“Where will our knowledge take you?”

Milestone Report 6: Hydraulics Report

Comprehensive Hydraulic Assessment

Brisbane River Catchment Flood Study

DRAFT FINAL

Prepared for the State of Queensland

December 2016

Document Control Sheet

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	Title:	Milestone Report 6 – Hydraulics Report
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	Client Reference:	DILGP-2327-14
Synopsis:	Milestone Report 6: BRCFS Hydraulics Report	

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	11th October 2016	CLB		WJS	
1	9th December 2016	CLB		WJS	

DISTRIBUTION

Destination	Revision										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
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Acknowledgements

This report has been prepared as part of the Hydraulic Assessment of the overall Brisbane River Catchment Flood Study which was funded by the Queensland State Government, Brisbane City Council, Ipswich City Council, Somerset Regional Council and Lockyer Valley Regional Council.

The on-going involvement and review by the Technical Working Group, consisting of the following organisations, are appreciated:

- Department of Infrastructure, Local Government and Planning (Client)
- Department of Natural Resources and Mines (Project Manager on behalf of Client)
- Department of Science, Information Technology and Innovation
- Department of Energy and Water Supply
- Seqwater
- Brisbane City Council
- Ipswich City Council
- Somerset Regional Council
- Lockyer Valley Regional Council
- Bureau of Meteorology
- Queensland Reconstruction Authority (post June 2016).

Executive Summary

The State of Queensland, in response to the Queensland Floods Commission of Inquiry, has commissioned BMT WBM to undertake a Comprehensive Hydraulic Assessment (this assessment) to deliver an up-to-date and fully calibrated detailed hydraulic model that accurately defines the flood behaviour of the lower Brisbane River, including major tributaries, downstream of Wivenhoe Dam. This assessment is a component of a broader framework of the Brisbane River Catchment Floodplain Studies (BRCFS) to provide a comprehensive plan to manage Brisbane River flood risk.

This Milestone Report 6: *Hydraulics Report*, is the sixth in a series of milestone reports delivered as part of the BRCFS Hydraulic Assessment (Figure A). It provides an overarching view and presents the key findings of the Hydraulic Assessment, including the methodologies developed and used, based on Milestone Reports 1 to 5.

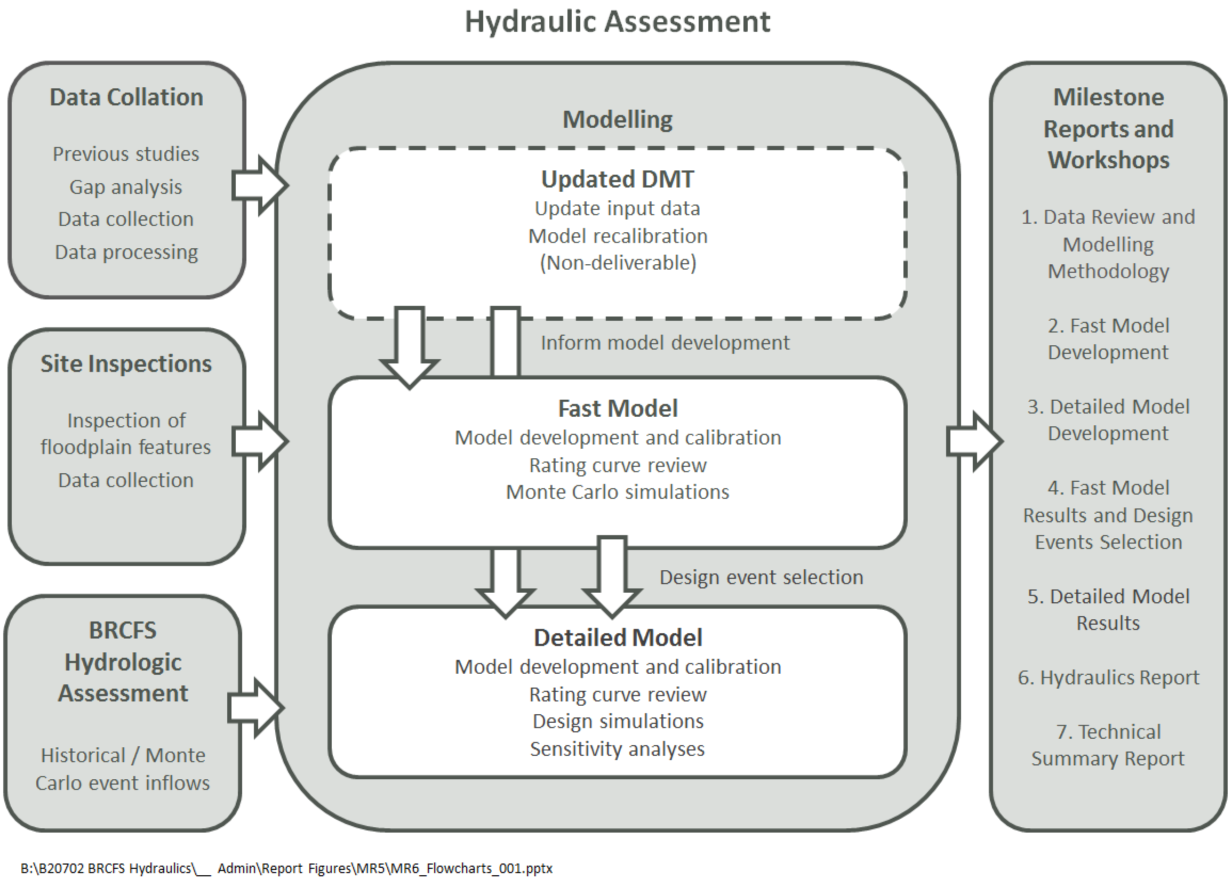


Figure A BRCFS Hydraulic Assessment

The Hydraulic Assessment component of the BRCFS has been prepared in accordance with the Invitation to Offer (ITO). The work has been advised and reviewed by a Technical Working Group (TWG) and an Independent Panel of Experts (IPE), and overseen by a Steering Committee under a governance arrangement. The Hydraulic Assessment interfaced closely with the BRCFS Hydrologic Assessment, the most comprehensive hydrologic assessment of the Brisbane River catchment to-date.

Two hydraulic models were developed and calibrated as part of the Hydraulic Assessment: the Fast Model and the Detailed Model. The Fast Model is a purely 1D hydraulic model with a target run time of 15 minutes or less per simulation as specified in the ITO. Its primary purpose is to simulate thousands of Monte Carlo (MC) events as provided by the Hydrologic Assessment to produce a more reliable Annual Exceedance Probability (AEP) flood level frequency analysis and to select AEP flood event ensembles to derive design flood surfaces using the Detailed Model. The MC methodology was used to account for the joint probability of tributary inflows, antecedent catchment conditions, initial dam levels and tidal conditions.

The Detailed Model is a 1D/2D hydraulic model that is designed to reproduce the hydraulic behaviour of the rivers, creeks and floodplains at a significantly higher resolution and accuracy than the Fast Model. It is used for producing flood maps and 3D surfaces of flood levels, depths, velocities and hydraulic hazard. The Detailed Model is one of the most comprehensive hydraulic models developed in Australia to-date.

This hydraulic assessment has utilised the latest available data to develop computer models; verified these models by calibrating and validating their results against five well documented historical floods and tidal conditions; and employed industry leading techniques such as MC statistical analyses to derive AEP design floods that encompass the effects on flood behaviour caused by the influence of Somerset and Wivenhoe Dams, and the variable responses of the Brisbane River and its major tributaries of Lockyer Creek and Bremer River. As such, the AEP design flood results from the Detailed Model should be considered significantly more reliable than any previous regional scale Brisbane River hydraulic assessments.

The Fast and Detailed Models are calibrated and verified to five historical events, namely those of 1974, 1996, 1999, 2011 and 2013 and to tidal conditions. Table A shows the comparison between the calibration/verification events to the recorded data for key selected locations.

Table A Summary of Calibration Events

	Peak Water Level (mAHD)											
	Lowood (Pump Stn)			Ipswich (CBD)*			Moggill Gauge			Brisbane (City Gauge)		
	Actual	FM	DM	Actual	FM	DM	Actual	FM	DM	Actual	FM	DM
1974	n/a	46.0	45.9	20.7	21.5	20.9	19.9	20.5	20.1	5.5	5.6	5.6
1996	34.0	34.5	35.2	11.3	12.3	13.8	7.1	8.3	8.5	2.1	2.1	1.9
1999	33.6	33.1	33.6	6.6	6.6	7.8	n/a	4.8	4.9	1.4	1.5	1.5
2011	46.3	46.3	46.1	19.3	19.2	19.2	18.2	18.2	18.4	4.5	4.4	4.5
2013	35.3	34.3	34.6	13.9	13.1	14.1	8.0	8.3	8.1	2.3	2.4	2.3

**The discrepancy in the results for the 1996 and 1999 events at Ipswich are considered primarily due to sedimentation in the Bremer River that was removed by dredging after 1999.*

Key observations from the model development and calibration/verification process are:

- Due to significant kinetic energy losses that occur at sharp river bends, rock ledges and major confluences, and which are not inherently modelled by the 1D form of the hydraulic equations, form (kinetic energy) losses at these features were applied to the Fast Model and resulted in an improved calibration.

- Using a combination of industry standard Manning's n and form loss values, a common set of hydraulic modelling parameters applied within the Fast Model was able to replicate the hydraulic behaviour across all calibration events and for tidal conditions.
- The Fast Model has a run time of around 4 mins for an 8 day flood on a standard single CPU core. This is within the 15 mins run time as stipulated by the ITO.
- The 2D hydraulic equations used by the Detailed Model inherently simulate the bulk (typically 70 to 80%) of kinetic energy losses at features such as sharp river bends, rock obstructions and major confluences. However not all the energy losses are accounted for such as those that occur in the vertical plane (eg. helicoidal circulations around a sharp bend) for which a 3D representation is required. Additional form (kinetic energy) losses were therefore applied within the Detailed Model, albeit of a significantly lower magnitude than for the Fast Model.
- As for the Fast Model, a common set of industry standard Manning's n and additional form loss values were derived for the Detailed Model, which were calibrated and verified to the complete range of historical events and tidal conditions tested.
- The effects of superelevation at river bends are reproduced in the in-bank 2D sections of the Detailed Model, and where recorded flood marks were available these concur with the Detailed Model's results. For example, there is a recorded 0.7m difference in flood level across the Story Bridge in 2011 that the Detailed Model reproduces. The Fast Model being 1D is not able to reproduce this effect.
- The Fast and Detailed Models were simulated for hypothetical extreme events: 1.5x1974 (similar to the estimated flows of the largest flood on record which occurred in 1893), 5x1974 and 8x1974. This ensured that the models were capable (in terms of schematisation and stability) of simulating such events.
- The simulated historical floods and the extreme events significantly vary in behaviour and size, and the ability of the Fast and Detailed Models to reproduce such a wide range of flood events and the tidal signal without varying parameters provides a high level of confidence for simulating design floods across the full range of AEPs.

Both Fast and Detailed Models have been subject to a rigorous internal QA process including model reviews and checks for consistency on modelled volumes and mass error. All simulated events performed within acceptable criteria as stipulated in the ITO. Furthermore, the Fast and Detailed Models' calibrations and AEP design event modelling has been endorsed by the Independent Panel of Experts appointed to oversee the study.

Reviews of the rating curves used by the Hydrologic Assessment compared with the stage-discharge outputs from the hydraulic modelling were carried out at several key stages during the development, calibration and design flood modelling of the Fast and Detailed Models. Importantly, the review demonstrates the hydraulic model results are in agreement with the Hydrologic Assessment's hydrologic modelling, a key requirement to ensure the hydrologic and hydraulic modelling are consistent. The review also highlights the uncertainties due to hysteresis in the stage-discharge relationships, especially due to backwater effects, and provided useful insights to the validity or refinement of rating curves under extreme flows.

After completion of the Fast Model's development and calibration, some 1.1[1] million hydrographs, including outflows from Wivenhoe Dam, were transferred from the Hydrologic Assessment's MC analysis to simulate 11,340[2] hypothetical events through the Fast Model. Peak flood levels and hydrographs from the 11,340 simulations were extracted at 28 Reporting Locations distributed along the main rivers and creeks as specified in the ITO. A MC peak flood level statistical analysis using the Total Probability Theorem was undertaken at each Reporting Location to determine indicative AEP flood levels based on the Fast Model.

Following the MC peak flood level statistical analysis, 60 MC events, which are representative of peak levels at all Reporting Locations across 11 AEPs ranging from 1 in 2 to 1 in 100,000 were selected from the total of 11,340 MC events. Each AEP is represented not by a single event, but by an ensemble typically containing 4 to 7 events (Table B). The event duration and catchment response was also taken into consideration to check that events within each ensemble covered a variety of rainfall-runoff characteristics. The selection process adopted a maximums of the maximums approach, so that the maximum of the peak flood levels from all the events in an AEP ensemble produced a flood level commensurate with the statistically derived Fast Model AEP flood levels at each of the 28 Reporting Locations.

Table B Events in each AEP Ensemble

AEP	% AEP	Number of Events in Ensemble
1 in 2	50%	7
1 in 5	20%	6
1 in 10	10%	5
1 in 20	5%	6
1 in 50	2%	6
1 in 100	1%	5
1 in 200	0.5%	7
1 in 500	0.2%	5
1 in 2,000	0.05%	5
1 in 10,000	0.01%	4
1 in 100,000	0.001%	4
	Total	60

The 60 events that make up the 11 AEP design event ensembles were simulated through the Detailed Model, and the maximums of the peak hydraulic outputs for each AEP ensemble were generated. The hydraulic outputs produced are peak flood level, depth, velocity and hydraulic hazard (DxV or depth multiplied by velocity). The peaks of each output are tracked independently throughout each event, therefore, the peak flow, for example, may not occur at the same time as the peak level.

Outputs from the Detailed Model are provided in the following formats:

- Maps of peak water level contours, depths, velocities and hydraulic hazard.

[1] Approximately 100 inflow hydrographs for each of the 11,340 events
[2] 9 event durations with 1,260 events of varying probability per duration

- Plots of water level and flow time-series data at Reporting Locations.
- Longitudinal peak water level profiles along Lockyer Creek, Bremer River and Brisbane River.
- Summary tables of peak levels and flows at Reporting Locations.
- Rating curves used and refined by the Hydrologic Assessment plotted against flow vs water level (stage-discharge) results at key gauges.

Table C provides a summary of the AEP design flood levels and flows at Lowood, Ipswich, Moggill and Brisbane CBD.

Table C Base Case Peak AEP Flood Levels and Flows at Lowood, Ipswich, Moggill and Brisbane

AEP 1 in …	Base Case Peak AEP Flood Levels and Flows^							
	Peak Level (mAHD)				Peak Flow (m^3/s)			
	Lowood (Pump Stn)	Ipswich (CBD)	Moggill Gauge	Brisbane (City Gauge)	Lowood (Pump Stn)	Ipswich (CBD)	Moggill Gauge	Brisbane (City Gauge)
2	n/a*	1.9	1.7	1.6	n/a&	n/a&	n/a&	n/a&
5	31.0	11.8	4.1	1.7	1,000	1,300	1,800	2,300
10	33.7	14.8	6.9	1.8	1,800	1,900	3,000	3,200
20	36.3	16.1	9.9	2.2	2,800	2,300	4,300	4,800
50	40.9	18.7	14.3	3.2	5,500	3,200	6,900	6,900
100	45.3	20.1	18.2	4.5	9,800	3,800	9,900	9,200
200	47.3	21.8	20.3	5.8	13,000	4,800	11,900	11,000
500	48.6	23.4	22.6	7.3	15,800	5,600	14,700	13,200
2,000	51.0	25.7	25.4	9.9	20,400	6,900	19,500	17,200
10,000#	54.5	29.0	28.8	14.7	29,300	9,300	28,400	25,700
100,000#	63.0	36.1	36.0	23.7	52,600	13,500	57,200	56,000

^ Peak flood levels and peak flows do not necessarily occur at the same time.

* 1 in 2 AEP flood level results only reliable for tidal zone.

& 1 in 2 AEP peak flows not provided as they are due to tidal influence, not flood influence.

Flood may exceed the maximum release capacity of Wivenhoe Dam (currently 28,000m^3/s) – treat results with caution.

Given the significance of the 1 in 100 AEP as a traditional reference flood, the following observations on the 1 in 100 AEP are provided.

- In the lower reaches of Lockyer Creek the 1 in 100 AEP flood level is typically higher than both the 1974 and 2011 floods although only by around 0.2m to 0.4m.
- For much of the Brisbane River between Wivenhoe Dam and Moggill, including the lower reaches of the Bremer, the 1 in 100 AEP flood is lower than both the 1974 and 2011 floods (e.g. at Lowood it is approximately 0.8m to 1.0m lower than both the 1974 and 2011).
- Near Ipswich CBD the 1 in 100 AEP flood is around 1m higher than the 2011 flood, but around 0.8m lower than the 1974 flood.

- In the lower reaches of the Brisbane River downstream of Centenary Bridge, the 1 in 100 AEP flood is typically 0.1m to 0.3m higher than the 2011 flood. In the Brisbane CBD the 1 in 100 AEP is 0.05m to 0.15m higher than 2011. This is approximately 1m lower than the flood level of the 1974 event.
- Near the estuary, downstream from the Gateway Motorway, the 1 in 100 AEP flood is similar to the peak level resulting from the storm surge experienced in the January 2013 event. This was higher than both the 2011 and 1974 flood levels.
- Backwater flooding from the Brisbane River occurs on numerous tributaries, most notably on the Bremer River and Oxley Creek but also on many local creeks on the lower Brisbane River such as Norman, Bulimba and Breakfast Creeks. This backwater flooding in the lower reaches of these creeks is likely to result in peak flood levels higher than that which would be experienced there from local 1 in 100 AEP flood events in the respective creeks.
- The rate of rise and duration of inundation of the 1 in 100 AEP flood varies depending on the ensemble event considered. The individual ensemble event that results in the highest flood level at any given location may not be the event that exhibits the fastest rate of rise or longest duration of inundation at that location.

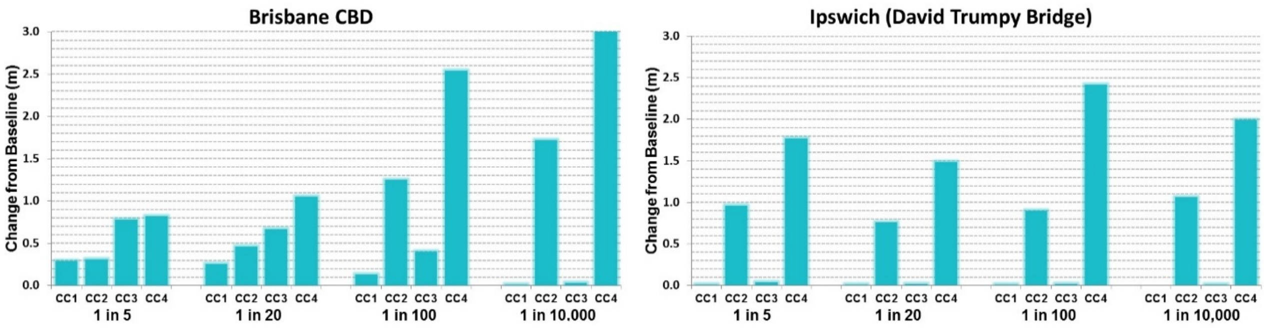
With regard to the 1 in 200 AEP flood, this is higher at all modelled locations than either of the two biggest floods of recent times: the 1974 and 2011 floods (noting that Wivenhoe Dam was not constructed at the time of the 1974 event). However, in Brisbane CBD it is only around 0.1m to 0.2m higher than the 1974 flood.

The event selection process and AEP design flood results from the Detailed Model have been endorsed by the IPE.

A range of sensitivity scenarios were carried out to estimate indicative changes to flood behaviour resulting from: (a) hypothetical future floodplain development case; (b) climate change; (c) Brisbane River bed level changes; and (d) the effect of major dams on historical events. It is important to clarify that the sensitivity scenarios undertaken using the 60 design events represent the impacts on the flood modelling outputs only for those individual events; it is not a definitive assessment on the change in flood level for a given AEP. If a more accurate assessment of the change in flood level AEP is required, there may be a need to repeat the MC analysis and selection of design events for that scenario. This is needed in order to produce an equivalent set of AEP peak flood levels, which can then be compared with the Base Case AEP levels.

The charts below summarise the effect of the Climate Change Sensitivity Scenarios for Brisbane CBD and Ipswich showing the indicative change in peak flood level under different combinations of rainfall increases and sea level rise.

Change in Peak Flood Level under Climate Change Sensitivity Scenarios



CC1 = No change to rainfall and 0.3m rise in sea level
CC2 = 10% increase in rainfall and 0.3m rise in sea level
CC3 = No change to rainfall and 0.8m rise in sea level
CC4 = 20% increase in rainfall and 0.8m rise in sea level

The Hydraulic Assessment provides the most comprehensive, up-to-date and accurate predictions of Brisbane River riverine flooding for a wide range of probabilities of occurrence. The hydraulic modelling forms a sound basis for benchmarking future flood management investigations and helping formulate planning controls for Brisbane River riverine flooding below Wivenhoe Dam. As with all modelling, the accuracy of the hydraulic modelling is subject to sources of uncertainty, and in this regard limitations and constraints of the Hydraulic Assessment and hydraulic models are documented, including guidance on the hydraulic modelling accuracy and validity of AEP design flood output. Importantly, an accurate understanding and appreciation of the hydraulic processes adopted in the modelling methodology is necessary to ensure the appropriate use of the Hydraulic Assessment outcomes.

Contents

Acknowledgements i
Executive Summary ii
List of Abbreviations and Terms xviii
1 Introduction 1-1
1.1 Brisbane River Catchment Floodplain Studies 1-1
1.2 Brisbane River Catchment Flood Study (BRCFS) 1-2
1.3 Objectives and Scope 1-3
1.4 Technical Review 1-4
1.5 This Report 1-6
2 Background 2-1
2.1 Catchment Description 2-1
2.2 Lower Brisbane River Hydraulics 2-2
2.3 Historical Floods of Significance 2-6
2.3.1 1974 Event 2-7
2.3.2 1996 Event 2-9
2.3.3 1999 Event 2-9
2.3.4 2011 Event 2-9
2.3.5 2013 Event 2-10
2.3.6 Summary of Calibration/Verification Event Peak Flows 2-10
2.4 BRCFS Hydrologic Assessment 2-11
2.5 Previous Hydraulic Modelling Investigations 2-12
3 Hydraulic Assessment Approach 3-1
3.1 Overview 3-1
3.2 Data Requirements 3-2
3.3 Hydraulic Modelling Software 3-2
3.4 Interfacing with Hydrologic Assessment 3-4
3.4.1 Rating Curve Reviews – Validation of Hydrologic and Hydraulic Modelling 3-4
3.4.2 Data and Knowledge Transfer 3-4
3.5 Fast Model 3-5
3.6 Detailed Model 3-5
3.7 Monte Carlo Analysis and Design Event Selection 3-6
3.8 Design Event Modelling 3-7
3.9 Model Result Outputs 3-7

4 Data Collection and Collation 4-1
4.1 Sources of Data 4-1
4.1.1 Data Collection Study 4-1
4.1.2 BRCFS Hydrologic Assessment Output Data 4-2
4.1.3 Data Gap Analysis and Collection 4-2
4.2 Topographic Data 4-7
4.2.1 Disaster Management Tool DEM (DMT DEM) 4-7
4.2.2 Bathymetric Data 4-8
4.2.3 Priority Ranking of Topographic Datasets 4-11
4.2.4 Breaklines 4-12
4.2.5 Historical Topographic Data 4-13
4.3 Hydrographic Data 4-13
4.3.1 Historical River Gauge Data 4-13
4.3.2 Historical Flood Mark Levels 4-16
4.3.3 Flow Gauging at Centenary Bridge 4-17
4.4 Hydraulic Structure Information 4-17
4.5 Land Use Data 4-19
4.6 Inflows 4-20
4.6.1 Historical Event Inflows 4-20
4.6.2 Design Case (Monte Carlo) Inflows 4-21
5 Fast Model: Development and Calibration 5-1
5.1 DMT Model Update 5-1
5.1.1 Extreme Event Hydraulic Hazard Mapping 5-2
5.1.2 Check on Fast Model Performance 5-2
5.2 Fast Model Data Inputs and Model Development 5-4
5.2.1 Fast Model Construct 5-4
5.2.2 Cross-Section Conveyance Approach 5-4
5.2.3 Fast Model Topography 5-5
5.2.4 Hydraulic Structures 5-5
5.2.5 Model Boundaries 5-6
5.2.6 Quality Control Checks 5-7
5.3 Fast Model Calibration 5-7
5.3.1 Approach 5-7
5.3.2 Calibration Parameters 5-8
5.3.3 Calibration & Verification Outcomes 5-10
5.4 Extreme Event Simulation 5-10

5.5 Rating Curve Consistency 5-12
5.6 Sensitivity Testing 5-12
6 Detailed Model: Development and Calibration 6-1
6.1 Aims of the Detailed Model 6-1
6.2 Data Inputs and Model Development 6-1
6.2.1 Detailed Model Construct 6-1
6.2.2 Detailed Model Topography 6-2
6.2.3 Hydraulic Structures 6-3
6.2.4 Model Extent and Boundaries 6-7
6.2.5 Quality Control Checks 6-8
6.3 Detailed Model Calibration 6-8
6.3.1 Approach 6-8
6.3.2 Calibration Parameters 6-9
6.3.3 Calibration Results 6-9
6.3.4 Calibration Conclusions 6-16
6.4 Extreme Event Simulation 6-16
6.5 Rating Curve Consistency 6-18
6.6 Sensitivity Testing – Model Development and Calibration 6-19
6.6.1 ST02 ±10% Change in Manning's n and Form Loss Values 6-19
6.6.2 ST10 Comparison with 20 m 2D Resolution 6-20
7 Fast Model Monte Carlo Analysis and Design Event Selection 7-1
7.1 Overview 7-1
7.1.1 Design Flood AEPs 7-1
7.1.2 Reporting Locations 7-2
7.2 Data Provided 7-4
7.3 Monte Carlo Events Simulation 7-4
7.3.1 Simulations 7-4
7.3.2 Checking of Results 7-5
7.4 Monte Carlo Annual Exceedance Probability (AEP) Analysis 7-7
7.4.1 Flood Level Frequency Analysis 7-7
7.4.2 Frequency Analysis Results 7-10
7.4.3 Cross Check with Hydrologic Assessment 7-11
7.5 Selection of Fast Model AEP Ensemble Events 7-12
7.5.1 Overview 7-12
7.5.2 Selection Criteria and Approach 7-12
7.6 Fine Tuning Selection of Events using Detailed Model 7-13

7.7 Final Events Selected 7-15
8 Design Event Modelling and Sensitivity Test Scenarios 8-1
8.1 Introduction 8-1
8.2 Naming Conventions 8-1
8.3 Detailed Model Base Case 8-3
8.4 Base Case Results 8-4
8.4.1 Drawings 8-4
8.4.2 Plots 8-5
8.4.3 Tables 8-6
8.4.4 Discussion on Flood Levels 8-6
8.4.5 Discussion on Flowpaths and Hydraulic Hazard 8-10
8.4.6 Comparison to Fast Model Results 8-12
8.4.7 Hydraulic Structure Reference Sheets 8-13
8.5 Sensitivity Test Scenarios 8-14
8.5.1 Introduction 8-14
8.5.2 Climate Change Scenarios 8-15
8.5.3 Bed Level Sensitivity Tests 8-16
8.5.4 Future Floodplain Scenario 8-18
8.5.5 No Dams Sensitivity Tests 8-19
8.6 Rating Curve Review 8-21
8.6.1 Introduction 8-21
8.6.2 Summary of Rating Curve Review 8-21
8.6.3 Example Rating Review Summary: Moggill (Brisbane River) 8-23
9 Limitations and Uncertainties 9-1
9.1 Riverine versus Local Flooding Effects 9-1
9.1.1 Local Tributary Flooding 9-1
9.1.2 Isolated Low-lying Areas 9-2
9.2 Validity of AEP in Areas Distant from Reporting Locations 9-3
9.3 Fast Model AEP Levels 9-3
9.4 Model Design 9-4
9.5 Velocity and Hydraulic Hazard Results 9-4
9.6 1 in 2 AEP Event 9-4
9.7 Limits of Mapping 9-5
9.8 Backflow Prevention Devices 9-5
9.9 Structure Blockage 9-5
9.10 Sensitivity Scenarios 9-5

9.11 Residual Modelling Uncertainties 9-6
9.12 Hydraulic Modelling Accuracy 9-7
10 Future Use 10-1
10.1 Triggers for Revisiting Hydraulic Assessment 10-1
10.2 Custodianship 10-2
11 Conclusions and Recommendations 11-1
12 References 12-1
Appendix A IPE Comments on Draft Report and Endorsement A-1
A3 Addendum A-1

List of Figures

Figure 1-1 Brisbane River Catchment Floodplain Studies 1-1
Figure 1-2 Current Governance for BRCFS (DNRM, 2016) 1-5
Figure 2-1 Brisbane River Catchment and Hydraulic Assessment Study Area 2-4
Figure 2-2 Brisbane River Sub-Catchments 2-5
Figure 2-3 Flood Level Markers on Regatta Hotel, Toowong (image courtesy of BCC) 2-7
Figure 3-1 BRCFS Hydraulic Assessment 3-1
Figure 3-2 Example Plot Showing Hydrograph Output 3-9
Figure 3-3 Example Plot Showing Longitudinal Section Output 3-9
Figure 3-4 Example Map Showing Calibration Points (Flood Marks) 3-10
Figure 4-1 Example of the Detailed Spatial Differentiation of Land Uses 4-19
Figure 5-1 Use of the Updated DMT Model in Development of the Fast Model 5-3
Figure 5-2 Example of Plot Output showing both Updated DMT and FM results 5-3
Figure 5-3 R1 Hydraulic Radius Formulation Approach 5-5
Figure 5-4 Mt Crosby Weir 5-6
Figure 5-5 Example of New High-Flow Flowpath for the 8x1974 Event 5-12
Figure 6-1 Removal of Cunningham Highway Raised Section for 1974 Topography 6-3
Figure 6-2 Example HSRS for Three Mile Bridge (1 of 2) 6-5
Figure 6-3 Example HSRS for Three Mile Bridge (2 of 2) 6-6
Figure 6-4 2013 Detailed Model Calibration - Statistical Assessment of Differences between Observed & Modelled Peak Flood Levels 6-10
Figure 6-5 Example of Reproduction of Superelevation at River Bends for the 2011 flood – Story Bridge Bend 6-14
Figure 6-6 2011 Detailed Model Calibration - Statistical Assessment of Differences between Observed & Modelled Peak Flood Levels 6-15

Figure 6-7 1974 Detailed Model Verification - Statistical Assessment of Differences between Observed & Modelled Peak Flood Levels 6-16
Figure 6-8 Rating Curves versus Hydraulic Modelling Calibration Results – Savages Crossing 6-19
Figure 7-1 Example Plot Used to Identify Numerical Instabilities 7-6
Figure 7-2 Example Level Maxima and Derived Level Frequency Relationship for 72 hour Event at Savages Crossing 7-8
Figure 7-3 Example Frequency Relationships for All Durations at Savages Crossing, and the Envelope of Level Maxima with AEP 7-9
Figure 7-4 Derived Level Frequency Relationships for Sites along the Lower Reaches of the Brisbane River 7-10
Figure 7-5 Comparison of Flood Frequency Relationships based on Results Obtained from the Hydrologic and Hydraulic Assessments 7-11
Figure 7-6 Flow Chart of Event Selection Methodology 7-13
Figure 8-1 Lowood Design and Historic Flood Levels 8-8
Figure 8-2 Ipswich CBD Design and Historic Flood Levels 8-9
Figure 8-3 Brisbane CBD (City Gauge) Design and Historic Flood Levels 8-9
Figure 8-4 Brisbane CBD: Hydraulic Hazard and onset of Breakout Flowpaths 8-11
Figure 8-5 Ipswich CBD: Hydraulic Hazard Backwater Inundation 8-12
Figure 8-6 Fernvale: Hydraulic Hazard and Bypass Flow 8-12
Figure 8-7 Change in Peak Flood Level under Climate Change Sensitivity Scenarios 8-15
Figure 8-8 Bed Level Change at Moggill (BL1 and BL2) 8-17
Figure 8-9 Brisbane CBD: Bed Level Sensitivity, D0100 AEP Event 8-18
Figure 8-10 2011 Wivenhoe Outflows 8-20
Figure 8-11 Rating Curves versus Hydraulic Modelling Calibration Results – Moggill 8-24
Figure 11-1 Change in Peak Flood Level under Climate Change Sensitivity Scenarios 11-5

List of Tables

Table 2-1 Comparison of Peak Flows at Key Locations for Five Calibration/Verification Events 2-11
Table 2-2 Summary of Studies Involving Development of Key Hydraulic Models 2-12
Table 2-3 Summary of Previous 1 in 100 AEP Flows and Levels at Brisbane Port Office 2-14
Table 4-1 Key Additional Datasets: Studies and Models 4-3
Table 4-2 Key Additional Datasets: Topographic Data 4-4
Table 4-3 Key Additional Datasets: Hydraulic Structures 4-5
Table 4-4 Key Additional Datasets: Land Use Data 4-6

Table 4-5	Key Additional Datasets: Historic Flood Data	4-7
Table 4-6	Breakline Categories	4-12
Table 4-7	Historical Availability of River Gauge Data for Calibration Events	4-15
Table 4-8	Historical Presence of Hydraulic Structures	4-18
Table 4-9	Rainfall Loss Comparisons for the 1974 Verification Event	4-21
Table 5-1	1893 Peak Water Level Summary	5-11
Table 5-2	General Sensitivity Tests on the Primary Calibration Parameters	5-13
Table 6-1	Detailed Model Extents	6-7
Table 7-1	Design Flood AEPs	7-2
Table 7-2	Reporting Locations	7-3
Table 7-3	Resolution of Non-Ascending AEP Peak Flood Levels	7-14
Table 7-4	Events in each AEP Ensemble after Fine-Tuning Selection using Detailed Model	7-15
Table 8-1	Scenario Acronyms used in Study	8-2
Table 8-2	Base Case (B15) Changes to the Detailed Model	8-4
Table 8-3	Summary of Peak Design Riverine Flood Levels and Flows at Lowood, Ipswich, Moggill and Brisbane	8-8
Table 8-4	Parameters used in the BRCFS Climate Change Sensitivity	8-15
Table 8-5	Future Floodplain Condition Scenario Results at Brisbane and Ipswich	8-19
Table 8-6	No Dams: Brisbane City Gauge	8-20
Table 8-7	No Dams: Ipswich CBD	8-21
Table 11-1	Summary of Peak Design Riverine Flood Levels and Flows at Lowood, Ipswich, Moggill and Brisbane	11-4

List of A3 Addendum Sheets

A3 Addendum Sheet 1	Gauges and Reporting Locations (MR3, Drawing 1)
A3 Addendum Sheet 2	Long Section Chainages (MR3, Drawing 2)
A3 Addendum Sheet 3	Bathymetric Data Sources (MR3, Drawing 3)
A3 Addendum Sheet 4	Modelled Hydraulic Structure Locations (MR2, Drawing 7)
A3 Addendum Sheet 5	Fast Model Layout (MR2, Drawing 9)
A3 Addendum Sheet 6	Fast Model Calibration and Verification Peak Level Comparison at Gauges (MR2, Table 4-3)
A3 Addendum Sheet 7	Detailed Model Layout (MR3, Drawing 7)
A3 Addendum Sheet 8	Detailed Model Calibration and Verification Peak Level Comparison at Gauges (MR3, Table 3-4)
A3 Addendum Sheet 9	DM and FM 2011 Calibration Lockyer Creek Water Level Gauges (MR3, Plot 13)
A3 Addendum Sheet 10	DM and FM 2011 Calibration Bremer River Water Level Gauges (MR3, Plot 14)
A3 Addendum Sheet 11	DM and FM 2011 Calibration Brisbane River Water Level Gauges (MR3, Plot 15)
A3 Addendum Sheet 12	DM and FM 2011 Calibration Centenary Bridge Flow Recordings (MR3, Plot 16)
A3 Addendum Sheet 13	Key Sheet for Calibration Drawings (MR3, Drawing 9)
A3 Addendum Sheet 14	DM 2011 Calibration – Region A (MR3, Drawing 17)
A3 Addendum Sheet 15	DM 2011 Calibration – Region B (MR3, Drawing 18)
A3 Addendum Sheet 16	DM 2011 Calibration – Region C (MR3, Drawing 19)
A3 Addendum Sheet 17	DM 2011 Calibration – Region D (MR3, Drawing 20)
A3 Addendum Sheet 18	DM 2011 Calibration – Region E (MR3, Drawing 21)
A3 Addendum Sheet 19	Key Sheet for Design Flood Mapping (MR5, Drawing 4)
A3 Addendum Sheet 20	Peak Water Surface Level Maps – 1 in 100 AEP – Region A (MR5, Drawing 5)
A3 Addendum Sheet 21	Peak Water Surface Level Maps – 1 in 100 AEP – Region B (MR5, Drawing 6)
A3 Addendum Sheet 22	Peak Water Surface Level Maps – 1 in 100 AEP – Region C (MR5, Drawing 7)
A3 Addendum Sheet 23	Peak Water Surface Level Maps – 1 in 100 AEP – Region D (MR5, Drawing 8)
A3 Addendum Sheet 24	Peak Water Surface Level Maps – 1 in 100 AEP – Region E (MR5, Drawing 9)
A3 Addendum Sheet 25	Peak Flood Depth Maps – 1 in 100 AEP – Region A (MR5, Drawing 10)
A3 Addendum Sheet 26	Peak Flood Depth Maps – 1 in 100 AEP – Region B (MR5, Drawing 11)
A3 Addendum Sheet 27	Peak Flood Depth Maps – 1 in 100 AEP – Region C (MR5, Drawing 12)
A3 Addendum Sheet 28	Peak Flood Depth Maps – 1 in 100 AEP – Region D (MR5, Drawing 13)
A3 Addendum Sheet 29	Peak Flood Depth Maps – 1 in 100 AEP – Region E (MR5, Drawing 14)
A3 Addendum Sheet 30	Peak Flood Velocity Maps – 1 in 100 AEP – Region A (MR5, Drawing 15)
A3 Addendum Sheet 31	Peak Flood Velocity Maps – 1 in 100 AEP – Region B (MR5, Drawing 16)
A3 Addendum Sheet 32	Peak Flood Velocity Maps – 1 in 100 AEP – Region C (MR5, Drawing 17)
A3 Addendum Sheet 33	Peak Flood Velocity Maps – 1 in 100 AEP – Region D (MR5, Drawing 18)
A3 Addendum Sheet 34	Peak Flood Velocity Maps – 1 in 100 AEP – Region E (MR5, Drawing 19)

A3 Addendum Sheet 35	Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region A (MR5, Drawing 20)
A3 Addendum Sheet 36	Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region B (MR5, Drawing 21)
A3 Addendum Sheet 37	Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region C (MR5, Drawing 22)
A3 Addendum Sheet 38	Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region D (MR5, Drawing 23)
A3 Addendum Sheet 39	Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region E (MR5, Drawing 24)
A3 Addendum Sheet 40	Ensemble Water Level and Flow Hydrographs – 1 in 100 (1%) AEP – Sheet 1 of 3 (MR5, Plot 16)
A3 Addendum Sheet 41	Ensemble Water Level and Flow Hydrographs – 1 in 100 (1%) AEP – Sheet 2 of 3 (MR5, Plot 17)
A3 Addendum Sheet 42	Ensemble Water Level and Flow Hydrographs – 1 in 100 (1%) AEP – Sheet 3 of 3 (MR5, Plot 18)
A3 Addendum Sheet 43	Brisbane River Longitudinal Profiles Maximums – All AEPs (MR5, Plot 45)
A3 Addendum Sheet 44	Bremer Lockyer Longitudinal Profiles Maximums – All AEPs (MR5, Plot 57)
A3 Addendum Sheet 45	Rating Curves Sheet 1 of 3 (MR5, Plot 58)
A3 Addendum Sheet 46	Rating Curves Sheet 2 of 3 (MR5, Plot 59)
A3 Addendum Sheet 47	Rating Curves Sheet 3 of 3 (MR5, Plot 60)
A3 Addendum Sheet 48	Rating Curves Extreme Sheet 1 of 3 (MR5, Plot 61)
A3 Addendum Sheet 49	Rating Curves Extreme Sheet 2 of 3 (MR5, Plot 62)
A3 Addendum Sheet 50	Rating Curves Extreme Sheet 3 of 3 (MR5, Plot 63)
A3 Addendum Sheet 51	Base Case (B15) Peak Levels and Flows (MR5, Addendum Table 1)

List of Abbreviations and Terms

1D	One dimensional
2D	Two dimensional
3D	Three-dimensional
AEP	Annual Exceedance Probability
AFRL	Adopted Flood Regulation Line
AHD	Australian Height Datum
ALS	Aerial Laser Survey
AWRC	Australian Water Resources Council
B15	Base Case circa 2015
Base Case	The river and floodplain conditions based on available data as of 2015 plus selected approved developments. Excludes backflow prevention devices. Used for AEP design flood simulations.
BCC	Brisbane City Council
BL1	Bed Level Scenario 1
BL2	Bed Level Scenario 2
BoM	Bureau of Meteorology
BRCFMS	Brisbane River Catchment Floodplain Management Study
BRCSFMP	Brisbane River Catchment Strategic Floodplain Management Plan
BRCFS	Brisbane River Catchment Flood Study
CC1	Climate Change Sensitivity Scenario 1
CC2	Climate Change Sensitivity Scenario 2
CC3	Climate Change Sensitivity Scenario 3
CC4	Climate Change Sensitivity Scenario 4
CBD	Central Business District
CMD	Coastal Management District
CND	Calibration event with No Dams
CPU	Central Processing Unit
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWD	Calibration event With Dams
DCS	BRCFS Data Collection Study (Aurecon, 2013)
DEHP	Department of Environment and Heritage Protection
DEM	Digital Elevation Model - a fixed grid of elevations sampled from a DTM
DILGP	Department of Infrastructure, Local Government and Planning DILGP (formerly the Department of State Development, Infrastructure and Planning, DSDIP)
DM	Detailed Model
DMT	Disaster Management Tool

DNRM	Department of Natural Resources and Mines
DPI	Department of Primary Industries (former)
DTM	Digital Terrain Model – a triangulation of raw elevation data points
DxV	Hydraulic hazard (flood hazard) equal to **D**epth x **V**elocity. DxV is tracked separately at every 2D cell at every computational timestep during a model simulation to produce maps of peak DxV.
FCoI	Floods Commission of Inquiry (Qld)
FEWS	Flood Early Warning System
FF1	Floodplain Future Condition Scenario 1
FM	Fast Model
GIS	Geographic Information System
H&H	Hydrologic and Hydraulic
Hydraulic Assessment	This study, the BRCFS Comprehensive Hydraulic Assessment
Hydrologic Assessment	BRCFS Comprehensive Hydrologic Assessment (Aurecon, 2015c)
ICC	Ipswich City Council
IFD	Intensity Frequency Duration data for design rainfalls
ITO	Invitation to Offer, ie. The Hydraulic Assessment Brief (DILGP, 2014)
IPE	Independent Panel of Experts (for the current Study)
LiDAR	Light Detection and Ranging
LVRC	Lockyer Valley Regional Council
MC	Monte Carlo
MR1	Milestone Report 1, Data Review and Modelling Methodology (BMT WBM, 2014)
MR2	Milestone Report 2, Fast Model Development and Calibration (BMT WBM, 2015a)
MR3	Milestone Report 3, Detailed Model Development and Calibration (BMT WBM, 2015b)
MR4	Milestone Report 4, Fast Model Results and Design Events Selection (BMT WBM, 2016a)
MR5	Milestone Report 5, Detailed Model Results (BMT WBM, 2016b)
MR6	Milestone Report 6, Detailed Model Results (This Report)
PMF	Probable Maximum Flood (Nominally 1 in 100,000 AEP)
Q-CAS	Queensland Climate Adaption Study
QC	Quality Control
SARA	State Assessment and Referral Agency
SEQ	South East Queensland
SPP	State Planning Policy
SRC	Somerset Regional Council
TWG	Technical Working Group
URBS	Unified River Basin Simulator. Rainfall runoff routing hydrologic modelling

	software used for the Hydrologic Assessment.
WSDOS	Wivenhoe and Somerset Dams Optimisation Study

1 Introduction

The Hydraulics Report, Milestone Report 6 of the Comprehensive Hydraulic Assessment for the Brisbane River Catchment Flood Study (BRCFS), provides an overarching summary and key findings of the Hydraulic Assessment. Detailed documentation is presented in Milestone Reports 1 to 5, which are cross-referenced throughout this report and listed in Section 1.5.

1.1 Brisbane River Catchment Floodplain Studies

The State of Queensland, acting through the Department of Infrastructure, Local Government and Planning (DILGP) and the Department of Natural Resources and Mines (DNRM) as project manager, has undertaken a Comprehensive Hydraulic Assessment (this assessment) resulting in the delivery of a fully calibrated hydraulic model that reproduces the flood behaviour of the lower Brisbane River including major tributaries downstream of Wivenhoe Dam.

This assessment is a component of a broader framework of the Brisbane River Catchment Floodplain Studies (shown in Figure 1-1) currently being undertaken by the Queensland Government in response to Recommendation 2.2 of the Queensland Floods Commission of Inquiry[3] to provide a comprehensive plan to manage Brisbane River flood risk.

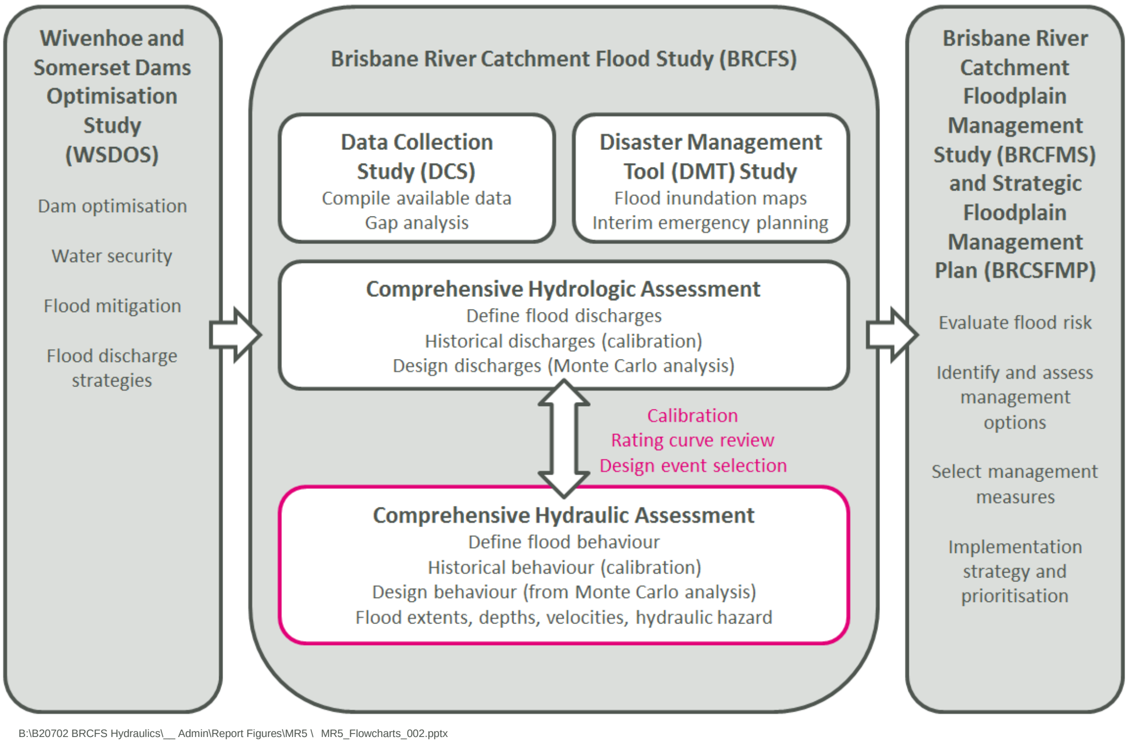


Figure 1-1 Brisbane River Catchment Floodplain Studies

[3] Final Report, Queensland Floods Commission of Inquiry, March 2012.

Based on Recommendation 2.2[3], this suite of studies follows the traditional and effective flood risk management framework endorsed as current best practice in Australia[4], which incorporates the following steps:

- A Flood Study: The **Brisbane River Catchment Flood Study (BRCFS)** is presently underway to define flood behaviour. The BRCFS comprises a Data Collection Study (DCS), Comprehensive Hydrologic Assessment and Comprehensive Hydraulic Assessment (see Section 1.2).
- A Floodplain Management Study: The **Brisbane River Catchment Floodplain Management Study (BRCFMS)** will subsequently evaluate flood risk based on the flood behaviour defined in the BRCFS and identify and assess a range of flood risk management options. Options that involve changes in hydrologic and/or hydraulic conditions will be assessed using the models developed for the BRCFS. A catchment-wide floodplain management strategy will be formulated.
- A Strategic Floodplain Management Plan: The **Brisbane River Catchment Strategic Floodplain Management Plan (BRCSFMP)** will select a range of flood risk management measures based on the catchment-wide floodplain management strategy in the BRCFMS to guide the current and future management of flood risk in different areas.

The **Wivenhoe and Somerset Dams Optimisation Study** (WSDOS) has also been carried out in response to the Queensland Floods Commission of Inquiry to investigate potential options to improve dam operations and flood mitigation, taking into consideration water supply security, dam safety and erosion.

1.2 Brisbane River Catchment Flood Study (BRCFS)

The Brisbane River Catchment Flood Study (BRCFS) comprises the following stages:

- **Data Collection Study (Aurecon, 2013):** The Data Collection Study (DCS) was completed by Aurecon in August 2013 and identified, compiled and reviewed readily available data and metadata, including a gap analysis.
- **Comprehensive Hydrologic Assessment (Aurecon, 2015c):** The Hydrologic Assessment commenced in 2013 and was finalised in June 2015. It defines flood flows for the Brisbane River catchment based on flood frequency analysis, design event analysis and hydrologic modelling using a Monte Carlo approach to cater for temporal and spatial variations in rainfall patterns, initial reservoir levels and other factors that affect catchment runoff. The Hydrologic Assessment also includes the configuration of a Delft-FEWS framework for data and simulation management.

[4] Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia, Australian Emergency Management Handbook 7, Australian Government Attorney-General's Department, 2013.

- **Comprehensive Hydraulic Assessment:** The Hydraulic Assessment (this assessment) defines the flood behaviour of the lower Brisbane River[5] on the basis of, and in conjunction with, the Hydrologic Assessment. Specifically, this assessment identifies flood extents, depths, velocities and hydraulic hazard, across the full extent of the floodplain, for a range of events up to and including the 1 in 100,000 AEP (Annual Exceedance Probability) which is known as "Extreme Flood – notionally 1 in 100,000 AEP" for the purpose of this Study. The components of the Hydraulic Assessment are outlined in Section 3.

In addition to the above stages, Brisbane City Council completed the BRCFS Digital Terrain Model Development and Bed Level Sensitivity Analysis (BCC, 2014a) and Disaster Management Tool Study (BCC, 2014b) for the BRCFS Steering Committee with the key objective of providing flood inundation maps for emergency planning. The DMT also provides significant and useful background for the development of the hydraulic models in this assessment.

1.3 Objectives and Scope

The objectives and scope of the BRCFS Hydraulics Assessment, are set out in Section 3.2 of the Invitation to Offer (ITO) (DILGP, 2014). This section is repeated below (note that the two figures referred to are not reproduced in this report):

3.1.1 The department is seeking Offers to undertake a comprehensive hydraulic assessment ('the project') as part of the Brisbane River Catchment Flood Study (BRCFS). The purpose of the BRCFS itself is to provide an up-to-date, consistent, robust and agreed set of methodologies (including hydrologic and hydraulic models) and flood estimation for the Brisbane River catchment and is being undertaken as the Queensland Government's response to the Recommendation 2.2 of the Queensland Floods Commission of Inquiry (QFCI) Final Report.

3.1.2 The primary objective of the BRCFS hydraulic study component is to model flooding in the Lower Brisbane River (using outputs from the BRCFS hydrologic modelling component which would include joint probability of flood occurring in the Brisbane and Bremer rivers), so as to quantify flood risk, and to provide to Councils and to State Government the technical information for land planning, infrastructure planning and design, and emergency management to reduce the flood risk to their communities. The hydraulic modelling will quantify the flood risk from a broad range of types of storm rainfall events over the catchment of the Brisbane River in combination with tidal conditions at the mouth of the Brisbane River, including tides and storm surge. In this context it is critically important that the hydraulic model has satisfactory calibration across the model domain for storage-elevation relationships, storage-conveyance relationships, performance to simulate tides and storm surge, performance to simulate passage of riverine floods from the upstream catchments, and performance to simulate tides in combination with riverine floods.

3.1.3 The hydraulic study will provide up-to-date, consistent and robust hydraulic models and analysis tools for the development of the Brisbane River Catchment Floodplain Management Study and Plan (BRCFMS and BRCFMP). Figure 1 [refer to ITO] shows the whole catchment area of the Brisbane River, being the area modelled as part of the hydrology study phase. Figure 2 [refer to ITO] is a locality plan of the lower Brisbane River and major tributaries downstream of Wivenhoe Dam. The proposed hydraulic models will be within this lower Brisbane River area.

3.1.4 The hydraulic modelling component will provide estimates of peak flood levels, depths, discharges, velocities, and flood hazard within the modelled area for a range of annual exceedance probabilities. In the context of the hydraulic study, 'flood hazard' is defined simply as the product of velocity and depth at a location. It is proposed that these flood estimates will apply to the current (approved) level of development of the catchment and floodplain, and the currently adopted mode of flood operation of Wivenhoe and Somerset Dams. The hydraulic modelling will also be used to provide flood estimates for the scenario without any of the major storages in place. It is also proposed that the hydraulic modelling will be used for

[5] For the purpose of the Hydraulic Assessment, the lower Brisbane River is defined as the reach downstream of Wivenhoe Dam to the mouth of the river. However it should be noted that the lower Brisbane has been defined differently in other studies, such as where the mid Brisbane is taken to be between Wivenhoe Dam and Mt Crosby Weir (e.g. Resilient Rivers Initiative and Mid Brisbane Irrigators), and the lower Brisbane as the areas downstream of Mt Crosby Weir (Healthy Waterways Report Card).

sensitivity analysis to provide flood estimates for a limited number of scenarios of climate change, river-bed level changes, and potential future development.

3.1.5 The hydraulic model developed for this project will be sufficiently detailed and robust to be potentially used if required for:

- *zoning the study area into broad categories for land planning, floodplain management and emergency response;*
- *assessing the impact of all development within the floodplain including filling, and construction of infrastructure;*
- *providing flood levels suitable for habitable floor levels at property level/scale;*
- *providing information to map flood hazard;*
- *providing water level hydrograph results to evaluate flood travel times and corresponding lead time for flood warning;*
- *assessment of floodplain risk management mitigation measures (as part of the floodplain management study and plan);analysis or hydraulic design of drainage systems, including major cross-drainage structures in the floodplain, and understanding hydraulic behaviour of structures at different levels of flooding to inform risks to structural integrity of structures such as bridges; and*
- *assessment of environmental impacts resulting from various development activities, proposals or policies.*

3.1.6 As a by-product of this hydraulic modelling component, the modelling should give greater certainty to the flow-water level rating relationships for certain key observation river gauges in the study area, that is:

- *Review/confirmation/derivation of rating relationships.*
- *Potential sensitivity analysis of hydraulic model roughness values to quantify potential rating uncertainty bounds, and/or temporal variation of the rating due to changes in vegetation over time.*
- *Development or review of dependent rating relationships where the rating relationship is dependent on a water level at a downstream location (e.g. Bremer River at Ipswich rating dependent on water level Brisbane River at Moggill, and Lockyer Creek at O'Reillys Weir rating is dependent on water level in Brisbane River).*
- *Further understanding and quantification of rating hysteresis (looped ratings) during flood events.*

The results from the hydraulic model will also be used to confirm or refine the flood routing characteristics of hydrologic flood routing models of the lower Brisbane River, which have been used in past planning and operational studies.

3.1.7 While the primary objectives of the hydraulic modelling component relate to planning, and floodplain risk management, the model(s) to be developed may have potential for use in real-time flood operation. Two hydraulic models are to be developed as part of this study: a 'fast' model, and a more detailed 2D model (as recommended by the IPE (2013)). The fast model (which will possibly be a 1D network model or a simplification of the detailed model and which would have short run-time to efficiently allow large number of Monte Carlo simulations to be carried out as part of the BRCFS) has the potential also for being used as an operational tool by Seqwater or Councils.

1.4 Technical Review

The Hydraulic Assessment component of the BRCFS has been overseen by the BRCFS Steering Committee (SC), and in accordance with the ITO, was regularly advised, critiqued and guided by a Technical Working Group (TWG) and an Independent Panel of Experts (IPE). Background to the formation of the TWG and IPE is provided in the ITO as follows:

The Brisbane River Catchment Studies Coordinating Technical Working Group (TWG) was formed in 2013 to coordinate technical advice and resolve technical issues in various work scopes. This group includes appropriate representatives from various stakeholder organisations and is coordinated by DSDIP (now DILGP). The group ensures that links remain between other related initiatives such as WSDOS and the present studies. An Independent Panel of Experts (IPE) comprising of eminent people with high level of expertise in related disciplines was also formed in 2013 to provide expert peer review, advice and technical/scientific guidance for various work *packages (including this consultancy) to be investigated as part of the Brisbane River Catchment Floodplain Studies Project*.

The TWG and IPE review and comment on each Draft Milestone Report. Delivery of each draft report is followed by a workshop in which the TWG and IPE are present. Both the TWG and IPE have input into reviewing and guiding the approaches adopted by the Hydraulic Assessment during the course of the study.

The involvement of the TWG and IPE has ensured the delivery of a technically robust study that meets the requirements of both the ITO and the QFCoI.

In addition, the IPE have endorsed all aspects of the methodologies and the key study findings as part of the study process. The current governance for the Flood Study phase is provided in Figure 1-2.

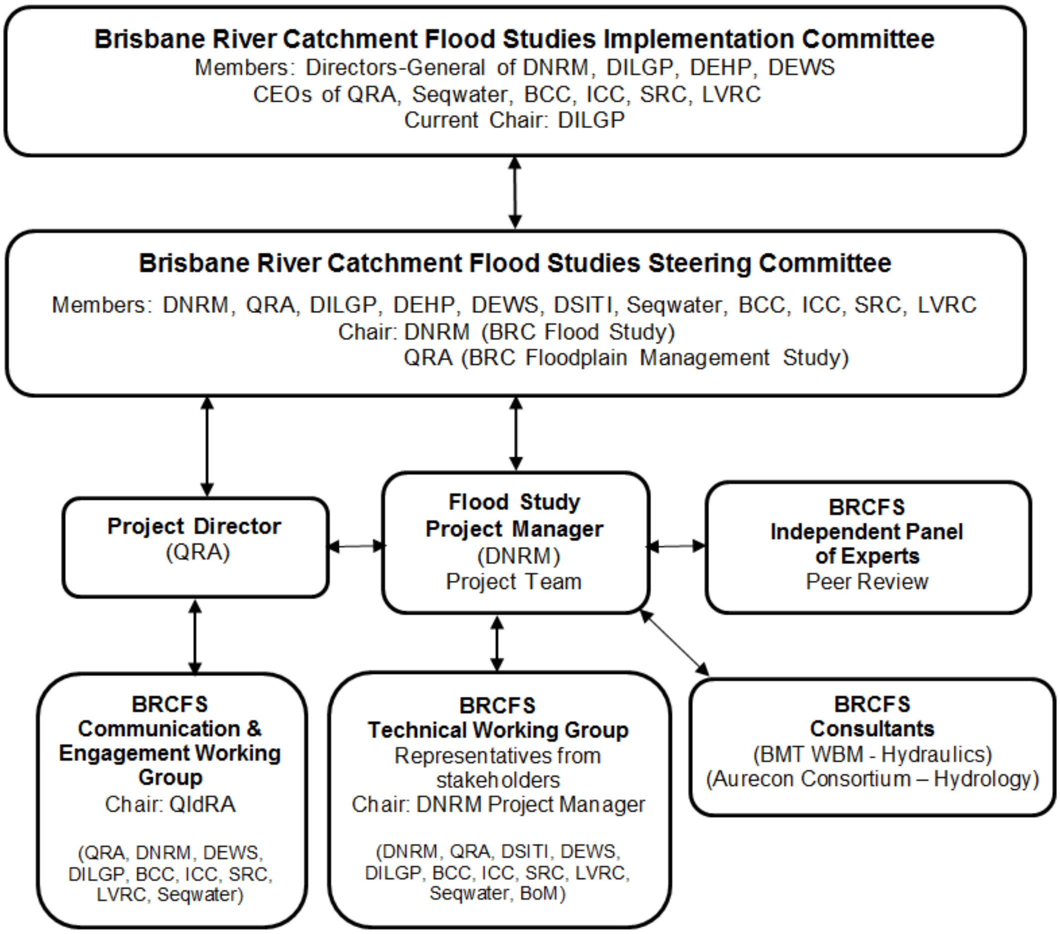


Figure 1-2 Current Governance for BRCFS (DNRM, 2016)

1.5 This Report

This report forms the sixth Milestone Report (MR6) for the Hydraulics Assessment component of the BRCFS. The purpose of this report is to collate and provide summary detail on previous Milestone Reports in one overarching report. The Milestone Reports drawn upon for this report are:

- Milestone Report 1 (MR1): Data Review and Modelling Methodology (BMT WBM, 2014)
- Milestone Report 2 (MR2): Fast Model Development and Calibration (BMT WBM, 2015a)
- Milestone Report 3 (MR3): Detailed Model Development and Calibration (BMT WBM, 2015b)
- Milestone Report 4 (MR4): Fast Model Results and Design Events Selection (BMT WBM, 2016a)
- Milestone Report 5 (MR5): Detailed Model Results (BMT WBM, 2016b).

To simplify the frequent referencing to Milestone Reports, this report uses report acronyms; for example Milestone Report 2 is referred to as 'MR2'. A full reference for each Milestone Report is provided at the end of this report.

An A3 addendum accompanies this report and includes a number of key drawings, plots and tables drawn from Milestone Reports 1 to 5. The content has been duplicated for ease of reference when considering this summary report.

This report is released as a Draft prior to the Workshop to be held on October 13, 2016, at which the findings outlined in this report will be presented and discussed with the IPE and TWG members. Following the Workshop, outcomes, key points and response to comments from the review and workshop will subsequently be incorporated into a 'Draft Final' report.

2 Background

2.1 Catchment Description

The Hydrologic Assessment provides the following overview of the Brisbane River catchment:

The Brisbane River catchment has a total catchment area of 13,570 km^2 to the Port Office Gauge which is located in the heart of Brisbane City. The catchment is bounded by the Great Dividing Range to the west and a number of smaller coastal ranges including the Brisbane, Jimna, D'Aguilar and Conondale Ranges to the north and east. Most of the Brisbane River catchment lies to the west of the coastal ranges. The catchment is complex in nature, combining urban and rural land, flood mitigation dams, tidal influences and numerous tributaries with the potential for individual or joint flooding.

The river system itself consists of the Brisbane River and a number of major tributaries. Cooyar Creek, Emu Creek and Cressbrook Creek are all major tributaries of the Upper Brisbane River. The Stanley River catchment is the only major tributary that flows from the Conondale and D'Aguilar Ranges. Lockyer Creek, incorporating Laidley Creek, flows from the escarpment of the Great Dividing Range and joins the Brisbane River just downstream of Wivenhoe Dam. The remaining tributary is the Bremer River which rises in the Little Liverpool Range and confluences with the Brisbane River at Ipswich. The Bremer River catchment includes the Warrill Creek and Purga Creek tributaries.

The Brisbane River is tidal to just below Mt Crosby Weir, which is located some 90 km from the mouth of the river. The Bremer River is also tidal in its lower reaches and it is affected by backwater when the Brisbane River is in flood.

The river system passes through numerous townships and two major cities. It also passes through rural and agricultural land. As such, flooding in the river has the potential to affect large numbers of residents and businesses.

The Brisbane River itself has two dams located in its upper reaches, both of which were built to supplement Brisbane's water supply and to provide flood mitigation. Wivenhoe Dam was built in 1985 and has a catchment area of approximately 7,020 km^2. Somerset Dam on Lake Somerset is located upstream of Lake Wivenhoe on the Stanley River near Kilcoy, and has a catchment area of 1,340 km^2. Therefore only around half the overall catchment is regulated. There are also numerous smaller dams located within the catchment on the tributaries to the Brisbane River. [6]

Figure 2-1 and Figure 2-2 show the Brisbane River catchment and the main sub-catchments respectively.

[6] Brisbane River Catchment Flood Study – Comprehensive Hydrologic Assessment; Data, Rating Curve and Historical Flood Review Report, prepared by Aurecon Australia Pty Ltd for Department of State Development, Infrastructure and Planning, March 2014 (Reference 238021, Revision 0).

2.2 Lower Brisbane River Hydraulics

The Lower (i.e. downstream of Wivenhoe Dam) Brisbane River Valley has a wide range of hydraulic complexities that makes it a very interesting and challenging task to hydrologically and hydraulically model. The lower catchment area is large, roughly half of the overall catchment area, and includes the major tributaries of Lockyer Creek and the Bremer River. These tributaries add to the complexity in terms of timing and shape of the flood hydrograph. The rainfall variation across the catchment is highly variable from the wetter coastal hinterland ranges to the drier areas in the west of the catchment. Wivenhoe Dam, and to a significantly lesser extent Somerset Dam, offer substantial flood storage capture and can significantly affect the shape and attenuation of the flood , and the severity of flooding downstream.

Hydraulically, the Brisbane River Valley is a mixture of conveyance and storage dominated reaches. Lockyer Creek, due to its flat wide topography is, in a large event, highly storage dominated, with substantial slow moving volumes of floodwaters being ‘stored’ on the floodplain from its catchment or by backwater from the Brisbane River. The Brisbane River from Pine Mountain to Mt Crosby is predominately conveyance dominated, with relatively minor floodplains, and floodwaters largely confined to an incised river valley. The river experiences high velocities and steep gradients through these reaches.

The Bremer River and the Brisbane River, downstream of Mt Crosby are a mixture of storage and conveyance with both having significant floodplains that store and/or help convey the flood water. The lower Brisbane River, unlike most large east coast Australian rivers, has few natural meanders, with many of the river’s reaches controlled by the hilly terrain. The hydraulic consequence is that substantially higher velocities driven by a steep gradient develop along the lower Brisbane River during a flood. Consequently, the Brisbane River banks are sometimes rock, bends can literally be a sharp 180º (e.g. Kangaroo Point) and the entire flood flow is often solely confined between the river banks with relatively little or no overbank flowpaths.

In addition, there are numerous river meanders that change from gentle backwaters to short-circuit flowpaths as the flood rises causing areas of severe flood risk and erosion potential due to the high flow velocities.

A number of river level gauges are present within the Brisbane River catchment. Most of these are automated with sensors that relay information on water heights to relevant agencies. They provide a key method of capturing data during high flow events that can be used in hydraulic model calibration. A3 Addendum Sheet 1 shows key gauges as referenced by the study within the extent of the hydraulic model with further details provided in Section 4.3.1. Also shown in A3 Addendum Sheet 1 are Reporting Locations used in design case modelling (see Section 7.1.2).

The travel time of a flood peak from Wivenhoe Dam to Brisbane City is highly dependent on the degree to which the flows on the Brisbane River coincide with respective flows on the major tributaries of Lockyer Creek and the Bremer River. It is also dependent on the magnitude of the flood as the attenuating effect of floodplain storage and the degree of ‘short-circuiting’ of river meanders varies with flood magnitude. Because of the tributaries influence, the travel time of floodwater does not necessarily correspond to the relative timings of a flood peak. Ignoring the influence of these tributaries, the travel time of a flood hydrograph, such as a ‘pulse’ release from

Wivenhoe Dam to Brisbane City is typically around 30 hours. This is similar to the timing of the flood peak as occurred in the 2011 event where the release from Wivenhoe dominated the downstream flood response. However in the 1974 event, the flood peaked in Brisbane approximately 24 hours after the peak at the Wivenhoe Dam site. This shorter time was most likely due to the greater flow and timing of the Lockyer and Bremer tributaries.

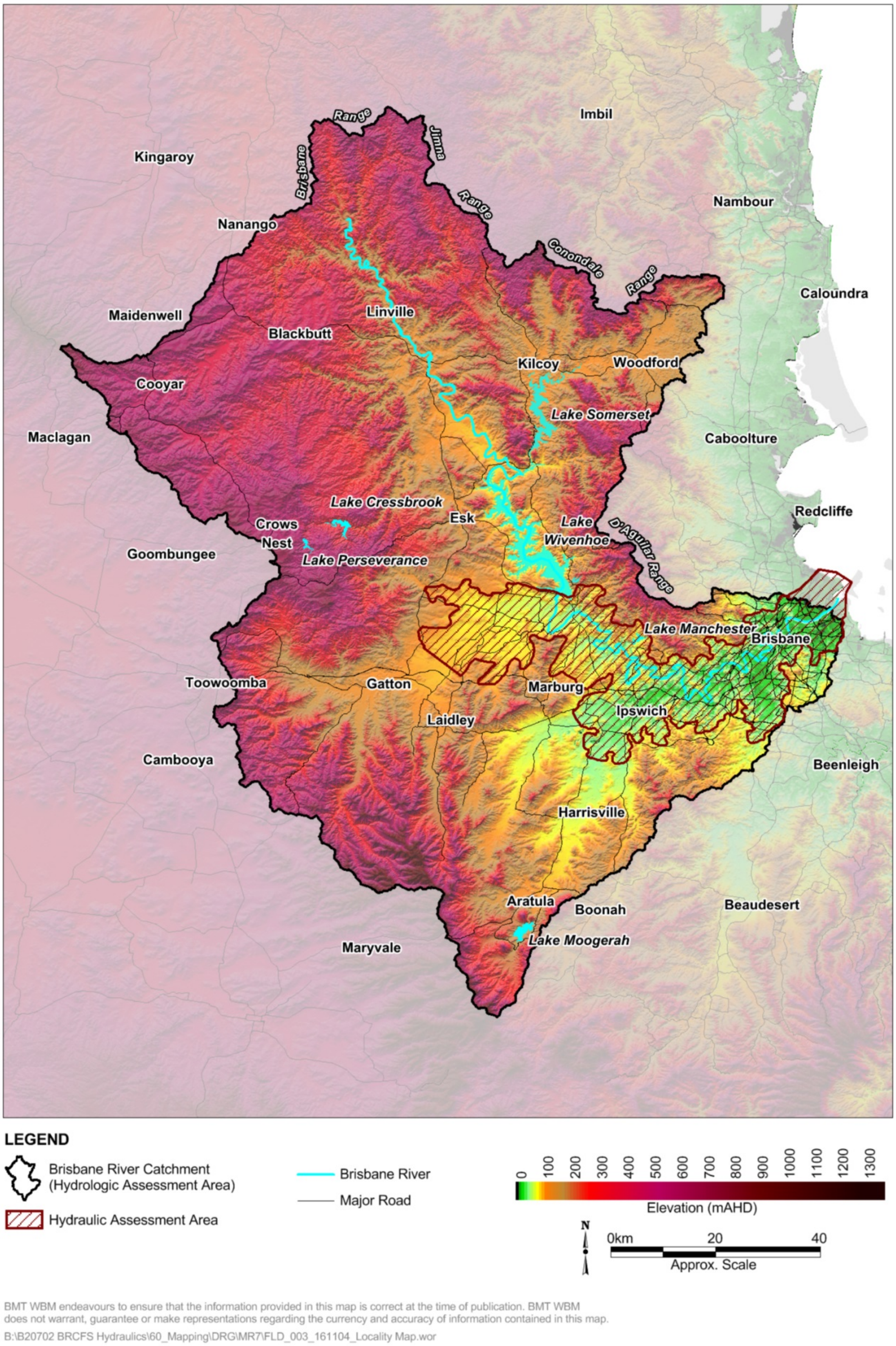


Figure 2-1 Brisbane River Catchment and Hydraulic Assessment Study Area

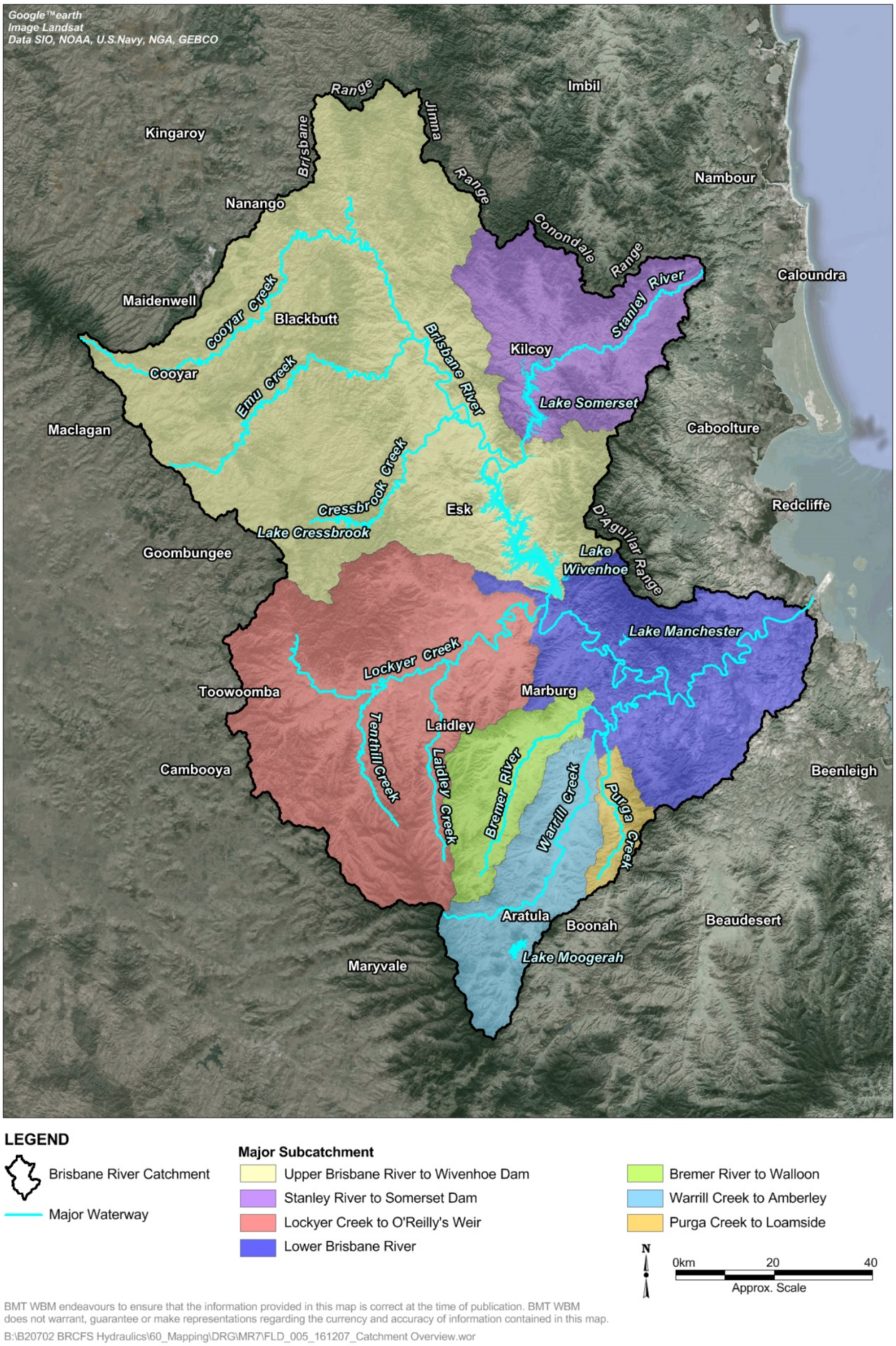


Figure 2-2 Brisbane River Sub-Catchments

2.3 Historical Floods of Significance

The Brisbane River has an extensive documented history of flooding dating back to the early exploration of the river by John Oxley in 1824.

Pre-European settlement there is oral history from the local Yuggera people that indicates a flood (larger than the largest known on the record) that occurred possibly around the 1700's to 1800's (BCC Personal Comms, 2016). Paleo hydrology studies are also currently being conduct1ed in the Brisbane River catchment and may in future provide further validation of the BRCFS outcomes.

It is to be noted that the content of this section is based on the information made readily available to this study and does not necessarily include all other historical information (including significant indigenous history) that is potentially available

The official flood records at the Brisbane Port Office Gauge commenced in 1841.

The largest floods on record occurred in the 19th century notably in 1841 and two significant events in 1893. However, prior to 1950's water level records were not systematically collected or complete except at a few stations such as Port Office gauge.

From the mid 1950's onwards the quality and quantity of available rainfall and river level data increased. The construction of Somerset Dam (completed in 1955) would also have a regulating influence on flows emanating from the Stanley River, one of the Upper Brisbane River's major tributaries.

The flood of 1974 caused major flooding throughout the Brisbane River catchment. Partly in response to this flood and also due to increasing water demand from the growing urban population, Wivenhoe Dam was constructed to provide a dual role of water supply and flood mitigation. Completed in 1985, the dam has a significant influence on flooding through its substantial flood mitigation storage. The mitigation storage is invoked through operation of radial gates that allows the dam to potentially more than double its full supply level capacity, and to control discharges so as to reduce the flows that coincide with the uncontrolled flows from the Lockyer and Bremer tributaries.

Figure 2-3 Flood Level Markers on Regatta Hotel, Toowong (image courtesy of BCC)

Following the construction of Wivenhoe Dam minor to major floods have occurred in the Brisbane River catchment with the most notable being in 1996, 1999, 2011 and 2013. For each of these floods Wivenhoe Dam played a significant role in reducing the flood peak and modifying the flood behaviour downstream. A large amount of good quality data is available from these events, as well the 1974 event, for use in hydrologic/hydraulic model calibration.

Due to the availability of data, the flood events of 1996, 1999, 2011 and 2013 have been used in this study for model calibration and verification purposes. Because of its significance, the large flood of 1974 is also included as a verification event although some of the data sets are of more limited quality. It should be noted that the historical events used in the calibration process (1974, 1996, 1999, 2011 and 2013) do not represent all significant historical events with records available.

The largest flood on record in 1893 is not included as a calibration or verification event, although some comparisons are made based on the limited information available. This flood was also not used by the Hydrologic Assessment for calibration/verification of the hydrologic modelling.

The following sections provide a brief description of each of the five calibration/verification events with an emphasis on the hydraulic aspects of relevance to this component of the study. An extensive summary of the flood history of the Brisbane River can be found on the Bureau of Meteorology website (http://www.bom.gov.au/qld/flood/fld_history/brisbane_history.shtml).

2.3.1 1974 Event

Decaying Tropical Cyclone Wanda provided initial rain that saturated the Brisbane River catchment during January 1974. Heavy rainfall persisted from the 24 January to the 29 January across the majority of the Brisbane River catchment including 650 mm recorded in a 5 day period within the CBD.

The rain led to major flooding resulting in widespread damage throughout the Brisbane River Catchment. It remains the highest flood since 1893 in Brisbane City where it peaked at 5.45 mAHD, and in Ipswich where it peaked at 20.7 mAHD at David Trumpy Bridge. The flood event occurred before the construction of Wivenhoe Dam and so for the purposes of the modelling undertaken in the hydrologic component of the study, the dam's influence was removed.

Due to the heavy localised rainfall within Brisbane City, local creeks within the city also experienced significant flooding in their upper and mid reaches followed by backwater inundation from the Brisbane River as it peaked in the early hours of 29 January 1974.

A large number of peak flood level marks were surveyed within the Brisbane and Ipswich metropolitan areas. These have been used to inform the verification of the flood model for the 1974 event.

2.3.2 1996 Event

The flood event of May 1996 is a valuable one for model calibration as Wivenhoe Dam retained all inflows from the upstream Brisbane and Stanley River catchments. This meant that the only catchments that contributed to inflows downstream of Wivenhoe Dam were the lower Brisbane, Lockyer Creek and the Bremer River.

The event itself caused severe flooding in Lockyer Creek, in places similar to that experienced in the 1974 flood. Major flooding occurred along the upper Bremer River and Warrill Creek but this reduced to minor flooding downstream at Ipswich due to little or no backwater effects from the Brisbane River. Due to the influence of Wivenhoe Dam it remained only a minor event on the lower Brisbane River except for some low lying areas within Brisbane that were affected by a combination of the flood event and higher than normal tides. The event is rated as a minor flood for model calibration purposes.

2.3.3 1999 Event

The event of early February 1999 was one of the largest floods to occur in recent times in the Upper Brisbane catchment and led to a significant inflow into Wivenhoe Dam. The dam heavily attenuated the peak inflow resulting in a peak outflow of less than 2,000 m^3/s compared with an estimated peak inflow of around 7,500 m^3/s. The 1999 event is therefore considered to be a relatively minor flood on the Brisbane River downstream of Wivenhoe Dam. The event was selected for use as a verification event for minor flooding.

2.3.4 2011 Event

The event of January 2011 occurred on the back of above average rainfall within South East Queensland resulting in the second highest flood in the Brisbane River catchment in the last 100 years after the January 1974 event. The peak level at the Brisbane City gauge was 4.46 mAHD (approximately 1 m lower than the 1974 event) and 19.25 mAHD at Ipswich. For much of the Lockyer Valley, the flooding was comparable to, and in places more extensive than, the 1974 event. In the lower Bremer River, the flooding resulted from a combination of backwater from the Brisbane River and significant flow in the Bremer River, though this flow was less than in the 1974 flood.

Inflows into Wivenhoe Dam showed a double peak, with each peak estimated to have flows in excess of 10,000 m^3/s. The dam storage attenuated the peaks, especially the first peak, resulting in the release of a single peaked flood with a maximum flow of around 7,500 m^3/s on the 11 January. During the subsequent drain down period for Wivenhoe Dam a reasonably constant release of around 3,500 m^3/s was made across a period of approximately four days.

For hydraulic modelling purposes the drain down period offers a valuable opportunity to calibrate the model for reasonably high flows as much of the Brisbane River is at near steady state (i.e. constant flow) conditions. The hydraulics under steady state conditions becomes solely a conveyance based problem (i.e. there are negligible storage effects that can attenuate the flood flows).

Flow gaugings using good quality instrumentation were also undertaken at Centenary Bridge around the time of the peak of the flood and during the recession of the flood and following drain down period. The maximum gauged flow at this location during the event was around 10,000 m^3/s.

In addition to the availability of data from river level gauges, surveyed peak flood level marks were captured in the aftermath of the 2011 event, particularly within the Brisbane and Ipswich areas. These flood marks, while not as comprehensive as those collected in 1974, provide a useful dataset to aid model calibration to the flood peak at locations other than the river gauges.

2.3.5 2013 Event

This event resulting from rainfall associated with Ex-Tropical Cyclone Oswald occurred in late January 2013.

High flows occurred on both Lockyer and Bremer tributaries although the peaks of these flows did not coincide with that in the Brisbane River as the Wivenhoe Dam gates were fully closed for a period of 30 hours, allowing the peak flows of Lockyer Creek and the Bremer River to pass into the Brisbane River with no coincident flows from the Upper Brisbane catchment. The volume of runoff entering Wivenhoe Dam was less than in 2011.

Notably the river event coincided with a storm surge rise in Moreton Bay resulting in large tides at the mouth of the Brisbane River.

On the whole, the flood event of 2013 remained largely in-bank within the study area, except for areas of the Lockyer Valley, which experienced a larger flood than elsewhere. Warrill Creek and to a lesser degree Purga Creek had notably high flows although the influence of these high flows diminished downstream at Ipswich.

As for the 2011 event, the 2013 event also had constant drain down releases from Wivenhoe Dam following the event with releases of around 1,700 to 1,800 m^3/s over a period of approximately four days.

During the event, gaugings were made from Centenary Bridge at Jindalee. The maximum gauged flow was around 4,000 m^3/s at around the peak of the event. Importantly for the study, the gaugings captured the flow occurring during the drain down period from Wivenhoe Dam which would help with model calibration.

Surveyed peak flood level marks were captured at a number of locations within Brisbane and the Lockyer Valley. These have been used to aid with model calibration to the flood peak.

2.3.6 Summary of Calibration/Verification Event Peak Flows

Table 2-1 provides a summary of peak inflows to the hydraulic model at key inflow locations for the five calibration/verification events. The inflows are taken from the hydrologic model developed for the BRCFS. The table provides an indication as to how the relative peak flow magnitudes of the five events compare. It should be noted that the table does not indicate the relative timings of the flows and should not therefore be used as an indicator of the magnitude of downstream flows as coincidental timings of flows can have a significant impact on flow magnitudes.

Table 2-1 Comparison of Peak Flows at Key Locations for Five Calibration/Verification Events

	Peak Flow from Hydrologic Model (m^3/s)				
	1974*	1996	1999	2011	2013
Brisbane River (Wivenhoe Dam outflow)**	7,100	0	1,800	7,500	1,800
Lockyer Creek	2,900	1,700	400	2,500	1,800
Bremer River***	2,000	1,000	400	2,000	1,200
Warrill Creek***	1,700	400	200	700	1,100
Purga Creek***	700	300	100	200	100

*The 1974 event does not include Wivenhoe Dam

**These flows (except for 1974) represent recorded flows from Wivenhoe Dam

***The 1974 event uses IL/CL scenario ST09 (see Section 4.6.1) for the Bremer River and Warrill and Purga Creeks

2.4 BRCFS Hydrologic Assessment

The objective of the BRCFS Comprehensive Hydrologic Assessment (Aurecon, 2015c) was to develop and apply a set of different methods for estimating design floods throughout the Brisbane River catchment. The techniques considered include:

- Flood Frequency Analysis (FFA).
- The standard Design Event Approach (DEA) as outlined in Australian Rainfall and Runoff (Engineers Australia, 1998).
- Monte Carlo Simulations (MCS).

The three methods were applied to estimate design flood flows throughout the 13,570 km^2 catchment of the Brisbane River for two different scenarios: ‘no-dams’ and ‘with-dams’ conditions.

Flood Frequency Analysis methods derive statistics of peak flows and flow volumes directly from observed flow records, whereas the Design Event Approach and Monte Carlo Simulation methods both rely on rainfall statistics in combination with a hydrologic model to compute peak flows and flow volumes at locations of interest. The hydrologic modelling was based on the URBS software and was calibrated to a range of historical flood events.

The Design Event Approach is a more traditional rainfall-based method which relies on a number of simplifications including the application of uniform temporal variations of rainfall over the catchment and the assumption that the resultant flood peak annual exceedance probability (AEP) is the same as the input rainfall AEP (i.e. assumes that the transformation of design rainfall to flood peak is AEP neutral).

The joint probability/Monte Carlo Simulation methodology removes many of the assumptions and limitations common to the Design Event Approach through the use of correlations between contributing variables. This was implemented in a Delft-FEWS environment.

There are, however, considerable challenges associated with capturing the influence of the main flood forcing factors in a realistic manner for this catchment, given the spatial and temporal aspects of the rainfall and the location of the main mitigation dams in relation to the downstream tributaries and urban centres which are the focus of the dam operations. The interaction of the various factors results in a large range of possible design flood estimates due to the variability of key inputs.

The Monte Carlo Simulation offers the best approach to handling a large range of variability in key inputs, and was the approach adopted for estimating AEP design flows.

The Hydrologic Assessment also included a review of the rating curves at several key locations (i.e. gauging stations) throughout the catchment. Where applicable, these rating curves are included on plots showing rating curves derived from the hydraulic modelling (see Section 8.6 for details).

2.5 Previous Hydraulic Modelling Investigations

Following the flooding in 1974, a series of 1:10,000 scale maps showing the floodplains of Brisbane and the surrounding suburbs were produced by the Coordinator General's Department of the Queensland State Government (Queensland Coordinator General, 1975). The maps were based on estimated longitudinal flood profiles for varying flood heights at the Brisbane City gauge with an ascribed frequency of occurrence extending to a 1 in 200 AEP event. Since production of these maps, a number of flood studies have been undertaken throughout the Brisbane River catchment which have utilised advances in numerical modelling. Table 2-2 provides a summary of the major studies undertaken prior to the BRCFS where a hydraulic model has been developed.

Since their original development a number of these models have been recalibrated or used with revised hydrological inputs. Key studies and revisions to studies that have provided 1 in 100 AEP peak levels and/or flows at the Brisbane City Gauge are listed in Table 2-3.

Table 2-2 Summary of Studies Involving Development of Key Hydraulic Models

Year	Study	Description
1991 to 1993	Brisbane River and Pine River Flood Study – various reports, DPI	Development and calibration of a WT42 hydrologic runoff-routing model and a hydraulic Rubicon model for the Brisbane River. These models subsequently formed the basis of many additional studies over the following years.
1998	Brisbane River Flood Study, SKM	A hydraulic MIKE 11 model was developed which extended from the Western Inner Bar to the upstream extent of the BCC local government area (79 km upstream). In addition to the main branch of the Brisbane River, the model also included branches for the lower reaches of key tributaries including the Bremer River and Oxley, Enoggera and Bulimba Creeks. The model utilised 197 surveyed cross sections provided by BCC.
2000	Ipswich Rivers Flood Studies, Phases 1 and 2,	The MIKE 11 hydraulic model developed for the Brisbane River Flood Study (SKM, 1998) was refined and extended into urbanised areas of Ipswich City including numerous local

Year	Study	Description
	SKM	tributaries
2004	Auxiliary Spillway Design, Wivenhoe Dam Alliance	MIKE-11 model of the auxiliary spillway releases downstream of Wivenhoe Dam. Re-estimation of design floods for Wivenhoe Dam using WT42 models.
2006	Sargent Consulting	Ipswich Rivers Flood Study Rationalisation Project Phase 3 to examine the variability in the 1 in 100 AEP flood and re-estimate design flows utilising a limited application of the Monte Carlo method for Ipswich Rivers Improvement Trust and Ipswich City Council.
2009	Flood Study of Fernvale and Lowood, BCC City Design	A flood study of Fernvale and Lowood was undertaken which developed a 1D/2D dynamically linked hydraulic model extending from Pointings Bridge on the Lockyer Creek in the west to Savages Crossing on the Brisbane River in the east. The model used LiDAR data captured in 2008 as the base topography. A cross section survey of Lockyer Creek and the Brisbane River was undertaken comprising 14 sections on Lockyer Creek and 32 sections on the Brisbane River at approximately 500 m intervals
2009	Brisbane River Hydraulic Model to PMF, BCC City Design	A 2D TUFLOW hydraulic model of the Brisbane River was developed to derive flood mapping for disaster management purposes. The model extends from Wivenhoe Dam to Moreton Bay and includes the downstream sections of the Bremer River and Lockyer, Warrill and Purga Creeks that are impacted by backwater flooding effects from the Brisbane River.
2012	Lockyer Creek Flood Risk Management Study, SKM	The study included development and calibration of a TUFLOW hydraulic model of the study area from Murphys Creek to Brightview
2014	Disaster Management Tool model, BCC City Design	A 2D hydraulic flood model using the TUFLOW GPU software was developed by BCC as part of the BRCFS and driven by disaster management needs.
Various	BCC Local Creek Models (various)	A number of hydraulic models have been developed of local Brisbane creeks including: • Breakfast / Enoggera Creek • Bulimba Creek • Moggill Creek • Norman Creek • Oxley Creek • Perrin Creek • Stable Swamp Creek
Various	ICC Local Creek Models (various)	A number of hydraulic models have been developed of local Ipswich creeks including: • Woogaroo Creek • Six Mile Creek • Goodna Creek • Bundamba Creek

Table 2-3 Summary of Previous 1 in 100 AEP Flows and Levels at Brisbane Port Office

Date	Study	1 in 100 AEP Flow	1 in 100 AEP Level
November 1975	Brisbane River Flood Investigations (Final Report) Snowy Mountains Engineering Corporation (SMEC).	unknown	3.7 m
1984	BCC Water Supply and Sewerage Department.	6,800 m^3/s	unknown
August 1993	Brisbane River and Pine River Flood Study Report No.13: Brisbane River Flood Hydrology Downstream Flooding Estimation. South East QLD Water Board August.	9,380 m^3/s	unknown
June 1998	Brisbane River Flood Study for Brisbane City Council. Sinclair Knight Merz (SKM).	9,200 m^3/s	5.34 m
June 1999	Brisbane River Flood Study (Draft) Sinclair Knight Merz (SKM).	8,600 m^3/s	5.0 m
December 1999	Further Investigations for the Brisbane River Flood Study Draft Report (BCC City Design).	8,000 m^3/s	4.7 m
September 2003	Review of Brisbane River Flood Study: Report to Brisbane City Council. Independent Review Panel (Russell Mein, Colin Apelt, John Macintosh, Erwin Weinmann).	6,000 m^3/s	3.3 m
December 2003	Further Investigations of Flood Frequency Analysis Incorporating Dam Operations and CRC-FORGE Rainfall Estimates – Brisbane River, Final Issue, SKM.	6,500 m^3/s	3.51 m
February 2004	Recalibration of the MIKE 11 Hydraulic Model and Determination of the 1 in 100 AEP Flood Levels, SKM.	6,000 m^3/s ([7])	3.16 m

The studies listed in Table 2-2 and Table 2-3 have offered significant inputs to the knowledge base and the development and calibration of the hydraulic models developed for the Hydraulic Assessment. Two studies that warrant further consideration due to their relevance and input to the BRCFS are the Brisbane River Flood Hydrology Models (Seqwater, 2013) and the Disaster Management Tool (DMT) Study (BCC, 2014). Additional details on these studies are provided below.

[7] This flow was used based on the IRP's recommendation.

Brisbane River Flood Hydrology Models (Seqwater, 2013)

This study was undertaken by Seqwater to support the Wivenhoe and Somerset Dams Optimisation Study (WSDOS) which itself was initiated in response to the Queensland Floods Commission of Inquiry to investigate potential alternative operations of the existing dams during floods. It is also used to inform Seqwater operational matters in relation to real time forecasting. The hydrology study developed seven URBS hydrologic models that represent major sub catchments of the Brisbane River basin (see Figure 2-2). These formed the basis for further hydrologic model development as part of the BRCFS in the Comprehensive Hydrologic Assessment component.

The study also undertook a review of the rating curves at key flood gauges with the Brisbane River catchment. The URBS models were calibrated to over 35 flood events and this was undertaken in conjunction with the rating curve reviews. This meant that the rating curves informed the calibration of the URBS models and the calibration results were also used to improve the curves. The Seqwater review investigated a broad range of data, however, the Seqwater review only had access to limited hydraulic modelling analyses and the curves were considered 'preliminary'. The resulting rating curves from the study are included as part of the rating curve review tasks of the Hydraulic Assessment for comparative purposes and are referred to as the 'Operational' curves.

Brisbane River Catchment Disaster Management Tool (BCC, 2014)

The Brisbane River Catchment Disaster Management Tool (DMT) study, herein the 'DMT Study' developed and delivered a broad scale 2D hydraulic flood model using the TUFLOW GPU software. The context for the development of the DMT was the occurrence of the 2013 event, which identified the need for an interim disaster management project and associated deliverables, whilst awaiting outcomes from the BRCFS. The study built upon the 2D model developed as part of the Brisbane River Hydraulic Model to PMF (BCC, 2009) using the latest readily available terrain data and calibrated against the 1974, 2011 and 2013 historic events while the two largest 1893 historical floods were used as additional events due to their large magnitude. Of note, the study utilised a Digital Terrain Model (DTM) developed as part of the Digital Terrain Model and Bed Level Sensitivity Analysis (BLSA) project (BCC, 2014). The primary output from the DMT Study was the production of 106 maps across the study area showing outputs from simulating 92 notional flood profiles.

The DMT Study is a precursor to the BRCFS Hydraulic Assessment and has two main uses for the Hydraulic Assessment study:

- Significant effort went into the development of the DTM. This forms the primary component of the base terrain in the current study.
- The DMT model has been used to guide the development of a 1D 'Fast Model', in particular identifying breakout flow routes under extreme flood flow conditions and allowing these flow routes to be incorporated into the Fast Model. It also provided initial guidance on the extent and design of the Detailed Model.

As such, the DMT study provides important information to the Hydraulic Assessment and its use is described further in Section 5.1.

3 Hydraulic Assessment Approach

The BRCFS Hydraulic Assessment (this study) includes the development and calibration of an integrated suite of hydraulic models which are ultimately used to select and simulate the design events to define flood behaviour and provide peak flood level surfaces and other key outputs across the study area. This section summarises the approach taken in producing the hydraulic models and outputs.

3.1 Overview

The Hydraulic Assessment includes the following tasks: data collation, site inspections, modelling, reporting and workshops. Figure 3-1 shows the relationships between the various components of the Hydraulic Assessment. Two models were developed and calibrated as part of the Hydraulic Assessment: the Fast Model and the Detailed Model. Brief descriptions of the Fast and Detailed Models are given in Section 3.4.1 and Section 3.6 respectively with further detail provided in Sections 5 and 6. Reports MR2 and MR3 should be referred to for full details on the development and calibration of the Fast and Detailed Models respectively.

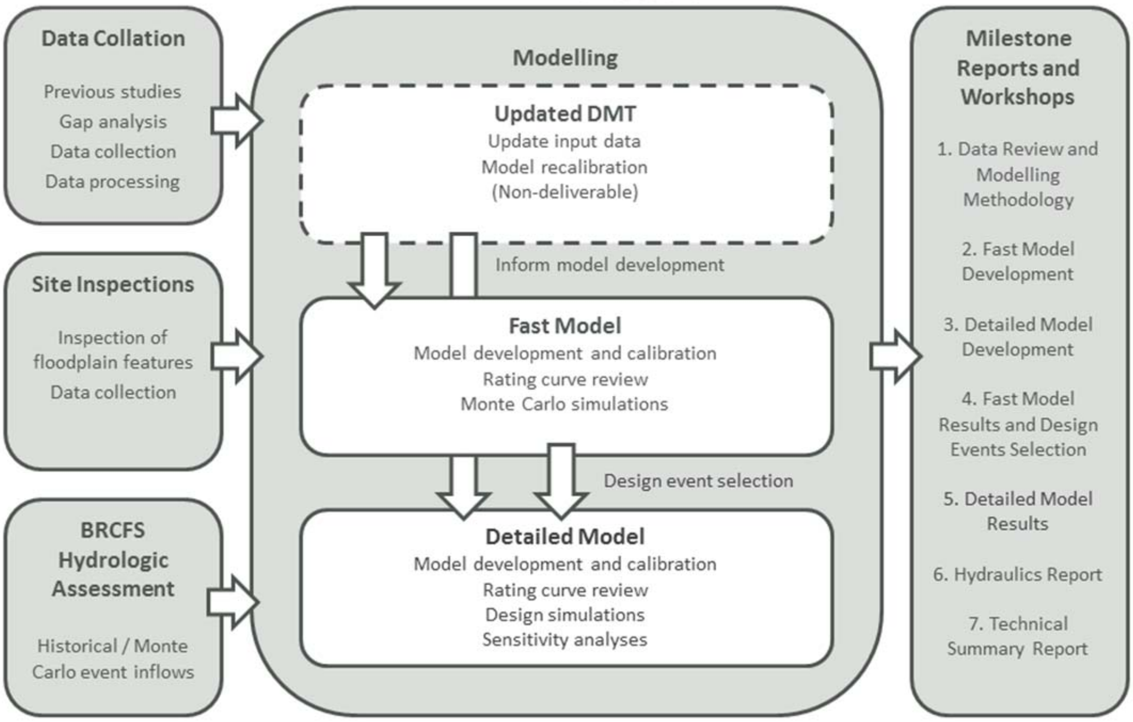


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Figure 3-1 BRCFS Hydraulic Assessment

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3.2 Data Requirements

The key data requirements for the hydraulic assessment can be summarised into the following generalised categories:

- Digital terrain data that can be used to build the ground and river bed surface in the model.
- Boundary data in the form of model inflows and downstream tidal conditions.
- Hydrometric data used for model calibration/verification such as recorded water level hydrographs, surveyed peak flood levels and flow gauging data.
- Land use data used to ascribe a hydraulic roughness category to the modelled surface.
- Data on hydraulic structures and other features such as road embankments that may have a hydraulic influence.

Many datasets were provided following a Data Collection Study (DCS) component of the BRCFS (Aurecon, 2013). Other datasets were sourced during the course of the hydraulic assessment or, in the case of the Monte Carlo event inflows, provided following conclusion of the Hydrologic Assessment. Section 4 discusses the key datasets used to inform the hydraulic modelling.

3.3 Hydraulic Modelling Software

The Brisbane River Valley is an interesting and challenging mix of storage and conveyance dominated hydraulic behaviour. In particular, the river in sections exhibits very high velocities in deep flowing water around river bends constrained by a hilly terrain (rather than river formed meanders).

Most dynamic hydraulic modelling software is capable of accurately representing storage effects. Storage is relatively easy to model provided:

- A good DEM is available to accurately define the ground surface.
- The river reaches and floodplain areas are modelled as separate but hydraulically connected.
- The model is a dynamic one (steady-state solutions do not model storage effects).

Modelling conveyance is more complicated. Simplified models that do not solve for inertia can be used by a knowledgeable modeller on gently flowing, slow moving systems where the momentum or inertia of the water is of minor influence. However, these models are not suited to the Brisbane River. For the Brisbane River, the modelling must take into account the inertia of the water (which is substantial when a river is flowing at 4 to 7 m/s and is 20 m deep, as in the case of the Brisbane River). Inertia is also essential to simulate the dynamic interaction and tidal propagation of the ocean tide. Due to the Brisbane River's deep, high velocity nature, the representation of sub-grid scale turbulence by the model (often referred to as eddy viscosity) is also highly desirable as this allows the model to take some account of the shearing effects of slow water against fast water that occurs around sharp river bends and constrictive structures.

Also of note, when solving the 1D form of the governing equations (St Venant equations) rather than the 2D or 3D forms, the 1D solution is unable to intrinsically simulate the significant energy losses that occur around sharp river bends with high velocities, of which there are numerous cases along the Brisbane River. The river bends need to have an additional energy loss derived and applied during the calibration process and/or based on benchmarking from a 2D and/or 3D model of the bend. 2D solutions that solve for inertia and eddy viscosity do simulate these losses, but may slightly under predict if there are significant vertical (helicoidal) circulations, so may require minor additional losses based on calibration and/or benchmarking against a 3D model.

There are several hydraulic modelling packages that are industry standard and suitable for simulating Brisbane River flood hydraulics. There are also software that are not suitable and should not be used. The TUFLOW software (developed by BMT WBM and used worldwide) was used for the BRCFS Hydraulic Assessment for the following reasons:

- TUFLOW is an integrated software platform that is commercially available, well established and widely used and supported by the industry in Australia and around the world. TUFLOW is developed, maintained and distributed by BMT WBM.
- TUFLOW is one of the most accurate and fastest computational schemes based on the results presented in the 2012 UK Environment Agency 2D hydraulic modelling benchmarking study (Neelz and Pender, 2013).
- TUFLOW supports a wide range of GIS and industry standard formats for input and output data. The formats supported by TUFLOW are directly compatible with the output formats requested by the ITO (i.e. ArcGIS).
- The software is used or accepted for use by all BRCFS councils. This is evidenced by the historic flood studies within the study area that have used TUFLOW including:
  - Brisbane River Disaster Management Tool (BCC City Projects Office, 2013).
  - Brisbane River Hydraulic Model to Probable Maximum Flood (PMF) (BCC Flood Management City Design, 2009).
  - Flood Study of Fernvale and Lowood (BCC Flood Management City Design, 2009).
  - Lockyer Valley Hydraulic Model (SKM, 2012).
  - Goodna Creek Flood Study and Flood Risk Management Plan (SKM, 2012).
  - Six Mile Creek Flood Study and Flood Risk Management Plan (SKM, 2012).
- TUFLOW has added value options for floodplain management that benefit future end users of the hydraulic model, such as:
  - Road closure information (identifying location and timing of road closure points).
  - Links between property information on ground and building levels to flood heights at gauges (to inform which buildings are inundated above floor and when).
  - Nominal floodplain storage/conveyance assessments (specified increases or decreases in flood storage and conveyance areas).
- TUFLOW software has been used to develop and simulate both the Fast and Detailed Models, as well as the DMT hydraulic model, with all three models sharing common databases.

The TUFLOW software meets all of the listed requirements under Section 3.7 of the ITO. This includes the requirement that the integrated 1D-2D (or 2D) software platform should be commercially available, well established and used and supported by the general industry.

3.4 Interfacing with Hydrologic Assessment

3.4.1 Rating Curve Reviews – Validation of Hydrologic and Hydraulic Modelling

To ensure there is consistency between hydrologic and hydraulic modelling a joint development and calibration of the hydrologic and hydraulic models is typically carried out. Joint calibration is the cyclic process whereby the results from the hydraulic model are used to inform, and revise if necessary, the inputs and parameters of the hydrologic model. The revised hydrologic model is then used to generate new outputs for fine-tuning the hydraulic model with this circular process continuing in an iterative way until both hydrologic and hydraulic models are considered calibrated and in general agreement.

As the Hydrologic and Hydraulic Assessments were separately commissioned and undertaken, a joint development and calibration exercise was not an option. Therefore, to check and demonstrate consistency between the hydrologic and hydraulic modelling flow versus water level (or stage-discharge), output from the hydraulic models was compared with the rating curves derived and adopted by the hydrologic modelling at key, preferably gauged, locations. Should an unacceptable mismatch between the rating curves and the stage-discharge output from the hydraulic modelling occur, this would trigger a cycle to re-visit and fine-tune the hydrologic modelling followed by a fine-tuning of the hydraulic modelling.

A critical component of the Hydraulic Assessment was to review and check the performance of the hydraulic modelling against the Hydrologic Assessment rating curves at several key stages. Details of the checks are provided in Section 7.4.3.

3.4.2 Data and Knowledge Transfer

Data from the Hydrologic Assessment needed by the Hydraulic Assessment, and assistance in interpreting and transferring the data, was constructively and efficiently carried out. These data and knowledge transfer included:

- The URBS hydrologic models for the calibration events and assistance with interpreting the models. Note that the hydrologic calibration parameters were not adjusted by the Hydraulic Assessment, other than for some sensitivity testing, however, around 100 additional flow hydrograph output locations were required to be added to the URBS modelling to provide distributed flow inputs to the hydraulic modelling.
- Rating curve data.
- Flow hydrographs and Moreton Bay storm tide water level hydrographs from 11,340 Monte Carlo events for simulation through the Fast Model.
- The Monte Carlo Simulation setup within Delft-FEWS to regenerate new flow hydrographs due to increases in rainfall for the Climate Change sensitivity tests using the Detailed Model.
- Inflows for calibration events.

- Inflows and Moreton Bay storm tide levels for 11,340 Monte Carlo generated synthetic events.

3.5 Fast Model

The Fast Model is a purely 1D hydraulic model with a target run time of 15 minutes or less per simulation as specified in the ITO. The original intention of the Fast Model was to undertake the simulation of around 500 Monte Carlo events which are then used to derive AEP peak flood levels at 28 Reporting Locations throughout the study area. These Reporting Locations extend from Wivenhoe Dam on the Brisbane River, Lyons Bridge on Lockyer Creek and Walloon on the Bremer River downstream to the Gateway Motorway on the Brisbane River and were set out in the ITO. They are shown on A3 Addendum Sheet 1 along with key river level gauges referenced by the study.

In order to ensure that the Fast Model was fit for purpose, a rigorous calibration exercise was undertaken with further simulation of hypothetical extreme flood events.

During the course of the Hydraulic Assessment the option of distributing Fast Model simulations across an array of computers that allowed for a full range of Monte Carlo flood events (in the order of 10,000) was considered feasible. After discussion and review by the TWG and IPE, it was considered that this would lead to a much improved estimate of AEP peak flood levels if statistically derived from a full suite of Monte Carlo events rather than a sub-set of 500. Ultimately the Fast Model was used to simulate 11,340 Monte Carlo events provided by the Hydrologic Assessment leading to the improved AEP statistical analysis of peak flood levels at Reporting Locations over that originally envisaged in the ITO.

The Fast Model development and calibration is summarised in Section 5 with further detail provided in MR2.

3.6 Detailed Model

The Detailed Model is a 1D/2D hydraulic model that is designed to reproduce the hydraulic behaviour of the rivers, creeks and floodplains at a significantly higher resolution than the Fast Model. The Detailed Model, whilst substantially slower to simulate a flood event than the Fast Model[8], is designed for producing flood maps and 3D surfaces of flood depths, water levels, hydraulic hazard, risk categories and other useful data for floodplain management planning initiatives. The model is also suited to predicting changes in flood levels and flow patterns due to past and proposed works, including flood mitigation measures and future developments.

The Detailed Model is calibrated to tidal conditions and the 2011 and 2013 flood events with verification to the 1996, 1999 and 1974 events.

The functions of the Detailed Model are to:

- Accurately reproduce the flood behaviour of the Brisbane River below Wivenhoe, Lockyer Creek and Bremer River at a sufficiently high resolution to produce mapping of flood levels, depths, velocities and hydraulic hazard for whole-of-catchment (below Wivenhoe Dam) planning purposes as per the requirements specified in the ITO.

[8] The indicative runtime for a 1 in 100 AEP flood event is 28 hours in the Detailed Model compared with a Fast Model time of around 8 minutes. (Run times based on a CPU core running at 4.0GHz.)

- Simulate the selected Monte Carlo events to produce the final estimates of AEP flood levels, depths, velocities and hydraulic hazard (depth times velocity) throughout the Hydraulic Assessment study area.
- Provide a tool that can be used into the future to quantify the impacts or changes in flood levels, depths velocities and hydraulic hazard due to: flood mitigation measures, urban developments, road and rail infrastructure, dredging and quarry operations, and other works that change the flood behaviour.
- Predict changes in flood behaviour caused by variations in climate, land-use, river bed and floodplain topography, and other factors into the future so that planning instruments can accommodate these effects.

A summary of the Detailed Model development, calibration and verification is provided in Section 6 with further detail in MR3. The AEP design event simulations and presentation of results including mapping are summarised in Section 8 with further detail in MR5.

3.7 Monte Carlo Analysis and Design Event Selection

Monte Carlo Simulation (MCS) is a method for calculating probabilities of "something" occurring (e.g. a flood) when there are uncertainties and/or variability in the variables that may combine to produce that "something". It is based upon drawing random samples of the variables, similar to playing roulette, and hence the technique was named after the Monaco city famous for its casino. The random sampling is undertaken in numerical computing environment.

The MCS method relies on numerous flood simulations taking different combinations of factors such as rain depth, rain temporal and spatial patterns, catchment losses etc from pre-defined probability distributions. When a sufficiently large number of events are generated, the variability of flooding can be adequately represented and a reliable estimate of flood probability can be assessed. Of particular importance is the representation of different rainfall patterns because the effect of Wivenhoe Dam and Somerset Dam flood mitigation on downstream flooding depends on whether rain falls upstream of the downstream of the dams and also the timing of upstream and downstream flows. The traditional approach to apply a uniform temporal pattern of rainfall over the entire catchment would not adequately represent the variable effect of dam flood mitigation that is evident in actual flood events.

Each hydrologic model simulation is termed a 'Monte Carlo (MC) event' from which flow hydrographs can be extracted in order to provide inflows to the hydraulic Fast Model. A large subset of hydrologic model outputs, representing the 'whole of catchment' rainfall scenario[9], was supplied for hydraulic modelling purposes; a total of11,340 MC events. Each one was simulated using the Fast Model to generate a large database of hydraulic model results. The analysis of these results involved undertaking a flood level frequency analysis using the TPT approach at the 28 Reporting Locations to estimate flood levels for a range of AEPs varying from the 1 in 2 (50%) to the 1 in 100,000 (0.001%).

[9] Whole of catchment rainfall represents the hydrologic simulations undertaken for the Brisbane City reporting location i.e. rainfall depth is generated for the whole of the catchment upstream from the Brisbane City gauge

Groups of Monte Carlo events for each AEP were then selected with each group termed an AEP ‘ensemble’. Each ensemble is representative of the AEP levels at the Reporting Locations. The resulting ensembles are considered a stepping stone to producing the final design levels which are derived by simulating the AEP ensembles through the Detailed Model.

A summary of the Monte Carlo analysis and event selection process is provided in Section 7 with further detail in MR4.

3.8 Design Event Modelling

The selected Monte Carlo events for the Detailed Model are sorted into 11 AEP groups or ensembles. This is analogous to the traditional industry practice of defining an AEP design event as being made up of several critical duration events. Typically the Monte Carlo events within each AEP ensemble are a mixture of short to long duration rainfall events that represent the variation in flood behaviour response across the Hydraulic Assessment study area. Each AEP ensemble is simulated through the Detailed Model to produce the following AEP design outputs (see also Section 3.9):

- Peak Water Surface Levels, Depths, Velocities and Hydraulic Hazard maps.
- Plots consisting of time series charts of flows and water levels at Reporting Locations and longitudinal profile plots of peak water surfaces.
- Tables of peak flows and water levels at Reporting Locations.

The Detailed Model was also used to simulate Sensitivity Scenarios to ascertain the hydraulic response of the catchment to the following:

- Future Floodplain Condition – a hypothetical loss of floodplain storage due to development.
- Climate Change Scenarios – increases in rainfall and sea level.
- Bed Level Scenarios – increasing and decreasing bed levels and its effect on river conveyance.
- No Dams or With Dams – assessing the influence of key dams on historic flood events.

A summary of the Design Event modelling including the Sensitivity Scenarios is provided in Section 8 with further detail in MR5.

3.9 Model Result Outputs

Hydraulic model results for the Fast and Detailed models are presented in a number of ways:

- **Plots** - these are presented at A3 size and are designed so that when viewing them in digital format they can be readily zoomed so that a much closer inspection of the results can be observed without losing image clarity. Four categories of plots are provided as follows:
  - Common to both Fast and Detailed models are a series of plots containing time-series data of flows and levels. For the calibration models these are presented for key gauges and include observed data alongside model results. For the design case modelling, these are at the Reporting Locations.

  - Longitudinal profiles are presented for both calibration and design case modelling. In the former, the plots include flood marks within 100 m and 500 m of the river/creek centreline for the 1974, 2011 and 2013 floods as available. Chainages shown on these plots are mapped on A3 Addendum Sheet 2.
  - Rating curves presenting flow vs level at key gauges and/or Reporting Locations.
  - For the 1974, 2011 and 2013 calibration/verification events flow recordings off Centenary Bridge are presented.

  Example plots of time-series and longitudinal output are shown in Figure 3-2 and Figure 3-3 respectively. In addition to the types of plot listed above, MR4 contains a number of plots for:

  - Quality control purposes on the thousands of Monte Carlo simulations.
  - Level frequency curves at the Reporting Locations.
  - Plots illustrating the event selection process.

- **Maps** – these are presented at A3 size. For calibration/verification events the drawings include comparisons between the observed and modelled peak flood levels at both gauges and flood marks for the larger events of 1974, 2011 and 2013. The comparisons are colour coded for ease of interpretation with the ranges selected relating directly to the recommended tolerances from the ITO: ±0.15 m, ±0.3 m and ±0.5 m. Colours for each of these difference ranges are provided in the drawing legends. Figure 3-4 shows an example map. Full A3 size maps showing results of the 2011 calibration are provided in A3 Addendum Sheet 14 to A3 Addendum Sheet 18.

  For design case results the following outputs are presented on drawings:

  - Peak Water Surface Levels – MR5 provides flood extents shown with 1 m interval contours of the peak flood level to mAHD. For this Hydraulics Report, intermediate 0.5 m contours have been added to the 1 in 100 AEP maps and are provided in the A3 Addendum.
  - Peak Flood Depth Maps – colour shaded mapping indicating five intervals of flood depth.
  - Peak Flood Velocity Maps – colour shaded mapping with six intervals of depth averaged velocity.
  - Peak Depth x Velocity (Hydraulic Hazard) Maps – colour shaded mapping with five intervals of hydraulic hazard. Hydraulic hazard is the product of flood depth and the depth averaged velocity. The peak hydraulic hazard is tracked during the model simulation and occurs when the product of flood depth and velocity is greatest.

- **Tables** - comparisons of observed and modelled peak flood levels at the gauges for each calibration/verification event and peak flows and levels at the Reporting Locations for all design case simulations. The peak values in the design case are the maximum values from each AEP ensemble.

- **Hydraulic Structure Reference Sheets (HSRS)** – these are prepared for key structures on the main waterways and include details of the structure itself along with modelled output on discharges, flow area and flow velocity under and over the structure and structure head loss.

The results are presented for the five calibration/verification events and the 1 in 100 and 1 in 2000 AEP design cases.

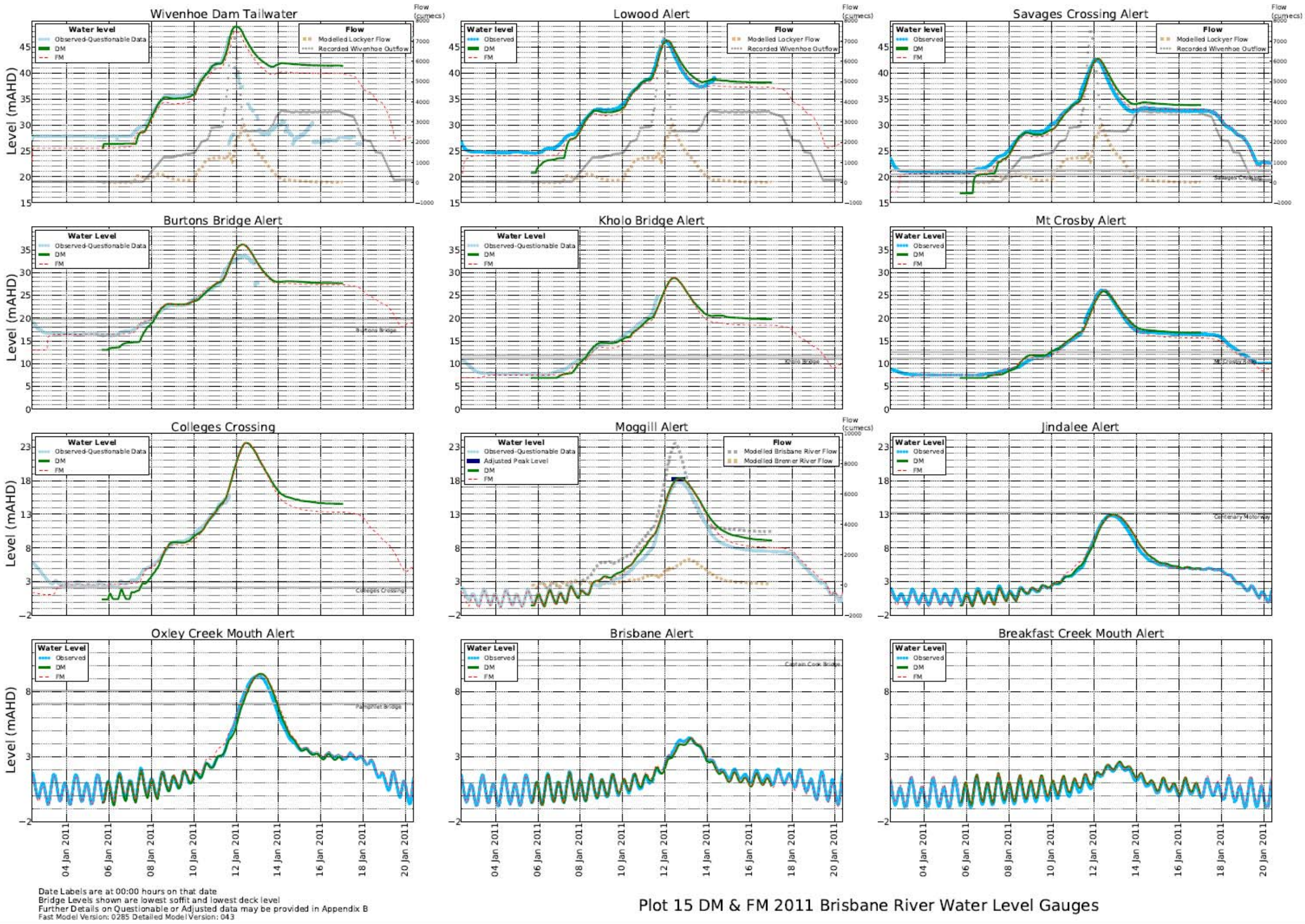


Figure 3-2 Example Plot Showing Hydrograph Output

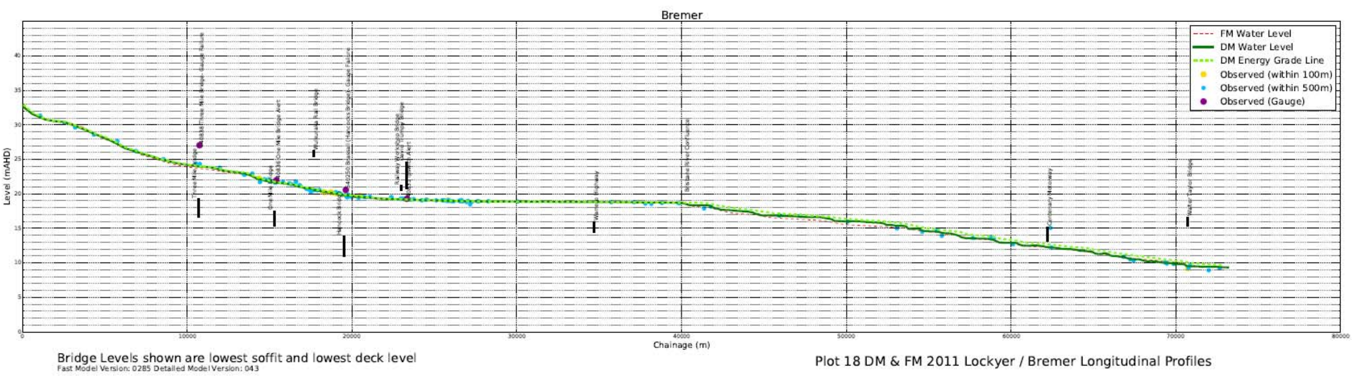


Figure 3-3 Example Plot Showing Longitudinal Section Output

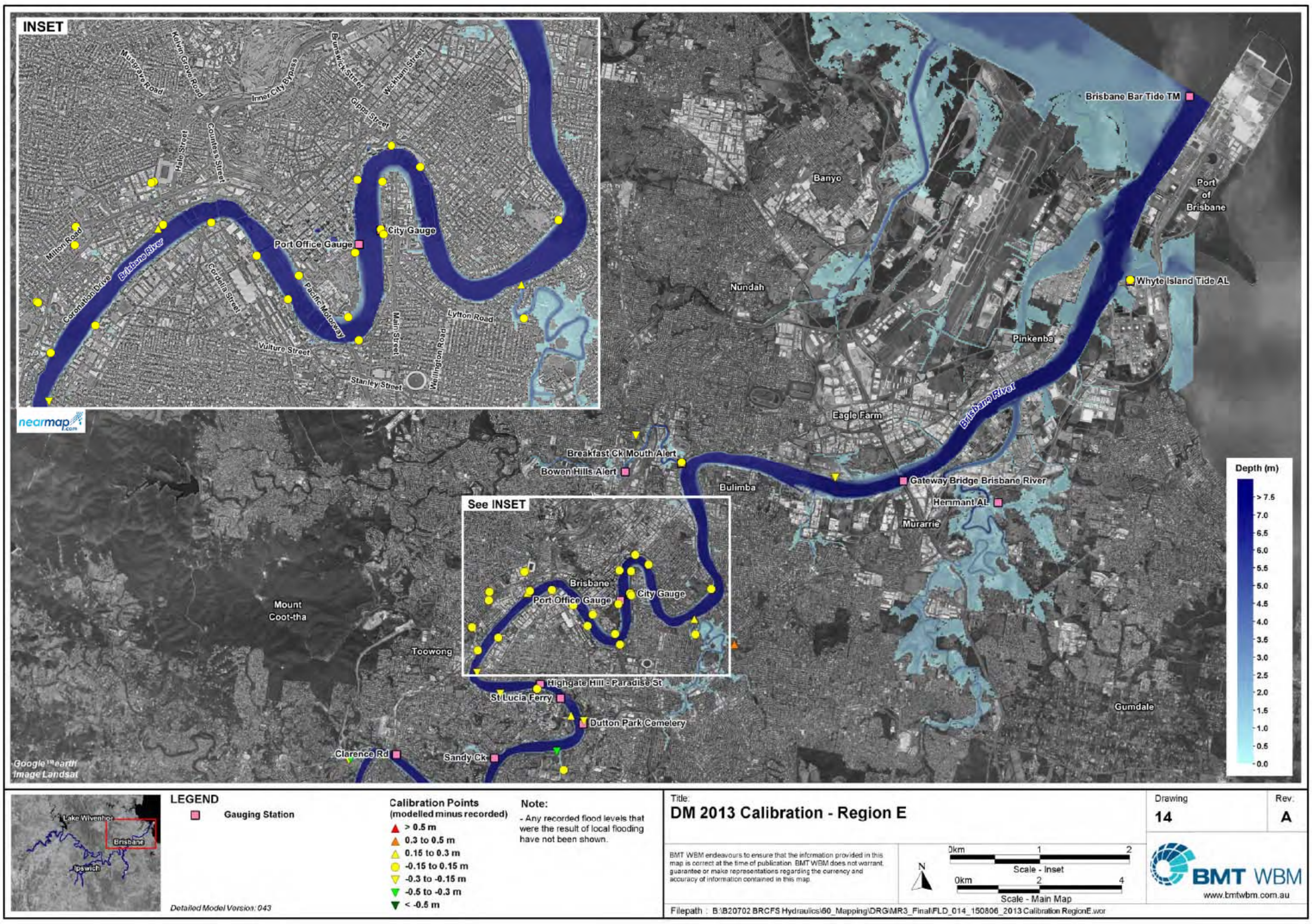


Figure 3-4 Example Map Showing Calibration Points (Flood Marks)

4 Data Collection and Collation

Data collection and collation along with a description of the key datasets used to develop the hydraulic models are summarised in this section. The datasets may be applicable to Fast Model, Detailed Model or both. Some of the datasets are not used directly by the models but have been used to inform model design and are included for that reason. Specific use of the datasets in the Fast and Detailed Models are given in Section 5 and 6 respectively. This section first summarises the main sources of data (Section 4.1) followed by summary descriptions of the key datasets used by the hydraulic modelling (Section 4.2 to Section 4.6).

4.1 Sources of Data

Data has been sourced for this study in three general ways as follows:

(1) The Data Collection Study (DCS), completed in 2013, resulted in the collation of a large amount of data which was provided to the Hydraulic Assessment at its commencement.

(2) Separate provisions of data consisting of outputs from the Hydrologic Assessment, chiefly inflow boundaries, were made at later dates during the course of the Hydraulic Assessment as they became available.

(3) Following a data gap analysis a number of additional datasets were identified and requested by BMT WBM and these were provided by the relevant BRCFS stakeholders, local councils and various agencies..

Data collection via these sources is described below. Additional information is contained within MR1.

4.1.1 Data Collection Study

The BRCFS Data Collection Study (DCS) (Aurecon, 2013) identified, compiled and reviewed readily available data and metadata, including a gap analysis, for the purposes of the various BRCFS investigations. This included collection of approximately 5 TB of digital data which was provided to the Hydraulic Assessment at the inception meeting on 8 July 2014. The data included amongst other items:

- Rainfall/Streamflow data.
- Topography data.
- Aerial Imagery.
- Previous flood studies undertaken within the catchment.

The DCS (2013) produced a Data Register using an Excel spreadsheet that details the information and datasets identified and collected. It also identified items not collected, not provided nor received.

4.1.2 BRCFS Hydrologic Assessment Output Data

Outputs from BRCFS Hydrologic Assessment provide a number of key inputs to the Hydraulic Assessment. Receipt of the key data outputs from the Hydrologic Assessment took place in two stages as follows:

(1) Data supply of the recalibrated hydrologic models[10], revised rating curves and other associated data (supplied October 2014).

(2) Data supply of the hydrologic models' output files for 11,340 Monte Carlo simulation events for use with the Fast Model (supplied September, 2015).

4.1.3 Data Gap Analysis and Collection

The data categories used in the DCS were simplified and rationalised into five categories to meet the needs of the hydraulic assessment:

(1) Previous Studies and Models

(2) Topographic Data

(3) Hydraulic Structure Data

(4) Land Use Data

(5) Historical Flood Data

Within these general categories a number of additional key datasets were identified and sourced. These datasets were either not originally supplied in the DCS or not available at the time of the DCS. Full details of the gap analysis are provided in MR1. Summaries are provided below of key additional datasets sourced and obtained following receipt of the DCS. The datasets are grouped by category as defined above.

Previous Studies and Models

The DCS supplied a number of previous studies and models. In some cases only the study reports were supplied and not the supporting data and in other cases the relevant study was not ready at the time of data supply. Table 4-1 lists relevant additional studies and models sourced by the Hydraulic Assessment.

[10] The URBS model was recalibrated to the events of January 1974, May 1996, February 1999, January 2011 and January 2013.

Table 4-1 Key Additional Datasets: Studies and Models

Item	Source (Date Supplied)	Description	Relevance to BRCFS Hydraulic Assessment
DMT Model	BCC (12/08/14)	DMT TUFLOW model of Lower Brisbane catchment	Provided significant and useful background information for the development of the BRCFS hydraulic models
DMT Report	Draft: BCC (29/09/14) Final: BCC (07/11/14)	Report accompanying the DMT Model	Supporting documentation of the DMT modelling as used by the Hydraulic Models
Rubicon Cross Section Data	DNRM (05/08/14)	Cross section data from the Brisbane River and Pine River Flood Study (DPI, 1994)	Potential use of data in hydraulic model
Brisbane Local Creek Models	BCC (29/09/14)	Eight local creek models within the BCC area	Potential use of some data in hydraulic model
BCC Coastal Plan Implementation Study Draft Report	BCC (07/10/14)	Storm tide study report (GHD, September 2014)	Potential use of storm tide boundaries in hydraulic model
BCC Coastal Plan Implementation Study Model	BCC (16/10/14)	Storm tide study model (GHD, September 2014)	Potential use of storm tide boundaries in hydraulic model
Lockyer Creek Flood Study Model	SKM (16/10/2014)	TUFLOW model of Lockyer Creek	Potential use of some data in hydraulic model

Topographic Data

The DMT Study identified several areas within the river channel as potentially benefitting from more accurate bathymetric data. At the time of the DMT study some bathymetric survey was underway. These bathymetric datasets have since become available and were sourced by the Hydraulic Assessment. Updated LiDAR survey also became available for the study and was sourced for use in the design event modelling. These additional datasets and other ones including localised topography datasets and cross section data sourced by the Hydraulic Assessment are listed in Table 4-2.

Table 4-2 Key Additional Datasets: Topographic Data

Item	Source (Date Supplied)	Description	Relevance to BRCFS Hydraulic Assessment
DMT DEM	BCC (12/08/14)	5 m and 10 m DEMs of Lower Brisbane Catchment	DEMs used in Hydraulic Models
Bremer Bathymetry	DNRM (05/08/14)	Grid containing bathymetry data of the tidal Bremer	Bathymetry used in Hydraulic Models
Lower Brisbane Bathymetry	PoB (29/08/14)	Bathymetry data of the Brisbane River extending from Newfarm to the river mouth	Bathymetry used in Hydraulic Models
Mt Crosby Weir Pool Data	Seqwater (16/09/14)	Cross section survey of weir pool upstream of Mt Crosby Weir	Bathymetry used in Hydraulic Models
ARI Cross Sections	DNRM (22/09/14)	Australian Rivers Institute Cross Section data of the Brisbane River	Potential use of data in hydraulic model
Brisbane Lower Tributaries DEM	GHD/BCC (16/10/14)	DEM of lower Brisbane River including bathymetric data of local creeks	Potential use of bathymetry data in hydraulic model
Lockyer DEM	DSITIA (21/10/14)	DEM of the Lockyer Creek catchment	Potential use of data in hydraulic model
Fernvale Quarry LiDAR	Seqwater (11/06/15)	Fernvale Quarry LiDAR	Potential use of data in hydraulic model
2014 DNRM LiDAR data	DNRM (23/06/15)	LiDAR data captured in 2014 across the BCC and ICC area	Potential use of data in hydraulic model

Hydraulic Structures

Prior to commencement of the Hydraulic Assessment, a review of the hydraulic structure data provided by the DCS found it was not collected in sufficient detail for the purposes of the Hydraulic Assessment. Therefore, the collection of this dataset was included in the ITO and designated as a high priority at the start of the Hydraulic Assessment. In addition to collecting details of the structure geometry, supplementary data such as structure photographs, date of construction/modification and structure ownership were sought. Some of the structure information was captured during site visits undertaken for the Hydraulic Assessment. The structure data along with hydraulic modelling results for the structures form the basis of the Hydraulic Structure Reference Sheets (HSRS) which is a key deliverable of the Hydraulic Assessment.

Table 4-3 summarises the additional hydraulic structure datasets sourced and collected by the Hydraulic Assessment.

Table 4-3 Key Additional Datasets: Hydraulic Structures

Item	Source (Date Supplied)	Description	Relevance to BRCFS Hydraulic Assessment
Riverwalk and Future Ferry terminals	BCC (08/08/14)	Design drawings	Used to inform hydraulic model as appropriate.
DTMR Bridge Data	DTMR (15/08/14 and 05/11/2014)	Design drawings of DTMR bridges	Used to inform hydraulic model as appropriate.
ICC Bridge Data	ICC (15/08/14)	Bridge locations and design drawings for ICC bridges	Used to inform hydraulic model as appropriate.
QR Bridge and Underpass Data	QR (20/08/14 and 18/12/14)	Design drawings of multiple QR Bridges and underpasses	Used to inform hydraulic model as appropriate.
SRC Structure Data	SRC (20/08/14)	Design drawings of bridges within SRC area including Twin Bridges, Pointings Bridge, Watsons Bridge, Burtons Bridge and Savages Crossing	Used to inform hydraulic model as appropriate.
Seqwater Weir and Bathymetric Data	Seqwater (16/09/14)	Design drawings of weirs and localised bathymetric survey around structures	Used to inform hydraulic model as appropriate.
DPWH Bridge Data	DPWH (07/11/14)	Design drawings of Goodwill and Kurilpa pedestrian bridges	Used to inform hydraulic model as appropriate.
Mt Crosby Plans	Seqwater (07/11/14)	Design drawings for Mt Crosby weir and overbridge	Used to inform hydraulic model as appropriate.
Stormwater Pipes	BCC (30/03/15)	Stormwater pipe data within the Brisbane CBD area	Used to inform hydraulic model as appropriate.
Howard Smith Wharves	BCC (20/08/15)	Flood assessment report for Howard Smith Wharves	Used to inform design case hydraulic model as appropriate.
Kingsford Smith Drive, Ferry Terminals and Riverwalk	BCC (03/09/15)	Design drawings for KSD upgrade, new ferry terminals and Riverwalk	Used to inform design case hydraulic model as appropriate.

Land Use Data

Land use planning zones and cadastral property holdings were provided for BCC (2013), ICC (2006) and SRC (2012) LGAs. These cadastral datasets were largely suitable for categorising hydraulic roughness criteria. Where available, updated datasets were sourced and obtained as shown in Table 4-4.

Table 4-4 Key Additional Datasets: Land Use Data

Item	Source (Date Supplied)	Description	Relevance to BRCFS Hydraulic Assessment
Brisbane Land Use Data	Qld Government Information Service (20/08/14)	2013 Land Use Data	Assign roughness categories to hydraulic model
SRC Zone Mapping	SRC (03/09/14)	Updated Zone Mapping within SRC area	Assign roughness categories to hydraulic model

Historical Flood Data

Historical flood data including inundation extents and flood level marks are important for producing a robust hydraulic model calibration. Gauge levels and flow recordings for the calibration events, along with gauge rating curves are well documented and were sourced from the Hydrologic Assessment. The most notable data gaps were surveyed historic flood marks, particularly for the 2011 event. Surveyed peak flood marks for the 2013 event were not available at the time of the DCS and so were also sourced by the Hydraulic Assessment. Table 4-5 lists the additional historic flood data sets sourced and provided for use in the Hydraulic Assessment.

Table 4-5 Key Additional Datasets: Historic Flood Data

Item	Source (Date Supplied)	Description	Relevance to BRCFS Hydraulic Assessment
Floodlines	Qld Government Information Service (11/08/14)	BCC 1893 floodline BCC and ICC 1974 floodline QLD 2011 floodlines	Model calibration/verification
SRC Historic Flood Extents	SRC (03/09/14)	1974, 2011 and 2013 flood extents	Model calibration/verification
BCC Surveyed Debris Marks	BCC (29/09/14)	2011 Event surveyed flood levels within BCC area	Model calibration/verification
1893 and 1974 Flood extent and isohyets	DNRM (22/10/14)	JPG files of 1893 and 1974 flood extents	Model calibration/verification
2013 Event surveyed flood marks	BCC (27/10/14 and 31/10/14)	Surveyed flood marks of the 2013 event within BCC area	Model calibration/verification
1974 and 2011 surveyed flood marks	ICC (27/10/14)	Surveyed flood marks of the 1974 and 2011 events within ICC area	Model calibration/verification
Event reports 1999, 2011 and 2013	Seqwater (17/11/14)	Seqwater event reports of 1999, 2011 and 2013 events	Model calibration/verification
Flood levels at Fernvale	SRC (04/05/15)	Surveyed flood levels at Fernvale Quarry	Model calibration/verification
LVRC Surveyed flood levels	LVRC (06/05/15)	2013 event surveyed peak flood levels with LVRC area	Model calibration/verification

4.2 Topographic Data

4.2.1 Disaster Management Tool DEM (DMT DEM)

As part of the Digital Terrain Model and Bed Level Sensitivity Analysis (BLSA) project (BCC, 2014a), a DEM was developed across the full hydraulic model study area. This DEM, referred to as the DMT DEM, represents an area of 5,140 km^2 and was based on the latest floodplain LiDAR and bathymetry (post-2011 flood) information available at the time of the DMT study. Further details on the background and development of the DMT DEM are provided in BCC (2014a) and BCC (2014b).

The BLSA project also identified data accuracy concerns and data gaps. In preparation for the hydraulic modelling, surveys of the Bremer and Brisbane River lower reaches (Port of Brisbane) as recommended in BCC (2014a) were acquired and used in conjunction with the DMT DEM. These new data and other relevant data are described in the following sections.

It was not possible to incorporate the new data into the DEM, instead, the new data has been utilised on a priority basis by the hydraulic model in order to inform hydraulic model topography. Both the new data and other relevant data are described in the following sections.

4.2.2 Bathymetric Data

Bathymetric data defines the shape of the ground surface below water. This data can be collected as cross-sections or hydrographic surveys. Cross-sections are typically perpendicular to the flow direction and may include components of above-water topography. Hydrographic survey is traditionally limited to the underwater ground surface and is typically provided as a closely spaced set of regularly spread points.

Bathymetric Datasets used to inform the hydraulic modelling are summarised below. A3 Addendum Sheet 3 shows the geographical extent of these datasets.

PoB Lower Brisbane and Lower Bremer (2014)

In August 2014, the Port of Brisbane (PoB) (on behalf of the Qld DNRM) provided a 5 m gridded DEM bathymetric data point set based on their hydrographic survey of the following areas:

- Bremer River - from West Ipswich downstream to the confluence with the Brisbane River.
- Brisbane River - from Parker Island (near the Gateway Bridge) downstream to Inner Bar.
- Brisbane River - from Shafston Reach downstream to the Quarries Reach (near the Gateway Bridge) (completed as a part of the BCC Kingsford Smith Drive Stage 3 project).

BMT WBM used these points to create three DEMs: Lower Bremer, Lower Brisbane 1 and Lower Brisbane 2. The use of these DEMs is discussed in Section 4.2.3.

Lower Brisbane River and Tributaries (GHD/BCC)

For the purpose of the Coastal Plan Implementation Plan Study undertaken for BCC (GHD, 2014), a DEM of the Lower Brisbane River and tributaries was developed. This DEM was developed from BCC LiDAR data and various sources of bathymetric data. Of particular interest to this study are the bathymetric components of the DEM. The bathymetric data used to create the DEM includes:

- Cross-sectional data (BCC) extending up into some tributary creeks (for example, Norman and Oxley Creeks).
- Hydrographic survey data extending up into some tributary creeks (for example, Breakfast Creek and Bulimba Creek).
- Other sources including Dredge Area MSL, Moreton Bay Channel data, MSQ and R plus L Bathymetry (naming of these sources was extracted directly from the explanatory text file that was received with the DEM).

The BCC (GHD, 2014) data typically captures the lower reaches of some of the tidal tributaries where the DMT DEM relied on manual modifications to lower the creek beds. Comparison of the BCC (GHD, 2014) DTM and the DMT DEM shows little or no difference in the overbank areas. In general, for the in-bank areas of the lower reaches of the Brisbane River (below Hamilton), the BCC (GHD, 2014) DTM gives higher bed levels than both the DMT DEM and the 2014 Port of

Brisbane bathymetry. The BCC (GHD, 2014) DTM has not been used in these regions, with priority given instead to the 2014 PoB bathymetric survey.

Mt Crosby Weir Pool (2007)

Seqwater commissioned a detailed hydrographic survey of the Mt Crosby weir pool in 2007, extending about 15 km upstream from the Mt Crosby Weir to Pine Mountain. This survey was undertaken as a set of bathymetric cross-sections spaced at 25 m intervals. These sections were used to create a bathymetric DEM of the Mt Crosby weir pool. The use of this DEM is discussed in Section 4.2.3.

Lowood-Fernvale Cross-Sections (2008)

As part of the Fernvale and Lowood Flood Study (BCC, 2009), cross-sections were surveyed on both the Brisbane River and Lockyer Creek in 2008. A total of 46 cross-sections were surveyed with 14 of these on Lockyer Creek and 32 on the Brisbane River, as shown in A3 Addendum Sheet 3. The spacing between sections is approximately 500 m. A comparison of these surveyed cross-section points with the DMT DEM data in this region revealed that the surveyed points are on average 0.42 m lower than the DMT DEM, with a standard deviation of 2.0 m. The DMT DEM is primarily based on LiDAR in this region and it is not uncommon for LiDAR to be higher than surveyed data due to the effects of vegetation and water. Furthermore, the cross-sections did not extend across the entire waterway and in some reaches they were at a spacing that was impractical for the hydraulic modelling.

It is noted that the DMT DEM compared well with the surveyed cross-section at a Seqwater gauge in the vicinity of the Lowood and this led to the understanding that BCC (2014a) undertook manual adjustment of the DMT DEM bathymetry using the invert levels from the Lowood Fernvale cross-sections (BCC, 2009a) in conjunction with aerial imagery to identify pools and riffles. It was therefore concluded that the DMT DEM suitably represents the cross-sectional area and river conveyance in the area covered by the Fernvale-Lowood cross sections and as such the DMT DEM was used to inform model topography in this area.

RUBICON Model Cross-Sections

In 1994, Qld DPI completed the Brisbane River and Pine River Flood Study (DPI, 1994) on behalf of the South East Queensland Water Board. RUBICON hydraulic modelling was undertaken using the following sources of in-bank topographic data:

- 40 cross sections of the Brisbane River surveyed by DPI (formerly the Queensland Water Resources Commission) in 1992 between Wivenhoe Dam and Colleges Crossing. A further 8 cross sections were available from a 1989 survey near Burtons Bridge.
- Cross sections of the Lockyer Creek surveyed by DPI in 1966.
- A hydrographic survey of the Brisbane River extending from the river mouth to just below Colleges Crossing from 1974.
- A hydrographic survey of the Bremer River from its junction with the Brisbane River to the Basin Reserve in Ipswich by the Bremer River Trust Fund in 1988.

As shown in A3 Addendum Sheet 3 these cross-sections are very widely spaced. In addition, some of the sections were surveyed many years ago, making their currency less certain. These two facts in combination make the cross-sections of limited value in the modelling undertaken for the current study. However, they have been used to provide further insights into in-bank topography on an as-required basis.

Ipswich City Council Cross-Sections

The Ipswich City Council cross-sections cover some of the minor tributaries of the Bremer River. The locations of these sections are outside the extent of the hydraulic models developed for the current study.

ARI Depth Soundings (2012)

Depth soundings of the Brisbane River were collected by the Australian Rivers Institute (ARI) in September/November 2012. The soundings extend from Wivenhoe downstream to the top end of the Mt Crosby weir pool (upstream of Mt Crosby) and result in small overlaps with the Lowood-Fernvale Cross-Sections and the Mt Crosby pool data at the upstream and downstream ends respectively. Comparisons of the ARI bathymetry within the LiDAR dataset found that ARI bathymetry values were 1.3 m lower on average than LIDAR, with a standard deviation of 1.4. This seems reasonable given that the LIDAR does not extend below water level and that ARI data was collected from a canoe.

The ARI data was not suited for incorporation into the Fast Model due to its large spatial variance in the horizontal and it often not being perpendicular to the flow direction. It was therefore not used in the Fast Model but did assist in the development of the Detailed Model for defining minimum bed elevations.

MIKE-11 Model Cross-Sections

The MIKE11 model of the Brisbane River has been reviewed and updated numerous times. It was initially developed by SKM (1998) using 197 surveyed cross-sections up to the extent of the BCC Council area (about 79 km upstream and about 10 km downstream of Colleges Crossing). The MIKE11 model was extended up into the Bremer River by SKM (2000) using surveyed cross-sections and photogrammetry of “questionable accuracy” to represent the modelled floodplain topography. In 2005, the SKM (2000) MIKE11 model was extended up to Wivenhoe Dam and into Lockyer Creek to assess the impacts of the Wivenhoe Dam upgrade (Wivenhoe Alliance, 2005). Cross-sections used to extend the model in 2005 were derived from:

- 5 m digital contours of Esk Shire Council area.
- Cross sections surveyed for DNR for the 1994 study (DNR, 1994) – the “Rubicon Model Cross-Sections”.

The most recent review and update of the MIKE11 model was undertaken by SKM (2011) for Seqwater. One significant key finding of this review was that the representation of cross-sections was not found to be appropriate for the magnitude of events relevant to that study.

More recent bathymetric survey now covers the majority of the rivers over which the surveyed MIKE11 cross-sections lie. For areas in which bathymetric survey is not available (e.g. upstream of the Mt Crosby weir pool to the Lowood-Fernvale cross-sections), the MIKE11 cross-sections are based on the Rubicon model cross-sections which are too greatly spaced to be of direct practical use in the hydraulic model topography. As such, the MIKE11 sections have not been used directly in the model but were used on an as-needed basis for checking purposes.

Seqwater Surveyed Cross-Sections at Gauge Sites

Cross-section information upstream and downstream of gauge sites is held by Seqwater and was supplied in September 2014. The cross-sections are not suitable for use in the model but have been used to provide an indication of potential accuracy or otherwise of the LiDAR data used in the in-bank sections of the Fast Model.

4.2.3 Priority Ranking of Topographic Datasets

For the purpose of the Hydraulic Assessment, each dataset has been given a priority ranking to ensure that the most suitable data is utilised within the relevant model area. This priority ranking is only applicable in areas where the datasets overlap. That is, in an area where only one dataset is available, then this dataset is the one used, regardless of its priority ranking. If datasets do not overlap, they may be assigned the same priority ranking as they are never in competition with each other. For example, there is no overlap between each Priority 1 dataset shown below for in-bank data.

Priority 1 Data (Highest Priority):

- Mt Crosby Weir Pool (2007).
- PoB Lower Brisbane and Lower Bremer (2014).

Priority 2 Data:

- Lower Brisbane River and Tributaries DEM (GHD).

Priority 3 Data (Lowest Priority):

- DMT DEM.

Checking as Required[11] (not directly incorporated within the model):

- ARI Cross-Sections (2012).
- RUBICON & MIKE11 Model Cross-Sections.
- Lowood-Fernvale Cross-Sections (2008).
- Seqwater Surveyed Cross-Sections at Gauges.

4.2.4 Breaklines

Breaklines are survey strings used to define continuous linear features. In relation to 2D modelling, they are used to define both the location and elevation of floodplain features such as levees and embankments that need to be specifically included in the DEM and/or the hydraulic model due to their ability to affect hydraulic behaviour. In the Detailed Model they are also used to define the bed levels for lengths of river or minor channels and gullies where no bathymetry data is used and/or the channel is too narrow to be adequately represented as a continuous linear feature in the DEM.

Table 4-6 categorises the breaklines into general types and states the source of elevation data allocated to the features. The 5 m DMT DEM, is the most common source for breaklines within the extent of the hydraulic model. An automated procedure was used to sample high or low points from the DMT DEM within a given search radius.

Table 4-6 Breakline Categories

Breakline Category	Description of Feature	Source of Elevation Data
Rail	Dataset of railway lines supplied by Queensland Rail	5 m DMT DEM
Road	Dataset of State carriageways supplied by DTMR	5 m DMT DEM
Ridge	Raised features such as farm levees, dam walls and minor roads likely to have a hydraulic influence digitised manually by BMT WBM	5 m DMT DEM
Gully	Minor channels or main channels with poor bathymetry digitised manually by BMT WBM	Various. Typically the 5 m DMT DEM but other sources are also used.
Riverbank	Breaklines used to define the banktop elevations within the Detailed Model along the boundary of the 1D/2D model interface. Digitised manually by BMT WBM	5 m DMT DEM

[11] The "checking as required" sections upstream of Mt Crosby weir pool were used in a number of ways to check that the topography/bathymetry actually used in this area (LiDAR and other data from the DMT DEM) reasonably represented the topography/bathymetry for the purposes of the Fast Model. For example, a sensitivity test was undertaken to test the significance of the difference between the datasets in the Fernvale Lowood area by assessing the difference in model results when using either the DMT DEM or the cross-sections. This sensitivity test demonstrated that model results were comparable. In summary, this is an example of what is meant by "checking as required" (see MR2 for further details on this process).

DMT Model (BCC, 2014b) results were used to limit the extent of manual digitisation required by only considering locations in high hydraulic hazard (DxV or depth multiplied by velocity) areas, as it is these areas that will potentially have the greatest impact on model results.

Slim flow obstructions including noise barriers, fences and hand railings are typically not present in LiDAR data or apparent from aerial imagery due to their "slim" nature. Thus, it was not possible to incorporate these features into the hydraulic models, simply because the data was not available and not able to be extracted from any existing dataset.

4.2.5 Historical Topographic Data

Topography of floodplains and channels can change over time. In particular, large events can have a major impact on in-bank channel form and vegetative condition. These parameters can then impact upon channel conveyance. For example, significant changes to river conveyance (in-bank bathymetry and roughness) occurred within the Brisbane River catchment due to damage to channels and stripping of vegetation caused by the 2011 event floodwaters. The area in the vicinity of Savages crossing was particularly affected. Michel Raymond from Seqwater (pers. comm., Nov 2014) noted that the impacts of this damage resulted in a general drop in water levels at Mt Crosby and Savages Crossing.

Development within the catchment, particularly raised linear features such as roads and railways, can also impact on hydraulic behaviour within the floodplain

Ideally, channels and floodplains would be surveyed periodically to ensure that changes to topography were recorded and that the relevant topographic dataset could be used in a hydraulic model during calibration to a particular historic event. However, this would be a costly exercise and has not been carried out for the Brisbane River catchment. Some limited amendments to the topography were made when modelling the 1974 event as follows:

- The raised Cunningham Highway near Amberley was at a lower elevation in 1974 and so the raised embankment was removed when modelling the 1974 event.
- The quarry near Fernvale had not started extraction operations and so features such as quarry pits, spoil heaps and noise bunds were removed.

These features were amended as they have the potential to significantly influence local hydraulics.

4.3 Hydrographic Data

4.3.1 Historical River Gauge Data

River gauges record water levels with flows derived from the recorded water levels using a rating curve. As part of the calibration process for a hydraulic model, the recorded water levels are compared to modelled water levels for each calibration event. A summary of the river gauges available for each calibration event is provided in Table 4-7. Gauges that are indicated as having data of questionable quality are discussed further in MR2.

The location of the river gauges is provided in A3 Addendum Sheet 1. As the GIS coordinates supplied with the gauge data generally indicate the position of the gauge hut/electronics rather than the pressure sensor (where the water level is actually measured), Seqwater (personal communication, Oct 2014) provided advice on the exact positioning of the pressure sensor for a number of critical gauge sites. This allowed the GIS point of measurement for each gauge to be moved from an out-of-bank location to the more correct in-bank main channel location. While some uncertainty remains on the precise location of some of these pressure sensors; the updated dataset is considered an improvement over that used previously.

Table 4-7 Historical Availability of River Gauge Data for Calibration Events

BoM Gauge No.	AWRC Gauge No.	Gauge Name	System	Historical Calibration Data				
				1974	1996	1999	2011	2013
540495	143891	Whyte Island Tide AL	Moreton Bay	x	x	x	Yes	Yes
40647	143935	Brisbane bar Tide TM	Moreton Bay	Yes	Yes	Yes	Yes	Yes
540129	143847	Hemmant AL	Lower Brisbane	x	x	x	Yes	?
MSQ: R046047A.86		Gateway Bridge	Lower Brisbane	x	Yes	Yes	Yes	x
540286	143877	Breakfast Creek Mouth Al	Lower Brisbane	x	x	x	Yes	Yes
540130	143851	Bowen Hills Alert	Lower Brisbane	x	x	x	Yes	Yes
540198	143838	City Gauge	Lower Brisbane	Yes	Yes	Yes	Yes	Yes
540274	143872	Oxley Ck Mouth AL	Lower Brisbane	x	x	x	Yes	Yes
540132	143848	East Brisbane Alert	Lower Brisbane	x	x	x	Yes	Yes
540192	143832	Jindalee Alert	Lower Brisbane	Yes	x	?	Yes	Yes
41472	-	Centenary Bridge	Lower Brisbane	Yes	x	x	Yes	x
540200	143924	Moggill Alert	Lower Brisbane	Yes	Yes	?	?	Yes
-		Clarence Rd	Lower Brisbane	Yes	x	x	x	x
-		Dutton Park Cemetery	Lower Brisbane	Yes	x	x	x	x
-		Highgate Hill - Paradise St	Lower Brisbane	Yes	x	x	x	x
-		Tennyson Powerhouse	Lower Brisbane	Yes	x	x	x	x
-		Sandy Creek	Lower Brisbane	Yes	x	x	x	x
-		St Lucia Ferry	Lower Brisbane	?	x	x	x	x
-		OxleyCkCorinda	Lower Brisbane	Yes	x	x	x	x
-		Yeronga St	Lower Brisbane	Yes	x	x	x	x
-		Tennyson	Lower Brisbane	Yes	x	x	x	x
540063	143868	Colleges Crossing Alert	Mid Brisbane	x	x	x	?	?
540199	143839	Mt Crosby AL	Mid Brisbane	Yes	Yes	Yes	Yes	Yes
540256	143864	Kholo Bridge AL	Mid Brisbane	x	x	x[11]	?	Yes
540606	143049	Lake Manchester HW TM	Mid Brisbane	x	x	x	Yes	Yes
540257	143856	Burtons Bridge	Mid Brisbane	x	x	x[11]	?	Yes
540066	143001C	Savages Crossing TM	Mid Brisbane	Yes	Yes	Yes	Yes	Yes
540182	143001A	Lowood Alert-B	Mid Brisbane	Yes	x	Yes	Yes	Yes
540178	143823	Wivenhoe Dam TW Alert-P	Mid Brisbane	x	x	?	?	Yes
40831	143954	Ipswich Alert	Bremer River	Yes	Yes	x	Yes	Yes
540250	143852	Brassall (Hancocks Bridge)	Bremer River	x	x	x	?	?
40836	14953	One Mile Bridge Alert	Bremer River	x	x	Yes	Yes	Yes
540550	143114	Berry's Lagoon Alert	Bremer River	x	x	x	?	Yes
40838	143956	Three Mile Bridge AL	Bremer River	x	x	Yes	?	?
540504	143896	Walloon AL	Bremer River	x	Yes	?	Yes	Yes
540249	143854	Bundamba (Hanlon St) Al	Bundamba Ck	x	x	x	Yes	?

BoM Gauge No.	AWRC Gauge No.	Gauge Name	System	Historical Calibration Data				
				1974	1996	1999	2011	2013
-	143114	Mary St	Bundamba Ck	Yes	x	x	x	x
540248	143857	Churchill Alert	Deebing Ck	x	x	x	Yes	Yes
540062	143983	Loamside Alert	Purga Creek	x	x	Yes	Yes	Yes
540210	143113	Loamside TM	Purga Creek	Yes	Yes	x	x	x
40816	143108	Amberley (DNRM) TM	Warrill Creek	Yes	Yes	Yes	Yes	Yes
540180	143825	Amberley-P (Greens Road)	Warrill Creek	x	Yes	Yes	Yes	x 13a
40874	143962	Brisbane Road Alert	Woogaroo Creek	x	x	x	Yes	?
540051	143207	O'Reilly's Weir AL	Lockyer Creek	x	?	Yes	Yes	x 13a
540544	143700	Rifle Range Rd Alert -P	Lockyer Creek	x	Yes	Yes	Yes	Yes
540174	143819	Lyons Bridge Alert-P	Lockyer Creek	Yes	x	Yes	?	x 13a
540149	143808	Glenore Grove Alert	Lockyer Creek	Yes	x	Yes	Yes	Yes

Yes	Data available and of sufficient quality for use in calibration
x	Data not available or gauge identified as erroneous by Seqwater
?	Data available but of questionable quality. Discussed in MR2.

13a – Assessment validated by Seqwater (2013a)
13b – Assessment validated by Seqwater (2013b)
11 – Assessment validated by Seqwater (2011)

4.3.2 Historical Flood Mark Levels

Historical flood mark records exist for the 1974, 2011 and 2013 flood events. These marks are considered to be peak flood levels at spot locations. These flood marks were surveyed after the event and are typically based on debris marks or watermarks. It is important to realise that debris and watermarks can be inaccurate for a number of reasons including:

- Dynamic hydraulic effects such as waves, eddies, pressure surges, bores or transient effects, which may not be accounted for in the model. For example, if the debris mark is located within a region of fast flowing floodwater it is possible that the floodwater has pushed the debris up against an obstacle, lodging it at a higher level than the surrounding flood level.
- Lodgement of debris at a level lower than the peak flood level. The reason for this is that for debris to be deposited, it needs to have somewhere to lodge and this elevation is not always at the peak flood level. For example, debris lodged in the fork of a tree or on the strands of a barb-wire fence may have been carried there by floodwater that went *higher* than the tree fork or fence wire, or was lodged on the receding arm of the flood, but this was not apparent after the event due to the lack of higher lodging places.

4.3.3 Flow Gauging at Centenary Bridge

Flow gauging carried out on the downstream side of Centenary Bridge during the 1974, 2011 and 2013 floods provides valuable data on the actual flows close to the peaks of these floods and also during the rising and falling stages. For the 2011 and 2013 floods, flows were also measured during the “steady-state” post flood Wivenhoe Dam releases, once again providing a check on discharges during controlled releases from Wivenhoe Dam. Of note is that the 1974 flow measurements are considered to be of lesser accuracy due to the use of older technology. Water levels off the downstream side were also recorded whilst the flow measurements were taken.

4.4 Hydraulic Structure Information

Hydraulic structure information was sourced from a variety of agencies and was received in a number of formats, including plans and existing hydraulic model representations. Table 4-8 contains a summary of the historical presence of hydraulic structures that has guided their inclusion in the hydraulic models. The location of each of these structures is shown in A3 Addendum Sheet 4 labelled with the ID shown in Table 4-8.

Some hydraulic structures have little impact on hydraulic behaviour (eg the Gateway Bridge), nonetheless they are incorporated into the model.

Table 4-8 Historical Presence of Hydraulic Structures

ID	Description	River Crossing	1974	1996	1999	2011	2013
ICC_056	Three Mile Bridge	Bremer River	Yes	Yes	Yes	Yes	Yes
ICC_057	One Mile Bridge	Bremer River	Yes	Yes	Yes	Yes	Yes
ICC_058	Hancock Bridge	Bremer River	Yes	Yes	Yes	Yes	Yes
QR_025	Railway Workshop Bridge	Bremer River	Yes	Yes	Yes	Yes	Yes
QR_103	Wulkuraka Rail Bridge	Bremer River	Yes	Yes	Yes	Yes	Yes
TMR_037	Warrego Hwy	Bremer River	Yes	Yes	Yes	Yes	Yes
TMR_043	David Trumpy Bridge	Bremer River	Yes	Yes	Yes	Yes	Yes
BCC_006	Story Bridge	Brisbane River	Yes	Yes	Yes	Yes	Yes
BCC_008	Goodwill Bridge	Brisbane River	x	x	x	Yes	Yes
BCC_009	Victoria Bridge	Brisbane River	Yes	Yes	Yes	Yes	Yes
BCC_010	Kurilpa Bridge	Brisbane River	x	x	x	Yes	Yes
BCC_011	William Jolly Bridge	Brisbane River	Yes	Yes	Yes	Yes	Yes
BCC_012	Go Between Bridge	Brisbane River	x	x	x	Yes	Yes
BCC_019	Green Bridge	Brisbane River	x	x	x	Yes	Yes
BCC_020	Walter Taylor Bridge	Brisbane River	Yes	Yes	Yes	Yes	Yes
BCC_021	Jack Pesch Bridge	Brisbane River	x	x	Yes	Yes	Yes
BCC_076	Kholo Rd Bridge	Brisbane River	Yes	Yes	Yes	Yes	Yes
BCC_077	Mt Crosby Weir	Brisbane River	Yes	Yes	Yes	Yes	Yes
QR_083	Albert Bridge	Brisbane River	Yes	Yes	Yes	Yes	Yes
QR_087	Merivale St Bridge	Brisbane River	x	Yes	Yes	Yes	Yes
SRC_073	Twin Bridges	Brisbane River	Yes	Yes	Yes	Yes	Yes
SRC_074	Savages Crossing	Brisbane River	Yes	Yes	Yes	Yes	Yes
SRC_075	Burtons Bridge	Brisbane River	Yes[12]	Yes[12]	Yes[12]	Yes	Yes
TMR_001	New Gateway Mtwy	Brisbane River	x	Yes	Yes	Yes	Yes
TMR_038	Captain Cook Bridge	Brisbane River	Yes	Yes	Yes	Yes	Yes
TMR_039	Centenary Hwy	Brisbane River	Yes	Yes	Yes	Yes	Yes
TMR_050	Brisbane Valley Highway	Brisbane River	x	Yes	Yes	Yes	Yes
TMR_078	Colleges Crossing - Mt Crosby Rd	Brisbane River	Yes	Yes	Yes	Yes	Yes
QR_065	Brisbane Valley Rail Trail near Mahons Rd	Lockyer Ck	Yes	Yes	Yes	Yes	Yes
SRC_063	Lyons Bridge	Lockyer Ck	Yes	Yes	Yes	Yes	Yes
SRC_064	Watsons Bridge	Lockyer Ck	x	Yes	Yes	Yes	Yes
SRC_070	Pointings Bridge	Lockyer Ck	x	x	x	Yes	Yes
SRC_071	O'Reilly's Weir	Lockyer Ck	Yes	Yes	Yes	Yes	Yes
BCC_023	Pamphlet Bridge - Graceville Ave	Oxley Ck	Yes	Yes	Yes	Yes	Yes
TMR_049	Cunningham Highway	Purga Ck	x	Yes	Yes	Yes	Yes
TMR_048	Cunningham Highway	Warrill Ck	x	Yes	Yes	Yes	Yes

x = not yet constructed

Note: A unique structure ID was assigned to each structure. The ID reflects the owner of the structure, followed by a number unique to that owner. Owner abbreviations are: **BCC** – Brisbane City Council; **DPW** – Department of Housing and Public Works; **ICC** – Ipswich City Council; **QR** – Queensland Rail; **SEQw** – Seqwater; **SRC** – Somerset Regional Council; **TMR** – Department of Transport and Main Roads.

[12] The survey drawing for Burtons Bridge (prepared in 2000) indicates that a new bridge was constructed around this time with the old bridge being removed. The design drawings for the old bridge were not provided and were not able to be sourced. As such, the model contains the new bridge data for all events, in lieu of the old data.

4.5 Land Use Data

Spatial land use data is used to assist in determining the spatial extent of model roughness values. The digital land use layers received for this study (collected by Aurecon, 2013) were not of sufficient spatial resolution (for modelling applications) to allow direct application of model roughness parameters based on land use extents. Land use extents were updated by manual digitisation using aerial photographs to locate the land-use layer polygon more accurately. An example of the refined land use delineation following the manual digitisation process is provided in Figure 4-1.

Roughness parameters for each land use area are discussed and provided in Section 5 and Section 6 for the Fast and Detailed Models respectively.

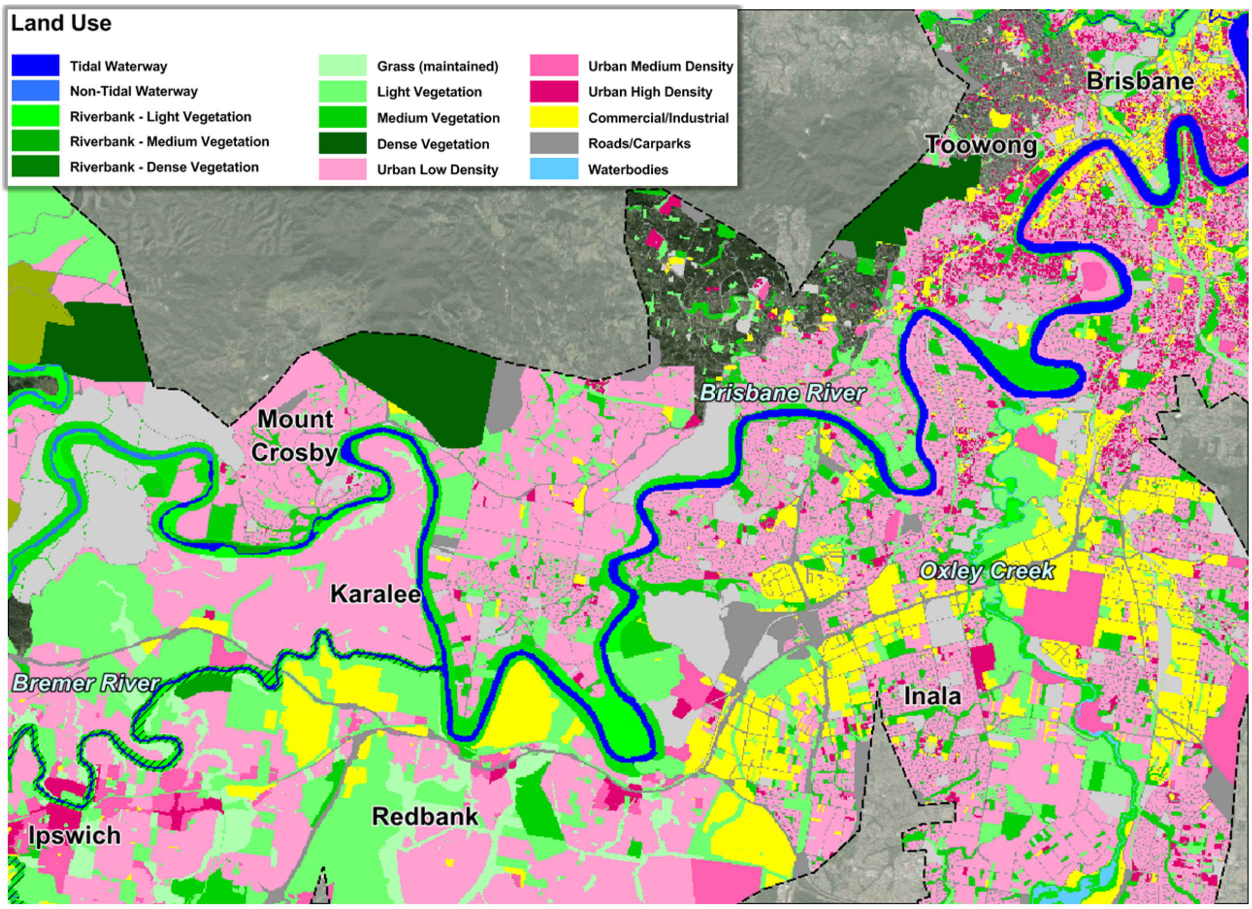


Figure 4-1 Example of the Detailed Spatial Differentiation of Land Uses

4.6 Inflows

Model Inflows are extracted from the hydrologic models and are applied to the Fast and Detailed models. Inflows are categorised into:

- Historical Event Inflows – for the five calibration/validation events of 1974, 1996, 1999, 2011 and 2013.
- Design Case (Monte Carlo) Inflows – for 11,340 individual Monte Carlo events used in deriving AEP flood levels.

Further details on the two categories of inflows are provided below.

4.6.1 Historical Event Inflows

Model inflows were extracted from the calibrated hydrologic models provided by the Hydrologic Assessment. These models were refined by the Hydrologic Assessment from those originally developed and calibrated by Seqwater (Seqwater, 2013).

Comparisons undertaken during the Hydraulic Assessment of the Hydrologic Assessment and Seqwater versions of the hydrologic models generally demonstrate that the Hydrologic Assessment models produces flows of greater volume than the Seqwater model, with the exception of the smaller events of 1996 and 1999. This is of interest to the Hydraulic Assessment as the previous DMT Model study undertaken by BCC (BCC, 2014a) found the need to use multipliers on the Seqwater model flows to achieve an acceptable calibration. BCC (2014a) contains further details on the rationale and application of the multipliers. However, with the exception of the 1974 verification event (see below), the current study has found that the flows output from the Hydrologic Assessment hydrologic model produce an acceptable calibration without the need for multipliers. This is related, in part, to the generally greater flow volumes output from the Hydrologic Assessment modelling for the larger historical events.

Special mention is made for the 1974 verification event. Wivenhoe Dam was not in existence in 1974, therefore the inflows to the model at the Wivenhoe Dam site were based on the hydrologic model generated hydrographs from the Upper Brisbane and Stanley River catchments. These flow estimates have higher uncertainty than using the estimated discharges through Wivenhoe Dam for the other calibration/verification events as there is high degree of certainty for the flow rate over a spillway.

For the 1974 hydrologic modelling it was noted that there is a significant difference between the Initial Loss (IL) / Continuing Loss (CL) used in the Bremer catchment by Seqwater (Seqwater, 2013b) in the original modelling and the updated modelling for the Hydrologic Assessment. These loss values are shown in Table 4-9. The Hydrologic Assessment used notably smaller IL/CL values for the Bremer, Purga and Warrill catchments which resulted in larger flow volumes being predicted by the Hydrologic Assessment modelling compared to those predicted by the Seqwater modelling.

Table 4-9 Rainfall Loss Comparisons for the 1974 Verification Event

January 1974 Event	Losses (IL/CL)	
Catchment	**Seqwater**	**Hydrologic Assessment**
Lockyer	50 / 2.5	40 / 1.8
Bremer	65 / 2.0	30 / 0.3
Purga	80 / 2.5	40 / 0.8
Warrill	79 / 2.0	8 / 0.5
Upper Brisbane	45 / 1.2	50 / 1.5

Given the additional uncertainty associated with the hydrology of the 1974 event, both sets of IL/CL values were retained for deriving flow inputs to the hydraulic models by adopting scenarios as follows:

- 1974 Event IL/CL Scenario 1: Use of BRCFS Hydrologic Assessment inflows.
- 1974 Event IL/CL Scenario 2: Use of Seqwater inflows.

As the Hydraulic Assessment further developed, 1974 event inflows were derived from a further IL/CL combination. This resulted from a Detailed Model Sensitivity Test 9 (ST09) whereby inflows were applied which used IL/CL values within the Bremer catchment (including Warrill and Purga Creeks) that were mid-way between the values adopted by Seqwater and the Hydrologic Assessment. This was termed the '1974_ST09 inflows' and was adopted for Detailed Model verification purposes (see Section 6.2.4).

4.6.2 Design Case (Monte Carlo) Inflows

The Hydrologic Assessment (Aurecon, 2015b) completed a Monte Carlo analysis at a range of locations throughout the Brisbane River Catchment to produce estimates of peak AEP flow rates at each location. Inflows for a subset of Monte Carlo events were then to be provided for use in the hydraulic models. A methodology for determining this subset of events from the tens of thousands of events considered in the Hydrologic Assessment evolved with the study. The ITO (DILGP, 2014) initially envisaged that due to limitations of hydraulic model run times and logistics, around 500 events would be selected. Through the hydraulic model development process and Hydrologic and Hydraulic Assessments interfacing discussions it was determined that it was feasible and highly preferable to run a much larger set of Monte Carlo events through the Fast Model.

In total, inflows for 11,340[13] separate events were supplied. These represent the events generated for the Brisbane City Gauge (ie. for the whole of the catchment rainfall AEP scenarios[14]) and for event durations of 12, 18, 24, 36, 48, 72, 96, 120 and 168 hours (9 durations in total).

The inflows were generated by the Hydrologic Assessment using the Delft-FEWS framework and were provided in NetCDF format based on a work specification prepared by the Hydraulic

[13] The Hydrologic Assessment considered 60 AEPs per event duration with 21 simulations performed per AEP. Thus the Hydrology Assessment simulated 1260 Monte Carlo events for each of 9 durations, leading to a total of 11,340 (9 x 1260) Monte Carlo events.
[14] The use of 'whole of catchment rainfall AEP scenarios' was a methodologic approach derived as part of the Hydrologic and Hydraulic interfacing process and is described further in MR4.

Assessment. In total, around 1.1 million hydrographs were provided (11,340 events x 100 inflow/boundary locations). Further detail on the methodology for Monte Carlo subset selection is provided in Section 7 with full details and the accompanying work specification found in MR4.

5 Fast Model: Development and Calibration

The Fast Model is a purely 1D model designed to simulate large numbers of flood events with run times of less than 15 minutes. Its primary purpose, as stipulated by the ITO, is to simulate 500 Monte Carlo events as provided by the Hydrologic Assessment, however, this was extended to 11,340 events to produce a more reliable Annual Exceedance Probability (AEP) flood level frequency analysis. This section begins by describing the updates to the DMT model, which helped in the Fast Model development process (Section 5.1). It then describes the development and calibration of the Fast Model including sensitivity testing on key model parameters/assumptions (Section 5.2 to 5.6).

5.1 DMT Model Update

The Disaster Management Tool (DMT) was developed by Brisbane City Council (BCC) for the then Department of State Development Infrastructure and Planning (DSDIP) and was finalised in June 2014 (BCC, 2014a) as an interim tool for disaster management. It serves a key purpose in the Hydraulic Assessment by informing the development of the Fast Model, particularly in the identification of overland flow routes and locations of breakout flow under extreme flow conditions.

Since the completion of the DMT Model, updated hydrology was made available as part of the BRCFS Hydrologic Assessment (Aurecon, 2014a,c). Furthermore, additional bathymetric survey was captured, collated or made available to the BRCFS[15] (see Section 4.2.2).

This study updates the DMT Model with these additional datasets and includes other updates to the model thereby providing an up-to-date tool used for informing the Fast Model development. This updated model is termed hereafter as the Updated DMT Model. The key updates to the DMT model can be summarised as follows:

- Revised hydrologic inflows from the Hydrologic Assessment (Seqwater inflows were previously used).
- Hydrologic sub-catchment inflows applied in a distributed manner along streamlines (previously lumped sub-catchment inflows).
- Inclusion of bathymetry datasets for the lower Brisbane, lower Bremer, Mt Crosby Weir Pool and lower local tidal creeks (see Section 4.2.2 for details on these datasets).
- Application of updated land use extents. Manning's n values are updated to reflect the revised land use classes but generally remained consistent with the values used in the original DMT for in bank areas.
- Minor changes to the model structure such as incorporating the use of 'event' files and disabling of localised output results.

Simulations of the Updated DMT Model were undertaken for the 1974, 2011 and 2013 events. This enabled a comparison of model performance against both recorded flood levels and the original DMT Model at key gauge locations. A detailed recalibration exercise was not undertaken as it is not

[15] For example the Mt Crosby Survey was not known to exist at the time of DMT and DTM & BLSA projects in 2013/2014 and was identified as part of the DCS completed for the BRCFS.

a requirement of the ITO and the key purpose of the Updated DMT model for the Hydraulic Assessment was to inform the development of the Fast Model, particularly under extreme flow conditions. Overall, the calibration of the Updated DMT Model to the 1974, 2011 and 2013 events remained comparable to the original model. On this basis the Updated DMT Model was considered suitable for informing the development of the Fast Model (see MR2 for further details including plots comparing the original and updated DMT models with observed data).

5.1.1 Extreme Event Hydraulic Hazard Mapping

Three hypothetical extreme events were simulated in the Updated DMT Model by scaling up the 1974 event inflows as follows: 2x1974, 5x1974 and 8x1974 flows. Hydraulic hazard (DxV or depth multiplied by velocity) mapping of these extreme hypothetical floods allowed breakouts and extreme overland flow paths to be identified. These were then defined as 1D channel locations and storage nodes in the Fast Model. Figure 5-1 shows an example of how the hydraulic hazard was able to inform the Fast Model schematisation. In Figure 5-1 the nodes and channels that form part of the Fast Model have been located so as to capture the extreme flow breakout locations and overland flow routes identified by the Updated DMT model, in addition to the main river flow paths.

5.1.2 Check on Fast Model Performance

As well as assisting in the schematisation of the Fast Model, the Updated DMT Model provides an additional cross-check on the Fast Model's performance. Updated DMT model output is therefore included on relevant Fast Model output plots. An example of this is shown in Figure 5-2 for the Brisbane River at Oxley Creek during the 2011 event. MR2 contains a full set of plots at all available gauges.

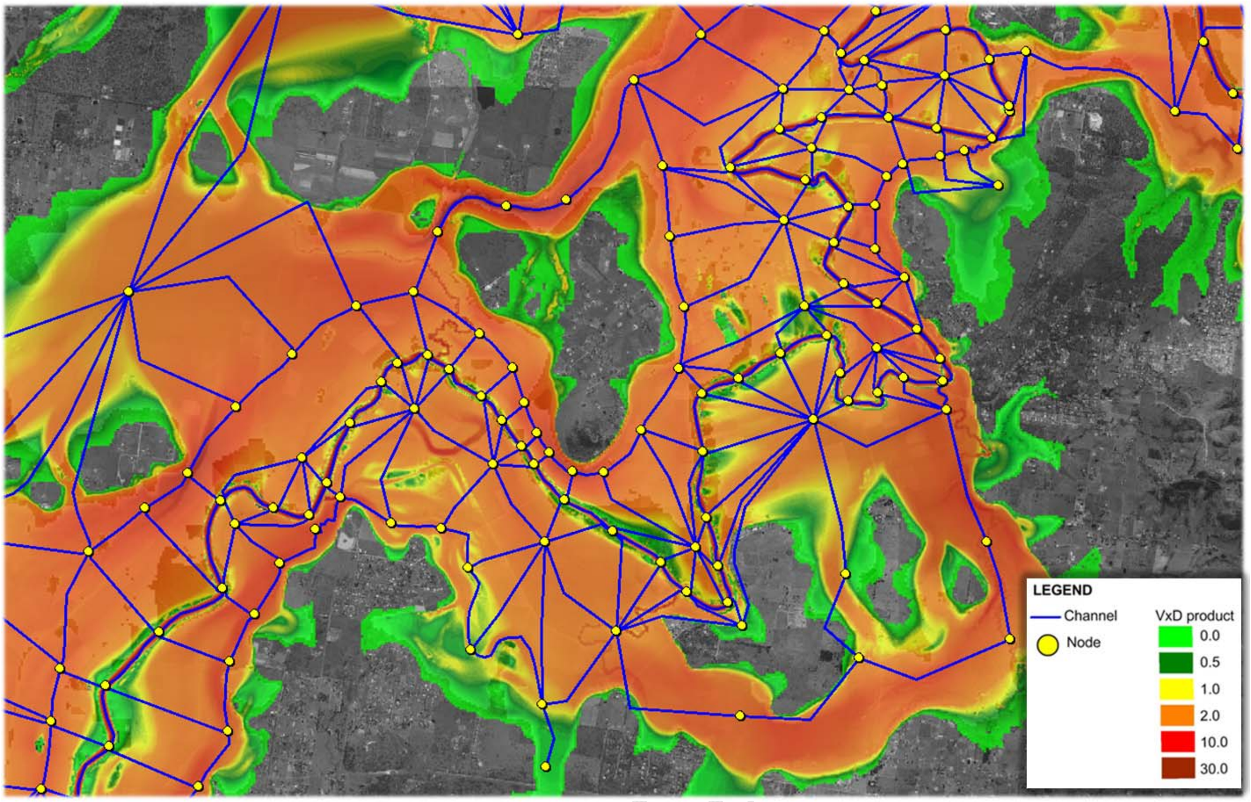


Figure 5-1 Use of the Updated DMT Model in Development of the Fast Model

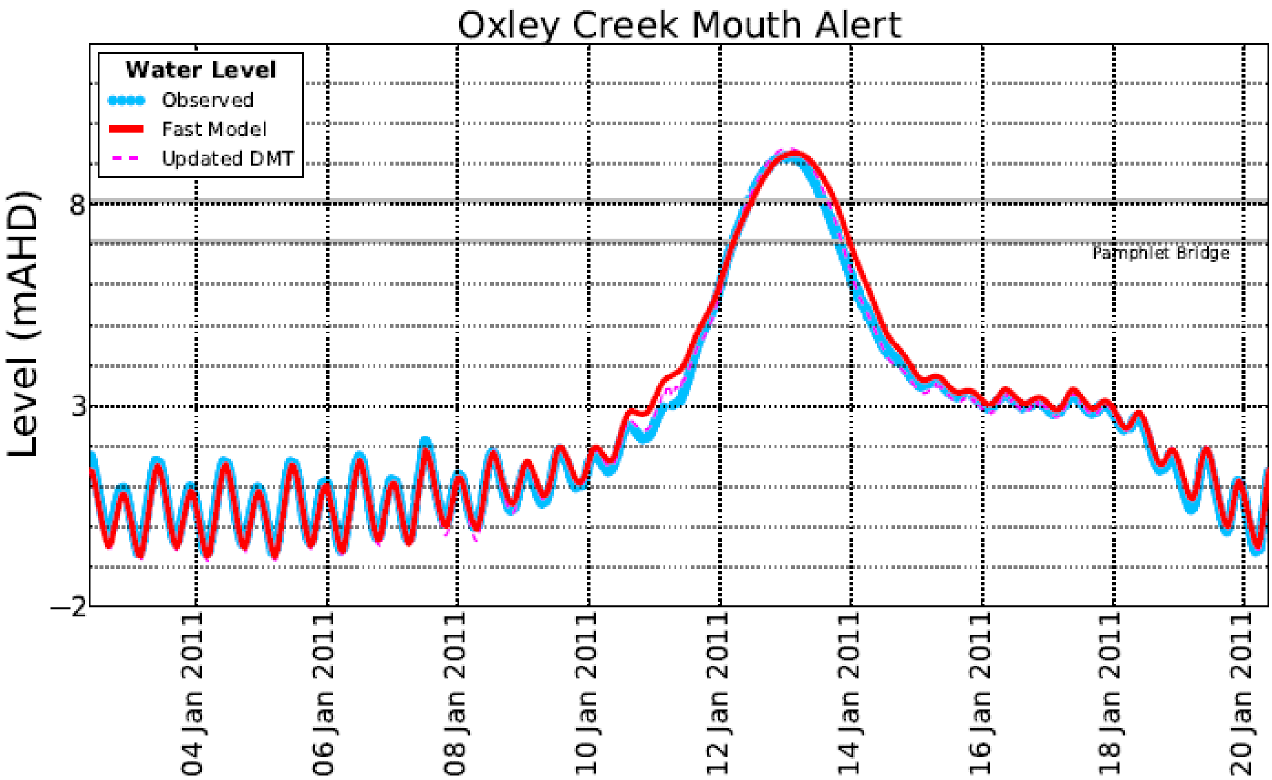


Figure 5-2 Example of Plot Output showing both Updated DMT and FM results

5.2 Fast Model Data Inputs and Model Development

5.2.1 Fast Model Construct

The Fast Model is based on the well-established hydraulic modelling approach of using a network of 1D channels and storage nodes that was commonplace prior to 2D flood modelling. The network of channels gives a quasi 2D effect by conveying water through flowpaths representing both the rivers/creeks and floodplains. Spill channels connect the river/creek and floodplain flowpaths. The Fast Model has some 2,350 channels or flow paths that are illustrated in A3 Addendum Sheet 5.

Each channel's hydraulic conveyance properties are based on cross-sections. For rivers and creeks the cross-sections typically extend from bank to bank and are extracted at each end of the channel. For links between the river or creek and their floodplains, the cross-section is typically based on the line of highest elevation (e.g. along the top of the levee). For floodplain (overland) flowpaths, the cross-sections are taken at representative locations across the floodplain and are of sufficient width to capture extreme flows.

Cross-sections were extracted from the various DEMs, with higher priority given to the more accurate DEM where overlap occurred. Details of each dataset and the relative priorities assigned are provided in Section 4.2.3.

The channels are hydraulically connected at nodes, which represent the storage of the system. Each node has a surface area versus height table defining the volume of water that a node can hold. For nodes connecting the in-bank river and creek channels, the storage is derived by multiplying the cross-section widths by half the in-bank channel lengths at varying heights. For nodes on the floodplain the storage is extracted from the DEM.

5.2.2 Cross-Section Conveyance Approach

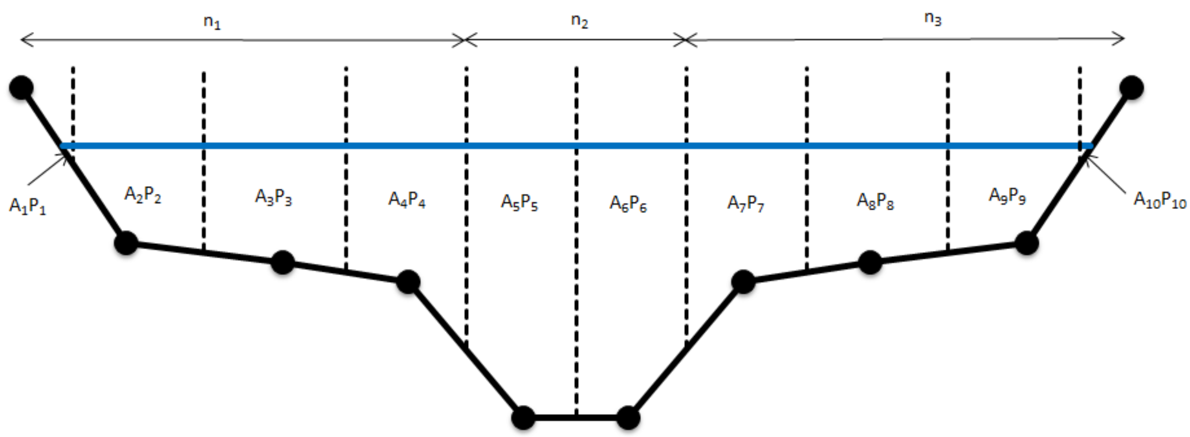
Cross section conveyance is calculated in the Fast Model according to the default formulation used by TUFLOW. This approach divides the cross section into separate parallel channels, with one parallel channel for each X (distance) value. The hydraulic radius for each parallel channel is then used to determine conveyance within that channel using the Manning's equation as follows:

$$K = \frac{1.0}{n} A R^{2/3}$$

Where:

K = conveyance of parallel channel section
n = Manning's n roughness coefficient
A = Flow Area (m^2)
R = Hydraulic Radius (m) = area/wetted perimeter

Conveyance values for all parallel channels in a cross section are then summed (see Figure 5-3).



$$K_{total} = K_1 + K_2 + K_3 + K_4 + K_5 + K_6 + K_7 + K_8 + K_9 + K_{10}$$

Figure 5-3 R1 Hydraulic Radius Formulation Approach

5.2.3 Fast Model Topography

The bathymetric and topographic data used to develop the Fast Model are described in Section 4.2 with priorities assigned to particular datasets described in Section 4.2.3. In summary, in-bank bathymetry consists of bathymetric survey or the DMT DEM and the floodplain topography is derived from the 5 m DMT DEM.

5.2.4 Hydraulic Structures

Details of hydraulic structures such as bridges, weirs and culverts were obtained from supplied and/or sourced drawings and existing models as described in Section 4.4.

Hydraulic structures are represented in the Fast Model as special channels. Due to their complexity, additional detail on the components that make up a bridge's representation in the Fast Model is as follows:

- A cross section (XZ) or height versus width (HW) table of the waterway area under the bridge.
- A weir channel used to represent the cross section of the bridge deck extending up either side of the river bank to simulate overtopping of the bridge deck.
- Automatically adjusted contraction and expansion of flow (entrance and exit) loss coefficients using approach and departure velocities.
- A table of height varying energy loss coefficients (LC table) representing piers, skew, and eccentricity, derived using AustRoads (1994)[16].
- A bridge deck surcharge discharge coefficient.

[16] Austroads have updated their publication series such that Austroads (2009) Guide to Bridge Technology Part 4 is seen as a replacement for the previous Austroads (1994) Waterway Design. However, Austroads (1994) still remains the most recent source of detailed technical guidance on application of losses to bridge structures, which is required to model hydraulic structures in a 1D model.

Due to the complexities of the Mt Crosby weir (multiple low flow openings of varying invert levels and an overbridge structure, see Figure 5-4) the structure was represented as a combination of zero-length rectangular culverts for the openings under the roadway, and a weir channel for flow over the overbridge. Small low flow sluice outlets at the base of the weir (not visible in Figure 5-4 as they are below the water surface) are assumed to remain closed which reflects current operational practice. As such they have not been included in the model.

Structures such as underpasses or large culverts through embankments within the floodplain are represented as circular, rectangular or irregular shaped culverts as appropriate.

Many hydraulic structures trap debris during a flood event. Debris can reduce hydraulic conveyance through and over the structure altering flow behaviour. Unless event specific evidence of significant debris build up was available, structures were assumed to be unblocked for the calibration events.

Figure 5-4 Mt Crosby Weir

5.2.5 Model Boundaries

The Fast Model boundaries consist of major river and creek inflows around the model's upstream periphery, localised internal inflows for the hydrologic model sub-catchments that fall within the model's extent and a tidal water level boundary at the mouth of the Brisbane River. On the Brisbane River the model starts immediately downstream of Wivenhoe Dam.

A3 Addendum Sheet 5 shows the Fast Model layout including locations of inflow boundaries.

Inflows, applied to these boundaries for the calibration/verification events are derived from the outputs of the hydrologic models developed by the Hydrologic Assessment. Special mention is made of the 1974 verification event which, for the Fast Model, utilises two inflow scenarios as follows:

- Scenario 1: Use of BRCFS Hydrologic Assessment inflows.

- Scenario 2: Use of Seqwater inflows.

Section 4.6.1 provides further details on the rationale behind maintaining two 1974 inflow scenarios.

The ‘Bremer’, ‘Warrill’ and ‘Purga’ hydrologic models include a base flow component. These base flows are applied to the hydraulic models as additional flow inputs. The ‘Lockyer’ and ‘Lower’ hydrologic models have no base flow inputs. Seqwater advised (verbal comm, Nov 2014) that Lockyer Creek exhibits a strong, but highly indeterminate and therefore difficult to estimate, base flow component. Consequently a good match in Lockyer Creek before the flood and on the flood recession would be difficult to achieve.

The downstream boundary is located at the mouth of the Brisbane River and for each calibration event, the recorded water level hydrograph at the Brisbane Bar gauge was applied.

5.2.6 Quality Control Checks

During the course of the modelling, a number of quality control checks were undertaken. Checks and findings are summarised as follows:

- **Mass conservation** within the hydraulic solution for both calibration and extreme events showed that peak mass balance error in the model does not exceed 0.14% which is considered low (ideally it should be less than 1%).
- **Flow volume checks between hydrologic and hydraulic modelling** were made by applying a steady state downstream boundary to the Fast Model to remove the tidal influence. Checks show good agreement for all calibration events with slightly higher volumes (up to 2.7%) in the Fast Model which is expected given that the hydrologic modelling does not output the volume remaining in the model at the end of the simulation, only that which reaches the Brisbane Bar output location.
- **Structure Head Loss checks** show model output is consistent with hand calculations and desktop checks.
- **Changes to the Fast Model are consistent with expectations**. For example, as part of the sensitivity test ST02 (see section 5.6), in which the Manning’s values are increased throughout the model domain, an increase in predicted flood levels is expected. In all such instances, results are consistent with expectations.
- **Model file naming, version control and data management protocols** are adhered to. This is of particular importance given that the Fast Model is to be used for simulating thousands of Monte Carlo events.

5.3 Fast Model Calibration

5.3.1 Approach

The Fast Model is used to simulate thousands of Monte Carlo events so as to extend the Hydrologic Assessment’s Monte Carlo analysis using a hydraulic model. The results extracted from the Fast Model to facilitate this process are at the 28 Reporting Locations along the main rivers (see A3 Addendum Sheet 1 for locations).

The Fast Model calibration, therefore, primarily focuses on the model's performance at the river and creek water level gauges, any flow recordings, and the flood marks along the rivers and creeks. Less importance was placed on the calibration to overbank flood marks well removed from the rivers and creeks.

The Fast Model was calibrated and verified using a staged approach as follows:

- Construct the tidal sections of the Brisbane River catchment and calibrate to the tidal signals in the lead up to the 2013 flood event.
- Extend the model to Mt Crosby and carry out a preliminary calibration using the hydrologic model hydrograph at Mt Crosby Weir for the 2013 minor flood. This step was carried out whilst waiting for the final calibrated hydrologic modelling produced by the Hydrologic Assessment.
- Calibrate the model to the near "steady-state" flow conditions that occurred during post-flood releases from Wivenhoe Dam during 2011 and 2013. The flow during these releases was nearly entirely in-bank.
- Extend the model out onto the floodplain using results from the Updated DMT Model to guide the location of overland flowpaths (example shown in Figure 5-1).
- Calibrate to the minor floods of 2013 and 1996.
- Verify the model against the minor flood of 1999.
- Calibrate to the major flood of 2011.
- Verify against the major flood of 1974.
- Simulate the model for a range of extreme synthetic flood events to ensure the model schematisation is capable of effectively and realistically modelling such events. The extreme events used to undertake this exercise are: 2 x 1974, 5 x 1974, 8 x 1974 and 1.5 x 1974 (the latter provides a peak flow of 16,500 m^3/s at Brisbane City, roughly approximating the largest of the 1893 flood events).
- Compare the Fast Model stage-discharge results with the Hydrologic Assessment's derived rating curves as a cross-check.
- Fine-tune the Fast Model calibration using preliminary results and flow behaviour from the Detailed Model calibration.

5.3.2 Calibration Parameters

Typically, the primary parameter available to calibrate hydraulic models is the Manning's n flow resistance. A key finding of this study was the need to incorporate additional form loss coefficients to represent the loss of kinetic energy, particularly at features such as bends, rock ledges or major confluences. This was a critical finding that allowed the same set of Manning's n and form loss parameters to be used for all five calibration/verification flood events and calibration to tidal recordings.

This finding was noted when, during the drain down (pseudo steady state) releases from Wivenhoe Dam during the 2011 and 2013 events, the Fast Model would not replicate the observed flood level at Moggill without using a higher Manning's n value than that determined as providing the best reproduction of tidal surge propagation in the Brisbane River. Use of a higher Manning's n for tidal sections of the Brisbane River could match the flood level at Moggill, but resulted in a dampening of the tidal signal. The higher Manning's n value required of around 0.04 was also well above industry standard values typically used for tidal reaches of 0.02 to 0.03.

Calibrating the model using Manning's n values in combination with the application of form losses achieved the desirable calibration results. Form losses were applied in the Fast Model in two ways:

- As a constant value to all in-bank channels (loss coefficients of 0.3/km in the lower Brisbane (downstream of Mt Crosby Weir to New Farm Park), and 0.2/km for all other in-bank channels were adopted).
- Targeted values at river bends, known rock outcrops and major confluences. Typically these varied from 0.5 to 1.5.

Justification for the use of form losses is made based on the physical characteristics of the Brisbane River. As investigated in Sargent (1978), the Brisbane River is effectively a series of rock controlled steps/ledges with sharp bends and rock outcrops. It is the view that the energy losses that result from these obstructions to flow are more closely approximated by the energy (form) loss equation, rather than the Manning's equation, which represents the roughness of the bed. Further detail on the rationale behind the use of additional form losses is given in MR2.

The final Manning's n values adopted for the calibration and verification simulations are maintained as consistent for all simulated events. For details on the values adopted, reference is made to MR2. It should be noted that these values are matched to the computational method employed by the Fast Model, and in particular the calculation of conveyance as discussed in Section 5.2.2.

5.3.3 Calibration & Verification Outcomes

A3 Addendum Sheet 6 summarises the peak recorded and modelled flood level for all calibration events at each gauge location for the Fast Model. A legend for this table is shown below the table in the bottom left corner. Accuracy tolerances for each area are provided in the second column. These accuracy tolerances are extracted directly from the ITO where they are provided to guide accuracy of peak *design* flood levels. They are used here to provide an indication as to how the differences between peak recorded and modelled flood levels sit in relation to the accuracy tolerances. A difference between peak and modelled flood level that is within tolerance is shaded in green, a difference that is outside tolerance is shaded in red.

In addition to the comparison of flood peaks, the Fast Model's performance against the five calibration and verification floods is presented as a series of plots. The plots consist of comparisons with the water level gauges, flow recordings off Centenary Bridge for the 1974, 2011 and 2013 events, and longitudinal profiles compared with flood marks within 100 m and 500 m of the river/creek centreline for the 1974, 2011 and 2013 floods. Reference is made to the MR2 Plot Addendum for a complete set of model outputs. Sample output is included in Section 6 of this report where Fast Model output is presented alongside Detailed Model output.

Special mention is made of the 1974 verification event. The results presented in A3 Addendum Sheet 6 for this event are based on the IL/CL Scenario 1 (see Section 4.6.1). Longitudinal section plots for this event where both IL/CL scenarios are presented show, in general, that peak debris level marks tend to lie between IL/CL Scenario 1 and Scenario 2 upstream of Ipswich. This suggests that the best estimate of the Bremer catchment inflows for 1974 is somewhere between the two IL/CL scenarios. This was considered further when determining the most appropriate inflows to use when verifying the Detailed Model against the 1974 event (see Section 6.2.4).

Overall, the simulated calibration/verification events vary substantially in their behaviour and size from purely tidal flows to major flooding. The Fast Model satisfactorily reproduces this wide range of flow behaviour without needing to vary calibration parameters. This view was endorsed by the IPE with an extract from the IPE feedback provided below.

> "*The calibration and validation of the Fast Hydraulic Model with these historical flood events are considered satisfactory in the context of the purpose for which the Fast Model has been developed*" IPE, January 2015

5.4 Extreme Event Simulation

As discussed in Section 5.1.1, the Updated DMT model was used to simulate extreme hypothetical events for use in assisting with the Fast Model development when schematising extreme flow breakouts and overland flow paths.

These extreme events, namely 2x, 5x, and 8x the inflows of the 1974 event, were simulated within the Fast Model with results compared to the Updated DMT model (and subsequent Detailed Model) as a check on the Fast Model's performance under these extreme flow conditions.

Following the Fast Model (MR2) Workshop it was requested that the 1893 event was also simulated in the Fast Model. This event was greater in flow magnitude in Brisbane than any other recorded event, including 1974 and 2011. As the Hydraulic Assessment is reliant on events produced by the Hydrologic Assessment and the Hydrologic Assessment did not model any of the 1893 events, the Hydraulic Assessment was not able to specifically model an 1893 event. As a compromise a pseudo-1893 event was simulated by applying flows of a similar magnitude to those estimated for the largest of the 1893 events. This was achieved by increasing the 1974 inflows by a factor of 1.5 to produce a peak flow in the Brisbane CBD of approximately 16,500 m^3/s and create a pseudo-1893 flood event. The tidal water level for the 1974 calibration event was used as a downstream boundary condition.

A summary of the observed peak water levels for the January and February events as well as the modelled water levels for the pseudo-1893 event is presented in Table 5-1. The modelled results generally agree well with the recorded peak water levels, particularly given the unknown accuracy of the recorded peak flood levels, the difference in the hydrograph shape and peak (derived from the 1974 event), and the historical changes to the river system and catchment (e.g. topography and vegetation) that are not considered in the model.

Table 5-1 1893 Peak Water Level Summary

Location	Observed Jan 1893 (m AHD)	Observed Feb 1893 (m AHD)	Modelled Pseudo-1893 (m AHD)
Lowood	50.07	-	48.3
Mt Crosby	32.00	31.28	32.2
Ipswich	24.50	23.60	24.9
Moggill	24.50	23.60	24.8
Centenary	17.90	16.60	16.4
Brisbane	8.35	8.09	8.5
Bar	1.33	1.26	1.5

A further example of how the Updated DMT model was used to identify extreme flow routes is shown in Figure 5-5 where the circled flowpaths allow break out from the Brisbane River into Dutton Park / Woolloongabba to occur in extreme events.

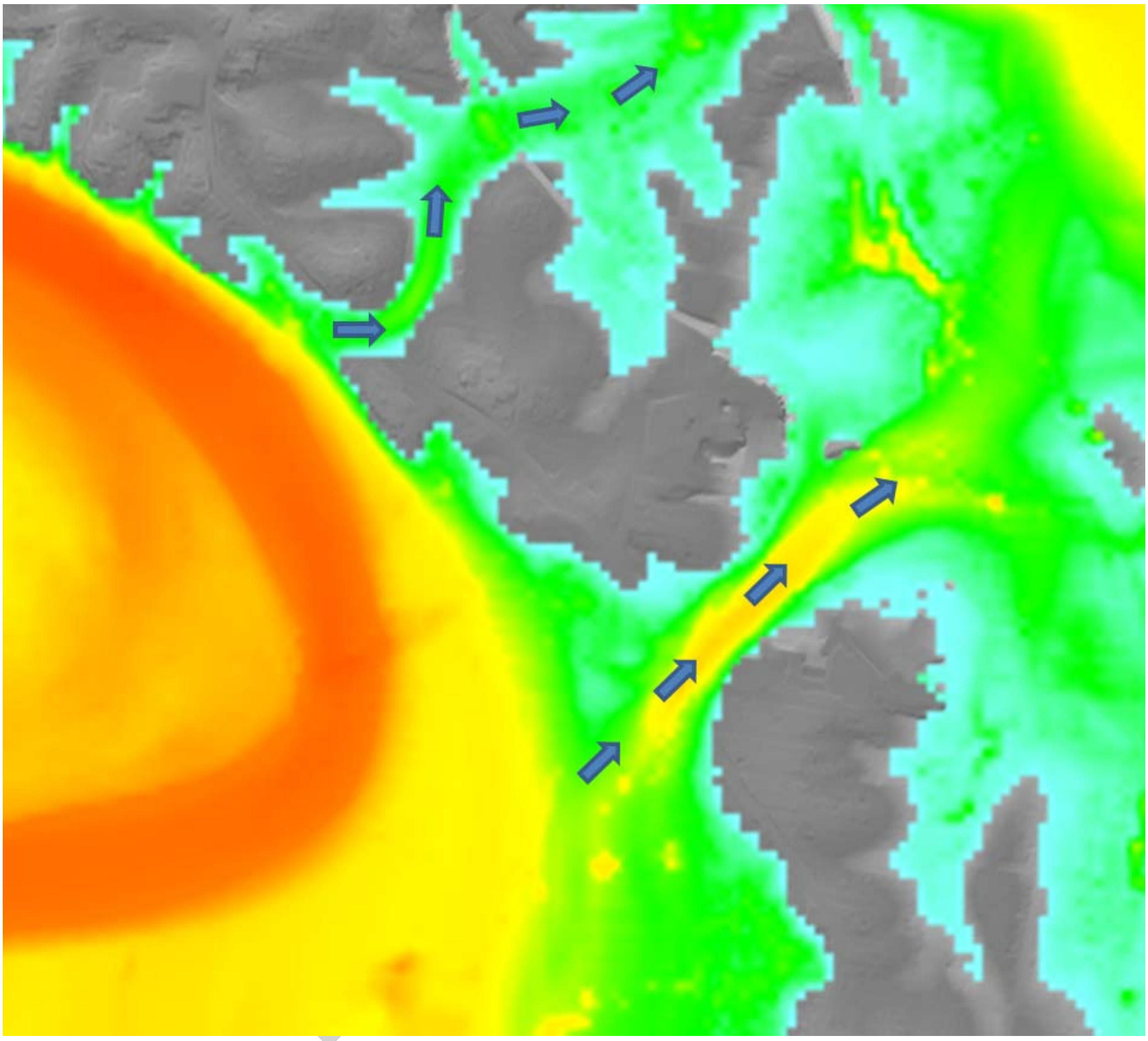


Figure 5-5 Example of New High-Flow Flowpath for the 8x1974 Event

5.5 Rating Curve Consistency

The stage-discharge outputs calculated by the Fast Model for each calibration/verification event are presented in MR2 and it was noted that, overall there is good consistency between the Fast Model results and the rating curves derived by Seqwater and the Hydrologic Assessment. Rating curves, including those from the Fast Model are discussed in greater detail in Section 6.5 and Section 8.6 where both Fast and Detailed model rating curves are presented for both calibration and design case modelling.

5.6 Sensitivity Testing

General sensitivity tests were carried out using the Fast Model to help understand the influence of key primary hydrologic and hydraulic calibration parameters. For these tests, the 2011 flood was chosen given its magnitude, period of steady-state discharges at minor flood levels after the flood peak, and critical timing of flood waves down the three major catchments.

The sensitivity tests performed are listed in Table 5-2 along with a brief summary of the results. Reference should be made to the MR2 Plot Addendum for supporting plots.

Table 5-2 General Sensitivity Tests on the Primary Calibration Parameters

Sensitivity Test	Description	Outcome
ST01	Manning's n only approach, with no general form losses along the river and no targeted form losses at bends, rock ledges and major confluences.	Confirmation that only by using a combination of Manning's n and form losses is it possible to reproduce: the tidal signal prior to flood flows; the peak flow; and the steady-state post flood releases from Wivenhoe Dam, using the one set of parameters.
ST02	Increase and decrease all Manning's n values and form losses by ±10%.	As expected, decreasing Manning's n reduces flood levels and increases flows whilst increasing Manning's n raises levels and reduces peak flow.
ST03	Increase and decrease the URBS hydrologic modelling alpha parameter by ±20%.	Minor changes observed in the Lockyer and Bremer catchments with no demonstrable benefit in calibration outcomes except for a minor improvement at Three Mile Bridge using a reduced Alpha. No observable change on the Brisbane River due to the dominance of the unaffected Wivenhoe Dam outflows.
ST04	Increase and decrease the URBS hydrologic modelling beta parameter by ±20%.	Similar outcomes to ST03 with no significant effect on Fast Model calibration.
ST05	Use Fernvale to Lowood Cross Sections in place of DMT DEM.	Concluded that use of the DMT DEM was justified as no calibration benefit in using the Fernvale to Lowood cross sections was realised.

6 Detailed Model: Development and Calibration

The Detailed Model is a 1D/2D hydraulic model that is designed to reproduce the hydraulic behaviour of the Brisbane River at a much higher resolution and accuracy than the Fast Model. The Detailed Model was subject to a rigorous model calibration after which it was used to simulate AEP ensemble events which, in turn, provide the final design AEP **riverine** flood surfaces for the BRCFS (see Section 8). This section describes the development and calibration of the Detailed Model.

6.1 Aims of the Detailed Model

The objectives of the Detailed Model are to:

- Accurately reproduce the flood behaviour of the Brisbane River, Lockyer Creek and Bremer River at a sufficiently high resolution to produce mapping of flood levels, depths, velocities and hydraulic hazard for regional planning purposes.
- Use the model into the future to quantify the impacts or changes in flood levels, depths and velocities and hydraulic hazard due to:
  - Flood mitigation measures, urban developments, road and rail infrastructure, dredging and quarry operations, and other works that change or alter the flood behaviour.
  - Changes in climate, land-use, sedimentation and erosion, or other factors that may or may not influence the flood behaviour into the future so that planning instruments can accommodate these effects.
- Improve the understanding of the rating curve relationships at key stream gauging stations, particularly at those locations affected by backwater. The Detailed Model results were used in the rating curve reconciliation process as discussed in Section 8.6.

6.2 Data Inputs and Model Development

6.2.1 Detailed Model Construct

The Detailed Model is predominately a 2D model which adopts a 30 m grid resolution across the entire 2D domain. A 1D in-bank representation is replicated from the Fast Model for Lockyer Creek and the Bremer River upstream from One Mile Bridge (including Purga and Warrill Creeks) where the 30 m resolution was considered too coarse to represent the in-bank topography. The following points are noted in regard to the 2D resolution.

- Representing the Brisbane River in-bank as 2D was highly preferable along its entire length, especially in areas such as Lowood/Fernvale and most sections downstream of Mt Crosby, due to the complexity and severity of the flow patterns.
- A 30 m 2D resolution over the entire Hydraulic Assessment area produced satisfactory results and practical run-times of one to two days per event, depending on the event duration, using the latest high-end PC chip technology as detailed in MR5.

Checks on the suitability of the 30 m grid were undertaken which included comparisons of results to those derived using a 20 m grid (see Section 6.6.2 for details). The 30 m grid resolution of the Detailed Model is endorsed by the IPE as meeting the requirements of the ITO (details of the endorsement are provided in MR3).

As such the IPE has deemed the Detailed Model is capable of providing flood levels suitable for setting habitable floor levels at property level/scale.

6.2.2 Detailed Model Topography

Topographic datasets used to inform the Detailed Model build are described in Section 4.2 along with the priority ranking applied for building the base topography. For the most part, the topography used to construct the Detailed Model is the same as that used for building the Fast Model. Notable exceptions are discussed below.

Gully Lines

Section 4.2.4 describes the general categories of breaklines used in this study. Additional mention is given here to the 'gully line' category. Gully lines are used by the Detailed Model for the following purposes:

- To ensure that the lowest bed elevation within a 2D channel cross section is being applied to at least one of the model grid cells.
- To enforce topographic representation of minor creeks and gullies within the wider floodplain where they may otherwise not form a continuous flow path in the model due to grid resolution.

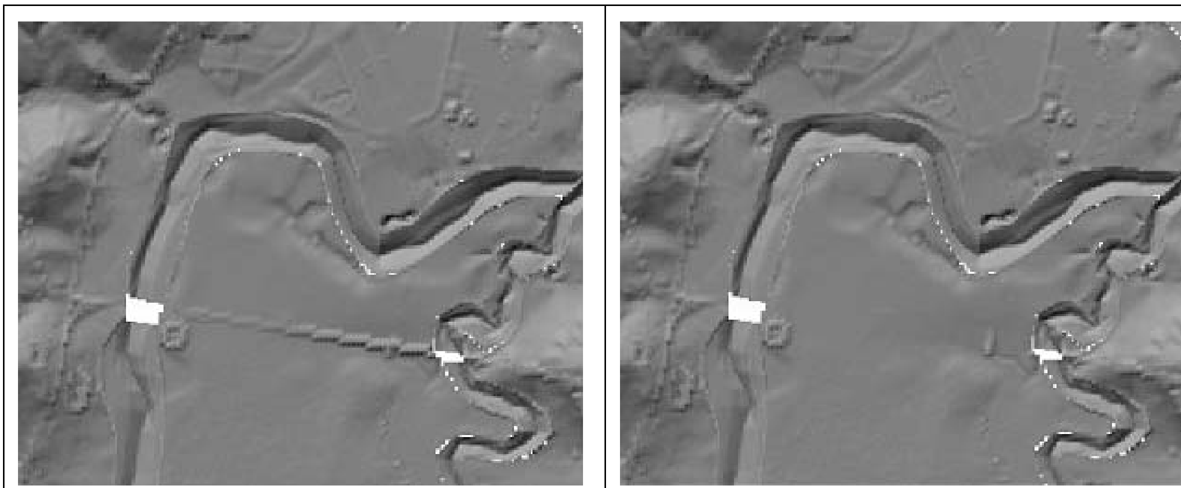
In the majority of instances, gully line elevations at breakline vertices are sampled from the base topography using a semi-automated process in which the lowest elevations at each line vertex are selected from within a defined search radius.

This process of using the base topography to define gully line elevations was not appropriate in the section of the Brisbane River from Wivenhoe Dam to the upstream limit of the Mt Crosby weir pool as the bed elevations are overstated in the base topography due to lack of bathymetry data. The approach taken to amend bed elevations along this reach consisted of sampling channel inverts from the Fernvale/Lowood cross-section survey and from the Australian Rivers Institute (ARI) cross-section survey (these cross-sections are described further in Section 4.2.2). The surveyed inverts of these cross-sections were joined with a breakline to ensure that the bed was lowered accordingly in the model topography. Whilst this approach is still considered approximate, it is an improvement over the reliance on the base topography.

Date Specific Topographic Amendments

Two amendments were made to the topography of the Detailed Model for simulation of the 1974 verification event.

(1) A raised section of the Cunningham Highway between Warrill and Purga Creeks was removed from the base topography for the 1974 runs (see Figure 6-1).



Before | After Removal

Figure 6-1 Removal of Cunningham Highway Raised Section for 1974 Topography

(2) The base topography of the sand and gravel quarry near Fernvale was modified by removing noise bunds and spoil heaps as quarrying had not yet commenced at the site in 1974.

6.2.3 Hydraulic Structures

Structures such as bridges, weirs and culverts were included in the Detailed Model if they had the potential to impact on flood behaviour along the main watercourses. This included all known structures crossing the main waterways and significant structures in backwater areas. Minor floodplain structures, such as culverts through railway embankments, were included where their omission would result in a constrained flood extent. Structures were removed from the model for calibration events that pre-dated the structure. This included a number of main bridges as indicated in Table 4-8.

Details of key structures were obtained from supplied and/or sourced drawings and existing models as described in Section 4.4.

Structures are represented within the Detailed Model using one of, or a combination of, the following methods:

- **1D special channels used to model major structures, typically bridges, in the 1D channel network.** These bridges are extracted from the Fast Model and are represented by a height versus width table of the under-bridge waterway, automatically adjusted entrance and exit loss coefficients, bridge deck surcharge discharge coefficient, and a table of energy loss coefficients with height derived using AustRoads (1994)[17].
- **2D Layered flow constrictions used to model bridges within the fully 2D model domain.** 100% blockages are applied within the model to represent the bridge deck, with additional

[17] Austroads have updated their publication series such that Austroads (2009) Guide to Bridge Technology Part 4 is seen as a replacement for the previous Austroads (1994) Waterway Design. However, Austroads (1994) still remains the most recent source of detailed technical guidance on application of losses to bridge structures, which is required to model hydraulic structures in a 1D model.

full/partial blockages to represent guard rails, etc. Energy losses are applied at different heights on a cell-by-cell basis to represent the effect of bridge piers, bridge deck, rails and other obstructions. The loss value used is based on that applied in the Fast Model, which was derived from AustRoads (1994)[17].

- **Nested 1D culvert elements connected to the 2D domain at either end.** This method is used for minor hydraulic features on the floodplain, such as culverts or embankment underpasses.

Mt Crosby weir represents a special case due to its complexity. The topography was adjusted in the model to raise the DEM to the deck level of the overbridge. The Fast Model representation of the culverts beneath the overbridge (see Section 5.2.4) was applied within the Detailed Model to convey flow beneath the overbridge. When water levels exceed the deck level, water can weir across the structure in the 2D domain. The small low flow culverts under the weir are understood to be blocked and even if fully operational would have negligible influence on flows/levels during flood events. They have not been included in the model.

Hydraulic Structure Reference Sheets (HSRS) have been developed for each mainstream hydraulic structure. The sheets provide details of each structure's geometry, document how they are represented in both the Fast and Detailed Models and report on flow, velocity and afflux for all calibration and extreme events. An example HSRS for Three Mile Bridge on the Bremer River is shown in Figure 6-2 and Figure 6-3. HSRS for each mainstream hydraulic structure is provided in MR5.

Pipes

Within the Brisbane City area, there are a number of large drainage pipes designed to convey local runoff (due to rainfall on local catchments) to the river. In large historical Brisbane River flood events, these pipes have allowed river water to back up into the lower-lying local areas causing inundation. In order to realistically simulate the inundation extent due to backwater in the Detailed Model, the larger pipes were required to be approximately represented in the model.

Pipe conveyance is not critical in this regard, provided the pipe sizes are reasonably indicative of the actual sizes. The presence of the pipes simply allows the river water to backup and enables the model to portray historical inundation extent in the backwater-affected areas

Following the 2011 event, a program began to fit these pipes with backflow prevention devices, which are designed to prevent river water backing up into low-lying areas. When modelling the 2013 event, pipes with known backflow prevention devices installed at the time of this event are modified in the model to prevent the occurrence of backflow. It is noted that during 2013 flood event the river level did not reach threshold/trigger levels for operating backflow prevention devices in Brisbane CBD and the Milton back-flow prevention device was not in operation at this time. For all other calibration events considered in the Hydraulic Assessment, backflow prevention devices are not included. Backflow prevention devices are also not included in the design case simulations (see Section 8.3 for further detail).

Three Mile Bridge (ICC_056) Structure

Structure Name	Three Mile Bridge		
Structure ID	ICC_056		
Owner	ICC	Waterway	Bremer River
Date of Construction	1970	AMTD	29310
Date of significant modification	2004	Co-ordinates (GDA 56)	473160.25E 6943533.27N
Source of Structure Information	Structural Design Drawings (2006)		
Link to data source	B:\B20702 BRCFS Hydraulics\10_Data Management\10_03_Structures\Structure_Details\BRM\ICC_056\		

Description	Concrete bridge		
BRIDGES		CULVERTS	
Lowest Point of Deck Soffit	16.7mAHD	Number of Barrels	-
Number of Piers in Waterway	2	Dimensions	-
Pier Width	0.55m	Length	-
		Upstream invert	-
		Downstream Invert	-
Lowest point of Deck/Embankment	19.2mAHD		
Rail height	1.3*m		
Span Length	25m		

*estimated

Included in Fast Model (FM)	Yes	FM Representation	XZ and LC table
Included in Detailed Model (DM)	Yes	DM Representation	1D Bridge and Weir Channels

Image Description	Three Mile Bridge, looking form upstream
Image Reference	BMT WBM (2015). *Three Mile Bridge (looking from upstream)* [digital photography]
Image Source	BMT WBM, 2015

Three Mile Bridge Hydraulic Structure Reference Sheet
Bremer River

BMT WBM

Figure 6-2 Example HSRS for Three Mile Bridge (1 of 2)

Three Mile Bridge (ICC_056) Characteristics

Structure Name	Three Mile Bridge
Structure ID	ICC_056
Link to model data	B:\B20702 BRCFS Hydraulics\50_Hydraulic_Models\200_Calibration_S2\TUFLOW\F\model\bg\CSV

FAST MODEL^

Event	Discharge (m³/s)*			Area (m²)*			Velocity (m/s)*			Peak Water Surface Level (mAHD)		Max Head Drop (m)*
	Under Structure	Over Structure	Total	Under Structure	Over Structure	Total	Under Structure	Over Structure	Total	US	DS*	
1974	57	1026	1082	257	1941	2198	0.2	0.5	0.5	26.38	26.37	0.01
1996	349	685	1033	257	408	665	1.4	1.7	1.6	21.19	21.13	0.06
1999	465	0	465	257	0	257	1.8	0.0	1.8	17.45	17.33	0.12
2011	244	1346	1591	257	1123	1380	1.0	1.2	1.2	23.70	23.68	0.03
2013	249	596	845	257	485	742	1.0	1.2	1.1	21.50	21.46	0.04
1 in 100 AEP	59	993	1052	257	1850	2107	0.2	0.5	0.5	26.08	26.08	0.01
1 in 2000 AEP	14	984	998	257	2978	3235	0.1	0.3	0.3	29.77	29.77	0.00

DETAILED MODEL^

Event	Discharge (m³/s)*			Area (m²)*			Velocity (m/s)*			Peak Water Surface Level (mAHD)		Max Head Drop (m)*
	Under Structure	Over Structure	Total	Under Structure	Over Structure	Total	Under Structure	Over Structure	Total	US	DS*	
1974	12	633	645	257	2010	2267	0.0	0.3	0.3	26.61	26.60	0.00
1996	288	685	973	257	485	742	1.1	1.4	1.3	21.50	21.46	0.04
1999	460	0	460	257	0	257	1.8	0.0	1.8	17.63	17.51	0.12
2011	214	1195	1408	257	1216	1473	0.8	1.0	1.0	24.01	23.99	0.02
2013	247	633	880	257	525	782	1.0	1.2	1.1	21.65	21.62	0.03
1 in 100 AEP	15	656	671	257	1928	2185	0.1	0.3	0.3	26.34	26.33	0.00
1 in 2000 AEP	1	460	462	257	2941	3198	0.0	0.2	0.1	29.65	29.65	0.00

* At time of peak water level on upstream side. Discharges can be significantly below peak values where significant backwater effects occur.

^ Consistent values may not occur between the Fast and Detailed Models due to dissimilarities between the models' solution schemes (1D vs 2D) and the coarse 1D FM discretisation of the floodplain. These differences tend to be emphasised where rapidly varying flow and high velocities occur in the vicinity of the structure or where the 1D FM discretisation includes some overbank floodplain flows in the structure representation.

Fast Model Version Number for Calibration Events: 285

Fast Model Version Number Design Events: 360

Detailed Model Version Number for Calibration Events: 605

Detailed Model Version Number for Design Events: 605

BLOCKAGE CONSIDERATION

Commentary	Recommendation to consider in future blockage assessment?	
	Blockage Below Obvert	Blockage Above Deck
Overtops frequently, will require blockage consideration below deck. Concrete barrier rails so therefore no further blockage above deck *ICC: No known record of notable blockage. Large waterway opening but immunity understood to be low, no more than 20yr ARI at best.*	Yes	No

Three Mile Bridge Hydraulic Structure Reference Sheet

Figure 6-3 Example HSRS for Three Mile Bridge (2 of 2)

6.2.4 Model Extent and Boundaries

The Detailed Model boundaries consist of the following:

- Major river and creek inflows around the model's upstream periphery.
- Localised internal inflows for hydrologic model sub-catchments that fall within the model's extent.
- Relatively minor baseflow inputs for the Bremer River and Warrill and Purga Creeks.
- A tidal water level boundary at the mouth of the Brisbane River.

In addition to the baseflow inputs described above, a very minor baseflow input is applied to the Brisbane River to aid with the initialisation of model runs. This baseflow is applied to a steep part of the river, upstream of the confluence with Black Snake Creek. It peaks at 20 m^3/s and has no discernible effect on the flood hydrograph for all events considered.

On the Brisbane River the model starts immediately downstream of Wivenhoe Dam. For Lockyer Creek, the upstream limit of the 2D modelled floodplain is immediately upstream of Glenore Grove although the dynamically linked 1D section of the model extends for a further 14 km upstream to Gatton. This is to ensure that any breakouts from the main creek between Gatton and Glenore Grove are accounted for in the model at the start of the 2D floodplain. For the Bremer the upstream limit of the model is immediately downstream of Five Mile Bridge near Walloon. Warrill Creek has its modelled upstream limit approximately 4 km upstream of Amberley (Greens Road) gauge and the upstream limit for Purga Creek is 1 km upstream of the Loamside Alert gauge. For the Bremer River and its tributaries additional nodal storage is provided at the most upstream locations to represent the upstream storage available in the floodplain which would be utilised under extreme events.

Model extents as specified in the project brief and those in the model are summarised in Table 6-1. A3 Addendum Sheet 7 shows the Detailed Model layout including locations of inflow boundaries.

Table 6-1 Detailed Model Extents

Watercourse	Minimum Upstream Limit (Specified in ITO)	Upstream Limit in Detailed Model (Distance Upstream from Minimum Extent)
Brisbane River	Wivenhoe Dam	Wivenhoe Dam (0 km)
Bremer River	Five Mile Bridge	Five Mile Bridge (0 km)
Purga Creek	Loamside Gauge	Loamside Gauge (1 km)
Warrill Creek	Amberley (Greens Road) Gauge	Amberley (Greens Road) Gauge (4 km)
Lockyer Creek	Lyons Bridge Gauge	Glenore Grove (26 km)
Oxley Creek	Beatty Road Gauge	Beatty Road Gauge (3 km)
Blunder Creek	King Avenue Gauge	King Avenue Gauge (0.5 km)

Inflows to the Detailed Model for the five calibration/verification events are derived from the outputs of the hydrologic models developed for the Hydrologic Assessment and are described in Section 4.6.1. Inflows are the same as used for the Fast Model except for the 1974 verification event where changes to the Hydrologic Assessment IL/CL values were made to improve the Detailed Model verification. These changes were made as a result of findings from the Fast Model in which inflows derived from two IL/CL scenarios were applied in the model and verification results were compared.

During the detailed model development it was determined that hydraulic model simulations adopting inflows derived from IL/CL values mid-way between those values used by Seqwater and the Hydrologic Assessment for the Bremer, Purga and Warrill catchments provided a better match to recorded peak flood levels than use of inflows from one or the other IL/CL scenarios. These revised 1974 inflows are termed ST09 (Sensitivity Test 9) inflows after the sensitivity test in which they were investigated and are adopted for use in the Detailed Model for the 1974 event.

For each calibration/verification event, the recorded water level hydrograph at the Brisbane Bar was applied in the Detailed and Fast Model as the downstream boundary.

6.2.5 Quality Control Checks

During the course of the calibration event modelling, a number of quality control checks were undertaken including checks on mass conservation within the hydraulic solution and checks on the inflow volumes being applied to the model (to ensure consistency with hydrologic modelling and the Fast Model). These checks demonstrated that all inflow volumes are being accounted for in the Detailed Model and that the computational solution is converging within acceptable bounds (peak mass balance error did not exceed +/-0.5% for any model simulation). MR3 provides further details on the checking process.

6.3 Detailed Model Calibration

6.3.1 Approach

The Detailed Model was calibrated and verified in a similar manner to the Fast Model, using a staged approach as follows:

- Undertake a tidal calibration using the tidal signals in the lead up to the 2013 flood event.
- Consider the learnings from the Fast Model calibration (Section 5.3 and MR2), particularly in relation to: a) targeted and general form losses, b) Bremer River 1974 verification, c) Bremer River behaviour and losses at the confluence. Add targeted form losses to the model as a factor of those form losses used in the Fast Model calibration.
- Calibrate to the minor flood of 2013.
- Verify the model against the minor floods of 1996 and 1999.
- Calibrate to the major flood of 2011.
- Verify against the major flood of 1974.

- Simulate the model for a range of extreme synthetic flood events to ensure the model schematisation is capable of effectively and realistically modelling such events. The extreme events used to undertake this exercise are: 5x1974, 8x1974 and 1.5x1974 (the latter produces a peak flow of around 16,200 m^3/s at Brisbane City, which is believed to be a similar peak flow to that estimated for one of the flood events of 1893).
- Compare the Detailed Model results with the Hydrologic Assessment's (Aurecon, 2015c) derived rating curves as a cross-check.

As the Detailed Model is a 2D model, calibration is undertaken not only to river gauge levels, flow recordings and flood marks in the main watercourses, but also to flood marks on the floodplains where they have been recorded and supplied for use in the study.

6.3.2 Calibration Parameters

The primary hydraulic parameters available to calibrate the Detailed Model are Manning's n flow resistance values and, for reasons discussed in Section 5.3.2, form losses.

The full 2D equations inherently model energy losses associated with flow being forced to change direction and speed. However some additional form losses may be required, particularly at locations where strong three-dimensional effects are likely or the obstructions are of similar or smaller size than the 2D elements (eg. a bridge pier). In all cases, the additional form loss required should be less than that required for a 1D representation which does not inherently model any energy losses due to changes in flow direction and speed.

Within the 2D domain targeted form loss coefficients are applied at sharp bends or rock outcrops. Typically these are around 20% of the equivalent values applied in the 1D Fast Model. Where the 1D in-bank Fast Model network is used in the Detailed Model (Lockyer Creek and upstream of One Mile Bridge on the Bremer River), the form losses as used in the Fast Model are retained.

For the 1D sections of the Detailed Model the Manning's n values remained unchanged from those used for the Fast Model. As for the Fast Model, the Detailed Model applies consistent Manning's n values for all simulated events within the Detailed Model (see MR3 for further details). .

6.3.3 Calibration Results

A brief summary of the performance of the Detailed Model for the five calibration/verification events follows. A3 Addendum Sheet 8 provides an overall summary of results at gauges. Reference should be made to MR3 for an in-depth discussion of calibration results.

2013 Tide / Minor flood Calibration

The following summary points are drawn from the 2013 event calibration:

- A satisfactory match to peak flood levels on the lower Brisbane River (downstream of Oxley Creek) is achieved with many levels within 0.1 m and within 0.05 m near the CBD.
- Minor under predictions of peak flood levels are evident between Moggill and Oxley Creek with the model typically 0.15 m to 0.4 m too low.
- A satisfactory match is shown for the flood extent within the SRC region, given the general limitations of such mapping.
- A satisfactory match is made for in-bank areas of Lockyer Creek with the LVRC region. Floodplain observed peak flood levels also correspond with those modelled. However, steep out of bank gradients mean that the observed (and modelled) flood levels are highly sensitive to small changes in positioning.

Figure 6-4 contains a statistical assessment of the range of differences between observed and modelled peak flood levels, including all flood marks and peak gauge levels. The colours were chosen to be consistent with those adopted for the difference between modelled and recorded flood marks in the calibration mapping presented in MR3. It can be seen that on average the 2013 peak modelled levels are within -0.01 m of the average of the recorded levels.

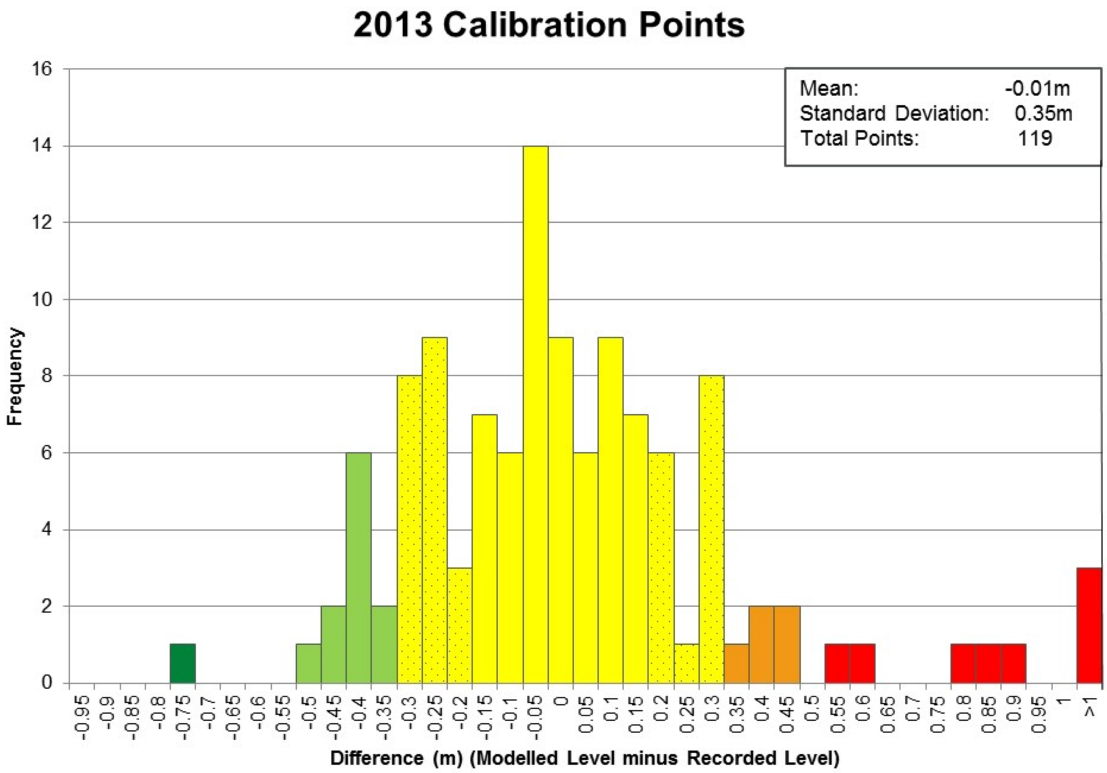


Figure 6-4 2013 Detailed Model Calibration - Statistical Assessment of Differences between Observed & Modelled Peak Flood Levels

1996 Minor Flood Verification

The minor flood of 1996 was used as a verification of the 2013 minor flood calibration. The 1996 flood largely remained in-bank, with some overtopping onto the Lockyer Creek floodplains.

In general there is agreement on the timing and magnitude of the modelled peaks with observed data where it exists. Peak levels are slightly over predicted at Moggill. This in turn is impacting on backwater flood elevations along the Bremer River.

The most notable difference between modelled and observed peak levels is at Ipswich where the modelled peak level of around 14 mAHD is significantly above the observed level (around 11 mAHD). Interestingly, the peak modelled 2013 flood level at Ipswich was also around 14 mAHD but for that event the model matches with the observed levels. This comparison suggests that other factors may be contributing to the difference observed for the 1996 event. We believe that the differences between modelled and recorded levels at Ipswich are primarily due to the following factors:

- Flows: Seqwater has advised[18] that the 1996 hydrologic model peak flows at Ipswich varied considerably between the Hydrologic Assessment (Aurecon, 2015a) value of 1850 m^3/s (used in the model) and the Seqwater (Seqwater, 2013b) value of 1460 m^3/s; a difference of 27%. Should the flows used in the Detailed Model have been of a lesser value (perhaps closer to the Seqwater value), peak modelled flood levels are likely to have been lower and thus closer to the observed peak flood levels at Ipswich.
- Bathymetry: Quentin Underwood from LVRC has advised[19] that dredging of the Bremer was occurring around the town bridge before 1996. Quentin has indicated that since 1996, dredging has ceased and bank collapses have occurred and, as such, he believes that the Bremer River in this region has become significantly shallower in that time. If this is the case then the current bathymetry included in the Detailed Model (surveyed in 2014) will result in the Model underestimating conveyance in this region for the 1996 (and 1999) events. As these events are minor flood events, in-bank conveyance is particularly influential on flood behaviour and the underestimation of conveyance will lead to an overestimation of flood levels, which is indeed occurring at the Ipswich gauge for both 1996 and 1999. However, the current bathymetry better represents the 2013 conveyance and hence modelled flood levels are better matched to observed levels for 2013.

In summary, it is the view that the overestimation of levels at Ipswich for the 1996 event is primarily due to a combination of the hydrology flow estimates, and historical changes to Bremer River bathymetry.

1999 Minor Flood Verification

The minor flood of 1999 was used as a second verification of the 2013 minor flood calibration. The following points are summarised:

[18] Comments received on Milestone Report 3 (this report) on 19 June 2015.
[19] At Workshop 3 (as part of this study) held on 14 May 2015, Quentin is a member of the Technical Working Group.

- There is an under prediction of flood levels in Lockyer Creek upstream of O'Reilly's Weir. Below the weir the peak levels match with observed levels due to the peak from Wivenhoe Dam showing a satisfactory agreement on levels.
- Peak flood levels in the Bremer including at Ipswich are generally overpredicted. This overestimation is believed to be most likely related to historical changes in bathymetry. This belief is based on advice from Quentin Underwood[19] that the Bremer River around Ipswich has become significantly shallower since dredging ceased around 1996 and bank collapses occurred (the bathymetry used in the model is based on 2014 survey data).
- There is agreement on both peak flood level magnitude and timing on the lower Brisbane River although the modelled peak level is noticeably higher at Moggill.
- For the same post flood dam release flow of 1,750 m^3/s, the 1999 recorded levels at Savages Crossing are approximately 1 m higher than those of 2013. This is likely attributed to the large flood event of 2011, which may have scoured river banks, removing vegetation and thereby increasing the hydraulic conveyance. The roughness values used in the model represent a compromise between the higher roughness of 1999 and smoother hydraulic roughness of 2013. As a result the model under predicts for 1999 and overpredicts for 2013 at Savages Crossing.

2011 Major Flood Calibration

The major flood of 2011 caused extensive flooding throughout the floodplains of Lockyer Creek, Bremer River and Brisbane River. The releases from Wivenhoe Dam played an important role in the hydraulic behaviour of the flood. The flood storage compartment of Wivenhoe was used to help contain and delay the first flood peak upstream of Wivenhoe Dam. However, during the second flood peak into the dam, major releases from the dam were required, sending a short, sharp hydrograph downstream that combined with flood flows from the Lockyer and Bremer catchments.

Plots comparing the modelled and recorded water level hydrographs for the 2011 event are shown in A3 Addendum Sheet 9 to A3 Addendum Sheet 11. Both Fast and Detailed model results are shown.

Flow gaugings at Centenary Bridge for the 2011 event are shown in A3 Addendum Sheet 12 along with Fast and Detailed flows and levels.

A3 Addendum Sheet 13 contains a key sheet of regions for which calibration to flood marks are presented in A3 Addendum Sheet 14 to A3 Addendum Sheet 18.

The following points are summarised:

- Both the timing and magnitude of the peak are reproduced by the model along Lockyer Creek. Within the Lockyer Creek floodplain predicted flood levels within the floodplain tend to be lower than those recorded, typically by up to 0.4 m lower although in many places levels are within 0.15 m.
- Within Fernvale, predicted flood levels, whilst within the tolerances set out for the study, are lower than recorded. Modelled flood levels match the recorded levels both upstream and downstream of Fernvale.

- Peak observed flood levels on the Warrill, Purga and Bremer Rivers match with those from the model including a satisfactory match to peak flood levels at the Ipswich Gauge.
- There is a satisfactory match between observed and modelled levels on the Brisbane River with the city gauge being within 0.01 m. This is illustrated in Figure 6-5 which also shows the accurate capture of superelevation around the Story Bridge bend in the 2011 event.
- At the Savages Crossing Gauge the post peak, Wivenhoe release is shown to result in higher modelled flood levels at the gauge than for observed. However, at the Mt Crosby Gauge the post peak release modelled levels compare satisfactorily with observed levels.
- At the Moggill gauge, there is a notable ‘attenuated’ recession limb on the hydrograph. This in turn impacts on the Bremer River. Downstream at the Jindalee gauge, this extended tail is only marginally apparent and is not noticeable at the Brisbane City Gauge where a satisfactory match to the overall hydrograph shape is achieved.
- At Centenary Bridge the levels and flows calculated by the Detailed and Fast Models agree with the range of levels and flows recorded during the peak of the flood and afterwards during the drain down phase (post flood) dam releases.

Overall the modelled flood extents correspond with the historical extent. In particular, much of the backwater flooding via stormwater pipes in Brisbane CBD has been captured by the model.

Figure 6-6 contains a statistical assessment of the range of differences between surveyed and modelled peak flood levels for over 500 flood marks and the peak gauge levels. The colours were chosen to be consistent with those adopted for flood marks. It can be seen that on average the 2011 peak modelled levels are within -0.07 m of the average of the recorded levels. Around 27% of marks were matched by the model to within +/- 0.05 m and 66% were within 0.15 m. This is considered to be a high level of accuracy, particularly given the potential for error with survey marks and uncertainties in the modelling.

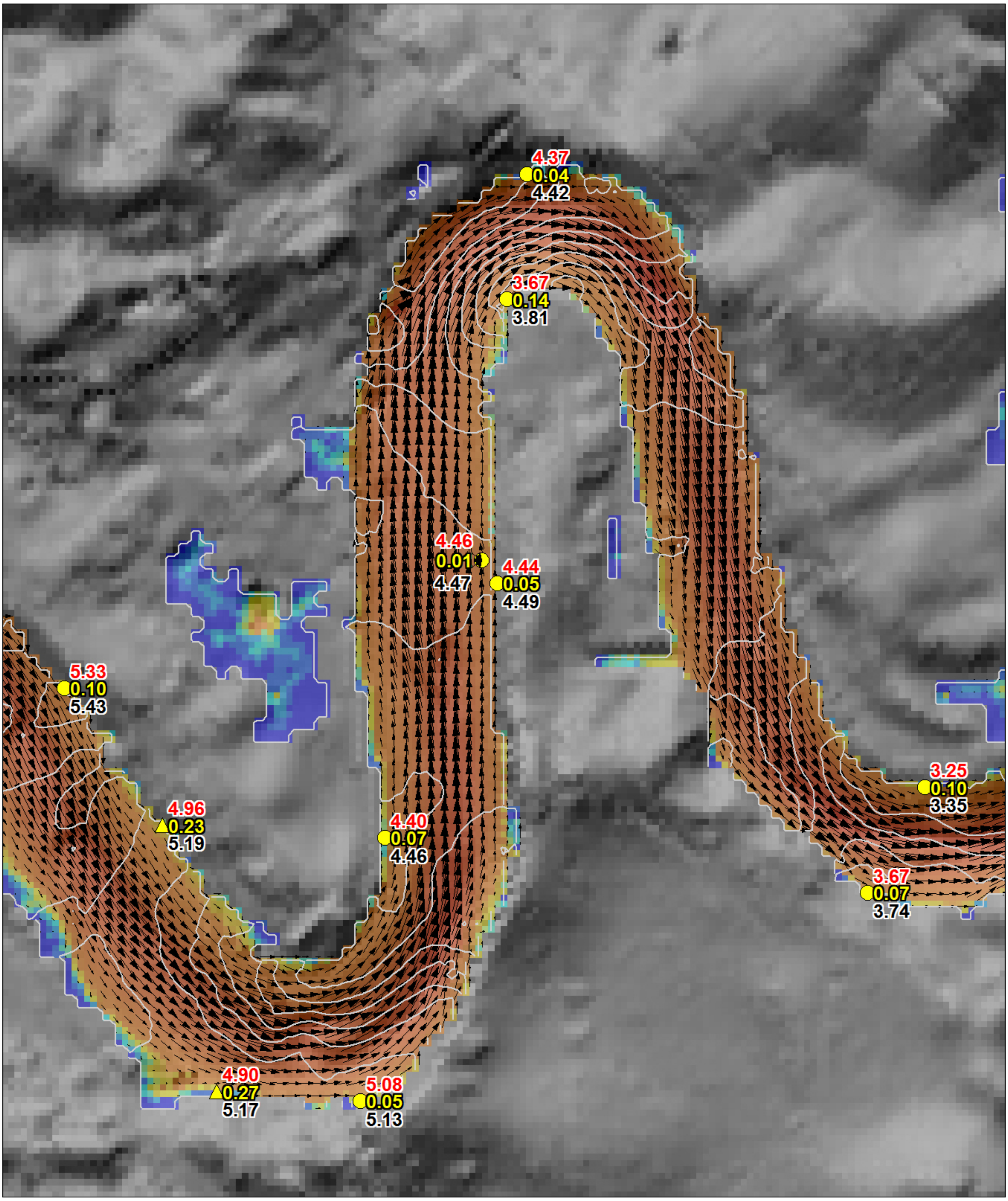


Figure 6-5 Example of Reproduction of Superelevation at River Bends for the 2011 flood – Story Bridge Bend

(Red font for surveyed level, black font for modelled level and yellow font for modelled minus surveyed)

(Water level contours at 0.1 m intervals)

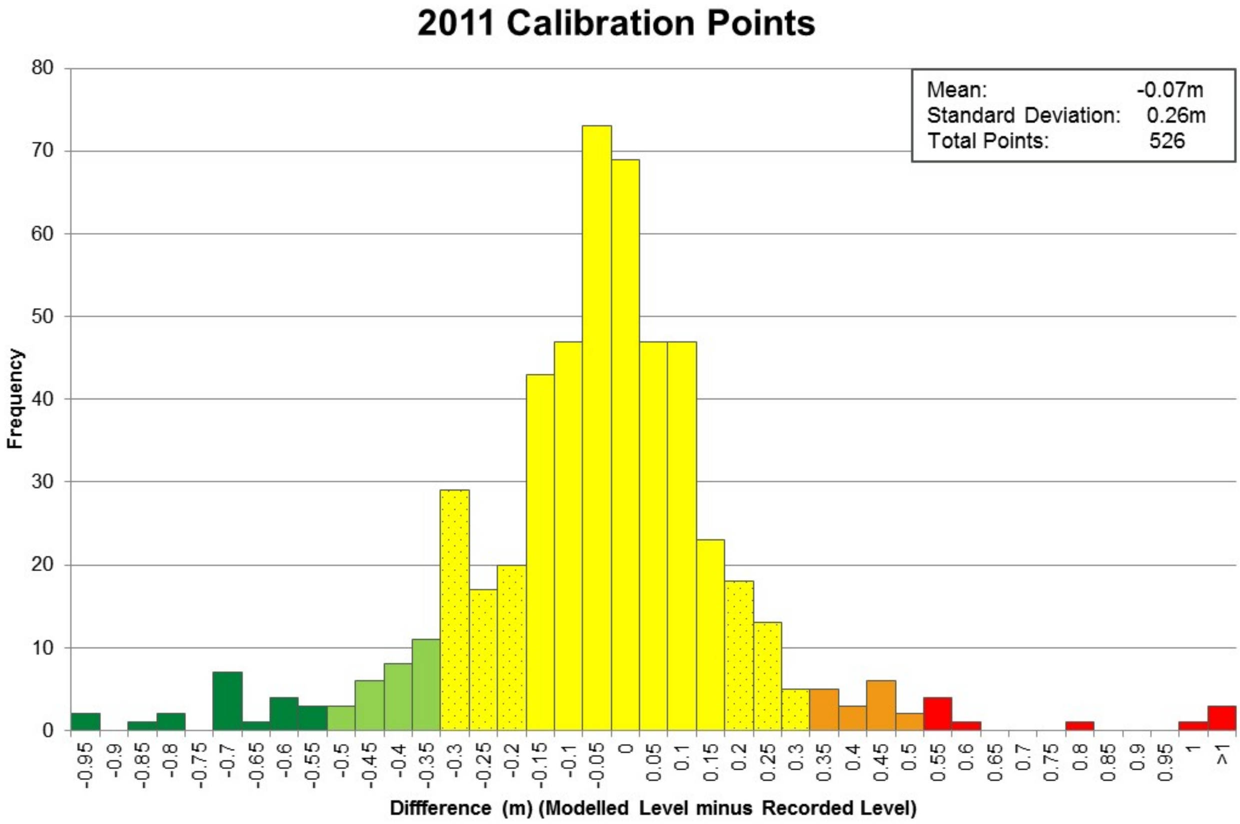


Figure 6-6 2011 Detailed Model Calibration - Statistical Assessment of Differences between Observed & Modelled Peak Flood Levels

1974 Flood Verification

The major flood of 1974 caused extensive flooding throughout the floodplains of Lockyer Creek, Bremer River and Brisbane River producing flood levels typically 1 to 2 metres higher than the 2011 flood in Brisbane.

In the absence of the ability to undertake a joint hydrologic and hydraulic calibration, the IL/CL values in the Bremer catchment for the 1974 event for the current assessment were modelled as the *average* of the Hydrologic Assessment and Seqwater values, ie. halfway between the IL/CL Scenario 1 (Hydrologic Assessment) and IL/CL Scenario 2 (see Section 4.6.1).

A significantly larger number of flood marks were collected after the 1974 flood compared with that collected from the 2011 flood, thereby giving a recorded profile that helps clearly identify changes in flood profile gradients due to sharp bends, meanders that are shortcut and rock ledges such as at Dutton Park.

Figure 6-7 contains a statistical assessment of the range of differences between observed and modelled peak flood levels, including all flood marks and peak gauge levels and shows a satisfactory verification to nearly 2,000 flood marks and the peak gauge levels with a mean difference of 0.05 m.

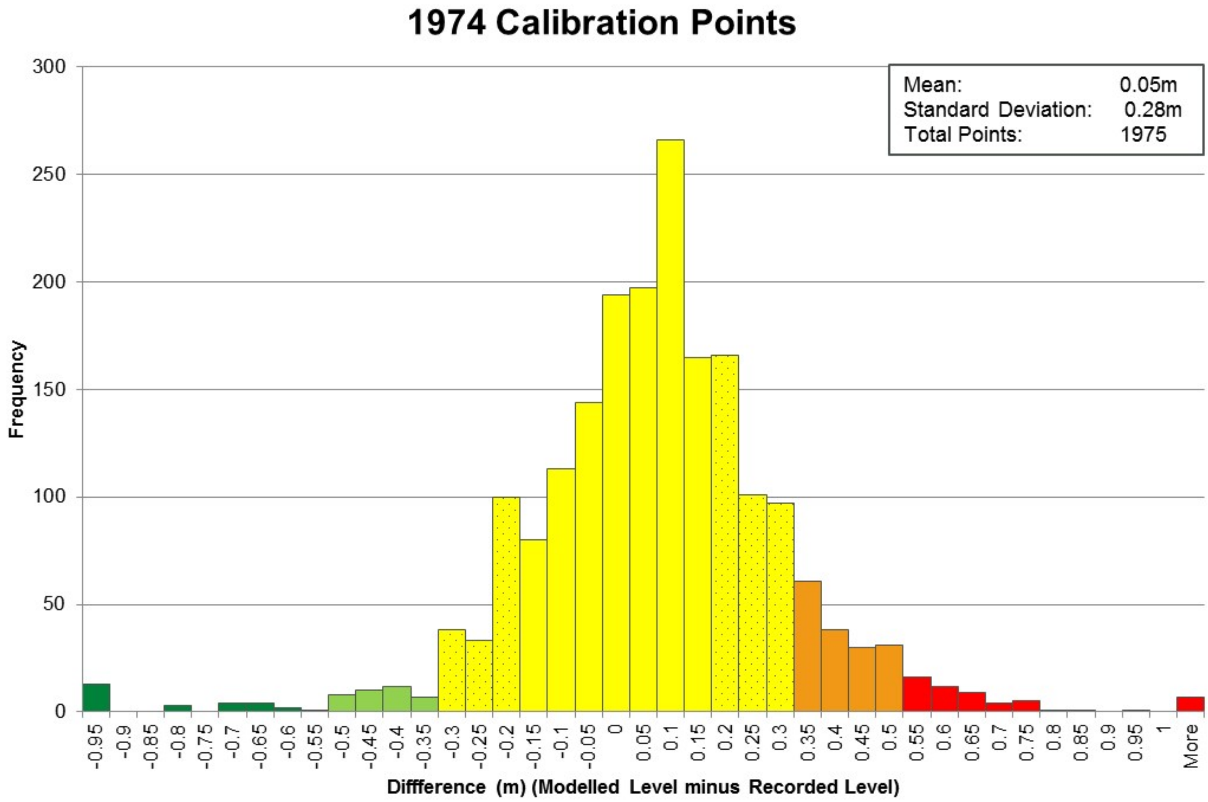


Figure 6-7 1974 Detailed Model Verification - Statistical Assessment of Differences between Observed & Modelled Peak Flood Levels

6.3.4 Calibration Conclusions

The Detailed Model calibration and verification to the five historical events has demonstrated a satisfactory performance of the model, meeting the accuracy tolerances as shown in A3 Addendum Sheet 8. This view was endorsed by the IPE following their review (see extract below).

> "*Recognising the uncertain accuracy of the observed data and the limited accuracy of topographic data, including that for the lower levels of some streams, the IPE considers that the accuracy of the calibration/verification of peak flood levels achieved is close to what is possible*" IPE, July 2015

6.4 Extreme Event Simulation

As for the Fast Model (see Section 5.4), simulation of extreme flows has been undertaken using the Detailed Model. The purpose of this exercise was to ensure that the model was both numerically stable and was of sufficient spatial extent to allow full propagation of Brisbane River backwater into tributary catchments.

Hypothetical extreme events consisting of 1.5x, 5x and 8x the 1974 flood event inflows were simulated within the Detailed Model. As well as checking the Detailed Model performance, it also allowed for a comparison of peak water levels with the Fast Model.

Overall, consistent peak water surface profiles were generally achieved between the Fast and Detailed models. A notable exception is the bend immediately downstream of the Breakfast Creek confluence. For extreme events, this bend becomes a major bottleneck with extremely high velocities and energy losses. It is expected that the 2D approach would be more accurate than the 1D.

Whilst the accuracy of the Fast Model at these extreme events might be less than the Detailed Model, this is not considered to be an issue in terms of the purpose and use of the Fast Model for the BRCFS Hydraulic Assessment, namely: to be used for running large numbers of Monte Carlo events, from which preliminary AEP levels can be derived and ensembles of events selected for each AEP.

The extreme events of 5x1974 and 8x1974 result in significant backwater inundation up the Lockyer Creek and Bremer River. The latter event in the Bremer indicates Brisbane River backwater influences extending to upstream to Amberley and beyond. As this backwater influence extends close to the upstream limit of the model, additional nodal storage is provided, corresponding to the storage within the floodplain upstream of the model extent. This is sufficient in scale to prevent any model boundary containing effects for events up to and including the largest of the design case floods (1 in 100,000 AEP, see Section 8.3).

6.5 Rating Curve Consistency

As discussed in Section 3.4.1, to reconcile whether the hydrologic and hydraulic modelling are consistent with each other, checks on the rating curves derived by the Hydrologic Assessment for the hydrologic modelling and the stage-discharge output from the hydraulic modelling were carried out. For the Detailed Model during the calibration phase, the rating curve checks (flow vs level) are presented in MR3 based on output for the five calibration/verification events. The Fast Model results are also shown for comparison along with the Hydrologic Assessment (Aurecon, 2015c) and Seqwater's 'Operational' curves (Seqwater, 2013) along with any historical flow measurements if available.

The review found consistency between the Detailed Model results and the rating curves derived by Seqwater (Seqwater, 2013) and the Hydrologic Assessment (Aurecon, 2015c), especially in the upper gauges before hydraulic effects such as hysteresis or looping occur due to backwater or tidal effects. Agreement at these upper gauges is essential as this is the transition area from the hydrologic modelling to the hydraulic modelling. Figure 6-8 shows the Fast and Detailed Model results for the five calibration events at Savages crossing. The red symbols are from the Fast Model, green from the Detailed Model, blue symbols are for the rating curves and yellow are streamflow measurements. The effect of hysteresis or looping is slight at Savages Crossing but is evident in the results, with the lower side of the loop (higher flows) occurring during the flood rise, and the higher side (lower flows) on the flood recession. Overall, the rating curves and hydraulic model results demonstrated satisfactory consistency after completion of the calibration phase.

Rating curves are discussed in greater detail in Section 8.6 where calibration and design model output for both Fast and Detailed Models is presented for the final overall check between the hydrologic derived rating curves and the hydraulic modelling.

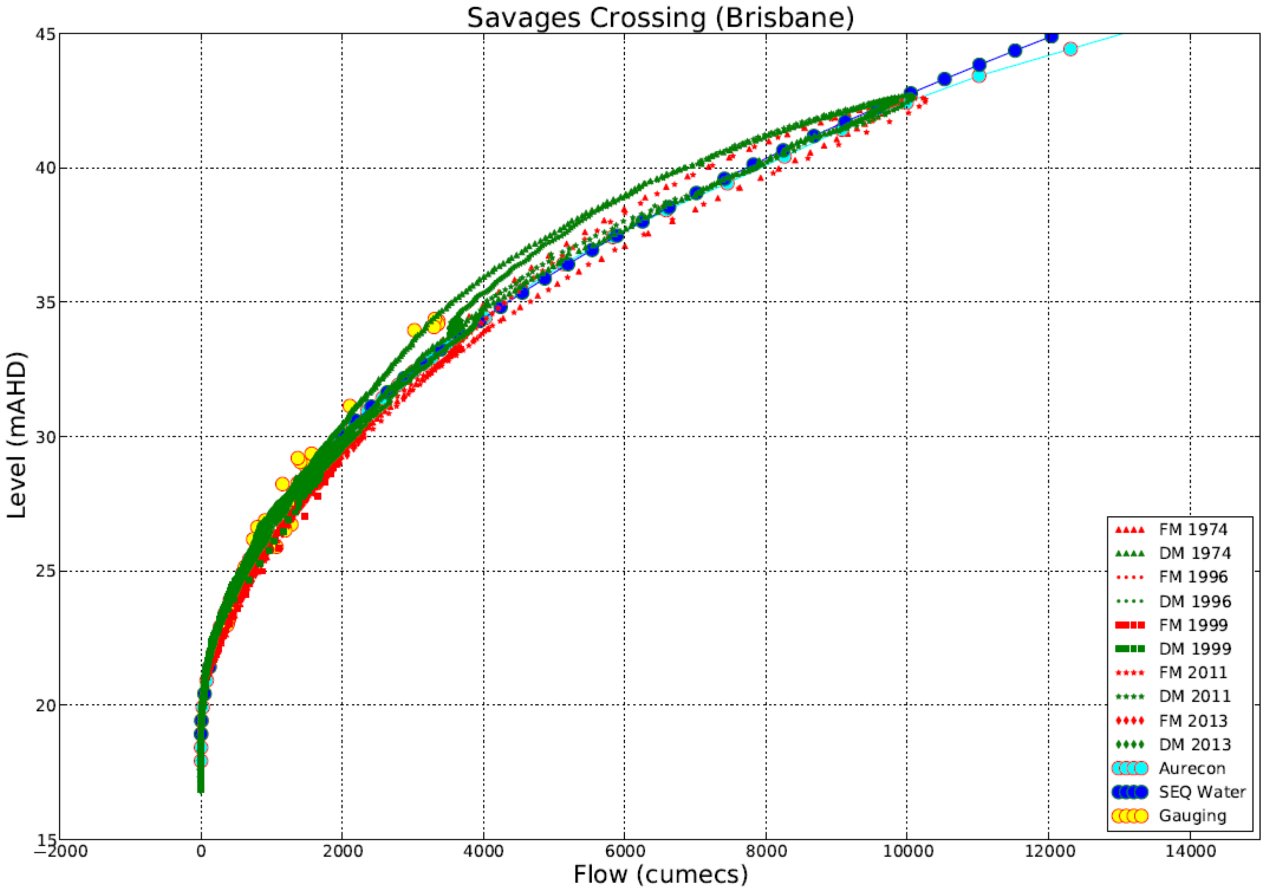


Figure 6-8 Rating Curves versus Hydraulic Modelling Calibration Results – Savages Crossing

6.6 Sensitivity Testing – Model Development and Calibration

Two Sensitivity Tests were undertaken using the Detailed Model. ST02 replicates the test undertaken on the Fast Model (see Section 5.6) where the Manning's n and bend losses were adjusted by ±10%. ST10[20] applied a 20 m resolution grid instead of the default 30 m grid. These tests are summarised below.

6.6.1 ST02 ±10% Change in Manning's n and Form Loss Values

Sensitivity Test 02 established the sensitivity of the Detailed Model to changes in Manning's n values and form loss values applied in the model. The test consisted of two model runs as follows:

- Increase Manning's n values and form loss values by 10%.
- Decrease Manning's n values and form loss values by 10%.

[20] Table 5-2 lists texts ST01 to ST05 as applied to the Fast Model. Tests ST06 to ST09 were for internal purposes and are not presented. Test ST10 is presented as its findings are of interest to the study.

Results from these tests are as would be expected, the 10% decrease gives higher flows for lower water levels and the 10% increase gives lower flows for higher water levels.

6.6.2 ST10 Comparison with 20 m 2D Resolution

Application of a 20 m resolution grid was carried out in part to ascertain whether using a finer resolution caused any major change or notable improvement in results, and to establish the practicality of using the finer grid model in terms of run times.

The 2011 event was used as the primary event to carry out the comparison between the 30 m and 20 m models.

For flood flows, the 20 m resolution tends to produce lower peak flood levels varying from no change to 0.8 m depending on the location. For tidal flows, there is negligible difference in the results throughout the tidal reaches of the river, with both models giving satisfactory results in terms of timing and amplitude.

Two additional 20 m model runs were undertaken by increasing the in-bank Manning's n values by 10% and 20% respectively. This was undertaken to achieve an improved calibration of the 20 m model to the 2011 flood recordings and to produce results more in-line with the 30 m resolution.

The reasons for the lower flood levels in the 20 m model and hence the need to increase the Manning's n values above those used in the 30 m model could be due to one or more of the following effects: although other unknown effects may also be contributing.

- The finer resolution would provide a slightly better reproduction of the river shape, and therefore conveyance, especially at lower flows, and where the river is narrowest.
- The 20 m resolution may be less prone to the "saw-tooth" effect that regular grids can experience if there are not sufficient cells across the waterway. The implicit 2nd order spatial solution scheme used by the TUFLOW software generally requires at least 3 or 4 cells across a major waterway to produce satisfactory results. If there are less cells, some constriction of flow can occur. This effect would be most pronounced in the narrower sections of the Brisbane and Bremer Rivers.
- Other somewhat unknown factors including slightly different velocity patterns at sharp river bends causing different energy losses and/or eddy viscosity effects may also contribute.

Given that the maximum difference of 0.8 m is less than 5% of the river conveyance and that different approaches to calculating a river's conveyance can vary the conveyance by 10%, it is considered that this difference is not outside expectations.

It was noted that the 20 m version of the Detailed Model takes around 4 times longer to run than the 30 m, bringing run times for the calibration events to 3 to 6 days depending on the event duration. Given that there are 60 individual events making up all of the design events, run times of this order are considered somewhat impractical, especially if investigating numerous flood mitigation and future development scenarios.

This view was endorsed by the IPE who considered that "a 30 m grid size represents the most practical compromise between the competing needs to produce a general purpose model that meets the requirements of the brief".

7 Fast Model Monte Carlo Analysis and Design Event Selection

This section describes the use of the calibrated Fast Model for simulating thousands of individual Monte Carlo events provided from the Hydrologic Assessment. The results from these simulations are used to statistically derive Annual Exceedance Probability (AEP) peak water levels using the Total Probability Theorem. The Monte Carlo Analysis approach is needed to take into account the wide range and variation in factors that affect flood behaviour such as the influence of Somerset and Wivenhoe Dams, and the variable responses to rainfall infiltration and rate of runoff of the Brisbane River, Lockyer Creek and Bremer River. A selection of the Monte Carlo events is then made, which as a group are representative of the AEP peak flood levels at the Reporting Locations. Finally, these selected events were cross-checked for consistency between AEPs using the calibrated Detailed Model prior to producing the final AEP design simulations as discussed in Section 8.

7.1 Overview

The Fast Model development and calibration is described in Section 5 with further detail provided in MR2. This Section describes the process through which 60 Monte Carlo events are selected to represent 11 different design flood AEPs. It follows three stages:

(1) **Stage 1:** Simulation of the 11,340[21] Hydrologic Assessment Monte Carlo events through the calibrated Fast Model retaining peak water levels and flows for each event at each Reporting Location.

(2) **Stage 2:** Undertaking a Monte Carlo flood level frequency analysis of the 11,340 events using the peak water levels to produce initial estimates of AEP levels at the Reporting Locations. Importantly, the level frequency analysis focuses on peak water level to include the effects of backwater, hysteresis (rating curve looping) and the tide or storm tide, as the peak flow may not occur at the time of peak level.

(3) **Stage 3:** Selection of a sub-set of the 11,340 Monte Carlo events that produce peak flood levels representative of the AEP levels derived in the previous stage. The expectation is that for any given AEP, an ensemble of events will be needed to match the AEP levels at all the Reporting Locations.

7.1.1 Design Flood AEPs

Design floods for eleven (11) Annual Exceedance Probabilities (AEPs) were derived based on Table 1 in the ITO (DILGP, 2014), which is reproduced in Table 7-1 below. This includes the 1 in 100,000 AEP event as this is the rarest event that can be estimated in a consistent and defensible manner across all sites in the study area.

[21] The Hydrologic Assessment considered 60 AEPs per event duration with 21 simulations performed per AEP. Thus the Hydrology Assessment simulated 1260 Monte Carlo events per duration. For the purpose of the Hydraulic Assessment, nine event durations were required (12 hours to 168 hours), leading to a total of 11,340 (9 x 1260) Monte Carlo events.

Table 7-1 Design Flood AEPs

AEP (%)	AEP (1 in ..)
50%	2
20%	5
10%	10
5%	20
2%	50
1%	100
0.5%	200
0.2%	500
0.05%	2,000
0.01%	10,000
0.001%	100,000

7.1.2 Reporting Locations

The hydraulic Monte Carlo AEP peak level frequency analysis was undertaken at 28 Reporting Locations. These locations were listed after Table 1 in the ITO (pages 23 and 24) and were subjected to a final review/confirmation by the IPE and TWG as part of Workshop 1 and documented in Appendix F of MR1. During this review "Brisbane River at City Gauge" was added and "Oxley Creek at Beatty Road" was removed as a Reporting Location.

Note that for the AEP analysis and selection of events, the Reporting Location "Brisbane River at Port Office" is the same as "Brisbane River at City Gauge" in terms of results as both are represented by the same 1D output node in the Fast Model.

The final 28 Reporting Locations are listed in Table 7-2 and their locations shown in A3 Addendum Sheet 1. A3 Addendum Sheet 1 also shows the locations within the Hydraulic Assessment study area of locations used by the Hydrologic Assessment (Aurecon, 2015b) for their Monte Carlo analyses.

Table 7-2 Reporting Locations

ID	Reporting Location	Description
RL_01	Lockyer Creek at Tarampa	At Rifle Range Road gauge
RL_02	Wivenhoe Dam Tailwater*	At gauge
RL_03	Lockyer Creek at Lyons Bridge	At gauge
RL_04	Brisbane River at Lowood Pump Station*	At gauge
RL_05	Brisbane River at Savages Crossing*	At gauge
RL_06	Brisbane River Upstream Mt Crosby Weir*	At gauge
RL_07	Brisbane River downstream Mt Crosby Weir	Downstream weir
RL_08	Brisbane River at Moggill*	Moggill ferry (mid river)
RL_09	Brisbane River at Jindalee*	Upstream Centenary Highway
RL_10	Brisbane River at Tennyson	Tennis Centre
RL_11	Brisbane River at Fairfield	Leyshon Park
RL_12	Brisbane River at Toowong	Regatta ferry terminal
RL_13	Port Office Gauge	At gauge (Edward Street)
RL_14	Brisbane City Gauge*	At gauge (Kangaroo Point)
RL_15	Brisbane River at Hawthorne	Hawthorne ferry terminal
RL_16	Brisbane River at Gateway Bridge	Upstream Gateway Bridge (mid river)
RL_17	Warrill Creek at Amberley*	At gauge
RL_18	Purga Creek at Loamside*	At gauge
RL_19	Bremer River at Walloon	At gauge
RL_20	Bremer River at Three Mile Bridge	Mid river
RL_21	Bremer River at One Mille Bridge	Mid river
RL_22	Bremer River at David Trumpy Bridge*	At gauge
RL_23	Bremer River at Hancock Bridge	At gauge
RL_24	Bremer River at Bundamba Confluence	Downstream confluence
RL_25	Bremer River at Warrego Highway	Upstream Warrego Highway (mid river)
RL_26	Bundamba Creek at Hanlon St Alert	At gauge
RL_27	Woogaroo Creek at Brisbane Road Alert	Downstream confluence
RL_28	Oxley Creek at Rocklea	Upstream Sherwood Road

* These locations are also Hydrologic Assessment Reporting Locations (Aurecon, 2015c)

7.2 Data Provided

Monte-Carlo hydraulic model simulations using the Fast Model were carried out using the Hydrologic Assessment Monte Carlo events generated for the Brisbane City Gauge (ie. for the whole of the catchment rainfall AEP scenarios)[22]. Monte Carlo event inflows were supplied to the Hydraulic Assessment by the Hydrologic Assessment in a NetCDF file containing:

- Discharge hydrographs at around 150 locations (around 100 of which are used in the hydraulic model). 1,260 events were supplied per duration (9 durations) giving 11,340 events in total.
- Downstream boundary data for all events.
- Rainfall data for all events.
- Metadata.

7.3 Monte Carlo Events Simulation

7.3.1 Simulations

The 11,340 events were simulated through the Fast Model by using an automatic batching script to push each simulation to available CPU cores across a network of office computers with varying CPU specifications. Depending on the availability of CPU cores, the process would take several days to a week.

The peak water levels and peak flows at each Reporting Location were tracked every computational timestep and written to a file at the completion of each simulation. In addition, other information to validate the model outputs was also tracked every timestep and reported within the same file.

The information retained included:

- Peak water level.
- Peak flow.
- Flow at peak water level.
- Water level at peak flow.
- Time of peak water level.
- Time of peak flow.
- Maximum change in water level during a computational timestep.
- Maximum change in flow during a computational timestep.

[22] As agreed through the Hydrology and Hydraulics Interfacing process the 'whole of catchment rainfall' approach was used for the provision of Monte Carlo Events. This corresponds to Option G/H as documented in MR4.

7.3.2 Checking of Results

The Fast Model simulations needed to be checked for any numerical instabilities causing unreliable peak flows and water levels. This was carried out using a range of statistical analyses and charts of the output from the 11,340 events. Comparisons were made of the following outputs:

- Fast Model vs hydrologic modelling peak flows.
- Peak water level vs peak flow.
- Water level verses flow at peak level and peak flow.
- Maximum change in water level over one timestep.
- Maximum change in flow over one timestep.
- Time of peak water level.
- Time of peak flow.

All of the above analyses were used to check for outliers. Of the checks undertaken, the review of the maximum changes in water level and flow over one timestep was the most useful for identifying events that have potential model instabilities. These events were identifiable by having an unusually large change in water level and/or flow over one computational timestep.

An example of this is shown for an event at the Tennyson Reporting Location where a relatively large change in flow of 984 m^3/s was noted in a single timestep. Following this initial identification, time histories of water level and flow were plotted (based on model outputs at one hourly intervals). This is shown below in Figure 7-1 where the black line is level and the blue line is flow. The peak water level (tracked at every computational timestep) is shown as a purple point marker. It can be seen that this peak level sits above the water level hydrograph. This is more apparent for the peak flow as shown by the red point which sits notably above the flow hydrograph.

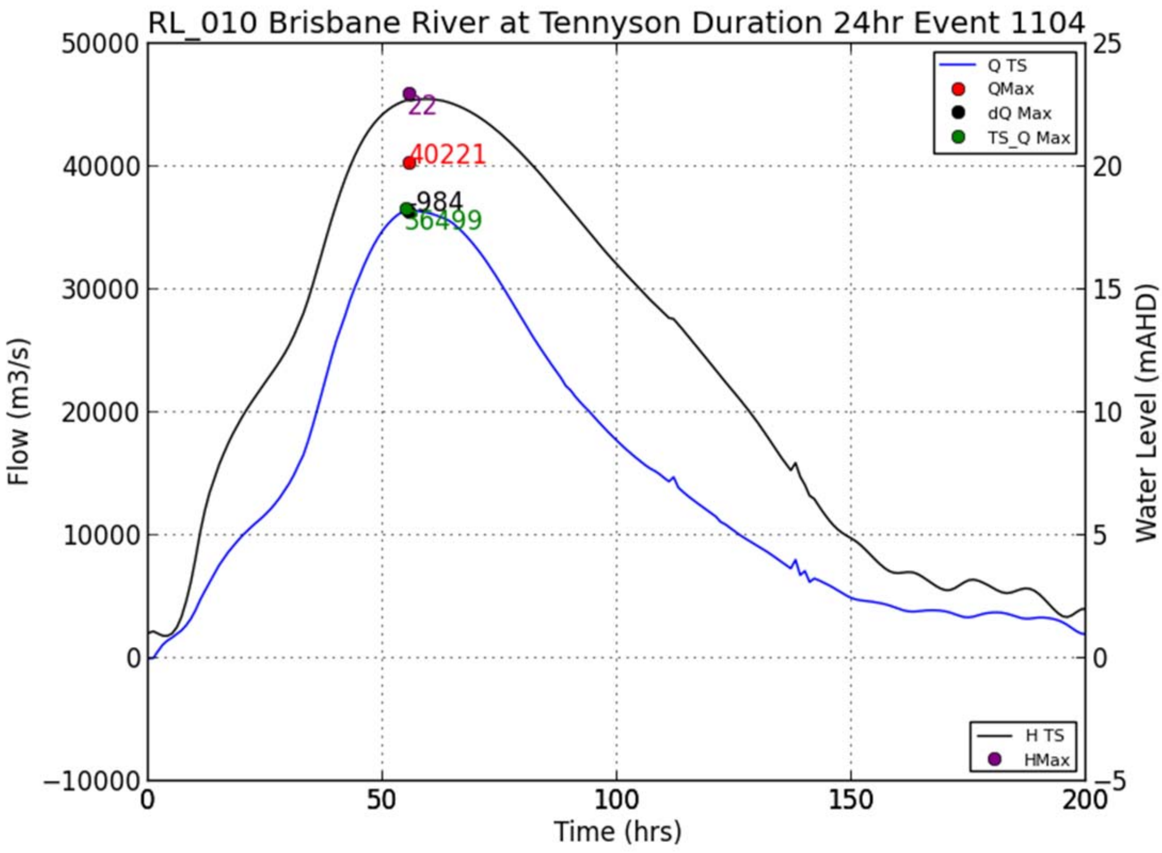


Figure 7-1 Example Plot Used to Identify Numerical Instabilities

The approach taken to rectify these problematic events was to replace the invalid peak water level and/or flow with the hydrograph maximum so as to retain a complete set of 11,340 events for the AEP level frequency analysis. An automated process was developed for achieving this and is documented in MR4.

In summary, of the 317,520 hydrographs (11,340 events times 28 Reporting Locations) 6 cases were filtered out based on water level criteria and all were for extreme events with peak flows in excess of 20,000 m^3/s. Likewise 156 cases (0.05% of all events) were filtered out based on peak flow criteria.

Fundamental checks on model performance were also undertaken such as checking the model mass error is within standard bounds. Mass Error values were well within the 1% target (a cumulative mass error exceeding 1% can be a sign of a simulation not performing well in terms of numerical convergence and/or numerical instabilities).

7.4 Monte Carlo Annual Exceedance Probability (AEP) Analysis

This section summarises the analyses undertaken to derive level frequency relationships (i.e. the relationships between maximum flood level and AEP) for all Reporting Locations. All analysis is undertaken with Wivenhoe and Somerset Dams in place.

The analysis used the peak water level and flow output from the 11,340 events simulated within the Fast Model.

7.4.1 Flood Level Frequency Analysis

The general approach adopted to estimate AEPs of peak flood levels is based on use of the Total Probability Theorem. The adopted solution was first developed for this type of Monte Carlo scheme by Nathan and Weinmann (2002), and is described in more detail in Nathan and Weinmann (2013).

For this implementation, the probability domain was divided into 24 intervals (with evenly spaced standardised normal variate bounds) between AEPs of 1 in 2 to 1 in 10^6. The number of simulation results that fell within each interval varied generally between 30 and 50. Within each probability interval, conditional probability estimates were derived for a total of 50 threshold levels, where the levels were selected to vary uniformly between the minimum and maximum values obtained from the set of 1,260 simulation results for each of the nine rainfall burst durations.

An example illustration of the information used to calculate the expected probabilities of the maximum levels at each site is shown in Figure 7-2. The plot shows the peak levels at Savages Crossing obtained from 1,260 simulations of flows resulting from 72 hour rainfall bursts (small circle symbols). These levels are plotted at AEPs corresponding to rainfalls over the whole Brisbane River catchment, as determined from the design rainfall information.

It is seen that there is considerably more scatter at frequent events than there is evident for rarer events; this merely reflects the fact that the flows rarer than 1:10^4 AEP were derived using fixed patterns of rainfall and those more frequent reflect the variability present in the spatially-varied temporal patterns, and for some sites, the more influential effect of Wivenhoe Dam on frequent events compared with extreme events. The blue curve represents the expected probability quantiles derived using the Total Probability Theorem, and (as expected) it is seen that this curve sits centrally within the scatter of points. There are a small number of maxima for events more frequent than the left hand limit of the plot (around 1 in 1.7 AEP), and while these points do contribute to exceedances of the lowest threshold considered, their influence is negligible.

Also shown in Figure 7-2 is the 1 in 100 AEP flood level derived using the Total Probability Theorem. It is of interest to note that the rainfall AEPs contributing to this estimate range between 1 in 20 and 1 in 2,000. That is, there are occasions in which a 1 in 20 AEP rainfall falls on a very wet catchment and produces a flood level with an AEP of 1 in 100; at the other end of the extreme, it is seen that there are 1 in 2,000 AEP rainfalls that occur on a very dry catchment that yield the same flood level. Of course, it is not merely antecedent catchment conditions that influence this flood response, as the temporal and spatial patterns of rainfall also influence the nature and timing of flood response. A worked example of how the expected probabilities are computed using the Total Probability Theorem is provided in Section 7.4 of Nathan and Weinmann (2013).

Once the expected probability quantiles were derived for each duration, the final relationship between peak flood level and AEP was derived as the envelope of all durations. An example family of such curves and the resulting envelope curve is shown in Figure 7-3.

The application of this scheme to the Fast Model simulation results is conceptually straightforward, though a bespoke framework was developed to suit the large number of sites and the nature of the data sets involved. The premise of the above scheme is that rainfalls have a dominant role in the production of peak flood levels, but that the maxima will vary due to the joint occurrence of other factors. This is a defensible assumption for riverine flooding, but special attention needed to be given to sites located on tributaries of the main channel of the Brisbane River (eg. the Bremer River). This is discussed in greater detail in MR4.

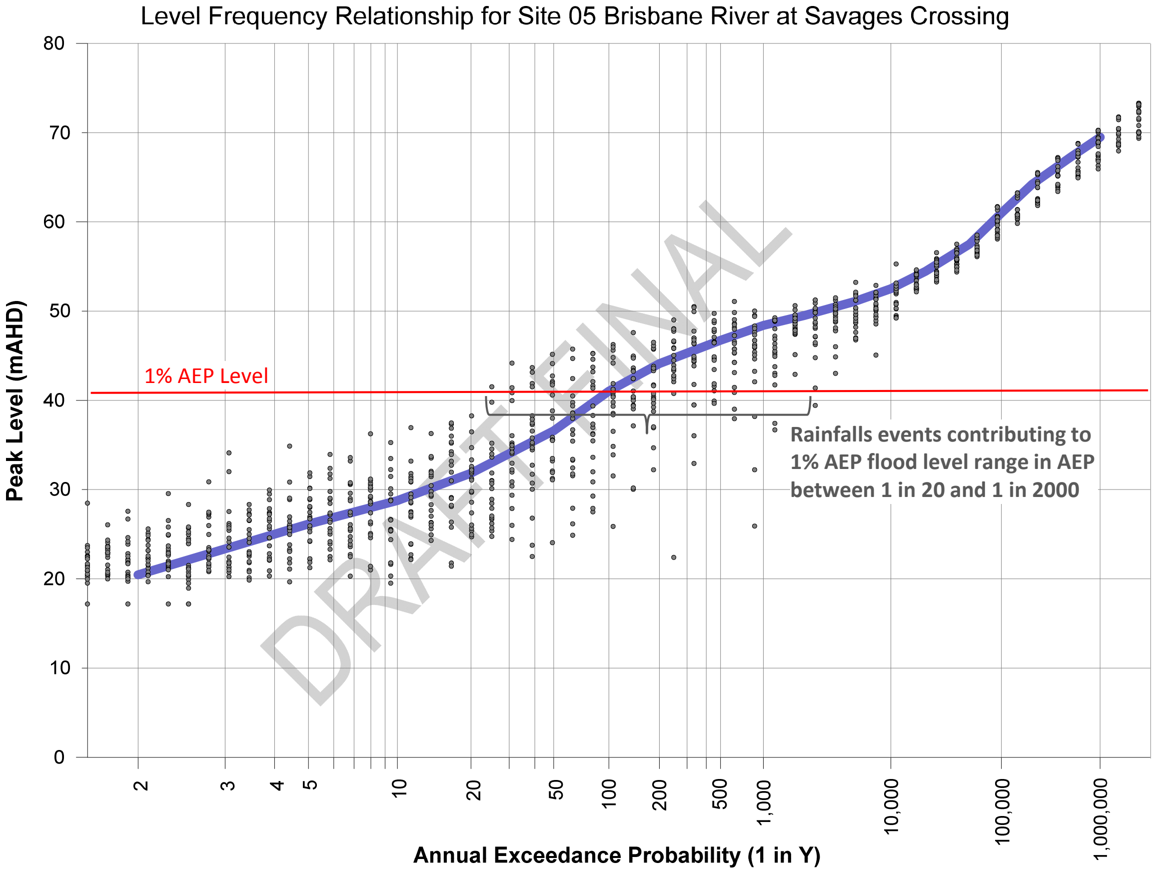


Figure 7-2 Example Level Maxima and Derived Level Frequency Relationship for 72 hour Event at Savages Crossing

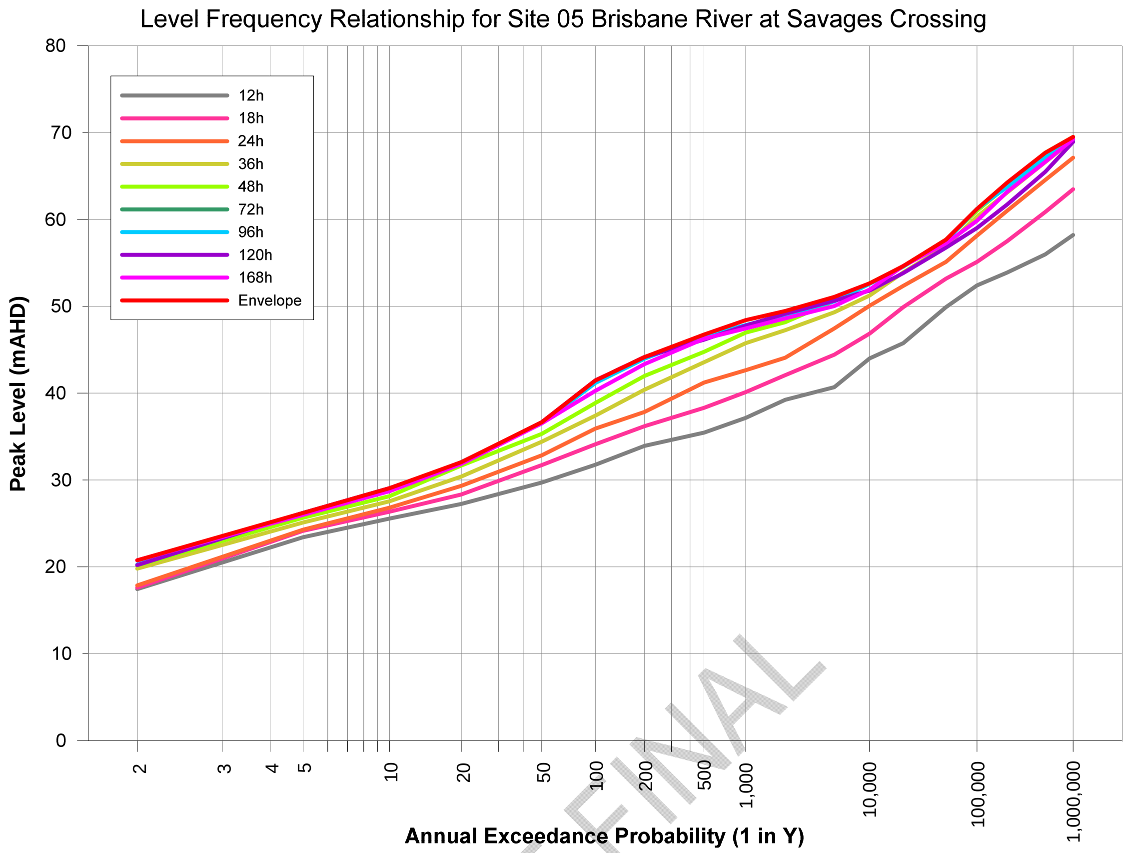


Figure 7-3 Example Frequency Relationships for All Durations at Savages Crossing, and the Envelope of Level Maxima with AEP

7.4.2 Frequency Analysis Results

Results are presented as peak AEP levels at Reporting Locations. A graphical example of this is shown below in Figure 7-4 for Reporting Locations on the Brisbane River although it needs to be recognised that a longitudinal flood profile joining the AEP levels (i.e. a vertical section through the curves shown in Figure 7-4) does not represent the flood behaviour from any single event, and it cannot be expected that any single flood will conform to this profile.

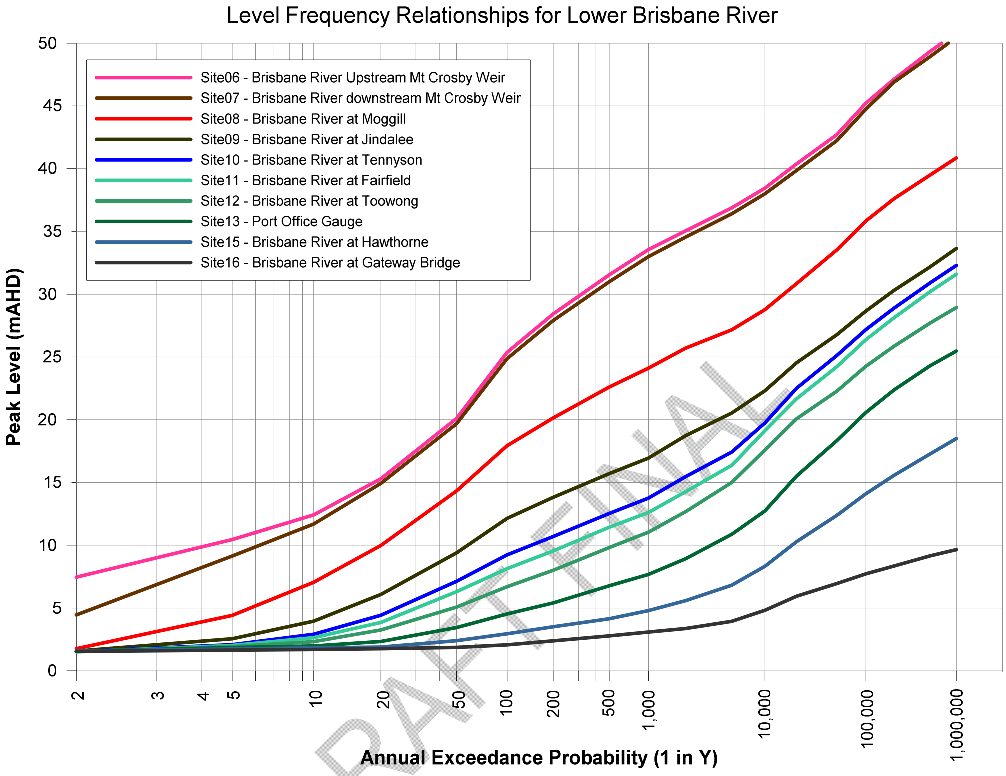


Figure 7-4 Derived Level Frequency Relationships for Sites along the Lower Reaches of the Brisbane River

7.4.3 Cross Check with Hydrologic Assessment

To facilitate a comparison with the Hydrologic Assessment, peak flows were extracted from the Fast Model and were analysed using the same approach as described above for levels. The Reporting Location at Savages Crossing was selected as this location would be expected to be reasonably free of backwater effects due to conditions in the lower Brisbane River.

The comparison between the two sets of results is shown in Figure 7-5, from which it is seen that there is a satisfactory level of agreement between the results. The difference in levels associated with the 1 in 2 AEP event may reflect differences in the treatment of the probability calculations of the first interval considered (this study adopts a geometric mean rather than arithmetic mean for computation of the conditional probabilities in the first and last intervals, as recommended in Nathan and Weinmann, 2013).

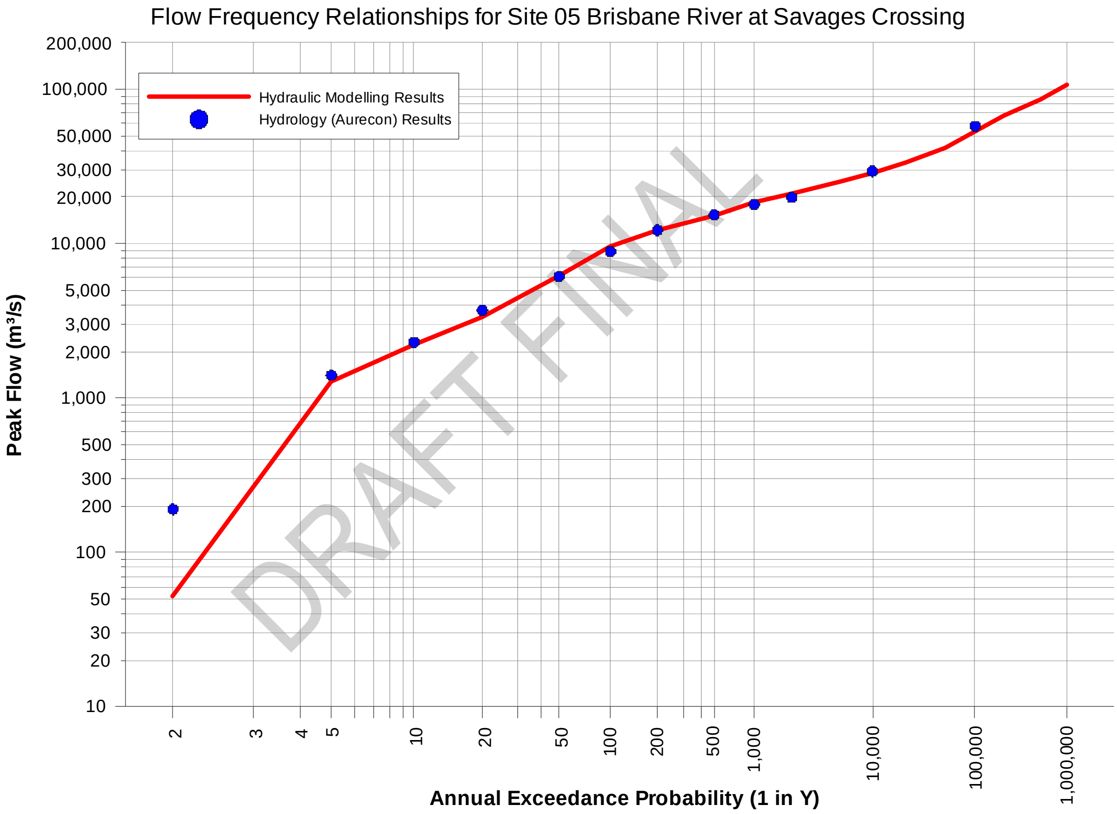


Figure 7-5 Comparison of Flood Frequency Relationships based on Results Obtained from the Hydrologic and Hydraulic Assessments

7.5 Selection of Fast Model AEP Ensemble Events

7.5.1 Overview

On the basis that no single Monte Carlo event will be representative of the AEP levels at all Reporting Locations, an ensemble of events is expected to define AEP peak flood levels across the Hydraulic Assessment study area. This is analogous to the use of several durations to derive the AEP levels throughout a catchment because the critical duration varies within the catchment with short, more intense rainfall durations typically dominating the upper catchment, and longer duration, larger volume events prevailing in the lower areas.

Events forming ensembles are selected based on peak water levels. The AEP flood level surface is then calculated as the maximum of the ensemble's flood peaks, sometimes referred to as the maximum of the maximums. This ensures that there is a smooth transition in peak AEP flood level throughout the Hydraulic Assessment study area.

7.5.2 Selection Criteria and Approach

In selecting the events that best approximate the AEP flood levels from the Monte Carlo level frequency analysis, the following criteria for each AEP are required:

- The critical event at a Reporting Location is the ensemble event that produces the highest flood level.
- The critical event at a Reporting Location must peak at or within an acceptable tolerance of the AEP level, referred to as the Critical Event Tolerance (CET).
- The CET at each Reporting Location should be the same or less than the desired design flood accuracy tolerances specified in the ITO as follows:
  - Brisbane River and tributaries upstream of Goodna (for non-urban areas), including Bremer River and Lockyer Creek ± 0.50 m.
  - Brisbane River downstream of Oxley Creek ± 0.15 m.
  - Brisbane River between Goodna and Oxley Creek ± 0.30 m.
  - Ipswich urban area ± 0.30 m.
- The critical event cannot exceed the AEP level at another Reporting Location (within the CET), otherwise the principle of taking the maximum of the maximums fails.

A staged process was followed as summarised in Figure 7-6 and described in detail in MR4.

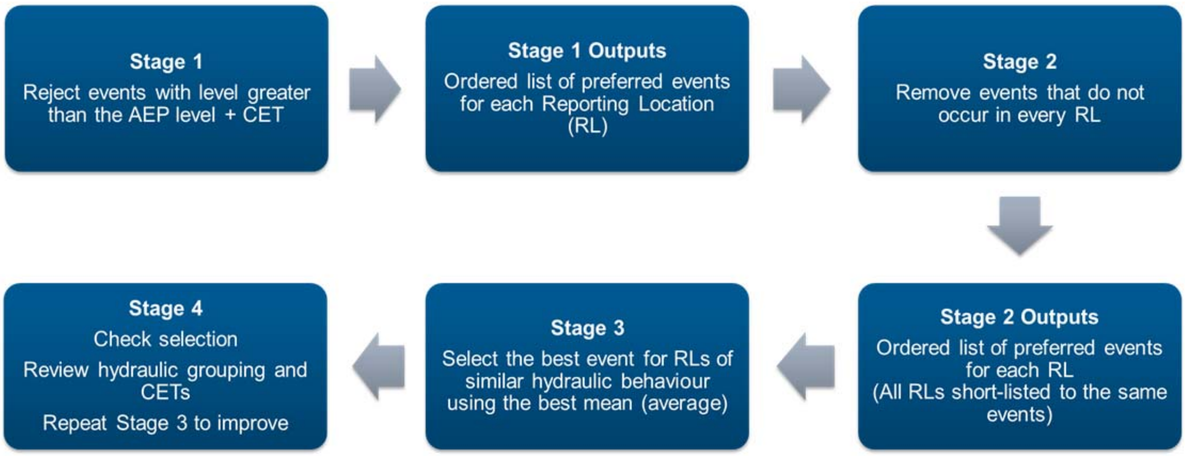


Figure 7-6 Flow Chart of Event Selection Methodology

7.6 Fine Tuning Selection of Events using Detailed Model

Following the initial event selection process (Section 7.5), minor refinements were made to the selection by cross-checking the design event levels, particularly in areas not well represented by the Reporting Locations, by simulating the events using the calibrated Detailed Model (Section 6). This allows for the checking for consistency of peak design levels in areas not well represented by the Reporting Location AEP analysis, for example, clarification of increasing flood levels with reducing AEP probability. These areas are typically located upstream and downstream of the Reporting Locations' coverage, or potentially on the floodplains where the hydraulic behaviour is not controlled by the main waterways, on which the Reporting Locations are located.

This checking process highlighted that peak flood levels did not always ascend with AEP rarity in some areas distant from the Reporting Locations. This is referred to as "non-ascending peak flood levels". These occurred in three locations as follows:

- In the upper sections of small tributaries that flow into the main waterways of Lockyer Creek, Bremer River and Brisbane River.
- In parts of the Lockyer floodplain, particular upstream of the first Reporting Location at Lyons Bridge.
- In the tidal section downstream of the Gateway Motorway, which is the most downstream Reporting Location.

All three instances were determined to be artefacts of the Monte Carlo process and due to the spatial resolution of the Reporting Locations. Discussion and agreement with the TWG and IPE was had to resolve these issues with outcomes summarised in Table 7-3 and presented in detail in MR4.

Table 7-3 Resolution of Non-Ascending AEP Peak Flood Levels

Non-Ascending Issue	Resolution
As part of the Monte Carlo process, a local (minor) tributary could experience a greater or lesser rainfall than the whole of the Brisbane River catchment rainfall. Where backwater effects from the main waterway have not dominated, the tributary may exhibit non-ascending AEP flood levels upstream of riverine backwater influence.	Apply minor tributary inflows directly to the main waterway at the tributary's confluence. Reduced routing effects of local catchment inflows due to this change were shown to have negligible influence on model results within the main waterways*.
Due to complex floodplains, elevated waterways and distances from Reporting Locations, targeted AEP flood levels from the frequency analysis at the Reporting Locations located within Lockyer Creek may not be representative of the flood levels on the floodplains.	Mapping amended to either: a) Indicate caution is required in interpreting results in affected areas distant from Reporting Locations; or b) Exclude affected areas from mapping eg Buaraba Creek which is local rather than regional flooding
Design flood levels below the Gateway Motorway (most downstream Reporting Location) showed that the peak ensemble levels would not necessarily ascend with increasing AEP rarity.	Storm tide levels at the hydraulic model downstream boundary were adjusted where necessary to correspond with design levels derived from the BCC Coastal Plan Implementation Study (GHD, 2014). The Hydrologic Assessment used GHD (2014) to derive storm tide boundaries for the Monte Carlo events. However, the randomised selection of storm tide events could cause a too high, or no storm tide events high enough amongst the selected events within an AEP ensemble.

*To ensure that the change in inflow locations had not adversely affected the model's performance, the five calibration events were re-simulated in the Detailed Model after adjustment of the local inflow boundary locations.

7.7 Final Events Selected

A finalised set of 60 events to represent 11 design AEP ensembles was derived as presented in Table 7-4. In Table 7-4 a five character AEP identifier is introduced. This identifier is used within the simulated event naming convention and provides a logical ordering to results files.

Table 7-4 Events in each AEP Ensemble after Fine-Tuning Selection using Detailed Model

AEP Identifier	AEP	% AEP	Number of Events in Ensemble
D0002	1 in 2	50%	7
D0005	1 in 5	20%	6
D0010	1 in 10	10%	5
D0020	1 in 20	5%	6
D0050	1 in 50	2%	6
D0100	1 in 100	1%	5
D0200	1 in 200	0.5%	7
D0500	1 in 500	0.2%	5
D2000	1 in 2,000	0.05%	5
DK010	1 in 10,000	0.01%	4
DK100	1 in 100,000	0.001%	4
		Total	60

The event selection process has been endorsed by the IPE following Workshop 4.

"*The IPE endorses Milestone Report 4 – fast model and design results*"
IPE, June 2016

8 Design Event Modelling and Sensitivity Test Scenarios

The 60 Monte Carlo events selected as being representative for the 11 AEP ensembles are to be run through the Detailed Model to derive the peak AEP design flood surfaces and associated output. This Section documents the design case as applied in the Detailed Model, the Base Case results and the outcomes of sensitivity scenarios tested in the model.

8.1 Introduction

This stage of the study consists of two general components:

- Simulation of 60 Monte Carlo flood events through the Detailed Model and use of the results to derive Base Case[23] design flood outputs for 11 AEP design floods.
- Assessment of the sensitivity of the Base Case results to changes associated with future climates, future development, changes in bed level and the influence of key dams.

A total of 213 simulations were carried out using the Detailed Model comprising:

- 60 design runs for the 11 AEPs (Base Case).
- 21 floodplain future condition sensitivity scenarios.
- 84 climate change sensitivity scenario runs.
- 42 bed level sensitivity runs.
- 6 calibration events No/With dams runs.

Results are presented in a several ways (see Section 3.9) including:

- Maps showing peak design flood elevations, depths, velocities and hydraulic hazard.
- Time series plots showing the change in flows/elevations with time.
- Tabulated results of peak flood elevations at Reporting Locations.

The agreed Base Case for derivation of design flood information required some modifications to the Detailed Model from that documented in MR3. This section includes descriptions of the modelled events along with those modifications to the Detailed Model.

8.2 Naming Conventions

In order to manage the large number of simulations carried out, design model runs are labelled as follows.

BR_D_MC_aaa_bbbbb_ccc_dddd_vvv

Where:

- BR signifies Brisbane River.
- D signifies Detailed Model.

[23] The Base Case is the Existing (Approved) Development Scenario as specified in the ITO and is current at the time of model simulation (2015)

- MC signifies the event is a Monte Carlo event.
- aaa is the scenario represented by 3 characters (see Table 8-1).
- bbbbb is the AEP represented by 5 characters, eg. D0500 for the 1 in 500 AEP event (refer to Table 7-4).
- ccc is the event rainfall burst duration in hours. There are nine durations ranging from 12 hours (012) to 168 hours (168).
- dddd is a unique Monte Carlo identifier assigned by the Hydrologic Assessment for each duration.
- vvv is the Detailed Model version number assigned for quality control purposes.

Table 8-1 lists the scenarios used by the Detailed Model for design simulations. This includes the Base Case (B15) scenario and sensitivity scenarios included in the assessment. Details on the Base Case results and sensitivity assessments are provided later in Section 8.4 and 8.5 respectively.

Table 8-1 Scenario Acronyms used in Study

aaa Acronym	Scenario
B15	**B**ase Case circa 20**15***
FF1	**F**uture **F**loodplain Condition (**1** variant)
CC1	**C**limate **C**hange **1**: 0.3 m rise in sea level
CC2	**C**limate **C**hange **2**: 0.3 m rise in sea level and 10% increase in rainfall
CC3	**C**limate **C**hange **3**: 0.8 m rise in sea level
CC4	**C**limate **C**hange **4**: 0.8 m rise in sea level and 20% increase in rainfall
BL1	**B**ed **L**evel **1**: Decrease in bed level (20% increase in conveyance)
BL2	**B**ed **L**evel **2**: Increase in bed level (20% decrease in conveyance)
CND	**C**alibration event with **N**o **D**ams
CWD	**C**alibration event **W**ith **D**ams

*The Base Case is dated 2015 as being the year in which the inclusions for the Base Case were agreed with the TWG.

The unique Monte Carlo identifier for each duration is a four digit number that ranges from 1 to 1260, representing the 1,260 events generated by the Hydrologic Assessment for each rainfall burst duration. By preceding this identifier with the duration, this gives a unique identifier for each of the 11,340 (9 x 1,260) Monte Carlo events. For example, 096_0774 is event number 774 for the 96 hour duration rainfall.

The version number is an internal quality control number used to assist during the model build process. The version number of the Detailed Model for the results within this report is 605 and is the same for all simulations presented. The simulations were carried out using TUFLOW Release Build 2016-03-AC.

Examples of the labelling system are presented below.

Example 1

BR_D_MC_B15_D0050_072_0653_605

This is a Base Case (B15) event that is part of the 1 in 50 AEP ensemble. It has a 72 hour rainfall duration with a Monte Carlo event identifier of 0653. The model version number is 605.

Example 2

BR_D_MC_CC3_DK010_036_1026_605

This is a climate change sensitivity scenario corresponding to the third climate scenario (CC3). The event is part of the 1 in 10,000 AEP ensemble (DK010). It has a 36 hour rainfall duration with a Monte Carlo identifier of 1026. The model version number is 605.

8.3 Detailed Model Base Case

The Base Case, referred to as B15 (**B**ase Case circa 20**15**), is simulated in the Detailed Model for the 11 AEP flood event ensembles in order to derive peak flood level, depth, velocity and hydraulic hazard output across the study area. The results are provided as tables of peak levels and flows, maps and plots of flows and levels over time at Reporting Locations. The output forms the key deliverable for the BRCFS and is the culmination of a significant investment in hydrologic and hydraulic catchment analysis and simulation.

The Detailed Model was developed, calibrated and verified as described in Section 6 and in detail in MR3. For determining design events, a number of modifications were required to be made to the model. Some of these modifications relate to physical features represented in the model whereas others were made to allow for simulation of events considerably larger than the largest calibration event. The changes are summarised in Table 8-2.

Table 8-2 Base Case (B15) Changes to the Detailed Model

Modification	Rationale
Use of 2014 DNRM LiDAR to represent floodplain terrain within ICC and BCC areas	This is more recent topographic data than that used by the DMT DEM and became available during the course of the study. Sensitivity testing of the updated LiDAR for the calibration events showed only minor differences in peak flood level (typically less than ±0.03 m. It has been incorporated into the Base Case as representing the most up to date terrain.
Inclusion of 2011 LiDAR for Fernvale Quarry	This dataset became available during the course of the study and supersedes the 2008 LiDAR in the DMT DEM across this location.
Inclusion of the Riverwalk structure	The feature was constructed in 2014 and has been incorporated into the Base Case.
Inclusion of Howard Smith Wharves	The development (to be constructed) is included in the Base Case based on a conceptual design.
Backflow Prevention Devices simulated as fully open	It is assumed (in consultation with the TWG) for design case modelling that any backflow prevention devices fitted to the stormwater pipes or trunk drainage systems are assumed to be fully open. Conservative modelled flood levels and extents are produced in those local areas that might otherwise be protected by the backflow prevention devices. Backflow prevention devices are considered to have negligible effect on riverine flood levels.
Incorporation of additional flood storage for extreme events on tributaries	Model domain extended as follows to allow for full propagation of backwater for events up to the 1 in 100,000 AEP event: • Additional nodal storage added to 1D upstream limits of Bremer, Purga and Warrill Creeks • Model 2D code region extended for minor tributaries

8.4 Base Case Results

Eleven AEP design flood ensembles have been simulated within the Detailed Model. For each AEP ensemble the peak (maximum) flood output at every model cell has been queried and the maximum value from that ensemble reported. This 'maximum of maximums' approach is used for all mapping output, ie. for peak flood levels, depths, velocities and DxV (hydraulic hazard), unless otherwise specified. In the case of the 1 in 2 AEP, the map output is shown within the tidal limits only for reasons as discussed in MR5.

8.4.1 Drawings

The Hydraulic Assessment provides peak outputs across the assessment area digitally for all AEP events. Drawings are divided into AEP design events and then further divided into five regions with one A3 page per region. A key sheet identifying the regions is provided in A3 Addendum Sheet 19.

Four model outputs are presented as follows:

- Peak Water Surface Levels – for MR5 mapping the flood extent is shown with 1 m interval contours giving peak level to mAHD. For the 1 in 100 AEP mapping shown in A3 Addendum Sheet 20 to A3 Addendum Sheet 24, intermediate 0.5 m contour intervals are also shown.
- Peak Flood Depth Maps – colour shaded mapping indicating five intervals of flood depth.
- Peak Flood Velocity Maps – colour shaded mapping with six intervals of depth averaged velocity.
- Peak Depth x Velocity (DxV or Hydraulic Hazard) Maps – colour shaded mapping with five intervals of hydraulic hazard. Hydraulic hazard is the product of flood depth and the depth averaged velocity. The peak hydraulic hazard is tracked during the model simulation and occurs when the product of flood depth and depth averaged velocity is greatest.

All mapping also includes the following:

- A dotted line indicating the ‘extreme flood’ extent, nominally taken to be the 1 in 100,000 AEP flood.
- Limit of mapping lines defining the upstream limits of where the design riverine flood mapping is considered applicable.
- A hatched area across flood extents shown in the Lockyer Valley Regional Council (LVRC) area and extending part way into Somerset Regional Council (SRC) area. This area is beyond the area specified in the ITO to be mapped and may be subject to higher localised creek flooding, therefore flood levels for design and planning purposes should be checked with the local council. The mapping is provided because it adds valuable insight into flood behaviour on the complex Lockyer Creek floodplain from the backwater interaction between Lockyer Creek and Brisbane River.

Mapping for the 1 in 100 AEP is included in the A3 Addendum accompanying this report (A3 Addendum Sheet 20 to A3 Addendum Sheet 39).

8.4.2 Plots

Plot output for the Base Case modelling includes:

- Time-series plots of flows/levels at Reporting Locations.
- Longitudinal peak water surface profiles.
- Rating curve (flow vs level) plots at gauges.

For the purposes of this report, the following plots are included:

- The 1 in 100 AEP time-series plots (A3 Addendum Sheet 40 to A3 Addendum Sheet 42).
- Longitudinal peak water surface profile maximums i.e. combined ensembles, for all events (A3 Addendum Sheet 43 and A3 Addendum Sheet 44).
- Rating Curves at gauges (A3 Addendum Sheet 45 to A3 Addendum Sheet 50).

8.4.3 Tables

A3 Addendum Sheet 51 presents riverine peak levels and flows at Reporting Locations for all design events and a summary table is provided as
Table 8-3. It should be noted that peak level and peak flow do not necessarily occur at the same time.

8.4.4 Discussion on Flood Levels

It can be seen from the mapping, plots and summary table of peak flood levels that, as expected, peak flood levels increase with increasing flood rarity.

Given the significance of the 1 in 100 AEP event as a traditional reference flood, some additional commentary has been provided for this event to aid understanding of the event magnitude in the context of historical events. Figure 8-1 to Figure 8-3 present design flood levels for 1 in 50 to 1 in 500 AEP along with the simulated 1974 and 2011 flood levels for Lowood, Ipswich and Brisbane respectively to assist with interpretation. For brevity, the smaller and larger design events are not shown. The following points are noted:

- In the lower reaches of Lockyer Creek the 1 in 100 AEP flood level is typically higher than both the 1974 and 2011 floods but only moderately so by around 0.2 m to 0.4 m. However, due to the complex nature of the lower Lockyer floodplain, in localised areas the historical events were higher.
- For much of the Brisbane River between Wivenhoe Dam and Moggill, including the lower reaches of the Bremer, the 1 in 100 AEP flood is lower than both the 2011 and the 1974 floods. For example near Lowood the 1 in 100 AEP flood is lower than both the 1974 and 2011 events by approximately 0.8 m to 1.0 m.
- Near Ipswich CBD the 1 in 100 AEP flood is around 1 m higher than the 2011 flood but around 0.8 m lower than the 1974 flood.
- The 1 in 100 AEP flood is higher than the 2011 flood in the lower reaches of the Brisbane River, downstream of Centenary Bridge. Typically it is between 0.1 m and 0.3 m higher and in the vicinity of Brisbane CBD the difference ranges from 0.1 m to 0.15 m.
- Near the estuary, downstream from the Gateway Motorway, the 1 in 100 AEP flood is similar to the peak level resulting from the storm surge experienced in the January 2013 event. This was higher than both the 2011 and 1974 flood levels.
- Backwater flooding from the Brisbane River occurs on numerous tributaries, most notably on the Bremer River and Oxley Creek but also on many local creeks on the lower Brisbane River such as Norman, Bulimba and Breakfast Creeks. Backwater flooding in the lower reaches of these creeks is likely to result in peak flood levels higher than that which would be experienced from a local 1 in 100 AEP flood event on the respective creeks.
- The rate of rise and duration of inundation of the 1 in 100 AEP flood varies depending on the ensemble event considered. The individual ensemble event that results in the highest flood level at any given location may not be the event that exhibits the fastest rate of rise or longest duration of inundation at that location. This is because the ensemble events have been

selected on the basis of satisfying peak flood level criteria only. For this reason, it is recommended that if rate of rise or duration of inundation is of specific interest in future studies, then consideration be given as to whether a suitable rate of rise at a particular location for a given AEP is given by: a) the critical event that provides the peak flood level AEP; or b) one of the AEP ensemble events; or c) one of the 11,340 Monte Carlo events. Whether or not a rate of rise estimated by one of these three options is suitable is dependent upon the accuracy required

With regard to the 1 in 200 AEP flood, this is higher at all modelled locations than either of the two biggest floods of recent times: the 1974 and 2011 floods, noting that Wivenhoe Dam was not constructed at the time of the 1974 event. However, at Brisbane CBD the 1 in 200 AEP flood is only slightly higher by around 0.1 m to 0.2 m than the 1974 flood.

The longitudinal peak water level profile maximums (i.e. combined ensembles) for all calibration and design events are presented in A3 Addendum Sheet 43 and A3 Addendum Sheet 44. These plots are useful for appreciating the hydraulic gradients along the main waterways and the change in flood level with change in AEP. Comparison of the design floods with the calibration events also provides guidance as to the AEP magnitude of each of the calibration events.

In interpreting the longitudinal profiles, the water level may appear to rise whilst travelling downstream. This is due to changes in the kinetic energy ($V^2/2g$) of the water. The water surface calculated in a 2D model is the actual water surface, which is the total energy of the water less its kinetic energy. Therefore, where the water slows down, the water surface can physically rise provided the dissipation of energy from bed friction and other effects is less than the total energy gradient. This effect is most noticeable downstream of a constriction where high velocities are generated in the constriction followed by a slowing down of the water downstream of the constriction.

There are numerous locations along the Brisbane River where this effect occurs due to the river being largely controlled by rock ledges and outcrops with little or no floodplain, both of which cause steep gradients, high velocities and numerous constrictions. For example, it is not uncommon for the Brisbane River to transition from say 5 m/s to say 3 m/s, which ignoring energy losses, represents a 0.8 m rise in water surface. If bed friction and other hydraulic losses are less than 0.8 m over the same length the water surface rises whilst moving downstream.

The ability to model the water surface in this manner is a feature of 2D models that utilise the full 2D hydraulic equations. These models are capable of representing the variation in water surface due to changes in kinetic energy (eg. rise in water level travelling downstream or the superelevation of the water surface around a bend).

The alignment of the line used to sample the longitudinal profile may also not follow exactly the line of highest water level, which varies between floods of different magnitude. Therefore, in combination with the variation in kinetic energy, a more pronounced increase, or decrease, in level can be evident in some locations, particularly downstream of flow constrictions and river bends.

Table 8-3 Summary of Peak Design Riverine Flood Levels and Flows at Lowood, Ipswich, Moggill and Brisbane

AEP 1 in …	Base Case Peak AEP Flood Levels and Flows^							
	Peak Level (mAHD)				Peak Flow (m^3/s)			
	Lowood (Pump Stn)	Ipswich (CBD)	Moggill Gauge	Brisbane (City Gauge)	Lowood (Pump Stn)	Ipswich (CBD)	Moggill Gauge	Brisbane (City Gauge)
2	n/a*	1.9	1.7	1.6	n/a&	n/a&	n/a&	n/a&
5	31.0	11.8	4.1	1.7	1,000	1,300	1,800	2,300
10	33.7	14.8	6.9	1.8	1,800	1,900	3,000	3,200
20	36.3	16.1	9.9	2.2	2,800	2,300	4,300	4,800
50	40.9	18.7	14.3	3.2	5,500	3,200	6,900	6,900
100	45.3	20.1	18.2	4.5	9,800	3,800	9,900	9,200
200	47.3	21.8	20.3	5.8	13,000	4,800	11,900	11,000
500	48.6	23.4	22.6	7.3	15,800	5,600	14,700	13,200
2,000	51.0	25.7	25.4	9.9	20,400	6,900	19,500	17,200
10,000#	54.5	29.0	28.8	14.7	29,300	9,300	28,400	25,700
100,000#	63.0	36.1	36.0	23.7	52,600	13,500	57,200	56,000

^ Peak flood levels and peak flows do not necessarily occur at the same time.
* 1 in 2 AEP flood level results only reliable for tidal zone.
& 1 in 2 AEP peak flows not provided as they are due to tidal influence, not flood influence.
# Flood may exceed the maximum release capacity of Wivenhoe Dam (currently 28,000m^3/s) – treat results with caution.

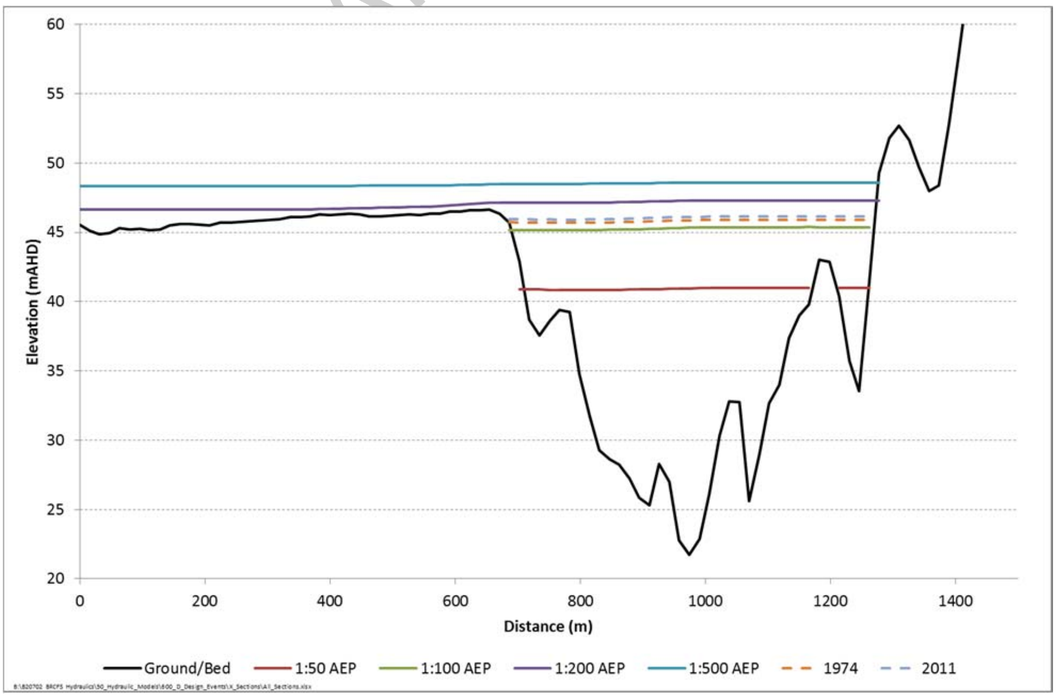


Figure 8-1 Lowood Design and Historic Flood Levels

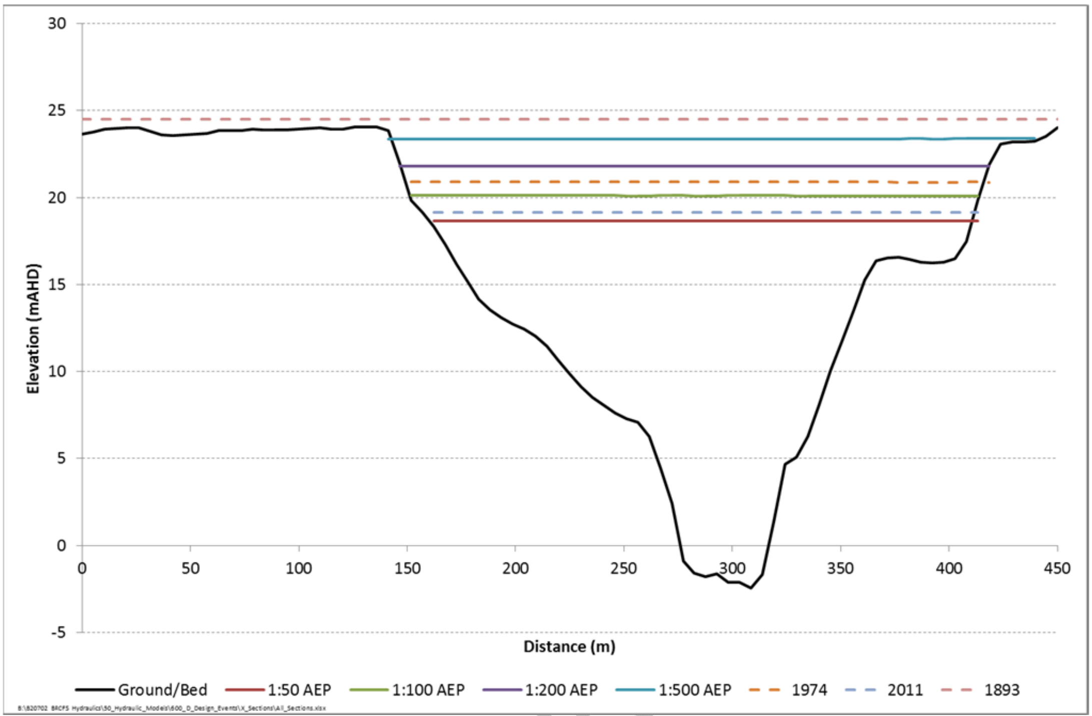


Figure 8-2 Ipswich CBD Design and Historic Flood Levels

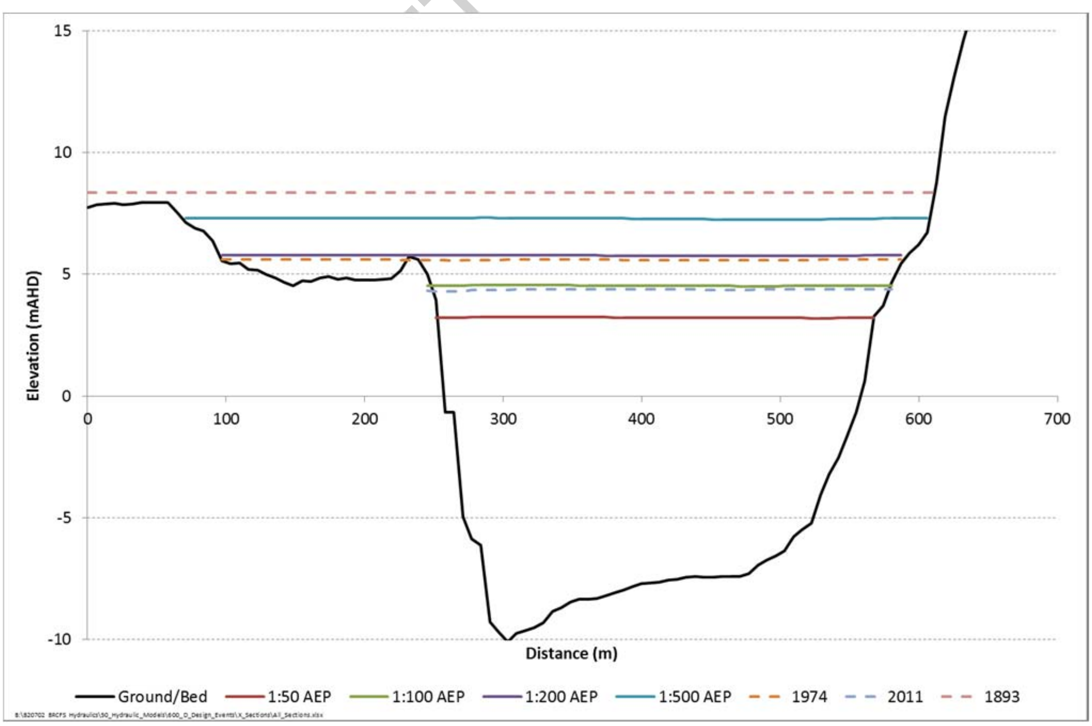


Figure 8-3 Brisbane CBD (City Gauge) Design and Historic Flood Levels

8.4.5 Discussion on Flowpaths and Hydraulic Hazard

In addition to peak flood level, peak depth, velocity and hydraulic hazard are mapped. The hydraulic hazard is a combination (product) of depth and velocity. Therefore, areas of high hydraulic hazard can be areas of deep water, fast flowing water, or both.

Typically areas with high hydraulic hazard values (1.2 or greater) are within the main rivers as would be expected. Areas with high hydraulic hazard values are also present in the floodplain where water may form deep overland flow routes such as some of those seen in the complex Lockyer Creek floodplain. High hydraulic hazard is also apparent in many tributaries into which the backwater from the main river extends. This water would typically have a very low velocity but the depth can be significant, leading to high hydraulic hazard values.

Within the Brisbane CBD minor inundation is shown for a 1 in 10 AEP flood in lower lying parts of Margaret Street. The extent of flooding increases significantly for the 1 in 100 AEP flood extending north along Albert Street and south into Alice Street and across into the Botanical Gardens. The floodwater originates from back up from the stormwater network (and potentially other underground conduits such as car parks) rather than overtopping of the river banks.

In the 1 in 100 AEP event the hydraulic hazard in these Brisbane CBD areas remains low with a typical value of 0.02. The 1 in 200 AEP flood indicates that overtopping of the riverbank along the Eagle Street waterfront occurs and much of the south eastern part of the CBD is inundated. However, hydraulic hazard remains low as the water is ponding with minimal velocity.

As flood magnitudes increase further, flow routes begin to establish through the CBD. This is apparent for events of the 1 in 500 AEP magnitude and greater. Initially the flow route is through the south eastern portion of the Botanical Gardens and, as the magnitude increases to the 1 in 2,000 AEP flood, much of the south eastern part of the Brisbane CBD effectively becomes part of the river (see Figure 8-4).

A notable change in flood behaviour occurs in the 1 in 10,000 AEP flood when floodwaters start to short circuit the CBD river meander by breaking over the bank between the William Jolly Bridge and North Quay and flowing through the CBD along main thoroughfares like Adelaide and Queen Street to re-join the river near Kangaroo Point. Almost all of the CBD is inundated under this extreme event with the flooding having high hydraulic hazard values (5.0 or greater) due to the depth and velocity of flow.

Short-circuiting of river meanders is widespread for the 1 in 10,000 AEP flood with other notable examples of established bypass flow routes in Brisbane, in addition to the CBD, at Fig Tree Pocket, Indooroopilly, Fairfield and St Lucia.

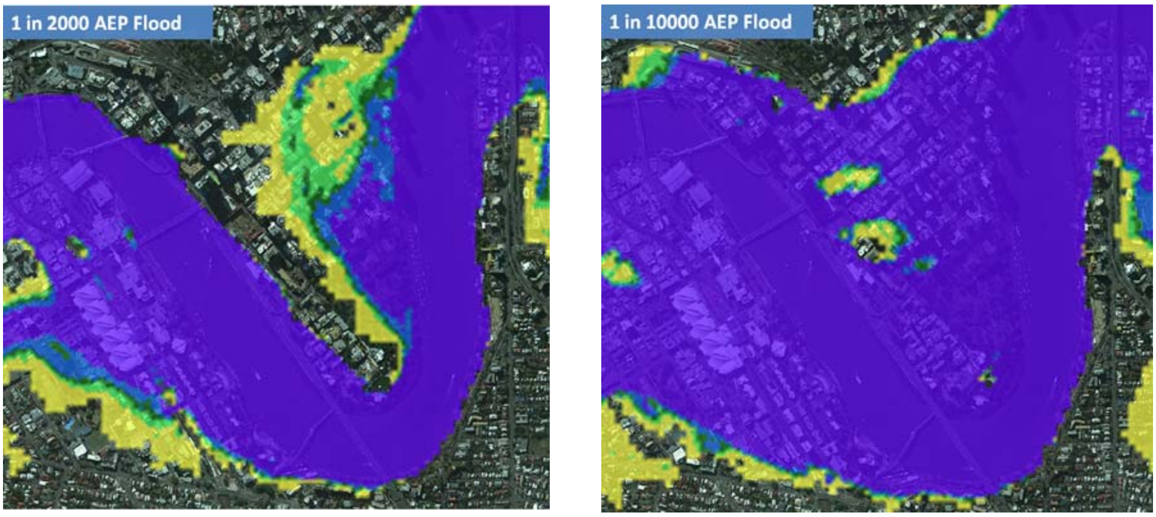


Figure 8-4 Brisbane CBD: Hydraulic Hazard and onset of Breakout Flowpaths

Ipswich CBD is subject to minor flooding in the 1 in 5 AEP flood with floodwaters backing up into the Marsden Parade area of the city. In the 1 in 10 and 1 in 20 AEP flood there is some inundation in parts of North Ipswich such as at the eastern ends of Lawrence and Canning Streets (see Figure 8-5).

In the 1 in 50 AEP flood there is an additional breakout near the Ipswich CBD into Timothy Molony Park and into surrounding streets. The two breakouts into the CBD are more extensive in the 1 in 100 AEP event (Figure 8-5), but retain relatively low hydraulic hazard values as the floodwater is predominately ponded backwater and not actively flowing.

For the 1 in 500 AEP flood, there is significant inundation of Ipswich CBD and North Ipswich along with other parts of the city.

The flood behaviour in the vicinity of the Ipswich CBD begins to change in the 1 in 10,000 AEP event as areas of backwater flooding begin to flow, effectively becoming part of the river. This results in high hydraulic hazard values in northern parts of the Ipswich CBD close to the Bremer River.

The 1 in 100,000 AEP event shows extreme levels of inundation, with the Bremer River meander at the Ipswich CBD short circuited by flow passing from Brassall through to Tivoli across much of North Ipswich.

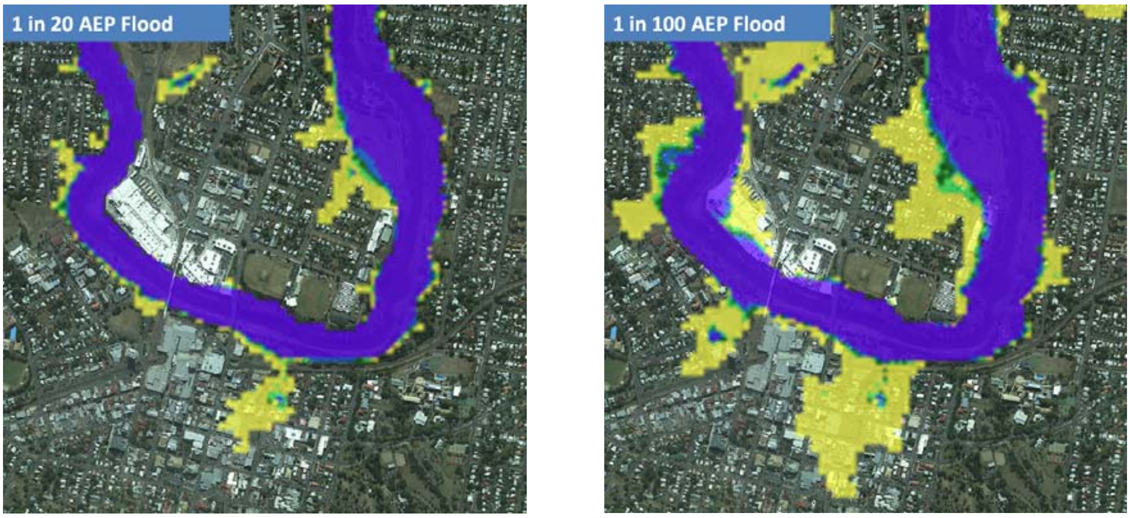


Figure 8-5 Ipswich CBD: Hydraulic Hazard Backwater Inundation

The town of Fernvale experienced flooding in the 2011 event via an overland flow route that bypassed the river bend upstream of the quarry. Design event modelling shows this flow route to become active in the 1 in 100 AEP flood with moderate hydraulic hazard values as the depth of flow is typically shallow. In the larger 1 in 200 AEP flood this flow route is more established and hazardous as can be seen in Figure 8-6. Inundation within Fernvale is relatively extensive.

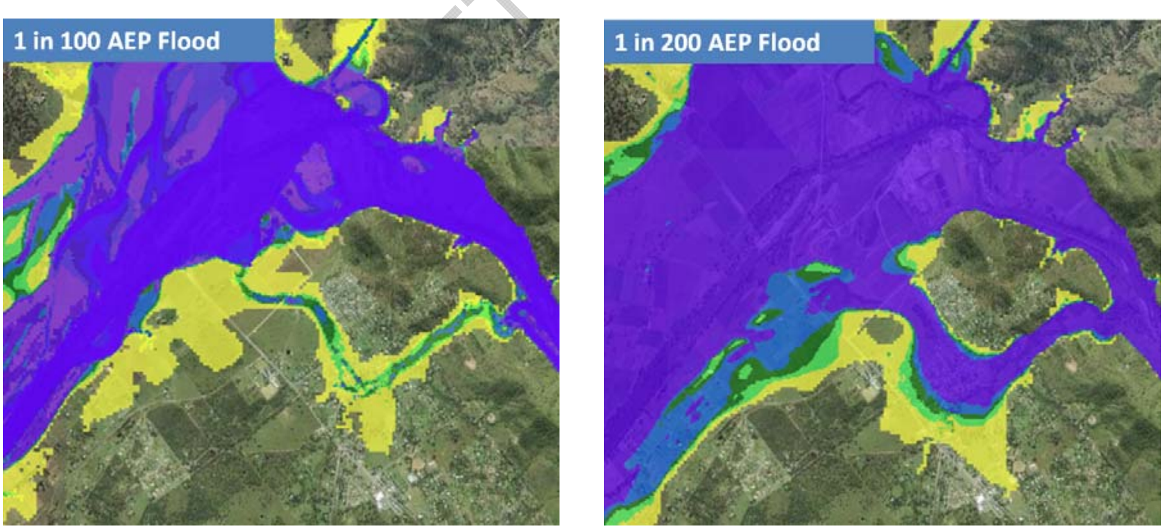


Figure 8-6 Fernvale: Hydraulic Hazard and Bypass Flow

8.4.6 Comparison to Fast Model Results

Peak flood levels from the Detailed Model for each AEP flood were compared with those from the Fast Model. MR5 Addendum Table 2 tabulates the change in level from the Fast Model to the Detailed Model. Key points are summarised as follows:

- The models show agreement for events ranging from the 1 in 20 to the 1 in 200 AEP flood. This is broadly within the range of the larger calibration events and encompasses the key design floods.
- The 1 in 100 AEP flood in particular typically exhibits close agreement between the models with the differences being within ±0.1 m for much of the lower Brisbane River.
- For more extreme floods there is overall agreement but there are some notable differences eg. for the 1 in 100,000 AEP flood on the lower Brisbane where the Detailed Model predicts higher levels. This is consistent with the findings during the models' development and calibration phases (MR2 and MR3) when comparing the 5x1974 and 8x1974 events, and is an artefact for the different modelling approaches. This was clarified by the IPE in their review of MR5 as follows: "*the primary purpose of the Fast Model was not to produce accurate absolute flood level estimates but to select events for input into the Detailed Model… Further, it was always expected that the two models would diverge at extreme flows."*
- There are some differences at Lyons Bridge (Lockyer Creek) with the Detailed Model generally predicting lower levels than the Fast Model (around 1 m lower in the 1 in 100 AEP flood). Given the complexity of the floodplain and the difficulties of representing and simplifying this complexity within a 1D model schematisation, differences of this magnitude are not unexpected and it is considered the Detailed Model to be more accurate than the Fast Model in these areas.

The differences between the Fast and Detailed Models are considered to have negligible or no impact on the study outcomes and that the final results from the Detailed Models are acceptable for the purpose of the flood study. This view was specifically endorsed by the IPE during their review of MR5. The Fast Model could undergo further refinement should future consideration be given to use of this model for simulating extreme floods, or used for other purposes.

8.4.7 Hydraulic Structure Reference Sheets

Hydraulic Structure Reference Sheets (HSRS) are presented for key structures along the main waterways. Base Case results are included for 1 in 100 and 1 in 2,000 AEPs along with simulated historical event results. Model output details included on the HSRS include discharges, flow area and flow velocity under and over the structure, and head loss across the structure. Preliminary guidance on whether or not to consider blockage in future assessments is also provided. An example of a HSRS is shown for Three Mile Bridge on the Bremer River in Figure 6-2 and Figure 6-3. The full set of HSRS is provided in MR5.

8.5 Sensitivity Test Scenarios

8.5.1 Introduction

Sensitivity testing was undertaken on roughness and form loss values as part of the calibration exercise documented in MR3. Sensitivity testing at the design stage is concerned with ascertaining the sensitivity of the design flood levels to potential changes in the catchment that may occur due to direct human influence, geomorphic or climatic processes for each of the selected events.

Sensitivity tests to be undertaken were specified in the ITO with the scope further refined in Workshop 4 Agenda Papers. In general, four categories of sensitivity test have been undertaken as follows:

- Climate Change scenarios (CC1, CC2, CC3, CC4).
- Bed Level scenarios (BL1, BL2).
- Floodplain Future Condition (FF1).
- Calibration events No/With Dams scenarios (CND, CWD).

A summary of each scenario and associated results is provided in the following sections. It should be noted that the methodology for the scenarios was agreed through the workshop process (with the TWG and subsequently endorsed by IPE) and may not necessarily reflect that originally intended and specified in the ITO.

It is important to clarify that the sensitivity scenarios undertaken using the 60 selected design events represent the impacts on the flood modelling outputs only for those individual events. The sensitivity scenarios do not produce equivalent AEP peak flood levels for that scenario.

For example, simulation of climate change using the events selected in the 1 in 100 AEP event ensemble, will not necessarily produce the 1 in 100 AEP climate change ensemble. This is because the hydrological impact due to climate change alters the hydrograph volumes, which may have a non-linear effect on the outflow hydrograph due to dam operations. The resulting flood levels are also dependent on hydrograph volume and timing in the mainstream waterway, tributaries and local inflows. For other physical change scenarios such as the floodplain future condition or bed level sensitivity scenarios, the storage-conveyance characteristics of the waterway and/or floodplains change, and hence a different selection of flood events may be necessary to define the AEP ensemble for the scenario. The impacts on flood levels are also not uniform across all events for each AEP at each location.

To undertake a sensitivity scenario to define an equivalent AEP event ensemble would require: a) the scenario to be applied to all 11,340 Monte Carlo events using the Fast Model, b) repeating the Total Probability Theorem analysis of the resulting peak flood levels of the 11,340 events at each Reporting Location, and c) repeating the event selection process to produce new AEP sensitivity event ensembles. As this has not been undertaken, the resulting sensitivity scenario impacts presented and discussed must be regarded as indicative only, and resulting peak flood levels not necessarily aligned to an AEP.

8.5.2 Climate Change Scenarios

The climate change sensitivity tests examine the impacts of climate change (storm rainfall characteristics and sea level rise) on design flood levels. Both mid- and high- range climate predictions have been assessed. Table 8-4 summarises the climate change parameters that have been adopted for sensitivity analysis:

Table 8-4 Parameters used in the BRCFS Climate Change Sensitivity

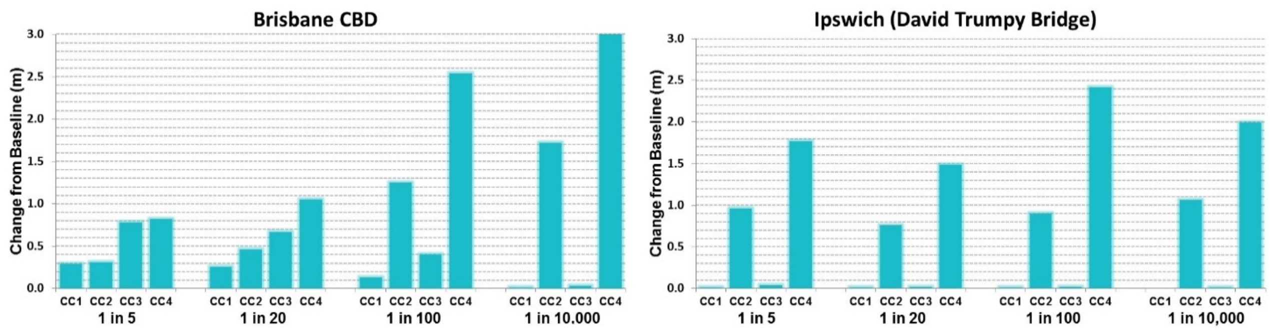
Parameter	2050	2100
Design rainfall depth (before losses)	+10%	+20%
Average sea-level rise	+0.3 m	+0.8 m

Four Climate Change scenarios are modelled based on combinations of the parameters given in Table 8-4 as follows:

- CC1 – 0.3 m sea level rise
- CC2 – 0.3 m sea level rise and 10% increase in rainfall
- CC3 – 0.8 m sea level rise
- CC4 – 0.8 m sea level rise and 20% increase in rainfall

Results

Results from these scenarios are derived for 1 in 5, 20, 100 and 10,000 AEPs. Peak level results at Brisbane and Ipswich CBD's are summarised graphically in Figure 8-7.



CC1 = No change to rainfall and 0.3 m rise in sea level

CC2 = 10% increase in rainfall and 0.3 m rise in sea level

CC3 = No change to rainfall and 0.8 m rise in sea level

CC4 = 20% increase in rainfall and 0.8 m rise in sea level

Figure 8-7 Change in Peak Flood Level under Climate Change Sensitivity Scenarios

For much of the Brisbane River the CC2 scenario (0.3 m rise in sea level and 10% increase in rainfall intensity) produces similar peak levels to the Base Case (B15) 1 in 200 AEP flood levels. The CC4 scenario (0.8 m rise in sea level and 20% increase in rainfall intensity) produces peak levels around 2.5 m above Base Case 1 in 100 AEP levels for Brisbane CBD and for parts of the lower Bremer peak levels for this scenario are around 3.75 m higher than the Base Case.

8.5.3 Bed Level Sensitivity Tests

The Queensland Floods Commission of Inquiry (QFCoI) recommended development of a suitable model that is “able to deal with the movement of sediment and changes in river beds during floods”. The hydraulic models developed for the BRCFS (Fast and Detailed models) are not sediment transport models. Developing a sediment transport model requires substantially more data than currently available. In lieu of a sediment transport model, the Detailed Model can be used to gain an understanding of the sensitivity of modelled peak flood levels due to potential changes in channel geometry caused by sediment movement. A methodology has been developed for this purpose in consultation with the TWG and IPE.

It relates a change in bed level to a desired change in channel conveyance. This is undertaken by increasing or decreasing the depth, y, by ${f_{\Delta K}}^{\frac{3}{5}}$ where $f_{\Delta K}$ is the change in conveyance as a factor (for example, for a 10% increase in conveyance, $f_{\Delta K} = 1.1$), as the depth is proportional to conveyance according to the relationship $K \propto y^{\frac{5}{3}}$ assuming that Manning’s n is unchanged and side friction is negligible or not relevant. For example, to increase conveyance by 10% in a cell with a 20 m depth of water will require a lowering of bed level by 1.18 m. Similarly, for a reduction in conveyance of 10% where the depth of water is 20 m will require an increase in bed level of 1.23 m. The Technical Working Group agreed that a ±20% conveyance change was appropriate for the upper and lower bounds of the assessment.

The changes to bed level are to be applied to the tidal reach of the Brisbane River from Karana Downs at the upstream end to the downstream end of the model at Moreton Bay. Known locations of solid rock outcrops were not subject to bed level adjustment.

The scenarios modelled are as follows:

- **BL1**: Increase in conveyance (decrease in bed level) results in approximately 38 million cubic metres of bed material removed. This equates approximately to an average 2 m decrease in bed level.
- **BL2**: Decrease in conveyance (increase in bed level) results in approximately 41 million cubic metres of bed material added. This equates approximately to an average 2 m increase in bed level.

An example of the adjustment at Moggill is shown in Figure 8-8 for the increases and decreases in conveyance.

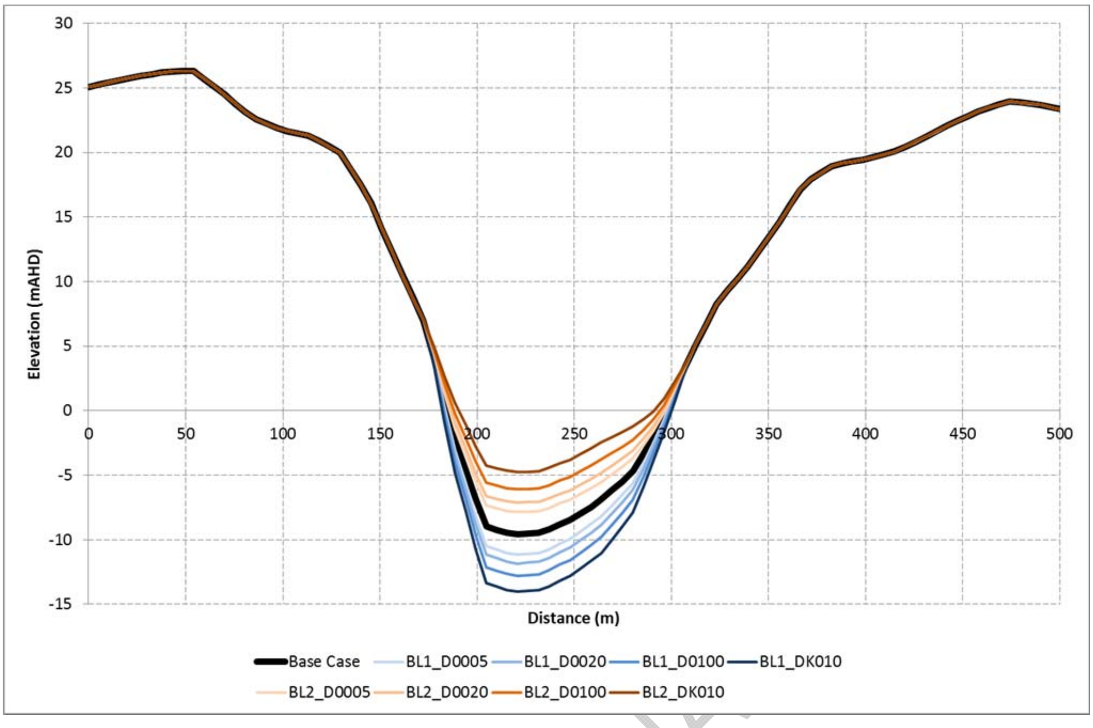


Figure 8-8 Bed Level Change at Moggill (BL1 and BL2)

Results

Figure 8-9 plots the 1 in 100 AEP peak flood levels at Brisbane CBD (City Gauge), for the BL1 and BL2 scenarios. To aid comparison, the Base Case (B15) peak level is also shown.

The decrease in bed level lowers peak 1 in 100 AEP flood levels at Brisbane CBD by around 0.7 m. Although there are no changes to bed level along the Bremer River, the peak level at Ipswich CBD decreases by around 0.3 m as a result of the increased conveyance on the Brisbane River.

The increase in bed level increases the 1 in 100 AEP peak flood level at Brisbane CBD by around 1 m. An increase in peak flood level of 0.5 m is also seen at Ipswich CBD despite no change in bed level along the Bremer River due to backwater effects from the higher Brisbane River.

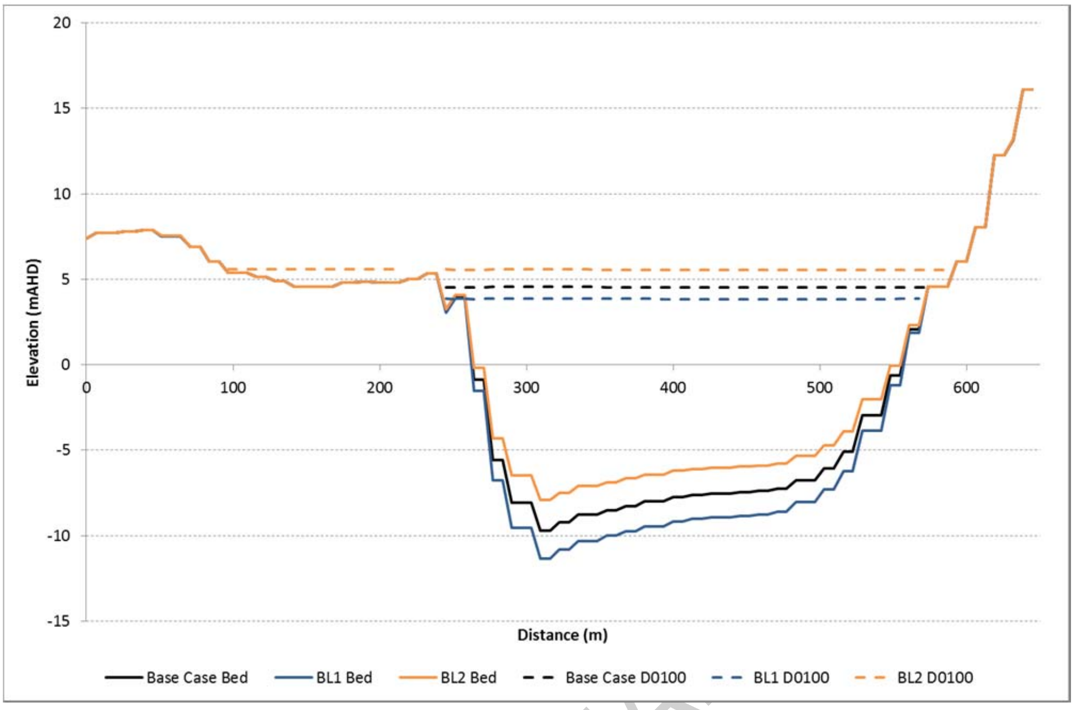


Figure 8-9 Brisbane CBD: Bed Level Sensitivity, D0100 AEP Event

8.5.4 Future Floodplain Scenario

An assessment has been undertaken to assess the sensitivity of flood levels to future conditions, such as development, which may include increases in ground levels in specific parts of the catchment. This sensitivity test simulates a **hypothetical** ultimate development catchment across the Brisbane City Council (BCC) and Ipswich City Council (ICC) local government areas. The assessment has the following key limitations:

- The modelling methodology agreed and implemented for this scenario assumes that the areas outside of the 'Flood Corridor' have ground levels raised so that they are flood free for all AEP events. In reality, the level of filling will vary across the floodplain and be limited to the planning controls specified by councils (for example, residential properties are typically raised to the 1 in 100 AEP plus a freeboard, while industrial properties are generally raised to a lower level). The degree of ground level increases adopted for this sensitivity test can therefore be considered, in reality, as excessive.
- As discussed in Section 8.5.1, this sensitivity scenario does not produce equivalent AEP peak flood levels. This is due to changes in the storage-conveyance characteristics of the floodplains due to the flooding filling that can potentially result in a different selection of flood events to define the AEP ensemble. Thus, the impacts must be regarded as indicative only.

Results

In all AEP events modelled for this scenario (1 in 100, 200, 500 and 10,000) the increase in ground levels outside a nominated floodplain within both BCC and ICC administrative areas has resulted in a throttling of flows compared to the Base Case (existing) case. The effect is more pronounced for the larger events considered. Table 8-5 summarises the resulting peak flood levels and changes from the Base Case for the Future Floodplain Condition Scenario.

For the extreme flows of the 1 in 10,000 AEP flood, the floodplain is highly constrained compared to Base Case conditions and significant increases are observed upstream of Tennyson (near the outlet of Oxley Creek). These increases extend all the way up the modelled lengths of the Bremer catchment and extend up the Brisbane River to Wivenhoe Dam and into the lower reaches of Lockyer Creek. Downstream of Tennyson, the peak flood levels are reduced as a result of the throttling effect of flows. Peak levels are around 2 m lower at the City Gauge in Brisbane CBD.

Table 8-5 Future Floodplain Condition Scenario Results at Brisbane and Ipswich

AEP	Brisbane (City Gauge)		Ipswich (David Trumpy Bridge)	
1 in …	FF1 Peak Flood Level (mAHD)	Change in Level from Base Case (m)	FF1 Peak Flood Level (mAHD)	Change in Level from Base Case (m)
100	4.4	-0.1	20.1	<0.1
200	5.6	-0.1	21.8	-0.1
500	7.2	-0.1	23.4	<0.1
10,000	12.7	-2.0	31.8	2.8

8.5.5 No Dams Sensitivity Tests

The ITO referred to a ‘no dam’ scenario in which the major storages of Wivenhoe, Somerset, Cressbrook, Perseverence, Manchester and Moogerah Dams were removed from the hydrologic models as applicable. The revised hydrologic flows would then be applied to the Detailed Model and results compared to a ‘with dams’ scenario to ascertain the dams’ roles in reducing flood levels for events modelled. This sensitivity analysis was carried out for five calibration events[24], namely 1974, 1996, 1999, 2011 and 2013. For all events other than 1974, the ‘with dams’ simulation is the same as that used in calibration i.e. all the dams listed above were in place at the time of the event. For the 1974 event an additional simulation was required in which Wivenhoe Dam was assumed present[25]. This allows for a ‘like for like’ comparison of the dams’ influences on the five calibration events.

No changes were required to the Detailed Model used for the calibration events other than to specify revised model inflows. Model inflows were derived from modified BRCFS hydrologic models. Figure 8-10 provides an example of inflows applied to the Detailed Model at the outlet of Wivenhoe Dam for the 2011 event in the ‘with dams’ and ‘no dams’ cases.

[24] Use of the five calibration events instead of the design events is a departure from the ITO and was agreed with the TWG and IPE.
[25] The assumed management of the dam used simulated Wivenhoe Dam outflows from the Wivenhoe and Somerset Dams Optimisation Study (WSDOS) based on the ‘Alternate Urban 3’ assumed operation. Dam outflows were supplied by Seqwater.

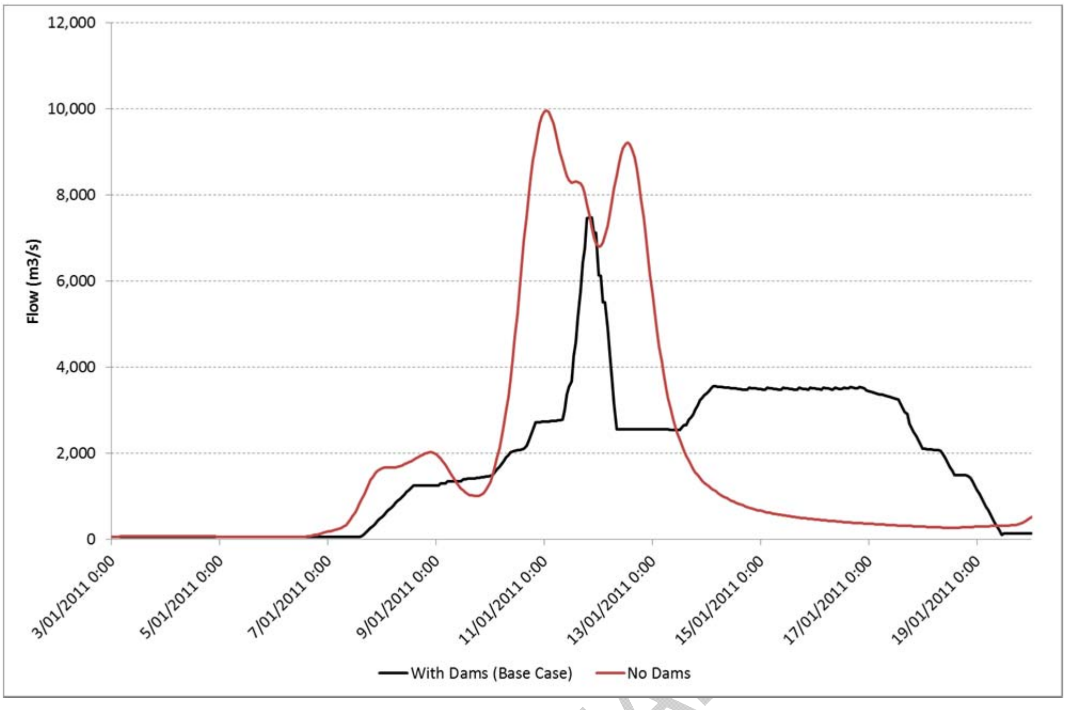


Figure 8-10 2011 Wivenhoe Outflows

Results

Table 8-6 and

Table 8-7 present a summary of the peak levels for the ‘no dams’ and ‘with dams’ scenarios at Brisbane and Ipswich CBDs respectively. It can be seen that under the with dams scenarios i.e. with Wivenhoe and the other dams, all five simulated events show lower peak flood levels than would have otherwise occurred under a ‘no dams’ scenario.

For the 2011 event the dams reduced the flood peak by approximately 2.0 m in Brisbane and 2.8 m at Ipswich for the model conditions simulated.

Table 8-6 No Dams: Brisbane City Gauge

Event	No Dams* (mAHD)	With Dams** (mAHD)	Decrease with Dams (m)
1974	6.3	3.9	-2.4
1996	2.7	1.9	-0.8
1999	3.3	1.5	-1.8
2011	6.5	4.5	-2.0
2013	3.1	2.2	-0.9

* Removal of Wivenhoe, Somerset, Cressbrook, Perseverence, Manchester and Moogerah Dams as applicable.

** For 1974, Wivenhoe and Cressbrook Dams are added to the model and so this is a hypothetical simulation. For all other events, ‘With Dams’ represents the actual dam configuration

Table 8-7 No Dams: Ipswich CBD

Event	No Dams (mAHD)	With Dams (mAHD)	Decrease with Dams (m)
1974	21.8	20.3	-1.5
1996	14.2	13.8	-0.4
1999	16.4	7.8	-8.6
2011	22.0	19.2	-2.8
2013	16.8	14.1	-2.7

8.6 Rating Curve Review

8.6.1 Introduction

The Fast and Detailed Models, as hydraulic models, produce data on how flow varies with water level (the stage-discharge relationship), from which the existing rating curves including those adopted for the Hydrologic Assessment can be compared and refined as appropriate. As discussed in Section 3.4.1, to reconcile whether the hydrologic and hydraulic modelling are consistent with each other checks on the rating curves derived by the Hydrologic Assessment for the hydrologic modelling and the stage-discharge output from the hydraulic modelling were carried out at during model calibration (see Section 6.5) and simulation of the design events.

Rating curves were generated at key gauges using model output from the Detailed Model for both calibration and design events. The rating curves are shown in A3 Addendum Sheet 45 to A3 Addendum Sheet 50 and include results from the Fast Model and the rating curves used for Operational purposes (see Section 2.5) and those generated from the Hydrologic Assessment.

Whilst the Hydraulic Assessment ITO sought to achieve a consistent, robust and agreed set of rating curves at key gauge sites, after discussions and agreement with the TWG (comprising of senior technical officers from various agencies including Seqwater, Bureau of Meteorology, four catchment Councils and DNRM) and IPE, it was agreed that the results from the hydraulic modelling should be used to help inform agencies of the sensitivity and uncertainty of the rating curves, and provide commentary on the validity of the rating curves. Different organisations utilise the rating curves for different purposes, and may choose or not choose to adopt or refine rating curves based on the findings of the Hydraulic Assessment. Hence it was agreed not to produce a single rating curve that can satisfy all users.

A review of the rating curves was therefore undertaken for the Hydraulic Assessment and is documented in MR5. An overarching summary of this review is provided in 8.6.2 with an example review for Moggill presented in 8.6.3.

8.6.2 Summary of Rating Curve Review

The stage-discharge relationship at a site can vary, sometimes significantly, resulting in different flows for a given water level. This variation known as hysteresis or looping in the curve occurs where the flood surface gradient and/or backwater effects vary during the flood. For example, flows are usually higher on the rising limb than the falling limb due to the steeper flood surface gradient on the flood rise. Where variable backwater effects occur, for example, the tide or the Brisbane River backing up the Bremer River, there can be considerable differences in flows resulting in substantial looping in the stage-discharge relationship. The greater the backwater effect the lower the flow. Of importance is that where there is little or no hysteresis in the relationship, a reliable rating curve can be derived. Where hysteresis does occur there is no single rating curve that can represent the stage-discharge relationship.

The rating curve review emphasises uncertainties in the stage-discharge relationships due to hysteresis. General observations from the review are as follows:

- The most noticeable differences occur during the in-bank stages of Glenore Grove and Rifle Range, and the higher stages of Loamside. For Glenore Grove and Rifle Range the in-bank differences could be due to the uncertainties associated with using LiDAR for in-bank areas and the inaccuracies associated with deriving the rating curves.
- There is some looping (hysteresis) effects at some gauges. Where this occurs the rating curves tend to match with the rising limb of the flood (ie. with the lower side of the hysteresis curve).
- As discussed in MR3, at gauges such as Mt Crosby and Moggill there is a noticeable difference between the major floods of 1974 and 2011, despite having similar peak flows at Mt Crosby. This is most likely due to the different flood shapes; the 2011 flood, due to the influence of Wivenhoe Dam, was a shorter, sharper shape with less volume than the 1974 event. The Bremer River flow entering at Moggill in 1974 was also greater than 2011 making 1974 larger than 2011 downstream of the rivers' confluence. This is aptly illustrated at the lower Brisbane gauges where the flood level was above 10 mAHD for around 3 days in 1974, but less than 2 days in 2011.
- The inclusion of the 60 design event results for the 11 AEPs has value added to the understanding of the level of uncertainty associated with hysteresis caused by backwater effects and different shaped hydrographs. From the design event results, the rating curves in some instances could be refined as appropriate, and extended to include extreme events.

8.6.3 Example Rating Review Summary: Moggill (Brisbane River)

The Seqwater and Hydrologic Assessment rating curves for Moggill on the Brisbane River are presented in A3 Addendum Sheet 46 and A3 Addendum Sheet 49, and reproduced in Figure 8-11. The curves are plotted against the stage-discharge results from the Fast and Detailed Models for the calibration and design events.

Aurecon, 2015c Commentary

Catchment:	Lower Brisbane River	Rating updated based on review of gaugings, steady-state release flows and DMT TUFLOW model results Rating provides generally good fit of steady flow release and hydrologic data, but no flow gauging available for comparison. Rating is considered to be reasonable, with a fairly well contained site. Revised rating tends to predict higher flows than previously estimated due to dynamic effects and attenuation evident in the TUFLOW model but not properly represented in the hydrologic model
Stream:	Brisbane River	
Site:	Moggill	
Gauge No:	143951	
Owner:	BoM/Seqwater	

Observations

- Similar to Mt Crosby Weir, for flows up to around 12,000 m^3/s, which covers all the calibration events, hysteresis effects in the model results are evident indicating the site, while a reasonable rating location for flows up to this magnitude, is subject to greater uncertainty in flow estimates. There is also greater separation between different flood events than for Savages Crossing further upstream that adds to the uncertainty in flow estimates.
- For larger events, the hysteresis effects evident in the calibration events remain as seen for the extreme events. Moggill is, therefore, suited as a rating site at all levels noting that there is uncertainty associated with hysteresis.
- The Seqwater and Hydrologic Assessment rating curves tend to match the rising limbs of the stage-discharge relationships from the Fast and Detailed Models. Of interest is that for flows above 4,500 m^3/s, the Hydrologic Assessment curve lies closer to the lower bound (higher flow) of the modelled events, while the Seqwater curve sits above the Hydrologic Assessment curve yielding a significantly lower flow.
- The evidence of the tide for flows below 2,000 m^3/s is apparent in the Fast and Detailed Models' results.

Conclusions and Preliminary Recommendations

- Moggill is a reasonable rating curve location for flows above 2,000 m^3/s, noting that there are uncertainties associated with hysteresis effects. For flows below 2,000 m^3/s there is a significant influence from varying tide levels.
- For flows above 4,500 m^3/s, the Hydrologic Assessment curve lies closer to the lower bound (rising limb) of events than the Seqwater curve and perhaps should be preferred. For flows above 12,000 m^3/s, the Hydrologic Assessment curve continues to match the rising limb relationship from the modelling and should the curve be further extended the rising limb from the Detailed Model results should be utilised.

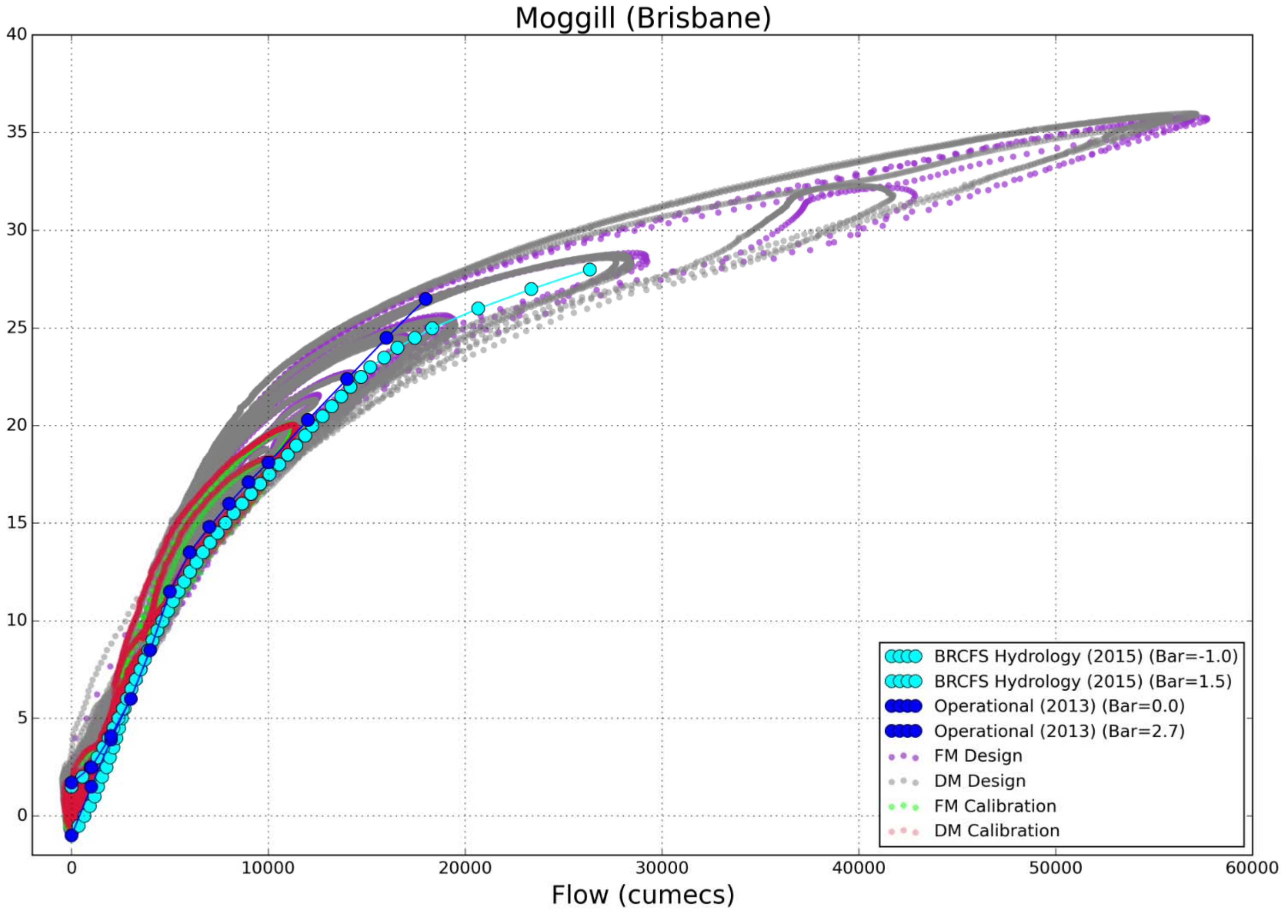


Figure 8-11 Rating Curves versus Hydraulic Modelling Calibration Results – Moggill

9 Limitations and Uncertainties

This BRCFS Hydraulic Assessment represents the most comprehensive hydraulic modelling assessment – and interfaces with the most comprehensive hydrologic assessment (Aurecon 2015c) – of the Brisbane River undertaken to date. As such, the AEP design flood results from the Detailed Model should be considered significantly more reliable and robust than any regional scale hydraulic assessments previously undertaken.

This Hydraulic Assessment has: utilised the latest data to develop computer models; verified these models by validating their results against five well documented historical floods; and employed industry leading techniques such as Monte Carlo simulation and statistical analysis to derive AEP flood levels that encompass the effects on flood behaviour caused by the influence of Somerset and Wivenhoe Dams, and the variable responses of the Brisbane River and its major tributaries of Lockyer Creek and Bremer River.

The modelling carried out for the Hydraulic Assessment emulates historical flood behaviour using industry standard and defensible approaches. Using the calibrated models, an up-to-date and accurate assessment of Brisbane River riverine flooding for AEPs ranging from 1 in 2 to 1 in 100,000 has been produced. The approach utilised industry leading techniques to derive AEP flood levels that take into account the complex effects on flood behaviour caused by: variations in rainfall and antecedent catchment conditions; Somerset and Wivenhoe Dams; ocean tidal conditions and joint probability of occurrence of variables. The outcome is best practice hydrologic and hydraulic modelling that provides key information and forms the basis for the BRCFMS and BRCSFMP.

However, as with all modelling, the modelling accuracy is subject to sources of uncertainty and limitations as documented in the technical reports. Importantly, an accurate understanding and appreciation of the hydrologic and hydraulic processes and of the modelling methodology and assumptions is essential to correctly interpret and apply the outcomes of the Hydraulic Assessment. The future of use of the Hydraulic Assessment outputs and the hydraulic models needs to take into account their limitations and constraints to ensure that the interpretation of the output and the application of the models into the future, are confined within the bounds and intent of the models' designs. These limitations and constraints are discussed in the following sections.

9.1 Riverine versus Local Flooding Effects

9.1.1 Local Tributary Flooding

Brisbane River riverine flooding is the inundation caused by flooding in the Brisbane River. As required by the ITO, to meet the objective of quantifying riverine flooding the modelling needs to include areas that experience inundation caused or exacerbated by elevated water levels in the Brisbane River; inundation of this nature is often referred to as flooding due to backwater effects. Notably, this includes the lower sections of Lockyer Creek and the Bremer River extending up into Warrill and Purga Creeks, but also includes all numerous smaller side tributaries.

Localised flooding, that is flooding caused by rainfall within a tributary's catchment, is a different flooding mechanism and may cause higher or lower flood levels, and different flood behaviour compared with backwater flooding from the Brisbane River. For example, a local creek may also be prone to flash flooding with little warning time and rapidly rising flood levels, which would contrast with backwater flooding that rises slowly and steadily as the Brisbane River rises.

Where the flood maps extend into the tributaries, the flood information provided is caused by Brisbane River backwater effects, and not that from local flooding. Note that all tributaries contribute runoff to the system for the flood events simulated, however, the rainfall onto the catchments of the local tributaries is typically not of the intensity and duration that would be representative of the critical storm event for simulating localised flooding of an equivalent AEP.

When information is sought on flood levels for local tributaries, both this assessment and that from local tributary modelling that may have been undertaken and in the ownership of local councils should be considered. Advice should be sought from the local council in such situations. Recommendations on integrating maximum flood surfaces derived from local studies with the riverine flooding surfaces from the BRCFS are summarised below. Note also the recommendation regarding isolated tidal flats in Section 9.1.2.

- The higher of the two surfaces should be used (ie. take the maximum of the local and riverine surfaces).
- Review the tailwater (river) conditions used at the downstream riverine boundary of the local flood modelling for consistency with the riverine flood levels from the BRCFS. If the original riverine boundary is deemed to be inconsistent, the local flood modelling should be reworked using a boundary consistent with the BRCFS allowing for joint probability considerations (ie. a 1 in 100 AEP local event peaking at the same time as a 1 in 100 AEP riverine flood has a much lower AEP of occurrence than a 1 in 100 AEP)
- Due to joint probability considerations, the expectation is that riverine boundaries used for existing local flood modelling would be lower than the Brisbane River riverine levels from the BRCFS (for the same AEP). Therefore, taking the maximum of the two surfaces as recommended above will produce a seamless transition between local and riverine flooding. The exception maybe for the creek outlets where the riverine flood level is controlled by the ocean storm tide and a higher storm tide level was used for the local flood study compared with those adopted for the BRCFS. In this case, the riverine or storm tide boundary would need to be reviewed as recommended above.

9.1.2 Isolated Low-lying Areas

Inconsistent differences between AEPs in the flood mapping of isolated low-lying areas can occur. These areas are where the ground levels lie below the starting (initial) water levels of the simulations, which are based on the Moreton Bay tide level at the start of the simulations. If these areas are not flooded by the Brisbane River, their peak water level will not be representative of riverine flooding, but of the initial water level plus any localised inflows. Due to the Monte Carlo approach, all 60 design events have a different (random) initial water level in Moreton Bay. For example, the maximum initial water level from the 1 in 100 AEP ensemble is 1.49 m compared to that for the 1 in 200 AEP of 1.06 m, hence some low-lying isolated areas have a greater flood extent for the 1 in 100 AEP than for the 1 in 200. Similar inconsistencies occur between other AEP ensembles, and a recommendation on how to manage them is provided below. These inconsistencies are not a characteristic of Brisbane River riverine flooding and are an artefact of the Monte Carlo approach.

To cater for these isolated low-lying ponded areas, it is recommend that in the process of reconciling the Brisbane River flood mapping with the local creek modelling discussed above (Section 9.1.1) that an additional criterion be applied. The criterion is that the design flood level anywhere cannot fall below the storm tide peak level for that AEP. This will ensure that no location has a flood level that is lower than the peak storm tide level in Moreton Bay.

9.2 Validity of AEP in Areas Distant from Reporting Locations

The derivation of design flood levels for each AEP was established using a Monte Carlo flood frequency analyses at each of the 28 Reporting Locations along the main rivers and creeks. For locations between Reporting Locations a small amount of uncertainty is introduced. Outside the area covered by the Reporting Locations, the assumptions that underpin the Monte Carlo assessment can become less valid, and therefore the assigned AEP less certain.

This issue is primarily confined to the mid-section of Lockyer Creek. The Detailed Model extends for a further 26 km upstream from the most upstream Reporting Location at Lyons Bridge, therefore the AEP of the flood extents and levels may begin to deviate from the AEP at the Reporting Locations. A hatched area is indicated on the design flood mapping showing this area. The map output is still presented within the hatched area as it is considered of value for assisting with understanding the flood behaviour on a complex floodplain. Within this area, the advice of the relevant local council should be sought if seeking to establish design flood levels for an AEP.

Other areas that maybe influenced by this “edge” effect are the areas upstream of the Reporting Locations on the Bremer River, and Warrill and Purga Creeks. However, these areas are of a significantly smaller extent than that on Lockyer Creek.

9.3 Fast Model AEP Levels

The design flood AEP levels statistically derived from the 11,340 events at each of the 28 Reporting Locations as documented in MR4 are based on using the Fast Model. These Fast Model AEP levels are a “stepping stone” to quantifying indicative AEP levels and for selecting a sub-set of the 11,340 Monte Carlo events that are representative of reproducing these AEP levels. The selected 60 design events, as simulated through the Detailed Model and presented in MR5, represent the final stage in producing reliable AEP flood levels, depths, velocities and hydraulic hazard caused by Brisbane River riverine flooding.

Whilst the Fast Model is not used in the Hydraulic Assessment for any other purpose besides the selection of the Monte Carlo events for the AEP design floods, it does have potential other uses where short run times are required or offer significant benefits. For example, although the absolute Fast Model AEP levels should not be used directly as they are a “stepping stone” to the final AEP levels, the Fast Model can still potentially be used for rapid assessment of a first pass selection process for estimating the shift or change in AEP levels for flood mitigation options. The Fast Model may also be adapted for operational purposes such as flood forecasting and warning, subject to comprehensive operational testing, and with capacity to maintain representativeness of current floodplain conditions. Specific refinements to the Fast Model may be required to suit applications beyond the objectives of the Hydraulic Assessment.

9.4 Model Design

The Detailed Model is designed to provide accurate flood mapping from Brisbane River riverine flooding at a regional scale based on present day conditions. Other than for tidal regions, the model has had limited calibration for very small flood events with less than around a 2,000 m^3/s peak flow. Furthermore, the model is not designed for quantifying flooding caused by localised flooding, as discussed above, or for flood impact assessments at an individual property scale. It is however suitable for determining riverine flood levels at the property scale noting the limitations on the mapping of extents. The model is designed for regional flood management planning and development control, and should only be used for modelling features that have a measureable influence on Brisbane River riverine flooding. Where detailed flood modelling is required at a local scale, information from the Detailed Model could be extracted to provide boundary information to the localised modelling.

9.5 Velocity and Hydraulic Hazard Results

Peak flood velocity and DxV (hydraulic hazard) maps, as with other maps, are presented at the regional scale and should be interpreted accordingly.

Mapping of velocity and DxV (hydraulic hazard) in 2D areas is based on a depth averaged velocity over a 30 m grid. To quantify variations in velocity with depth and sub-grid features would require higher resolution 3D modelling.

Mapping of velocity and DxV (hydraulic hazard) for 1D in-bank channel sections, for example Lockyer Creek and upstream of One Mile Bridge on the Bremer River, uses an estimate of velocity and depth based on parallel channel flow analysis[26] and should be interpreted as such.

9.6 1 in 2 AEP Event

The Hydrologic Assessment reports 1 in 2 AEP peak flood flows which are generated from catchment runoff (Aurecon, 2015), however, the URBS hydrologic model does not account for tidal influences on flows in the tidal reaches of the river. The hydraulic modelling carried out for the Hydraulic Assessment simulates catchment runoff flows in combination with tides to determine probable flood levels. For the 1 in 2 AEP flood event the peak flows in the tidal reaches are dominated by tidal influence and these flows are higher than the catchment runoff flow. Reporting 1 in 2 AEP peak flood levels from the model simulations in the tidal zone is reasonable as they are caused by Moreton Bay storm tide conditions, however, it is not possible to report a meaningful peak catchment flow from the hydraulic model for the 1 in 2 AEP within the tidal influence.

For areas upstream of the tidal zone, the analysis to derive AEP levels at Reporting Locations for the 1 in 2 AEP in MR4 is considered to be influenced by the water level in Wivenhoe Dam and variable antecedent conditions in Lockyer Creek and the Brisbane and Bremer Rivers above the

[26] Parallel channel analysis is an approach typically used for determining channel conveyance in 1D models whereby the channel is divided into separate panels, either at a fixed interval or wherever there is a change in bed resistance (Manning's n). Further detail is provided in MR2.

tidal limits[27]. There is therefore significant uncertainty associated with the 1 in 2 AEP levels outside of the areas influenced by the storm tide. It was agreed with the TWG and IPE that mapping for the 1 in 2 AEP should be confined to the tidal limits where there is greater confidence in the results. Use of the 1 in 2 AEP levels beyond the tidal limits is not recommended.

9.7 Limits of Mapping

The extent of flood mapping has been limited to the area of the Detailed Model's 2D representation, but excludes those areas in which the modelled flood behaviour is not considered to reasonably represent a design flood level as controlled by the effects of Brisbane River backwater. These limits are shown on the maps as a line denoted in the legend as "Limit of Detailed Modelling".

Mapping along the 1D in-bank channel sections, for example Lockyer Creek and upstream of One Mile Bridge on the Bremer River, uses a parallel channel flow analysis over a triangulated surface. Minor gaps or sudden transitions may occur in the transition from the triangulated surface 1D results to the 2D domain gridded surface along the 1D/2D interface.

9.8 Backflow Prevention Devices

The Detailed Model assumes that no backflow prevention devices were fitted to the stormwater pipes or trunk drainage systems, for the design case modelling. It is important to note that this will result in a conservative (worst case) modelled flood level and extent in those local areas that are typically protected by the backflow prevention devices. For those events for which the devices would otherwise provide protection, the apparent impact on peak flood levels and extent of inundation in the local areas can be significant (also see Section 9.1).

9.9 Structure Blockage

The Detailed Model assumes no blockage allowance to hydraulic structures other than that directly as a result of the structure itself such as a bridge deck. Application of blockage to structures may increase peak flood levels in some locations and decrease them in others. Preliminary guidance on the likelihood of structure blockage is provided in the Hydraulic Structure Reference Sheets presented in MR5.

9.10 Sensitivity Scenarios

The sensitivity scenarios undertaken and presented in MR5 using the selected design events, represent the impacts on the flood modelling outputs only for those individual events. The scenarios do not necessarily produce equivalent AEP peak flood levels for that scenario, especially if the scenario represents a significant change to volume of flow and/or flood behaviour from, for example, major works. In order to derive equivalent AEP events under these scenarios, the scenario would need to be applied to all 11,340 Monte Carlo events using the Fast Model followed by a Total Probability Theorem analysis on the resulting peak flood levels at each Reporting Location. The event selection process would then need to be undertaken with the selected events

[27] The tidal zone is considered to extend downstream from just below Mt Crosby Weir on the Brisbane River and downstream of Hancocks Bridge on the Bremer River.

run through the Detailed Model to produce revised AEP ensembles. Sensitivity scenario results therefore need to be interpreted with caution.

9.11 Residual Modelling Uncertainties

Considerations that can cause residual uncertainty in the estimated flood levels and flows are:

- Any uncertainties inherent in the Hydrologic Assessment that affect the inflows to the Detailed Model – these uncertainties have been minimised through calibration of hydrologic and hydraulic models to the same historical events, and through cross-checks and reviews of stage-discharge relationships (rating curves) at key locations covered by both the hydrologic and hydraulic modelling.
- Uncertainties in hydraulic modelling parameters and Detailed Model discretisation – these have been minimised through adopting industry standard parameter values derived and fine-tuned through calibration and verification of the Detailed Model to observed tide and flood behaviour.
- Assumptions with regard to dam operations under these hypothetical events, including a no dam failure assumption. However, it is noted that considerable uncertainty has been removed by the hydrologic and hydraulic modelling due to the incorporation of the operation of Somerset and Wivenhoe Dams in the modelling process.
- The Monte Carlo statistical approach has facilitated a major reduction in uncertainty by allowing the consideration of a wide range of variables that effect Brisbane River flooding. However, as with all statistical methods, there are statistical errors associated with the Monte Carlo approach carried out in both the Hydrologic and Hydraulic Assessments. Quantification of the statistical error would require repeating the Monte Carlo analyses using different sampling of the input variable distributions and comparing the results. Some insight to the statistical error in the Hydraulic Assessment is provided in the analysis provided in Appendix E of MR4.
- The in-bank topographic data where the 2D bathymetry or 1D cross-sections are reliant on LiDAR. These areas are notably:
  - Lockyer Creek
  - Between Wivenhoe Dam and Pine Mountain
  - Downstream of Mt Crosby Weir to the start of the bathymetric survey
  - Non-tidal reaches of Bremer, Warrill and Purga Creeks.

  Reduction of the uncertainty in these areas would require detailed in-bank surveys. The uncertainty would be greatest for frequent AEP (small flood) events, reducing to negligible for extreme floods.
- Limited historical flood data for rare and extreme floods for the calibration and verification of the hydrologic and hydraulic models. Until such time that the models' performance can be benchmarked against an extreme event, there would be greater uncertainties on extreme flood predictions than on AEP events falling within the range of the calibration events (ie. up to around 11,500 m^3/s as observed in 1974).

- The calibration of the hydraulic models to the 2011 flood highlighted unusually high energy losses in the vicinity of the Fernvale Quarry, therefore, any assessments in this area should take this into consideration.
- The influence of farm levees and other works either not well defined or captured by the available LiDAR surveys, or built subsequent to the LiDAR surveys, particularly on the flood levels in the Lockyer Creek floodplains.
- For the 1D sections of the Detailed Model, where there are high in-bank velocities causing a significant variation in water level across the river/creek at a sharp bend (ie. superelevation).

9.12 Hydraulic Modelling Accuracy

For the calibration of the Detailed Model, given that the significant majority of levels, including flood marks, fall within the desired ITO tolerances for the model calibration and verification events, including tidal flows, and that these events represent a reasonably wide range in terms of flood magnitudes and behaviour, the ITO tolerances are considered to be indicative of the confidence limits of the accuracy of the hydraulic modelling for these calibration events. The tolerances are:

- Brisbane River downstream of Oxley Creek ± 0.15 m
- Brisbane River between Goodna and Oxley Creek ± 0.30 m
- Ipswich urban area ± 0.30 m
- Brisbane River and tributaries upstream of Goodna (for non-urban areas), including Bremer River and Lockyer Creek ± 0.50 m.

The above target tolerances were achieved within different reaches across the whole modelled area for all the calibration events. For events outside the range of the calibration events, these tolerances, from a hydraulic modelling viewpoint, would increase due to lack of good quality calibration data, but by how much is difficult to quantify. However, the more extreme the event, the greater the uncertainties and therefore the appropriate tolerances. It should also be noted that for these extreme events, there is greater uncertainty in the hydrologic derivation of the flows.

It is important to note that due to the potential sources of errors and residual uncertainties discussed above, and the need to take into account the sensitivity of peak water levels to the local topography, parameter uncertainties, and other effects, it is not necessarily appropriate to simply apply these tolerances when setting planning levels and freeboards. The sensitivity of peak flood levels to residual uncertainties in the hydrologic and hydraulic modelling, future catchment conditions and development, climate change, and local topographic effects, need to be taken into account.

For example, peak water levels along Lockyer Creek change little once the creek is overtopped due to the large floodplain, whereas many sections of the Brisbane River the flood levels increase significantly with a relatively small increase in flows due to the absence of a large floodplain. A more appropriate approach to considering residual uncertainty in flood planning levels is to use a freeboard that incorporates the effects of a shift in AEP probability. For example, if freeboard for a 1 in 100 AEP level is to be considered, the freeboard could be based on the greater of the tolerances above (or some other minimum freeboard amount) and the difference in peak level between the 1 in 200 and 1 in 100 AEP flood levels, noting that potential influences on AEP peak levels such as climate change may also need to be taken into account. A similar approach can be taken in assigning flood risk using hydraulic hazard (DxV) values and depth averaged velocities for structure design.

In terms of accurately predicting flood warning times, the Fast and Detailed Model calibrations demonstrate a consistent and matched reproduction of the travel time and shape of the flood wave for all calibration floods after accounting for any bias carried through from the hydrologic modelling.

10 Future Use

10.1 Triggers for Revisiting Hydraulic Assessment

Whilst the Hydraulic Assessment is a highly comprehensive detailed investigation, the current situation can change and triggers for revisiting or reworking sections should be appreciated. Examples of future events that would potentially trigger a review of the assessments include, but are not limited to:

- A major flood event. The hydrologic and hydraulic model calibrations would benefit from being checked by verifying to the flood event. Given the exhaustive calibration carried out, a future flood event is considered as a low risk in needing to rework the modelling, and this exercise is more likely to be carried out as a demonstration of the robustness of the modelling. Whilst some fine-tuning of the models' calibrations may result, it is unlikely that this would cause a demonstrable change in the majority of design flood levels. The exception maybe for floods greater than around 11,500 m^3/s as observed in 1974, for which there are presently no historical floods with detailed recordings available for model calibration.
- Change in design rainfall data. The hydrological modelling techniques employed by the BRCFS are leading edge and are consistent with best practice recommended in Australian Rainfall and Runoff 2016. The studies have made best use of all available data and demonstrated that the techniques adopted reproduce at site frequency analysis within the credible range of extrapolation (up to 1 in 100 AEP). On this basis, a significant increase in rainfall and streamflow record would be needed to trigger hydraulic reassessment. However, a significant change in design rainfall should trigger a review and update of design floods only. It is noted that recent changes in design rainfall for events up to 1 in 100 AEP by the Bureau of Meteorology in late November 2016 are considered to be minor and are of no consequence to the study outcomes. Rarer rainfalls between 1 in 200 AEP and 1 in 2000 AEP are scheduled for release early next year and will need to be reviewed. Given the uncertainty of the design rainfall in this range, non-minor changes are probably best addressed by simple probability adjustment of the events that have been run and mapped.
- More certain predictions on the effect of climate change. This trigger would only affect the review and update of the design floods and/or the assumptions used in climate change sensitivity scenarios.
- Major improvement in hydrologic or hydraulic modelling techniques. Hydrologic and hydraulic modelling techniques have advanced considerably as computing performance has evolved and new numerical techniques have developed. The Hydrologic and Hydraulic Assessments have utilised established, but leading edge approaches, as well as industry leading innovations such as the implementation of the Monte Carlo statistical method. The modelling carried out is therefore of low risk of being replaced or significantly bettered in the near future. The successful calibration of the models to a range of historical events underpins the performance of the hydrologic and hydraulic modelling approaches as a robust platform that can be used into the future. Should a new hydrologic or hydraulic modelling technique be demonstrated as a worthwhile improvement over those methods used that produces significant differences in the

calibration parameters for historic floods, this would trigger close to a complete rework of the Hydrologic and/or Hydraulic Assessments.

- Significant change in operation rules of Somerset and Wivenhoe Dams e.g. modification to the Loss of Communications emergency flood operation rules of Somerset and/or Wivenhoe Dams that causes a significant change in dam flood releases would affect the derivation of the design floods. Depending on the significance, this trigger may require reworking of the hydrologic and hydraulic Monte Carlo analyses and the design floods.
- Raising of Wivenhoe Dam or any other major civil works that cause a significant alteration of Brisbane River flood behaviour. This does not include works such as levees that only have a localised or minor effect on riverine flood levels. This trigger would require reworking of the hydrologic and hydraulic Monte Carlo analyses and the design floods.
- Future Works that produce significant change to the channel or floodplain flow conveyance, significant increase or decrease of storage volume in flood inundation areas, or have a combined significant impact on conveyance and storage, with those impacts extending beyond the local vicinity of the works (e.g. more than several kilometres away) may require revision of some parts of the hydraulic model study and mapping. The extent of revision that would be required would need to be ascertained after preliminary assessment of the works which would initially be assessed with the Detailed Model.

10.2 Custodianship

To ensure continuing relevance and useability of the BRCFS models, future maintenance and custodianship of the models should be managed by appropriate experienced professional(s). This matter is being addressed by the Queensland Government in conjunction with the local governments, with DSITI as the data custodian.

11 Conclusions and Recommendations

The hydraulic modelling carried out for the BRCFS Hydraulic Assessment provides the most comprehensive, up-to-date and accurate predictions of Brisbane River riverine flooding for a wide range of probabilities of occurrence. The modelling forms the basis for future flood management investigations and formulation of planning controls for the Brisbane River, tributaries and floodplains affected by flooding caused by the Brisbane River below Wivenhoe Dam.

The following conclusions, drawn from those documented in MR1 to MR5, represent the salient points and findings of the BRCFS Hydraulic Assessment.

Data Collection and Collation

A significant volume of data was supplied from the Data Collection Study (DCS) and the Hydrologic Assessment. These data were assessed for gaps and additional data sourced. Of particular note was the collation of a number of useful datasets including:

- Standardised sets of flood marks for the 1974, 2011 and 2013 events within the study area.
- Hydraulic Structure Reference Sheets (HSRS) that document key structures.

Fast Model Development and Calibration

The Fast Model is a 1D network hydraulic model comprised of approximately 2,350 channels interconnected to represent the in-bank and overland flowpaths. Key points of the Fast Model are:

- The Fast Model was calibrated and verified to the floods of 1974, 1996, 1999, 2011 and 2013, with the calibration focus on reproducing the flood gradients and hydrograph timing along the main waterways where the Reporting Locations for the Monte Carlo AEP analysis are located.
- Calibration solely by adjusting Manning's n values was demonstrated to not be feasible unless different n values were adopted for different river heights and n values were increased above industry standards at sharp bends and rock ledges. Form (energy) losses, particularly at sharp river bends, rock ledges and major confluences, are not inherently modelled by the 1D form of the equations, and were needed to reproduce the timing of the flood wave and the varying gradients along the Brisbane River. Using the combination of Manning's n and form losses, a common set of hydraulic modelling parameters across the full range of calibration events plus tidal conditions was achieved using parameter values that are within industry standard bounds.
- The model has a run time of around 4 mins for an 8 day flood on a standard single CPU core. This is within the 15 mins run time as stipulated by the ITO.
- The Fast Model has been used for simulating extreme events and as such is considered sufficiently robust and accurate to simulate the full range of Monte Carlo events supplied by the Hydrologic Assessment.

Detailed Model Development and Calibration

The Detailed Model has been developed as a 1D/2D hydraulic model. The 1D sections extend along the in-bank sections of Lockyer Creek and the in-bank sections of the Bremer River, and Warrill and Purga Creeks upstream of One Mile Bridge. The remainder of the model is represented as a 30 m 2D regular grid with ground elevations sampled on a 15 m grid. The 1D sections are based on those in the Fast Model. Key points are as follows:

- The Detailed Model has been calibrated to tidal conditions, a minor flood (2013) and a major flood (2011), and verified to two minor floods (1996 and 1999) and a major flood (1974). The model produces a match with tidal conditions and all five events when compared with water level hydrographs at gauges, flow gaugings and flood marks. As for the Fast Model this was achieved using the same set of hydraulic modelling calibration parameters.
- The Manning's n values are typical of those used in the industry.
- As for the Fast Model, a satisfactory calibration cannot be achieved by solely adjusting Manning's n values. Additional form (energy) losses at sharp river bends and rock ledges were needed to reproduce the timing of the flood wave and the recorded gradients along sections of the Brisbane River. The 2D hydraulic equations used by the Detailed Model are able to simulate the bulk (typically 70 to 80%) of these losses, but not all the losses can be reproduced such as those that occur in the vertical plane (eg. helicoidal circulations around a sharp bend) for which a 3D representation would be required to reproduce. Note that the form losses applied to the Fast Model, which uses the 1D equations (which do not inherently simulate energy losses), are much greater than the additional form losses needed for the Detailed Model's 2D representation.
- The effects of superelevation at river bends are reproduced in the in-bank 2D sections of the Detailed Model, and where recorded flood marks were available these concur with the Detailed Model's results. For example, there is a recorded 0.7 m difference in flood level across the Story Bridge in 2011 that the Detailed Model reproduces. The Fast Model using the 1D equations is not able to produce this effect.
- A 1.5x1974 event was simulated to roughly approximate the estimates of peak flows in Brisbane for the 1893 events and comparisons made to peak 1893 flood levels showing a consistent agreement. The model also simulated two extreme events: 5x1974 and 8x1974.
- Reducing the 2D resolution from a 30 m to a 20 m cell size does not provide any major improvement in the model calibration or the model's ability to meet the Detailed Model's objectives, plus the longer run times of the 20 m resolution (3 to 6 days for each design event) is impractical based on current day PC chip technology.
- The simulated historical floods and the extreme events significantly vary in behaviour and size, and the ability of the Detailed Model to reproduce such a wide range of events without varying parameters provides a high level of confidence for simulating design floods across the full range of AEPs.

Fast Model Monte Carlo Analysis and Design Event Selection

The Fast Model was used to simulate 11,340 Monte Carlo events. Following this a Monte Carlo statistical analysis using the Total Probability Theorem approach at 28 Reporting Locations was undertaken to estimate flood levels for a range of Annual Exceedance Probabilities (AEP) varying from the 1 in 2 AEP to 1 in 100,000 AEP. Groups of Monte Carlo events for each AEP (AEP ensembles) were then selected resulting in a total of 60 events covering the 11 AEPs. Key points are:

- Event ensembles for each of the 11 AEPs have been compiled that produce peak levels at each Reporting Location within the desired flood level tolerances specified in the ITO.
- The process of deriving AEP levels and selecting design event ensembles is a stepping stone to producing the final AEP design levels from using the Detailed Model. The AEP levels derived in this manner are not the final AEP design levels, but levels statistically derived from the 11,340 Monte Carlo events simulated using the Fast Model. The final AEP hydraulic modelling outputs are produced by the Detailed Model.

Design Event Modelling

The AEP design event flood modelling simulated the selected 60 critical Monte Carlo flood events as documented in MR4 through the Detailed Model representing the 11 AEP ensembles from the 1 in 2 to 1 in 100,000 AEP.

Results from the design flood modelling are presented as a series of maps, plots and tables, which together provide spatial and temporal information on riverine flooding for different AEPs. Maps for the 1 in 100 AEP are provided in the accompanying A3 Addendum, whilst digital maps for all other AEP floods are provided as a Digital Addendum to MR5.

Table 11-1 provides a summary of peak AEP flood levels and flows at Lowood, Ipswich, Moggill and Brisbane CBD.

Sensitivity scenarios have also been simulated in accordance with the ITO and results are presented, primarily as tables of peak flood levels and flows along with the change from the peak baseline value. For the Climate Change sensitivity tests digital mapping of water level, depth, velocity and hydraulic hazard for the 1 in 100 AEP flood is provided in the MR5 Digital Addendum. For the No/With Dams sensitivity tests maps showing the change in peak flood level due to the dams for the historical events are provided in the MR5 Digital Addendum.

The Figure 11-1 presents an example of the results from the Climate Change Sensitivity Tests showing the change in peak flood level under different combinations of rainfall increases and sea level rise.

Rating Curve Reviews

Reviews of the rating curves used by the Hydrologic Assessment compared with the stage-discharge outputs from the hydraulic modelling was carried out at several key stages during the development, calibration and design flood modelling of the Fast and Detailed Models. Importantly, the review demonstrates the hydraulic models are consistent with the Hydrologic Assessment's hydrologic modelling, a key requirement of the ITO. The review also highlights the uncertainties in the stage-discharge relationships due to hysteresis in the stage-discharge relationships, especially due to backwater effects, and provided useful insights to the validity or refinement of rating curves under extreme flows.

Limitations

Limitations and constraints of the Hydraulic Assessment and hydraulic models are documented, including guidance on the hydraulic modelling accuracy and validity of AEP design flood output in areas distant from Reporting Locations.

QA and IPE Endorsement

The Detailed Model has been subject to a rigorous internal QA process including model reviews and checks for consistency on modelled volumes and mass error. All simulated events performed within acceptable criteria. Furthermore, the Fast and Detailed Models' calibrations and AEP design event modelling has been endorsed by the Independent Panel of Experts appointed to oversee the study.

Table 11-1 Summary of Peak Design Riverine Flood Levels and Flows at Lowood, Ipswich, Moggill and Brisbane

AEP 1 in …	Base Case Peak Design Flood Levels and Flows^							
	Lowood (Pump Station)		Ipswich (David Trumpy Bridge)		Moggill		Brisbane (City Gauge)	
	Peak Level (mAHD)	Peak Flow (m^3/s)	Peak Level (mAHD)	Peak Flow (m^3/s)	Peak Level (mAHD)	Peak Flow (m^3/s)	Peak Level (mAHD)	Peak Flow (m^3/s)
2*	n/a	n/a	1.9	n/a	1.7	n/a	1.6	n/a
5	31.0	1,000	11.8	1,300	4.1	1,800	1.7	2,300
10	33.7	1,800	14.8	1,900	6.9	3,000	1.8	3,200
20	36.3	2,800	16.1	2,300	9.9	4,300	2.2	4,800
50	40.9	5,500	18.7	3,200	14.3	6,900	3.2	6,900
100	45.3	9,800	20.1	3,800	18.2	9,900	4.5	9,200
200	47.3	13,000	21.8	4,800	20.3	11,900	5.8	11,000
500	48.6	15,800	23.4	5,600	22.60	14,700	7.3	13,200
2,000	51.0	20,400	25.7	6,900	25.43	19,500	9.9	17,200
10,000#	54.5	29,300	29.0	9,300	28.77	28,400	14.7	25,700
100,000#	63.0	52,600	36.1	13,500	35.99	57,200	23.7	56,000

^ Peak flood levels and peak flows do not necessarily occur at the same time.
* 1 in 2 AEP event results only reliable for tidal zone. Flows not provided as due to tidal influence, not flood influence.
# Flood may exceed the maximum release capacity of Wivenhoe Dam (currently 28,000 m^3/s) – treat results with caution.

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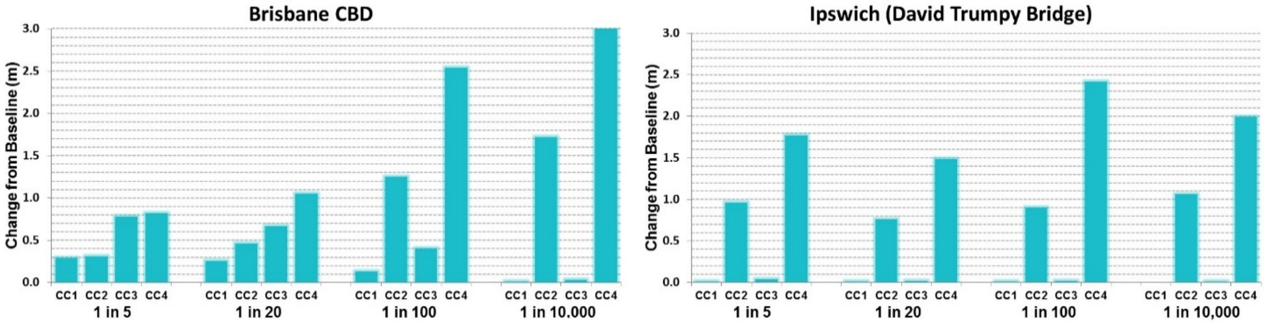

CC1 = No change to rainfall and 0.3 m rise in sea level

CC2 = 10% increase in rainfall and 0.3 m rise in sea level

CC3 = No change to rainfall and 0.8 m rise in sea level

CC4 = 20% increase in rainfall and 0.8 m rise in sea level

Figure 11-1 Change in Peak Flood Level under Climate Change Sensitivity Scenarios

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Appendix A IPE Comments on Draft Report and Endorsement

Independent Panel of Experts for the Brisbane River Catchment Flood Study

Review of Milestone Report 6: Hydraulics Report

Comprehensive Hydraulic Assessment

Introduction

The MR6 report by BMT WBM summaries the work carried out in the hydraulics phases of the Brisbane River Catchment Flood Study (BRCFS).

This report is a detailed summary of reports MR1 to MR5. The approach adopted in the Hydraulics phase was to develop a fast model that could be run in a Monte Carlo environment and a detailed model that could produce high resolution spatial output that describes the flood characteristics of the Brisbane River catchment. Integral to both models was a detailed calibration against observed hydrographs and peak levels. The Monte Carlo approach adopted in the hydraulics phase of this study was built upon the work carried out in the hydrology phase and allows the design results to properly account for the variable ways flooding can occur on the catchment. The fast model allows for this robust Monte Carlo approach to be used with a model that properly reflects the complex hydraulic behaviour of the Brisbane River.

The reports summarised in MR6 that have previously been reviewed by the IPE are listed in the table below along with the chapters of MR 6 they relate to:

Report	Chapter of MR 6
MR 1 - Data Review and modelling methodology	3 and 4
MR 2 - Fast model development and calibration	5
MR 3 - Detailed model development and calibration	6
MR 4 - Fast Model Results and event selection	7
MR 5 - Detailed model results	8

The fast and detailed models developed in this study meet the brief requirements. The fast model has a very practical run time that exceeds the brief requirement and allows the practical use of Monte Carlo techniques. The detailed model allows flood behaviour to be estimated through the study area for design events from 1 in 2 AEP to 1 in 100,000 AEP using 60 design runs to represent 11 design probabilities. The outputs include, flood levels, depth, velocity and hydraulic hazard. The model is a suitable tool for subsequent floodplain management studies.

The IPE has previously endorsed each of the final reports MR1 to MR5. The IPE endorses the MR6 report as a satisfactory summary of all of those Milestone Reports.

17 November 2016

Hydraulics IPE

Mark Babister (Chair) — Managing Director WMAWater

Prof Colin Apelt — Emeritus Prof UQ UniQuest Pty Ltd

Dr John Macintosh — Director Water Solutions

Appendix A Minor editorial comments

Item No.	Page No.	Section	Para/Line/Dot Point/Table etc	Issue/Comments	Suggestion
1	6	Executive summary	second dot point	The last sentence is rather vague; *"This backwater flooding is likely to be higher than for the local 1 in 100 AEP flood events."*	Replace with; *"This backwater flooding in the lower reaches of these creeks is likely to result in peak flood levels higher than that which would be experienced there from local 1 in 100 AEP flood events in the respective creeks"*
2	2	1.2	Footnote 4	Text is incomplete	Complete text of footnote 4
3	27	3.9	Para 1 / line 5	Text "For A3 maps of results" incomplete?	Complete text
4	27	3.9	Last dot point / line 1	Typo "there are"	Change to "these are"
5	32	4.1.3	First para / line 6	Typo "is listed"	Change to "are listed"
6	86	6.5.2	Last para	The discussion is left in the air.	Refer to MR3 and add closing paragraph based on; *"The IPE believe that 30m grid size represents the most practical compromise between the competing needs to produce a general purpose model that meets the requirements of the brief."*
7	100	7.6	Table 7-3 / column 2 bottom entry	Text is unclear.	Change last part to "The Hydrologic Assessment used GHD, 2014, to derive storm tide boundaries for the Monte Carlo events. *However, the randomised* selection of storm tide events could cause a too high, or no storm tide events high enough amongst the selected events within an AEP ensemble. "
8	118	8.5.5	First para / line 6	Typo "2013For"	Change to "2013. For"

9	A3 Addendum	Sheet 8	1 D channels	The colour used to show "1D Channels in 2D Domain" is very similar to that of the Brisbane River channel downstream from Brisbane CBD.	Although this is a copy from MR3, could a more contrasting colour be used here? (A minor point)
10	59	5.3.2	Last para	Need to state that the calibrated Manning's n values are matched to the method of calculation of conveyance (Section 5.2.2)	Append the sentence "It should be noted that these values are matched to the computational method employed by the FM, and in particular the calculation of conveyance as discussed in Section 5.2.2"

A3 Addendum

A3 Addendum Sheet 1 Gauges and Reporting Locations (MR3, Drawing 1)
A3 Addendum Sheet 2 Long Section Chainages (MR3, Drawing 2)
A3 Addendum Sheet 3 Bathymetric Data Sources (MR3, Drawing 3)
A3 Addendum Sheet 4 Modelled Hydraulic Structure Locations (MR2, Drawing 7)
A3 Addendum Sheet 5 Fast Model Layout (MR2, Drawing 9)
A3 Addendum Sheet 6 Fast Model Calibration and Verification Peak Level Comparison at Gauges (MR2, Table 4-3)
A3 Addendum Sheet 7 Detailed Model Layout (MR3, Drawing 7)
A3 Addendum Sheet 8 Detailed Model Calibration and Verification Peak Level Comparison at Gauges (MR3, Table 3-4)
A3 Addendum Sheet 9 DM and FM 2011 Calibration Lockyer Creek Water Level Gauges (MR3, Plot 13)
A3 Addendum Sheet 10 DM and FM 2011 Calibration Bremer River Water Level Gauges (MR3, Plot 14)
A3 Addendum Sheet 11 DM and FM 2011 Calibration Brisbane River Water Level Gauges (MR3, Plot 15)
A3 Addendum Sheet 12 DM and FM 2011 Calibration Centenary Bridge Flow Recordings (MR3, Plot 16)
A3 Addendum Sheet 13 Key Sheet for Calibration Drawings (MR3, Drawing 9)
A3 Addendum Sheet 14 DM 2011 Calibration – Region A (MR3, Drawing 17)
A3 Addendum Sheet 15 DM 2011 Calibration – Region B (MR3, Drawing 18)
A3 Addendum Sheet 16 DM 2011 Calibration – Region C (MR3, Drawing 19)
A3 Addendum Sheet 17 DM 2011 Calibration – Region D (MR3, Drawing 20)
A3 Addendum Sheet 18 DM 2011 Calibration – Region E (MR3, Drawing 21)
A3 Addendum Sheet 19 Key Sheet for Design Flood Mapping (MR5, Drawing 4)
A3 Addendum Sheet 20 Peak Water Surface Level Maps – 1 in 100 AEP – Region A (MR5, Drawing 5)
A3 Addendum Sheet 21 Peak Water Surface Level Maps – 1 in 100 AEP – Region B (MR5, Drawing 6)
A3 Addendum Sheet 22 Peak Water Surface Level Maps – 1 in 100 AEP – Region C (MR5, Drawing 7)
A3 Addendum Sheet 23 Peak Water Surface Level Maps – 1 in 100 AEP – Region D (MR5, Drawing 8)
A3 Addendum Sheet 24 Peak Water Surface Level Maps – 1 in 100 AEP – Region E (MR5, Drawing 9)
A3 Addendum Sheet 25 Peak Flood Depth Maps – 1 in 100 AEP – Region A (MR5, Drawing 10)
A3 Addendum Sheet 26 Peak Flood Depth Maps – 1 in 100 AEP – Region B (MR5, Drawing 11)
A3 Addendum Sheet 27 Peak Flood Depth Maps – 1 in 100 AEP – Region C (MR5, Drawing 12)
A3 Addendum Sheet 28 Peak Flood Depth Maps – 1 in 100 AEP – Region D (MR5, Drawing 13)
A3 Addendum Sheet 29 Peak Flood Depth Maps – 1 in 100 AEP – Region E (MR5, Drawing 14)
A3 Addendum Sheet 30 Peak Flood Velocity Maps – 1 in 100 AEP – Region A (MR5, Drawing 15)
A3 Addendum Sheet 31 Peak Flood Velocity Maps – 1 in 100 AEP – Region B (MR5, Drawing 16)
A3 Addendum Sheet 32 Peak Flood Velocity Maps – 1 in 100 AEP – Region C (MR5, Drawing 17)
A3 Addendum Sheet 33 Peak Flood Velocity Maps – 1 in 100 AEP – Region D (MR5, Drawing 18)
A3 Addendum Sheet 34 Peak Flood Velocity Maps – 1 in 100 AEP – Region E (MR5, Drawing 19)
A3 Addendum Sheet 35 Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region A (MR5, Drawing 20)
A3 Addendum Sheet 36 Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region B (MR5, Drawing 21)
A3 Addendum Sheet 37 Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region C (MR5, Drawing 22)
A3 Addendum Sheet 38 Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region D (MR5, Drawing 23)

A3 Addendum Sheet 39 Depth x Velocity (Hydraulic Hazard) Maps – 1 in 100 AEP – Region E (MR5, Drawing 24)
A3 Addendum Sheet 40 Ensemble Water Level and Flow Hydrographs – 1 in 100 (1%) AEP – Sheet 1 of 3 (MR5, Plot 16)
A3 Addendum Sheet 41 Ensemble Water Level and Flow Hydrographs – 1 in 100 (1%) AEP – Sheet 2 of 3 (MR5, Plot 17)
A3 Addendum Sheet 42 Ensemble Water Level and Flow Hydrographs – 1 in 100 (1%) AEP – Sheet 3 of 3 (MR5, Plot 18)
A3 Addendum Sheet 43 Brisbane River Longitudinal Profiles Maximums – All AEPs (MR5, Plot 45)
A3 Addendum Sheet 44 Bremer Lockyer Longitudinal Profiles Maximums – All AEPs (MR5, Plot 57)
A3 Addendum Sheet 45 Rating Curves Sheet 1 of 3 (MR5, Plot 58)
A3 Addendum Sheet 46 Rating Curves Sheet 2 of 3 (MR5, Plot 59)
A3 Addendum Sheet 47 Rating Curves Sheet 3 of 3 (MR5, Plot 60)
A3 Addendum Sheet 48 Rating Curves Extreme Sheet 1 of 3 (MR5, Plot 61)
A3 Addendum Sheet 49 Rating Curves Extreme Sheet 2 of 3 (MR5, Plot 62)
A3 Addendum Sheet 50 Rating Curves Extreme Sheet 3 of 3 (MR5, Plot 63)
A3 Addendum Sheet 51 Base Case (B15) Peak Levels and Flows (MR5, Addendum Table 1)

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