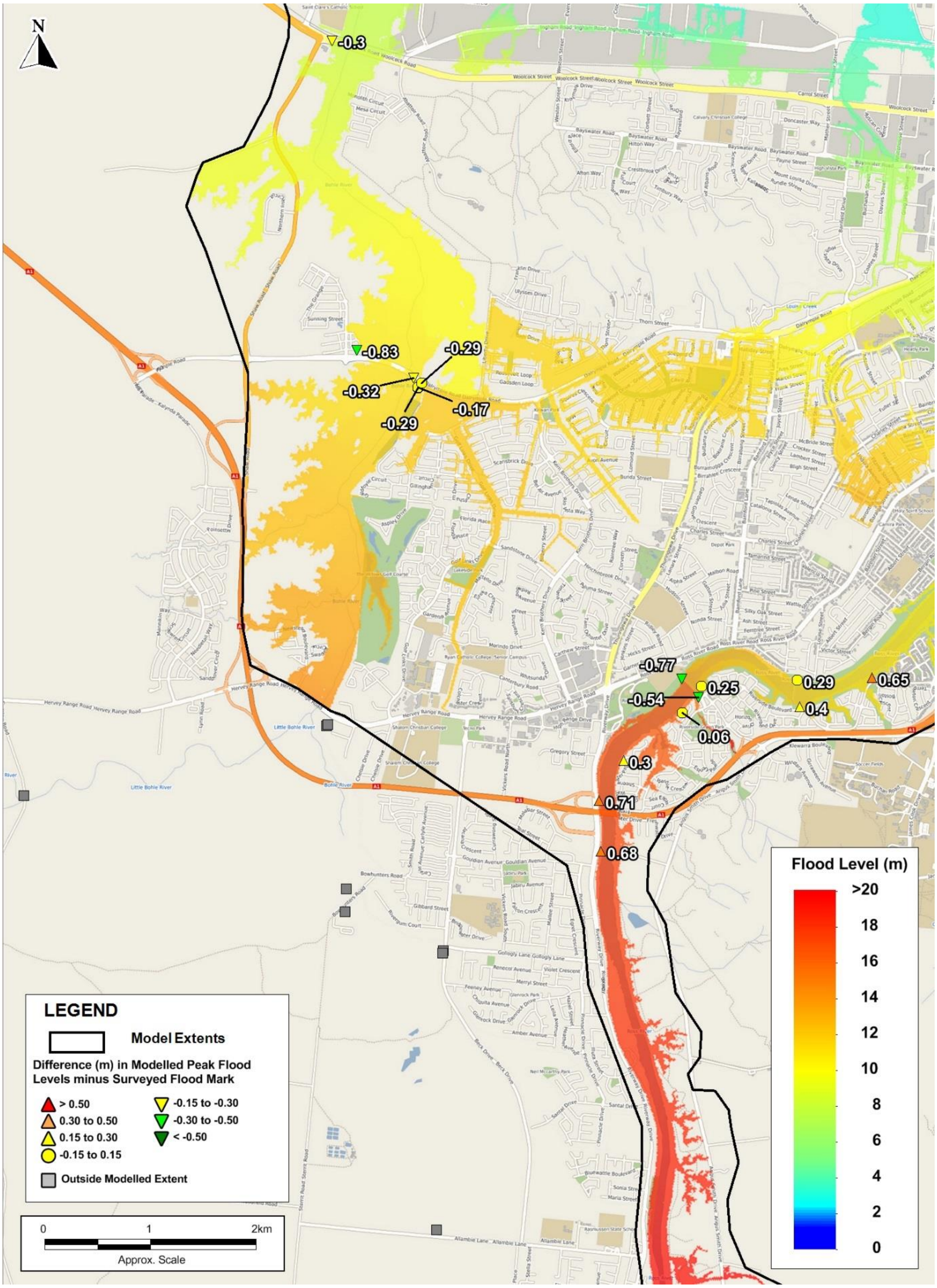

Figure 5-10 Peak flood levels and calibration summary

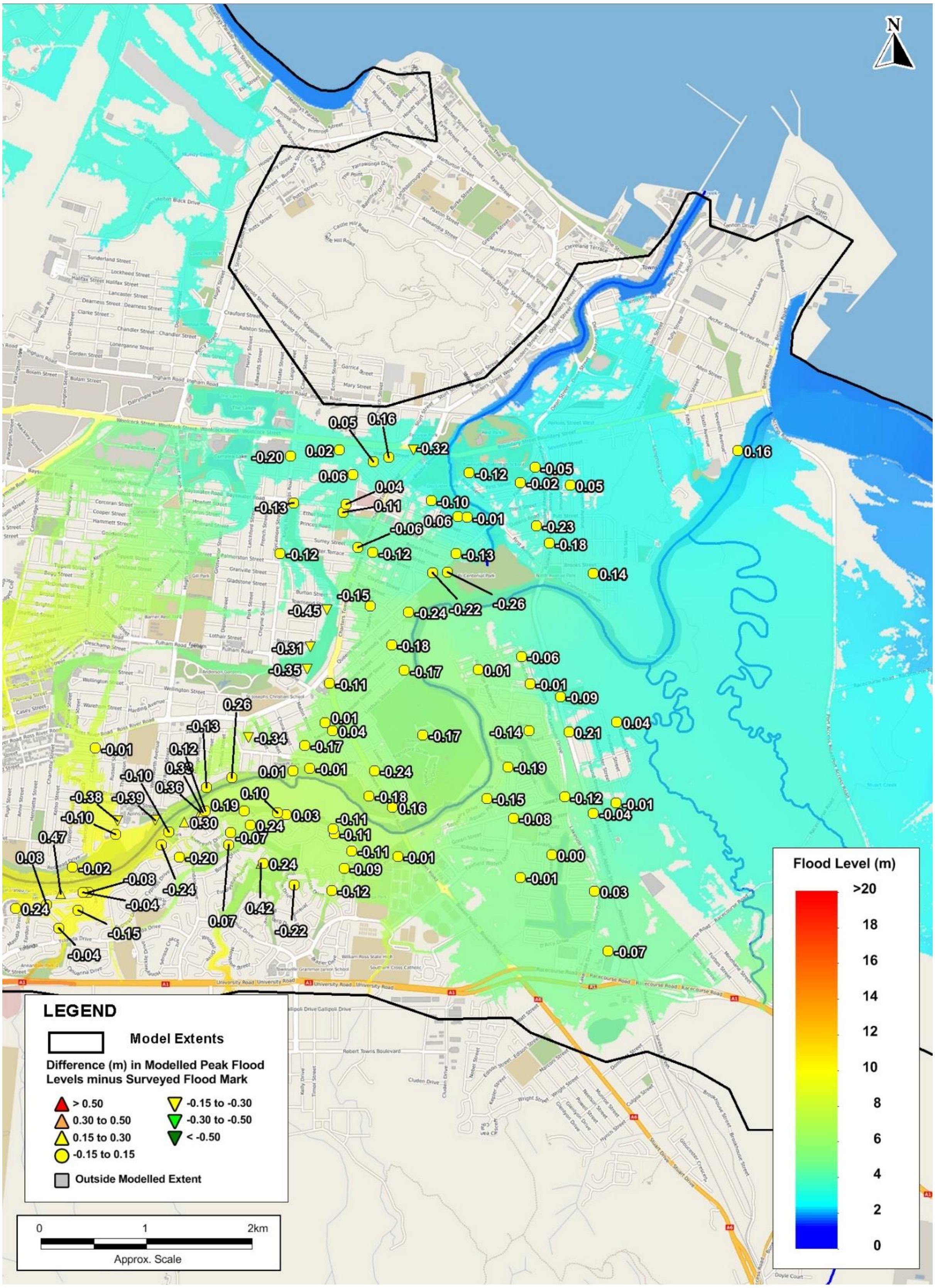

Figure 5-11 Peak flood levels and calibration summary

6 Scenarios

6.1 Summary

A range of scenarios have been assessed to understand the impact that alternate operation of the dam would have had on downstream flooding. Each scenario is compared to the actual event to determine impacts in terms of:

- Discharge;
- Peak flood level and flood extents; and
- Time of peak flood levels.

There are uncertainties associated with flood modelling. The flood mapping presented for the February 2019 event in Section 5 is the best estimate of flood behaviour based on the data available for calibration and verification of the model.

The scenario assessments presented here are relative assessments. Therefore, inaccuracies associated with modelling will be present within the February 2019 event model **and** the scenario model simulations. The relevance of this is that any potential inaccuracies will have little, or no, influence on the impacts that are presented. Impacts should be assessed on a regional scale, and the mapping should not be used to assess changes in flood behaviour on an individual lot scale.

The following scenarios have been assessed:

- Scenario 1 – As operated during the flood event (i.e. February 2019 event as it happened).
- Scenario 2 – If the Dam was not in existence.
- Scenario 3 – If Dam was operated in accordance with standard operating procedures and specifications and the relevant aspects of the Ross River Dam Emergency Action Plan (EAP).
- Scenario 4 – If dam release had occurred earlier.

Refer to the following sections where each scenario is described, and the impacts discussed.

6.2 Scenario 1: As operated during the flood event

6.2.1 Description

The timeline of the event is provided in Section 4.1. This simulation is provided as the baseline for comparison of the scenarios.

6.2.2 Flood Behaviour

Simulated peak flood levels are presented in Figure 6-1, Figure 6-2 and Figure 6-3. Note that the mapping is based on 2016 LiDAR survey and does not account for development that has taken place since the survey.

Some key points of interest are:

- Flows in the Ross River are mostly contained within the river channel until the river reaches the Nathan Street (Bruce Highway) bridge. Beyond the Nathan Street Bridge to Aplin's Weir and beyond, low lying suburbs along the river experience inundation.
- Upstream from Aplin's Weir, there appears to be a small breakout of flow on the left (northern) bank, allowing water to flow into the Mindham Park Drain and on to Ross Creek.
- From upstream of the Bowen Road Bridge to the golf course upstream from Rooney's Bridge, there was breakout from the left bank, with high velocities observed across Bowen Road. Around Rooney's Bridge area, breakout flows across the left bank, flowed into Ross Creek.
- On the right (southern) bank, there was breakout of flow upstream from Bowen Road Bridge, with water entering the Gordon Creek catchment. Between Bowen Road Bridge and Rooney's Bridge, there was significant inundation of the low-lying suburbs.

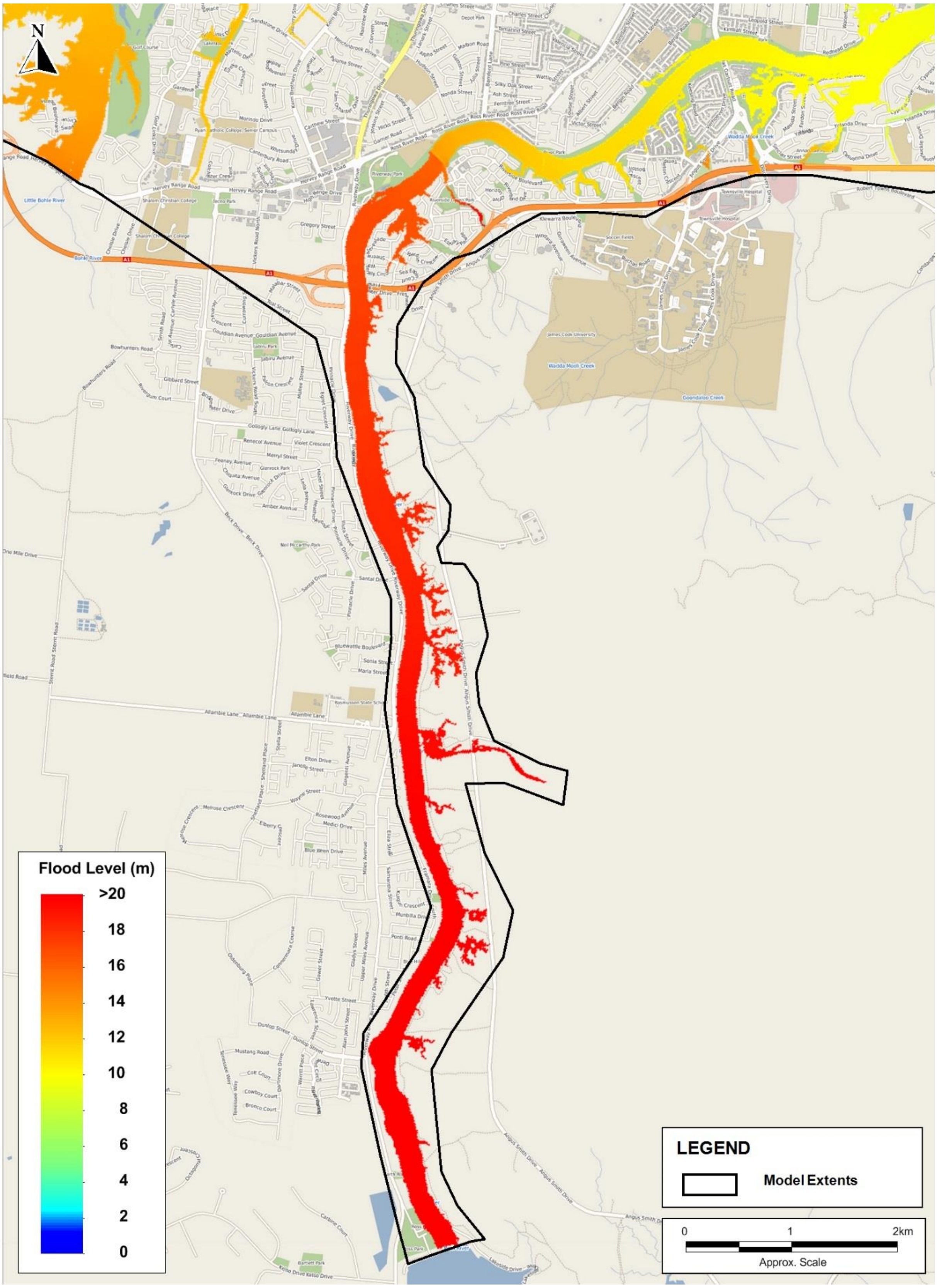

Figure 6-1 Peak flood levels – Scenario 1 – 2019 event as it happened

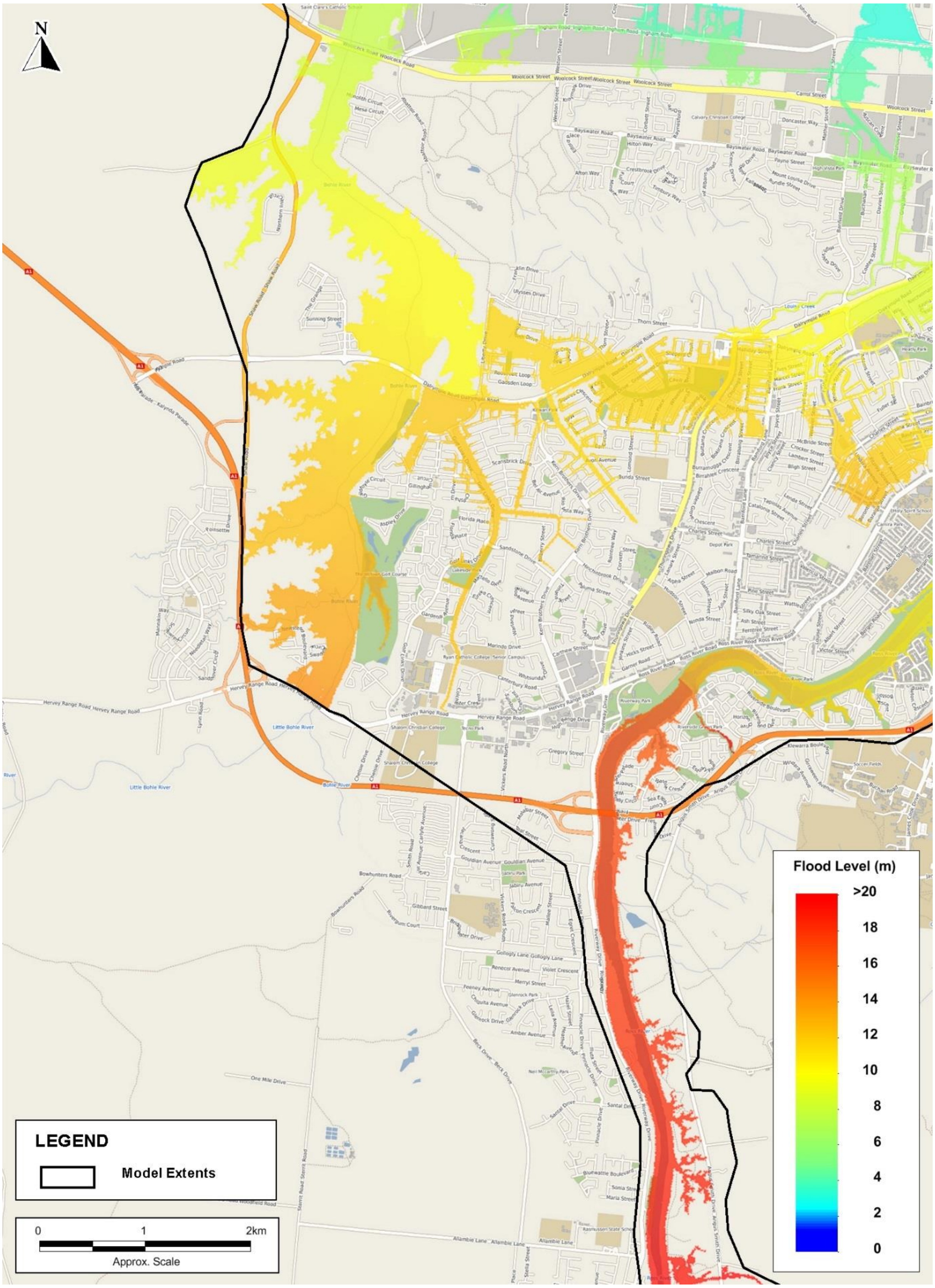

Figure 6-2 Peak flood levels – Scenario 1 – 2019 event as it happened

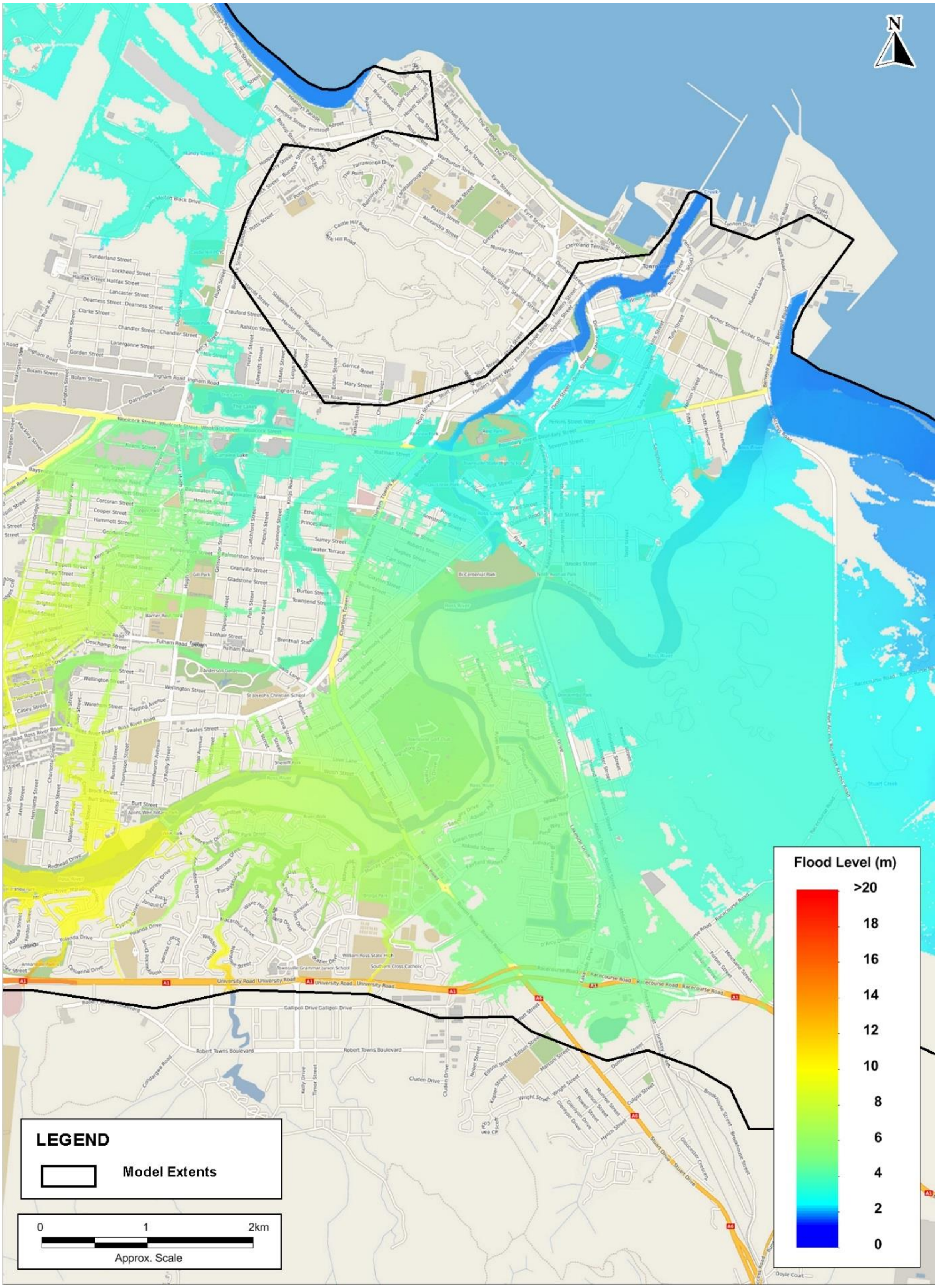

Figure 6-3 Peak flood levels – Scenario 1 – 2019 event as it happened

6.3 Scenario 2 – If the Dam was not in existence

6.3.1 Description

The flood model was updated to remove the Ross River Dam. Upstream inflows, accounting for infiltration losses, were applied directly to the Ross River at the dam location. Peak flood level grids from the 2019 event (as it happened) Scenario 1 were subtracted from the Scenario 2 grids. The result is a grid of 'impacts', indicating how much higher flood levels would have been under this scenario, as well as how much additional areas would have been inundated.

The peak discharge for the 'no dam' scenario is presented in Figure 6-4. Discharge has been calculated using the URBS hydrology model.

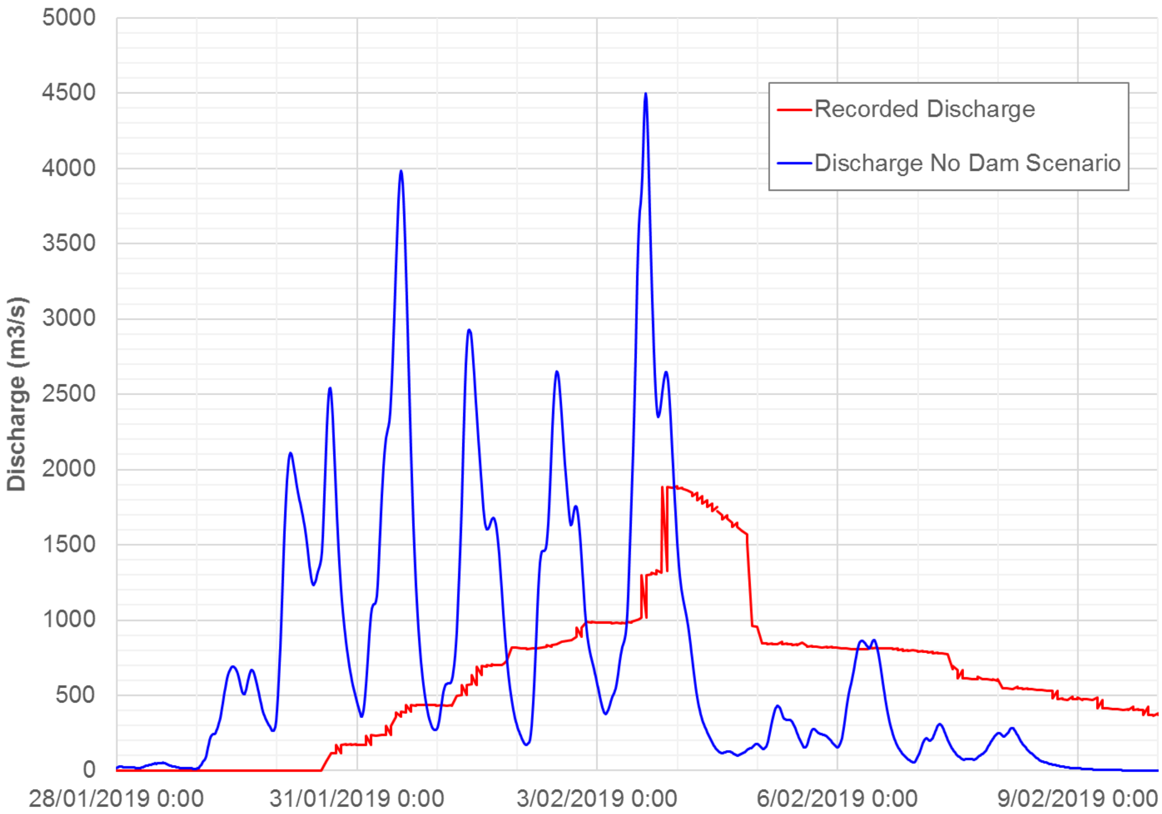

Figure 6-4 Ross River discharge for No Dam scenario

6.3.2 Flood Behaviour

Differences in peak flood levels are presented in Figure 6-5, Figure 6-6 and Figure 6-7.

Some key points of interest are:

- The areas which experienced flooding in the event would have had an additional 0.5m depth of inundation should the dam not have existed.
- A large area (shown in magenta in the following figures) would have also experienced flooding in this scenario. These areas are not expected to have been impacted by the Ross River during the 2019 event.

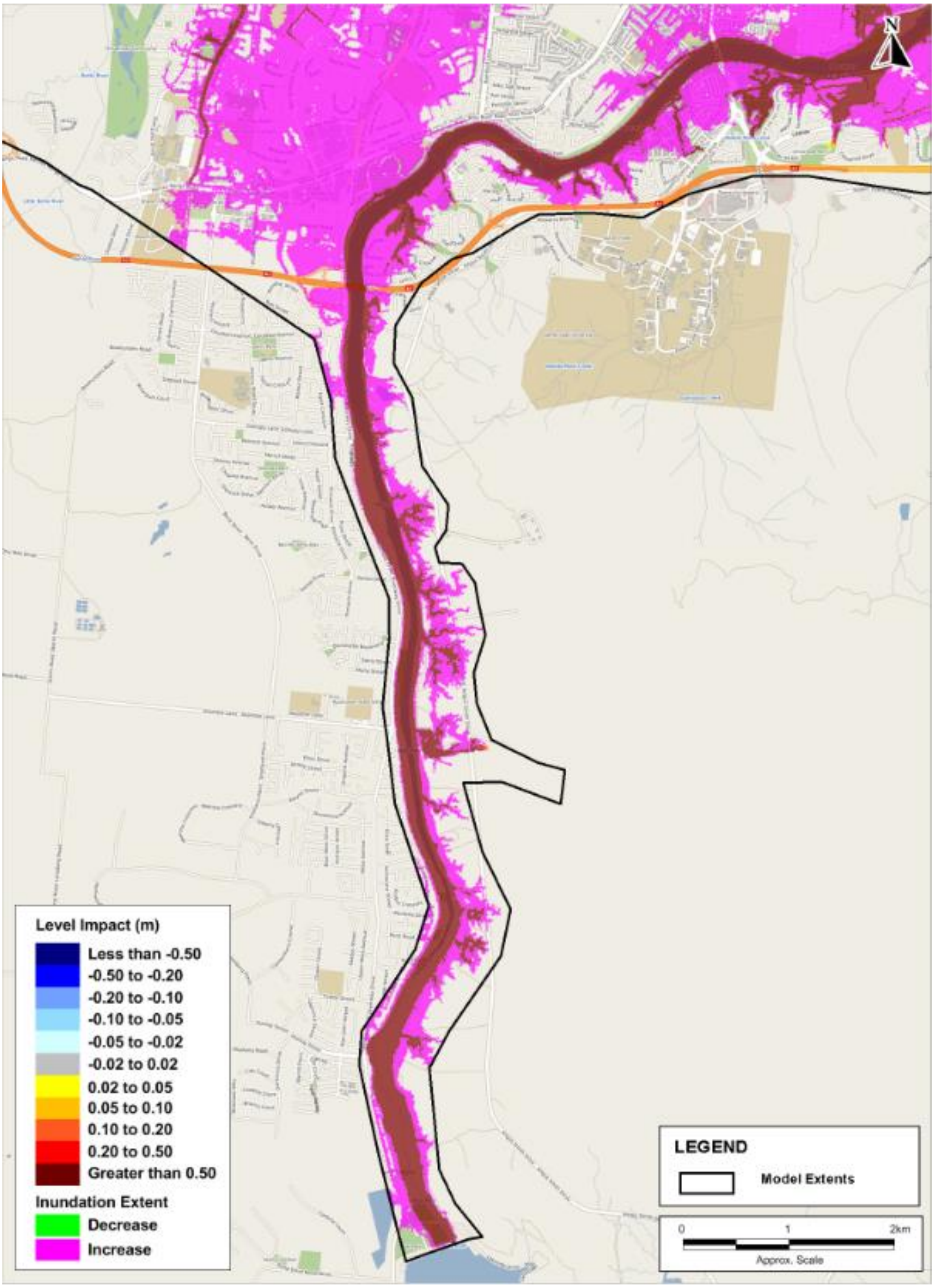

Figure 6-5 Peak flood level impacts - Scenario 2 – If the Dam was not in existence[5]

[5] Flooding in the Upper Bohle is not shown as it is not influenced by the Ross River.

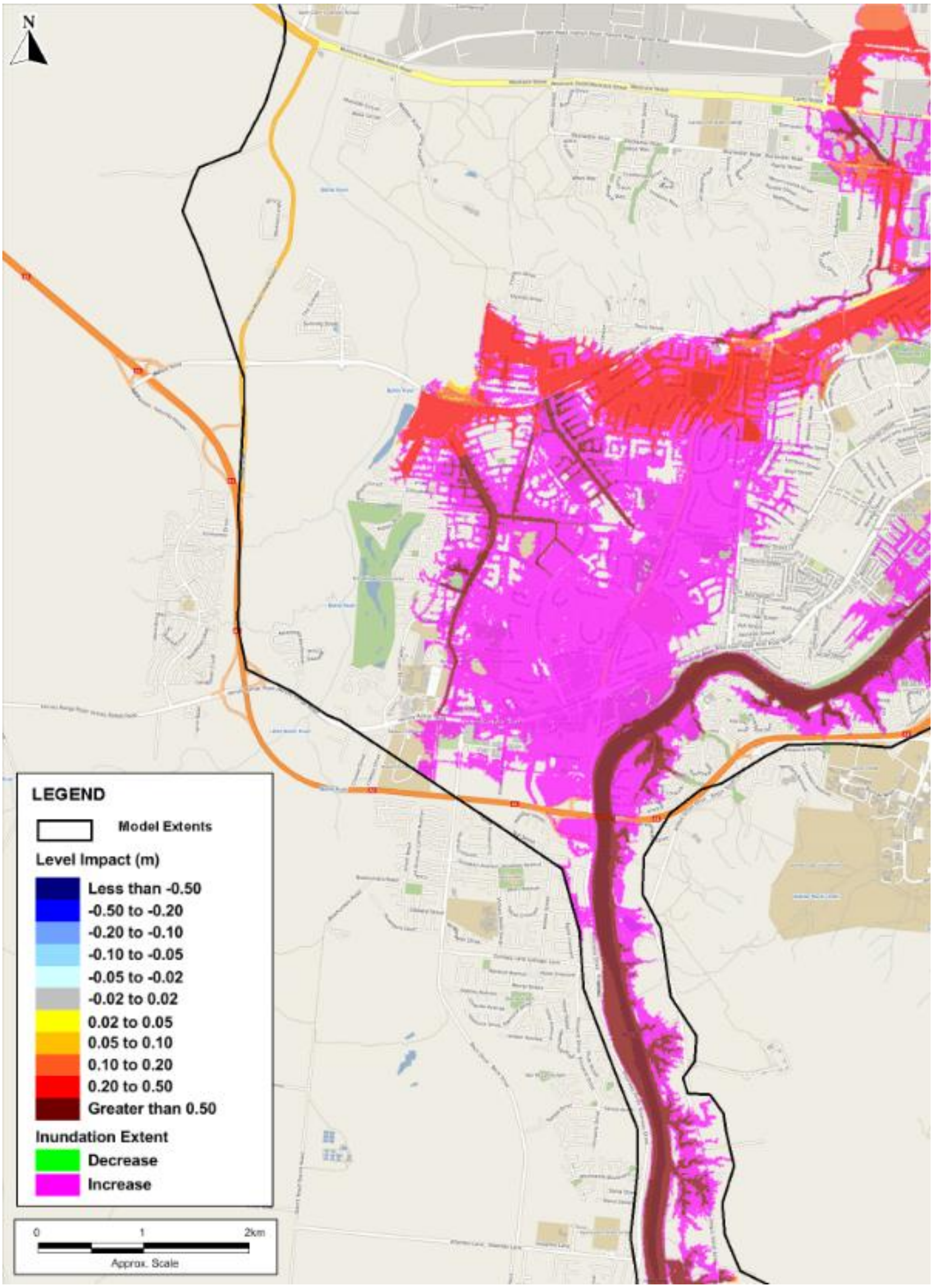

Figure 6-6 Peak flood level impacts - Scenario 2 – If the Dam was not in existence[6]

[6] Flooding in the Upper Bohle is not shown as it is not influenced by the Ross River.

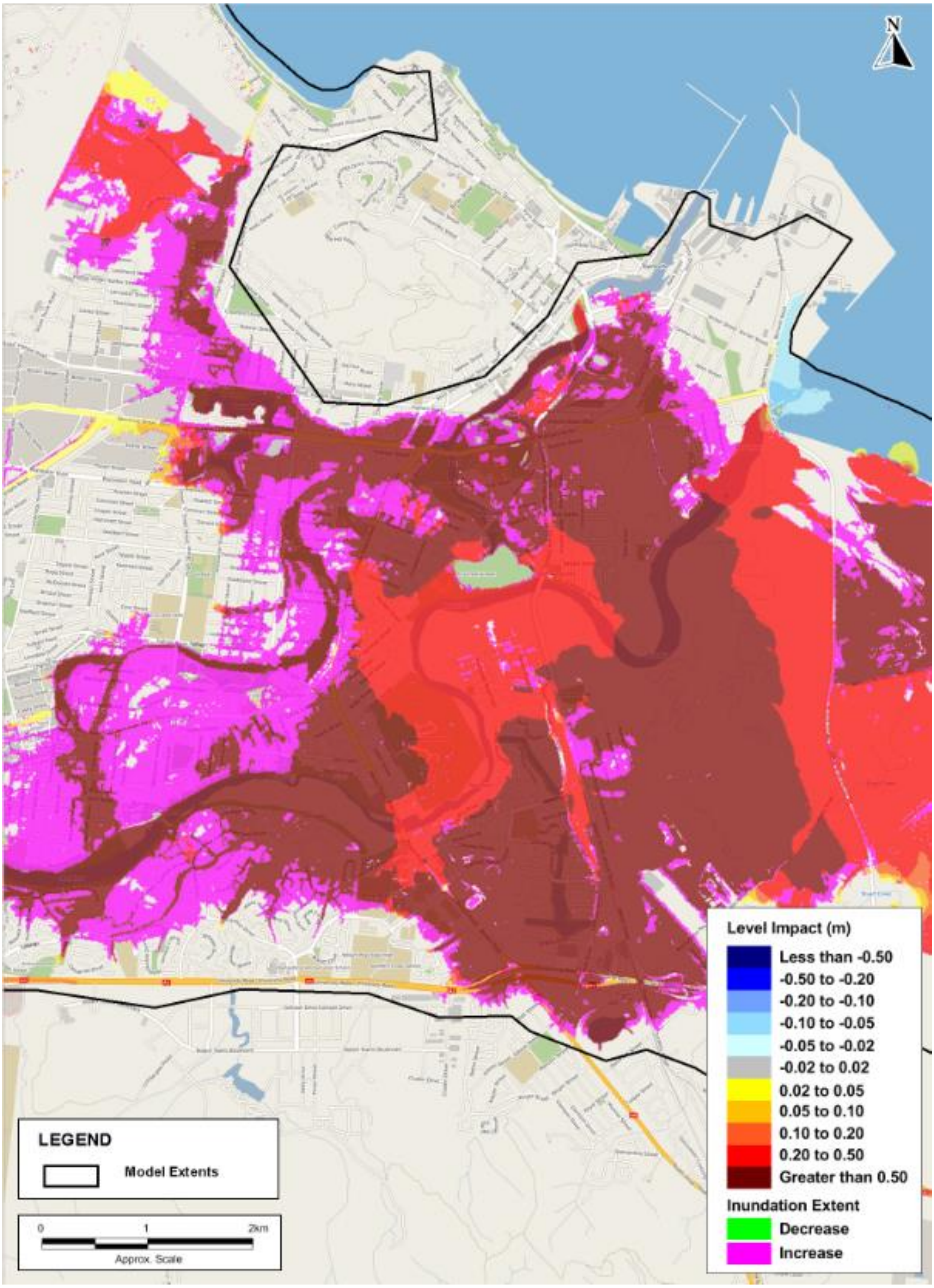

Figure 6-7 Peak flood level impacts - Scenario 2 – If the Dam was not in existence

6.4 Scenario 3 – If Dam was operated in accordance with standard operating procedures

6.4.1 Description

The expected outflow from the dam was calculated for the scenario where the dam was operated in accordance with the standard operating procedures (SOPs). The peak discharge scenario is presented in Figure 6-8.

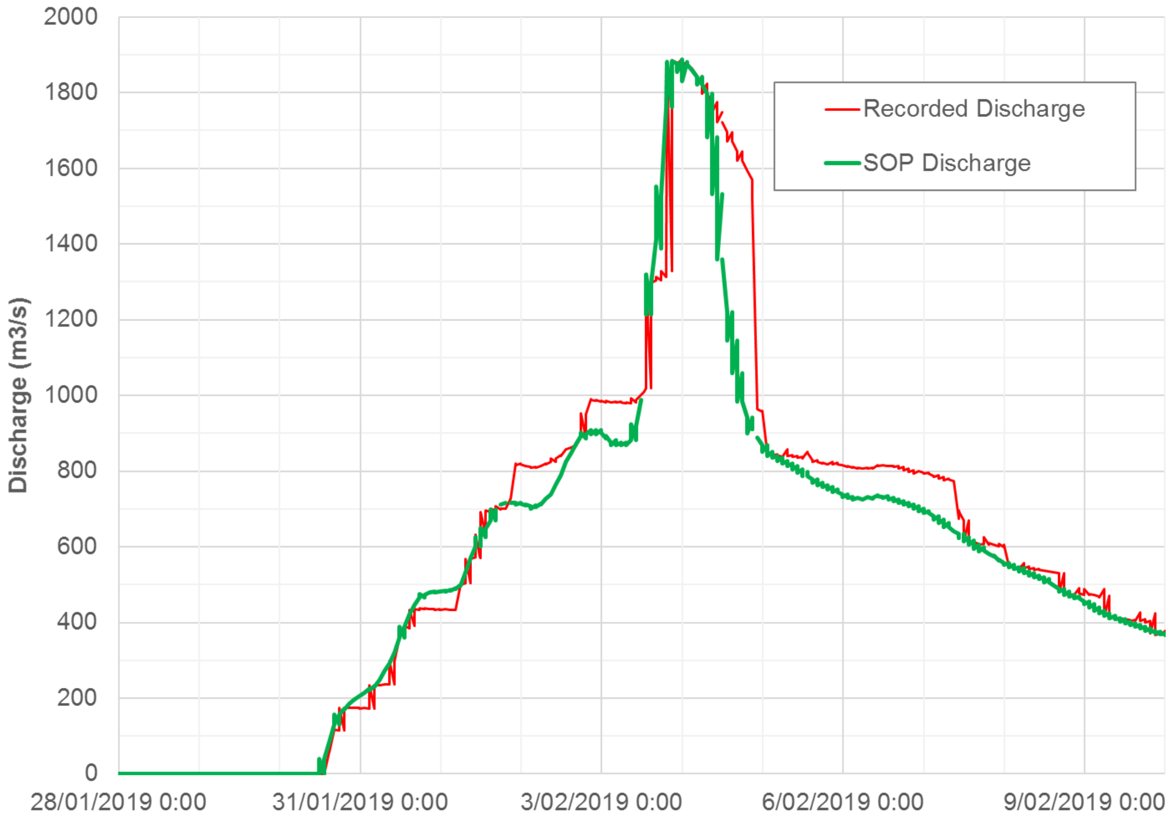

Figure 6-8 Ross River discharge for standard operating procedure scenario

Water level observations in the dam exhibit some noise (fluctuations in recorded values). Development of a dam model that is perfectly calibrated to the event has not been possible, since the sensitivity of water levels to gate operations, results in large differences in discharge from the dam. Therefore, some assumptions have been made in the calculation of scenario discharge hydrographs:

- Discharge associated with different water levels has been interpolated between gate operation trigger levels. In reality, the gates open in a stepwise manner once a particular trigger is reached, and the discharge remains relatively constant until the next gate trigger is reached. This accounts for the steps in the red line in Figure 6-8. The volumetric difference between the two hydrographs leading to the peak of the event is approximately 4% (greater volume in the SOP scenario).

- Calculation of a stepwise discharge hydrograph results in rapid fluctuations in discharge due to the water level observations. A similar level of inaccuracy is present using this method of calculation.
- The water level in the dam has not been adjusted to account for the early releases. Without the manual operation (early releases), the final water level in the dam would have been slightly higher, resulting in higher discharge.

Changes to the peak water level would have affected the timing of peak discharge, which would have affected the interaction of the peak flood wave with the tide. Flooding in the lower Ross River is very sensitive to the tide. Peak flood levels in the Townsville area in the SOP scenario would have occurred 1.5 hours before the actual peak.

Given the variables involved in calculating minor changes to dam discharges and associated flooding impacts, the above assumptions are considered acceptable for assessing the potential impacts.

6.4.2 Flood Behaviour

Potential differences in peak flood levels are presented in Figure 6-9 and Figure 6-10.

Some key points of interest are:

- From the Ross River Dam to the Nathan Street (Bruce Highway) Bridge, there would have been no difference in peak flood levels.
- A large part of the Gordon Creek catchment could have experienced higher flood levels by up to 50mm.
- Along the Mindham Park Drain, peak flood levels could have been up to 100mm higher.
- In the Woolcock Street area around National Creek, peak flood levels could have been up to 50mm higher.

Note that some of the impact shown may be attributable to the additional 4% volume in the SOP scenario, although the timing is also different. Note also that the impact shown does not occur at the same time in all areas.

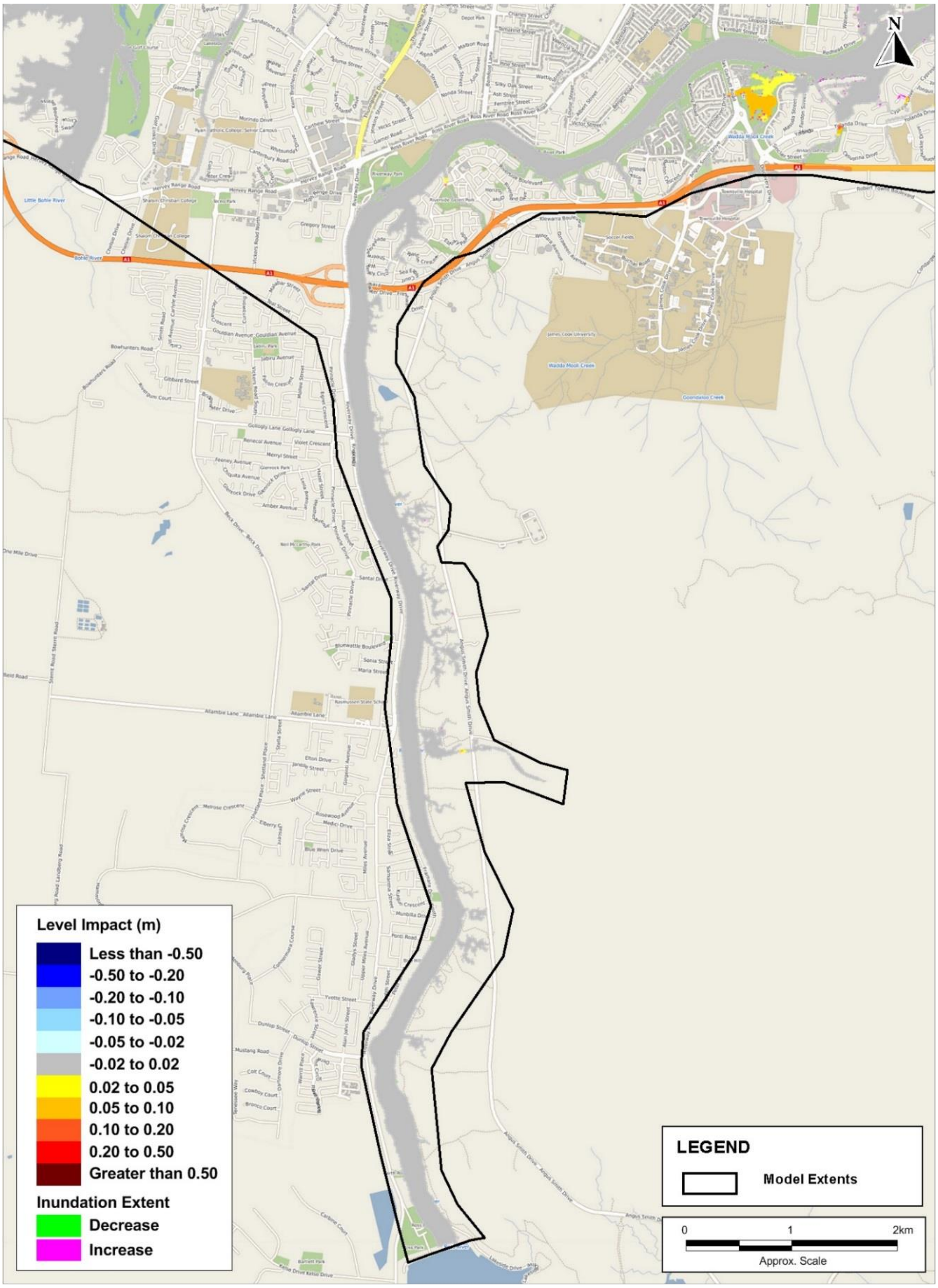

Figure 6-9 Peak flood level impacts - Scenario 3 – If the Dam was operated in accordance with Standard Operating Procedures[7]

[7] Flooding in the Upper Bohle is not shown as it is not influenced by the Ross River.

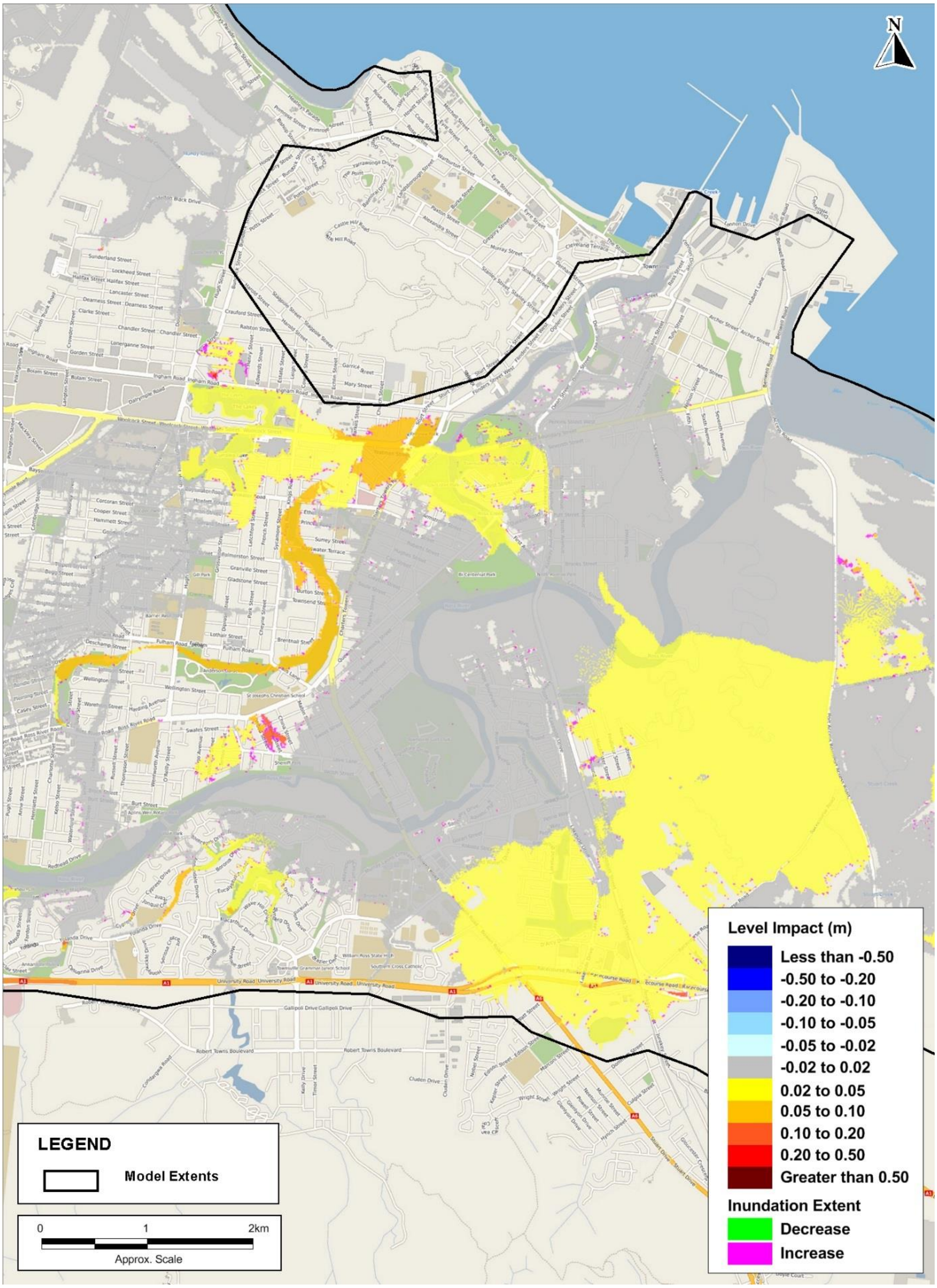

Figure 6-10 Peak flood level impacts - Scenario 3 – If the Dam was operated in accordance with Standard Operating Procedures

6.5 Scenario 4 – If dam release had occurred earlier

6.5.1 Description

The potential for increased dam releases has been assessed. The *Ross River Flood Study Baseline Flooding Assessment* (Townsville City Council, 2013) identifies that the Ross River has a capacity of approximately 500m^3/s before water exceeds the banks and inundates properties. The flood model developed for this review was used to test the river capacity verifying the findings from the flood study.

The model was also used to simulate a scenario representing local tributary inflows downstream from the dam, with no release from the dam. This allowed the peak flow rate in the Ross River at Aplin's Weir (from local inflows) to be calculated for the early part of the event, to identify how much spare capacity the river had before properties were affected. The local inflow component was assessed to be 150m^3/s.

Subtracting the calculated 150m^3/s flow from the 500m^3/s peak capacity results in 350m^3/s of residual capacity in the Ross River. This represents the maximum release from the dam that could have occurred without flooding downstream properties.

In this hypothetical scenario, it has been assumed that dam releases would not have occurred until the dam had reached full supply level. At this point, 350m^3/s would have been released for a period of 21 hours until the water level in the dam would have led to more than 350m^3/s release under the current operational rules. Refer to Figure 6-8 for potential early release discharge comparison.

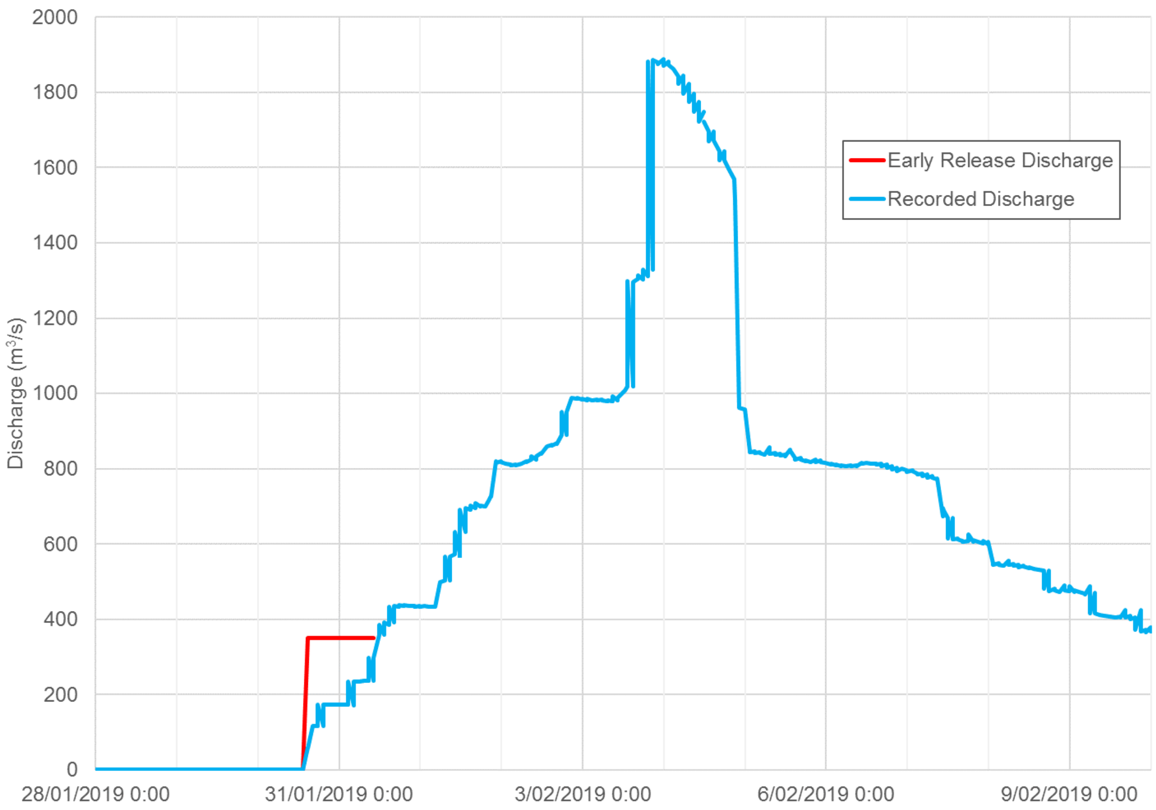

Figure 6-11 Ross River Dam discharge for early release scenario

6.5.2 Flood Behaviour

Analysis indicates water levels in the dam would not have been noticeably affected by this release scenario, and that the peak discharge (rate and timing) would not have differed from the actual event.

Modelling for this scenario has not been undertaken since the volumetric difference associated with the early release is within the error margin associated with the calculation of inflows due to the poor quality of water level records. Therefore, mapping would present an unreliable representation of the impacts of this scenario. The actual flood level impact would be negligible compared to actual flooding levels.

7 Conclusions

7.1 Responses to the Scope of Works

The scope of work for this independent review required the following:

- ***An assessment of the inflows and outflows from Ross River Dam for the event and an assessment of the Annual Exceedance Probability (AEP) of the event. An assessment of tributary inflows downstream of Ross River Dam.***

  The inflows and outflows have been assessed. Dam inflows were responsive to the intense rainfall bursts on each day throughout the event. At the peak, it is expected that around 4,500m^3/s entered the dam, though there is some uncertainty with this estimate due to irregular gauge level fluctuations. The peak outflow was recorded to be 1,888m^3/s indicating significant attenuation from the dam.

  The AEP has been assessed in the context of rainfall, water levels and discharge. Whilst some rain gauges reported rainfall in excess of the 0.05% AEP (or 2,000 year average recurrence interval) the February 2019 event is considered to have an AEP between 0.5% and 0.1% (500 – 1,000 year ARI). The event is most likely to be closer to a 0.1% AEP (1,000 year ARI).

  Tributary inflows are only expected to have contributed 150m^3/s to the flow within the Ross River.

- ***An assessment of the possible flooding impacts on communities downstream of the dam:***
  - ***If the Dam was not in existence***
  - ***If Dam was operated in accordance with standard operating procedures and specifications and the relevant aspects of the Ross River Dam Emergency Action Plan (EAP)***
  - ***As operated during the flood event***
  - ***If dam release had occurred earlier***

  The four scenarios have been assessed, with the following outcomes:

  - If the dam was not in existence, the discharge in the Lower Ross River would have been more than double what was actually experienced in the event. This would have caused higher flood levels by more than 0.5m and much broader flood extents, inundating areas that were not affected during the flood, including breakout into the Bohle River.
  - If the dam was operated in accordance with the standard operating procedures, peak flood levels would have been up to 100mm higher in some areas. The manual operation of the dam did not worsen flooding in any area over that which would have occurred under standard operating procedures.
  - There was very little scope for releasing water earlier in the event, without adversely impacting properties, or allowing releases before the dam was full. Should early releases have been permitted under the EAP, the peak flood levels and timing would not have been noticeably different from the actual event when flooding constraints are taken into account.

7.2 Key Findings

The key findings from this review are:

- **Operational**
  - SunWater acted in accordance with their obligations under the Emergency Action Plan. The four periods of manual operation of the dam gates were under the direction of Council.
  - The manual operation of the dam resulted in lower water levels in some parts of Townsville than would have occurred under standard operating procedures. There were no areas that experienced higher flood levels due to the manual operation.
- **Monitoring**
  - There is a suitable distribution of rain gauges throughout the Ross River catchment for monitoring regional rainfall events and informing flood forecasting and warning activities.
  - The gauge network operated effectively during the event, except for a small percentage of sites.
  - There is inadequate monitoring of river levels upstream from the Ross River Dam; however this did not significantly impact on the operation of the dam and the management of the flood.
  - The instrumentation used for monitoring dam levels appears to have malfunctioned, giving inaccurate levels to plus or minus 150mm at times.
  - There is no redundancy for dam level recording which is a critical input to dam operations.
  - The river gauges throughout the Ross River catchment did not perform well as a whole. Some sites failed, whilst others exhibit noise within the records.
  - There is no river gauge on the upstream reaches of Ross Creek, meaning that the discharge of water from the Ross River cannot be verified.
- **Prediction**
  - The predicted releases from the dam in terms of rate of discharge and expected inundation were well understood.
- **Flood Mapping**
  - Council's flood modelling and mapping appears to be robust. In accordance with best management practise, the flood modelling should be revisited, calibrating to the February 2019 event.
- **Warning**
  - Whilst evacuation warnings and orders were effectively communicated to the community, communication of the extent and depth of inundation to the affected community could be improved.
- **Awareness**
  - Awareness of flood risk appears to be low amongst the community.

8 Qualifications

There are uncertainties associated with flood modelling. The flood mapping presented is the best estimate of flood behaviour based on the limited data available for calibration and verification of the model at the time of the review. With additional data, refinements and improvements to the modelling may be possible.

The scenario assessments presented here are relative assessments. Therefore, uncertainties associated with modelling will be present within the February 2019 event model and the scenario model simulations. The relevance of this is that any potential inaccuracies will have little, or no, influence on the impacts that are presented. Impacts should be assessed on a regional scale, and the mapping should not be used to assess changes in flood behaviour on an individual lot scale. Insufficient field water level data has been recovered to date to allow a high degree of confidence in flood levels predicted by modelling.

There is uncertainty in rainfall across the Ross River catchment due to limitations in the number and location of rainfall stations. Hence, there is uncertainty in the accuracy of rainfall / runoff predictions, and associated flood predictions. All floods can be different and future observed flooding characteristics may vary from model predictions presented.

The report has assessed various scenarios for alternate dam situations from a theoretical viewpoint to provide information on the range of potential effects of the dam on the broader Ross River catchment. Some of these options may not be feasible from a water security or public safety viewpoint, and this report should not be seen as an endorsement of such alternate scenarios assessed. Some scenarios would be in breach of the current approved dam operation manual and any change to the manual would require approval from the State's Dam Safety Officer.

The review has relied upon an extensive amount of data and information provided by IGEM, SunWater, DNRM, the Bureau of Meteorology and Townsville City Council. The accuracy of our report is limited to the accuracy and completeness of this data and information.

The report has been specifically prepared to address the Statement of Works (Appendix A), which defined specific questions to be addressed, and as such may be unsuitable for other purposes. Any third party should seek clarification from BMT Eastern Australia Pty Ltd as to whether the report is suitable for the proposed use.

Appendix A Statement of Work Request

Queensland Government

1.1 INTRODUCTION

On Friday, 8 February 2019, as the communities affected by the monsoonal trough rainfall and floods entered the recovery phase, the Minister for Fire and Emergency Services tasked the Inspector-General Emergency Management (IGEM) to review key preparedness and response elements for this event, including the operation of impacted dams.

The purpose of this review is to identify lessons that will inform continuous improvement in Queensland Disaster Management Arrangements.

The agency requires the services of the supplier to assess the performance of Ross River Dam in the lead-up to, and during, the late January/early February 2019 flood event and the impact the dam's operations had on flooding downstream of the Dam

1.2 SCOPE

To report on the impact of the rainfall event associated with the 2019 Monsoon Trough and quantify any affect operations of the Ross River Dam had on associated flooding downstream of the Dam.

Assess the performance of Ross River Dam in the lead-up to, and during, the late January/early February 2019 flood event and the impact the dam's operations had on flooding downstream of the Dam.

1.3 BACKGROUND

A monsoon trough and embedded tropical low tracked slowly south over the Cape York Peninsular during 26 and 30 January 2019. Coastal locations between Innisfail and Cooktown received the highest falls during this period. By 28 January 2019 the rainfall had shifted south, and the impact area was widespread from Cairns to Mackay, with the focus area centred around Townsville.

The deluge of rain that fell across northern and inland Queensland during late January and February 2019 had catastrophic impacts to the agricultural industry and saw evacuations, mass inundation to residential and commercial properties and isolation of communities.

Some of the locations most affected by this event include: Townsville City, Paluma, Woolshed, Upper Bluewater, Julie Creek and Richmond. The deluge broke some records not seen in sixty-six years and made new records of never before seen rainfall figures.

The rainfall fell across multiple dam catchments and resulted in emergency action plans being enacted. The dam response will form part of this review with a focus on the Ross River Dam.

The review team will work closely with Queensland Fire and Emergency Services, Queensland Police Service, local, State, Federal agencies and other relevant entities to identify outcomes and lessons that will inform continuous improvement.

1.4 MANDATORY REQUIREMENTS

The supplier will be engaged in accordance with Standing Offer Arrangement (SOA) DSITIASD01 under which the organisation is an approved supplier for SOA Category 1 and 14 which are relevant to this Statement of Work Request.

1.5 LIST OF RELEVANT DOCUMENTS

Ross River Flood Study Base-Line Flooding Assessment, January 2013.

1.6 REQUIREMENTS

Specifically deliver:

1. An assessment of the inflows and outflows from Ross River Dam for the event and an assessment of the Annual Exceedance Probability of the event. An assessment of tributary inflows downstream of Ross River Dam.
2. An assessment of the possible flooding impacts on communities downstream of the dam:
   - If the Dam was not in existence
   - If Dam was operated in accordance with standard operating procedures and specifications and the relevant aspects of the Ross River Dam Emergency Action Plan (EAP)
   - As operated during the flood event
   - If dam release had occurred earlier
3. A report on the outcomes of the assessments which includes details of the:
   - Methodologies applied in undertaking the assessment
   - Data which was incorporated into the assessment
   - Results and conclusions of the assessment and the facts and evidence on which these conclusions were based.

This information will be used to inform consultation with local communities and stakeholders.

1.7 TIMEFRAME

The Inspector-General Emergency Management will deliver his review, to which this report contributes, on 17 June 2019. An interim report/findings is required to be presented to IGEM by 17 April. The final report should be delivered by 8 May 2019.

1.8 WARRANTY AND SUPPORT

This is provided for under the SOA DSITIASD01 terms and conditions.

1.9 PRICING

A quote is to provide a firm price to undertake the work specified in this Statement of Work Request, including GST exclusive value, GST amount and the total price.

1.10 PAYMENT OF FEES

Payment of fees is dealt with under the SOA DSITIASD01 term and conditions.

1.11 PROJECT MANAGER

The project manager contact details are:

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BMT has a proven record in addressing today's engineering and environmental issues.

Our dedication to developing innovative approaches and solutions enhances our ability to meet our client's most challenging needs.

BMT in Environment

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