FRFRPS OA Update
Department of Transport and Main Roads
21-Mar-2019

Lower Fitzroy River Floodplain

2019 Baseline Model Update Report

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Client: Department of Transport and Main Roads

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21-Mar-2019

Job No.: 60578201

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Quality Information

Document Lower Fitzroy River Floodplain

Ref 60578201

Date 21-Mar-2019

Prepared by Jordan Maultby

Reviewed by Richard Corbett

Revision History

Rev	Revision Date	Details	Authorised	
			Name/Position	Signature
0	08-Mar-2019	Draft for Client Review	Ben McMaster Rockhampton Office Manager	Original Signed
A	21-Mar-2019	Final Issue	Ben McMaster Rockhampton Office Manager	Original Signed

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Glossary / Abbreviations

1-D	One Dimensional
2-D	Two Dimensional
AECOM	AECOM Australia Pty Ltd
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR&R	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
CMPS&F	Camp Scott and Furphy
DEM	Digital Elevation Model
DNRM	Queensland Department of Natural Resources and Mines
D/S	Downstream
FFA	Flood Frequency Analysis
FM	Flexible Mesh
FRFS	Fitzroy River Flood Study (Aurecon, 2011)
FRFRPS	Fitzroy River Floodplain and Road Planning Study (AECOM, 2012)
GIS	Geographical Information Systems
HPC	Heavily Parallelised Compute
LiDAR	Light Detecting and Ranging
LFCSH	2-D Layered Flow Constriction Shape
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
MIKE FLOOD	1-D / 2-D Hydraulic modelling software
OA	Options Analysis
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PWSL	Peak Water Surface Level
QUDM	Queensland Urban Drainage Manual
RCP	Reinforced Concrete Pipe
RCBC	Reinforced Concrete Box Culvert
RRC	Rockhampton Regional Council
SRFL	South Rockhampton Flood Levee
TMR	Queensland Department of Transport and Main Roads
TUFLOW	1-D / 2-D Hydraulic modelling software
URBS	Rainfall runoff routing (hydrologic) modelling software
U/S	Upstream
WSL	Water Surface Level
Note:	Rockhampton Flood Gauge Datum = AHD + 1.448m

Executive Summary

E1 Background

AECOM Australia Pty Ltd (AECOM) has been engaged by the Department of Transport and Main Roads (TMR), to update the Fitzroy River Floodplain and Road Planning Study (FRFRPS) Options Analysis (OA) undertaken by AECOM in 2012. As a separate task to the FRFRPS OA Update, AECOM were also commissioned by TMR to undertake an update to the TUFLOW hydraulic model of the Fitzroy River at Rockhampton.

The existing model is held by Rockhampton Regional Council (RRC) and was last updated by AECOM in 2014. Model updates are required by TMR prior to commencing detailed planning associated with the Rockhampton Ring Road project.

Details of the baseline model updates are the subject of this report.

The Fitzroy River, which flows through the city of Rockhampton in the state of Queensland, drains a catchment of approximately 142,000 km^2 and is one of the largest catchments on the east coast of Australia. Due to its immense size and fan-like shape, the Fitzroy River catchment is capable of producing severe flooding following heavy rainfall events in any of its major tributaries.

Rockhampton is located approximately 60 kilometres from the mouth of the Fitzroy River at Keppel Bay. The Fitzroy River at Rockhampton and adjacent townships has a long and well documented history of flooding with flood records dating back to 1859.

Generally in times of flood the magnitude of the flow is such that the main river channel is overtopped. To the northwest of Rockhampton at the Pink Lily meander significant overbank flow occurs in major flood events when the upstream river discharge exceeds 6,200 m^3/s (1 in 6-year AEP). This results in flood flows spreading over a broad floodplain to the west and south of Rockhampton. This floodwater re-joins the Fitzroy River south west of the city at Gavial Creek.

The inundation of the floodplain can result in the closure of Rockhampton Airport, the Bruce Highway, the Capricorn Highway and the North Coast Rail Line. The Bruce Highway and North Coast Rail Line can also be cut by floodwaters at the Alligator Creek Crossing near Yaamba (30 kilometres north of Rockhampton).

As major floods can last for several weeks there is often an extensive disruption to road, rail and air traffic, though construction of the Yeppen North and South Bridges has significantly reduced disruption to road traffic entering and exiting Rockhampton from the south. Extensive property damage can also occur within Rockhampton during flood events which can result in significant direct losses and pose a safety risk to the population.

E2 Need for this Update

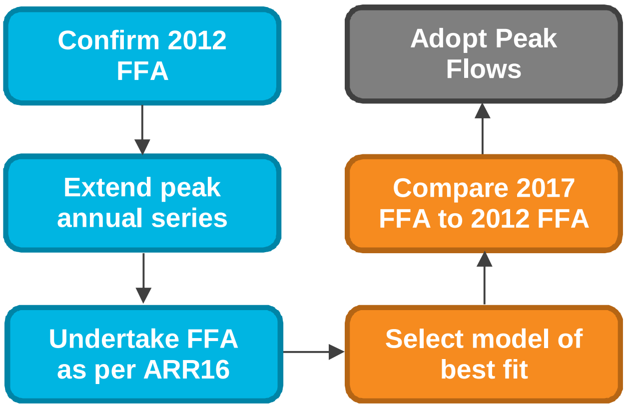
This report details the latest development of the baseline Fitzroy River TUFLOW model which will support design of several key infrastructure projects within the lower Fitzroy catchment. The 2019 update has been required for the following reasons:

1. Introduction of the 2016 edition of Australian Rainfall and Runoff (ARR) guidelines, which present new methods for estimation of flood quantiles (FFA).
2. Occurrence of a recent major flood event not included in the latest (2012) FFA peak annual series.
3. Completion of the 2015/16 Rockhampton LiDAR project, which is currently the best complete topographic dataset covering the lower Fitzroy catchment and captures numerous changes in land use and infrastructure (including the Yeppen North and South Bridges) within the modelled extent.
4. A need to quantify the effect of ongoing lateral migration, erosion and deposition patterns associated with the geometry of the Fitzroy River and implications for channel-floodplain connectivity.

5. Introduction of enhanced hydraulic modelling software TUFLOW HPC, which is able to utilise parallel processing using GPU hardware (traditionally CPU) and minimise runtimes. The 2018 TUFLOW release also includes numerous other enhancements and improvements in comparison to legacy versions.
6. Re-Calibration using the most comprehensive flood record dataset available, which is Council's database of 879 surveyed flood extents and heights captured throughout the 2017 flood event.

E3 Hydrologic Assessment Update

The purpose of the hydrologic assessment update was to re-assess the design event peak discharges upstream of Rockhampton using updated methodology and technology as per latest ARR16 guidance. Hydrological analysis was undertaken to determine the design flood hydrographs for various design events. The general approach taken to define design flood quantiles within the study area was:



The statistical analysis undertaken within this investigation revealed that inclusion of the additional 5 years of flood data and use of ARR16-complaint TUFLOW FLIKE resulted in minimal change (<1%) to the probabilistic estimates of the 2%, 1% and 0.5% AEP peak discharges. Whilst increasing disparity was observed for other flood magnitudes, all were within 5% of the 2012 expected quantiles. It is also noted than events less frequent than a 0.5% AEP event are subject to rapidly increasing uncertainty due to extrapolation of the probability distribution.

Given the statistical rigor of the 2012 FFA (which has been validated in this report) and negligible change to the 2%, 1% and 0.5% AEP flood magnitudes in the 2017 FFA, **the estimated peak flood quantiles determined in the 2012 FFA were maintained within this study**. The adopted estimated quantiles and confidence limits are shown in Table E1.

Table E1 Adopted Design Event Peak Discharges

AEP (%)	Estimated Flow (m^3/s)
18	5,685
10	8,228
5	10,771
2	14,133
1	16,676
0.5	19,219
0.2	22,581
0.05	27,667
PMF	56,713

E4 Hydraulic Model Update

The Fitzroy River TUFLOW hydraulic model developed as part of the SRFL project (AECOM, 2014) underwent a number of updates associated with new datasets and technology. These are summarised as follows:

- **TUFLOW Model Build:** Updated from 2013-12-AA (Classic) to 2018-03-AC (GPU HPC).
- **Model Resolution:** improved from 25m to 15m Cartesian grid.
- **Topographic Updates:**
  - 2015/16 Rockhampton LiDAR Project.
  - Bathymetric survey of Fitzroy River channel at Pink Lily Meander.
  - Detailed survey of channel banks and floodplain between Pink Lily Meander and Ridgelands Road.
  - Survey of Rockhampton Airport Runway
  - As Constructed survey of Yeppen North and South bridges.
- **Hydraulic Structures:**
  - Improved digitisation of hydraulic structures, especially the Fitzroy River Barrage.
  - Inclusion of the Yeppen North and South bridges.
  - Inclusion of culverts providing backwater extent connectivity within airport precinct.
- **Hydraulic Roughness:** Re-delineation based on recent aerial imagery and model re-calibration.

E5 Hydraulic Model Re-Calibration and Re-Validation

Following inclusion of the abovementioned updates the model was re-calibrated to the 2017 flood event and re-validated to the 2011 and 1991 flood events.

The 2017 flood event was selected as the calibration event due to the significant recorded flood height and extent dataset captured by RRC throughout the duration of the event, which included 879 reference points, 421 being proximal to the peak. A strong calibration was achieved to the 2017 event throughout the model extent with 88% of modelled points within ±0.15m (adopted calibration tolerance) of recorded flood heights and 99% within ±0.30m.

The model was then validated to the 2011 and 1991 major flood events using the same model parameters, aside from:

- Inflows (based on actual gauge data at The Gap station).
- Pre-Yeppen North and South Bridge topography (2009 LiDAR).
- Pre-development topography at quarries within the western floodplain.
- Pre-2017 topography at the Pink Lily Meander (2015/16 LiDAR).

A strong validation of the model performance was achieved for the 2011 and 1991 events, with 86% of modelled levels being within the adopted ±0.30m validation tolerance for both events.

Figure E1 presents a scatter plot of the modelled and recorded results for each of the calibration and validation events described above. Based on the results it can be concluded that 87% of modelled peak flood heights were within tolerance across the model domain for events between a 1 in 15 year AEP event (2017) and 1 in 56 year AEP (1991) flood magnitude.

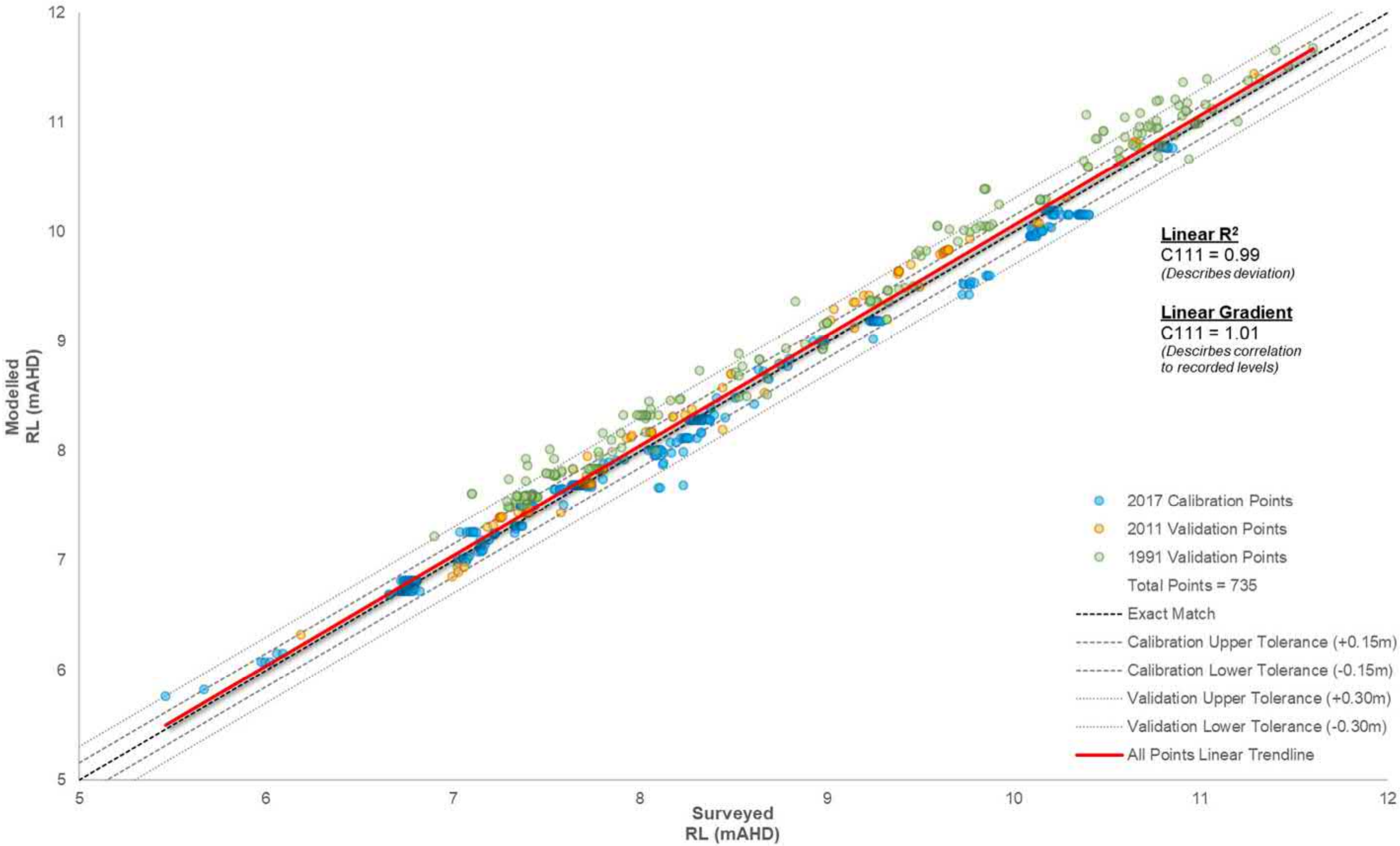


Figure E1 Full Dataset (735 points) Scatter Plot

E6 Implications

Simulation of design events within the updated baseline Fitzroy River TUFLOW model outlined higher predicted peak flood heights to the previously adopted 2014 results. This has potential implications for infrastructure projects within the Lower Fitzroy Catchment and as such it is important to understand the factors driving this change. These are summarised as follows:

- **Topographic Datasets:** ground levels within the 2016 LiDAR data are generally 0.18m higher than the 2009 LiDAR data which directly translates to an increased peak flood height. T
- **Pink Lily Meander Migration**: continued lateral migration of the Pink Lily meander results in increased flows entering the western floodplain.
- **Hydraulic Structures:** improved digitisation of hydraulic structures, especially the Fitzroy River Barrage and low-level Yeppen North bridges (road and rail) has increased peak flood heights within the western floodplain.
- **Hydraulic Roughness:** changes to ground roughness related to more recent aerial imagery and model re-calibration generally saw an increase in roughness throughout the western floodplain.
- **Downstream Model Boundary:** depositional processes were noted near the downstream boundary which effectively reduces the capacity of the channel-floodplain for a given flood stage. Updating the 1-D / 2-D boundary to match 2015/16 LiDAR has resulted in increased flood levels.
- **Improved Model Resolution**: improved digitisation of key channels provided more accurate channel conveyance characteristics.

Changes in predicted 1% AEP peak flood heights at key TMR infrastructure are summarised below.

- +0.15m to +0.18m at the Yeppen North and South Bridges.
- +0.17m across the Capricorn Highway.
- +0.14m to +0.16m throughout the western floodplain between Pink Lily and the Capricorn Highway.
- +0.20m within the Fitzroy River near Limestone Creek.

Changes in predicted 1% AEP peak flood heights at key RRC infrastructure are summarised below.

- +0.13m to +0.21m within the Rockhampton Airport Precinct.
- +0.25m to +0.27m upstream of the Barrage, near the proposed Splitters Creek levee alignment.
- +0.27m to +0.33m adjacent to the North Rockhampton Flood Mitigation Area (north of Lakes Creek Road).
- +0.30m to +0.38m across Port Curtis, near the proposed SRFL alignment.

E7 Recommendations

Based on the outcomes of this study it is recommended that:

- Changes in topography are monitored within the Pink Lily meander and western floodplain as aerial datasets become. Stabilisation of the meander is strongly recommended and is aligned to recommendations made in the 1992 Rockhampton Flood Management Study.
- The model is validated to future flood events as recorded flood data allows. If an opportunity arises, it is recommended that the model is validated or re-calibrated to a flood event close to the 1% AEP magnitude to confirm model performance during the DFE.
- Changes in peak flood levels, behaviour and extents are communicated to key stakeholders and that infrastructure projects within the modelled Fitzroy River extents utilise the updated Fitzroy River model as the basis for design.
- TMR and RRC maintain consistent use of the updated TUFLOW model and any major floodplain changes are recorded and included in the model in a structured manner.

1.0 Project Background

1.1 Introduction

AECOM Australia Pty Ltd (AECOM) has been engaged by the Department of Transport and Main Roads (TMR), to update the Fitzroy River Floodplain and Road Planning Study (FRFRPS) Options Analysis (OA) undertaken by AECOM in 2012. Reference should be made to the FRFRPS OA Update Report (AECOM, 2018) for the outcomes of these works.

As a separate task to the FRFRPS OA Update, AECOM were also commissioned by TMR to undertake an update to the TUFLOW hydraulic model of the Fitzroy River at Rockhampton. The existing model is held by Rockhampton Regional Council (RRC) and was last updated by AECOM in 2014. Model updates are required by TMR prior to commencing detailed planning associated with the Rockhampton Ring Road project.

Details of the baseline model updates are the subject of this report.

1.2 Fitzroy River Catchment

The Fitzroy River, which flows through the city of Rockhampton in the state of Queensland, drains a catchment of approximately 142,000 km^2 and is one of the largest catchments on the east coast of Australia. The catchment extends from the Carnarvon Gorge National Park in the West to Rockhampton on the central Queensland coast and is predominantly dominated by agriculture (grazing, dry land cropping, irrigated cotton and horticulture) and by mining (coal, magnesite, nickel and historically gold and silver).

Due to its immense size and fan-like shape, the Fitzroy River catchment is capable of producing severe flooding following heavy rainfall events in any of its major tributaries. These are the Dawson, Mackenzie and Connors Rivers which rise in the eastern coastal ranges and the Great Dividing Range and join together about 100 kilometres west of Rockhampton. Major floods can result from either the Dawson or the Connors-Mackenzie River catchments. Significant flooding in the Rockhampton area can also occur from heavy rain in the local area below Riverslea.

Rockhampton is located approximately 60 kilometres from the mouth of the Fitzroy River at Keppel Bay. The Fitzroy River at Rockhampton and adjacent townships has a long and well documented history of flooding with flood records dating back to 1859. The highest recorded flood occurred in January 1918 and reached 10.11 metres (8.66 m AHD) on the Rockhampton flood gauge. The most recent major flood occurred in 2017 (fourth highest on record) and reached 8.90 metres on the Rockhampton flood gauge (7.45m AHD). Other notable floods include the 1991 flood and 2011 flood, which reached 9.3 metres and 9.2 metres on the Rockhampton flood gauge respectively (7.85m AHD and 7.75m AHD respectively).

Generally in times of flood, the magnitude of the flow is such that the main river channel is overtopped. To the northwest of Rockhampton at the Pink Lily meander significant overbank flow occurs in major flood events when the upstream river discharge exceeds 6,200 m^3/s (~1 in 6 year AEP). This results in flood flows spreading over a broad floodplain to the west and south of Rockhampton. This floodwater re-joins the Fitzroy River south west of the city at Gavial Creek.

The inundation of the floodplain can result in the closure of Rockhampton Airport, the Bruce Highway, the Capricorn Highway and the North Coast Rail Line. The Bruce Highway and North Coast Rail Line can also be cut by floodwaters at the Alligator Creek Crossing near Yaamba (30 kilometres north of Rockhampton).

As major floods can last for several weeks there is often an extensive disruption to road, rail and air traffic. Extensive property damage can also occur within Rockhampton during flood events which can result in significant direct losses and pose a safety risk to the population. The recent construction of the Yeppen North and Yeppen South high level bridges has provided access into Rockhampton from the south, for Fitzroy River flood events up to and including the 1% AEP. This infrastructure has significantly reduced disruption to road traffic entering and exiting Rockhampton from the south.

1.3 Local Catchments

There are a number of local tributaries which drain local runoff to the Fitzroy River. These local tributaries, which typically have main channel widths of 10 m to 20 m and main channel depths of less than 4 m, include:

- Alligator Creek.
- Limestone Creek.
- Etna Creek.
- Ramsay Creek.
- Splitters Creek.
- Lion Creek.
- Moores Creek.
- Neerkol Creek.
- Scrubby Creek.
- Gavial Creek.

Significant quantities of runoff can be conveyed by the local tributaries following high rainfall in the local Rockhampton area. In some cases this runoff can intensify flooding at Rockhampton, however the local catchment runoff generally discharges through to the ocean prior to peak floodwaters reaching Rockhampton from the major upstream tributaries.

A broad scale hydrologic model was developed within the Fitzroy River Floodplain and Road Planning Study (FRFRPS) study (AECOM, 2012) to simulate runoff characteristics of the local catchments between Yaamba and Port Alma. This study indicated critical storm durations between 18 hours and 24 hours for the majority of the local catchments and confirmed that increases in peak flow as a result of the local catchments was negligible (refer to Figure 1).

The simulation of local catchment flood events has not been undertaken within the scope of this report. Consideration of local catchment impacts is recommended during hydraulic design and assessment of infrastructure within the floodplain and adjacent local catchments.

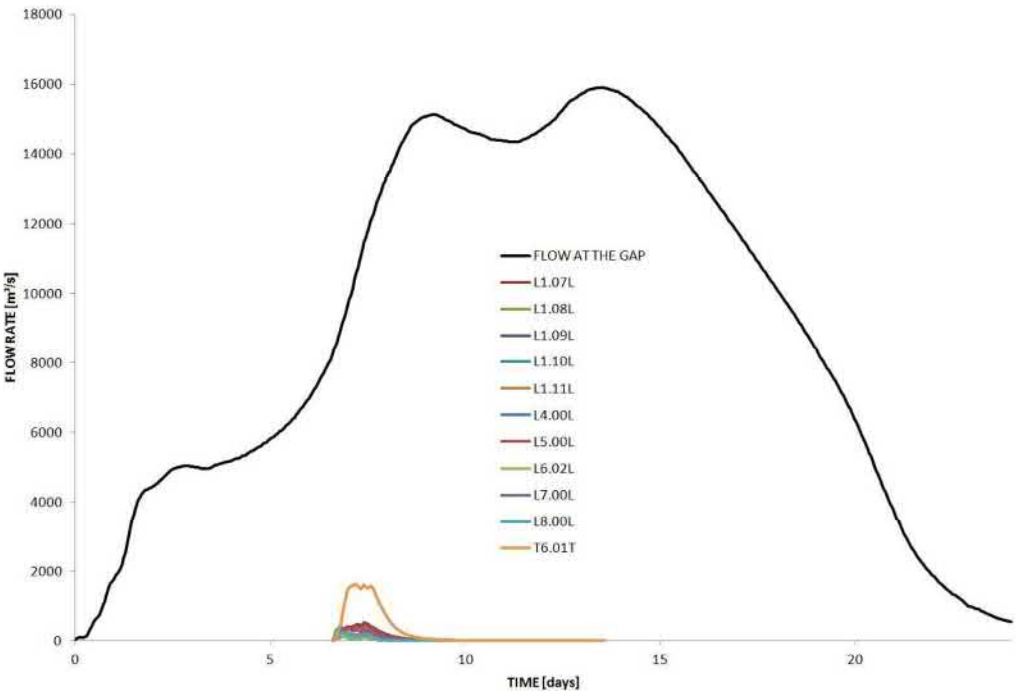


Figure 1 1% AEP Fitzroy River and Local Catchment Inflows (reproduced from FRFRPS Volume 3 report)

1.4 Project Objectives

The key objectives of the baseline modelling updates are to:

- Review hydrologic inputs provided from Flood Frequency Analysis (FFA) using the latest methods outlined in Australian Rainfall and Runoff (ARR) 2016.
- Incorporate latest LiDAR (2015/16), ground survey and as-constructed survey data sets.
- Utilise latest aerial imagery (2016) to update ground roughness.
- Use the latest Heavily Parallelised Compute (HPC) version of TUFLOW, to allow model grid size reduction resulting in improved model resolution.
- Review and update two-dimensional (2-D) Layered Flow Constriction Shape (LFCSH) representation of major bridge and culvert structures.
- Model re-calibration to the most recent 2017 Fitzroy River flood event. Notably this is the first event to occur since construction of the Yeppen Crossing Upgrades.
- Model re-validation to the 2011, 2008 and 1991 Fitzroy River flood events.
- Re-simulation of design flood events, including discussion of any perceived implications to TMR or RRC as a result of flood level changes.
- Provide concluding remarks highlighting recommendations and future modelling enhancements as periodic data updates are collected and modelling technology evolves in the future.

1.5 Report Structure

This report is structured as follows:

- Section 2.0 → Discussion of previous Fitzroy River Floodplain hydraulic studies.
- Section 3.0 → Presents the available data used within this study.
- Section 4.0 → Details the hydrologic assessment updates.
- Section 5.0 → Details the Fitzroy River TUFLOW model updates and development.
- Section 6.0 → Analysis of the TUFLOW model calibration and validation results.
- Section 7.0 → Analysis of the TUFLOW model design event results.
- Section 8.0 → Discussion of implications of updates to Fitzroy River TUFLOW hydraulic model.
- Section 9.0 → Conclusion and recommendations.

1.6 Notes on Flood Frequency

The frequency of flood events is generally referred to as Annual Exceedance Probability (AEP) or Average Recurrence Interval (ARI). For example, for a 5% AEP flood event, there is a 5% probability that there will be floods of equal or greater magnitude each year. As another example, for a flood with a 5 year ARI, there will be floods of equal or greater magnitude once in 5 years on average. The correspondence between AEP and ARI is presented below. **In this report, the AEP terminology has been adopted to describe the frequency of flooding.**

Table 1 AEP to ARI Comparison

Annual Exceedance Probability (AEP) %	Average Recurrence Interval (ARI) Years
18	5
5	20
1	100
0.05	2000

1.7 Limitations and Assumptions

Whilst a detailed model development process has been undertaken which included re-calibration and re-validation to recorded flood events, it is important that the following fundamental themes are noted:

- All models are coarse simplifications of very complex processes. No model can therefore be perfect, and no model can represent all of the important processes accurately.
- Model accuracy and reliability will always be limited by the accuracy of the terrain and other input data.
- Model accuracy and reliability will always be limited by the reliability / uncertainty of the inflow data.
- No model is 'correct' therefore the results require interpretation and the application of engineering judgement.
- A model developed for a specific purpose is probably unsuitable for another purpose without modification, adjustment, and recalibration. The responsibility must always remain with the modeller to determine whether the model is suitable for a given problem.
- Predicted design event water surface elevations and flood extents may not reflect actual flooding conditions.

In undertaking the review and subsequent updates to the hydrologic inputs and hydraulic model, the following key uncertainties were noted:

- Current and future Fitzroy River conveyance characteristics:
  - Budget and timing constraints have meant that new bathymetric survey of the river reach through and downstream of Rockhampton was not feasible as part of this investigation.
  - Whilst the conveyance characteristics along the city reach are predicted to remain relatively stable due to bank protection works and the natural bed rock; the cross sectional characteristics upstream of the Barrage and downstream of The Bend are likely to continue to change due to ongoing geomorphic processes, which could have an impact on flood conveyance and breakout characteristics.
  - It is suggested that sensitivity analyses be undertaken in future hydraulic assessments to assess the potential implications of long term changes to river channel characteristics.
- Long term climate change:
  - The potential impacts of climate change (i.e. increase in rainfall intensity and sea level rise) have not been assessed as part of this model update but should be considered when assessing future floodplain infrastructure.
- Hydraulic roughness:
  - The adopted Manning's roughness values are based on calibration / validation process for the model.
  - Sensitivity analysis can reveal if the water level prediction varies significantly for relatively small changes in Manning's 'n' and may inform decisions relating to freeboard provision for infrastructure, emergency management, planning and land use decisions within the floodplain.
  - The sensitivity of the model to changes in the roughness parameter was not assessed. The influence of the manning's 'n' roughness on the hydraulic performance of the floodplain should be considered when assessing future floodplain infrastructure.

2.0 Previous Studies

2.1 Overview

A number of previous flood studies have been undertaken for the Fitzroy River at Rockhampton including:

- Report on Fitzroy River Barrage (Department of Local Government Queensland, 1964).
- The Yeppen Model (Department of Civil Engineering – Capricornia Institute of Advanced Education, 1977).
- Rockhampton Flood Management Study (RFMS, Camp Scott and Furphy, 1992).
- Rockhampton Airport Runway Extension – Flood Study (GHD, 1998).
- Rockhampton City Floodplain Management Policy – Rockhampton Flood Mapping (Willing and Partners Consulting Group, 1999).
- Lower Splitters Creek Flood Study (Fisher Stewart, 2001).
- Rookwood and Eden Bann Weirs Design Hydrology Report (SunWater, 2008).
- Fitzroy River Flood Study (FRFS, Aurecon, 2011).
- Fitzroy River Floodplain and Road Planning Study (FRFRPS, AECOM, 2012).
- Fitzroy River Floodplain and Road Planning Study – Options Analysis (FRFRPS OA, AECOM, 2012) & Options Analysis Update (FRFRPS OA Update, AECOM, 2018).
- South Rockhampton Flood Levee (SRFL) Feasibility Assessment, Preliminary Design and Detail Design (AECOM, 2014 to present)

The RFMS, FRFS, FRFRPS and SRFL are arguably the most comprehensive studies undertaken in the region and are discussed in further detail in the following sections.

2.2 Rockhampton Flood Management Study (RFMS)

Following the January 1991 flood event, which resulted in flood damage and closure of transport links causing major economic and social problems in the Rockhampton region, the RFMS was undertaken. Local, state and federal government agencies agreed that a study would enable better management of the Fitzroy River floodplain at Rockhampton.

The Queensland Water Resources Commission engaged Camp Scott and Furphy (CMPS&F) to undertake the study, which was to consider aspects of existing and future flood management, in order to make recommendations aimed at reducing the impact of future floods in Rockhampton.

The study included:

- Investigating the characteristics of Fitzroy River flooding including flood mechanisms, flood hydrology and extreme floods.
- Flood damage assessment including flood damage modelling to estimate direct flood damages for a range of flood levels; and indirect losses from transport link closures causing disruption to business capacity.
- Appraisal of current flood management issues and options for future flood management.

The study was delivered in two phases, the first of which included:

- A study into the characteristics of Fitzroy River flooding;
- Assessment of flood damages;
- Flood management options appraisal;
- Future flood management recommendations and Community consultation.

Options identified in Phase 1, which were deemed to warrant further study, were investigated in Phase 2. Non-structural flood management recommendations (which could be implemented immediately) and structural mitigation works were also detailed, costed and prioritised in Phase 2.

A summary of the findings and recommendations of the study are detailed below:

- Flood Damages
    - The study estimated that the total cost of flood damages resulting from the 1991 flood event was approximately $50 million, although this figure was said to be imprecise. Of the $50 million, it was estimated that the cost as a result of direct damages was $15 million. By way of contrast, the cost as a result of indirect damages was approximated to be $35 million.
    - The annual average damage (the long term average of flood damage over a period of time which includes the likely range of floods) was estimated to be $5.2 million per annum at 1992 prices. This represented the annual cost to the national economy of doing nothing to improve flood management or mitigate flood damage.
- Recommendations for Non-Structural Flood Management Measures
    - Flood maps were prepared as part of the study and showed the extent of inundation for 2%, 1% and 0.5% AEP floods. These were recommended to be used by the Rockhampton City Council on an interim basis before the adoption of formal maps for planning purposes.
    - It was recommended that a flood standard of the 1% AEP flood be adopted for planning purposes. It was also recommended that no new developments be permitted in designated floodways. Where new development is permitted in other flood prone areas, the minimum habitable floor level should be 0.5 m above the 1% AEP flood level.
    - Various other management measures were recommended for immediate implementation, including: flood warning measures, counter disaster planning, operations measures and other measures to increase public flood preparedness and community flood response.
- Recommendations for Structural Flood Mitigation Measures
    - Improving the flood immunity of the Yeppen Crossing was regarded the highest priority. The hydraulic model study demonstrated that the flood immunity could be improved to 2% AEP by doubling the bridge waterway area which would involve increasing the length of the bridges from 420 m to 840 m, together with raising the highway/rail embankment sections between the bridges. The cost of the upgrades was estimated to be $15.6 million on the basis of the 1992 road width.
    - Constructing a levee to protect Lower Dawson Road, Port Curtis, Depot Hill and the Lower CBD was also recommended as a high priority measure. The construction of a levee was recommended to follow the proposed improvement to Yeppen Crossing for hydraulic reasons. The levee was recommended to protect up to the 1% AEP flood and would significantly reduce flood damage and social impacts for the bulk of the urban area on the south side of the river.
    - The construction of a levee to protect the Rockhampton Airport was recommended, but with a lower level of priority. It was noted that the levee would be difficult to justify in an economic sense.
    - Lower level priority works which were also recommended: a levee to prevent direct overflow from the Fitzroy River into Splitters Creek, the stabilisation of the high bank at Pink Lily, the fitting of flood gates on creeks on the northern river bank and the fitting of flood valves on the storm drainage outlets.

The RFMS consolidated all previous reports as well as available historical flood information and was the base source of knowledge for hydrology and hydraulic assessments in the Rockhampton area until the completion of the FRFS and FRFRPS projects (discussed below).

2.3 Fitzroy River Flood Study (FRFS)

Commencing in 2008, RRC engaged Aurecon to undertake the Fitzroy River Flood Study, having received funding through the Federal and State Governments under the Natural Disaster Mitigation Program (NDMP).

RRC indicated that the FRFS would be vital to provide a modern tool for emergency management and would help to understand flood hazard risk and assist the local Disaster Management Group to plan emergency evacuations.

One aim of the FRFS was to update the previous flood study conducted by Camp Scott and Furphy in 1992. This was achieved by using updated modelling tools to define the flood behaviour in the area and taking into account changes that have occurred in the floodplain. This was followed by assessment of the resultant flood hazard.

The objective of the FRFS was to provide floodplain mapping of the Rockhampton region, to assist Council in future development assessment and emergency management planning activities.

The study entailed the:

- collection of survey and topographic data in the area;
- review and analysis of existing flood data;
- preparation of mapping including flood levels, depths and velocities;
- identification of key areas at risk during flood events; and
- refinement of existing emergency management procedures.

The following provides a summary of the modelling:

- The hydraulic model was developed using the computer software package TUFLOW.
- The model boundaries were approximately 10km upstream and downstream of the urban area of the city.
- The study / model’s inputs include LIDAR of the Rockhampton urban area and immediate surrounds.
- The model was calibrated to the 1988, 1991 and 2008 flood events.

The FRFS concluded in July 2011 with the delivery of a detailed hydraulic report, associated flood mapping and a two-dimensional TUFLOW numerical hydraulic model, which utilised a 50m Cartesian grid.

2.4 Fitzroy River Floodplain and Road Planning Study (FRFRPS)

In June 2009, the Australian Federal government announced the commencement of a three-year study to identify the preferred alignment for future road and rail transport in Central Queensland.

The Fitzroy River Floodplain and Road Planning Study (FRFRPS), led by the Department of Transport and Main Roads (TMR), was undertaken in order to identify and evaluate options to address the issues of flood immunity, traffic capacity, freight movement and amenity of the Bruce Highway through Rockhampton.

Flood immunity and flood impacts associated with the FRFRPS were extensively investigated. Outcomes of the hydraulic investigations were reported in four report volumes which made up the Hydraulic Assessment Report, as follows:

- Volume 1 – Data Compendium
  - Summarised data relevant to lower Fitzroy River flooding at Rockhampton.
  - Described the major historical floods and flood behaviour.
  - Identified changes over time within the catchment and floodplain likely to impact on flooding (infrastructure and river geometry).
  - Critically examined all data to be used in subsequent hydrologic / hydraulic model development.
- Volume 2 – Hydrology
  - Reviewed the Fitzroy River catchment hydrologic mechanisms associated with flooding at Rockhampton.
  - Determined the design inflow hydrographs for application to the hydraulic model.
- Volume 3 – Preliminary Hydraulics
  - Detailed the development of the MIKE FLOOD hydraulic model that was subsequently used to determine design parameters for the proposed road alignments and to assess impacts of the proposed design.
  - Detailed the sensitivity analyses undertaken for the hydraulic model as part of the model development process.
  - Outlines calibration and validation works undertaken using data from major historical Fitzroy River flood events.
  - Provided baseline flooding conditions for a range of design flood events.
- Volume 4 – Hydraulic Analysis of Options and Preferred Option.
  - Assessment of hydraulic impacts associated with potential upgrade options within the overall framework of the study.

Recommendations of the study included upgrades to Yeppen North, Yeppen South, Capricorn Highway and the Rockhampton Ring Road. These projects are at various stages of development and have necessitated further detailed hydraulic analysis, which have been reported separately.

Upon review of the FRFS TUFLOW model and associated data, it was found that:

- Development of the TUFLOW model associated with the FRFS was still ongoing at the commencement of the FRFRPS and the finalised model was not available in timeframes required for the study.
- The adopted TUFLOW model grid size was deemed too large to adequately represent the existing and proposed road alignments required as part of the FRFRPS.
- The model extent was focussed on the Rockhampton urban area (for emergency management purposes) and the proposed road alignments for the FRFRPS were found to be in close proximity to the model extents. As a result it was likely that the TUFLOW model would need to be extended to ensure the model boundaries would not influence flooding at the proposed road alignments.

Based on the outcomes of the review of the FRFS model, it was agreed with TMR Hydraulics Branch that a MIKE FLOOD Flexible Mesh (FM) hydraulic model be developed and utilised for the FRFRPS.

2.5 South Rockhampton Flood Levee Feasibility Assessment, Preliminary Design and Detail Design (SRFL)

The South Rockhampton Flood Levee (SRFL) project represents one of the most significant regional flood mitigation projects currently proposed in Queensland. The SRFL was identified as a high priority mitigation measure that was strongly recommended in the Rockhampton Flood Management Study (CMPS&F, 1992). Construction of the levee will significantly reduce flood damage and social impacts for the majority of the urban area in South Rockhampton.

The SRFL feasibility assessment, preliminary design and detail design was completed by AECOM (2014) as a joint initiate of RRC, the Queensland Government and the Australian Federal Government.

The primary objective of the SRFL was to protect residential and commercial properties within areas of Port Curtis, Depot Hill and the Rockhampton CBD against Fitzroy River flooding. These areas are to be protected up to and including the 1% AEP event, which is the Defined Flood Event for RRC. The levee is approximately 8.8km long generally consisting of earth fill embankment, with portions being crib wall, vertical flood walls and temporary flood barrier systems.

A key task was the update and further development of RRC's existing TUFLOW hydraulic model of the Fitzroy River, to ensure the model was suitable to inform and assess the SRFL infrastructure. The updated hydraulic model setup is detailed in the SRFL Hydraulic Model Development and Comparison Report (AECOM, 2014). The model setup and extents are shown in Figure 2.

The TUFLOW hydraulic model developed for the SRFL project has been used by RRC moving forward and is the base model for this Fitzroy River TUFLOW Model Update.

2.6 Fitzroy River Floodplain and Road Planning Study – Options Analysis Update (FRFRPS OA Update)

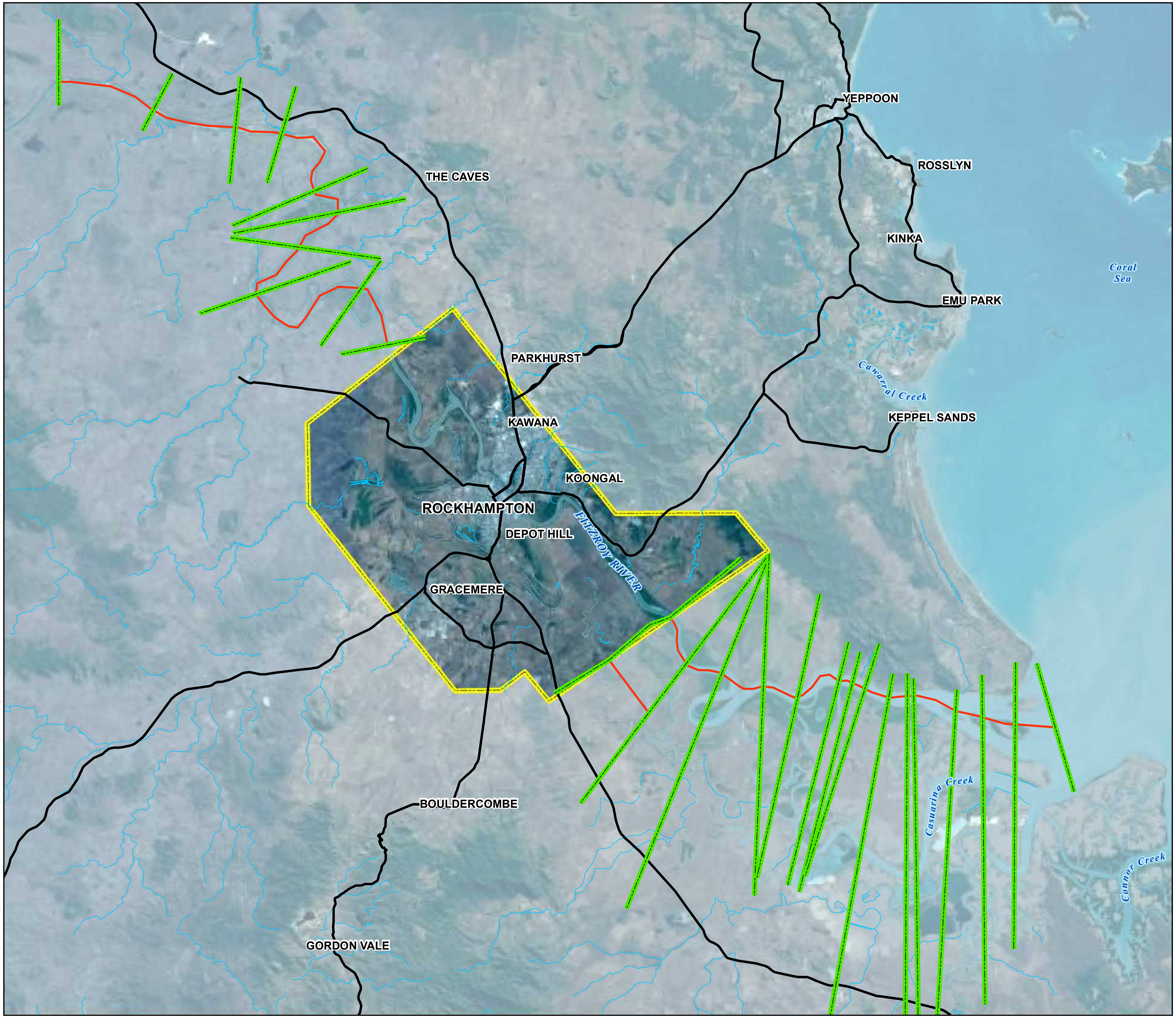
After completion of the FRFRPS project in 2011, AECOM undertook an Options Analysis for the Rockhampton Ring Road (RRR) in 2012. At that time it was assumed the RRR would need to replicate the flood immunity of the Yeppen North and Yeppen South infrastructure. As the Yeppen infrastructure forms part of the national highway network, the desired level of flood immunity is the 1% AEP flood event. This is backed by public perception, that any lower level of flood immunity, such as the 2% AEP flood event, would not provide a reasonable level of access into Rockhampton during flood events. This has been further demonstrated through recent flood history, with Rockhampton experiencing three floods of 2% AEP or greater in the past 30 years (1991, 2011 and 2017).

At the time of the RRR Options Analysis in 2012 the SRFL was not being considered by RRC. However, RRC has now completed the feasibility study, preliminary design and detail design for the SRFL (completed in 2014), and is currently undertaking early works for the construction of the levee system. The combination of the SRFL and Yeppen infrastructure will provide 1% AEP Fitzroy River flood immune access into Rockhampton via Yeppen South, Yeppen North and Lower Dawson Road.

The requirement for the RRR to provide 1% AEP flood immunity is therefore less important. It is primarily for this reason that TMR engaged AECOM to update the 2012 RRR Options Analysis, to further investigate options prior to completing the Preliminary Evaluation (PE) and Business Case (BC) phases of the project. The OA Update (AECOM, 2018) further developed the options assessed in 2012 and sought to further analyse and understand interactions between the RRR and other planned flood mitigation infrastructure within the western floodplain.

As a separate task to the OA Update, TMR engaged AECOM to update the 2014 RRC TUFLOW model of the Fitzroy River, which is the subject of this report.

The updated baseline model will be adopted by TMR and RRC for future floodplain management and assessment of infrastructure projects.



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LEGEND

- 1D Cross Section
- 1D Network
- Main Roads
- Watercourse Line
- Watercourse / Ocean Area
- 2D Model Boundary

Data sources:

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

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

Existing Fitzroy River Model Overview and Extent

PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	7/11/2018
VERSION:	01

Figure 2

A3 size

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3.0 Available Data

3.1 General

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

- Previous studies (See Section 2.0).
- TUFLOW hydraulic model.
- Stream gauging data.
- Tidal data.
- Topographical data.
- Details of hydraulic structures within the study area.
- Historical flood records for the 2013, 2015 and 2017 flood events.

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

3.2 Selection of the Hydraulic Model

There is a long history of hydraulic investigations undertaken for the Fitzroy River:

- Fitzroy River Barrage Study (Department of Local Government, 1964).
- The Yeppen Model (Capricornia Institute of Advanced Education, 1977).
- Rockhampton Flood Management Study (CMPS&F, 1992).
- Rockhampton Floodplain Management Policy (Willing & Partners, 1999).
- Lower Splitters Creek Flood Study (Fisher Stewart, 2001).
- Fitzroy River Flood Study (Aurecon, 2011).
- Fitzroy River Floodplain and Road Planning Study (AECOM, 2012).
- SRFL Planning and Design (AECOM, 2014).

Hydraulic modelling of the Fitzroy River at Rockhampton has been undertaken by various consultants, using a number of different modelling software packages. Table 2 provides a chronological order of numerical hydraulic modelling undertaken since the original Rockhampton Flood Management Study.

Table 2 Hydraulic Model Development History

<table>
<tr><th>Year</th><th>Software</th><th>Study</th><th>Commissioned By</th><th>Developed By</th></tr>
<tr><td>1992</td><td>MIKE11</td><td>Rockhampton Flood Management Study</td><td>Queensland Water Resources</td><td>Camp Scott and Furphy</td></tr>
<tr><td>2011</td><td>TUFLOW Classic</td><td>Fitzroy River Flood Study</td><td>RRC</td><td>Aurecon</td></tr>
<tr><td>2011</td><td>MIKE FLOOD</td><td>FRFRPS</td><td>TMR</td><td>AECOM</td></tr>
<tr><td>Oct 2013</td><td colspan="4">Memo prepared by AECOM for TMR & RRC – Technical Comparison of the RFMS, FRFS and FRFRPS.</td></tr>
<tr><td rowspan="3">2014</td><td>TUFLOW Classic</td><td rowspan="2">SRFL Planning and Design</td><td>RRC</td><td rowspan="2">AECOM</td></tr>
<tr><td>MIKE FLOOD</td><td>TMR</td></tr>
<tr><td colspan="4">SRFL Model Development and Comparison Report prepared by AECOM, for RRC and TMR.</td></tr>
<tr><td>2014-2017</td><td>TUFLOW Classic</td><td>Number of model refinements</td><td>RRC</td><td>AECOM</td></tr>
<tr><td>Dec 2017</td><td colspan="4">Decision made by TMR Hydraulics Branch to adopt the TUFLOW model moving forward</td></tr>
</table>

This updated baseline TUFLOW model developed through this project will be used by TMR and RRC for current and future design / planning projects relating to Rockhampton Ring Road, SRFL, Rockhampton Airport Levee (RAL) and Splitters Creek Levee (SCL).

3.1 Stream Gauging Data

Recorded water level data and rating curves for stream gauging stations on the Fitzroy River were obtained from the Department on Natural Resources, Mines and Energy (DNRME). River and flow height data provided by DNRME has been recorded at several stations since 1914, as described in described in Table 3 and below.

Table 3 Summary of DNRME Stream Gauging Stations

Station Number	Station Name	Period of Record	Catchment Area (km^2)	Δ_{AREA} to 130005A	Flood Event				
					1918	*1954*	*1991*	*2011*	*2017*
130001A	Yaamba	1914 - 1927	136,400	600km^2 (0.4%)	✓	×	×	×	×
130001B	McMurdos	1927 - 1951	136,400		×	×	×	×	×
130001C	Yaamba	1950 - 1973	136,400		×	✓	×	×	×
130002A	Wattlebank	1918 - 1958	135,900	100 km^2 (0.1%)	×	✓	×	×	×
130002B	Wattlebank	1994 - 2002	135,900		×	×	×	×	×
130005A	The Gap	1964 - Now	135,800	-	×	×	✓	✓	✓

Figure 3 provides a timeline of available gauging data, with key historical flood events also shown.

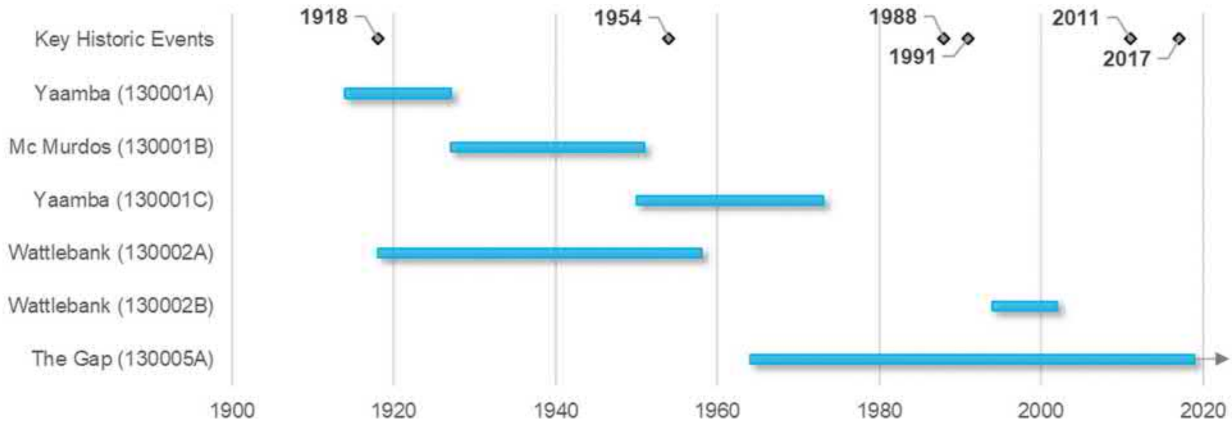


Figure 3 Timeline of DNRME Stream Gauging Stations

3.1.1 Review of Rating Curves

The rating curve at The Gap station is of fundamental importance to the hydrologic assessment within this study as the streamflow data makes up the majority of annual maximum data (see Section 4.3.4).

DNRME (then Water Resources Commission) carried out a review of the rating in 1990, which saw flow estimates substantially reduce. Consequently, the rating curve was later reviewed in detail by Camp Scott Furphy during the Rockhampton Flood Management Study in 1992.

A joint site inspection was carried out by Camp Scott Furphy and Water Resources Commission staff who described the station as being a single channel up to about 30m (gauge height). This provided an exceptionally high degree of flood flow containment resulting in minimal variance in the rating curve gradient for high flows until this containment level is exceeded. The review of the rating curve (and in particular the extension of the curve for high stage flows) concluded that the rating was as accurate as possible at that time and therefore appropriate for use. The level of accuracy was anticipated to be relatively high due to the geometric characteristics of The Gap station and relatively low degree of extrapolation necessary at the site.

DNRME have since re-gauged the site following recent flood events. The rating curve updated in 1992 is shown by the grey line in Figure 4 and was compiled from flow-height data during the 1991 flood event. The updated rating is shown by the blue line and was compiled from new flow-height data during the 2011 and 2017. Whilst notable differences are seen for smaller flood stages, discharges beyond 13,000m^3/s quickly converge with the extrapolated ratings for the 1% AEP design discharge being within 0.1m for each rating. This finding is important given the significance of the 1% AEP event as the adopted DFE. Given this, the latest rating curve was deemed acceptable for use in this study.

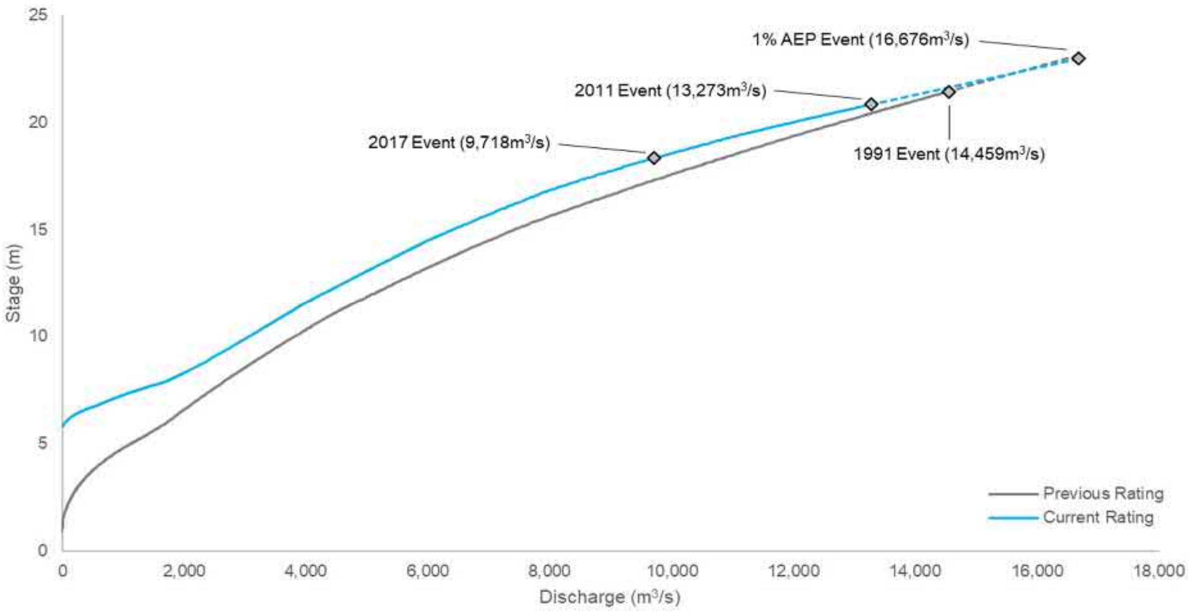


Figure 4 The Gap (130005A) Gauge Rating Curve Comparison

3.2 Tidal Data

Historic tidal data used in the 2008, 2011 and 2017 flood events were obtained from open data made available by Maritime Safety Queensland (MSQ). Tidal data for the 1991 flood event was provided during previous model development phases by TMR – Maritime Branch. The tidal time series data was translated to mAHD based on MSQ's Queensland Tide Tables appendix.

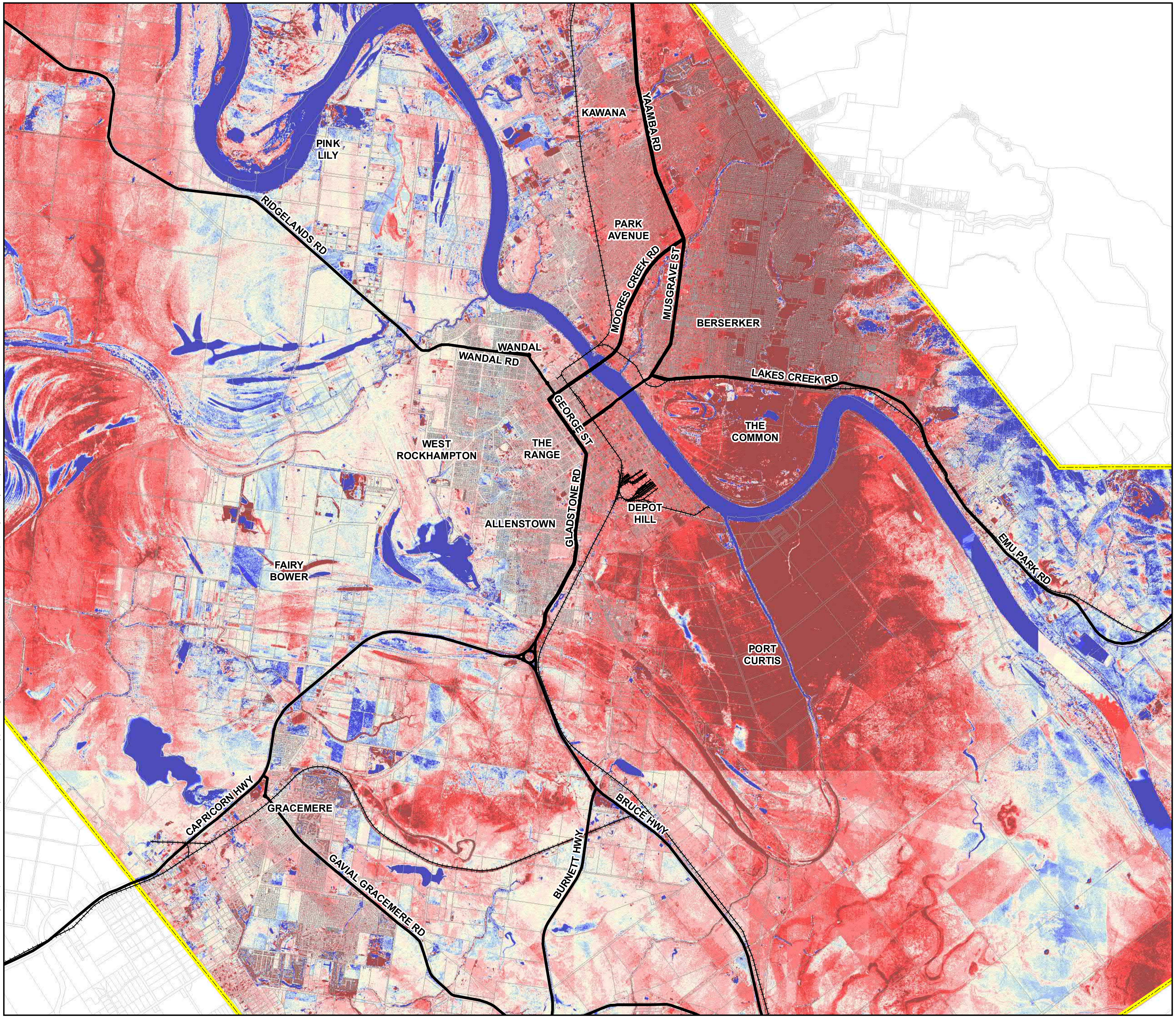
3.3 Topographic Data

3.3.1 2015/16 LiDAR Data

The topographical information used for the Fitzroy River model was provided by RRC in the form of LiDAR survey, which was undertaken between 30 September 2015 and 23 January 2016 by AAM Pty Ltd. The 2015/16 LiDAR package has also been made freely available by Geoscience Australia at the following web address: http://elevation.fsdf.org.au/.

The LiDAR points were used to generate a base Digital Elevation Model (DEM) with a grid spacing of 1m. It is stated in the report provided by AAM Pty Ltd that the Horizontal Spatial Accuracy is estimated to be ±0.40m and the Vertical Spatial Accuracy is estimated to be ±0.15m, on **clear open ground**. Council undertook elevation checks and commented that the accuracy of the LiDAR is within the ±0.15m vertical tolerance on hard surfaces.

Figure 5 presents the difference map between the 20019 and 2016 LiDAR datasets, which is further supported by the histogram shown in Figure 6. As can be observed, the differences are significant between datasets with the majority of changes being an increase in height in the 2016 dataset. Approximately 75% of cells have increased, in line with the average vertical difference of +0.18m (i.e. the 2015/16 dataset is 0.18m higher on average). It was also noted that the area of Port Curtis saw increases between 0.30m to 0.60m. Whilst error between the datasets is likely a factor, it is also probable that the Fitzroy River deposits sediment within these areas during its receding limb. Implications are discussed further in Section 8.1.



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LEGEND

- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- Cadastre

Difference (m)

- < -0.3
- -0.3 to -0.225
- -0.225 to -0.15
- -0.15 to -0.075
- -0.075 to -0.02
- -0.02 to 0.02
- 0.02 to 0.075
- 0.075 to 0.15
- 0.15 to 0.225
- 0.225 to 0.3
- > 0.3

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

Difference in Topography
2015/16 LiDAR minus 2009 LiDAR

PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	7/03/2019
VERSION:	01

Figure 5

A3 size

Filename: P:\605x\60578201\4. Tech Work Area\4.99 GIS\02_MXDs\FR18\Report\Figures\MXD\Figure 4 - Topographic Dif Map.mxd

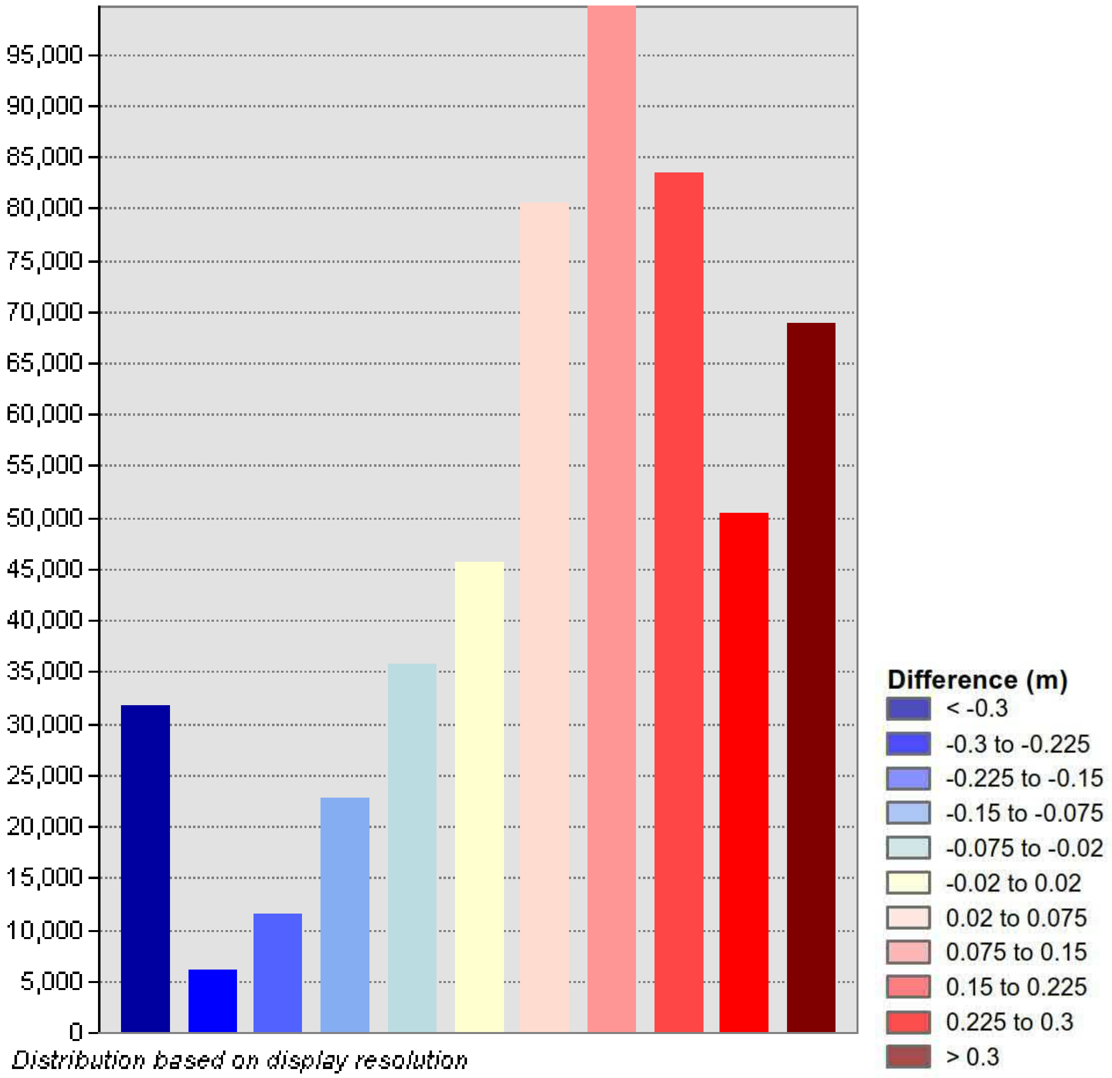


Figure 6 Histogram of Difference in LiDAR Datasets (2015/16 minus 2009)

3.3.2 Detailed Survey

In addition to the 2015/16 LiDAR data, several detailed survey datasets were superimposed to ensure the model surface represents the most accurate data available at the time. This included:

- As Constructed survey of the Yeppen North and Yeppen Floodplain Upgrade projects (Bruce Highway).
- As Constructed survey of the Capricorn Highway between the Yeppen Crossing and Gracemere.
- As Constructed survey of the Rockhampton Airport runways.
- Detailed survey of the natural surface between the Fitzroy River meander at Pink Lily and Ridgelands Road.

It is noted than for validation events prior to the construction of the Yeppen North and South Bridges, pre-construction topography (2009 LiDAR) was read in within the project extent to ensure topographic conditions matched the time of the flood event.

3.3.3 Bathymetric Survey

The 2001 bathymetric profile of the Fitzroy River was brought across from the previous stages of model development. The data used to generate this profile was in the form of bathymetric cross sections captured by DNRME in 2001 (then DNRM).

The Fitzroy River bathymetric profile was supplemented by 2019 survey of the river bed and banks at the Pink Lily meander in order to capture ongoing lateral migration, change in bank crest levels (a key hydraulic control) and morphologic changes as a result of deposition, erosion and anthropogenic activities (i.e. Pink Lily Sands). Changes between 2001 and 2019 bathymetric datasets were notable due to the abovementioned reasons and were stitched into the model surface with a number of ‘smoothing’ TUFLOW Z-Shape polygons.

3.4 Hydraulic Structures

A comprehensive investigation has been undertaken to identify the hydraulic structures associated with the road and rail networks within the study area. The following sources were used for identification of the hydraulic structures:

- TMR’s working drawings for the State Controlled Road networks within the Rockhampton region.
- Queensland Rail’s drawings and sections for the North Coast Rail Line and Yeppoon Branch Rail Line.
- Aurizon’s drawings and sections for the Blackwater Rail Line.
- RRC’s latest infrastructure databases, including infrastructure within the Rockhampton Airport Precinct.

44 sets of culvert crossings and 15 bridges were identified and digitised within the hydraulic model extent. It is worth noting that numerous minor structures (which were not expected to convey significant flows) were not incorporated into the hydraulic model. Table 4 shows the list of the major structures within the study area which were incorporated into the hydraulic model.

Table 4 Critical Hydraulic Structures Incorporated to the Hydraulic Model

Drainage Structure	Configuration	Digitisation
State Controlled Road Network		
Neville Hewitt Bridge (New Bridge)	6/70m spans	2D
Fitzroy Bridge (Old Bridge)	7/60m spans	2D
Yeppen North Low Level Bridge	20/10m spans	2D
Yeppen North High Level Bridge	21/20m spans	2D
Henry Johnson Highway Bridge	10/10m spans	2D
Darumbal Bridge	7/10m spans	2D
Scrubby Creek Bridge	6/10m spans	2D
Yeppen South High Level Slip Lane Bridge	16/35m spans	2D
Yeppen South High Level Bridge	47/35m spans	2D
North Coast Railway		
North Coast Rail Fitzroy Bridge	4/70m spans	2D
South Rockhampton	2/2.7 x 1.8m RCBC	1D
	3/1.5 x 1.0m RCBC	1D
	2/1.8m RCP	1D
Yeppen North Rail Bridge	20/10m spans	2D
Henry Johnson Rail Bridge	11/10m spans	2D
Darumbal Rail Bridge	7/10m spans	2D
Yeppen Floodplain Culverts	13/3.0 x 3.0m RCBC	2D
Scrubby Creek Rail Bridge	7/10m spans	2D
Other		
Fitzroy River Barrage	25/14m spans (18 with gates)	2D
Airport Runway	Bebo Arch	1D
Nine Mile Road	1/3.0 x 3.0m RCBC	1D
	2/3.0 x 2.4m RCBC	1D
	4/3.0 x 2.1m RCBC	1D
Hunter Street	7/1.8 x 1.2m RCBC	1D

3.5 Calibration / Validation Data

3.5.1 Streamflow Data

Section 3.2 describes collation of the stream gauging data from DNRM which was subsequently used for model calibration and validation.

3.5.2 Anecdotal Data

Anecdotal data for previously assessed flood events was adopted from parent studies, with the available data for each event summarised below.

- 1991 Validation Event – 207 points at peak.
- 2008 Validation Event – 15 points at debris and water level marks.
- 2011 Validation Event – 107 points at peak, 153 points 4 days post-peak and 206 points 6 days post-peak

In addition to the above, RRC were able to capture 877 time-stamped flood levels using a Real Time Kinematic (RTK) satellite navigation device during the 2017 flood event. These surveyed flood extents and heights provided a detailed understanding of the flood behaviour throughout the floodplain and city reach of the lower Fitzroy River. Of the 877 points, 421 were proximal to the peak and used to calibrate the modelled peak flood surface. Other time-stamped points were used to gauge the model's ability to correctly simulate the rising and receding limbs of the flood wave (see Section 6.2).

3.5.3 Recorded Flood Heights

Recorded flood heights were obtained from BOM at the Rockhampton Flood Gauge for the 1991, 2008, 2011 and 2017 flood events. These time varying gauge heights were converted to AHD using conversions provided by BOM.

4.0 Hydrologic Assessment Update

4.1 Background

The purpose of the hydrologic assessment update was to re-assess the design event peak discharges upstream of Rockhampton using updated methodology and technology as per latest ARR16 guidance. A number of flood frequency studies have been completed for Rockhampton since 1939, with each of the adopted peak discharges presented in Table 5 and shown chronologically in Figure 7.

Table 5 Summary of FFA Results for Rockhampton

Source	Year	Peak Discharge (m^3/s)			
		2% AEP	1% AEP	0.5% AEP	0.1% AEP
Rockhampton City Council	1939		17,500	20,300	28,000
Department of Local Government	1964	18,400	21,500	25,000	33,000
Irrigation Water Supply Commission	1977		26,000		45,000
Water Resources Commission	1989	14,700	17,400	19,900	25,500
Camp Scott Furphy	1992	14,200	16,400	19,000	24,000
Aurecon	2011	12,675	15,876	19,547	30,258
AECOM	2012	14,133	16,676	19,219	25,124
SunWater	2015	13,600	16,500		

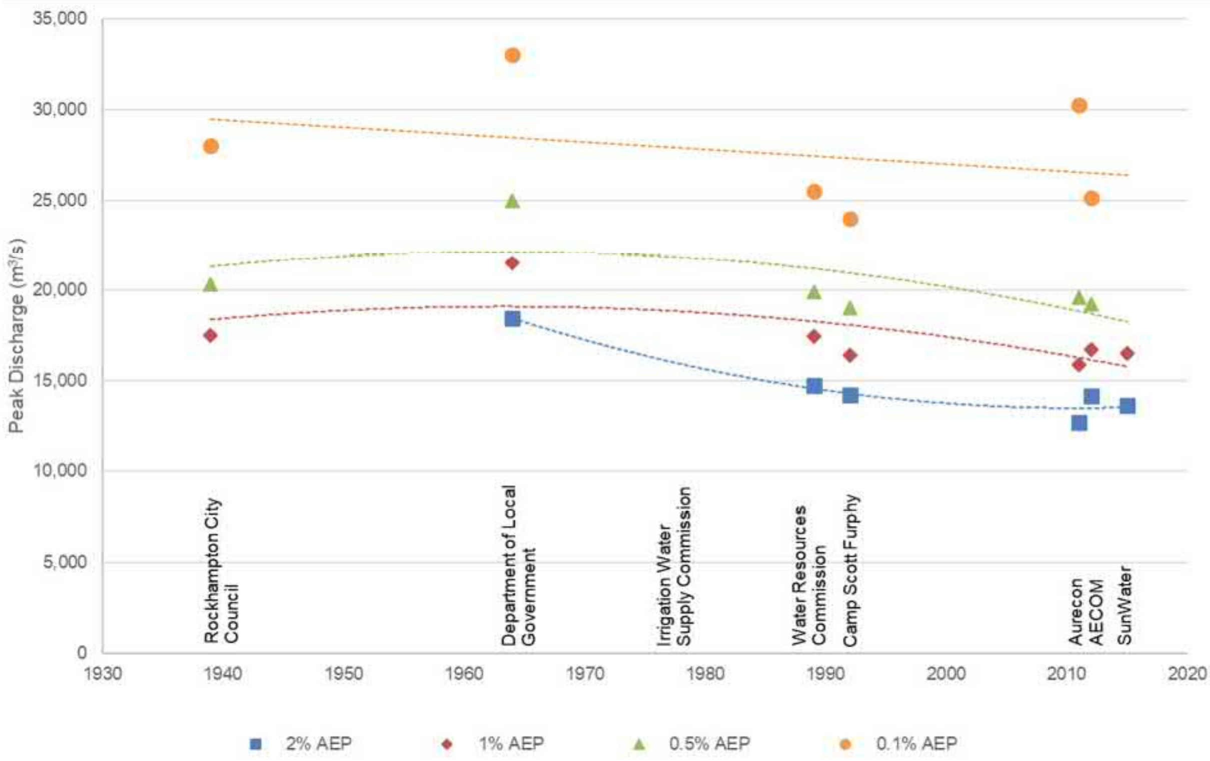
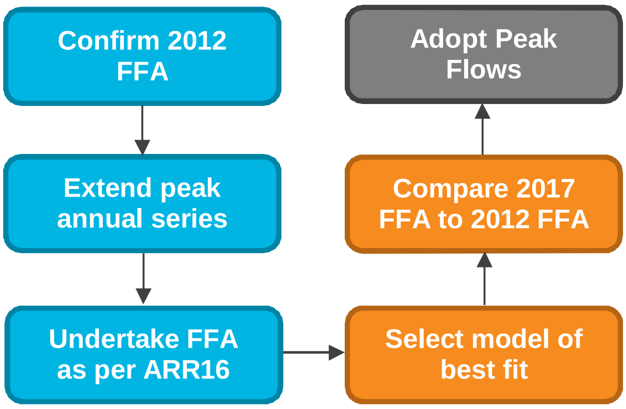


Figure 7 Timeline of FFA Results for Rockhampton

Aside from peak discharges, AECOM previously undertook a review of inflow hydrographs adopted within the FRFS (Aurecon 2011) and FRFRPS (AECOM 2012) in order to determine the most appropriate hydrographs for use in the SRFL project. Based on the review undertaken, it was concluded that the FRFRPS hydrographs was more reliable due to the underlying methodology adopted. The choice of hydrograph was based on extreme value analysis of historical events for both duration and volume in which it was found that the 1991 hydrograph best represented the relationship between AEP, runoff volume and event duration. The choice of the FRFRPS hydrograph also resulted in more conservative peak flood heights. Therefore, the FRFRPS hydrograph shape was adopted for the SRFL Project.

4.2 Adopted Methodology

Hydrological analysis was undertaken to determine the design flood hydrographs for various design events. The general approach taken to define design flood quantiles within the study area was:



4.3 At Site Flood Frequency Analysis

4.3.1 Overview

Flood peaks are the product of a complex joint probability process involving the interaction of many random variables associated with the rainfall event, antecedent conditions and rainfall-runoff transformation. Peak flood records represent the integrated response of the storm event with the catchment. They provide a direct measure of flood exceedance probabilities. As a result, flood frequency analysis is less susceptible to bias, possibly large, that can affect alternative methods based on design rainfall (Kuczera et al., 2003).

FFA is generally based on data extracted from continuous flow records or event-based observations for extreme events. It should be noted that FFA can be conducted using:

- An annual flood series, where the highest flow in each year is selected, whether it is a major flood or not. For N years of record, the annual flood series will consist of N values.
- A partial flood series, where the series consists of all floods with peak discharges above a selected base value, regardless of the number of such floods occurring each year. The number of floods K generally will differ from the number of years of record N, and will be dependent on the base discharge.

The shape of a flood frequency curve reflects the interaction of hydrologic factors for a catchment and the flood response at the specified site that the flood data was available.

4.3.2 Assessment Method

For analytical treatment of flood studies, a probability model must be selected to fit the data. There is no universally accepted flood probability model. Many types of probability distributions have been applied to flood frequency analyses and the appropriateness of these distributions can be tested by examining the fit of each distribution to observed flood data.

For the purposes of this assessment, there were several different probability models used to find the best fit to the peak annual series. These were:

- Generalised Pareto.
- Generalised Extreme Value.
- Gumbel.
- Log Normal.
- Log Pearson Type III.

These probability models were fitted to the data using LH moments and Bayesian inference methods, with the latter being able to handle gauged and censored data, errors in data and regional information.

The Bayesian approach to calibrating flood probability models is numerically complex and has been implemented using the TUFLOW FLIKE extreme value analysis package. The package, originally developed by the University of Newcastle, is compliant with ARR16 guidelines.

4.3.3 Confirmation of 2012 FFA Results

In order to validate the previously derived probabilistic estimates, the peak annual series as at 2012 was assessed in accordance with ARR16 methodology using TUFLOW FLIKE. Each of the abovementioned probability models was fitted using both Bayesian and LH moment inference methods and compared to their fit against the Cunnane plotting position of historic events. Each model was also tested with appropriate censoring of non-flood events.

Of all fits, the Generalised Extreme Value probability model fitted the best using an optimized L moment shift of 4. The probability plot is shown in Figure 8 and the following points can be made:

- All events are well-within the 5% and 95% confidence limits.
- The left-hand tail fits the plotted events well.
- The right-hand tail also fits the plotted events well, particularly around the 1% AEP event. This is particularly evident in Figure 9.
- The shape of the GEV model is close to that of the Log-Normal model adopted in 2012.

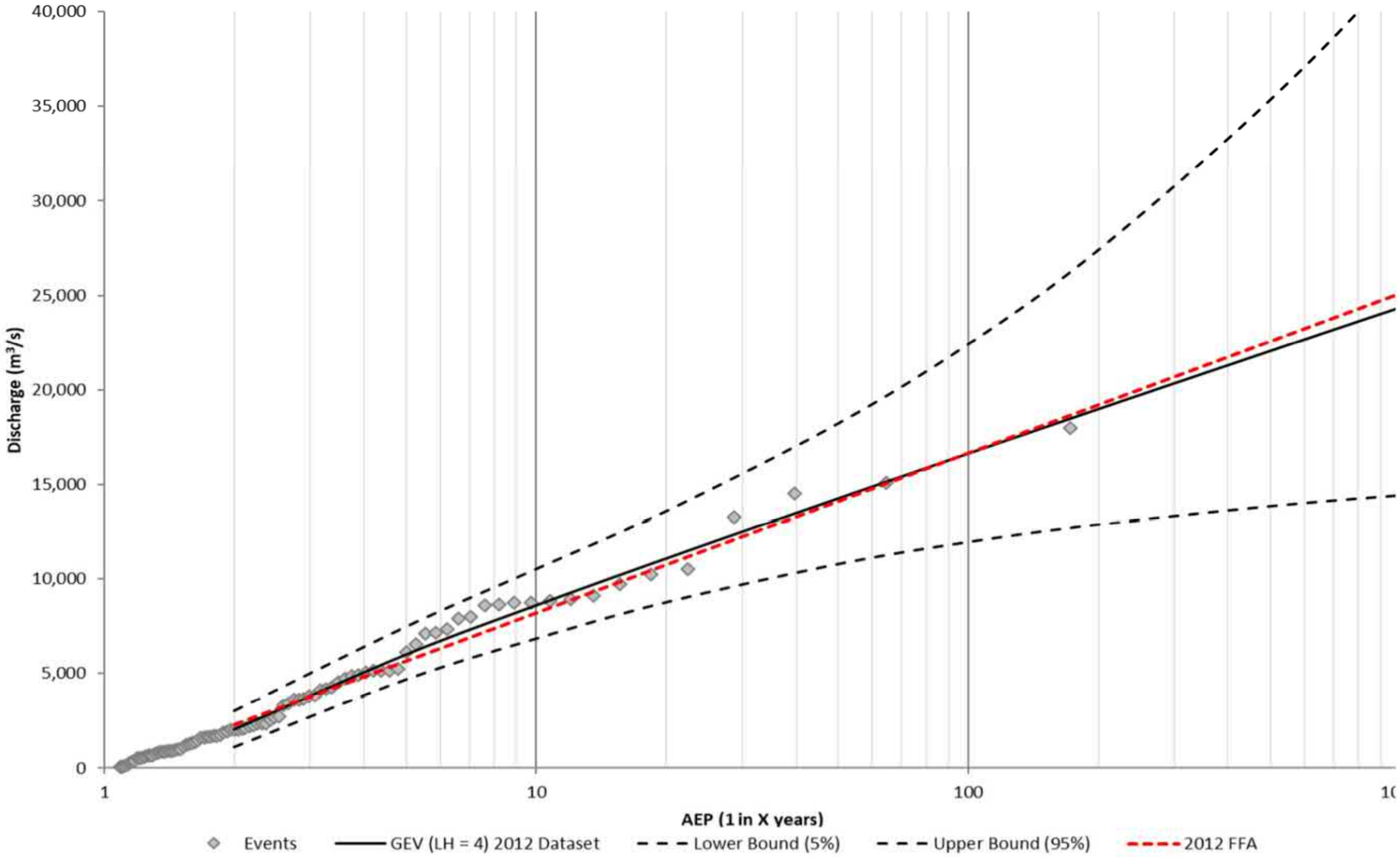


Figure 8 Adopted GEV (LH = 4) Distribution (2012 data)

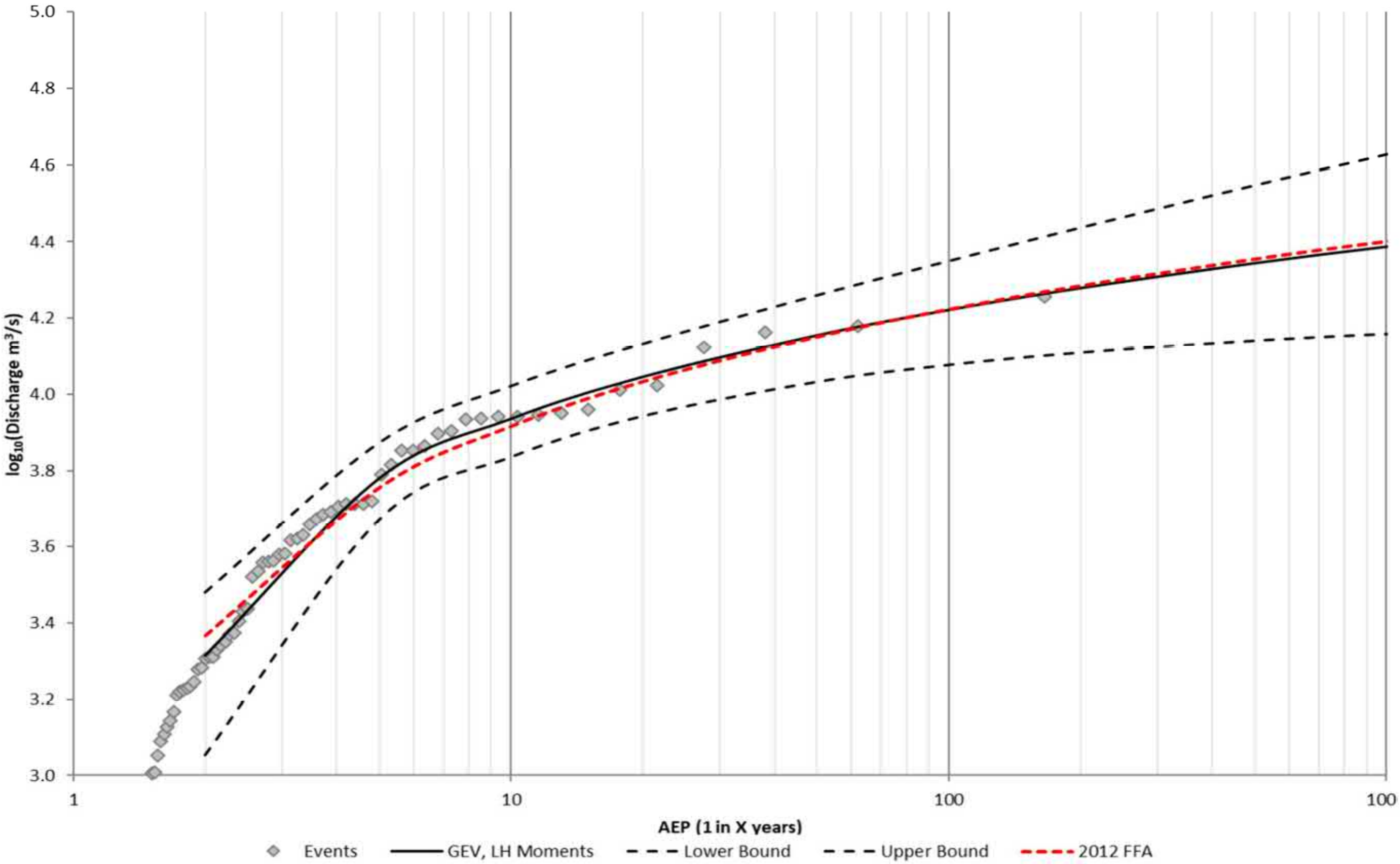


Figure 9 Adopted GEV (LH = 4) Distribution (log_{10} Vertical Scale)

Table 6 Comparison of Fitted Models to 2012 Dataset

AEP (1 in X years)	2012 FFA Flood Quantiles (m^3/s)	Revised 2012 FFA Flood Quantiles (m^3/s)	Difference (m^3/s)
10	8,228	8,620	**391 (5%)**
20	10,771	11,098	**326 (3%)**
50	14,133	14,283	**150 (1%)**
100	16,676	16,653	**-23 (0%)**
200	19,219	19,000	**-219 (-1%)**
500	22,581	22,076	**-505 (-2%)**
1,000	25,124	24,385	**-739 (-3%)**
2,000	27,667	26,680	**-987 (-4%)**
5,000	31,029	29,691	**-1,337 (-4%)**
10,000	33,572	31,954	**-1,618 (-5%)**

The results presented in Table 6 shows the similarity in estimated flood quantiles between the 2012 assessment and the updated assessment using the latest ARR16 fitting techniques. The comparable results obtained from both fitted models prove the validity of the 2012 FFA results.

4.3.4 Compilation of Additional Gauge Data

The FFA undertaken in 2012 was reviewed to include recent flood records, including the 2017 Fitzroy River flood. The combined annual peak discharge data set used in the latest FFA is shown in Figure 10. The dataset was compiled using the following gauge records with a length of record spanning from 1915 to 2017 (103 years inclusive). These stations are within close proximity to each other, noting the insignificant difference in catchment area as a proportion of the total area (up to 0.4%; see Table 3).

Further information about data gap filling and input data preparation is documented in the FRFRPS Volume 2 Report – Hydrologic Assessment (AECOM, 2009) and further discussed in the SRFL Inflow Hydrograph Review Report (AECOM, 2014). The annual maxima series has been constructed as follows:

- The Gap (130005A) – 1970 to Present (49 years)
- Yaamba (130001C) – 1951 to 1969 (19 years)
- McMurdos (130001B) – 1928 to 1950 (23 years)
- Wattlebank (130002A) – 1927 (1 year)
- Yaamba (130001A) – 1915 to 1926 (12 years)

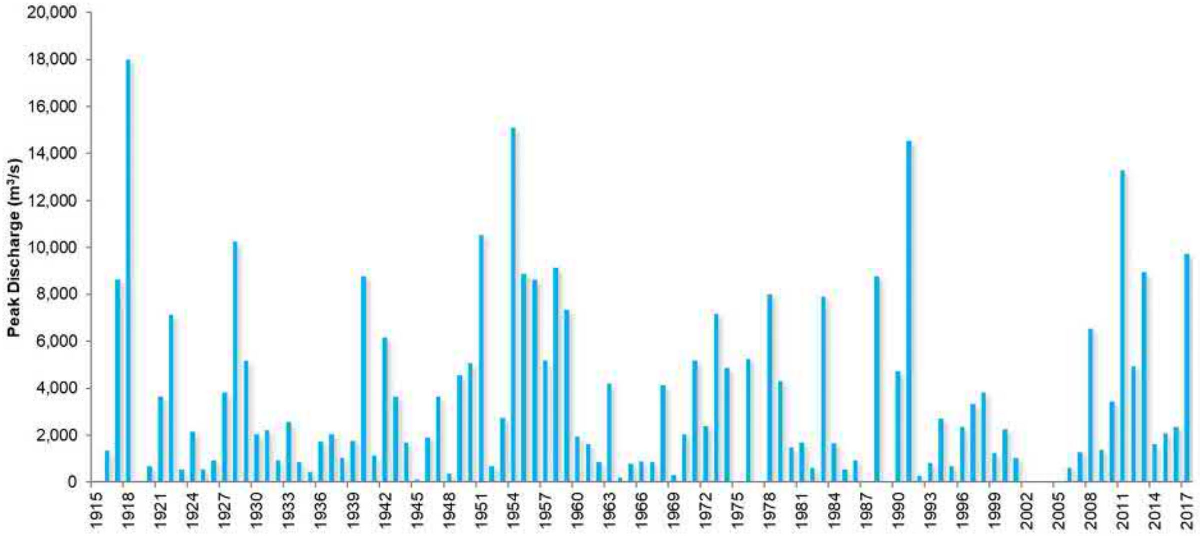


Figure 10 Annual maximum data series used in FFA update

4.3.5 2018 FFA Results

As detailed in Section 4.3.3, the peak annual series as at 2017 was assessed in accordance with ARR16 methodology using TUFLOW FLIKE. Each of the probability models was fitted using both Bayesian and LH moment inference methods and compared to their fit against the Cunnane plotting position of historic events. Each model was also tested with appropriate censoring of non-flood events.

Of all model fits, the following three proved to fit the plotted events closest:

- Log Pearson III (Censored)
- Gumbel (Censored)
- GEV (L-moments, No Censoring)

Figure 11 shows a comparison between the peak annual dataset and each of the fitted models. The vertical axis is plotted using a $\log_{10}$ scale in order to improve the visibility of each fit. This analysis showed the GEV (L-Moments) produced the closest comparison to observed data especially at the 1% AEP and adjacent magnitudes. Therefore, the GEV (with LH = 4) was chosen as the preferred statistical model for the FFA update (Figure 12).

Extrapolation of the frequency curve beyond the limit of the available data was undertaken in order to estimate the peak discharges for extreme floods (i.e. the 0.5% AEP event and above). It must be noted that this extrapolation is subject to a wide error band and is therefore has considerable uncertainty.

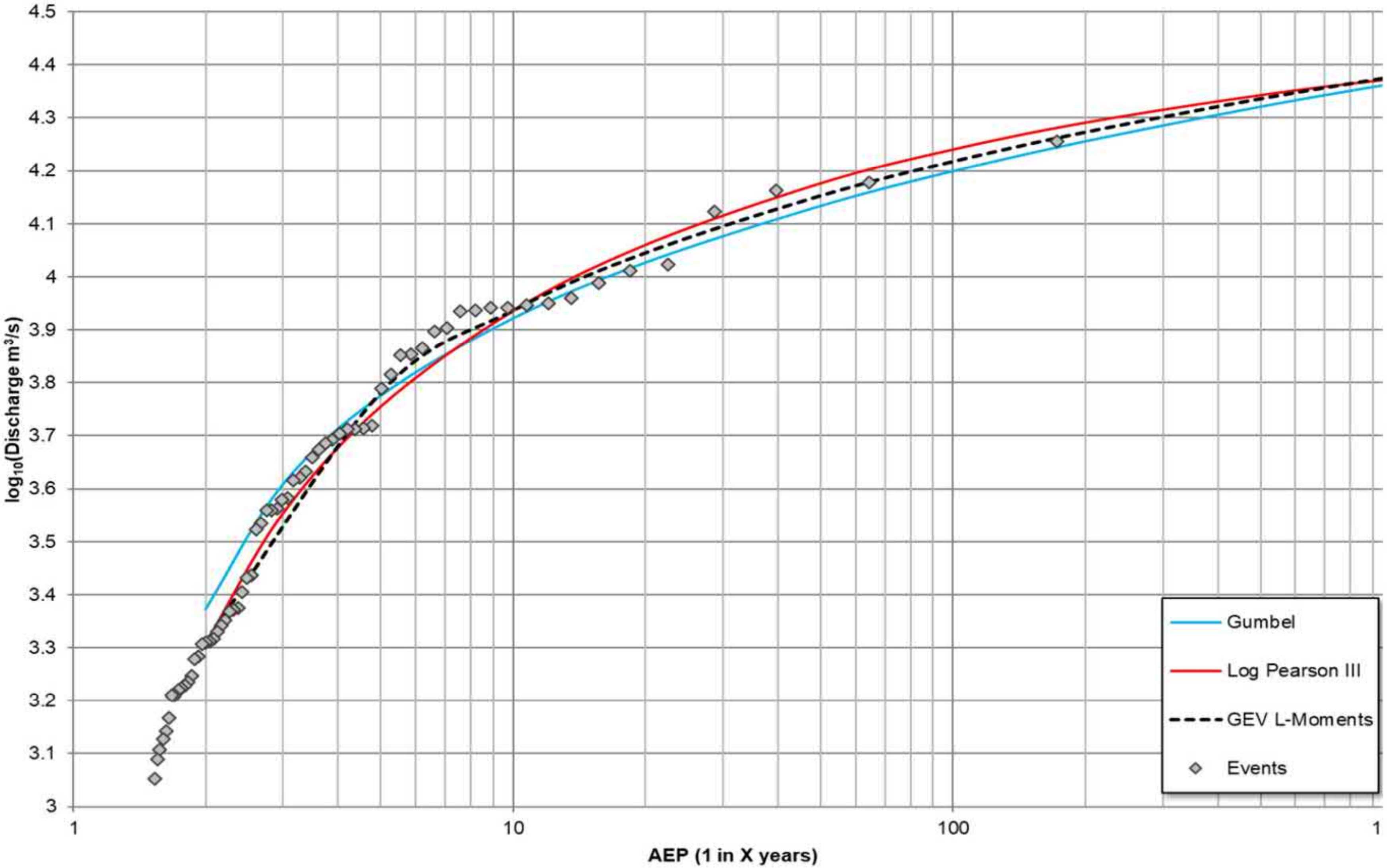


Figure 11 Comparison of Probability Models

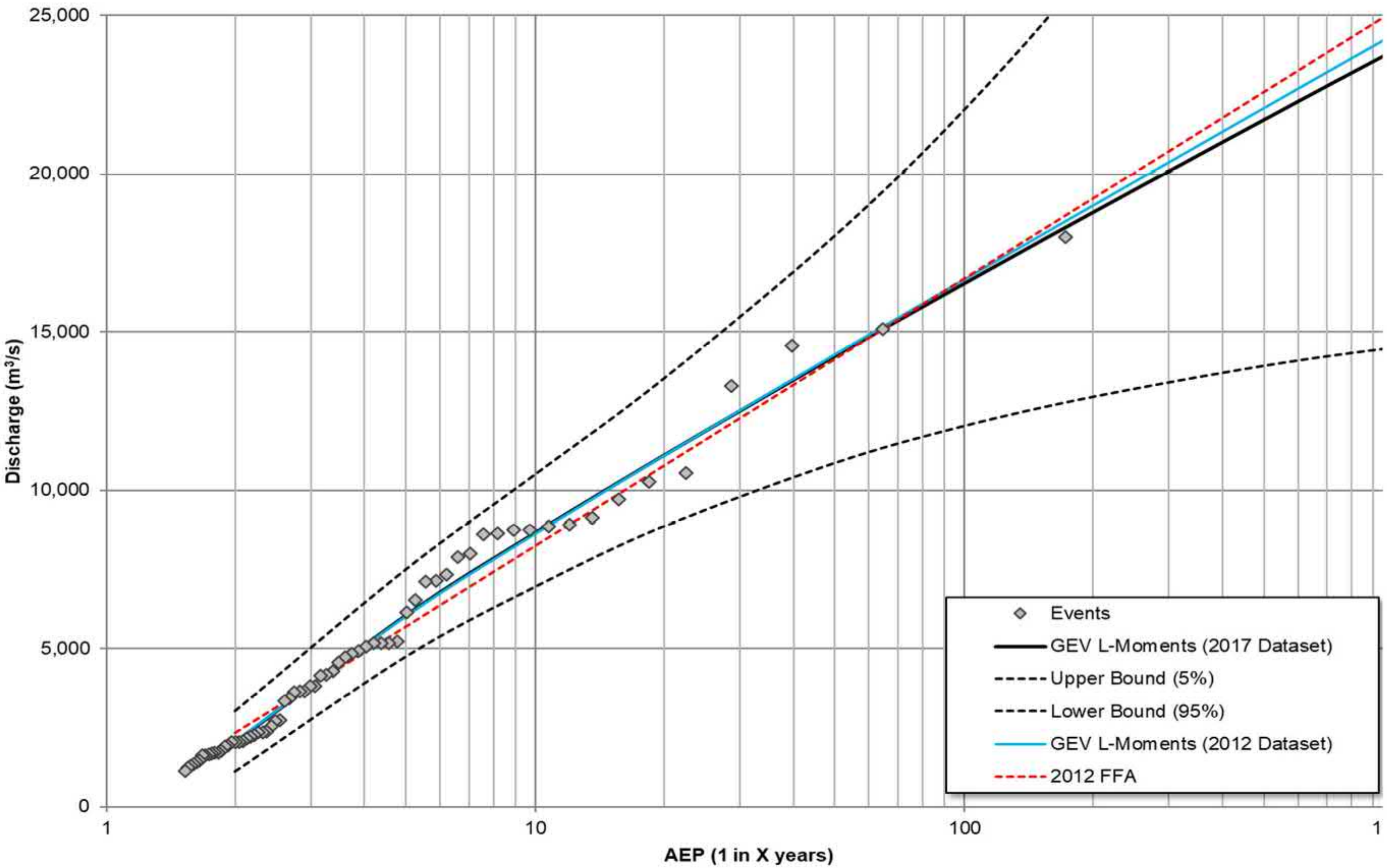


Figure 12 Adopted GEV (LH = 4) Distribution

Figure 12 also includes the fitted models to the 2012 dataset in order to compare results of each distribution. The results are tabulated in Table 7.

Table 7 Expected Flood Quantiles for Adopted Datasets and Probability Models

AEP (1 in X yrs)	2012 FFA Flood Quantiles (m^3/s)	2012 Dataset, GEV (LH = 4) Flood Quantiles (m^3/s)	Difference to 2012 FFA (m^3/s)	2017 Dataset, GEV (LH = 4) Flood Quantiles (m^3/s)	Difference to 2012 Dataset, GEV (LH = 4) (m^3/s)
10	8,228	8,620	**391 (5%)**	8,661	**41 (~0%)**
20	10,771	11,098	**326 (3%)**	11,115	**17 (~0%)**
50	14,133	14,283	**150 (1%)**	14,235	**-48 (~0%)**
100	16,676	16,653	**-23 (~0%)**	16,532	**-121 (-1%)**
200	19,219	19,000	**-219 (-1%)**	18,786	**-215 (-1%)**
500	22,581	22,076	**-505 (-2%)**	21,708	**-369 (-2%)**
1,000	25,124	24,385	**-739 (-3%)**	23,878	**-508 (-2%)**
2,000	27,667	26,680	**-987 (-4%)**	26,014	**-666 (-2%)**
5,000	31,029	29,691	**-1337 (-4%)**	28,788	**-903 (-3%)**
10,000	33,572	31,954	**-1618 (-5%)**	30,851	**-1103 (-3%)**

Based on the results in Table 7, the 2% AEP, 1% AEP and 0.5% AEP expected quantiles are within 1% across all probability models. This provides a high degree of confidence in the previously determined 1% AEP peak discharge of 16,676m^3/s.

Increasing variance is evident towards the left-hand and right-hand tails. However, the majority of disparity within the between the 2017 Dataset GEV (LH = 4) fit and 2012 FFA is linked to the model used to fit the dataset. Inclusion of the additional 5 years in the 2017 dataset causes negligible change for AEP's more frequent than a 1 in 500 year event.

Closer investigation into the coefficient of determination for the various datasets and models shows:

- 2012 FFA (Log-Normal) R^2 = **0.9872**
- 2012 Dataset GEV (LH = 4) R^2 = **0.9127**
- 2017 Dataset GEV (LH = 4) R^2 = **0.9336**

Whilst the R^2 is not an all-encompassing indicator of probability model suitability, it does outline a notably better fit for the 2012 FFA Log-Normal model when compared to the GEV models.

4.3.6 Adopted FFA Results

The statistical analysis undertaken within Sections 4.3.3 to 4.3.5 showed that inclusion of the additional 5 years of flood data and use of ARR16-complaint TUFLOW FLIKE resulted in minimal change to the probabilistic estimates of the 2%, 1% and 0.5% AEP peak discharges. Whilst increasing disparity was observed for other flood magnitudes, all were within 5% of the 2012 expected quantiles. It is also noted than events less frequent than a 0.5% AEP event are subject to rapidly increasing uncertainty due to extrapolation of the probability distribution.

Given the statistical rigor of the 2012 FFA (which has been validated in this report) and negligible change to the 2%, 1% and 0.5% AEP flood magnitudes in the 2017 FFA, **the estimated peak flood quantiles determined in the 2012 FFA were maintained within this study**. The adopted estimated quantiles and confidence limits are shown in Table 8.

Table 8 Adopted Design Event Peak Discharges

AEP (%)	Estimated Flow (m^3/s)
18	5,685
10	8,228
5	10,771
2	14,133
1	16,676
0.5	19,219
0.2	22,581
0.05	27,667
PMF	56,713

4.3.7 Adopted Inflow Hydrographs

As discussed in Section 4.1, AECOM undertook a detailed inflow hydrograph review in 2014 in order to determine the most appropriate inflow hydrograph to adopt for the Fitzroy River model (Inflow Hydrograph Review Report, 2014). The investigation concluded that the 1991 historical flood event hydrograph best represented the relationship between AEP, runoff volume and event duration.

Therefore the 1991 hydrograph has been maintained and adopted for probabilistic events used in this study.

5.0 Hydraulic Model Updates

5.1 Overview

The Fitzroy River TUFLOW hydraulic model developed as part of the SRFL project (AECOM, 2014) was made available for use in the FRFRPS OA Update hydraulic investigation. Since completion of the SRFL project in 2014 the topography within the floodplain has changed due to land developments and major infrastructure.

In 2016 aerial survey in the form of LiDAR was flown across the Rockhampton Region to capture these developments, superseding topographical data used as part of the SRFL study (which was flown in 2009). There have also been advances to hydraulic modelling software packages and computational power in recent years, allowing for improved model stability and reduced simulation times. The additional Fitzroy River gauge data at Yaamba from 2014-2018 (including the 2017 flood event) provides further opportunities to review the Flood Frequency Analysis (FFA) and undertake additional hydraulic model calibration.

The subsequent updates made to the 2014 hydraulic model have been broken into the following categories which are covered in further detail below:

- Fundamental hydraulic model updates.
- Model re-calibration and re-validation.

5.2 Fundamental Model Updates

5.2.1 Updated TUFLOW Software

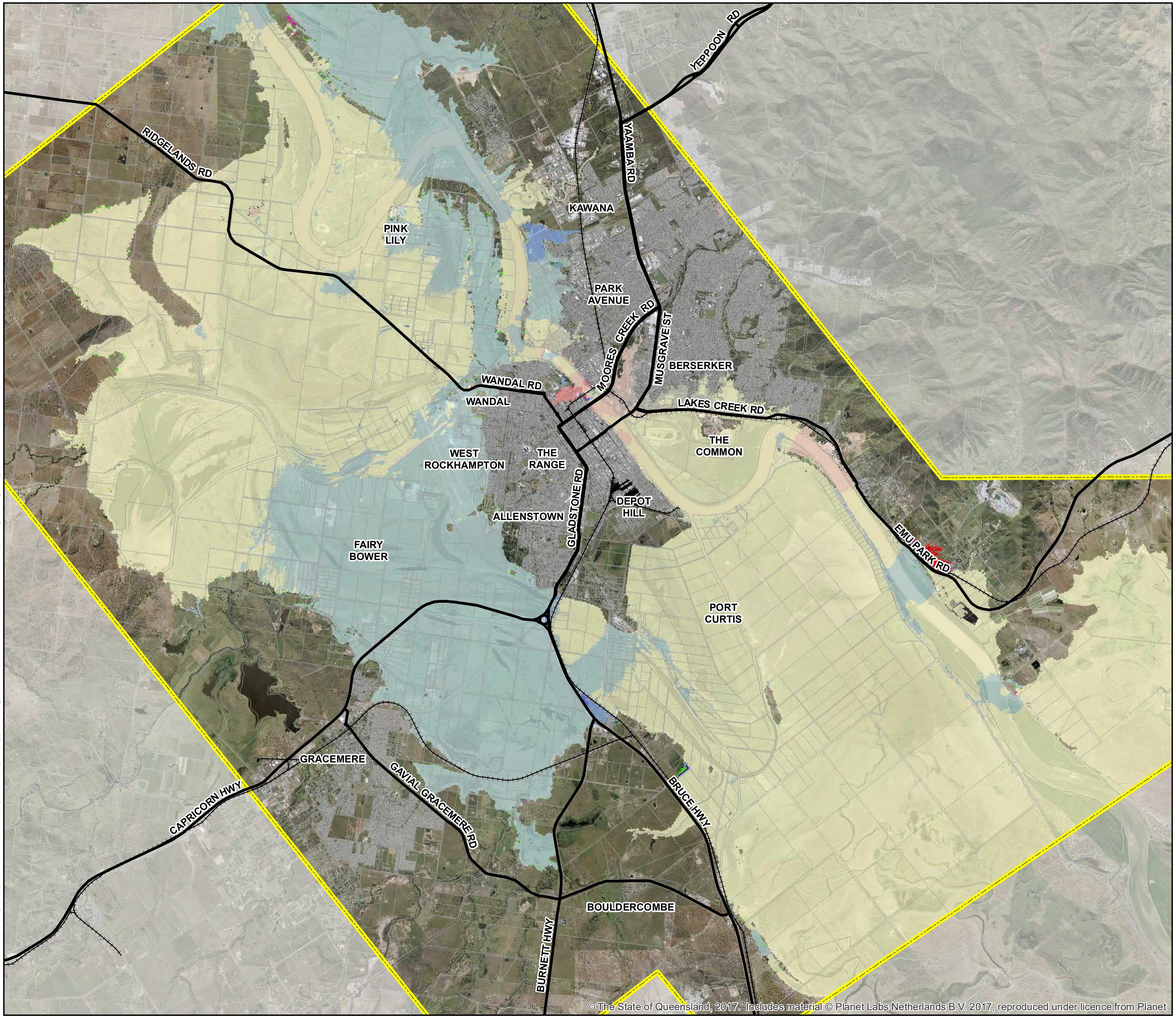
The existing Fitzroy River TUFLOW model (SRFL, AECOM 2014) was run initially without any changes and in the same software version as the original model (2013-12-AA version of TUFLOW Classic). This was undertaken to ensure that model provided by RRC could reproduce the previous results and that model integrity had been maintained. The simulation confirmed that model integrity had been maintained and results were the same as those previously reported.

TUFLOW HPC Version 2018-03-AB (refer Appendix A for further information) has been used for this model update. With no other changes to the TUFLOW model setup, simulation time for the 1% AEP event was reduced from 89 hours to 7 hours. A comparison between the 1% AEP Peak Water Surface Elevation (PWSE) results for the 2013-12-AA and 2018-03-AB versions of TUFLOW are shown in Figure 13.

Comparison of the 2018-03-AB to 2013-12-AA results shows a difference in PWSE of ±50mm across a majority of the modelled area. Areas where differences in PWSE are predicted to be greater than ±50mm include:

- The western floodplain upstream of the Yeppen Crossing, where a reduction in PWSE of between 50mm and 100mm is predicted.
- A reduction in PWSE of up to 200mm at the Scrubby Creek crossing between the Bruce Highway and North Coast Rail Line bridges.
- Localised area around the Fitzroy River rail bridge, where flood levels are predicted to increase by average of 100mm upstream and decrease by average of 150mm downstream of the bridge.
- A reduction in PWSE of up to 80mm within Scrubby Creek, in the vicinity of Farm Street.
- An increase in PWSE of up to 200mm along Rockhampton-Emu Park Road, in the vicinity of Nerimbera School Road.

These changes to PWSE and flood extents are within modelling tolerance and considered acceptable for the simulation time reductions gained.



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LEGEND

- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- Cadastre

Difference (m)

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

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

Difference in Peak Flood Heights
TUFLOW 2018-03-AB minus 2013-12-AA
1% AEP Event

PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	19/02/2019
VERSION:	01

Figure
13

A3 size

Filename: P:\605x\60578201\4. Tech Work Area\4.99 GIS\02_MXDs\FR18\Report\Figures\MXD\Figure 4 - Comparison Between Tuflow 2018 and 2013 Results.mxd

5.2.2 Grid Cell Size

To better represent existing and proposed road / rail infrastructure within the Fitzroy River floodplain a smaller grid cell size was required. To establish an appropriate grid size the estimated simulation time was calculated for a range of grid cell sizes. Table 9 provides a summary of the estimated simulation times.

Table 9 Estimated HPC Simulation Time – Different Grid Cell Sizes

Grid Cell Size	Estimated Simulation Time
25m	7 hrs
20m	13 hrs
15m	**30 hrs**
12m	59 hrs
10m	102 hrs

A 15m grid was determined to be an adequate resolution to model finer scale elements such as road/rail embankments, while retaining reasonable model run times.

Figure 14 through Figure 16 provide a comparison between the previous 25m grid model Digital Elevation Model (DEM) versus the updated 15m grid DEM at various scales. It can be seen that road formations and estuaries have much better definition in the 15m DEM, which provides a better representation of actual site conditions.

5.2.3 Topographic Updates

A number of topographic updates were applied to the TUFLOW model to better represent current conditions. Each of the updates are described in more detail below.

5.2.3.1 Base Topography (LiDAR) Updates

The base topography used for the 2014 TUFLOW model was constructed using LiDAR survey captured in 2009. Since then additional LiDAR survey has been captured across the Rockhampton Region. It was decided that the base topography within the model would be updated to the latest 2016 LiDAR survey.

5.2.3.2 Additional Topography Updates

The refinement of the model grid cell size not only provides more detail but requires key hydraulic controls to be better defined within the floodplain. To ensure that the updated model more accurately represented creek channel inverts and road / rail embankments, the latest LiDAR levels were extracted along creek, road and rail centrelines and input directly into the model topography.

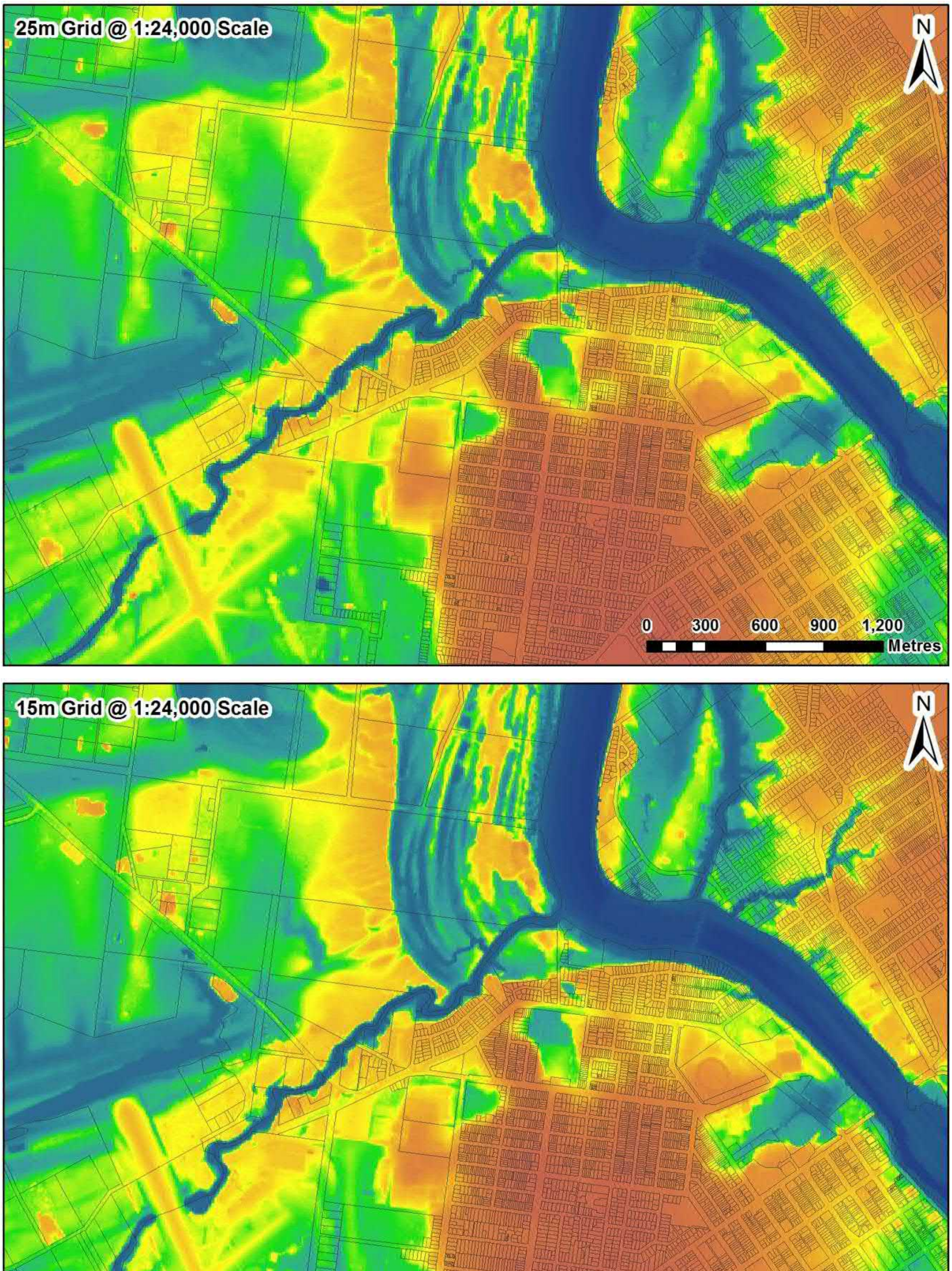


Figure 14 Comparison of Model Grid Cell Sizes -1:24000 Scale

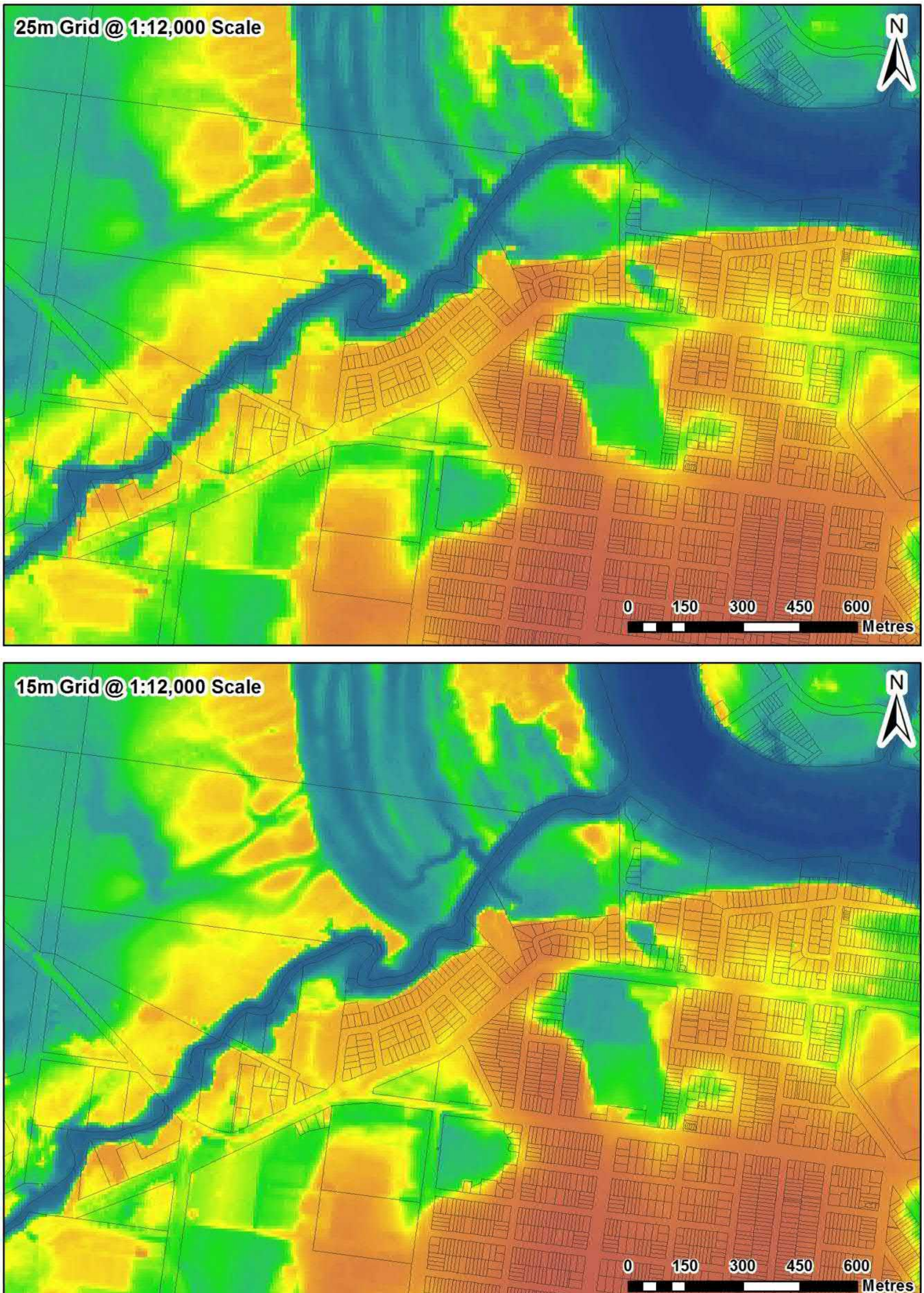


Figure 15 Comparison of Model Grid Cell Sizes -1:12000 Scale

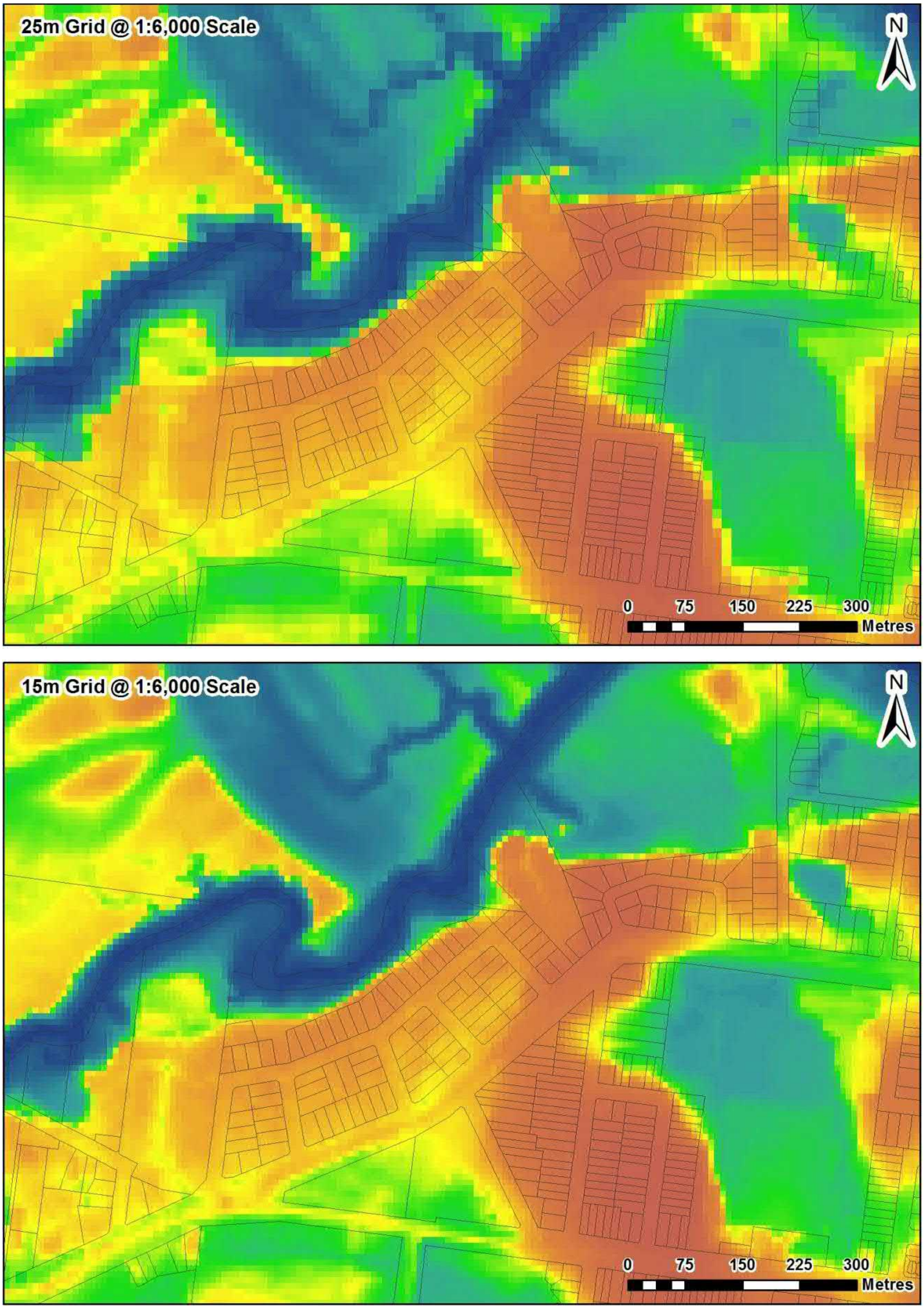


Figure 16 Comparison of Model Grid Cell Sizes -1:6000 Scale

5.2.4 Roughness Value Updates

The roughness values for the updated TUFLOW model were based on land use planning data provided by RRC. From this dataset, land use classifications were categorised into their relevant roughness value category based on the intended use or anticipated ground cover for the provided description. By updating the roughness values to the latest land use planning data this ensured that developments across the floodplain since previous modelling work were captured and represented appropriately.

The latest road and intersection parcels were also sourced from the QSpatial databases and used to create the road reserve roughness regions. Some other significant hardstand areas such as the airport runways were added as additional elements to this layer, traced from the aerial photography.

Light, medium and heavy vegetation areas as well as lagoons, creeks and riverine areas were traced using the latest aerial imagery (captured in 2016).

5.2.5 Bridge Modelling

The adopted approach to modelling the proposed and existing bridges in TUFLOW is to use 2-D layered flow constriction shapes. This approach was adopted as the pier diameters are represented by a small proportion of a cell width (i.e. sub-grid) and would not be adequately represented in the 2-D domain.

The initial form loss, which defines the head loss experienced across the bridge structure, was derived from Figure 7 of the FHWA publication “Hydraulics of Bridge Waterways HDS 1 March 1978 - Author: Joseph N. Bradley, FHWA, Bridge Division”, which is reproduced in Figure 17. Each bridge/structure was reviewed and/or benchmarked against a HEC-RAS model.

To use the chart, calculate the ratio of the water area occupied by piers to the gross water area of the constriction and the angularity of the piers. These inputs are used to calculate "J". The value k_p is entered as the form loss coefficient for each particular level.

5.2.6 Culverts / Drainage Structures

The finer scale grid enabled the inclusion of nine additional culverts not previously included in the 25m grid model. These culverts allow flood waters to backflow and reach their full flood extent within the hydraulic model. The inclusion of these culverts results in a better calibration and validation outcome as explain in section 6.0.

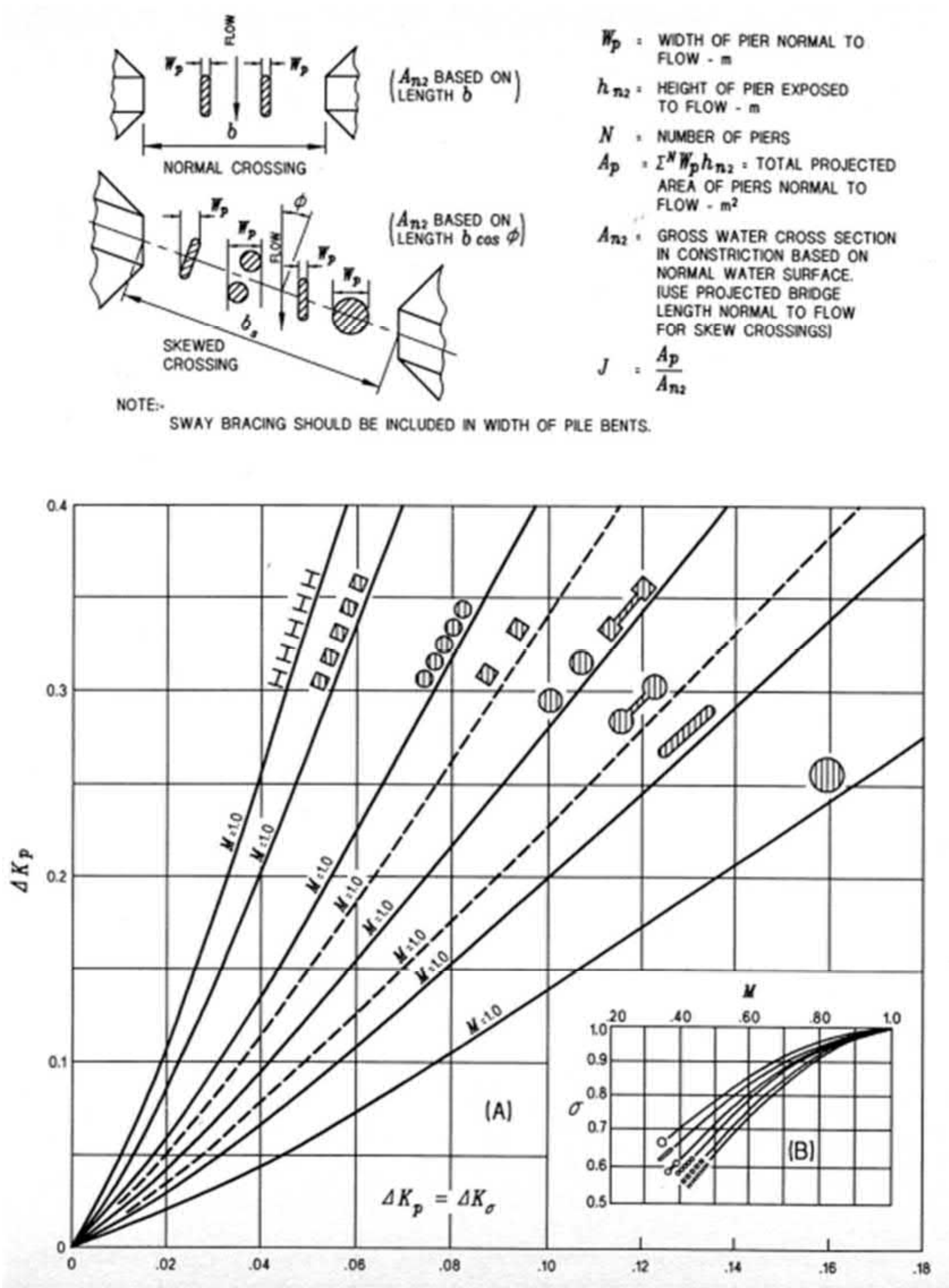


Figure 17 Incremental Backwater Coefficient for Piers (Figure 7 from Hydraulics of Bridge and Waterways, 1978)

5.3 Model Re-Calibration and Re-Validation

Previously the TUFLOW model was calibrated to the 2011 event and validated to the 2008 and 1991 events. With the occurrence of the 2017 Fitzroy River flood event, coupled with the large number of fundamental changes applied to the model, a model re-calibration and re-validation was undertaken. The updated model was therefore calibrated to the 2017 flood event associated with TC Debbie and validated to the 2011, 2008 and 1991 flood events.

Model schematisation and topography updates were required to facilitate improved model calibration and validation to historic flood records. The following general changes were applied to the model during the re-calibration / re-validation process and are discussed further below:

- Changes to the downstream 1-D network cross sections.
- Changes to overland flow roughness values.
- Topographic adjustments to embankment forcing and natural channel forming - z-shp and z-line shapes.
- Changes to Pink Lily breakout and Ridgelands Road downstream of the Pink Lily breakout.
- Lion Creek bathymetric survey added. Channels around the Main Drain refined using z-shp's. Changes to some culvert inlets/outlets and blockage factors around the Main Drain.
- North Rockhampton Flood Mitigation Investigation (NRFMI) levees.
- Additional pipes added under Lakes Creek Road and Yeppoon Branch Rail Line as well as around the Main Drain to the south of the city to allow backflow.
- Change to parametrisation of bridges over the main river channel and Yeppen South and North Bridges.

5.3.1 Downstream 1-D Network Cross Sections

The downstream reach of the Fitzroy River and western floodplain between the southern 2-D model boundary and Port Alma is represented as a 1-D network with cross sections obtained from the LiDAR survey. In the 2014 model these sections were based on the 2009 LiDAR survey. These were updated as part of the 2018 model update to utilise the latest 2016 LiDAR survey.

Figure 18 shows a comparison between the previous and updated D/S 1-D cross sections at 280m downstream (CH280) of the southern 2-D model boundary.

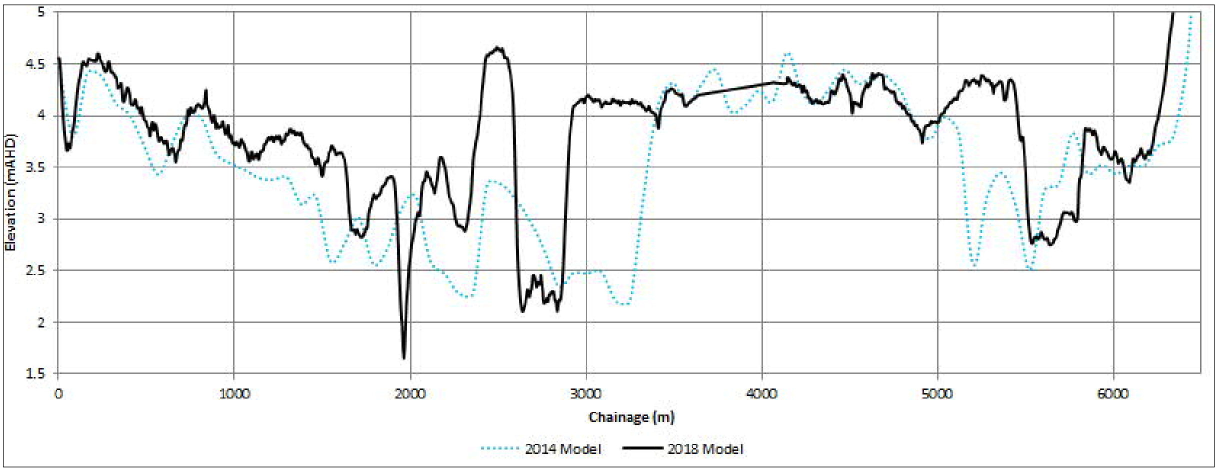


Figure 18 Downstream 1-D Network Cross Section Comparison (CH280)

Figure 18 demonstrates there have been changes within the lower Fitzroy River floodplain, during the time between the 2009 and 2016 LiDAR. This is particularly evident around small watercourses and streams. While it is noted below in Section 6.7 that there is a difference between the 2016 and 2009 LiDAR levels, generally 0.18m higher in the 2016 LiDAR, the remaining differences between the 1-D cross sections can be attributed to fluvial deposition. This would result in a reduction in conveyance across the western floodplain.

5.3.1.1 Validation Event 1-D Cross Sections

It is noted that changing the downstream cross sections to match 2016 LiDAR for the validation events caused levels within the 2-D model to rise due to the decrease in conveyance area. It was decided to simulate the validation events with cross sections cut from the 2009 LiDAR, as those cross sections more closely represent conditions at the time of the validation events.

5.3.2 Downstream 2-D Model Boundary

Changes to the downstream 2-D model boundary were introduced during the 2018 model update, to better represent downstream river and floodplain conditions. These include:

- Introduce new eastern bank overflow channel at the 2-D model boundary to more accurately simulate eastern overbank flood conveyance.
- The downstream 2-D model connection has been split into western overbank, main river and eastern overbank channel. These cross sections connect to the downstream cross section which extends across the whole floodplain to represent Fitzroy River and overbank flows.
- Western overbank, main river and eastern overbank channel include mid cross sections to avoid interpolation of flow conveyance when used in reach end sections.
- The 2-D model boundary splits at the left and right river banks and are modelled without weighting factors, to force the resulting water level on 2-D model domain.

The above changes to the downstream 2-D model boundary and 1-D cross sections provide a more representative and responsive downstream boundary condition. Overall the changes result in slightly reduced floodplain conveyance within the downstream 1-D channels. Changes to roughness within the downstream 1-D channel were introduced to increase flow conveyance and provide a better comparison to observed historical flood levels. Details of 1-D roughness changes are discussed below.

5.3.3 Downstream 1-D Network Roughness

The 2014 TUFLOW model set floodplain roughness in the downstream 1-D network to 0.05 for the river channel and 0.1 for the overbank channels based on the results of calibration to historical events. During the updated calibration and validation modelling, the following 1-D roughness values were tested:

- River Channel Roughness:
  - With the original 0.05 ‘n’ value.
  - With a decrease to the ‘n’ value to 0.045 to offset reduction of conveyance in 1-D channels.
  - Further reduction of the ‘n’ value to 0.04 to achieve a better match to historic flood levels.
- Overbank Roughness
  - With the original 0.10 ‘n’ value.
  - With a decrease to the ‘n’ value to 0.095 to offset reduction of conveyance in 1-D channels.
  - Further reduction of the ‘n’ value to 0.09 to achieve a better match to historic flood levels.

Through the calibration process it was found that the ‘n’ value of 0.04 for the river channel and 0.09 for the overbank channels provided the best results when compared to the surveyed flood levels throughout the western and eastern floodplain.

5.3.4 Floodplain Roughness within 2-D Model Domain

The 2014 TUFLOW model categorised the floodplain into different roughness categories spatially based on land use and aerial imagery. The categories over the floodplain are primarily made up of rural, open space, roads, lagoons, light vegetation, medium vegetation and heavy vegetation.

Initial calibration results showed that the model was predicting lower flood levels in the western floodplain, while results of validation simulations predicted higher flood levels in the same area. To reduce flood levels in the validation models (where events occurred in January with dry conditions over the floodplain) and increase flood levels in the calibration model (in March, vegetation expected to be more predominant) the light vegetation category was altered seasonally.

The light vegetation category roughness ‘n’ value was increased from 0.05 to 0.055 for the calibration event (2017 event) and decreased to 0.045 for the validation events (1991, 2008, 2011 events). This change assisted in aligning modelled flood levels to the surveyed levels for each event.

5.3.5 River Roughness within 2-D Model Domain

In the 2014 TUFLOW model, the Fitzroy River was assigned an ‘n’ value of 0.035 for the full extent of the river within the 2-D model domain. The following iterations to the river roughness values were tested:

- Increasing the river roughness to an ‘n’ value of 0.04 for the full extent of the river within the 2-D model domain.
- Decreasing the river roughness to an ‘n’ value of 0.03 for the full extent of the river within the 2-D model domain.
- Increasing the river roughness to an ‘n’ value of only 0.0385 for the full extent of the river within the 2-D model domain.
- Increasing the river roughness to an ‘n’ value of 0.0365 over the majority of its length with a small section between the city bridges set to 0.041 to represent the rocky outcrops prominent through this portion of the Fitzroy River reach.

Through an iterative calibration process, the final change of a varying river roughness (0.0365 for the majority with 0.041 in the city reach) was found to best align modelled flood levels with the historic levels. This was confirmed by comparing recorded and modelled flood levels across the historic events and creating long sections along the main river channel.

5.3.6 Pink Lily Breakout

Through the calibration process the Pink Lily Breakout to the north of Ridgelands Road was found to be highly influential on peak levels across the western floodplain. A more detailed investigation into the LiDAR in this area suggested the filtering of trees and vegetation in the post-processed data may not be accurate in representing current conditions at the site. It was determined the Pink Lily Breakout was allowing too much water from the Fitzroy River to flow into the western floodplain during validation events and not enough in the calibration event.

To gain confidence in the current geometry of the meander bathymetry and bank location, survey of the river bed, banks and surrounding natural surface was undertaken in early 2019 and layered into the model topography. This data was read into the model topography for the 2017 calibration event as well as all design events.

Generally, incorporation of the feature survey (Fitzroy River banks to Ridgelands Road within the breakout area) lowered the model topography by 135mm and confirmed the ongoing lateral migration of the Pink Lily meander. Bathymetric survey was also incorporated, revealing deepening of the thalweg against the outer bend and deposition of bed material at the inner bend, which is consistent with the channel migration towards Ridgelands Road. Of particular note was the evidence of sand extraction which has removed between 2m – 5m of material of the channel bed from the downstream portion of the meander. Continuing extraction of bed material upstream of the existing extent has the potential to increase the proportion of floodwaters captured within the main channel, and subsequently should be monitored to understand implications for downstream infrastructure.

5.3.7 Yeppen Crossing

As the validation models represent flood events (1991, 2008 and 2011) prior to the completion of the Yeppen Crossing Upgrade, the Yeppen North and Yeppen South infrastructure captured in the 2016 LiDAR needed to be removed, to represent the ground conditions at the time of the validation event.

To do this, the 2009 LiDAR (from the 2014 model) was stamped in over the 2016 LiDAR for the extent of the Yeppen crossing upgrade, effectively removing the post-validation event works from the model topography.

5.3.8 Other Topographic Changes

Comparison of the LiDAR data sets identified two major excavation sites within the western floodplain, which were present in the 2016 LiDAR and not in the 2009 LiDAR. Historic aerial imagery confirmed that the sites were not present during the validation events.

These areas were subsequently removed for the validation events (1991, 2008 and 2011) and replaced with 2009 LiDAR at the site.

5.3.9 Bridge and Barrage LFCSH Adjustments

Bridges within the 2-D model domain are represented as Layered Flow Construction Shape (LFCSH) elements as per the methodology discussed in Section 5.2.4. Several of these structures serve as crucial controls for flood behaviour across the western and Yeppen floodplains, and as such have been modified to achieve a head loss which:

- Matches well with anecdotal pictures of the structures during the assessed historical flood events; and
- Achieves a balanced calibration / validation result for recorded flood heights upstream and downstream of the structure.

The final blockage and form loss coefficients adopted for each layered flow constriction digitised within the model are shown in Table 10. The most crucial structure within this table is the Fitzroy River Barrage which has an extent of influence covering the entire Yeppen floodplain and Fitzroy River upstream of The Common. Anecdotal pictures and aerial images of the Barrage during the 2011 and 2017 flood events are presented in Plate 1. Combined with recorded peak flood heights upstream and downstream of the structure, the pictures indicate:

- Head loss is primarily caused by the physical blockage of conveyance area by the piers (which constitute 13% of the cross sectional area);
- Higher head loss occurs within the southern (LHS in the pictures) and middle portion of the structure where velocities are higher;
- Head loss across the structure is likely less than 500mm in both the 2011 and 2017 events; and
- There is potentially more head loss during smaller events (such as the 2017 event) due to influence of the spillway, which can be derived from the shape of the water surface around the piers and surface turbulence downstream of the structure.

Initial modelling of the structure using traditionally-derived form loss coefficients resulted in head losses of up to 650mm during the 2017 event and 700mm during the 2011 event. Consequently, the majority of modelled peak flood heights immediately upstream of the Barrage and throughout the western floodplain were (generally) 200mm higher than recorded levels, especially in the 2011 event. Consequently, the L_1 FLC was reduced to 0.0000 in an attempt to achieve the observations listed above. The result was:

- head losses of up to 350mm during the 2017 event and 300mm during the 2011 event.
- Reduction in modelled peak flood heights upstream of the Barrage during the 2017 event without removing calibration points from accepted tolerances; and
- Reduction in modelled peak flood heights upstream of the Barrage during the 2011 event resulting in all validation points being within accepted tolerances.

Simulation of the 1991 flood event with these conditions also resulted in a well-balanced validation of recorded flood levels throughout the model extent. Given the well-balanced calibration / validation results and anecdotal flood behaviour noted above, a L_1 FLC of 0.0000 was adopted for the Barrage.

Plate 1 “At Peak” Fitzroy River Barrage Anecdotal Pictures (2011 – above | 2017 – below)

Table 10 Final Bridge LFCSH Attributes

Bridge / Structure	L_1 Obvert	L_1 % Blocked	L_1 FLC
Barrage	10.54	13.0	0.0000
North Coast Rail Bridge	11.60	2.4	0.0389
Neville Hewitt Bridge (New Bridge)	12.18	2.1	0.0392
Fitzroy Bridge (Old Bridge)	9.70	3.5	0.0575
Yeppen North Low Level Bridge	7.60	5.9	0.2770
Yeppen North High Level Bridge	Varies	6.8	0.3314
Yeppen North Rail Bridge	7.50	9.0	0.3675
Henry Johnson Highway Bridge	7.60	4.4	0.1592
Henry Johnson Rail Bridge	7.50	6.1	0.2304
Darumbal Highway Bridge	7.60	4.8	0.1743
Darumbal Rail Bridge	7.50	10.4	0.3355
Scrubby Creek Highway Bridge	7.60	4.3	0.1870
Scrubby Creek Rail Bridge	7.50	11.8	0.1666
Yeppen High Level Slip Lane Bridge	Varies	4.3	0.1865
Yeppen South High Level Bridge	Varies	5.5	0.2047

6.0 Model Calibration and Validation Results

6.1 Overview

The updated Fitzroy River TUFLOW model was calibrated to the 2017 flood event associated with Tropical Cyclone Debbie, which represents the most recent and well-documented major Fitzroy River flood event at Rockhampton. This event is particularly important for model calibration as it represents the first major flood post construction of the Yeppen North and South upgrades.

After modifications to revert the updated model back to historic conditions (where appropriate, refer Section 3.4), the model was validated to the 2011, 2008 and 1991 flood events.

6.2 2017 Calibration Event

The correlation between modelled and recorded water levels for the 2017 event at the Rockhampton Gauge is shown in Figure 19. This shows a difference between calculated and recorded peak water surface levels of -0.09 m which is deemed to be acceptable. There is an excellent match in both shape and timing throughout the flood event, albeit the modelled results remain slightly below recorded levels during the receding limb.

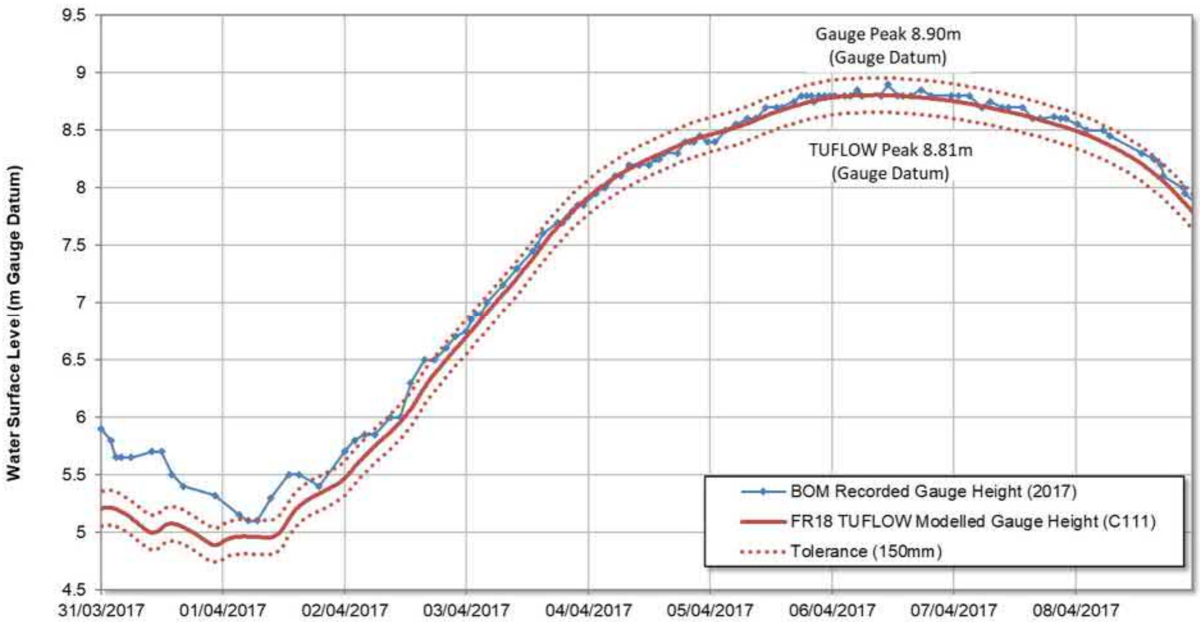


Figure 19 2017 Calibration Event – Rockhampton Flood Gauge Comparison

RRC officers collected 879 surveyed flood levels during the 2017 Fitzroy River flood event, across three days from 4 to 7 April 2017. Data collection covered key flood locations in North Rockhampton, South Rockhampton, West Rockhampton, Wandal, Gracemere, Fairybower and the Rockhampton Airport. AECOM staff provided guidance to RRC on the location of flood records required for future model calibration.

As some of the points were collected prior to the flood peak or at the same location across a number of days, it was necessary to screen the dataset used for flood peak comparison. Of the 879 points collected, 421 locations were used to calibrate the peak flood heights for the updated TUFLOW model.

In addition to the Rockhampton Flood Gauge comparison shown above, results of the updated TUFLOW model comparison are presented below in the following forms and discussed below:

- Statistical analysis of the calibration, as presented in Figure 30 and Figure 21.
- A long section plot along the main river channel (refer Figure 22).
- Where flood levels were recorded at the same location over a number of days, time series comparison plots were created to check correlation (refer Figure 24 through Figure 29).

- Comparison plots showing the modelled correlation to the 421 recorded flood levels, which are presented in Figure 30 and Figure 31.

Key outcomes include:

- Of the 421 recorded points, 369 (88%) of the calculated values were within tolerance (±0.15m).
- 6 points were significantly outside the tolerance (<-0.30m or >0.30m), however were related to backwater areas connected through the subsurface network. One of these locations was Jardine Park in which the backflow prevention device failed and resulting floodwater pumped to prevent impacts to the community. All points were within (or immediately adjacent to) the inundation extents.
- The average difference (absolute) between the calculated and recorded water levels is 0.08m, with a standard deviation of 0.07m.
- As seen in Figure 21, the calibration event's linear R^2 fit was 0.99 with a statistical mean of -0.03m below recorded flood heights. This strong correlation between calculated and recorded flood levels is also reflected in the distribution plot shown in Figure 20.
- A good match was achieved within the main River channel (from upstream of the Barrage to the southern 2-D model boundary outlet), along Quay Street and within the Main Drain area, including Lower Dawson Road and Gladstone Road. The long section provided in Figure 22 further demonstrates the good match within the main River channel.
- In North Rockhampton, a good match was achieved in the areas surrounding Limestone Creek, Splitters Creek, Moores Creek, Frenchmans Creek, Thozets Creek and the Lakes Creek Road Landfill.

The time series plot provided in Figure 25 to Figure 29 demonstrates how the updated TUFLOW model adequately represents the rising limb of the flood event, within a ±0.15m tolerance.

- Modelled levels within the western floodplain are generally lower than recorded but within 0.10m to 0.20m of recorded heights.
- Directly upstream of Yeppen North, modelled levels range from 0.03m to 0.08m lower than recorded, while modelled levels in the Fairy Bower area are 0.09m to 0.18m lower.

Overall the updated TUFLOW model provides an excellent correlation to recorded levels within the main River channel and flood water backup areas of Main Drain, Limestone Creek, Splitters Creek, Moores Creek, Frenchmans Creek, Thozets Creek and the Lakes Creek Road Landfill.

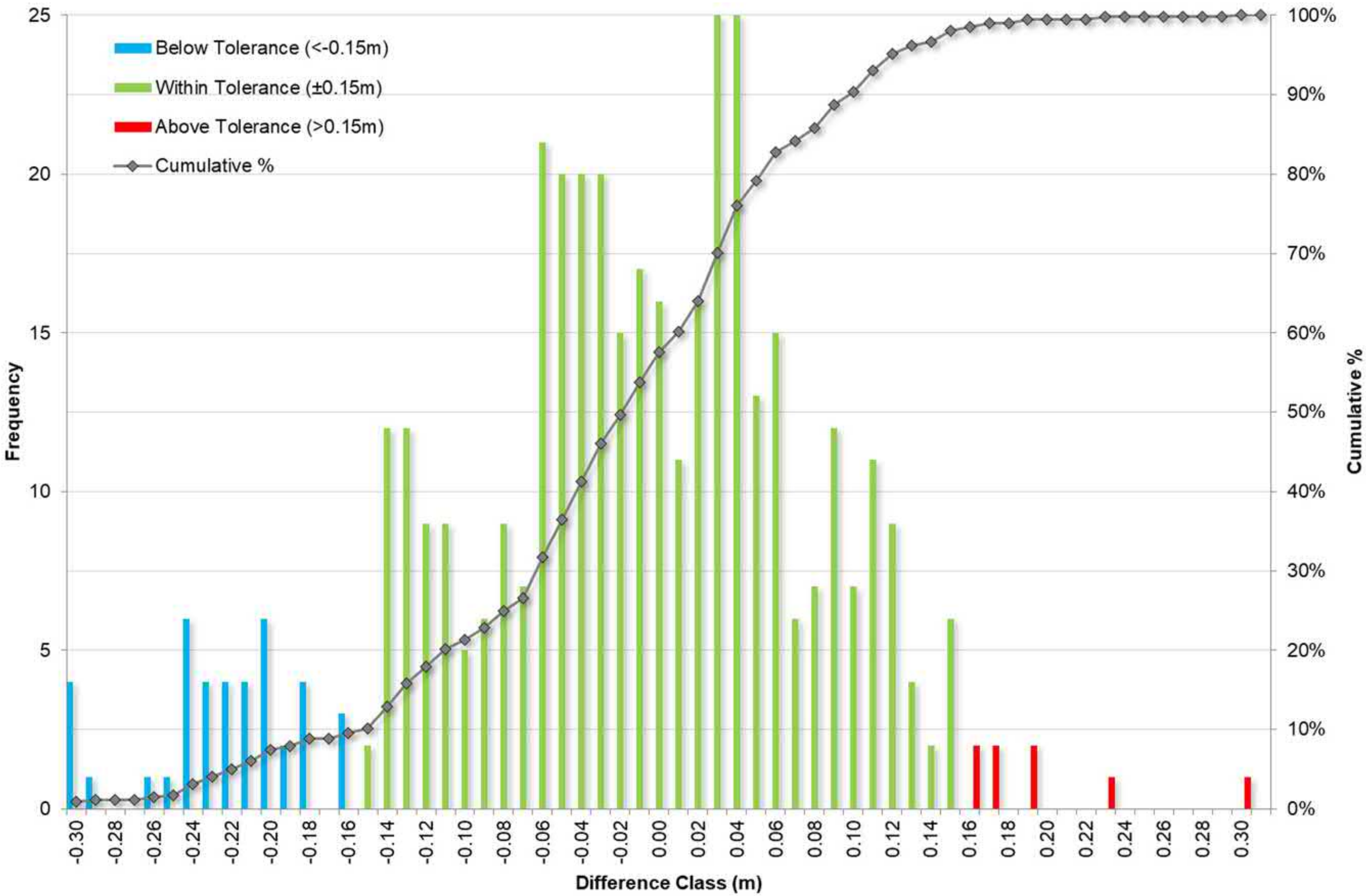


Figure 20 2017 Calibration Event Histogram

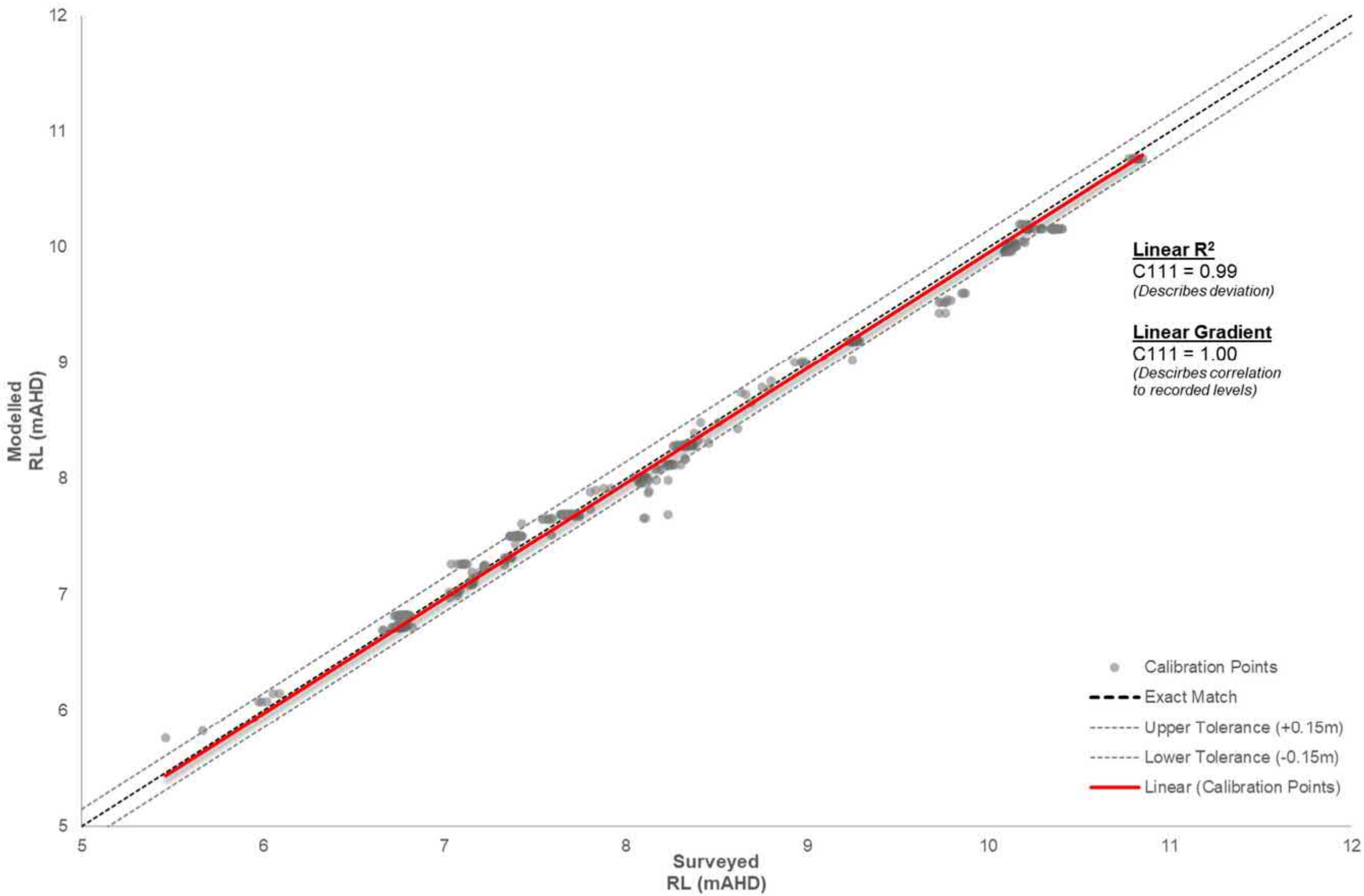


Figure 21 2017 Event Calibration Scatter Plot

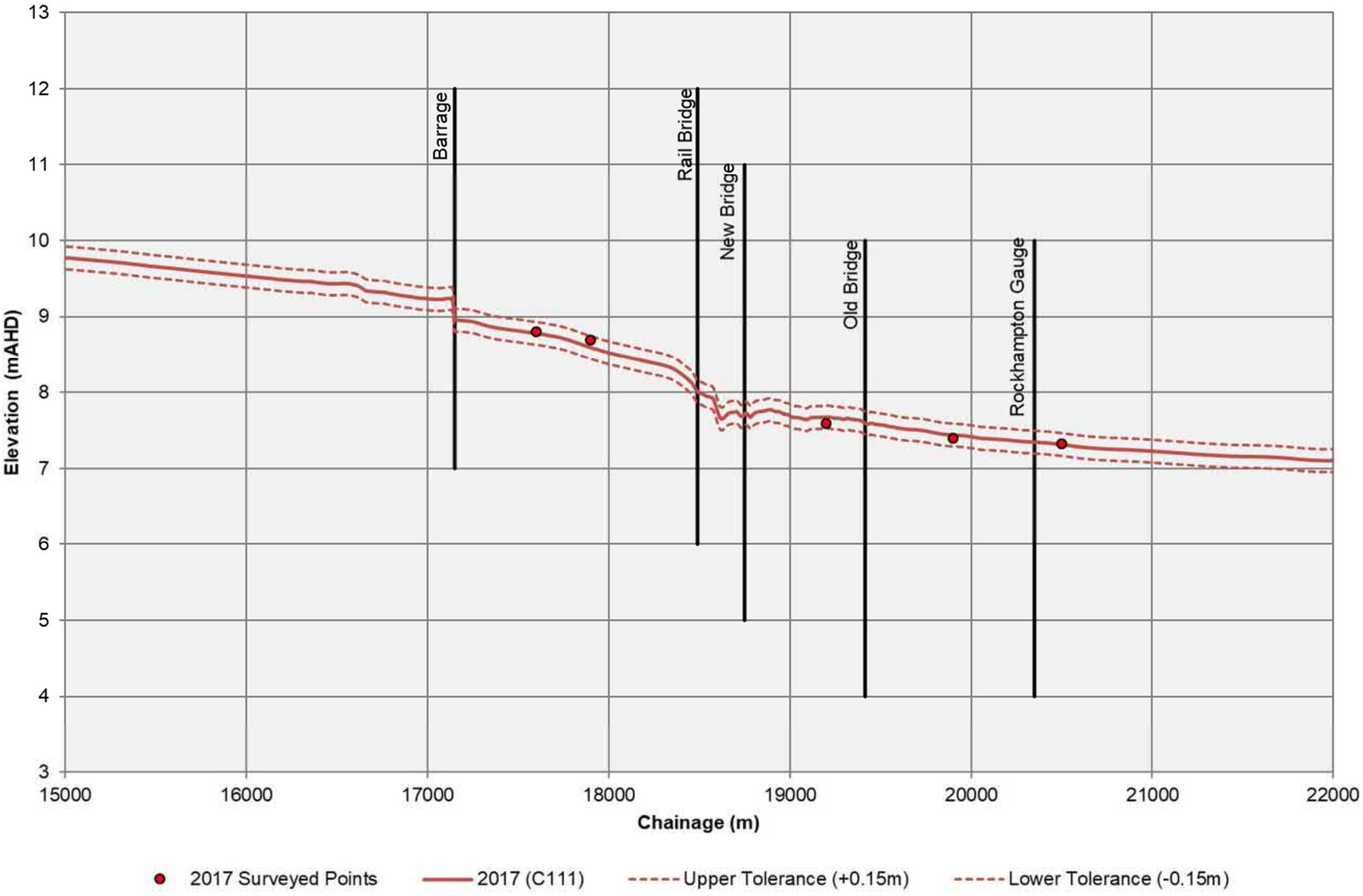


Figure 22 2017 Event Calibration – Long section Along Main River Channel

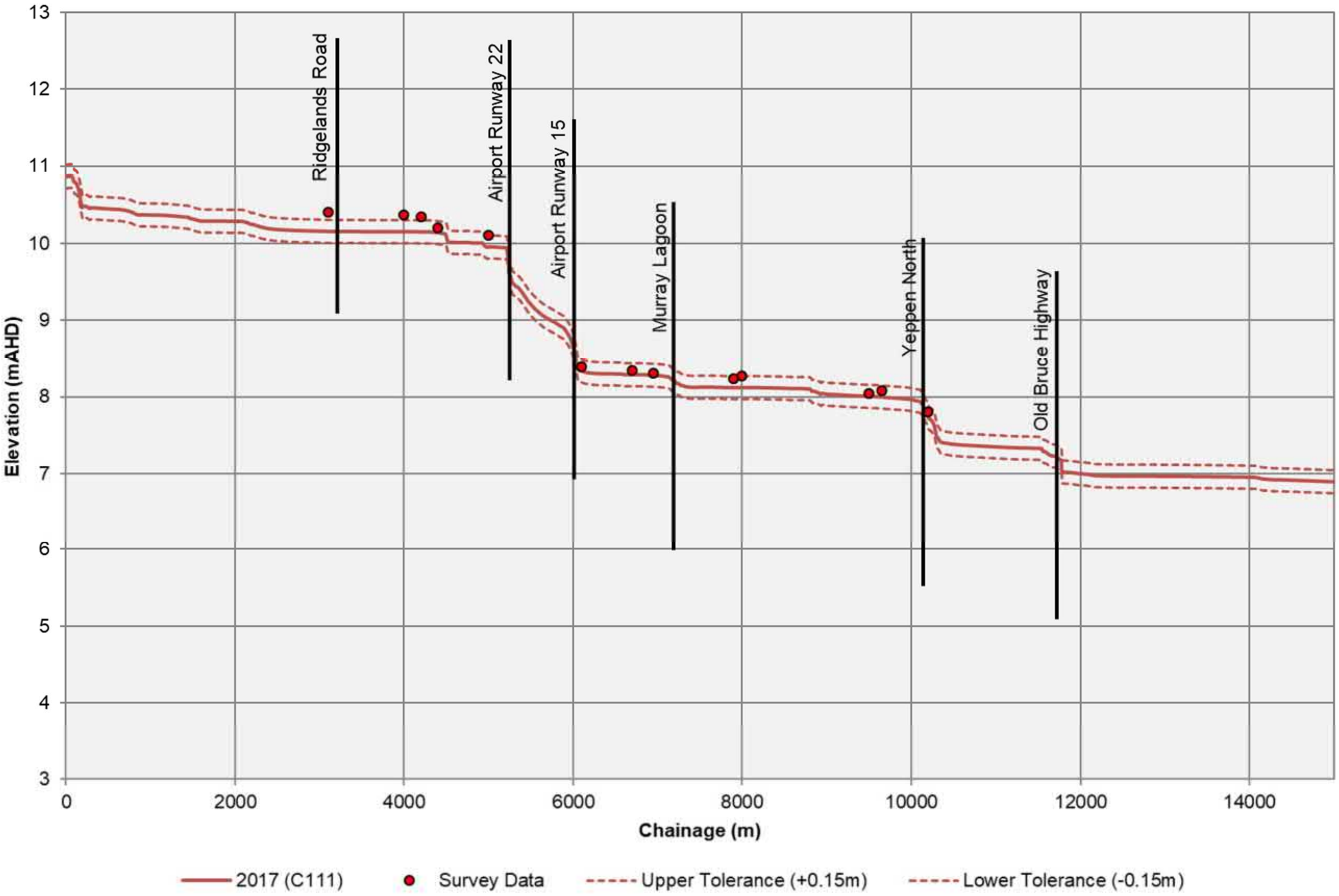


Figure 23 2017 Event Calibration – Long section Along Western Floodplain

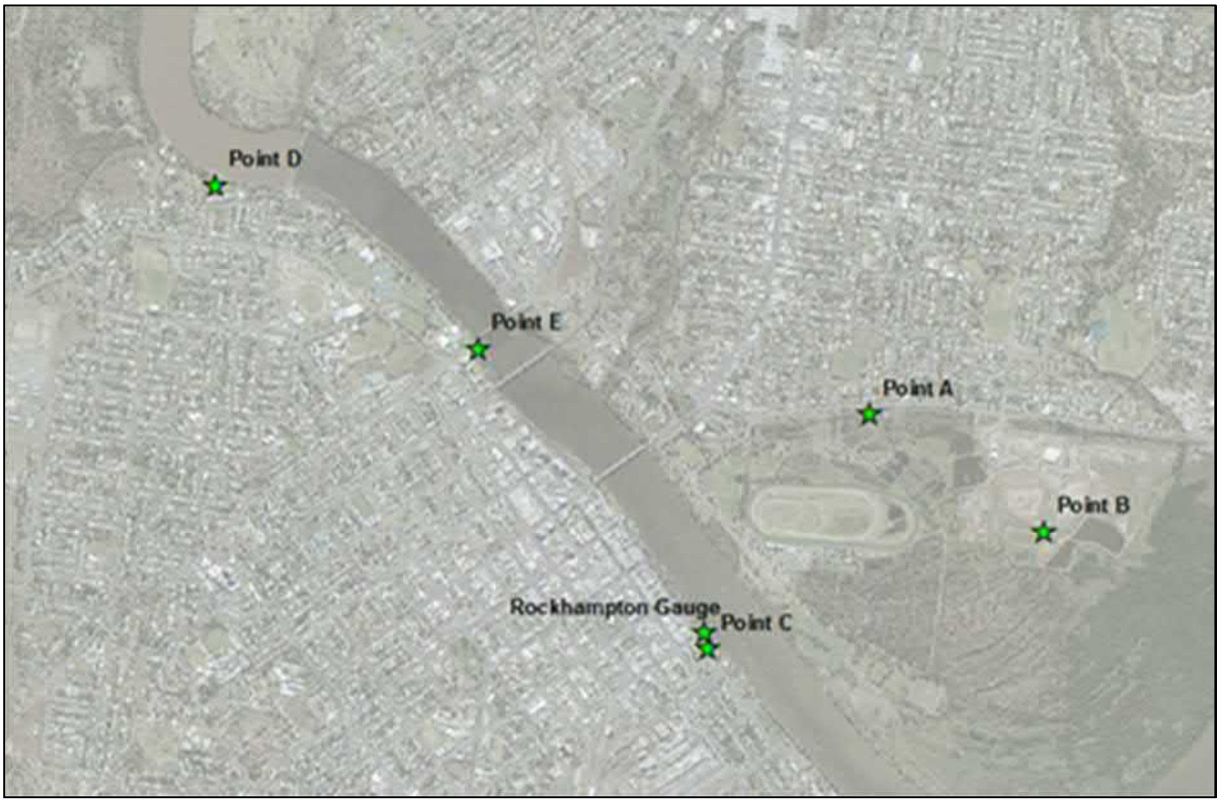


Figure 24 2017 Event Calibration – Comparison Point Locations

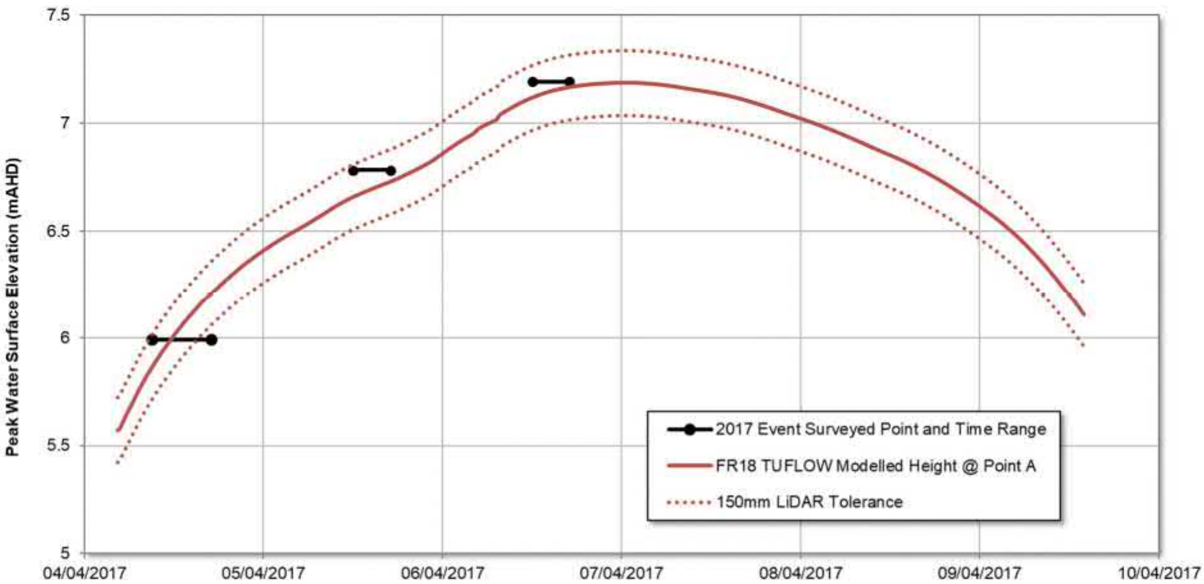


Figure 25 2017 Event Calibration – Point A

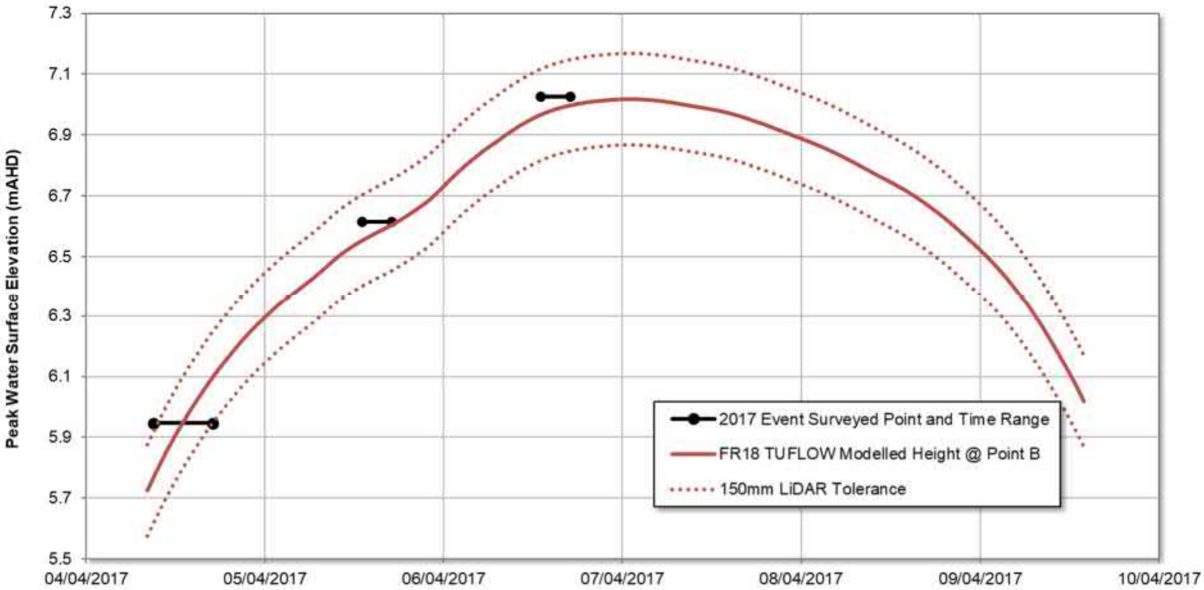


Figure 26 2017 Event Calibration – Point B

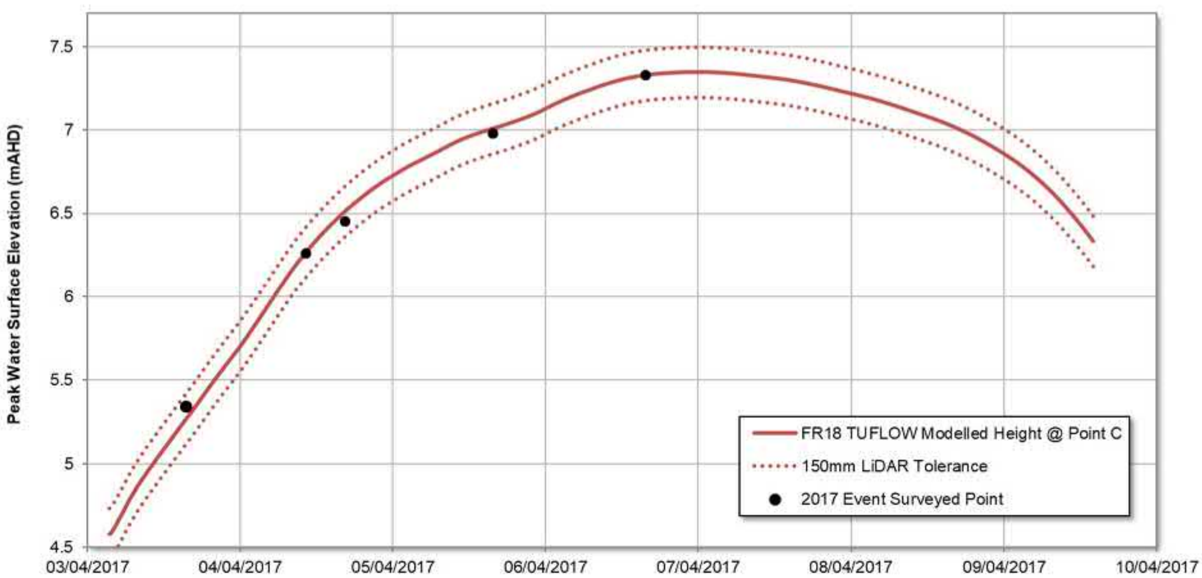


Figure 27 2017 Event Calibration – Point C

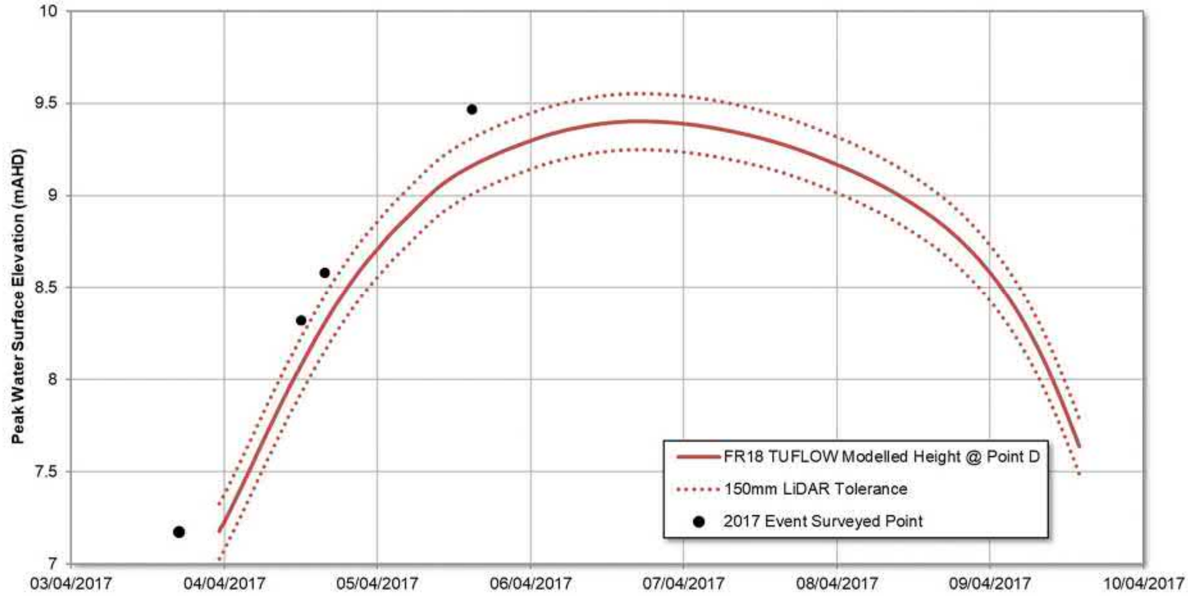


Figure 28 2017 Event Calibration – Point D

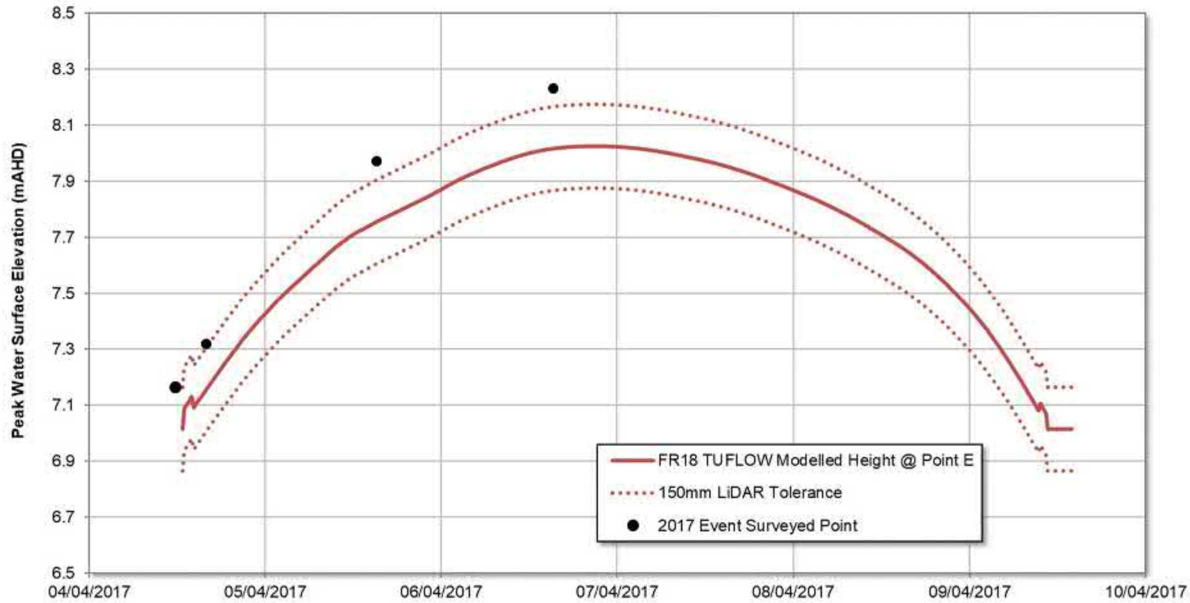
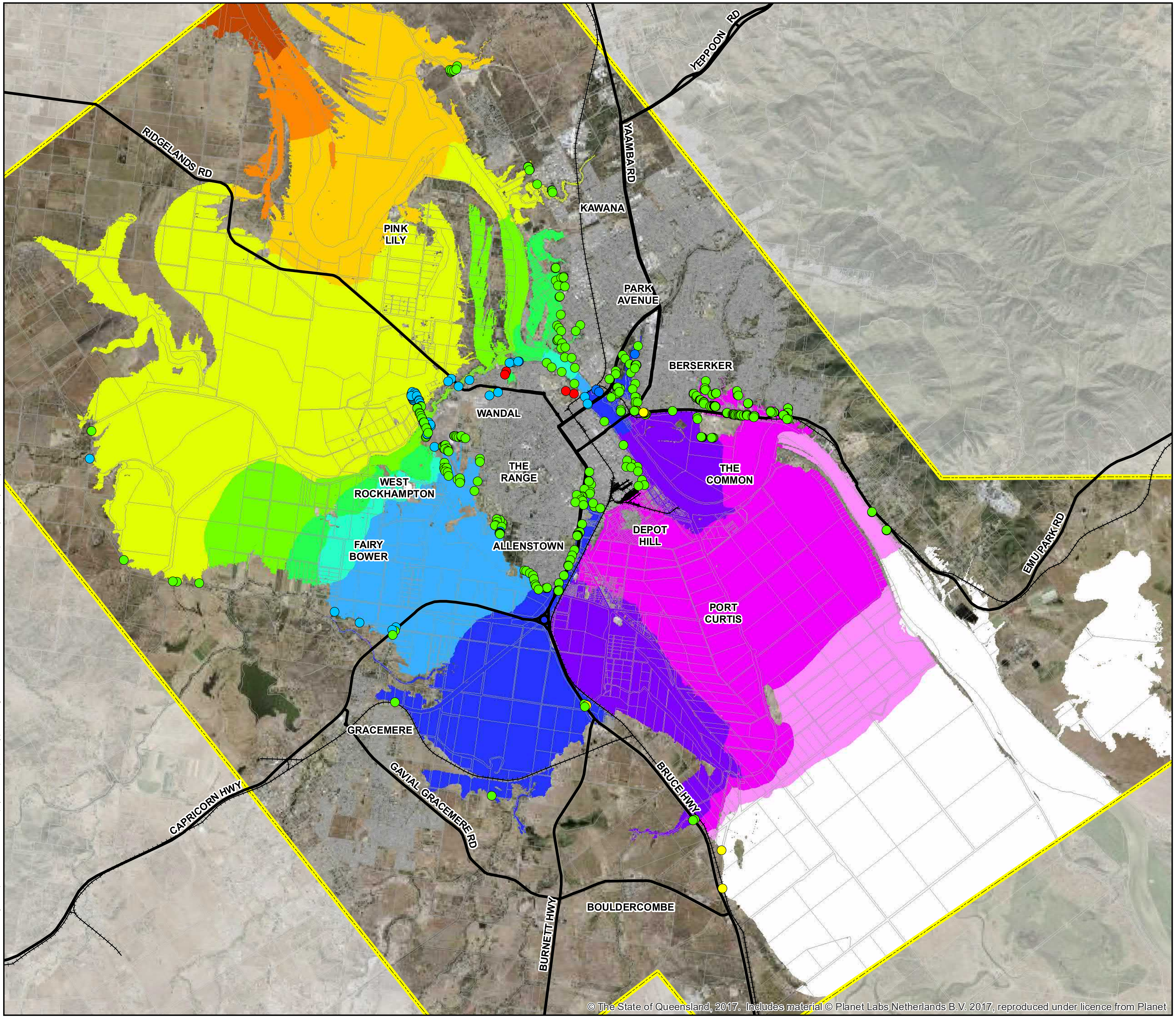


Figure 29 2017 Event Calibration – Point E



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LEGEND

Water Level Difference (m)

Calculated - Recorded

- > 0.30
- 0.15 to 0.30
- 0.15 to -0.15 (In Tolerance)
- -0.30 to -0.15
- < -0.30
- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- Cadastre

Peak Water Surface Level (mAHD)

- < 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5
- 8.5 - 9
- 9 - 9.5
- 9.5 - 10
- 10 - 10.5
- 10.5 - 11
- 11 - 11.5
- 11.5 - 12
- > 12

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

2017 Event Calibration (C111)
Peak Flood Levels
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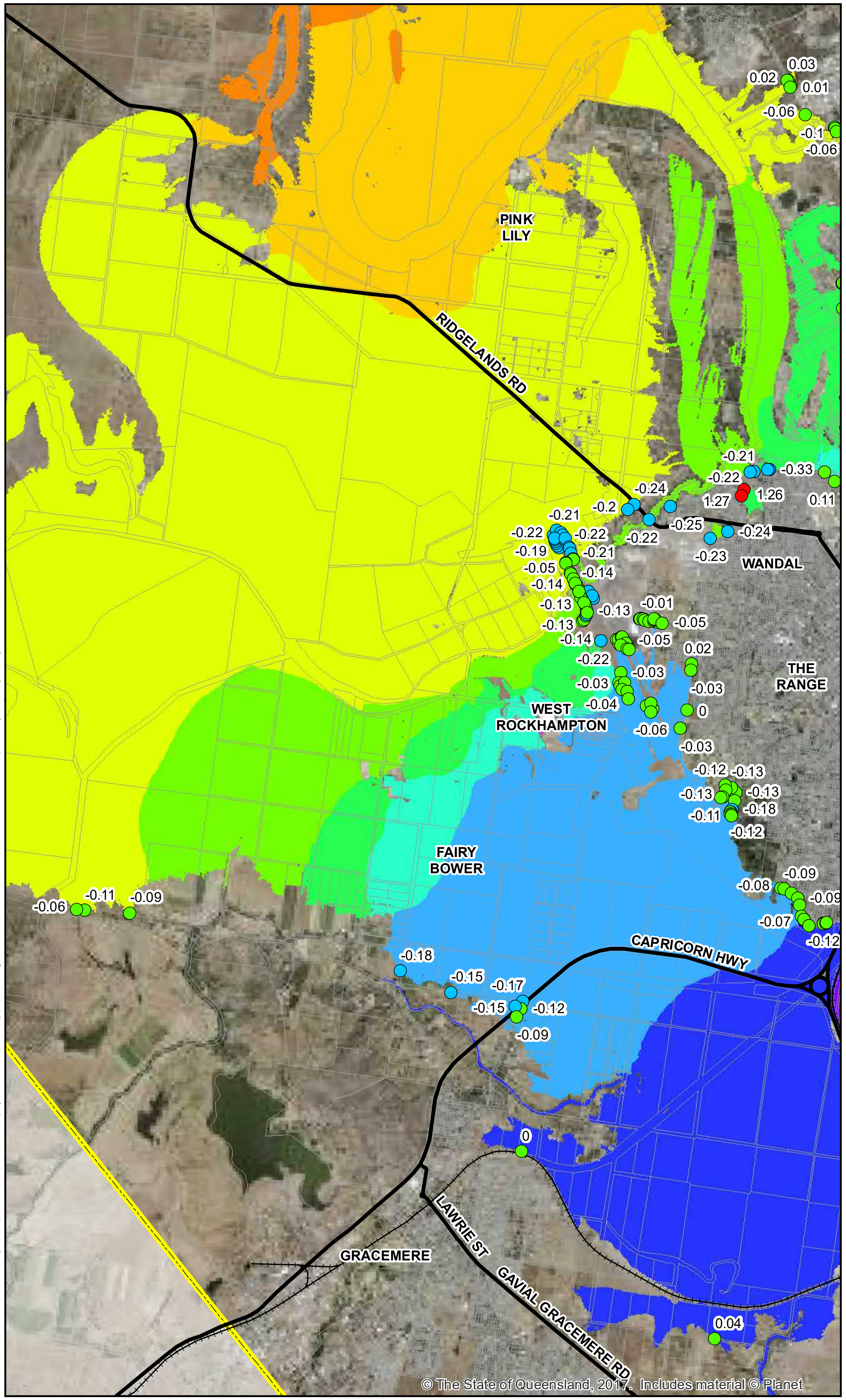

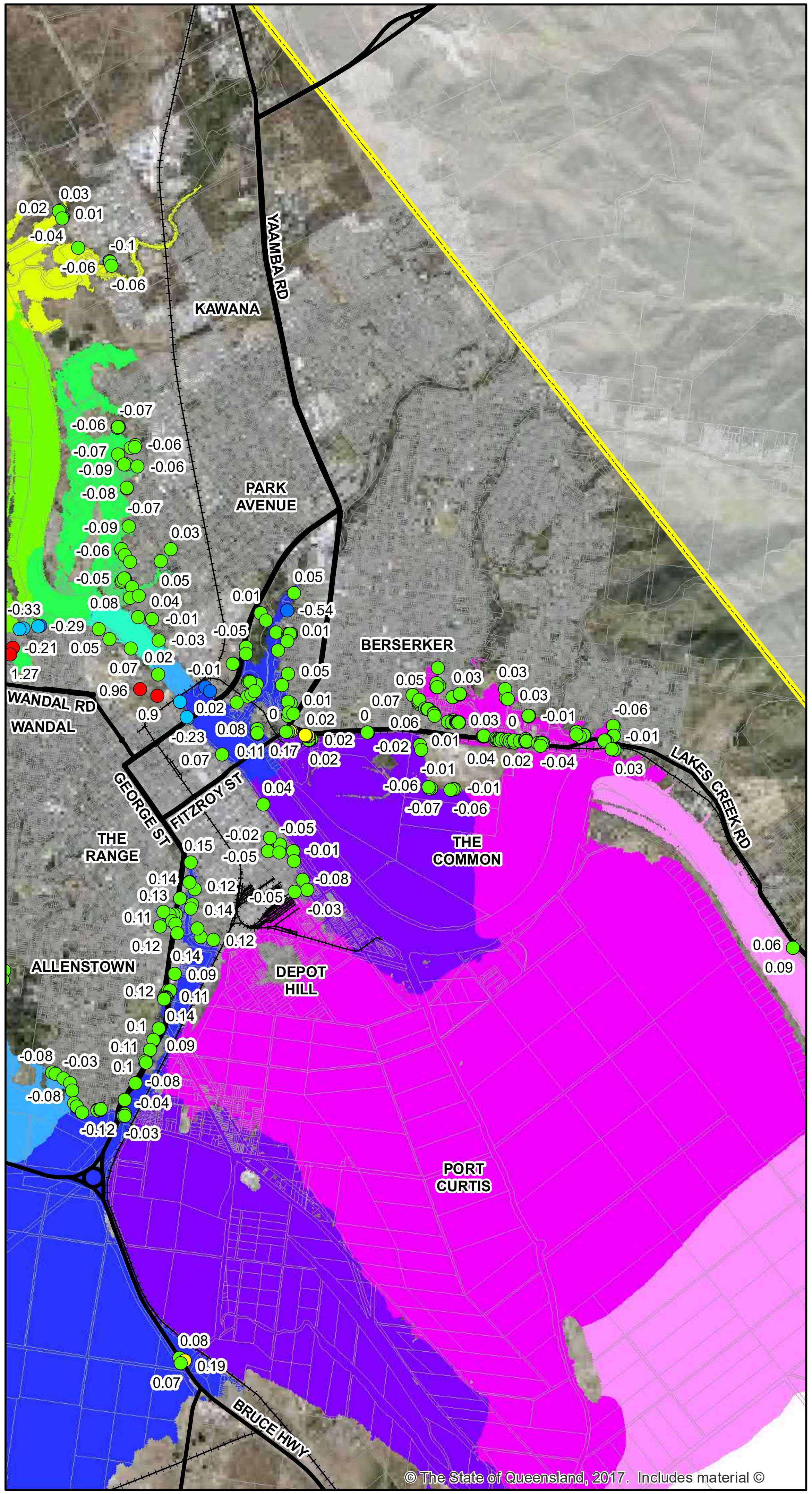

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LEGEND

Water Level Difference (m)
Calculated - Recorded
- > 0.30
- 0.15 to 0.30
- 0.15 to -0.15 (In Tolerance)
- -0.30 to -0.15
- < -0.30
- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- Cadastre

Peak Water Surface Level (mAHD)
- < 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5
- 8.5 - 9
- 9 - 9.5
- 9.5 - 10
- 10 - 10.5
- 10.5 - 11
- 11 - 11.5
- 11.5 - 12
- > 12

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

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Fitzroy River TUFLOW Model Update

2017 Event Calibration (C111)
Peak Flood Levels
Results

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VERSION:	01

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6.3 2011 Event Validation

The correlation between modelled and recorded water levels for the 2011 event at the Rockhampton Gauge is shown in Figure 32. This figure shows a difference between modelled and recorded peak water surface levels of 0.11m which is within acceptable validation limits of ±0.30m. There is a reasonable match in both the shape and timing throughout the flood event, with modelled results being higher than recorded levels throughout the flood event.

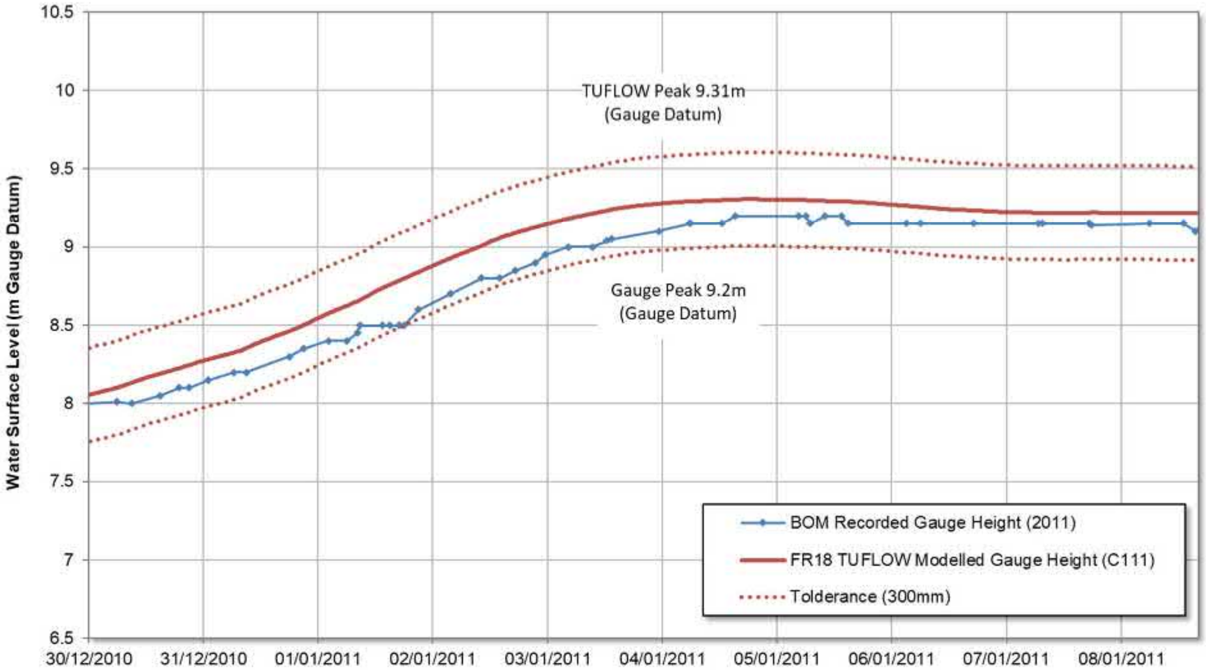


Figure 32 2011 Event Validation – Rockhampton Flood Gauge Comparison

The comparison between modelled and recorded water levels undertaken in the original SRFL study (AECOM, 2014) is reproduced in Figure 33. It is noted that the latest model updates have predicted higher flood levels when compared to recorded levels.

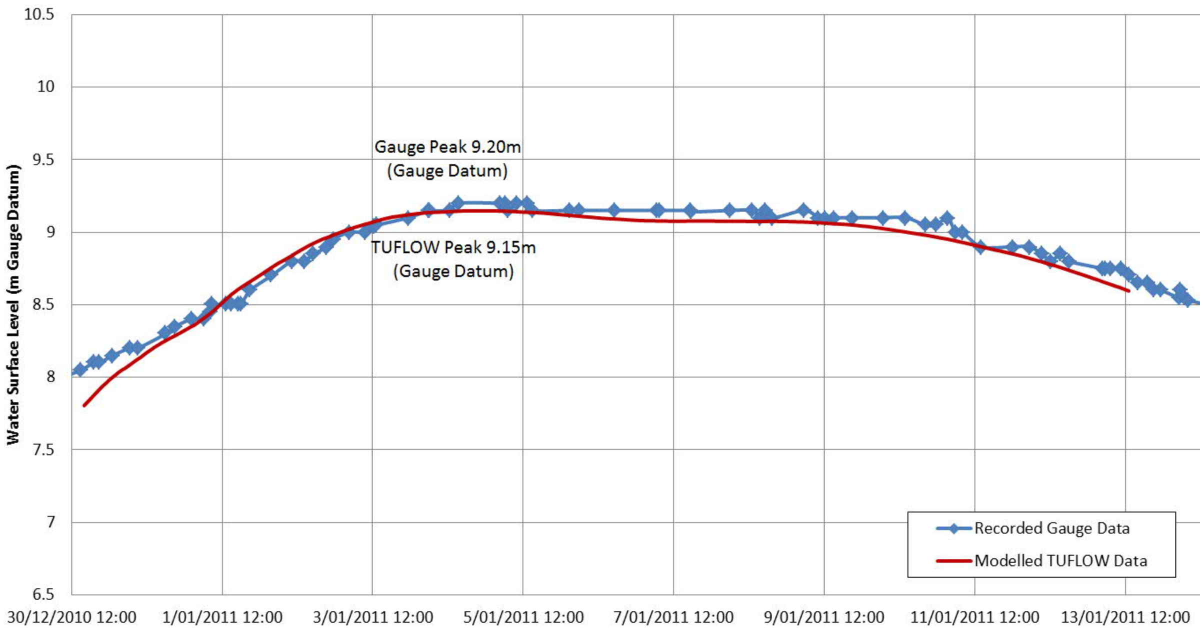


Figure 33 SRFL Rockhampton Flood Gauge Comparison – 2011 Event (source: AECOM, 2014)

Of particular interest were two surface water level data sets recorded by RRC, on a boat across the western floodplain, on the 8th and 10th of January 2011. A summary of the model validation results for the two 2011 flood event data sets has been provided in Table 11 and represented on Figure 38 and Figure 39.

In comparing the modelled flood levels to the RRC recorded data, it is noted:

- Dataset 1 was captured on 08/01/2011 and Dataset 2 was captured two days later on 10/01/2011. The flood event peaked on 04/01/2011.
- Inspection of the modelled flood heights throughout Dataset 1 at 100hrs post-peak (approximately 08/01/2011) revealed heights had receded by 0.10m. This resulted in the modelled water surface level having an average difference of 0.02m to recorded water levels, a standard deviation of 0.08m and a minimum and maximum differences being -0.21m and 0.16m, respectively.
- Inspection of the modelled flood heights throughout Dataset 2 at 150hrs post-peak (approximately 10/01/2011) revealed flood heights had receded by 0.33m. This resulted in the modelled water surface level having an average difference of 0.13m to recorded water levels, a standard deviation of 0.07m and a minimum and maximum differences being -0.21m and 0.30m, respectively.
- As can be concluded from Table 11, the time-corrected differences correlate well with the recorded flood heights with all being within ±0.30m, which is within acceptable tolerances.

Table 11 Summary of the Model Calibration Results for RRC 2011 Data Sets

	RRC Data Set 1	RRC Data Set 2
Date of Records	8/01/2011	10/01/2011
Location	Lion Creek Floodplain	Yeppen floodplain (U/S Bruce Highway)
Average Difference (time-corrected)	+0.02m	+0.13m
Standard Deviation	0.08m	0.07m
Maximum Difference	+0.16m	+0.30m
Minimum Difference	-0.21m	-0.21m

In addition to the datasets shown above, TMR recorded peak flood levels at another 107 locations around the City and Pink Lily, which were originally compiled for use in the FRFRPS. These records were used to validate the peak water surface of the updated TUFLOW model. The comparisons presented in Figure 34 to Figure 39 present the results of the 2011 validation event.

Key outcomes include:

- Of the 107 recorded points 107 (100%) of the calculated values were within the ±0.30m which is well within validation tolerances.
- The average difference (absolute) between the calculated and recorded water levels is 0.11m, with a standard deviation of 0.08m.
- As seen in Figure 35, the validation event's linear R^2 fit was 0.99 with a statistical mean of +0.09m above recorded flood heights. This strong correlation between calculated and recorded flood levels is also reflecting in the distribution shown in Figure 34.

The model results presented above indicate the TUFLOW model provides a good representation of the peak flood levels throughout the main river channel and western floodplain. Given these results, the 2011 flood event proves to be an acceptable validation of the model.

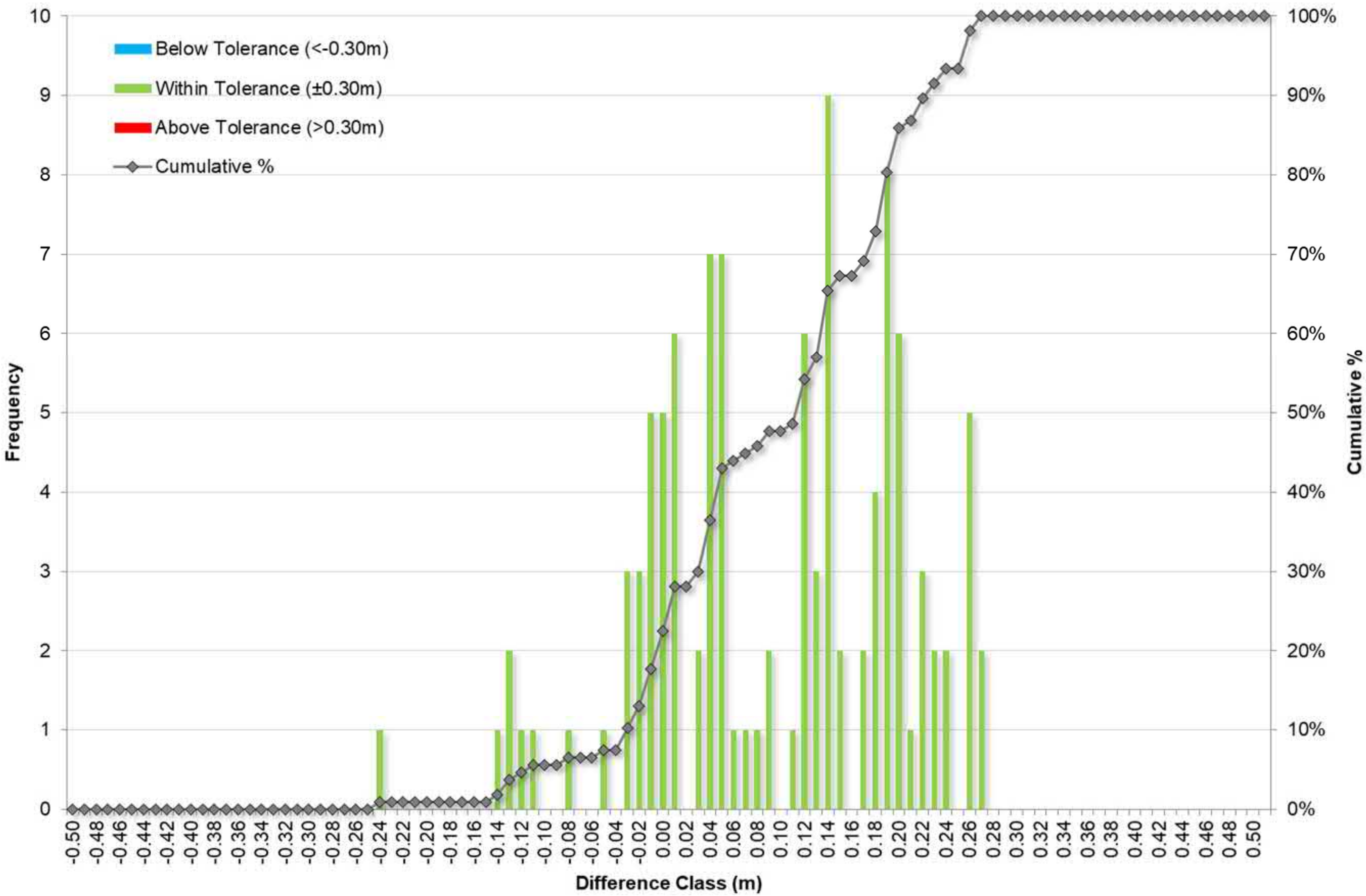


Figure 34 2011 Event Calibration Distribution

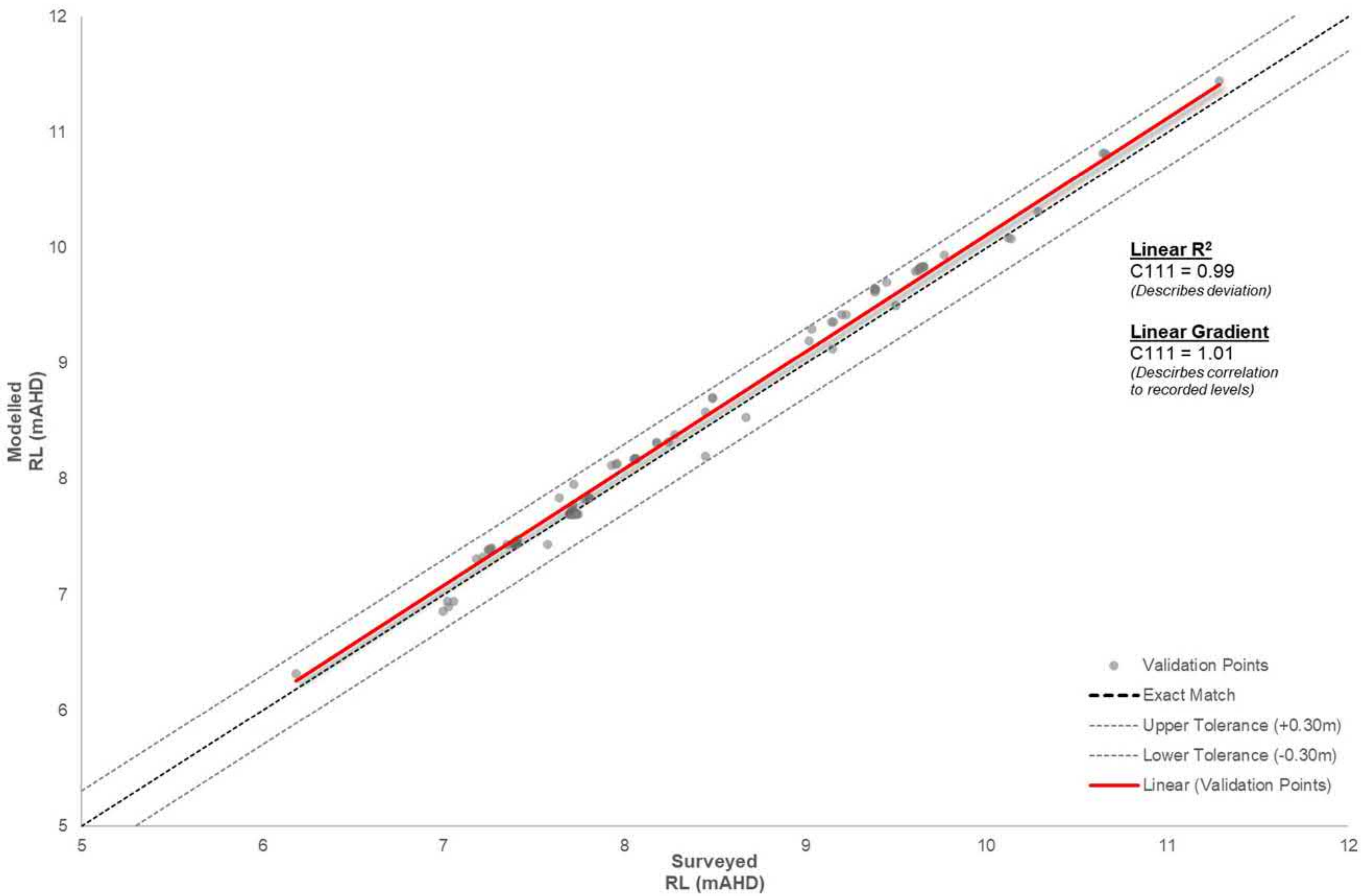


Figure 35 2011 Event Calibration Scatter Plot

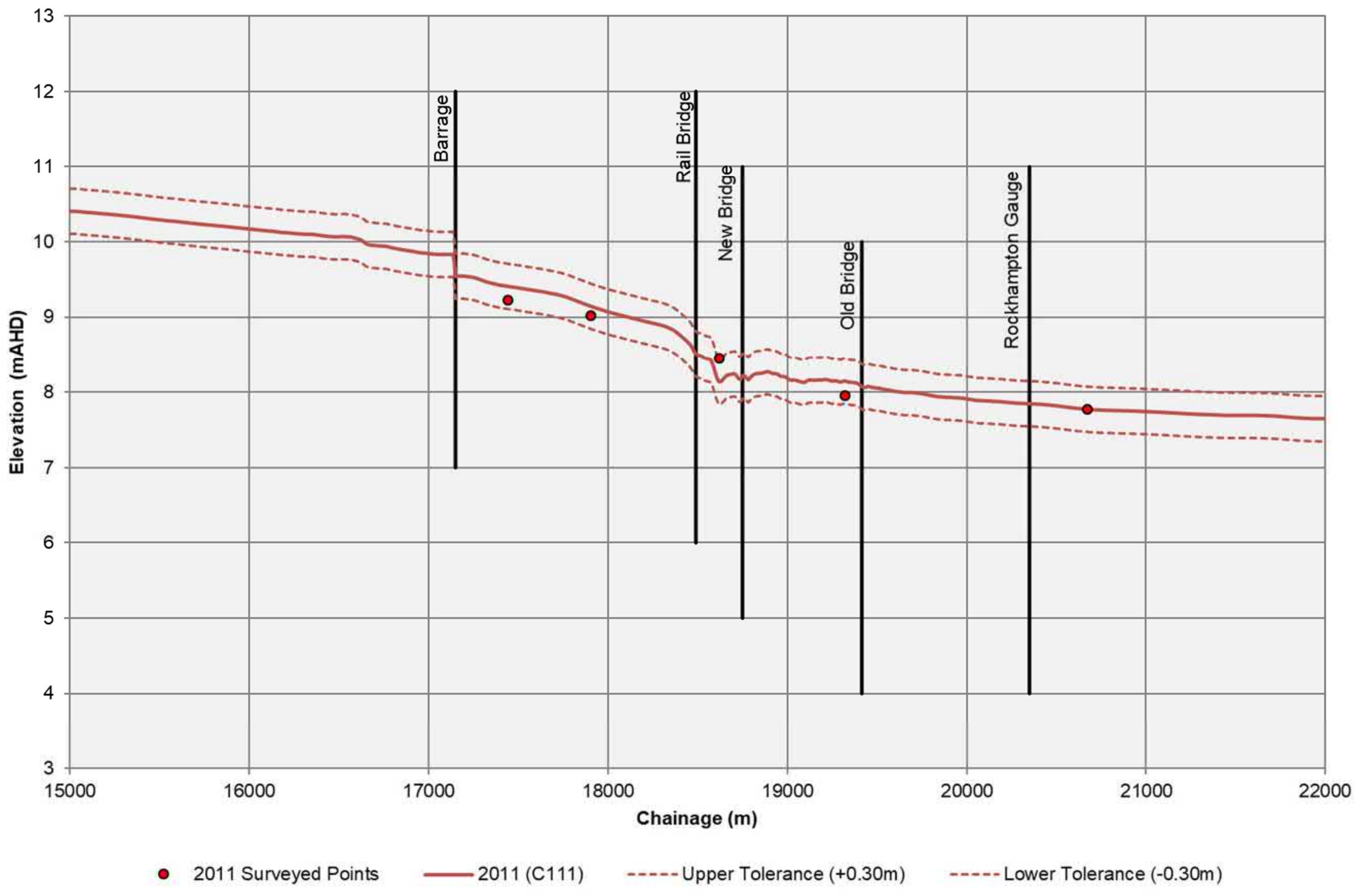


Figure 36 2011 Event Calibration – Long section Along Main River Channel

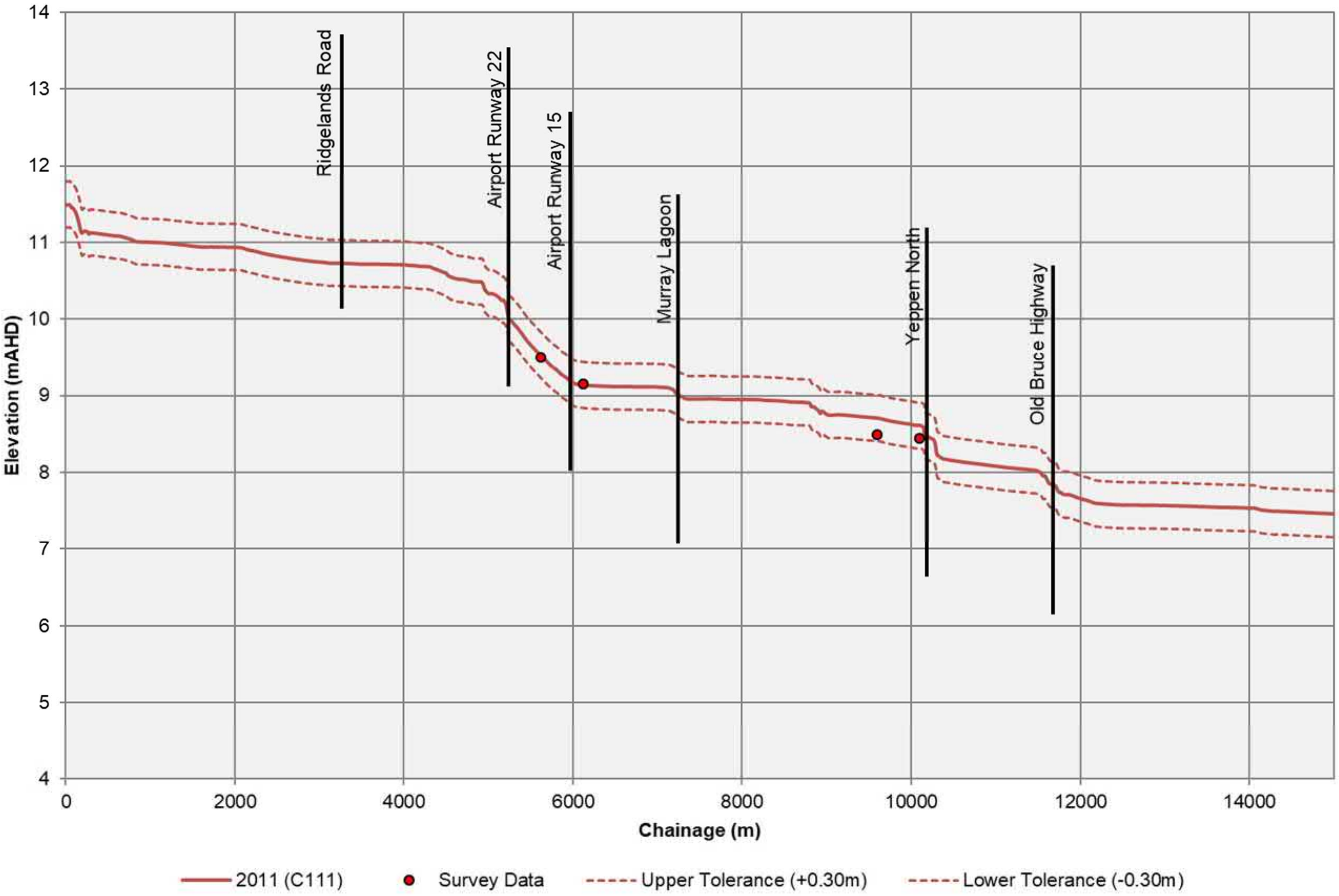
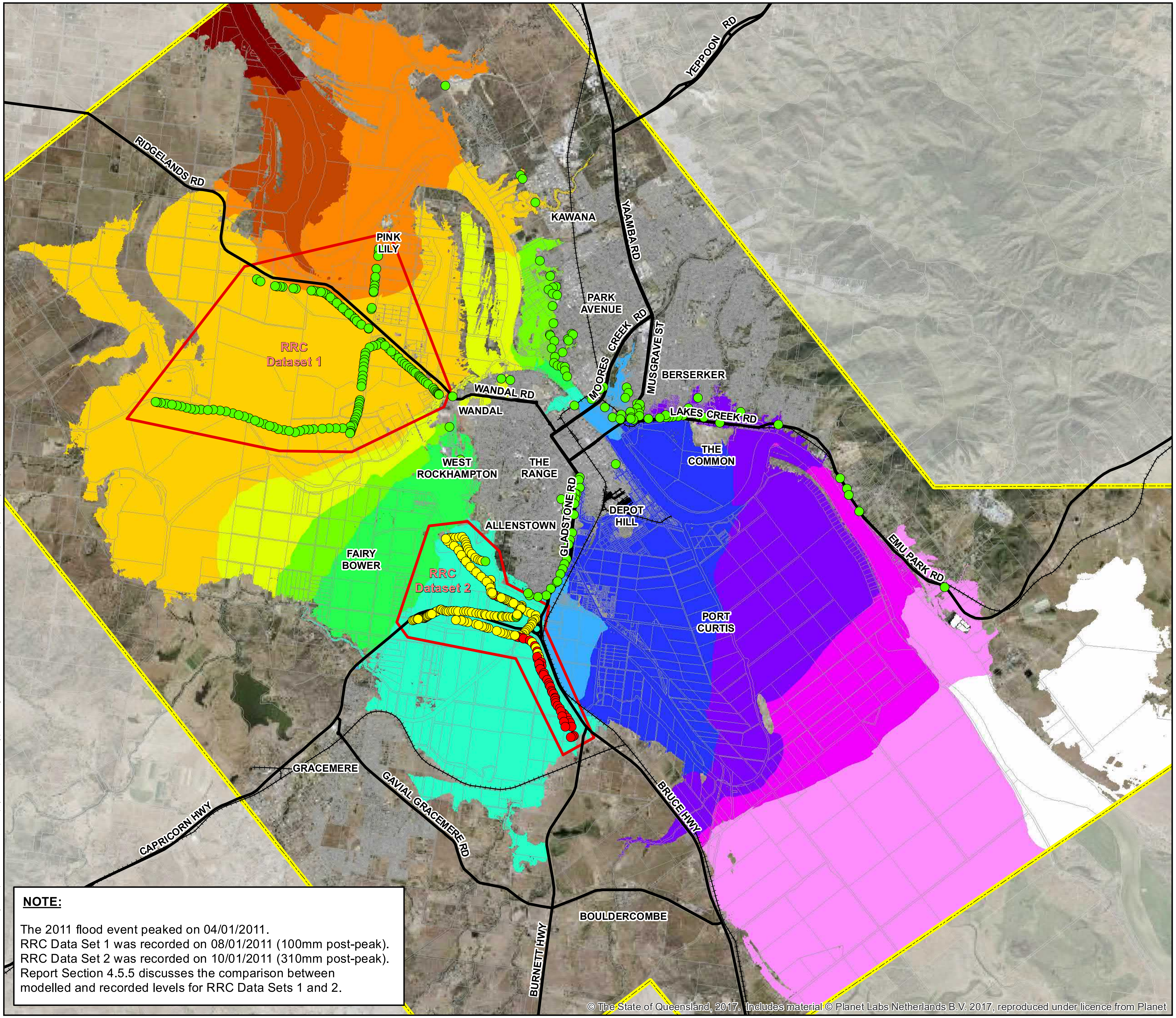


Figure 37 2011 Event Calibration – Long section Along Western Floodplain



NOTE:

The 2011 flood event peaked on 04/01/2011.
RRC Data Set 1 was recorded on 08/01/2011 (100mm post-peak).
RRC Data Set 2 was recorded on 10/01/2011 (310mm post-peak).
Report Section 4.5.5 discusses the comparison between modelled and recorded levels for RRC Data Sets 1 and 2.

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Data sources:
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CREATED BY	briggh
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VERSION:	01

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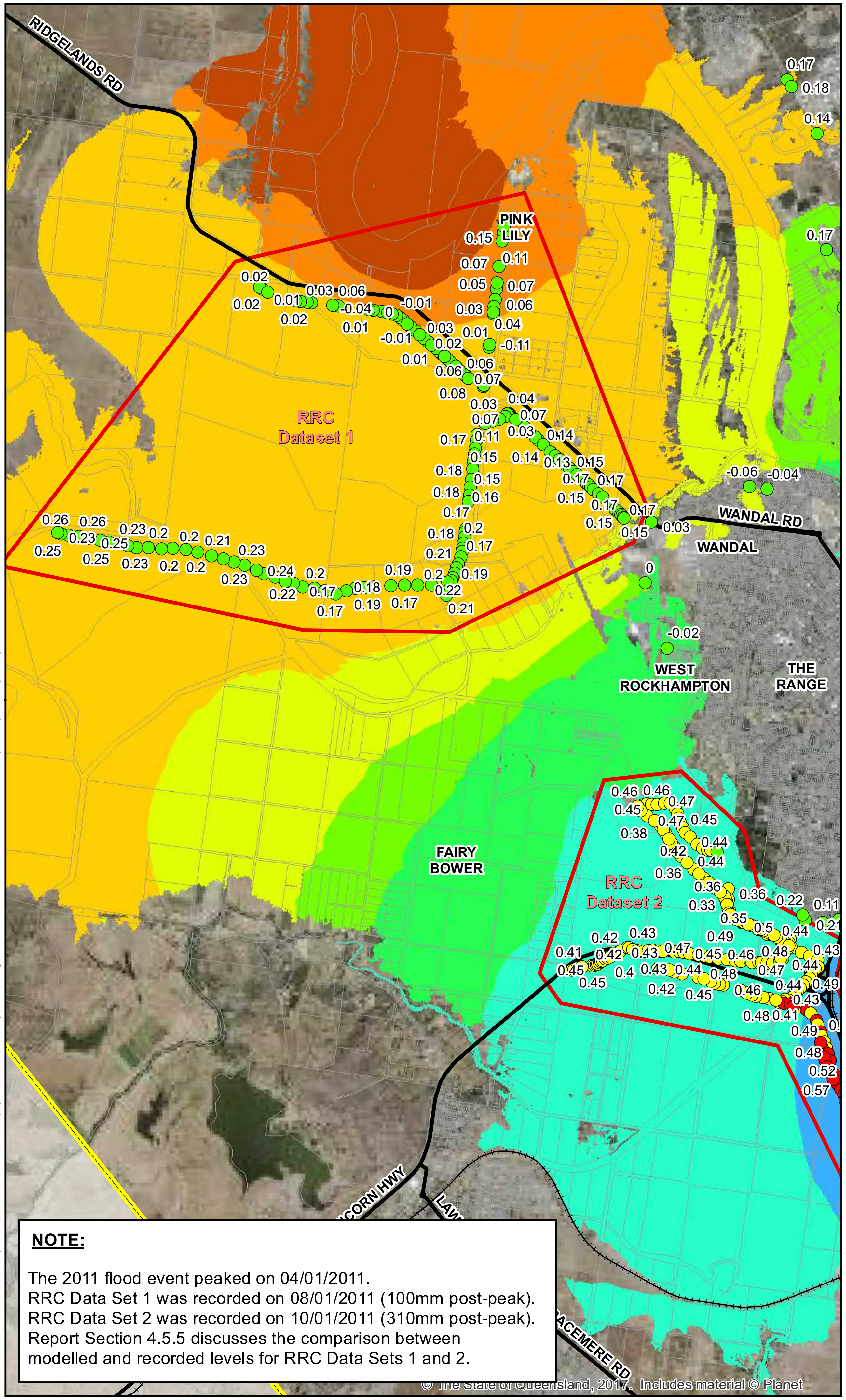
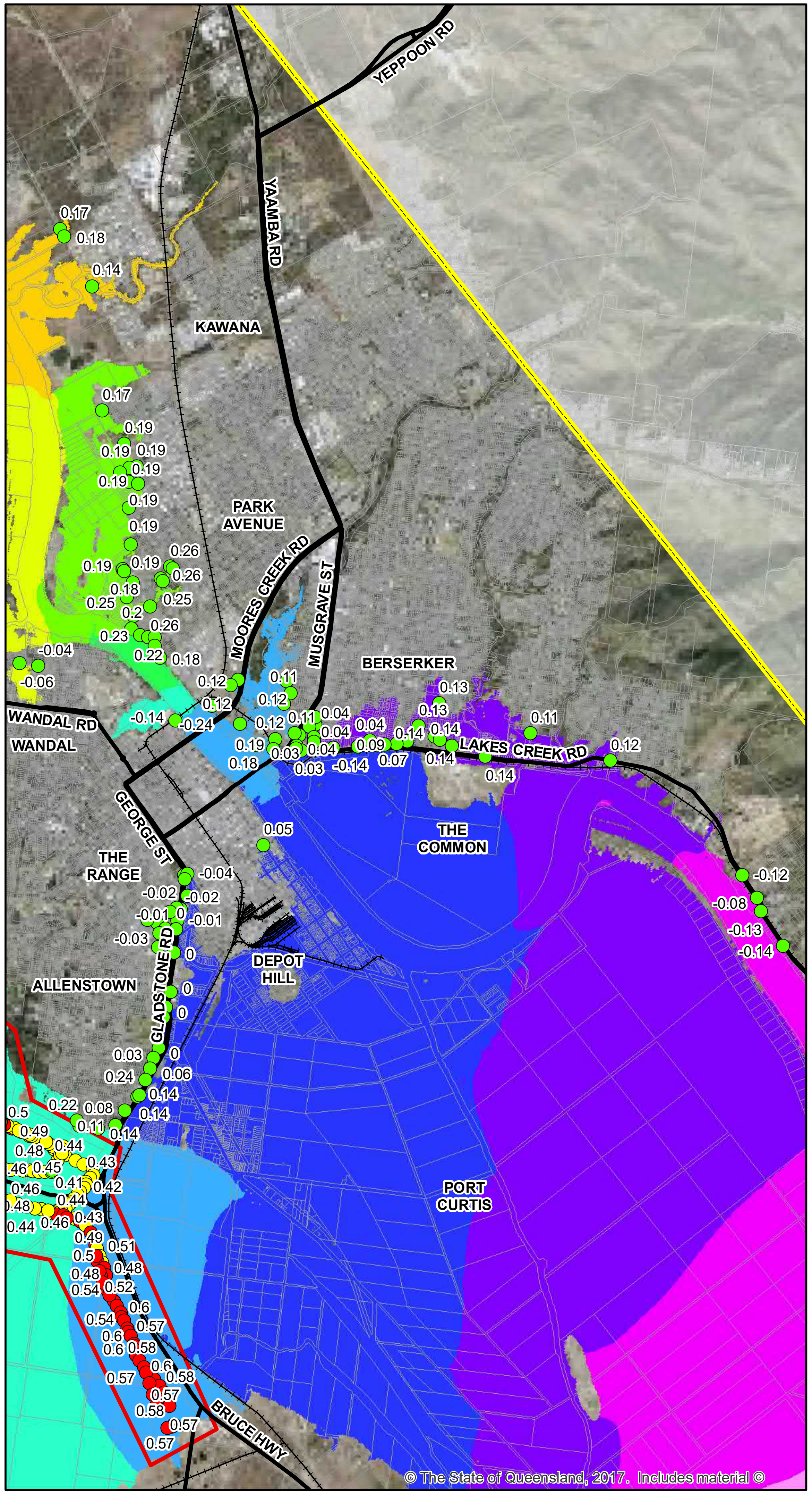


NOTE:

The 2011 flood event peaked on 04/01/2011.
RRC Data Set 1 was recorded on 08/01/2011 (100mm post-peak).
RRC Data Set 2 was recorded on 10/01/2011 (310mm post-peak).
Report Section 4.5.5 discusses the comparison between modelled and recorded levels for RRC Data Sets 1 and 2.



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GDA 1994 MGA Zone 56

0 0.5 1 2 3
Kilometres

1:55,000 (when printed at A3)

LEGEND

Water Level Difference (m)
Calculated - Recorded

- \> 0.50
- 0.30 to 0.50
- -0.30 to 0.30 (In Tolerance)
- -0.50 to -0.30
- < -0.50
- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- RRC Dataset Area
- Cadastre

Peak Water Surface Level (mAHD)

- < 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5
- 8.5 - 9
- 9 - 9.5
- 9.5 - 10
- 10 - 10.5
- 10.5 - 11
- 11 - 11.5
- 11.5 - 12
- \> 12

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

2011 Event Validation (C111)
Peak Flood Levels
Results

PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	20/03/2019
VERSION:	01

Figure
39

A3 size

6.4 1991 Event Validation

The correlation between modelled and recorded water levels for the 1991 event at the Rockhampton Gauge is shown in Figure 40. This figure shows a difference between modelled and recorded peak water surface levels of 0.17m which is within acceptable validation limits of ±0.30m. There is a very good match in both shape and timing throughout the flood event.

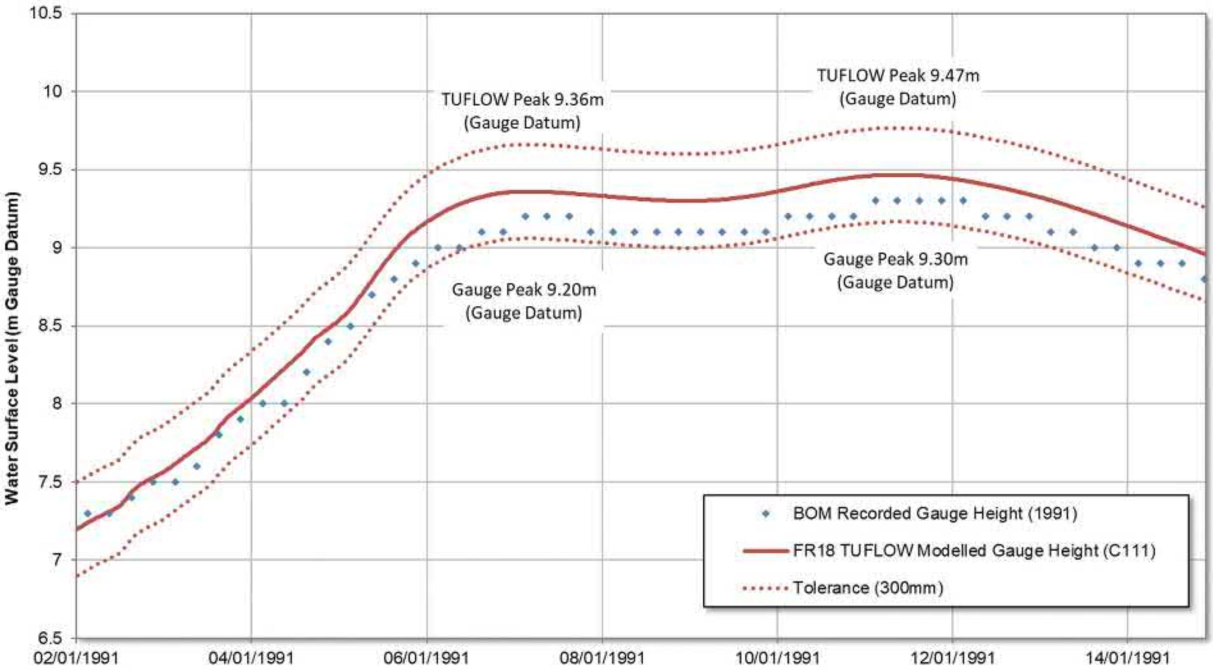


Figure 40 1991 Event Validation – Rockhampton Flood Gauge Comparison

The comparison between modelled and recorded water levels undertaken in the original SRFL study is reproduced in Figure 41. It is noted that the updated model predicts higher flood levels when compared to the 2014 predictions.

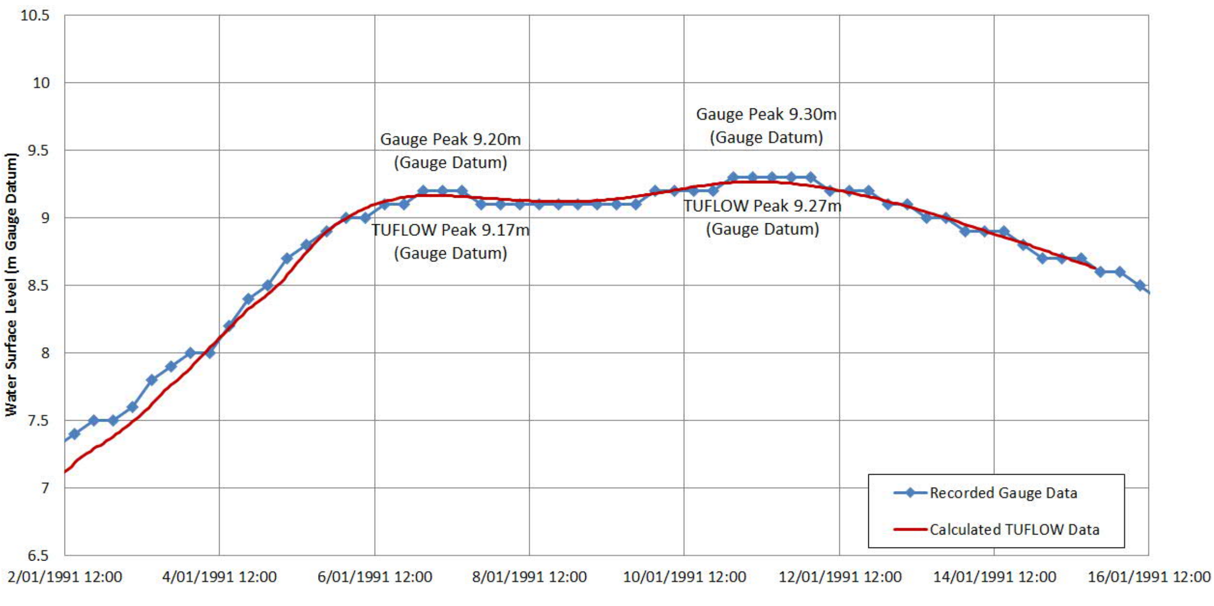


Figure 41 SRFL Rockhampton Flood Gauge Comparison – 1991 Event (source: AECOM, 2014)

Peak flood levels were recorded at 207 locations around the City and Pink Lily and compiled for use in the original FRFS. These records were used to validate the peak water surface of the updated TUFLOW model. The comparisons presented in Figure 42 to Figure 47 present the results of the 1991 validation event.

Key outcomes include:

- Of the 207 recorded points 162 (78%) of the calculated values were the ±0.30m validation tolerance.
- The average difference (absolute) between the calculated and recorded water levels is 0.22m, with a standard deviation of 0.15m.
- Eight (8) points were significantly outside the acceptable tolerances (<-0.50m or >0.50m) and were all modelled higher than recorded levels. Five (5) of these were at locations within the main channel and floodplain where flood depths are high. The remaining three (3) were within Garland Park (adjacent the airport precinct).
  - It is believed that the 1200mm RCP connecting Garland Park to Lion Creek may have been blocked during this event. This pipe drives the flood levels within Garland Park during the 1991 event. Without its influence, peak flood levels would be driven by backwater from the airport precinct, which have a peak level within 0.1m of the recorded heights within Garland Park.
- As seen in Figure 35, the validation event's linear R^2 fit was 0.99 with a statistical mean of +0.20m above recorded flood heights. This correlation between calculated and recorded flood levels is also shown in Figure 34 where it can be observed that whilst the majority of differences lie within the ±0.30m range, the model is generally predicting peak flood heights greater than those recorded.

As in the 2011 validation, the model results presented above indicate that whilst generally high, the TUFLOW model still provides a good representation of the peak flood levels with 78% of results within tolerance. Given these results, the 1991 flood event proves to be an acceptable validation of the model.

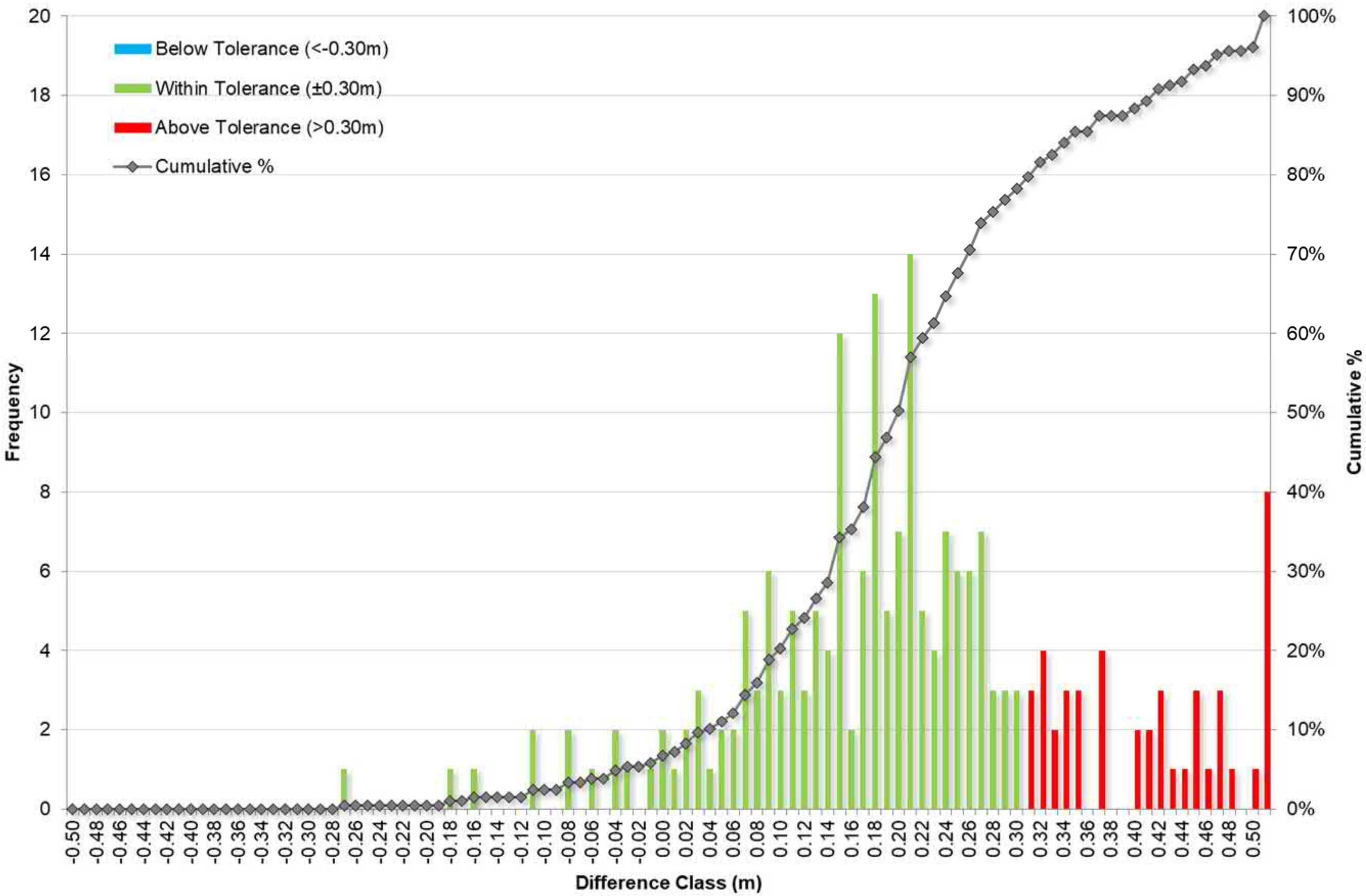


Figure 42 1991 Event Calibration Distribution

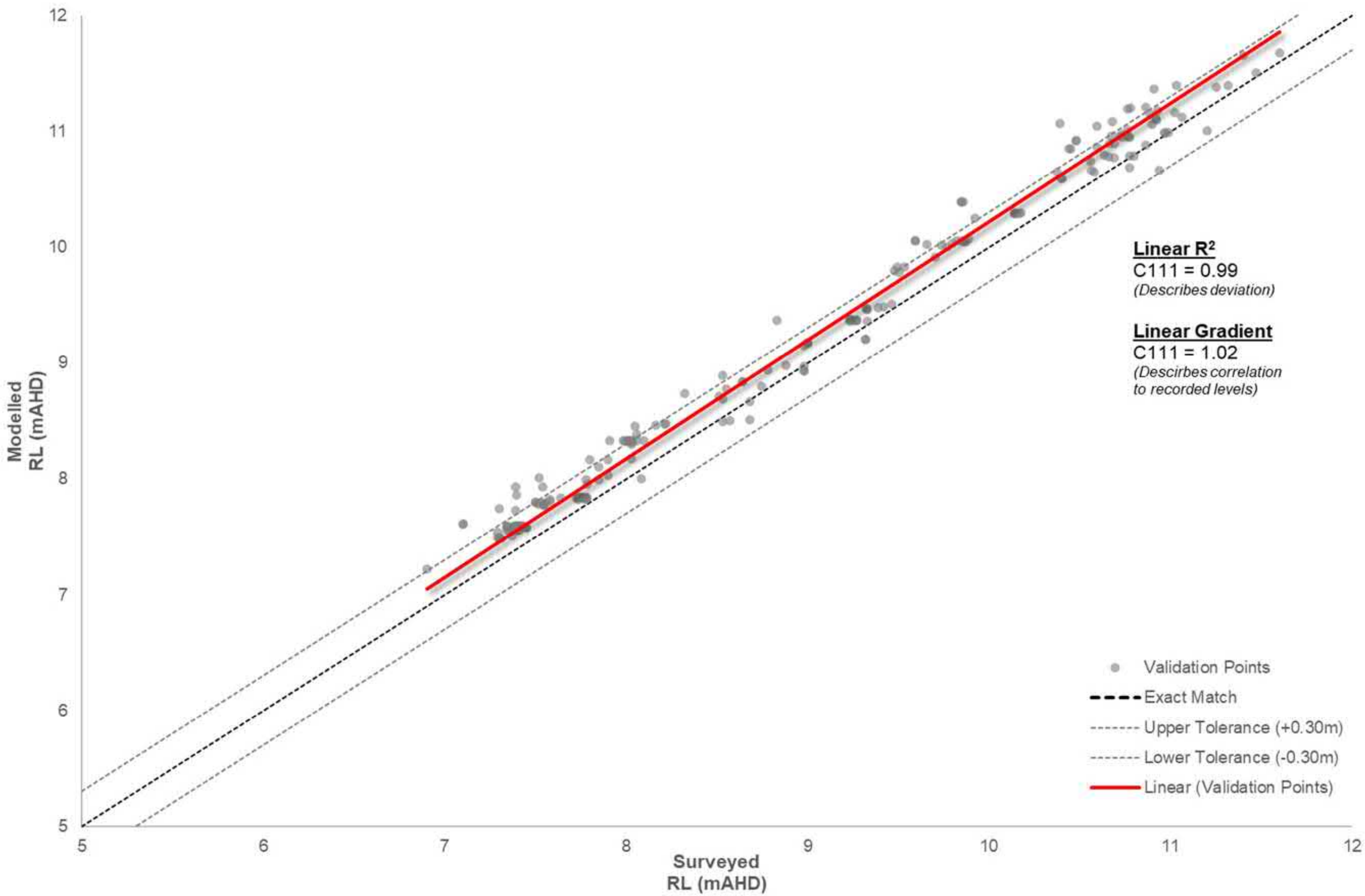


Figure 43 1991 Event Calibration Scatter Plot

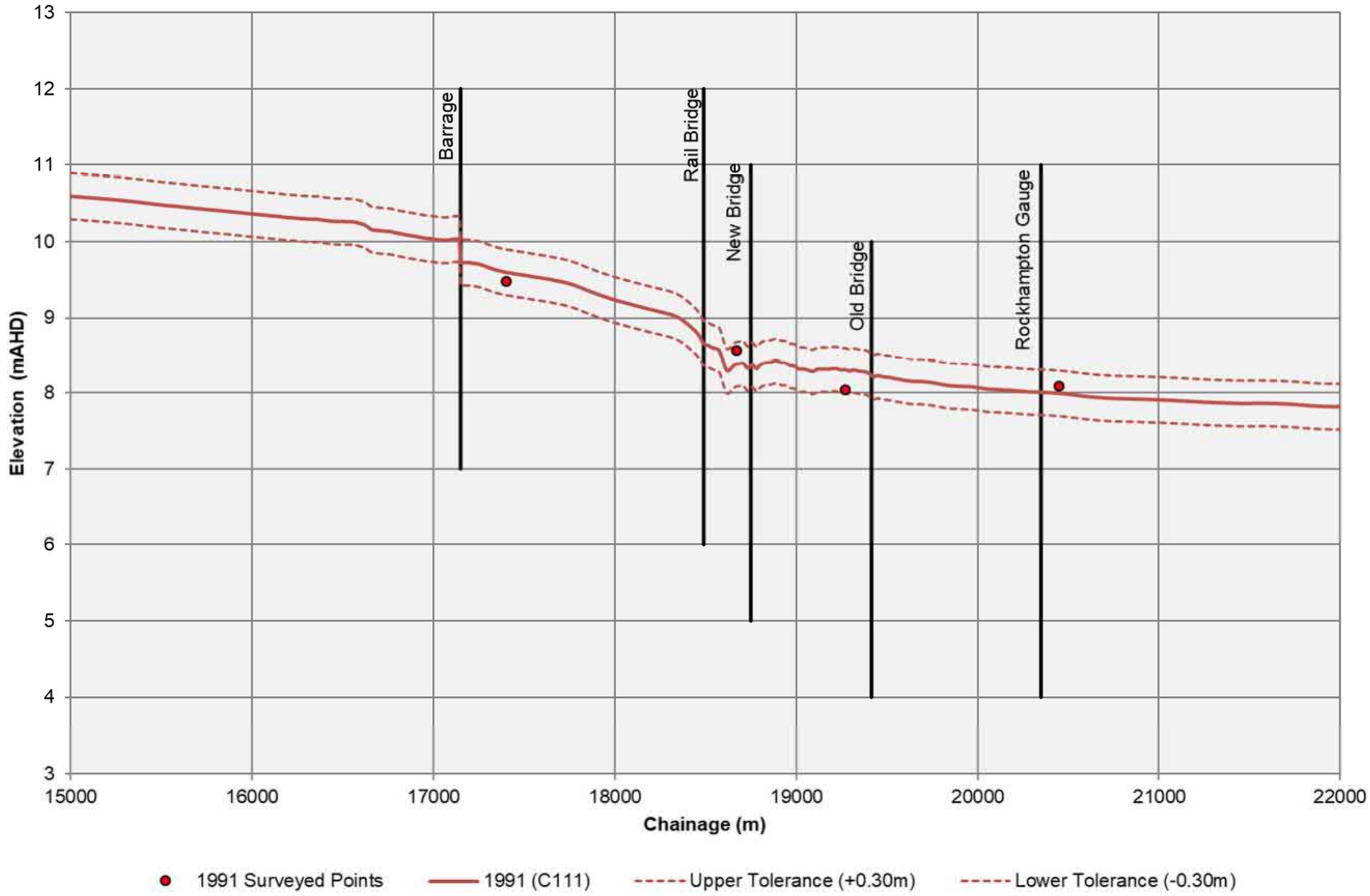


Figure 44 1991 Event Validation – Long section Along Main River Channel

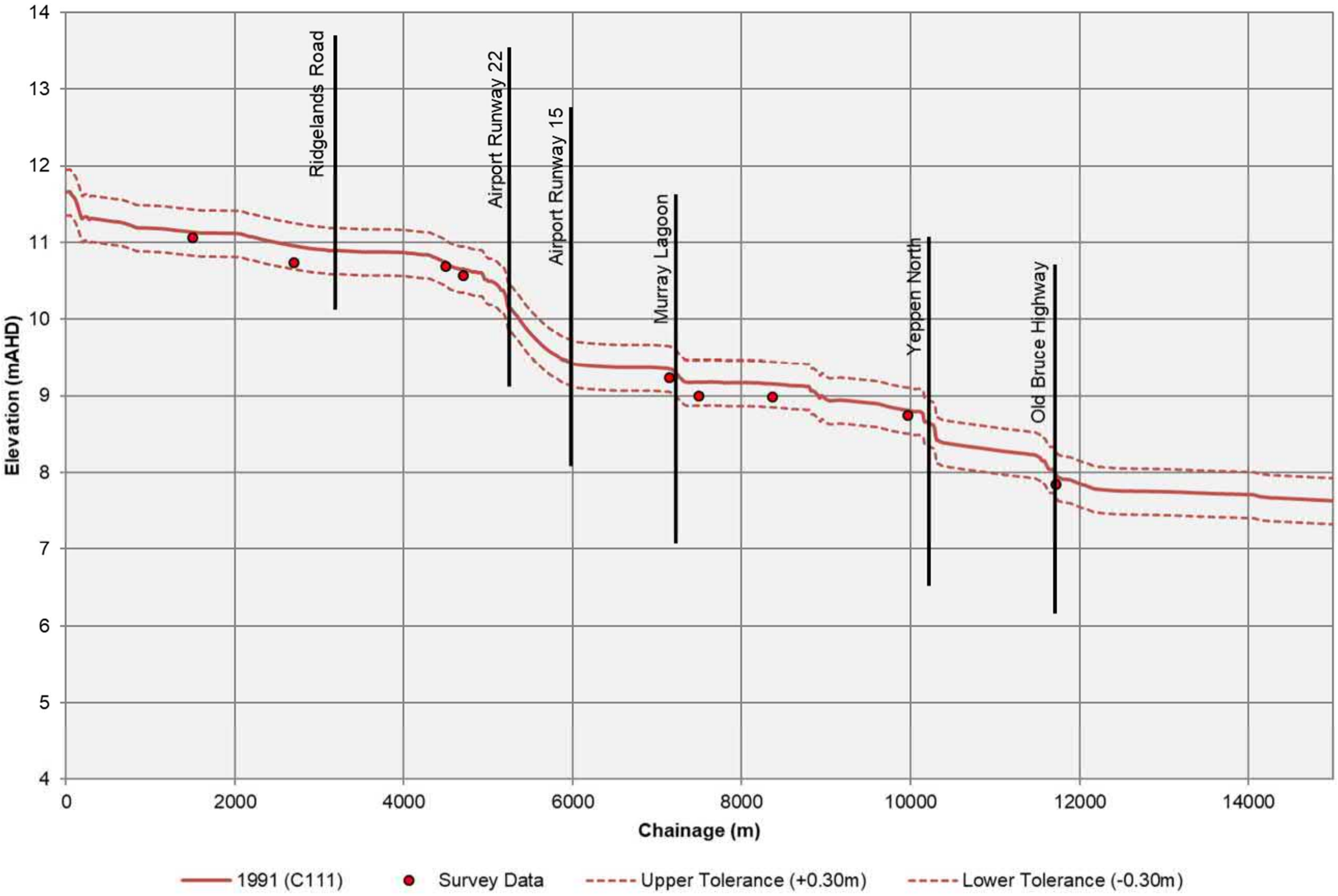
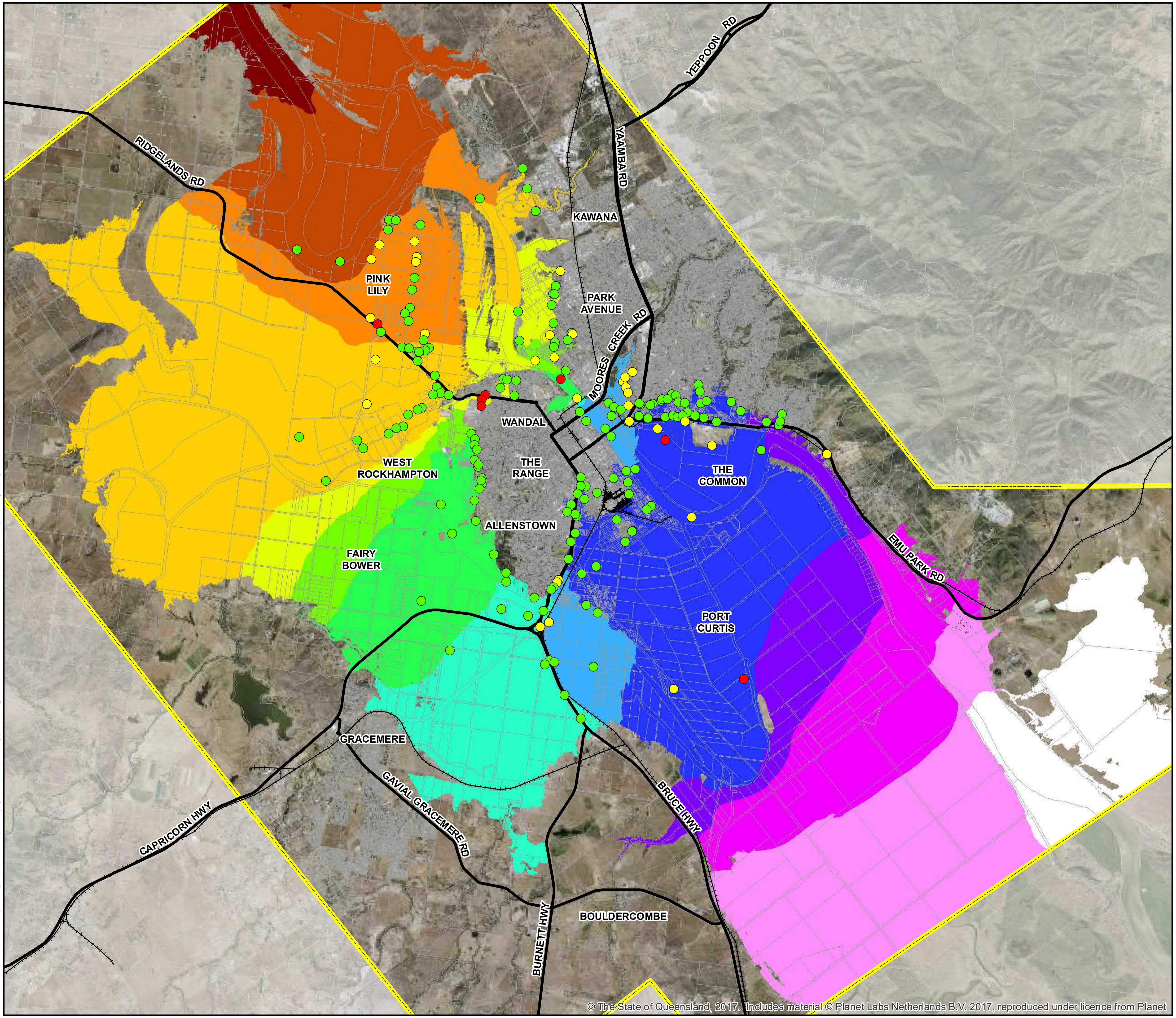


Figure 45 1991 Event Validation – Long section Along Western Floodplain



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0 1 2 4
Kilometres

1:80,000 (when printed at A3)

LEGEND

Water Level Difference (m)
Calculated - Recorded
- > 0.50
- 0.30 to 0.50
- -0.30 to 0.30 (In Tolerance)
- -0.50 to -0.30
- < -0.50

- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- Cadastre

Peak Water Surface Level (mAHD)
- < 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5
- 8.5 - 9
- 9 - 9.5
- 9.5 - 10
- 10 - 10.5
- 10.5 - 11
- 11 - 11.5
- 11.5 - 12
- > 12

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

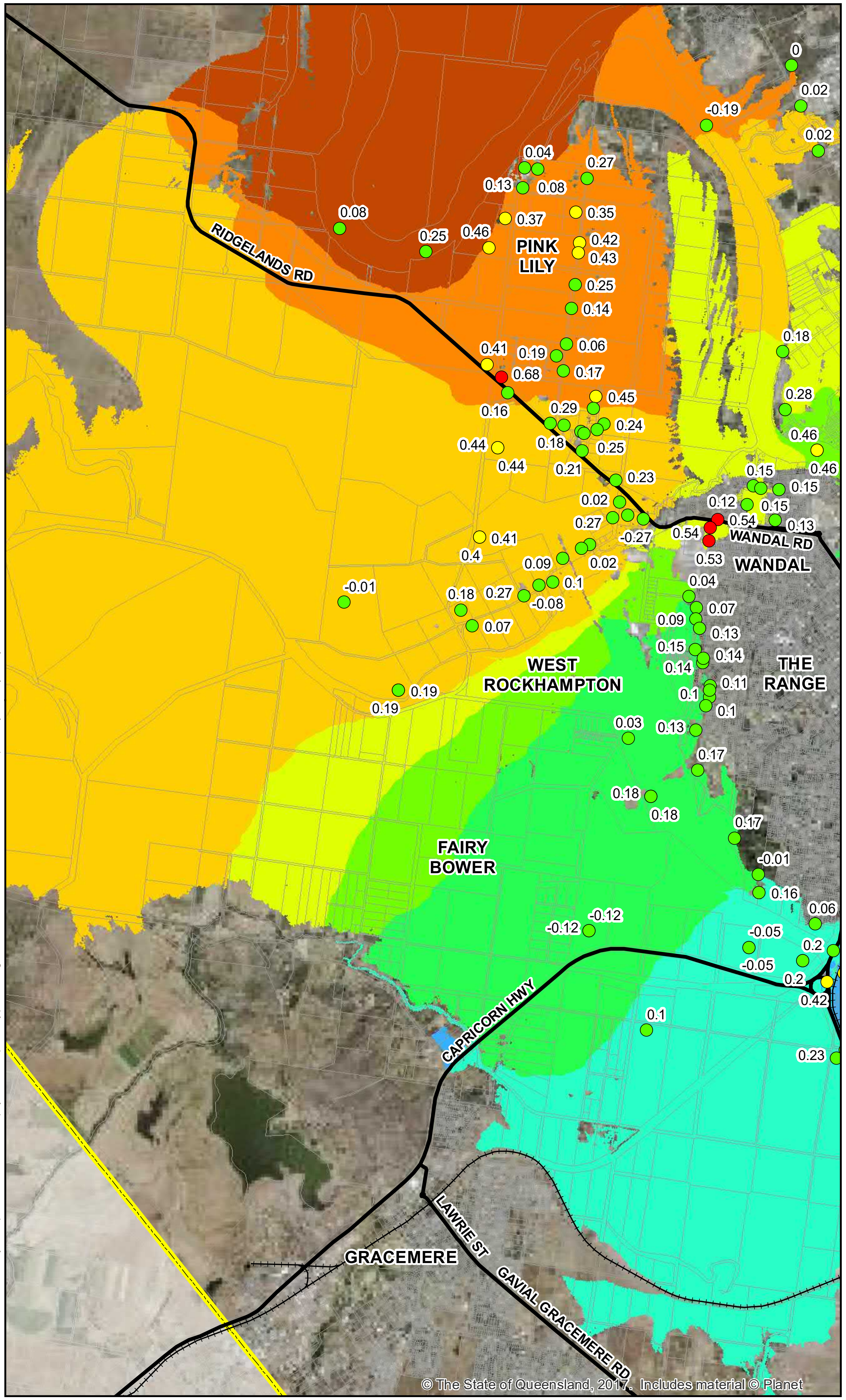
1991 Event Validation (C111)
Peak Flood Levels
Results

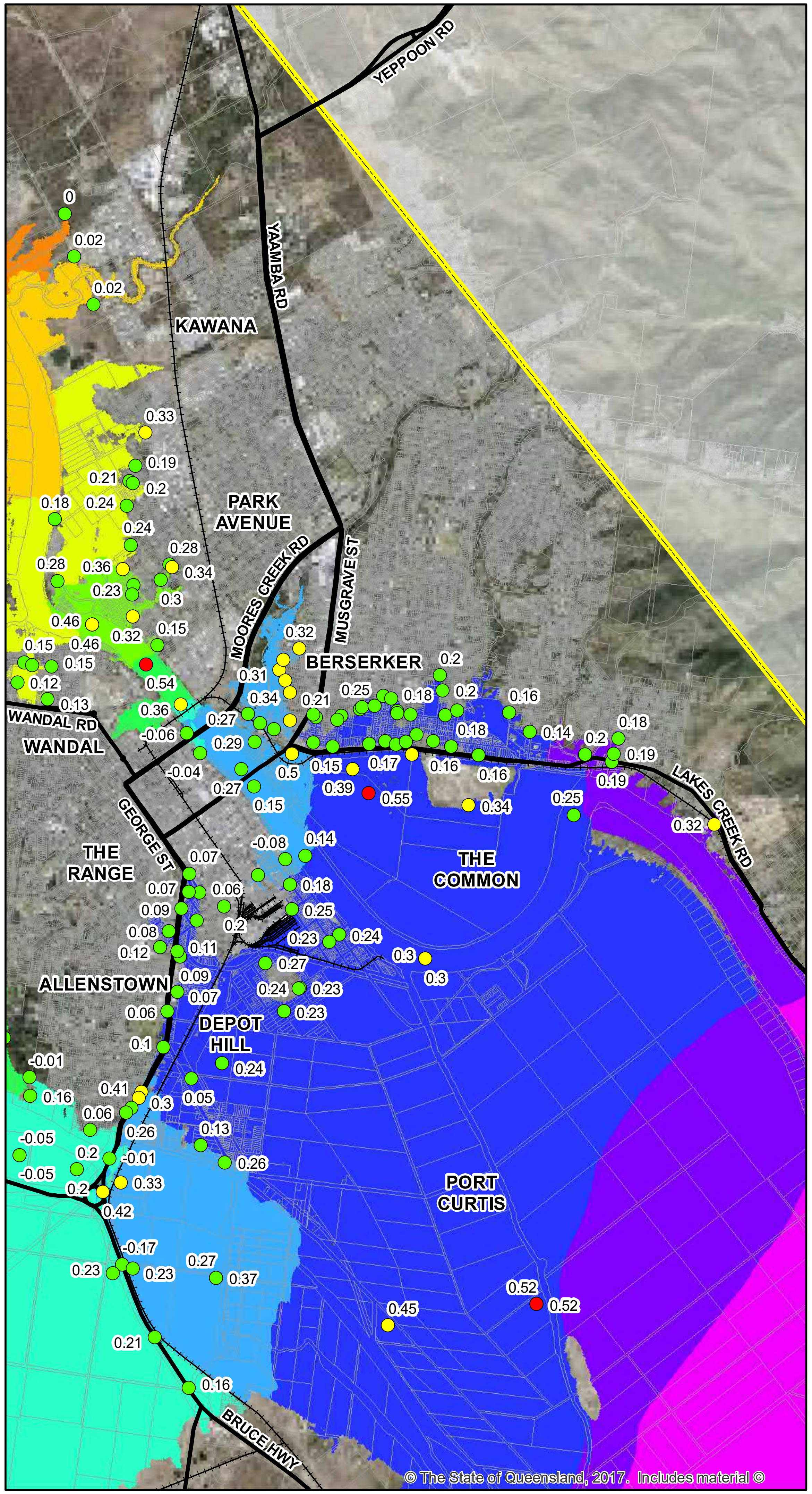
PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	14/02/2019
VERSION:	01

Figure
46

A3 size

Filename: P:\605x\60578201\4. Tech Work Area\4.99 GIS\02_MXDs\FR18\Report\Figures\MXD\Figure 24 - C111_1991_Map01.mxd





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GDA 1994 MGA Zone 56

0 0.5 1 2 3
Kilometres

1:55,000 (when printed at A3)

LEGEND

Water Level Difference (m)
Calculated - Recorded
- > 0.50
- 0.30 to 0.50
- -0.30 to 0.30 (In Tolerance)
- -0.50 to -0.30
- < -0.50

- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- Cadastre

Peak Water Surface Level (mAHD)
- < 6
- 6 - 6.5
- 6.5 - 7
- 7 - 7.5
- 7.5 - 8
- 8 - 8.5
- 8.5 - 9
- 9 - 9.5
- 9.5 - 10
- 10 - 10.5
- 10.5 - 11
- 11 - 11.5
- 11.5 - 12
- > 12

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

1991 Event Validation (C111)
Peak Flood Levels
Results

PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	20/03/2019
VERSION:	01

Figure 47

6.5 2008 Event Validation

Unlike the calibration event (2017) and validation events (2011 and 1991) which have recorded flood levels based on survey data taken during the event, the collection of 2008 event data was based upon flood debris marks and anecdotal flood information. Closer inspection of the anecdotal records reveals that nine (9) of the 15 points are below ground level, adding to the uncertainty within this dataset.

The 2014 TUFLOW model was shown to correlate well with the Rockhampton Gauge data. The updated TUFLOW model results were calculated to be approximately 0.50m higher than the previous model. Inspection into the applied inflows revealed a 7% discrepancy between peak flows applied at the upstream 1D boundary, with the 2018 model applying 6,531m^3/s and the 2014 model applying only 6,086m^3/s. This discrepancy was traced back to an update to the rating curve at The Gap gauge station. This update was made following the 2014 model development and resulted in the change in peak flow for the 2008 flood event. This increased flow is the primary reason why the updated model predicts higher flood heights than the 2014 model.

A difference of -2% was also noted for the 2011 flood event, with the updated model applying a flow of 13,274m^3/s which is 239m^3/s less than that applied in 2014. Based on this information it was reasoned that the new gauge rating is driven towards larger flood events, however this has not been confirmed.

Coupled with the fact that the 2008 event included a coincident local catchment event it is suggested that the relatively small data set (15 points) is unable to adequately serve as a model validation in comparison to the 2011 and 1991 datasets.

Consequently, it is recommended that a future, well-documented bank-full flood event (with a peak flow between 5,000m^3/s and 7,000m^3/s) is simulated within the updated TUFLOW model to test the model performance during more frequent flood events.

6.6 Combined Analysis

As outlines above, the updated Fitzroy River model has been re-calibrated to a range of historic flood events, each having a different magnitude. The estimated flood magnitude for the assessed events is presented in Table 12. In an effort to understand the holistic performance of the model across the range of simulated historic events, results for the 2017, 2011 and 1991 flood events have been combined into a single dataset for analytical purposes. The number of recorded points and number of modelled heights within acceptable tolerances have also been included in Table 12.

Table 12 Flood Event Summary

Event	AEP	ARI (years)	Recorded Points (Peak)	Points Within Tolerance
1991	1.8%	56	207	162 (78%)
2011	2.4%	42	107	107 (100%)
2017	6.7%	15	421	369 (88%)
Total	**6.7% - 1.8%**	**15yrs – 56yrs**	**735**	**719 (87%)**

Based on the results above, it can be concluded that 87% of modelled peak flood heights were within tolerance across the model domain for events between a 1 in 15 year (6.6% AEP) and 1 in 56 year (1.8% AEP) flood magnitude.

Figure 48 presents a scatter plot of the modelled and recorded results for each of the events described above. The average difference for the combined dataset was determined to be +0.06m, with a standard deviation of 0.16m. These statistics support the data trends shown in Figure 48 where the dataset's linear trendline returns an R^2 fit of 0.99. Also of key note is that the trendline has a near-perfect gradient (where a perfect gradient is 1.0) and rests marginally above the "Exact Match" line across the range of recorded flood heights (5.5mAHD to 11.5mAHD). Hence, the model is generally 60mm "high" throughout the model domain.

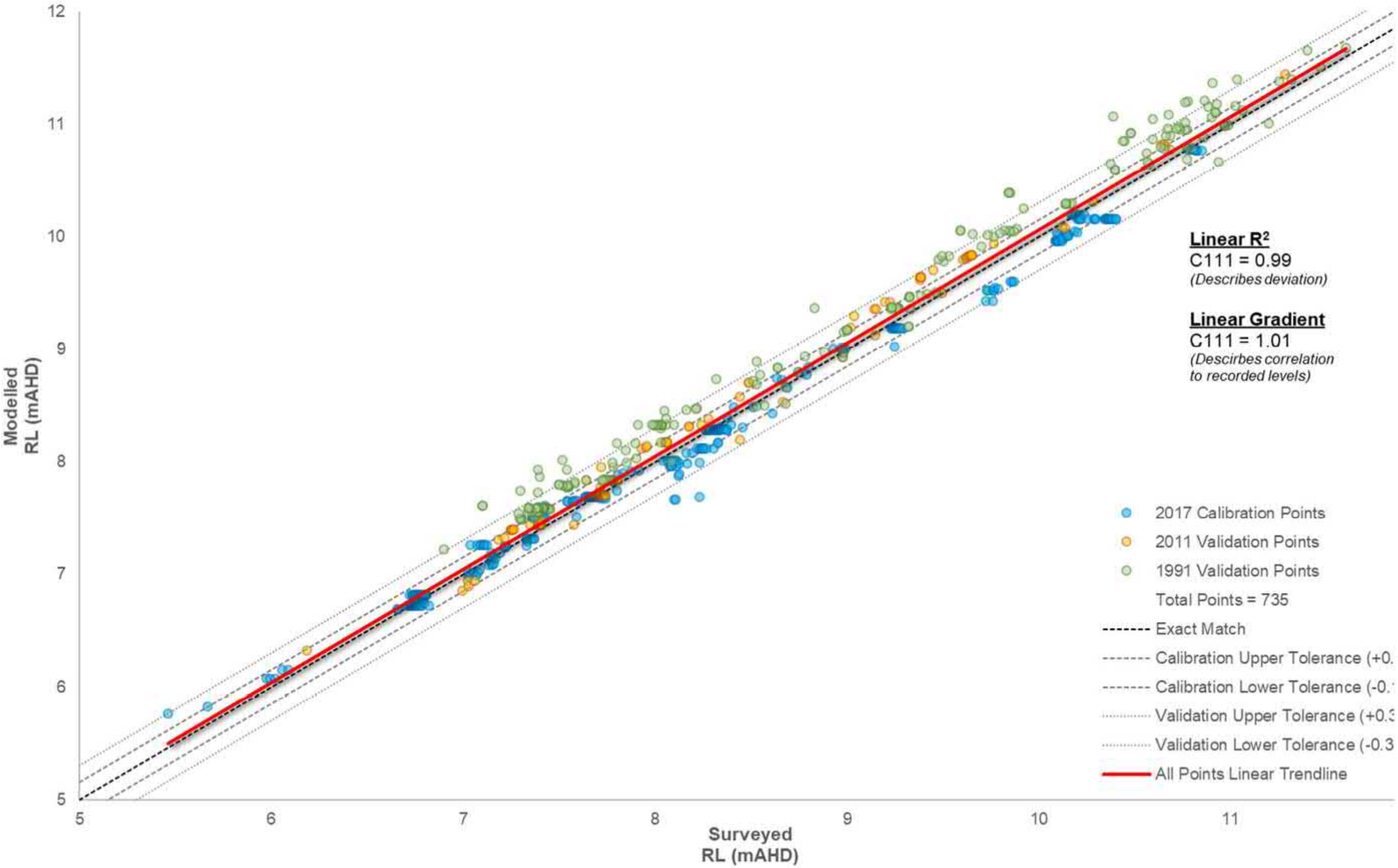


Figure 48 Full Dataset (735 points) Scatter Plot

6.7 Future Works

6.7.1 Baseline Model Updates

In order to gain further confidence in the modelled results it is recommended that:

- The model is further validated against a future 'bank-full' flood event (see Section 6.5).
- The model is re-calibrated to a future flood event which is close to a 1% AEP event.

It is recommended that TMR and RRC maintain consistent use of the updated TUFLOW model and any major floodplain changes are recorded and included in the model in a structured manner.

6.7.2 Model Refinements for Rockhampton Ring Road Project

It is noted that a number of additional model refinements will be considered for the baseline Fitzroy River TUFLOW model adopted for the upcoming Rockhampton Ring Road Business Case. These include:

- A refined model resolution (expected to reduce to 10m cell size), for improved digitisation of embankments and key hydraulic structures associated with various design options.
- Reduced 2-D hydraulic model extent (western floodplain only).
- Reduced flood hydrograph for simulations not requiring calculation of TOS and AATOS.
- Inclusion of the final SRFL alignment in the baseline scenario.
- Assessment of climate change scenarios.
- Sensitivity analyses.

In addition to the above updates, consideration of local catchment intersecting the proposed Rockhampton Ring Road alignment will be undertaken using several existing rain-on-grid models (separate to the Fitzroy River TUFLOW model). This includes (from north to south):

- Limestone Creek.
- Wandal & West Rockhampton.
- Lion Creek.
- Neerkol Creek.

7.0 Design Event Comparison

7.1 Overview

Design event simulations were completed for the 5%, 2%, 1%, 0.5%, 0.2% and 0.05% AEP events following completion of the calibration and validation process. Peak discharges and flow hydrographs were applied based on hydrologic inputs discussed in Section 4.0.

Table 13 summarises the hydraulic model setup and key parameters.

Table 13 Hydraulic Model Setup Overview

Parameter	2018 Fitzroy River TUFLOW Model
Completion Date	2018
AEP's Assessed	5%, 2%, 1%, 0.5%, 0.2%, 0.05% AEP
Hydrologic Modelling	Inflow peak from FFA at The Gap (west of Yaamba) Hydrograph shape based on 1991 historic event at The Gap
Hydraulic Model Software	TUFLOW HPC version 2018-03-AC
Grid Size	15m
DEM (year flown)	2016
Roughness	Spatially varying and depth constant values
Eddy Viscosity	Smagorinsky
Model Calibration	Calibrated to 2017 event, validated to 2011 and 1991 events.
Downstream Model Boundary	Tidal boundary on the south-western boundary. Recorded tidal levels used for historic event. Mean High Water Springs used for Design Events.
Timesteps	Adaptive Timestep as per TUFLOW HPC
Sensitivity Testing	Nil – recommended when model is being used for future infrastructure projects

Figure 49 provides a comparison between predicted design event peak flood levels at the Rockhampton Gauge, for the 2018 and 2014 TULOW models as well as the 1992 RFMS. The graphic shows that at the Rockhampton Flood Gauge 2018 design flood levels are predicted to increase from the 2014 study by:

- 0.24m in a 5% AEP event.
- 0.26m in a 1% AEP event.

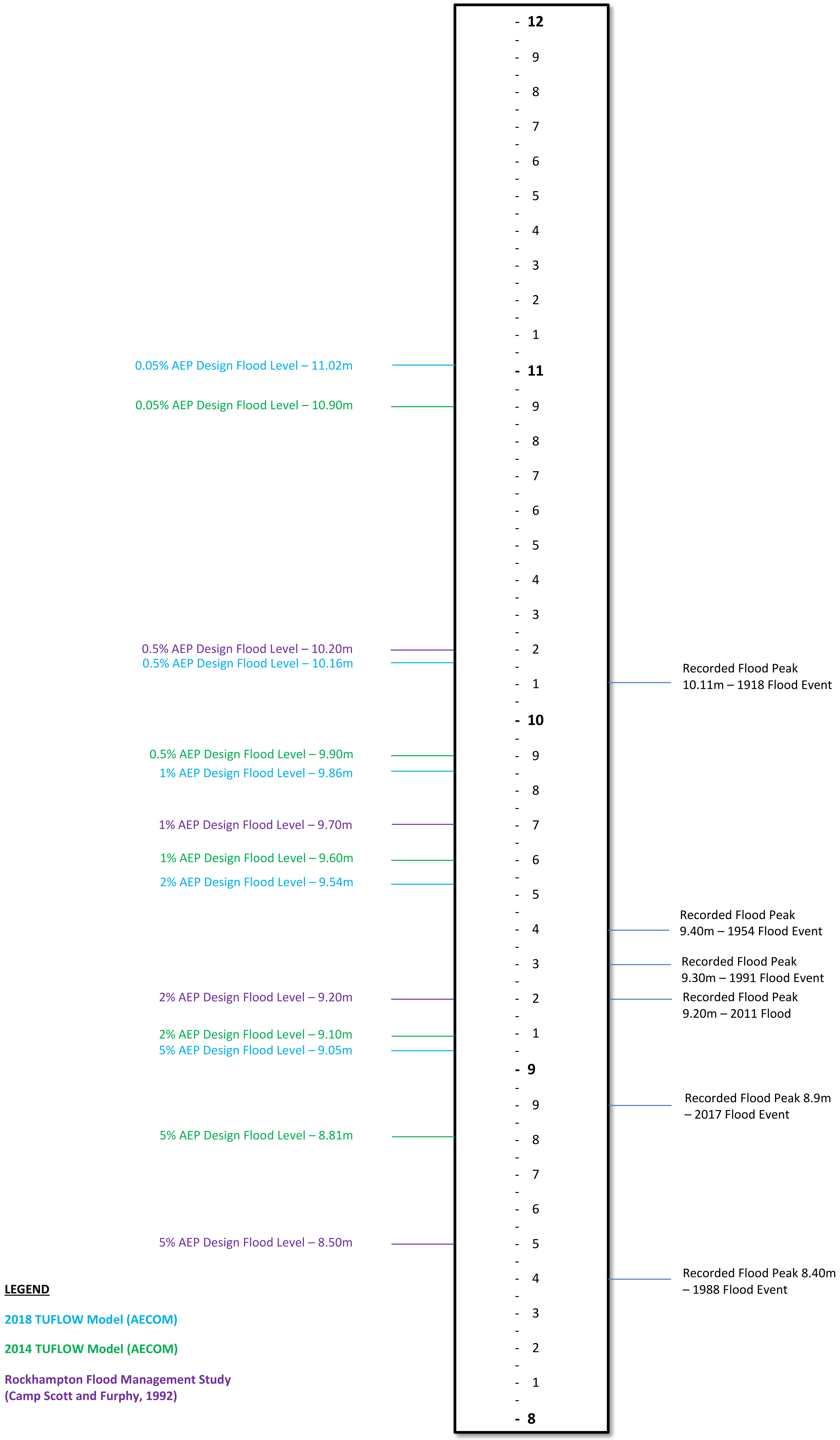
Figure 50 and Figure 51 show the difference in PWSE between the 2018 and 2014 Baseline TUFLOW models for the 5% AEP and 1% AEP events respectively. It can be seen that:

- For the 5% AEP Difference in PWSE (Figure 50):
  - Peak flood heights and extents have increased across the entirety of the 2-D model except where localised filling has occurred (private properties, quarries and Lakes Creek Road Landfill).
  - Within the western floodplain:
    - Increase of up to 0.12m from the upstream 2-D model extent to Ridgelands Road.
    - Increase of 0.20m between Ridgelands Road and Rockhampton Airport.
    - Increase of 0.31m within Rockhampton Airport Precinct, coupled with increase peak flood extents (due to finer topography and subsurface network improvements).
    - Increase of 0.32m to 0.35m from Capricorn Highway to Old Bruce Highway.

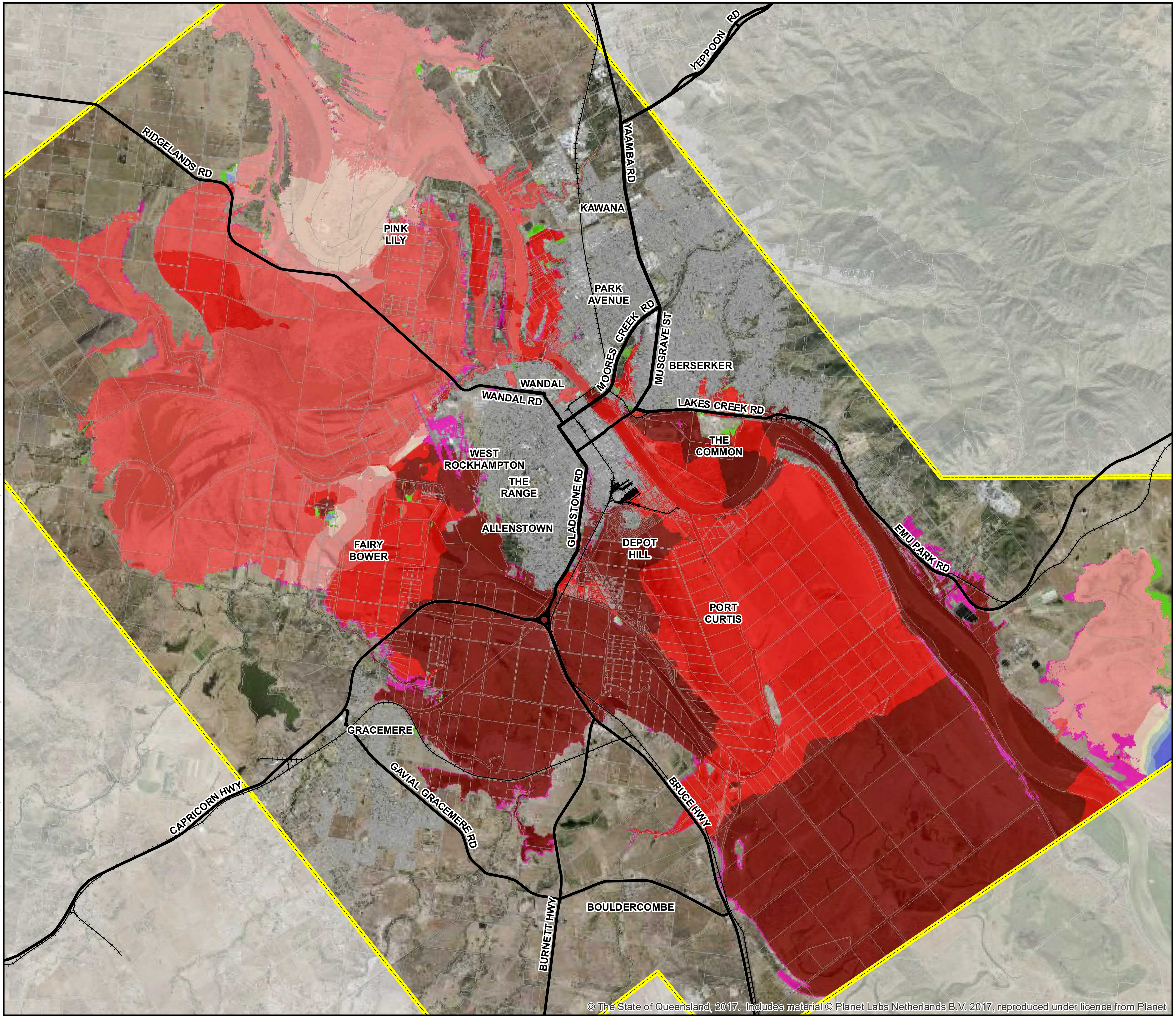
  - Within the main river channel:
    - Increase of up to 0.30m directly upstream of the Barrage.
    - Increase of 0.18m between Barrage and rail bridge.
    - Increase of 0.25m to 0.31m from rail bridge to The Bend.
  - Within backwater areas:
    - Increase of 0.30m to 0.45m within South Rockhampton and Depot Hill.
    - Increase of 0.21m to 0.28m in Moores Creek, Thozets Creek, Garland Park, Jardine Park, Frenchmans Creek / the North Rockhampton Flood Mitigation Area (north of Lakes Creek Road), Alf Kele Park, Wackford Street (adjacent the Barrage) and Splitters Creek.
- For the 1% AEP Difference in PWSE (Figure 51):
  - Peak flood heights and extents have increased across the entirety of the 2-D model except where localised filling has occurred (private properties, quarries and Lakes Creek Road Landfill).
  - Within the western floodplain:
    - Increase of up to 0.08m from the upstream 2-D model extent to Ridgelands Road.
    - Increase of 0.10m to 0.15m between Ridgelands Road and Yeppen North / South.
    - Increase of 0.25m to 0.35m from Yeppen North / Yeppen South to Gavial Creek.
    - Increase of 0.40m to 0.70m from Gavial Creek to downstream 2-D model extent.
  - Within the main river channel:
    - Increase of up to 0.40m directly upstream of the Barrage.
    - Increase of 0.20m between Barrage and rail bridge.
    - Increase of 0.25m to 0.40m from rail bridge to The Bend.
  - Within backwater areas:
    - Increase of 0.30m to 0.35m in Moores Creek, Thozets Creek, Garland Park, Jardine Park and South Rockhampton.
    - Increase of 0.20m to 0.27m in remaining backwater areas, namely Frenchmans Creek / the North Rockhampton Flood Mitigation Area (north of Lakes Creek Road), Alf Kele Park, Wackford Street (adjacent the Barrage), Splitters Creek and Limestone Creek.

The simulated flood heights have increased by an average of 0.22m for the 1% AEP flood event, ranging from 0.10m to 0.35m in areas of interest. This is predominantly attributed to the increase in ground levels within the 2016 LiDAR data, which are generally 0.18m higher than the 2009 LiDAR data. This, alongside implications of increased flood levels for key stakeholders, is further discussed in Section 8.0.

Figure 49 -Comparison of Flood Levels at the Rockhampton Flood Gauge (all levels in Gauge Datum (AHD + 1.448m)



**All levels in Gauge Datum (AHD + 1.448 m)*



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0 1 2 4
Kilometres

1:80,000 (when printed at A3)

LEGEND

- Main Roads
- QLD Railway Line
- Hydraulic Model Extent Boundary
- Cadastre

Difference (m)

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

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

Difference in Peak Flood Heights
2018 Model minus 2014 Model
5% AEP Event

PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	19/02/2019
VERSION:	01

Figure
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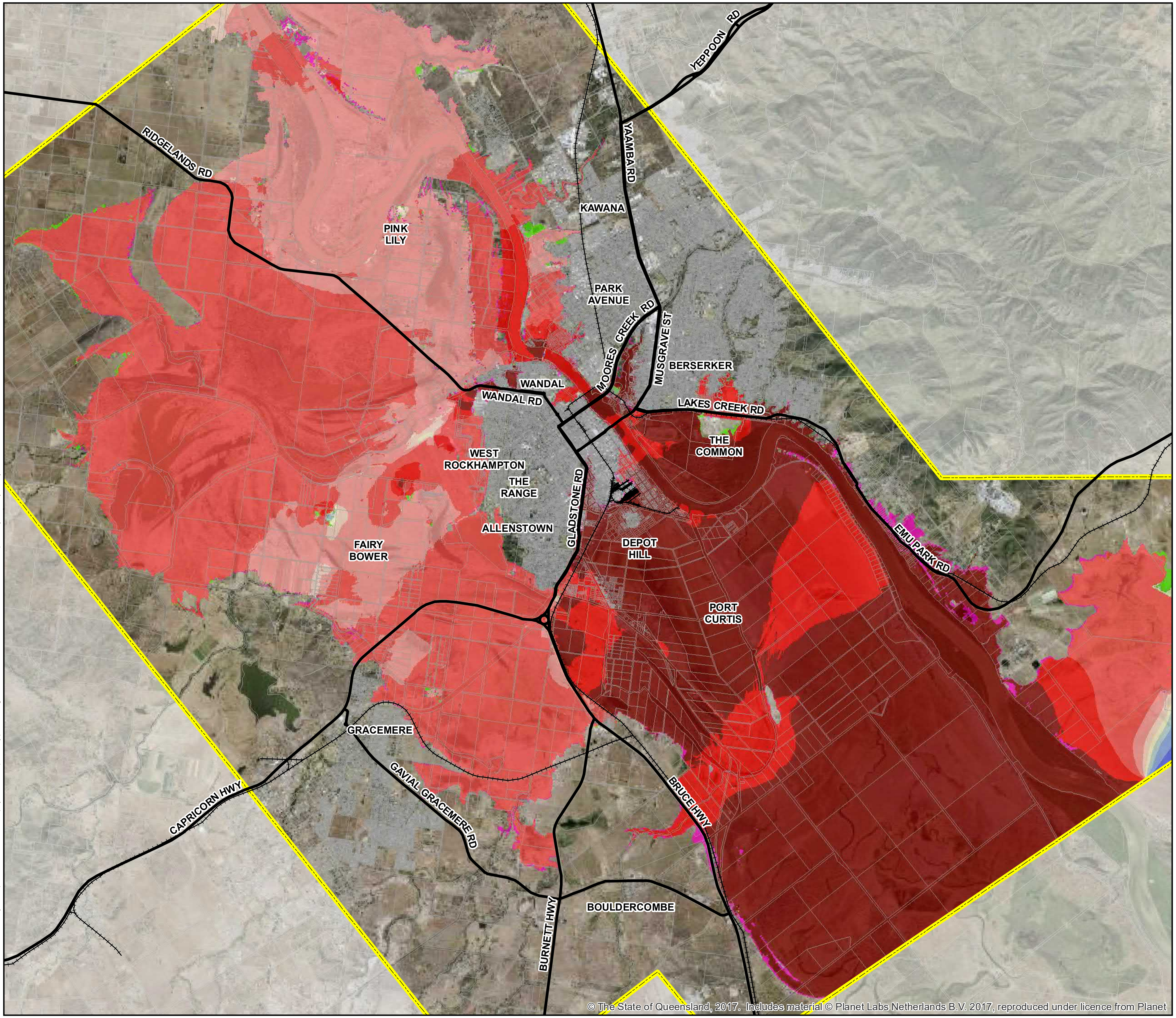
A3 size

Filename: P:\605x\60578201\4. Tech Work Area\4.99 GIS\02_MXDs\FR18\Report\Figures\MXD\Figure 33 - E100_20y_PSWE Diff to D120.mxd



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Kilometres

1:80,000 (when printed at A3)

LEGEND

- Main Roads
- QLD Railway Line
- NRFMI_Clip
- Hydraulic Model Extent Boundary
- Cadastre

Difference (m)

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

Data sources:
Base Data (c) 2018 (QLD Gov)
Imagery (c) 2018 (Esri)

FRFRPS OPTIONS ANALYSIS UPDATE
Fitzroy River TUFLOW Model Update

Difference in Peak Flood Heights
2018 Model minus 2014 Model
1% AEP Event

PROJECT ID	60578201
CREATED BY	briggh
LAST MODIFIED	19/02/2019
VERSION:	01

Figure
51

A3 size

Filename: P:\605x\60578201\4. Tech Work Area\4.99 GIS\02_MXDs\FR18\Report\Figures\MXD\Figure 34 - E100_100y_PSWE Diff to D120.mxd

8.0 Implications of Updated Design Flood Levels

8.1 Increased Flood Levels

Updates to the Fitzroy River TUFLOW model have resulted in changes to the expected peak flood heights for design events across the modelled extent. This has potential implications for infrastructure projects within the Lower Fitzroy Catchment and as such it is important to understand the factors driving this change. These are summarised as follows:

- **Topographic Datasets:** ground levels within the 2016 LiDAR data are generally 0.18m higher than the 2009 LiDAR data. This directly translates to an increased peak flood height. The 2016 topography across the floodplain and backwater areas adjacent the Fitzroy River near Port Curtis are also notably higher, with differences generally ranging between 0.30 to 0.60m. This has influenced peak flood heights in the lower Yeppen Floodplain, The Common, lower North Rockhampton, Port Curtis and Depot Hill.
- **Pink Lily Meander Migration**: continued lateral migration of the Pink Lily meander has resulted in increased flows entering the western floodplain, increasing peak flood heights until Gavial Creek (downstream of the Yeppen Crossing)
- **Hydraulic Structures:** improved digitisation of hydraulic structures, especially the Fitzroy River Barrage and low-level Yeppen North bridges (road and rail) has increased peak flood heights within the western floodplain between Ridgelands Road and the Yeppen crossing.
- **Hydraulic Roughness:** changes to ground roughness related to more recent aerial imagery and model re-calibration generally saw an increase in roughness throughout the western floodplain.
- **Downstream Model Boundary:** depositional processes were noted near the downstream boundary which effectively reduces the capacity of the channel-floodplain for a given flood stage. Updating the 1-D / 2-D boundary to match 2015/16 LiDAR has resulted in increased flood levels which influence the water surface near the SRFL and Yeppen Bridges due to limited energy gradient between the lower Fitzroy Reach at Rockhampton and the downstream 2-D model boundary.
- **Improved Model Resolution**: improved digitisation of key channels provided more accurate channel conveyance characteristics.

8.2 Potential Implications to TMR

Updates to the TUFLOW model have resulted in modelled flood levels in the Yeppen area increasing from those predicted in the FRFRPS Western Road Corridor (WRC) Options Analysis Update, Yeppen North, Yeppen South and Capricorn Highway Duplication hydraulic assessments.

In order to understand the implications of these flood level increases on existing and planned floodplain infrastructure, it is necessary to compare 2018 predicted levels to previously modelled flood heights.

Updates to the TUFLOW model have increased PWSE's across the 2-D model domain in comparison to 2014 levels, with the following increases noted for the 1% AEP event (refer Figure 51):

- 0.15m to 0.18m at the Yeppen North and South Bridges.
- 0.17m across the Capricorn Highway.
- 0.14m to 0.16m throughout the western floodplain between Pink Lily and the Capricorn Highway.
- 0.20m within the Fitzroy River near Limestone Creek.

TMR have indicated they plan to utilise the latest TUFLOW model for the current Rockhampton Ring Road Preliminary Evaluation and Business Case. This is recommended to ensure that infrastructure levels are based on revised modelling.

8.3 Potential Implications to RRC

It is understood that the 2014 Fitzroy River TUFLOW model has been ratified by Council. As there have been significant updates to the TUFLOW model as part of this investigation, Council should consider the need to adopt the new levels predicted from the updated model for use in future floodplain management and planning scheme overlays.

Updates to the TUFLOW model have increased PWSE's across the 2-D model domain in comparison to 2014 flood heights; with the following increases noted for the 1% AEP event (refer Figure 51):

- 0.13m to 0.21m within the Rockhampton Airport Precinct.
- 0.25m to 0.27m upstream of the Barrage, near the proposed Splitters Creek levee alignment.
- 0.27m to 0.33m adjacent to the North Rockhampton Flood Mitigation Area (north of Lakes Creek Road).
- 0.30m to 0.38m across Port Curtis, near the proposed SRFL alignment.

As previously noted, the predominant reasons for increased PWSE within the updated TUFLOW model are the use of 2016 LiDAR data, ongoing migration of the Pink Lily Meander and downstream model boundary. The increases to PWSE will have direct impacts to Defined Flood Event (DFE) immunity of key infrastructure, such as the Rockhampton Airport Levee, Splitters Creek levee, SRFL and NRFMI schemes.

9.0 Conclusion and Recommendations

9.1 Conclusion

A structured approach was taken in updating the 2014 Fitzroy River TUFLOW model to include 2016 LiDAR, aerial imagery and as-constructed infrastructure as well as the 2017 Fitzroy River flood information. The TUFLOW model version was updated to take advantage of recent developments in modelling software and utilise the latest HPC advancements, to reduce grid size and improve model resolution.

Review of the previous FFA to include the 2017 flood showed minor changes to design event discharges, leading to the decision to retain the 2014 inflow hydrographs for this current study. Model re-calibration was undertaken to recorded flood levels from the 2017 flood event, with model re-validation being completed for the 2011, 1991 and 2008 events.

9.1.1 Calibration Results

A strong calibration was achieved to the 2017 event throughout the model extent with 88% of modelled points within ±0.15m of recorded flood heights. The calibration event had an average difference (not absolute) of -0.03m throughout the modelled extent.

Calibration scenarios revealed the western floodplain was highly sensitive to hydraulic parameters set for the Barrage, with careful testing allowing for balanced correlation to recorded peak flood heights upstream and downstream of the structure. Topographic levels within the breakout zones and Fitzroy River channel at the Pink Lily meander also proved to control the peak flood heights within the western floodplain. Consequently, detailed survey of these areas was collected and incorporated for the 2017 and design flood events.

Continual migration of the Pink Lily meander will continue to increase the proportion of flood waters entering the western floodplain as the outer banks progress southwards towards lower ground elevations. Events which are close to the Pink Lily breakout magnitude (i.e. 10% AEP) will be affected most by the continual meander, whilst larger events (i.e. 1% AEP) will notice less of an increase change. However, it is worth noting that any increase to breakout flows within the western floodplain will reduce the flood immunity of nearby infrastructure.

9.1.2 Validation Results

A strong validation of the model performance was achieved for the 2011 and 1991 events, with 85% of modelled levels being within the ±0.30m tolerance for both events. The 2008 event was discredited as a validation event due to the erroneous, limited dataset. As such, validation to a future, well-documented, bank-full flood event is recommended to validate the model's performance during more frequent flood events.

9.2 Recommendations

Based on the outcomes of this study it is recommended that:

- Changes in topography are monitored within the Pink Lily meander and western floodplain as aerial datasets become available in order to understand the impact of ongoing channel migration. Stabilisation of the meander is strongly recommended and is aligned to recommendations made in the 1992 Rockhampton Flood Management Study.
- It is recommended that the model is validated to future flood events as recorded flood data allows. If an opportunity arises, it is recommended that the model is validated or re-calibrated to a flood event close to the 1% AEP magnitude in order to confirm model performance during the DFE.
- It is recommended that the changes in peak flood levels, behaviour and extents are communicated to key stakeholders and that infrastructure projects within the modelled Fitzroy River extents utilise the updated Fitzroy River model as the basis for design.
- It is recommended that TMR and RRC maintain consistent use of the updated TUFLOW model and any major floodplain changes are recorded and included in the model in a structured manner.

Appendix A

TUFLOW HPC Release Notes

Appendix A TUFLOW HPC Release Notes

The recent release of the HPC version of TUFLOW software allows the simulation of dynamically linked 1-D/2-D hydraulic models using the GPU solver, rather than the CPU solver applied in the TUFLOW Classic version. TUFLOW GPU is a 2-D fixed grid hydrodynamic solver that uses an explicit finite volume solution that is 1st order in space and 4th order in time (1st and 2nd order in time solutions are also available but are not recommended). TUFLOW GPU uses adaptive time stepping with the ability to revert back in time should a numerical inconsistency occur, thereby providing extreme numerical stability. The solution solves the full 2-D free-surface equations including the inertia and sub-grid turbulence (eddy viscosity) terms.

The HPC version of TUFLOW essentially provides the speed of a GPU TUFLOW model, with the ability to model 1-D structures, which to date has only been able in the Classic CPU version of the TUFLOW platform. The TUFLOW HPC solver resolves the 2-D Shallow Water Equations (SWE) on the same uniform Cartesian grid as used by TUFLOW Classic (CPU version), using a finite volume scheme. The key differences between the HPC solver and previous solvers include:

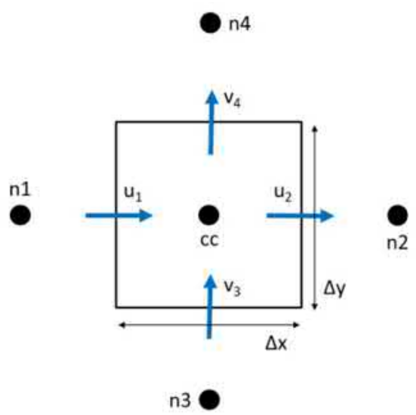
- HPC solves fluxes at cell sides and cell mid-sides, which removes the numerical noise (and checker-boarding) which was sometimes observed with the previous GPU solver. This was previously an issue as the GPU's first order approach to the finite volume scheme ignored parameters at cell mid-sides.
- HPC, like the GPU solver, utilises an adaptive time step and resultantly can wind down the time step to ensure model stability.

TUFLOW HPC 2-D Solver (TUFLOW GPU Mark II)

HPC 2-D Solution Scheme – Description

The TUFLOW HPC solver resolves the 2-D Shallow Water Equations (SWE) on the same uniform Cartesian grid as used by TUFLOW Classic, using a finite volume scheme. Water depth/level is calculated at the cell centres, and velocity components at the cell mid-sides or faces in the same manner as TUFLOW Classic.

The finite volume scheme applies the conservation of mass over the cell for calculating the rate of change of cell depth. The cell centre (for the cell in question) is given the notation cc, while the surrounding neighbours are given the notation n1.n4. The u velocity at the left and right faces are notated u1 and u2, and the v velocities at the bottom and top faces are notated v3 and v4. The cell width and height are Δx and Δy respectively. The time rate of change for the cell averaged depth is shown below.



$$\frac{A\partial h}{\partial t} = \Phi_1 - \Phi_2 + \Phi_3 - \Phi_4 + S_Q$$

The volume fluxes across the four cell sides and the net volume from source boundaries determine the rate of volume change and the change in depth. Source boundaries include SA, ST and RF boundaries, soil infiltration, evaporation, and any flow linkages to 1-D elements via SX links. By computing the face fluxes for all model faces, and referencing these when computing the depth derivative for each cell, volume conservation is guaranteed to numerical precision.

The calculation of the cell side volume fluxes is available in either 1st or 2nd order spatially. For the1st order scheme, this is uses depth of the upstream cell (often referred to as upwinding), bounded to be greater than or equal to 0, and less than or equal to the surface elevation of the upstream cell less the bed elevation at the cell side mid-point. For the 2nd order scheme the depth at the face is computed as the average of the two cell averaged depths, however, this method in its simplest form is not total variation diminishing (TVD) and is known to be unstable. A hybrid method is implemented in which the depth at the cell face transitions from interpolated depth, in the limit of a smoothing varying solution, to the upstream depth (1st order upwinding) when the solution shows short scale reversal or upstream controlled supercritical flow.

The solution of the cell side fluxes includes the inertia and sub-grid scale turbulence (eddy or kinematic turbulent viscosity) term. The same options for the eddy viscosity coefficient calculation in Classic (constant, Smagorinsky or a combination of constant and Smagorinsky) are available, and the default values for both schemes are presently set the same. BMT WBM are doing further research in this area, as there is some dependency on cell size for this term.

The face fluxes may also be factored down by flow constriction factors where sub-grid-scale interfering geometries exist.

The calculation steps are highly independent. The calculation of flux for one cell face may be performed independently of the other faces, and likewise the summation of flux for each cell volume may be performed independently of the other cell volumes. Applying the same algorithm to millions of data elements is ideally suited to modern multi-core CPUs, and particularly suited to GPU hardware acceleration.

The 1st order approach can experience numerical diffusion like all 1st order schemes, and does not resolve strongly two-dimensional hydraulics (e.g. flow expansion downstream of a constriction) as well as a 2nd order solution. The 2nd order solution demonstrates no discernible numerical diffusion, and resolves complex 2-D hydraulics, including hydraulic jumps.

TUFLOW HPC versus 2016-03 TUFLOW GPU

The TUFLOW HPC scheme differs from the original TUFLOW GPU scheme, in that TUFLOW GPU is only a 1st order upwinded solver that calculates water level/depth and velocities all at the cell centres and ignores the ground elevations and other parameters at the cell mid-sides.

TUFLOW GPU's 1st order only approach can experience numerical diffusion like all 1st order schemes and does not resolve strongly two-dimensional hydraulics (e.g. flow expansion downstream of a constriction) as well as a 2nd order solution. TUFLOW GPU also does not support the higher resolution topographic sampling at cell mid-sides, and therefore does not support functionality such as thin breaklines to represent narrow obstructions such as concrete levees and fences. The primary difference between TUFLOW GPU and TUFLOW HPC 1st order, is that TUFLOW HPC 1st order, like 2nd order, solves fluxes at the cell sides and utilises cell mid-side elevations and roughness values.

TUFLOW GPU results, can also exhibit significant numerical noise (unsteadiness) and checkerboarding (oscillating water levels from one cell to the next). These issues do not occur for TUFLOW HPC, primarily due to the solving of fluxes at the cell faces, rather than the cell centres.

TUFLOW GPU also does not include the new functionality of 1-D linking and numerous other additions to TUFLOW HPC. The TUFLOW GPU option is provided for legacy models, noting that the TUFLOW GPU code has essentially been frozen and unlikely to be further enhanced.

TUFLOW GPU is generally faster than TUFLOW HPC due to its simpler solution, smaller memory footprint, simpler code base and limited features