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Technical Summary Report
Comprehensive Hydrologic and Hydraulic Assessments
Brisbane River Catchment Flood Study

FINAL

Prepared for the State of Queensland

February 2017

BRCFS Technical Summary Report
Hydrologic and Hydraulic Assessments

Prepared for:	State of Queensland
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- Department of Natural Resources and Mines
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- Department of Energy and Water Supply
- Department of Infrastructure, Local Government and Planning
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- Seqwater
- Brisbane City Council
- Ipswich City Council
- Somerset Regional Council
- Lockyer Valley Regional Council
- Bureau of Meteorology.

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Caveats and Use of Report

This report is the Technical Summary Report for the Brisbane River Catchment Flood Study (BRCFS). The document provides an overview of the Hydrologic and Hydraulic Assessments and draws out key concepts and findings.

It should be noted that this Study is for the assessment of riverine flooding downstream of Wivenhoe Dam. For local creek flooding refer to the local councils.

For readers who desire more detail, refer to the series of detailed technical reports as follows (for references see Section 12.1):

Hydrologic Assessment Technical Reports:

- Hydrologic Milestone Report 1: Data, Rating Curve and Historical Review Report.
- Hydrologic Milestone Report 2: Hydrologic Model Calibration and Validation Review Report.
- Hydrologic Milestone Report 3: Hydrologic Model Recalibration Report.
- Hydrologic Milestone Report 4: Assessment of Implications of Climate Change on Flood Estimation.
- Hydrologic Milestone Report 5: Dam Operations Module Implementation Report.
- Hydrologic Milestone Report 6: Flood Frequency Analysis Report.
- Hydrologic Milestone Report 7: Design Event Approach Report.
- Hydrologic Milestone Report 8: Monte Carlo Simulation Report.
- Hydrologic Milestone Report 9: Reconciled and Recommended Flood Frequency Estimates Report.
- Hydrologic Milestone Report 10: Draft Final Hydrology Report

Hydraulic Assessment Technical Reports:

- Hydraulic Milestone Report 1: Data Review and Modelling Methodology
- Hydraulic Milestone Report 2: Fast Model Development and Calibration
- Hydraulic Milestone Report 3: Detailed Model Development and Calibration
- Hydraulic Milestone Report 4: Fast Model Results and Design Events Selection
- Hydraulic Milestone Report 5: Detailed Model Results
- Hydraulic Milestone Report 6: Hydraulics Report

Executive Summary

Introduction

The Queensland Floods Commission of Inquiry Final Report issued in March 2012, contains a recommendation 2.2 to conduct a flood study of the Brisbane River catchment. In accordance with this recommendation, the State of Queensland has undertaken the Brisbane River Catchment Flood Study (BRCFS) in phases:

- Phase 1: Data Collection, Collation, Review and Storage of Existing Data
- Phase 2A: Comprehensive Hydrologic Assessment
- Phase 2B: Comprehensive Hydraulic Assessment

Following the completion of the BRCFS the Brisbane River Catchment Floodplain Management Study (BRCFMS) and Brisbane River Catchment Strategic Floodplain Management Plan (BRCSFMP) are to be carried out. This Technical Summary Report presents an overview of Phases 2A and 2B, namely the Hydrologic and Hydraulic Assessments.

The Hydrologic and Hydraulic Assessments were carried out in accordance with their respective Invitations to Offer (the study briefs or ITOs). The work was 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 with most members involved for the full duration of the BRCFS. The Department of Infrastructure, Local Government and Planning (DILGP) administered the assessments along with the Department of Natural Resources and Mines (DNRM) as project manager. A key requirement was that the Hydrologic and Hydraulic Assessments interfaced closely.

The assessments are the most comprehensive, up-to-date and accurate analysis of Brisbane River riverine flooding. The latest available data was used to develop computer models, and these models were validated by calibrating and verifying their results against well documented historical floods. Industry leading techniques were used to derive floods of different probability of occurrence that take into account the effects on flood behaviour caused by variations in: rainfall and antecedent catchment conditions; Somerset and Wivenhoe Dam reservoir levels and operations; and ocean tidal conditions. The outcome is best practice hydrologic and hydraulic modelling that provides reliable information and a sound foundation for the BRCFMS and BRCSFMP.

Objective

As stated in the ITOs, the objective and scope of the BRCFS 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."* The intent being to deliver best practice estimates of Brisbane River flooding for different probabilities of occurrence, for example, the 1 in 100 AEP (Annual Exceedance Probability) flood, which has a 1% chance of being equalled or exceeded within every year.

Achieving the above objective requires:

- Calibrated hydrologic models that convert catchment rainfall into creek/river flow at various points of interest, and includes representations of different forms of flood storage (e.g. floodplains, reservoirs).
- Development and application of state-of-the-art methods and analytical techniques that provide best practice estimates of flood flows and volumes for a wide range of exceedance probabilities across the entire Brisbane River catchment system.
- A high resolution, calibrated hydraulic model that accurately defines the flood behaviour of the Brisbane River below Wivenhoe Dam, and the lower sections of the major tributaries of Lockyer Creek and the Bremer River, for a wide range of floods from small to extreme. The hydraulic model must be able to accurately simulate the flood progression and produce flood levels, depths and velocities (water speeds) along the waterways and over the floodplains.
- Leading edge and innovative statistical analyses to derive synthetic floods of different AEPs that take into account the complexity and variability of Brisbane River catchment flooding.
- Rating curve consistency where the hydrologic modelling transitions to the hydraulic modelling. For the two types of modelling to be compatible in the transition from hydrologic to hydraulic modelling, the stage-discharge relationship (water level versus flow relationship, i.e. a rating curve) must be consistent between both types of modelling.

The BRCFS has engaged a wide-ranging and thorough approach by encompassing the latest proven and established techniques; innovation through use of the Monte Carlo Simulation method; and model testing through validation to historical floods.

Of special note is the Monte Carlo Simulation method, which is used for calculating probabilities of “something” occurring (e.g. a flood) when there are uncertainties and/or variability in the variables that combine to produce that “something”. For flooding, it is applied by generating thousands of synthetic floods based upon random sampling of variables, such as rainfall, dryness of the catchment and dam reservoir levels. From this database of synthetic floods a probabilistic analysis can be carried out to determine the AEP of a flood.

By taking this wide-ranging and thorough approach in scope, along with an exceptionally high level of technical review via the Technical Working Group (TWG) and Independent Panel of Experts (IPE), the BRCFS is the most complex and comprehensive flood study undertaken in Australia to-date.

Riverine versus Local Flooding

The focus of the BRCFS is to quantify flooding caused by Brisbane River riverine flooding, which includes areas that experience inundation caused or exacerbated by elevated water levels in the Brisbane River. Therefore, the lower sections of Lockyer Creek and the Bremer River extending up into Warrill and Purga Creeks, and all smaller side tributaries, need to be included in the hydraulic modelling.

Localised flooding caused by concentrated 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 riverine flooding. For example, a local creek may be prone to flash flooding with little warning time and rapidly rising flood levels, which contrasts with riverine flooding that rises slowly and steadily as the Brisbane River rises.

The modelling carried out for the BRCFS is for Brisbane River riverine flooding, and not for local flooding. When information is sought on flooding in Brisbane River tributaries, both riverine and local flooding needs to be considered, with advice sought from the local council in regards to local flooding.

Outcomes

Key outcomes from the BRCFS Hydrologic and Hydraulic Assessments are:

- Calibrated hydrologic models for deriving floods from design rainfall events covering the entire Brisbane River Catchment, and which interface with the hydraulic modelling.
- A simplified Wivenhoe and Somerset Dam operations model integrated with the hydrologic models, allowing the hydrologic simulation of the entire Brisbane River catchment.
- A framework integrating the hydrologic and dam operation models for generating tens of thousands of synthetic rainfall and storm tide events, from which flood flow estimates for different AEPs using the Monte Carlo Simulation (MCS) method are derived. The framework also considers the joint probability of floods occurring in the Brisbane and Bremer Rivers (and other major tributaries as appropriate). The Monte Carlo/joint probability analysis framework is the most comprehensive, leading-edge analysis of its kind in Australia.
- A hydraulic model (the Fast Model) that simulates a flood in around 5 minutes. The model is capable of accurately reproducing the flood behaviour along the main rivers and creeks including the Brisbane River below Wivenhoe Dam, and the lower sections of Lockyer Creek and the Bremer River. It was used for deriving estimates of different flood level AEPs using the Monte Carlo method.
- The Detailed Model, the most comprehensive and accurate hydraulic model yet developed for simulating riverine flooding caused by the Brisbane River below Wivenhoe Dam, including that which occurs in the lower sections of Lockyer Creek, the Bremer River and other downstream creek tributaries that are subject to flooding from high levels in the Brisbane River. The model is of a much higher resolution and accuracy than the Fast Model, and is therefore not suited for use in a Monte Carlo analysis due to its long compute times. The Detailed Model was designed and is used for producing high quality hydraulic output at a fine resolution and accuracy for different AEPs, including flood levels, depths and velocities.
- Successful calibration and verification of the hydrologic and hydraulic models to the historical floods of 1974, 1996, 1999, 2011, 2013 and tidal conditions, using in each model a single set of industry standard parameters. The calibration and verification of models was highly meticulous, involving the matching of the models' results with thousands of flood level recordings and flow measurements.
- The development of a Monte Carlo statistical analysis for deriving indicative peak flood levels for different AEPs using the results from the Fast Model for tens of thousands of synthetic floods.
- The development of a process for selecting a small sub-set of the synthetic floods that are representative of the AEP peak flood levels derived from the Monte Carlo analysis. The resulting 60 synthetic floods cover 11 AEPs from the 1 in 2 to the 1 in 100,000 AEP, with each AEP being an ensemble of 4 to 7 synthetic floods. The peak flood level at any one location is taken as the highest flood level of all the floods in an ensemble.
- The 60 synthetic floods were simulated through the Detailed Model to produce high resolution maps of peak flood levels, depths, velocities and hazard, and other outputs including tables of peak levels and

flows and a variety of charts. The Detailed Model and its results form the hydraulic modelling foundation for the BRCFMS.

- Sensitivity tests were carried out using the Detailed Model to provide indicative estimates on changes to flood behaviour resulting from: (a) a hypothetical future floodplain development case; (b) potential climate change influence on storm rainfall intensity and ocean levels; (c) Brisbane River bed level changes; and (d) the effect of the major dams on historical floods. These tests provide insight to the likely change in flood levels, flow patterns and hydraulic hazard as a consequence of these scenarios.
- Stream flow rating curves at gauging stations that were revised for the Hydrologic Assessment have been reconciled and are in alignment with the Hydraulic Assessment. This adds increased confidence to the quality and limitations of use of the rating curves for dam operations, and for flood forecasting and warning.

Hydrologic Assessment

The Hydrologic Assessment developed and applied consistent and robust hydrologic models using rainfall-runoff-routing software known as URBS. This software simulates rainfall falling on catchments to produce surface runoff and the accumulation of runoff to streams as flood flow. The assessment then used analytical techniques to provide the best estimates of flood flows and flood volumes for different probabilities of occurrence across the entire Brisbane River catchment. A simplified Wivenhoe and Somerset Dam operations model based on certain assumptions was developed and integrated within the hydrologic modelling. The outcomes from the Hydrologic Assessment are a critical input to the Hydraulic Assessment.

Hydrologic Assessment Approach

Three approaches were used to estimate peak discharges and flow volumes throughout the catchment for a range of AEPs, followed by a reconciliation of the results from the three methods to arrive at best estimates of the different AEP flows at locations across the catchment. The three methods utilised are known as the:

- Flood Frequency Analysis (FFA)
- Design Event Approach (DEA)
- Monte Carlo Simulation (MCS) method

MCS is the only approach that is able to meet the objectives of the BRCFS. However, MCS is relatively new to flood modelling, so the first two industry established approaches were used to demonstrate and reconcile whether MCS produces defendable results by comparison of the three methods at locations within the catchment unaffected by dams.

DEA and MCS are both referred to as ‘rainfall based methods’, as they both rely on rainfall statistics in combination with a rainfall-runoff (hydrologic) model to compute peak flows and flow volumes at locations of interest. For FFA, peak flows and flow volumes for given AEPs are derived directly from statistical analysis of estimated historical flood flows from observed historical flood levels at stream gauging sites and the corresponding gauge rating curves.

MCS uses probability distributions of variables (unknowns) to generate large data sets of synthetic floods. In effect, MCS is akin to generating thousands of years of synthetic flood records from which, for example, the 1 in 100 AEP flood flow or level can be derived. MCS was efficiently implemented in a Delft-FEWS framework.

The MCS approach for deriving different AEP flood flow and level estimates has significant advantages over traditional approaches in that it can consider relevant physical processes that contribute to flooding. The MCS technique is particularly applicable to the Brisbane River catchment as it can cater for variations in factors that influence river flooding, namely variations in: spatial and temporal rainfall; antecedent (wet to dry) catchment conditions; initial reservoir levels; dam operations; and storm surge and tidal conditions. MCS can also address joint probability of occurrence of variables such as flows in the Brisbane and Bremer Rivers. The main practical disadvantage of using MCS is that it is more complex and time-consuming to implement, however, these challenges were overcome in the BRCFS through innovative developments in both the Hydrologic and Hydraulic Assessments.

Two scenarios were examined in the Hydrologic Assessment: a 'no-dams condition' and a 'with-dams condition'. The dams referred to are Somerset Dam and Wivenhoe Dam, both of which have flood mitigation capability in addition to water supply functions, as well as Cressbrook Creek, Lake Manchester, Moogerah and Perseverance dams. These latter four dams do not actively provide flood mitigation, but can have a measurable but minor influence on flooding depending on the level of their reservoirs at the onset of a flood.

For the 'no-dams condition', DEA and MCS results were generated for 22 hydrologic reporting locations across the entire Brisbane River catchment. FFA results were produced for 18 locations, as other locations had limited or no reliable available historical (observed) data, which is required for undertaking an FFA.

For the 'with-dams condition', the number of years of historical records available since the construction of Wivenhoe Dam is not sufficient to justify conducting an FFA, as an FFA is a statistical assessment requiring a sufficient period of record. Further, industry standard flood frequency analyses are not necessarily appropriate for sites influenced by flood mitigation dams. Therefore, only DEA and MCS results were generated for the 'with-dams condition', although these estimates were compared against available rated flow records where possible. The 'with-dams condition' estimates were derived for the Stanley River at Somerset Dam; six locations along the Lower Brisbane River: Wivenhoe Dam, Savages Crossing, Mt Crosby Weir, Moggill, Centenary Bridge and Brisbane City; and for the Bremer River at Ipswich.

For both the 'no-dams condition' and 'with-dams condition', the flow estimates for varying AEPs from the different methods were reconciled at each location to arrive at the best estimate of flow versus AEP.

Hydrologic Assessment Outcomes

The Hydrologic Assessment outputs and findings are summarised as follows:

- Recalibrated hydrologic models of the sub-catchments, suitable for AEP flood estimation by DEA and Monte Carlo Simulation (MCS) for the no-dams and with-dams scenarios.
- Estimates of different AEP peak flood flows and volumes ranging from the 1 in 2 AEP to extreme floods for PMP rainfall (the largest rainfall depth that could conceivably occur over the catchment). These estimates were produced for the 'no-dams condition' and the 'with-dams condition' at locations across the catchment.
- Ensembles of statistically generated AEP flood hydrographs (i.e. time history of flow) suitable for input to hydraulic models.
- Ensembles of statistically generated AEP ocean water level hydrographs, including a storm surge component, suitable for input to hydraulic models.

- Flood flow estimates at locations across the catchment for a range of AEPs based upon the standard DEA currently used by the industry.
- Estimates of peak flow and flood volume flood frequency curves (and their confidence limits) at the nominated locations.
- Stream gauge rating curves for key gauging station locations adopted for the hydrologic study.
- An evaluation of the overall performance of three alternative methods: FFA, DEA and MCS over the range of floods investigated.
- Estimates of the AEP of significant historic (actual) floods.
- A comparison of the combined effect of the dams shows that the dams can reduce peak flow rates for the 1 in 100 AEP flood by 29% to 42% immediately downstream of Wivenhoe Dam, with this effect diminishing downstream. The mitigation effect of the dams on Brisbane River flows extends over the full range of flood magnitudes, but lessens for larger floods. Flows in Lockyer Creek are not affected outside the areas influenced by flooding from the Brisbane River. For the 'with-dams' scenario, Moogerah Dam slightly reduces peak flows in the Bremer River.
- The estimates derived from MCS reflect the wide range of natural variability in contributing factors such as: rainfall depth and distribution in time and space; antecedent catchment conditions including catchment wetness (rainfall loss rates); and initial reservoir levels. Available records of past floods do not cover this wide range of variability, and traditional methods of flood estimation have thus proved inadequate for the Brisbane River catchment.

Hydraulic Assessment

Using outputs from the Hydrologic Assessment, the Hydraulic Assessment used hydraulic models to produce flood levels, depths and velocities along the waterways and over the floodplains. Two hydraulic models were developed and calibrated using the TUFLOW software, namely: the Fast Model and the Detailed Model. The Fast Model is a simplistic model designed for use in a MCS, while the Detailed Model is intended for high resolution, accurate calculation of flood behaviour.

Hydraulic Models

The Fast Model is a purely one-dimensional (1D) hydraulic model with a target run time of 15 minutes or less per simulation as specified in the ITO. 1D models use the most simplified form of the free-surface fluid flow equations and are quick to compute. The Fast Model's primary purpose is to simulate thousands of synthetically generated floods for a Monte Carlo analysis (hence the need for a quick compute time). The peak flood levels from these synthetic floods were used to determine AEP flood levels at locations downstream of Wivenhoe Dam.

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 1D only Fast Model. The Detailed Model primarily uses the 2D form of the free-surface fluid flow equations, which are significantly more accurate in reproducing complex flow effects (such as occurs in the Brisbane River) than the 1D form, but take significantly longer to compute. The Detailed Model is used for producing flood maps and 3D surfaces of flood levels, depths, velocities and hydraulic hazard (a component of flood risk).

The Fast and Detailed Models were calibrated and verified to five historical floods, namely those of 1974, 1996, 1999, 2011 and 2013, and to tidal conditions with no flood flows. The calibration parameters were derived through thousands of simulations testing different combinations, whilst remaining consistent with Brisbane River's physical characteristics. Importantly, the final parameters are consistent with industry standard values, and for each model, a single set of parameters produces a reproduction of all five historical floods across all flow regimes ranging from tidal flows to the major floods of 1974 and 2011.

Both Fast and Detailed Models were subject to rigorous internal quality assurance processes including model reviews and checks for consistency on modelled volumes and mass error. All simulated floods performed within the acceptable criteria as stipulated in the ITO and the hydraulic modelling calibration has been endorsed by the IPE. As such, the results from the hydraulic modelling should be considered significantly more reliable than any previous regional scale Brisbane River hydraulic assessment.

Monte Carlo Peak Flood Level Analysis

After completion of the Fast Model's development and calibration, approximately 1.1 million hydrographs[1], including outflows from Wivenhoe Dam, were transferred from the Hydrologic Assessment's MCS to simulate 11,340[2] synthetic floods through the Fast Model. Peak flood levels and hydrographs from the 11,340 simulations were extracted at 28 hydraulic reporting locations distributed along the main rivers and creeks. A Monte Carlo peak flood level statistical analysis was undertaken at each location to determine indicative AEP flood levels.

From the 11,340 synthetic floods, 60 were selected that together are representative of the Fast Model AEP peak flood levels at all 28 locations, across 11 AEPs ranging from 1 in 2 to 1 in 100,000 AEP. Each AEP is represented not by a single flood, but by an ensemble made up of 4 to 7 floods. Representation of the variation in rainfall duration and catchment response was also taken into consideration in selecting the 60 floods through manual checks of other factors, such as rate of rise, hydrograph shape and volume.

The 60 synthetic floods that make up the 11 AEP ensembles were simulated through the Detailed Model to produce hydraulic outputs for each AEP ensemble. The hydraulic output types are peak flood level, depth, velocity and hydraulic hazard. Hydraulic hazard is the depth multiplied by velocity; a measure of the hazard of deep and/or fast flowing water. The peaks of each output type are tracked independently throughout each synthetic flood, therefore the peak flow, peak velocity, or peak hydraulic hazard, may not occur at the same time as the peak level.

AEP Flood Levels and Results

Table A provides a summary of the AEP peak flood levels and flows as calculated by the Detailed Model at Lowood, Ipswich, Moggill and Brisbane CBD for the Base Case, which represents present day (2015) conditions.

It is important to note that floods will occur that exceed the 1 in 100 AEP flood level, and provision for this residual risk should be taken into account. Due to the nature of the Brisbane River being an incised river system with only minor floodplains, the residual risk can be substantial with significant increases in flood levels and flood extent between AEPs. For rare floods (e.g. 1 in 500 AEP, or 1 in 2,000 AEP) the flood levels are a few metres higher and the flood extent is much larger. The 1 in 500 AEP flood has a rare chance of occurring in one year, but the chance of 1 in 500 AEP flood level occurring within a 50 year exposure period is about 10%.

[1] Approximately 100 inflow hydrographs for each of the 11,340 events.
[2] Consists of 21 simulations per AEP for 60 AEPs; and 9 event durations (12 hours to 168 hours).

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

- In the lower reaches of Lockyer Creek floodplain, the 1 in 100 AEP flood level is comparable to both the 1974 and 2011 floods although is higher in some places (typically 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 level is lower than both the 1974 and 2011 floods (e.g. at Lowood it is approximately 0.8m to 1.0m lower than both 1974 and 2011 floods).
- Near Ipswich CBD the 1 in 100 AEP flood level 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 level is typically 0.1m to 0.3m higher than the 2011 flood. In the Brisbane CBD region, the 1 in 100 AEP flood level is the same or up to 0.2m higher than 2011, and around 1.0m lower than the 1974 flood.
- Downstream from the Gateway Motorway, the 1 in 100 AEP flood level is similar to the peak level resulting from the storm surge experienced in the January 2013 flood, which was higher than that experienced during 2011 and 1974 floods.

The 1 in 200 AEP flood 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 in 1974). However, in the Brisbane CBD the 1 in 200 AEP flood is only around 0.1m to 0.2m higher than the 1974 flood.

Table A 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

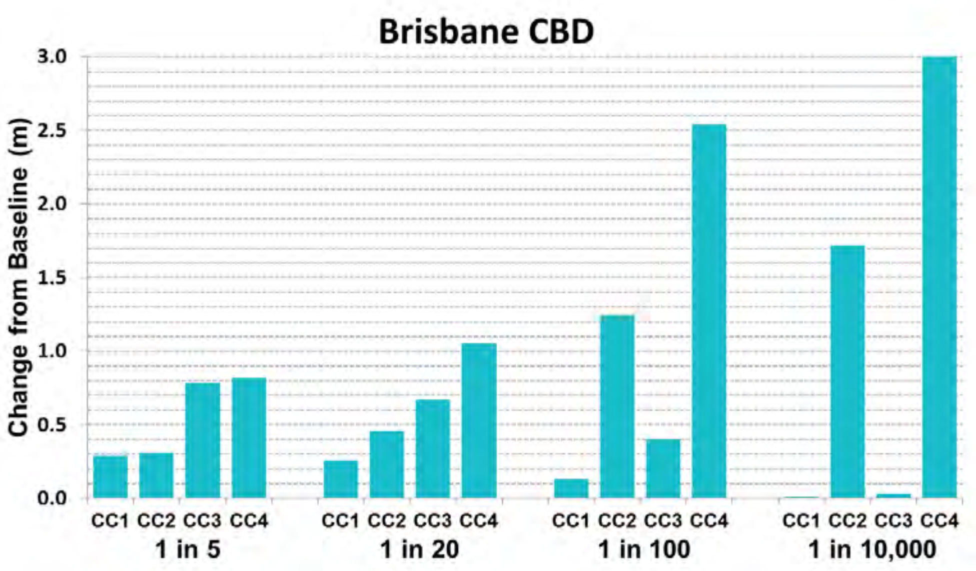
^ Peak flood levels and peak flows do not necessarily occur at the same time.
* 1 in 2 AEP flood level results only reliable for tidal zone.
& 1 in 2 AEP peak flows not provided as they are due to tidal influence, not flood influence.
# Flood may exceed the maximum release capacity of Wivenhoe Dam (currently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

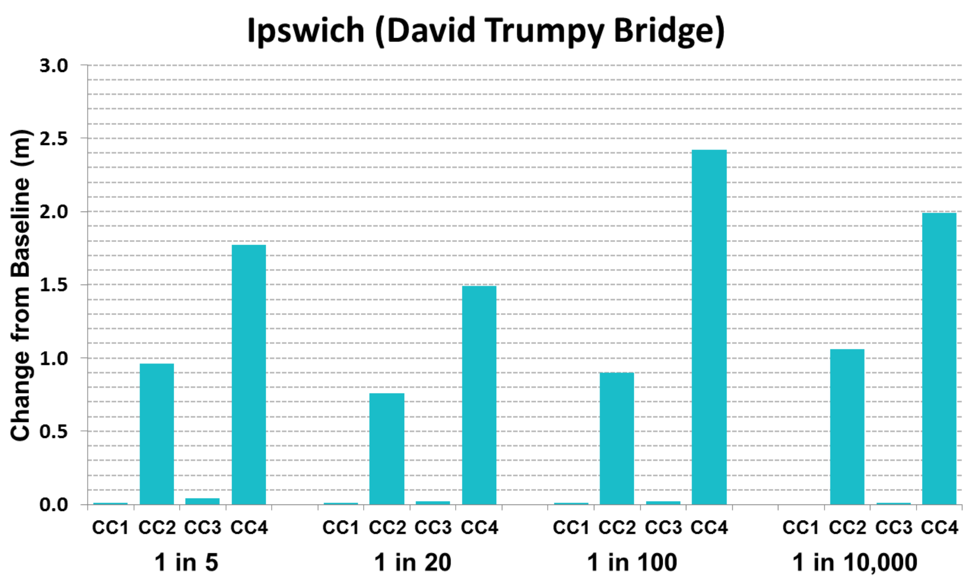
Sensitivity Tests

A range of sensitivity tests were carried out using the Detailed Model to provide indicative estimates on changes to flood behaviour resulting from: (a) hypothetical future floodplain development case; (b) potential climate change influence on storm rainfall intensity and ocean levels; (c) Brisbane River bed level changes; and (d) the effect of dams on historical floods.

The charts below summarise the Climate Change Sensitivity Tests 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

Rating Curve Reconciliation

Reviews of the rating curves used in the hydrologic modelling with the water level versus flow (stage-discharge) outputs from the hydraulic modelling were carried out at several key stages during the development, calibration and AEP flood modelling using the Fast and Detailed Models. The reviews demonstrate that the hydraulic modelling is commensurate with the rating curves from the Hydrologic Assessment, a key requirement to ensure the hydrologic and hydraulic modelling are consistent. They also provide useful insights to the validity or refinement of the rating curves under backwater effects and under extreme flows.

Conclusion

The BRCFS is the most comprehensive, up-to-date and accurate assessment of Brisbane River riverine flooding for AEPs ranging from 1 in 2 to 1 in 100,000. The latest available data was used to develop hydrologic and hydraulic models, and these models were validated by calibrating and verifying their results against well documented historical floods and tidal conditions. Industry leading techniques were used to derive AEP floods that take into account the complex effects on flood behaviour caused by variations in: rainfall and antecedent catchment conditions; Somerset and Wivenhoe Dam reservoir levels and operations; and ocean tidal conditions, along with the joint probability of occurrence of these variables.

The outcome is best practice hydrologic and hydraulic modelling that will provide key information and form a reliable basis for the BRCFMS and BRCSFMP and for the foreseeable future. Triggers that may initiate a review or rework of some components of the Hydrologic and/or Hydraulic Assessments are documented for future reference. For example, if Wivenhoe Dam is raised, this is likely to have a significant effect on Brisbane River flooding, thus necessitating a rework of affected components.

The nature of modelling is that there are sources of uncertainty and constraints of use, and these are documented in the technical reports. Of most importance, is that an accurate understanding and appreciation of the hydrologic and hydraulic processes, and of the modelling methodology and assumptions utilised, is essential to correctly interpreting and applying the outcomes of the BRCFS.

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Glossary and Explanation

1D	One dimensional
2D	Two dimensional
3D	Three dimensional
AEP	Annual Exceedance Probability
AEP ensemble	A collection of Monte Carlo events that together comprise an ensemble for a given Annual Exceedance Probability (AEP) in relation to peak flood levels.
AHD	Australian Height Datum
ARR	Australian Rainfall and Runoff
B15	**B**ase Case circa 20**15**
BCC	Brisbane City Council
BCC (CPO)	Brisbane City Council (City Projects Office)
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
Breaklines	Survey strings used to define continuous linear features
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
CEWG	Community and Engagement Working Group
CND	Calibration event with No Dams
CPO	City Projects Office
CPU	Central Processing Unit
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCS	BRCFS Data Collection Study (Aurecon, 2013)
DEA	Design Event Approach. A semi-probabilistic approach to establish flood levels, which only accounts for the variability of the rainfall intensity
DEM	Digital Elevation Model – a fixed grid of elevations sampled from a DTM
Delft-FEWS	Delft-FEWS is an open data handling platform developed by Deltares. The Monte Carlo framework for the BRCFS Hydrologic Assessment was implemented in Delft-FEWS
Design Flood	Hypothetical floods used for planning and floodplain management investigations. They may be comprised of a single design event or multiple events grouped into an ensemble. A design flood is defined by its probability of occurrence, for example the 1 in 100 Annual Exceedance Probability (AEP).
DILGP	Department of Infrastructure, Local Government and Planning DILGP (formerly the Department of State Development, Infrastructure and Planning, DSDIP)

DMT	Disaster Management Tool (BCC CPO, BCC 2014a and BCC 2014b)
DMT DEM	Digital Elevation Model developed and used in the Brisbane River Catchment Disaster Management Tool study (BCC CPO , BCC 2014a and BCC 2014b)
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 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.
Event (Flood)	Used (in the context of this study) to describe a flood occurrence. It can be a historical flood event, a design flood event or a Monte Carlo (MC) flood event.
FEWS	Flood Early Warning System
FF1	Floodplain Future Condition Scenario 1
FFA	Flood Frequency Analysis. A statistical analysis technique used to estimate the magnitude or frequency of flooding.
GIS	Geographic Information System
GSDM	Generalised Short Duration Method of extreme precipitation estimation for storms of less than 6 hour duration and catchments of less than 1,000 km^2. (BoM, 2003)
GTSMR	Revised Generalised Tropical Storm Method of extreme precipitation estimation for storms of tropical origin. Applicable to storm durations of up to 168 hours and catchments up to 150,000km^2 (BoM, 2003).
Hydraulic Assessment	BRCFS Comprehensive Hydraulic Assessment (BMT WBM, 2016)
Hydraulic Milestone Report	One of the technical milestone reports produce for the Hydraulic Assessment. These are numbered with corresponding titles, which are provided in Section 12 References.
Hydrologic Assessment	BRCFS Comprehensive Hydrologic Assessment (Aurecon, 2015)
Hydrologic Milestone Report	One of the technical milestone reports produce for the Hydrologic Assessment. These are numbered with corresponding titles, which are provided in Section 12 References.
ICC	Ipswich City Council
IFD	Intensity-Frequency-Duration
ITO	Invitation to Offer, i.e. the Hydrologic and Hydraulic Assessment Briefs (DSDIP, 2013 and DILGP, 2014 respectively)
IPE	Independent Panel of Experts
LiDAR	Light Detection and Ranging, an aerial ground survey technique
LOC	Loss of Communications dam operating procedure
LVRC	Lockyer Valley Regional Council
MC Event	Monte Carlo event – one of the event realisations applied in a MCS – also see definition of “event” above. Each event has a stochastic set of variables, with each variable (e.g. rainfall) having a random probability distribution or pattern.
MCS	Monte Carlo Simulation – application of the Monte Carlo (MC) method
PMF	Probable Maximum Flood (nominally the 1 in 100,000 AEP in the Hydraulic Assessment)
PMP	Probable Maximum Precipitation - the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends (CSIRO, 2000; EA 2003; WMO, 2009)
QC	Quality Control
QFCoI	Queensland Floods Commission of Inquiry (QFCoI, 2012)

QRA	Queensland Reconstruction Authority
SEQ	South-East Queensland
SPP	State Planning Policy
SRC	Somerset Regional Council
TWG	Technical Working Group
URBS	Unified River Basin Simulator. A rainfall runoff routing hydrologic model (Carroll, 2012a)
WSDOS	Wivenhoe and Somerset Dams Optimisation Study

1 Introduction

1.1 Background

The QFCoI Final Report (QFCOI, 2012) issued in March 2012, recommended that a flood study be undertaken of the Brisbane River catchment (Recommendation 2.2). The Brisbane River Catchment Flood Study (BRCFS) was commissioned by the Queensland Government, in response to Recommendation 2.2 and has the overarching objective of determining flood behaviour for floods of different probabilities.

Recommendation 2.12 of the QFCoI, sets out the need to develop comprehensive floodplain management plans. These will follow from, and be informed by, the BRCFS. The overall process will follow the flood risk management framework endorsed as current best practice in Australia[3] and incorporates the following steps:

- A Flood Study (this study) titled the **Brisbane River Catchment Flood Study (BRCFS)**.
- A Floodplain Management Study titled the **Brisbane River Catchment Floodplain Management Study (BRCFMS)** to evaluate flood risk based on the flood behaviour defined in the BRCFS and identify and assess a range of flood risk management options.
- A Strategic Floodplain Management Plan titled the **Brisbane River Catchment Strategic Floodplain Management Plan (BRCSFMP)** to select a range of flood risk management measures based on the regional floodplain management strategy from the BRCFMS to guide the current and future management of riverine flood risk below Wivenhoe Dam and modelled reaches of the Bremer River and Lockyer Creek.

In addition, the **Wivenhoe and Somerset Dams Optimisation Study** (WSDOS) (DEWS, 2014) was completed in 2014 in response to the QFCoI to investigate potential options to improve dam operations and flood mitigation, taking into consideration water supply security, dam safety and erosion. This study included comprehensive data collection and historical flood event calibration as reported in the report Brisbane River Flood Hydrology Models (Seqwater 2013).

This report is the Technical Summary Report of the BRCFS. The Department of Infrastructure, Local Government and Planning (DILGP) and the Department of Natural Resources and Mines (DNRM) as project manager, administered the study.

1.2 Objectives and Scope

The objective of the BRCFS *"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" "as the Queensland Government's response to the Recommendation 2.2 of the Queensland Floods Commission of Inquiry (QFCI) Final Report."* (DSDIP, 2013; DILGP, 2014).

Achieving the above objective requires:

- Development and application of state-of-the-art methods that produce consistent and robust calibrated hydrologic models and analytical techniques that provide best practice estimates of

[3] 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.

flood flows and volumes for a wide range of probabilities across the entire Brisbane River system.

- Development of a high resolution calibrated hydraulic model that accurately defines the flood behaviour of the Brisbane River below Wivenhoe Dam, including the major tributaries of Lockyer Creek and the Bremer River for a wide range of flood events from minor to major to extreme.
- Consistency between the hydrologic and hydraulic modelling. The hydrologic modelling simulates the rainfall-runoff process and the effect of dam storages and operations to produce flow hydrographs (discharge over time) for the hydraulic model. The hydraulic model uses these flow hydrographs to simulate the progression of a flood to produce flood levels, depths and velocities (water speeds) along the waterways and over the floodplains. For the hydrologic modelling to be commensurate with the hydraulic modelling, the stage-discharge relationship (i.e. a rating curve) at key locations where these two types of modelling overlap needs to be consistent.
- Leading edge and innovative statistical analyses to derive floods of different exceedance probability (the design floods) that take into account the substantial complexity and variability of Brisbane River catchment flooding, as these cannot be adequately evaluated using traditional industry approaches. In particular, the statistical analyses need to address variations in: spatial and temporal rainfall; antecedent (wet to dry) catchment conditions; initial Wivenhoe and Somerset lake levels (which affect flooding downstream and dam operations); and storm surge and tidal conditions.

While new data, advances in numerical techniques and continued improvements in computer hardware and software mean that hydrologic and hydraulic modelling are always evolving, the BRCFS encompasses: the latest proven and established innovation; and modelling that is validated to historical Brisbane River flood events. By taking this wide-ranging and thorough approach in scope, along with an exceptionally high level of technical review via the Technical Working Group (TWG) and Independent Panel of Experts (IPE), the BRCFS aims to produce the most comprehensive study feasible.

1.3 Study Overview

The BRCFS was completed in three separate phases. These were the:

- Phase 1: Data Collection Study (DCS)
- Phase 2A: Comprehensive Hydrologic Assessment
- Phase 2B: Comprehensive Hydraulic Assessment.

The Data Collection Study (Aurecon, 2013) was completed in August 2013 and identified, compiled and reviewed readily available data and metadata, including a gap analysis.

The Comprehensive Hydrologic Assessment (Aurecon, 2015) commenced in 2013 and was finalised in May 2015. It defines flood flows for the Brisbane River catchment based on Flood Frequency Analyses (FFA), the Design Event Approach (DEA) and a hydrologic modelling approach that caters for temporal and spatial variations in rainfall patterns, initial reservoir levels and other factors that affect catchment runoff using the (Monte Carlo Simulation (MCS) method.

The Comprehensive Hydraulic Assessment completed in February 2017 defines the flood behaviour of the Brisbane River below Wivenhoe Dam, and the lower sections of the major tributaries of Lockyer Creek and the Bremer River, for a wide range of flood events from small to extreme. The assessment establishes flood extents, depths, velocities and hydraulic hazard (a measure of the hazard of deep and/or fast flowing water) across the full extent of the floodplain for eleven statistical flood events ranging from the 1 in 2 to the 1 in 100,000 AEP (Annual Exceedance Probability).

In addition to the above phases the State Government, as part of the BRCFS, commissioned the Disaster Management Tool (DMT) Study (BCC, 2014a and 2014b) as an interim measure until the more comprehensive Hydrologic and Hydraulic Assessments were completed. The DMT study was carried out by Brisbane City Council City Projects Office (BCC CPO) to produce interim flood inundation maps for emergency planning. The DMT study also identified critical data gaps and led to the commission of hydrographic survey of the Lower Brisbane and Lower Bremer Rivers undertaken by the Port of Brisbane (PoB) (PoB, 2014).

The relationships between the components and the broader framework of the Brisbane River Catchment Floodplain Studies are shown in Figure 1-1. Figure 1-2 illustrates the Brisbane River catchment and the study area for outputs from the Hydraulic Assessment. The Hydrologic Assessment study area covers the entire Brisbane River catchment.

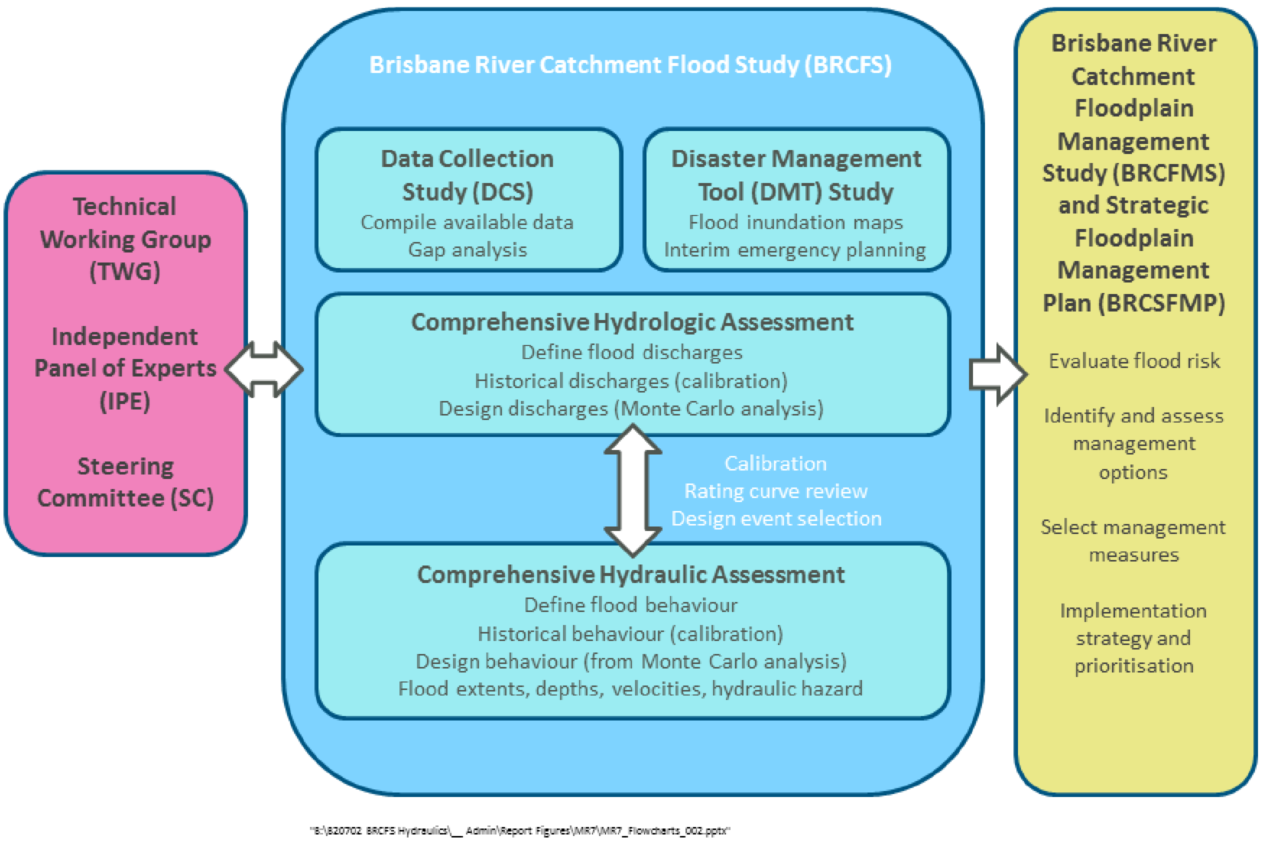


Figure 1-1 Brisbane River Catchment Flood Studies

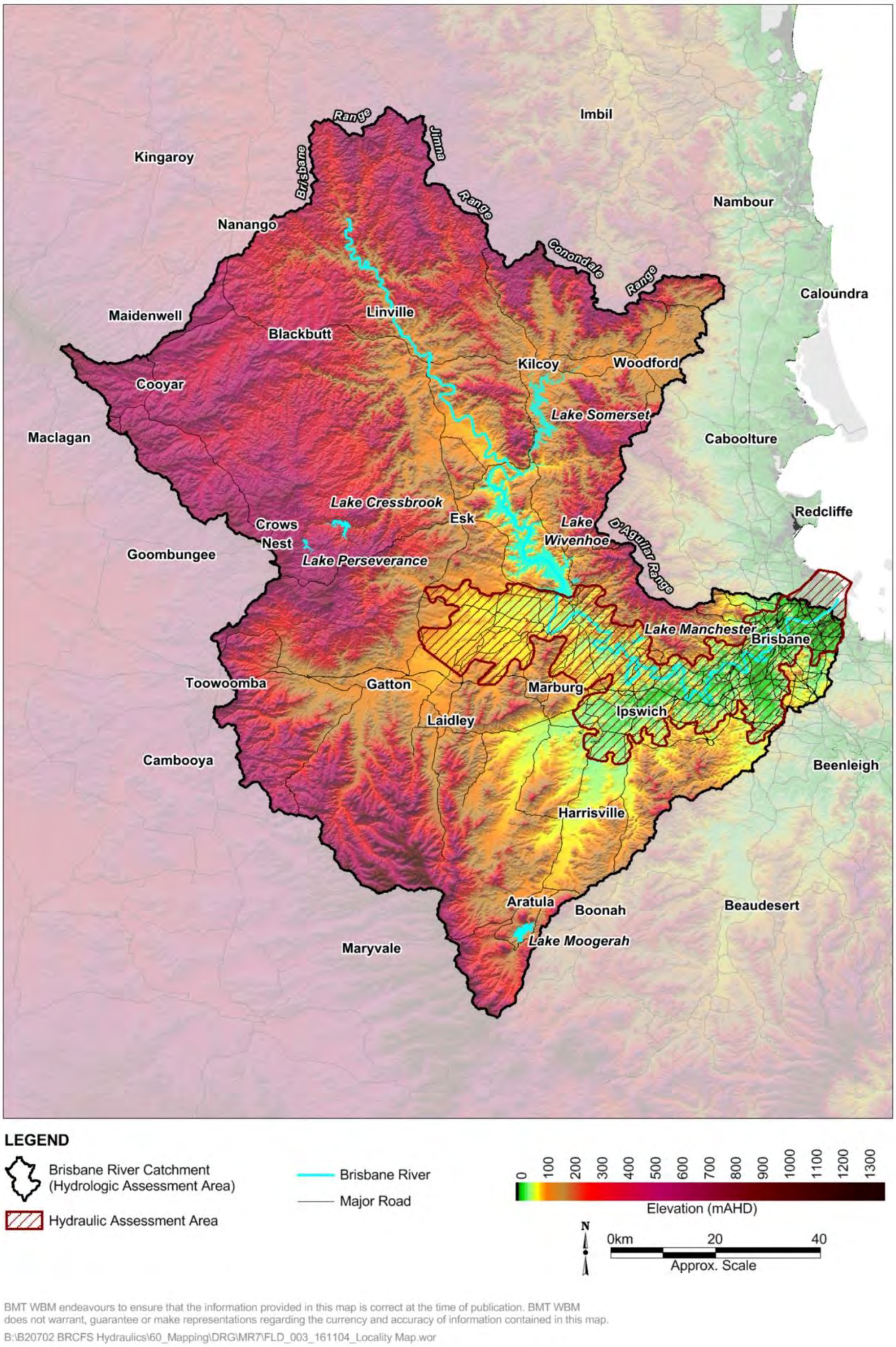


Figure 1-2 Brisbane River Catchment and Hydraulic Assessment Study Area

1.4 Report Structure

This document is a technical summary of the BRCFS Hydrologic and Hydraulic Assessments.

The remainder of this document is structured as follows:

- **Section 2** describes the Brisbane River catchment, its history of flooding, hydrologic and hydraulic modelling and previous studies.
- **Section 3** sets out the approach to the BRCFS with an overview of the Hydrologic Assessment and Hydraulic Assessments' tasks, and the interface between the two assessments.
- **Section 4** summarises key datasets used in the study and the various sources of these datasets.
- **Section 5** presents a summary of the Hydrologic Assessment including adopted methodologies, choice of methods, hydrologic modelling, model calibration and a summary of hydrologic modelling results.
- **Section 6** provides an overview of the Hydraulic Assessment including hydraulic model development, calibration and application of the hydraulic models, and application of the Monte Carlo method and the simulation of AEP ensembles.
- **Section 7** contains a summary of the hydraulic flood modelling results including design flood mapping. These results represent the primary end outputs of the BRCFS.
- **Section 8** describes how the hydraulic modelling has been used to test and quantify the change in flooding due to varying conditions. Scenarios tested include several climate change consequences, effect of river bed level deposition/excavation and with/without dams.
- **Section 9** sets out how the BRCFS has addressed the expectations of the Queensland Floods Commission of Inquiry.
- **Section 10** outlines high level limitations and constraints of the work carried out so that the outputs and outcomes are interpreted and applied within context.
- **Section 11** summarises the main conclusions of the study.

2 Brisbane River Catchment

2.1 Catchment Description

The Brisbane River catchment has a total area of approximately 13,500 km^2 upstream of the Brisbane CBD. 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 a mixture of urban development, rural land and natural forest. Flood mitigation dams, notably Wivenhoe and Somerset Dams, have a pronounced influence on flooding. In the lower reaches flooding is affected by tidal influences.

The river system consists of the Brisbane River with a range of small to large tributaries with Lockyer Creek and the Bremer River being the major tributaries downstream of Wivenhoe Dam.

The Brisbane River is tidal downstream of 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 the Brisbane River when in flood.

The Brisbane River itself has two major 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 completed in 1985 and has a catchment area of approximately 7,000 km^2. Somerset Dam is located upstream of Lake Wivenhoe on the Stanley River near Kilcoy, and has a catchment area of approximately 1,300 km^2. These dams regulate around half the overall Brisbane River catchment.

Figure 2-1 illustrates the seven main Brisbane River sub-catchments.

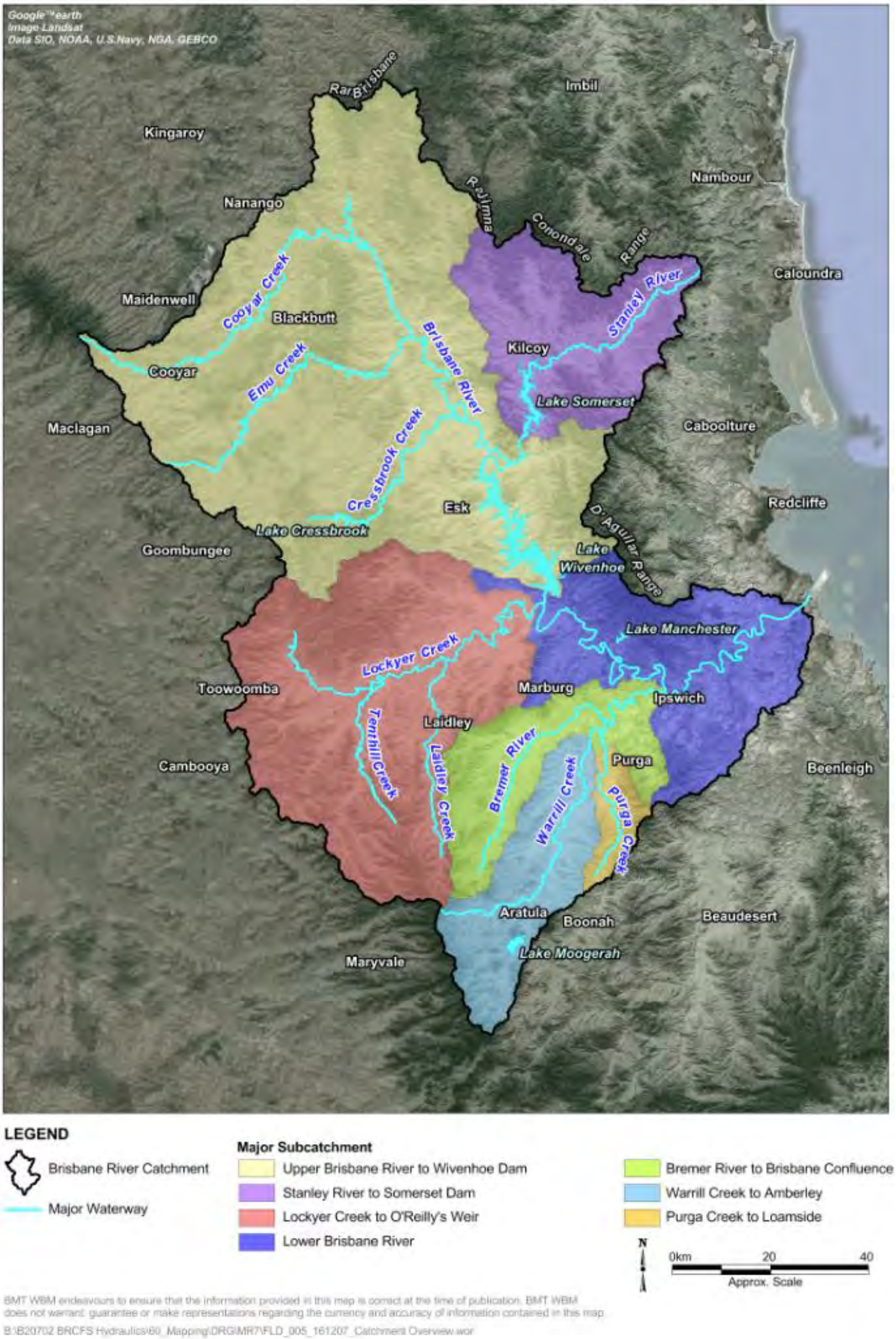


Figure 2-1 Brisbane River Sub-Catchments

2.2 History of Flooding

The Brisbane River has an extensive documented history of recorded floods since European settlement, with records 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 (anecdotal).

The largest floods recorded for the Brisbane River since official flood records began in 1841 have occurred in the 19th century, notably in 1841 and two major events in 1893. After the 1890s, the next largest floods were in 1974 and 2011. The 1841 and 1893 floods reached similar levels at the Brisbane CBD and remain the largest on record by a significant margin. Up until the mid-1950s the quantity and quality of recorded rainfall and flood level data is very limited.

The 1974 flood caused major flooding throughout the Brisbane River catchment. In response, and 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 1986, the dam has a substantial influence on flooding and can more than double its full supply level capacity to mitigate and alleviate flood flows that coincide with the uncontrolled flows from the Lockyer and Bremer tributaries downstream.

Following the construction of Wivenhoe Dam, minor to major floods have occurred on the Brisbane River with the most notable being in 1996, 1999, 2011 and 2013. Wivenhoe Dam played a significant role in reducing the flood peak and modifying the flood behaviour downstream in all these events.

The historical flood records show that floods can occur at any time of year. The summer season produces the highest frequency of floods often associated with cyclones, monsoon, and troughs. Significant floods have also occurred in autumn, winter and spring often associated with east coast lows. Records of rainfall patterns have also showed that floods have occurred with rainfall moving into the catchment from any direction. Some rainfall events producing flooding in South East Queensland have rain originating offshore from the east or north east (e.g. Jan 2011), over land from the west to east (e.g. Nov 2008), or down from the north (e.g. Jan 2013). The variability of the movement of the rainfall patterns is particularly important for the Brisbane River catchment as it produces variability in the relative timing of flood flows from different tributaries in the catchment. This means that the traditional approach of applying a uniform temporal pattern of rainfall over the entire catchment would not adequately represent the variability of potential flooding from rainfall events.

Due to the availability of good quality data, the flood events of 1974, 1996, 1999, 2011 and 2013 were used for calibration and verification of the hydrologic and hydraulic modelling.

An extensive summary of the flood history of the Brisbane River can be found on the Bureau of Meteorology website[4]. Note that the flood record presented does not take into account the flood mitigation effects of Somerset and Wivenhoe Dams, therefore, floods occurring prior to the

[4] http://www.bom.gov.au/qld/flood/fld_history/brisbane_history.shtml

construction of these dams would attain a different (lower) level today than that recorded. Other changes such as river/port dredging and catchment land-use would also affect flood levels.

2.3 Flooding Characteristics and Representation in Models

The Brisbane River catchment has a wide range of complexities that make it very interesting and challenging to hydrologically and hydraulically model. Approximately half of the total catchment area drains into Wivenhoe Dam, located on the Brisbane River, and the dam therefore has a significant influence on flooding. The catchment downstream of Wivenhoe Dam has three major branches, namely the main Brisbane River branch, and the major tributaries of Lockyer Creek and the Bremer River. The timing and magnitude of flood peaks in the three major branches is highly influential on the peak magnitude of flooding in the major urban centres of Ipswich and Brisbane.

The spatial and temporal variability of rainfall across the Brisbane River catchment can result in very different runoff responses within the catchment. It is extremely important to recognise this variability and to try to take into account the effects of storm movement when assessing the likelihood and magnitude of flooding within the catchment.

The Hydrologic Assessment covers the whole of the Brisbane River catchment and was able to draw upon work conducted by Seqwater (2013) which was undertaken for the Wivenhoe Somerset Dam Optimisation Study, (DEWS, 2014). Although there is significant overlap, the BRCFS hydrologic model has a different purpose and focus, including but not limited to:

- Increased emphasis on catchments downstream from Wivenhoe Dam
- Ability to model synthetic flood events much larger than those for which the Seqwater model was calibrated.

This required several amendments to the hydrologic model. Some challenging aspects of the refinement of the hydrologic model was to ensure that storage routing in the Lower Brisbane River was effectively represented as there were limited locations at which the model could be calibrated. There were also considerable difficulties in establishing consistent rating curves in the tidally affected reaches, due to the lack of high stage records. Re-calibration of the model to a number of flood events provides some confidence that the resultant model parameters are representative, but it is acknowledged that each event had a unique set of parameters that provided the best fit.

The Monte Carlo Framework is ideal at capturing the variability of the flood generating factors in the Brisbane River catchment through the establishment of the relevant statistical properties, including mutual correlations of each of the factors.

Hydraulic modelling commences below Wivenhoe Dam (see Figure 1-1) where the hydraulic characteristics of the Brisbane River valley are a mixture of conveyance and storage dominated reaches. A reach is conveyance dominated where there is little storage volume due to no, or relatively small, floodplains that can be inundated by flood water. These typically do not attenuate the flood. A storage dominated reach is where there are substantial floodplain areas that provide temporary storage for flood waters and attenuate the flood. The lower reaches of Lockyer Creek are a good example of a storage dominated system with its large flat and wide floodplains. The Brisbane River from Pine Mountain to Mt Crosby is predominantly conveyance dominated, with relatively minor floodplains, and floodwaters largely confined to an incised river valley.

Conveyance dominated reaches experience high velocities and steep gradients, while floodwater in storage dominated sections tends to be slower rising and typically exhibits lower velocities.

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. There are also relatively few floodplains to attenuate the flood peak. The hydraulic consequence is that substantially higher velocities driven by a steep flood gradient develop along the Brisbane River during a flood. In places, the Brisbane River banks are sometimes formed by rock and bends can literally be a sharp 180º (e.g. Kangaroo Point), with the entire flood flow often solely confined between the river banks with relatively little or no overbank flows. In large to extreme floods, overbank flowpaths can develop that change the flood behaviour from gentle backwater inundation to a short-circuit flowpath with fast flowing water that becomes a severe flood hazard.

The hydraulic modelling needs to account for all of these effects along with the interaction between flood and tide or storm tide surge in the lower tidal reaches. This is suited to the application of Monte Carlo approach (see Section 3.1).

2.4 Moreton Bay Storm Tide

Moreton Bay ocean tide levels and timing, and the probability of a storm surge occurring during a flood event, affect flooding characteristics in the lower tidal reaches of the Brisbane River. The effect is most pronounced near the mouth of the Brisbane River; progressively dissipating upstream. The effect of the tide decreases in larger flows. For example, in the smaller floods of 1996, 1999 and 2013 tidal effects were evident up as far as Centenary Bridge/Jindalee gauges, while in the 1974 and 2011 events the influence of the tide was slight at the Brisbane City Gauge and non-evident at the Oxley Creek gauge, which is well downstream of Jindalee.

Tidal and storm surge effects and propagation up the Brisbane River need to be considered and included in the hydraulic modelling to produce reliable flood levels for the lower reaches of the Brisbane River, and low lying areas of affected tributaries such as Norman, Breakfast and Bulimba Creeks.

2.5 Wivenhoe and Somerset Dams

Wivenhoe and Somerset dams were both built to supplement Brisbane's water supply and provide flood mitigation. Somerset Dam was completed in 1953 and is located upstream of Lake Wivenhoe on the Stanley River. Wivenhoe Dam was completed in 1985 and, with a catchment area of approximately 7,000 km^2 (including the Somerset Dam catchment), represents half of the overall Brisbane River catchment.

Wivenhoe Dam has a maximum combined water supply storage and floodwater storage to the level of the dam crest at 80.0 mAHD of 3,135,000 ML, of which 37% is allocated to water supply and 63% to flood mitigation. Somerset Dam's maximum combined water supply storage and floodwater storage to the level of the dam crest at 107.5 mAHD is 904,000 ML of which 379,000 ML (41%) is water supply storage and 524,000 ML (59% is flood water storage).

Wivenhoe and Somerset dams have a significant impact on flooding by their capacity to temporarily store flood water and regulate the outflow in small and moderate floods. In large to rare and extreme floods there is less regulation of the outflow such as when gates are fully open at Wivenhoe Dam and the fuse plug spillway may operate. For smaller floods the effect of the dams is greater than for larger to extreme events. In the 1996 flood event, the entire inflow to Somerset and Wivenhoe dams was captured such that there were no outflows from Wivenhoe Dam. The 1999 and 2013 floods also were greatly modified by the flood mitigation effects of the dams. The 2011 flood was also significantly changed, but due to the wet antecedent conditions and larger volume of water entering Lake Wivenhoe, a larger release of water was required than in any preceding flood since the dam was built. For more extreme events (greater than the floods of 1841, 1893, 1974 and 2011), the dams' ability to mitigate flooding will be further diminished due to the sheer quantity of water.

There are also a number of smaller dams located within the catchment on the tributaries to the Brisbane River that are used predominately for industrial, irrigation or town water supply. Four of these smaller dams are considered sufficiently influential to be included in the Hydrologic Assessment modelling. These dams were Perseverance Dam, Cressbrook Creek Dam, Lake Manchester and Moogerah Dam.

Figure 2-2 Wivenhoe Dam Spillway Releases (October 2010)

2.6 Previous Studies

A number of flood studies have previously been undertaken throughout the Brisbane River catchment with early studies typically undertaken following a significant flood e.g. 1893. Table 2-1 provides a summary of relatively recent (1977 onwards) major investigations of relevance to the Hydrologic and Hydraulic Assessments.

Table 2-1 Summary of Major Studies of Relevance

Year	Study	Description
1977	Report on the Hydrology of Wivenhoe Dam, Hausler and Porter, IWSC	Unit hydrographs and flood frequency techniques to assess design flood estimates for the dam design.
1978	Brisbane River Flood Frequency Studies. Hegerty, BCC	Flood frequency assessments of the likely impacts of Wivenhoe Dam.
1984	Wivenhoe Dam – Report on Downstream Flooding. Weeks, QWRC	WT42 runoff-routing modelling of the design floods of the Brisbane River catchment to the Port Office.
1985	Hydrology Report for Manual of Operational procedures for Flood Mitigation for Wivenhoe and Somerset Dam. Hegerty and Weeks. BCC and QWRC	WT42 runoff-routing and flood frequency techniques to estimate design floods for Wivenhoe Dam.
1991 to 1993	Brisbane River and Pine River Flood Study – various reports, DPI	Development and calibration of a WT42 hydrologic and Rubicon hydraulic model for the Brisbane River. The models formed the basis of many subsequent studies.
1998 to 2004	Brisbane River Flood Study, SKM	Hydrologic and hydraulic modelling for BCC. The hydraulic modelling also included the Bremer River and Oxley, Enoggera and Bulimba Creeks.
2000	Ipswich Rivers Flood Studies, Phases 1 and 2, SKM	The hydraulic model developed for the Brisbane River Flood Study (SKM, 1998) was refined and extended into urbanised areas of Ipswich City including numerous local 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 developed a TUFLOW 1D/2D hydraulic model extending from Pointings Bridge on Lockyer Creek to Savages Crossing on the Brisbane River.
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 lower sections of the Bremer River and Lockyer, Warrill and Purga Creeks.
2012	Lockyer Creek Flood Risk Management Study, SKM	The study included development and calibration of a TUFLOW 1D/2D hydraulic model from Murphys Creek to Brightview
2012	Queensland Floods	Instigated in response to the Jan 2011 flood event in the

Year	Study	Description
	Commission of Inquiry (QFCOI)	Brisbane River catchment. It contains a recommendation (Recommendation 2.2) that required a flood study be undertaken of the Brisbane River catchment.
2013	Wivenhoe and Somerset Dam Optimisation Study	Undertaken by DEWS/Seqwater in response to QFCoI recommendations (mainly Recommendation 17.3) to assess and present various options for operating the Wivenhoe and Somerset Dams, enabling the government to make informed decisions on their future operation. This study included comprehensive data collection and historical flood event calibration as reported in the report Brisbane River Flood Hydrology Models (Seqwater 2013b).
2013	Brisbane River Flood Hydrology, Seqwater	Development and calibration of URBS models of entire Brisbane River Catchment for WSDOS.
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 and ICC Local Creek Models (various)	Hydrologic and hydraulic models have been developed for local BCC and ICC creeks.

3 Study Approach

3.1 Overview

"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" to be carried out in response to Recommendation 2.2 of the Queensland Floods Commission of Inquiry (QFCoI) Final Report (QFCOI, 2012). To meet this objective, the study approaches for the Hydrologic and Hydraulic Assessments were prepared and documented in their respective ITOs (DSDIP, 2013 and DILGP, 2014).

For both assessments, there was a necessity to carry out tasks using leading-edge technologies and to develop and construct innovative outcomes. To ensure the implementation of these technical and innovative challenges was achieved, the workflow was reviewed and guided by the Technical Working Group (TWG) and an Independent Panel of Experts (IPE) and overseen by a Steering Committee. Most members were involved for the full duration of the BRCFS and the groups are listed in Appendix B. The current governance for the Flood Study phase is provided in Figure 3-1. Also of importance was that the Hydrologic and Hydraulic Assessments interfaced closely so that the overlapping technical challenges and rigor of the two assessments were aligned.

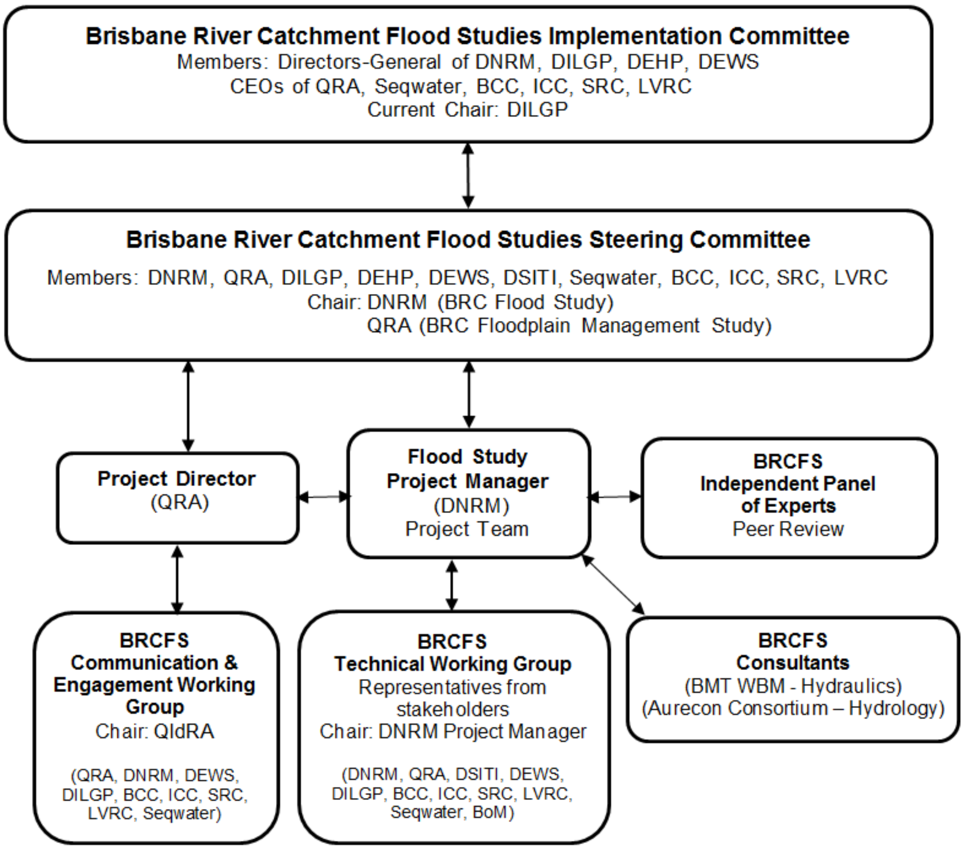


Figure 3-1 Current Governance for BRCFS (DNRM, 2016)

At the core of both the Hydrologic and Hydraulic Assessments is the use of the Monte Carlo Simulations (MCS) method. The Monte Carlo concept is used for calculating probabilities of “something” occurring (e.g. a flood), when there are uncertainties and/or variability in the variables that combine to produce that “something”. For flooding, it is applied by generating thousands of synthetic floods based upon random sampling of variables, such as rainfall, dryness of the catchment and dam reservoir levels. From this database of synthetic floods a probabilistic analysis can be carried out to determine the AEP of a flood.

The MCS method as applied to the BRCFS uses probability distributions of variables (unknowns) to generate a large number of unique flood events with different combinations of contributing factors such as rainfall patterns, losses and initial dam levels from which, for example, the 1 in 100 AEP flood flows and levels can be derived. MCS is particularly useful in flood modelling where variable combinations of contributing factors to flood magnitude are not readily represented in traditional approaches, as is the case for the Brisbane River catchment.

By using the MCS approach, allowance was made for variations in: spatial and temporal rainfall; antecedent (wet to dry) catchment conditions; initial Wivenhoe and Somerset lake levels (which affect flooding downstream and dam operations); and storm surge and tidal conditions. Historically, the challenge in using MCS methods is that they have much greater computational demands and are laborious to implement. However, with the advent of faster computers and improved MCS statistical methods, along with innovative approaches implemented during the Hydrologic and Hydraulic Assessments, a MCS approach to the complex and challenging Brisbane River catchment was achieved.

Figure 3-2 presents a simplified overall flowchart of the key modelling steps in the hydrologic and hydraulic phases. Key processes are further explained in the appropriate sections of this report.

3.2 Hydrologic Assessment

The purpose of the Hydrologic Assessment is to develop and apply state of the art methods that produce consistent and robust hydrologic models and analytical techniques that provide best estimates of a range of flood flows and flood volumes for annual exceedance probabilities (AEP) across the entire Brisbane River system.

The study has produced a number of tools including consolidated stream flow rating curves, a comprehensive set of calibrated hydrologic models of the entire Brisbane River Catchment, a dam operations model of the flood mitigation dams and a Monte Carlo Simulation (MCS) framework for estimating stochastic design flood estimates.

A reconciliation process has been adopted to assimilate the estimates of peak flows and flood volumes for the different assessment methods (DEA, FFA, MCS) for the various locations nominated for investigation. This process has endeavoured to make use of the strengths of each of the assessment techniques and the best use of the available data/information to produce consistent and robust estimates across the entire flood frequency range.

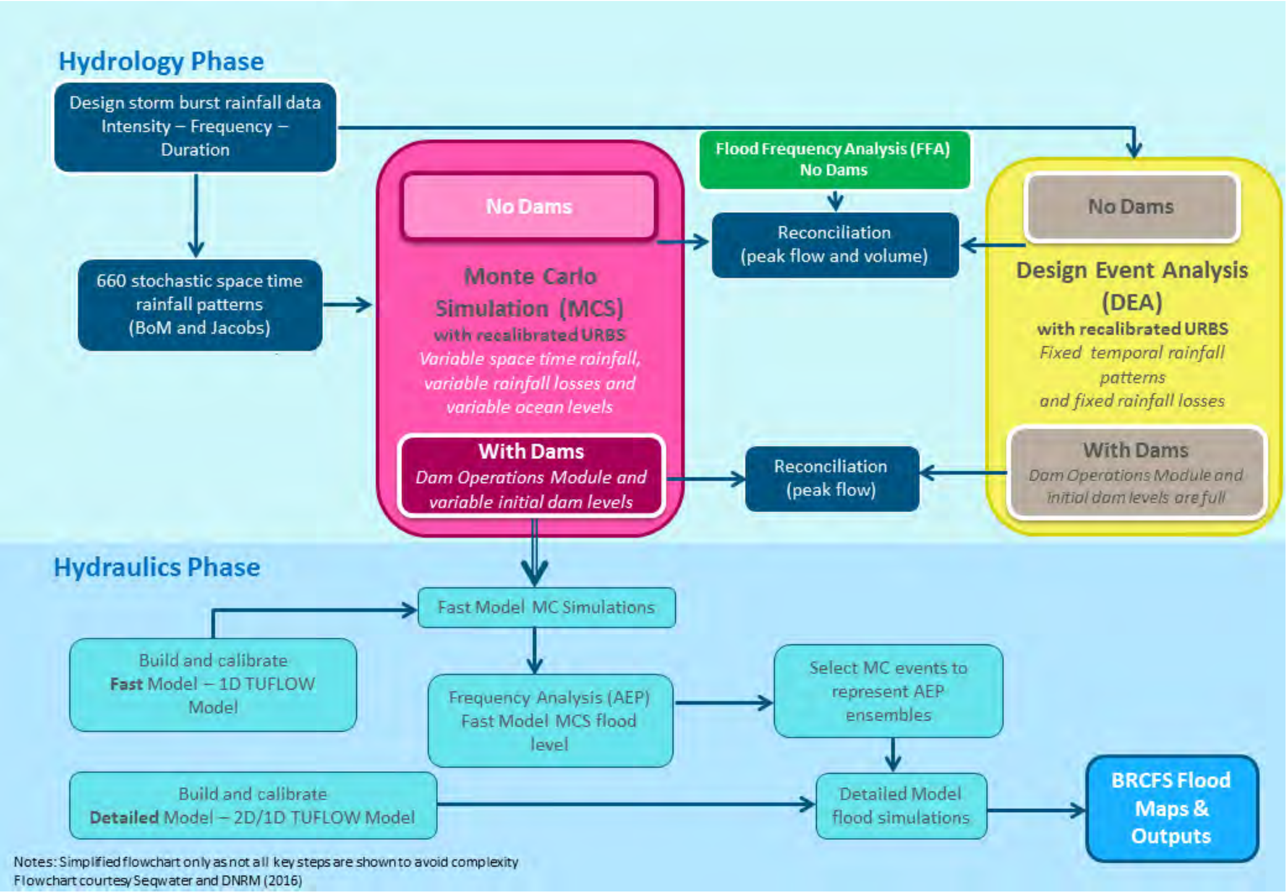


Figure 3-2 BRCFS Key Modelling Steps in Hydrologic and Hydraulic Assessments

The resultant Monte-Carlo Simulation framework is considered to have advantages over more “traditional” approaches in flood risk analysis in that it explicitly considers variability of significant factors that contribute to the magnitude of flood events. A practical disadvantage is that it is generally more complex to implement, but this has been addressed by constructing the MCS framework in the Delft-FEWS environment that enables efficient data management, manipulation and visualisation.

3.3 Consistency between Hydrologic/Hydraulic Assessments

As the Hydrologic and Hydraulic Assessments were carried out as separate undertakings, a joint development and calibration of the hydrologic and hydraulic modelling was not feasible. Therefore, to check and demonstrate consistency between the hydrologic and hydraulic modelling, flow versus water level (the stage-discharge relationship) output from the hydraulic models was compared with the rating curves derived and adopted by the hydrologic modelling at key locations. Should an unacceptable mismatch between the rating curves used by the hydrologic modelling and the stage-discharge output from the hydraulic modelling have occurred, the need to revise and fine-tune the hydrologic modelling would have been triggered, followed by a fine-tuning of the hydraulic modelling. Therefore, 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.

3.4 Hydraulic Assessment

The Hydraulic Assessment *"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 BRCSFMP)"* (Hydraulic ITO (DILGP, 2014), Section 3.1.3). This was achieved using the approach discussed below.

Good quality data was sourced for the Hydraulic Assessment via the DCS (Aurecon, 2013) and DMT Study by BCC CPO (BCC 2014a, BCC 2014b). Data was also collected during the assessment if gaps became apparent. These data included: LiDAR, bathymetric and road/rail/embankment surveys; recorded hydrometric data for model calibration/verification; land use data; bridge/culvert structure details; urban drainage infrastructure; and incorporated future developments. The latest and most up-to-date data sets were utilised for the design flood simulations.

Two hydraulic models using the TUFLOW software were developed and calibrated: the Fast Model and the Detailed Model. The Fast Model is used to screen the large set of Monte Carlo Simulation outputs to a more manageable set of representative events to be run through the Detailed Model. The Fast Model, as the name implies, required a target run time of 15 minutes or less per simulation, so as to simulate in the order of 500 statistically generated MC flood events. From the large number of MC flood simulations using the Fast Model a statistical analysis at 28 locations (referred to as the Reporting Locations) along the main waterways was carried out to derive AEP peak flood level estimates. During the course of the Hydraulic Assessment it because feasible to increase the number of MC events for simulation in the Fast Model from 500 to 11,340 (see Section 6.4.2). This substantially improved the robustness of the AEP peak flood level estimates.

As the Detailed Model has much longer run times it is not practical to simulate all 11,340 MC events. Therefore, a sub-set of 60 MC events was selected to form 11 AEP ensembles ranging from the 1 in 2 AEP to the 1 in 100,000 AEP flood. These ensembles were selected to match the AEP flood levels at the Reporting Locations and then enable mapping of AEP flood levels across the floodplain to include areas between the reporting locations.

The Detailed Model is a 1D/2D hydraulic model that has a significantly higher resolution and much better accuracy over the floodplains than the Fast Model. Its prime purpose is for producing flood maps and 3D surfaces of flood levels, depths, velocities and hazard. The Detailed Model is the most comprehensive and complex hydraulic model developed for the Brisbane River catchment.

The Fast and Detailed Models were calibrated and verified to five historical events of 1974, 1996, 1999, 2011 and 2013, and to tidal conditions. This validation of the hydraulic models using industry standard parameters is critical to demonstrating the models' authenticity and robustness.

The 60 MC events that make up the 11 AEP ensembles were simulated through the Detailed Model, and the peak hydraulic outputs for each AEP ensemble were generated. The hydraulic results produced were peak flood level, depth, velocity and hydraulic hazard (DxV or depth multiplied by velocity), and were presented in the form of maps, tables and a variety of charts.

Sensitivity test scenarios were simulated using the Detailed Model to estimate indicative changes to flooding from: (a) 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.

4 Data Collection and Collation

A data collection and collation exercise was undertaken to inform the study and hydrologic and hydraulic model development. This section summarises the key categories of source data utilised in the study. Some of the datasets within these categories are not used directly by the models but have been used to inform model design and therefore remain a key dataset for the purposes of the study.

4.1 Rainfall

Historical rainfall data in the form of daily rainfall and pluviograph records is required for the calibration of the hydrologic model and as input into the MCS analysis. This information was sourced from the Bureau of Meteorology (BoM) and also from Seqwater (Seqwater, 2013). Data received from BoM and Seqwater were of varied quality. However the Seqwater data was already processed into 48 flood events and was of most use for the assessment.

Intensity-frequency-duration (IFD) data is required for input to the Design Event Approach (DEA) and Monte Carlo Simulation (MCS) analyses. This data is available for two separate IFD datasets: that produced for the 1987 version of Australian Rainfall and Runoff (ARR), (Engineers Australia, 1987); and that produced in 2013 for the current update of ARR (BoM, 2013). On the recommendation of the IPE, the 2013 IFD data set was adopted for the purpose of this study. This data covers the range of design rainfalls from 1 in 2 AEP to 1 in 100 AEP.

The BoM released its final update of IFD data for ARR (BoM, 2016) in November 2016 for the 1 in 2 to 1 in 100 AEP rainfall events. The IFD data for the 1 in 200 to 1 in 2000 AEP rainfall events is scheduled to be released in about February 2017.

For the large to rare flood magnitude range, CRC-Forge (Hargraves, 2005) design rainfall estimates were used. This covers the range of rainfall estimates up to the 1 in 2,000 AEP, the limit of credible extrapolation. For extreme rainfall estimates (Probable Maximum Precipitation), the generalised techniques described by the GSDM and GTSMR (BoM, 2003) were adopted. The techniques specified in Book VI of ARR (Engineers Australia, 2003), have been used to interpolate design rainfall estimates between the 1 in 2,000 AEP and the Probable Maximum Precipitation (PMP).

Temporal patterns for the DEA were obtained from ARR (Engineers Australia, 1987) for the North-East Coast Zone and also from the GTSMR and GSDM extreme rainfall estimation guidebooks. For the MCS, temporal and spatial rainfall patterns were obtained from stochastically generated space-time patterns developed by the BoM and Jacobs (2013) for Seqwater.

4.2 Historical Flood Records

4.2.1 Stream Gauges

Up-to-date continuous gauge recordings for DNRM gauges were collected from the DNRM website. Limited continuous gauge recordings were collected from BoM. This information is required for determining peak flow and volumetric flood frequency analyses and is used in the re-calibration of the hydrologic model and calibration of the hydraulic models.

4.2.2 Flood Marks

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. The 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.

4.2.3 Flow Gaugings 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.

4.2.4 Flood Extents

Information on historical flood extents has been sourced for the major flood events of 1974 and 2011. This has been obtained from a variety of sources including the Queensland Government Information Service and direct from local Councils. Some aerial imagery was available which was captured during the flood events (see Figure 4-1). Extents and imagery were used to inform the hydraulic model calibration.

Figure 4-1 Aerial Imagery of the 2011 Flood at Suncorp Stadium

4.2.5 Anecdotal Information

Anecdotal information was obtained during the course of the study from TWG members and assisted in resolving unknowns in historical event behaviour, historical data and related consequences. Examples that were utilised to assist in model development and calibration include:

- 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 downstream of Savages crossing was particularly affected. The TWG noted that the impacts of this damage resulted in a general drop in water levels at Mt Crosby and Savages Crossing. This was confirmed with further TWG anecdotal recollections of large deposits of sediment at Savages Crossing following the 2011 flood event.
- Historical changes in bathymetry in the Bremer River were noted anecdotally by the TWG. It is believed that Bremer River around Ipswich has become significantly shallower since dredging ceased around 1996 and bank collapses have occurred. Without historical bathymetric survey

information it is not possible to confirm this advice or subsequent assumptions although this type of anecdotal evidence is useful when assessing model calibration results.

- Surveyed 2011 flood marks at Fernvale that were used during model calibration were found to be approximated by surveyors, rather than accurately recorded. This was brought to light following difficulty with model calibration in that area and subsequent discussions with Council staff.

4.3 Topographic Data

4.3.1 LiDAR Data

As part of the Digital Terrain Model and Bed Level Sensitivity Analysis (BLSA) project (BCC CPO, 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). Figure 4-2 presents an image of the DEM for the Inner Brisbane area.

During the course of the study more recent topographic data across the floodplain became available. This consisted of LiDAR data across the Brisbane and Ipswich LGA areas, which was captured in 2014 by DNRM. Sensitivity testing of the 2014 DNRM LiDAR for the calibration events showed only minor differences in peak flood level (typically less than ±0.03m). The 2014 DNRM LiDAR was incorporated into the Base Case for design modelling as it represents the most up to date, detailed and spatially extensive terrain dataset available.

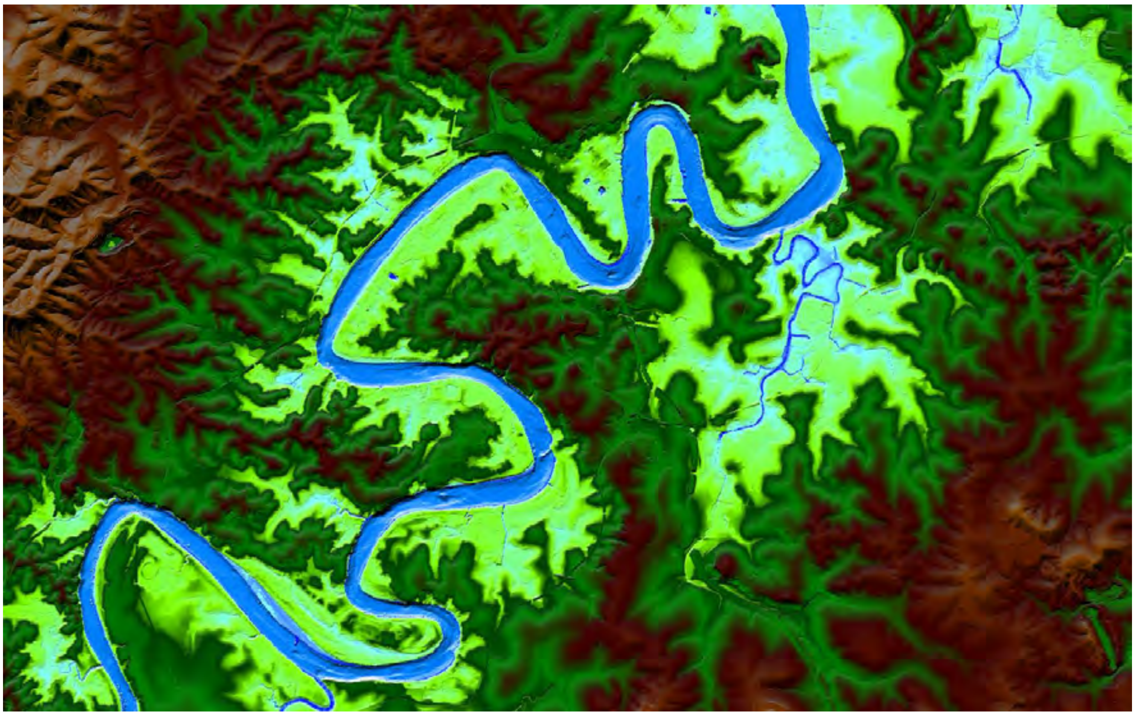


Figure 4-2 Terrain Data: Inner Brisbane

4.3.2 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.

Breaklines have been derived and classed into 'Road, Rail, Ridges and Gullies. These are applied in the hydraulic models to improve the representation of the modelled terrain.

4.3.3 Bathymetric Data

Bathymetric data defines the shape of the ground surface below water. Prior to the BRCFS Hydraulic Assessment, the BLSA project BCC (2014a) identified data accuracy concerns and data gaps, primarily concerning bathymetry. In preparation for the hydraulic modelling undertaken for the BRCFS, high resolution bathymetric survey of the Bremer and Brisbane lower river reaches, as recommended in BCC (2014a), was acquired by the Port of Brisbane (PoB, 2014) and used in the hydraulic modelling in conjunction with the DMT DEM and the 2014 DNRM LiDAR. Where bathymetric data was not available (either as specific datasets or as part of the DMT DEM) breaklines or bed elevations as shown by LiDAR data have been relied upon. This is typically in areas where the normal water depth is shallow and LiDAR has been able to capture the majority of the channel. Figure 4-3 illustrates the improvement of the DEM using bathymetric survey data.

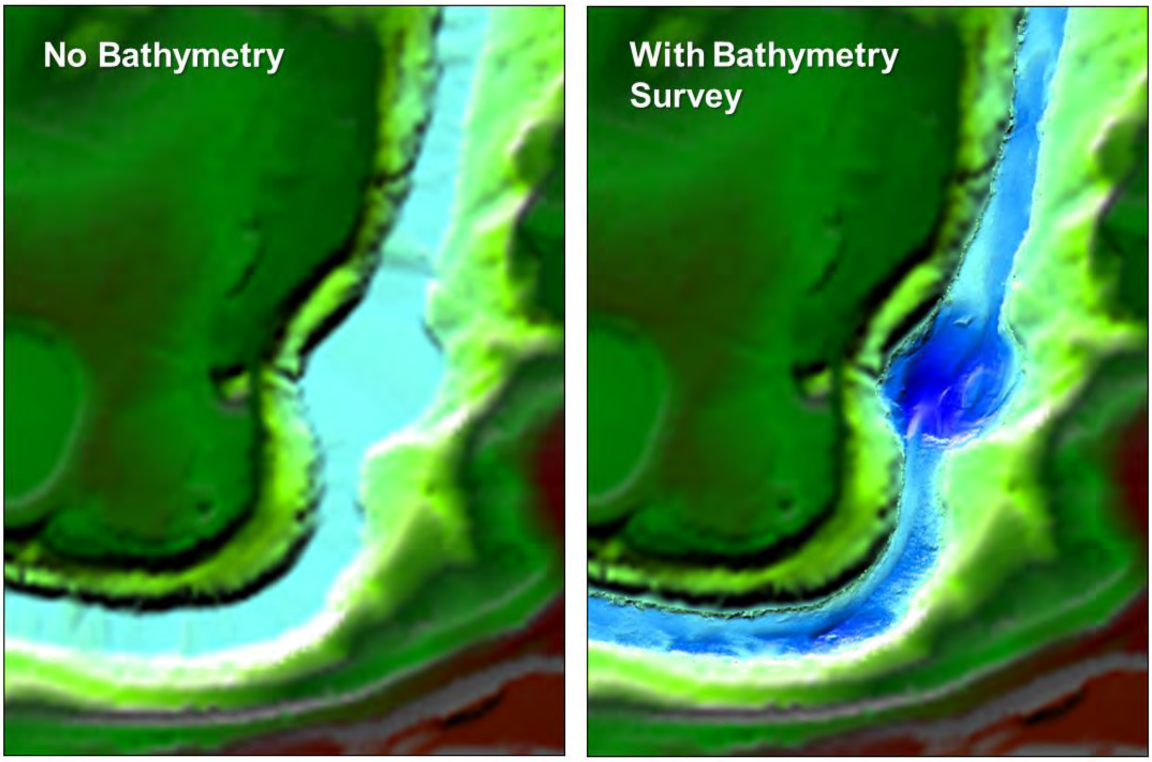


Figure 4-3 Bathymetric Updates: Bremer River in Ipswich

4.4 Hydraulic Structures

Structures such as bridges, weirs and culverts were included in the hydraulic models 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. This includes stormwater pipes in the inner Brisbane area which have the potential to convey backflow from the river into low lying areas behind the river banks. Structures were removed from the model for calibration flood events that occurred before the structure was built.

Data for structures were sourced from various agencies and supplemented with information gathered from site visits (Figure 4-4). Main river structure details, including relevant hydraulic model output are contained within Hydraulic Structure Reference Sheets (HSRS) which are a key output from the study. As shown in the example HSRS provided in Figure 4-5, these sheets include relevant information on the location and dimensions of the structure, hydraulic model performance and indications for potential blockage of the structure.

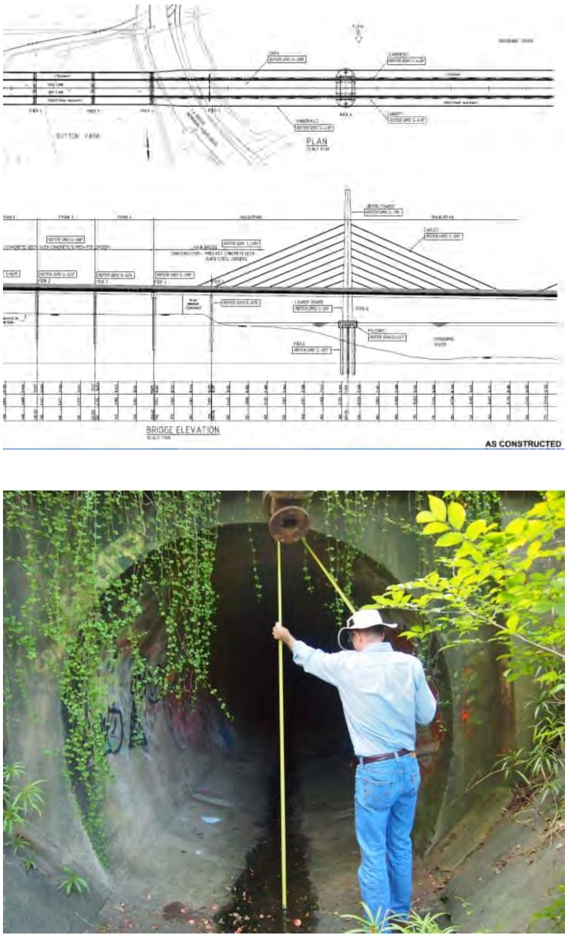


Figure 4-4 Structure Data Collection from Design Drawings (above) and Field Investigations (below)

Story Bridge (BCC_006) Structure

Structure Name	Story Bridge		
Structure ID	BCC_006		
Owner	TMR	**Waterway**	Brisbane River
Date of Construction	1940	**AMTD**	21740
Date of significant modification	-	**Co-ordinates (GDA 56)**	503498.12E 6962171.33N
Source of Structure Information	Hydraulic Structure Reference Sheet (SKM 1999) Structural Design Drawings (1938)		
Link to data source	B:\B20702 BRCFS Hydraulics\10_Data Management\10_03_Structures\Structure_Details\BRI\BCC_006 Storey Bridge\		

Description	Suspension Bridge, Steel truss superstructure		
BRIDGES		**CULVERTS**	
Lowest Point of Deck Soffit	29.8mAHD	**Number of Barrels**	-
Number of Piers in Waterway	2	**Dimensions**	-
Pier Width	9.6m	**Length**	-
		Upstream invert	-
		Downstream Invert	-
Lowest point of Deck/Embankment	33.5mAHD		
Rail height	1.1*m		
Span Length	82-281m		

*estimated

Included in Fast Model (FM)	Yes	**FM Representation**	HW and LC table
Included in Detailed Model (DM)	Yes	**DM Representation**	2D Layered Flow Constriction

Image Description	Story Bridge, looking upstream
Image Reference	Macey, C.R. (2007). *Story Bridge* [digital photography]. Retrieved from below source
Image Source	http://de.wikipedia.org/wiki/Story_Bridge#mediaviewer/File:Story_Bridge_Panorama.jpg

Figure 4-5 Structure Data Summarised in Hydraulic Structure Reference Sheets

4.5 Land Use Data

Spatial land use data is used to assist in determining impervious areas for hydrologic modelling and for attributing surface roughness values in hydraulic modelling. For the purposes of the hydraulic modelling for current conditions, land use extents available from existing datasets were updated by manual digitisation using aerial photographs to improve land use categorisation, particularly in areas adjacent to major waterways. An example of the refined land use delineation following the manual digitisation process is provided in Figure 4-6.

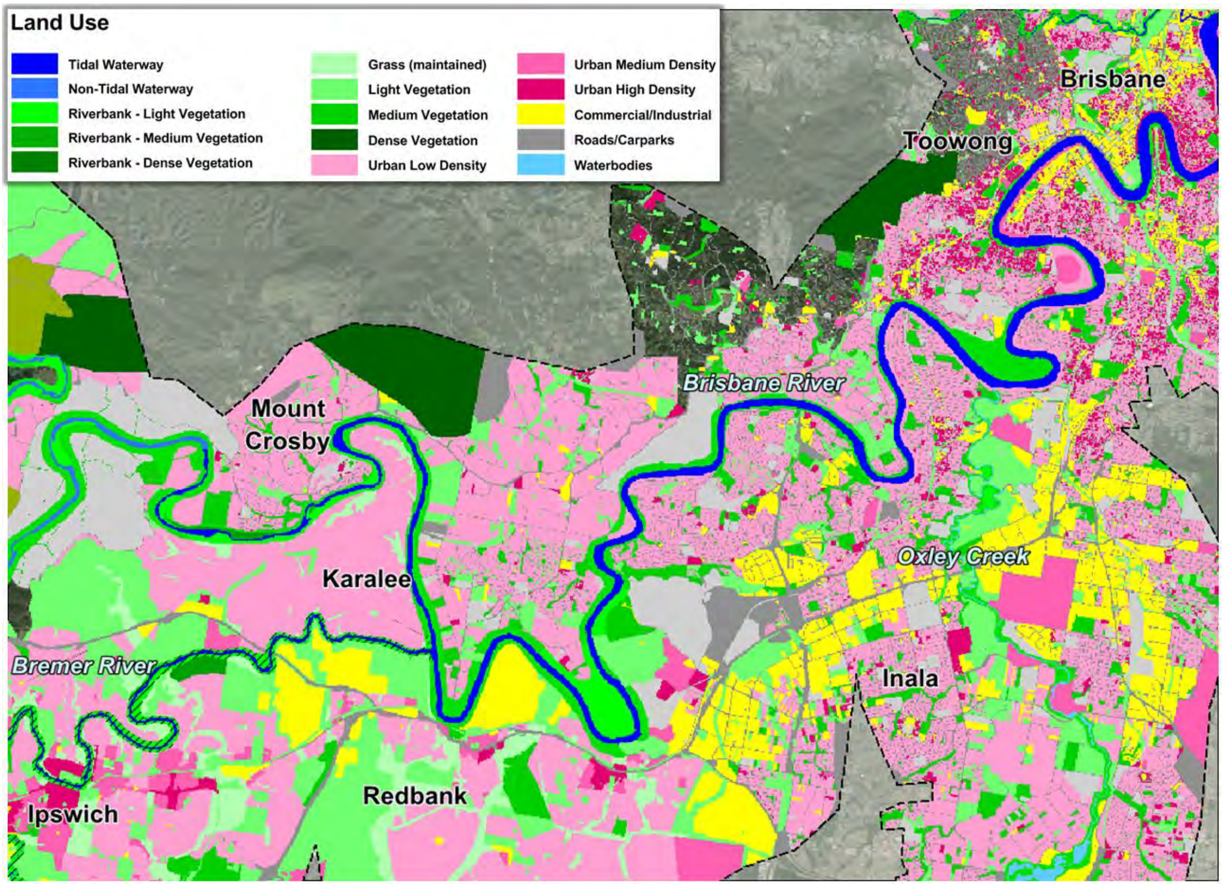


Figure 4-6 Example of the Detailed Spatial Differentiation of Land Uses

4.6 Tidal Data

Predicted series of tide levels for the mouth of the Brisbane River were obtained from the BoM publication of standard astronomical tide data, which is available on the BoM website. Estimates of the storm surge were obtained from the Coastal Plan Implementation Study (Draft) carried out for Brisbane City Council by GHD (GHD, 2014). As part of the Hydrologic Assessment, The storm surge estimates were combined with an astronomical tide series taken from a monthly series of 'average' tidal conditions. Multiple time series of combined tide and surge were generated in this way with different combinations of peak ocean water level and timings of the peak of the surge with the tide.

5 Hydrologic Assessment

5.1 Introduction

The primary objective of the Hydrologic Assessment is to develop and apply analytical techniques, including calibrating reliable hydrologic models and to provide:

- Best estimates and indications of uncertainty in peak flow and flood volume estimates at Hydrologic Assessment Reporting Locations throughout the Brisbane River catchment; and
- Sets of hydrographs generated by MCS at input locations to the hydraulic models.

Three independent assessment techniques are used to estimate peak discharges and flow volumes for a range of Annual Exceedance Probabilities (AEP):

(1) Flood Frequency Analysis (FFA)

(2) Design Event Approach (DEA)

(3) Monte Carlo Simulation (MCS).

The DEA and MCS methods are both referred to as ‘rainfall based methods’, as they both rely on rainfall statistics in combination with a rainfall-runoff model to compute peak flows and flow volumes at locations of interest. With the FFA method, peak flows and flow volumes for given AEPs are derived directly from observed flows.

A reconciliation process has been adopted to assimilate the estimates of peak flows and flood volumes for the different assessment methods for the various locations nominated for investigation. This process has endeavoured to make use of the strengths of each of the assessment techniques and the best use of the available data/information to produce consistent and robust estimates across the entire flood frequency range.

5.2 Rating Curve Review

Understanding the relationship between water level and flow at gauge stations and the derivation of accurate discharge rating curves is a fundamental step to developing a robust catchment hydrologic assessment. Accurate high flow rating curves provide the basis for site specific flood frequency and historic event flow estimation.

The Brisbane River catchment contains over 70 currently active flood level gauges as well as numerous other gauges that have operated historically. The gauges are operated by different stakeholders (DNRM, Seqwater and BoM) and provide records that are of varying quality, reliability and usefulness to the BRCFS. The objectives of the rating curve review were therefore to:

- Identify key stream gauges that are of use to the BRCFS.
- Identify and improve if possible the level of confidence in the at-site gauge rating.
- Ensure catchment-wide consistency between the gauges.

5.2.1 Rating curve review process

The initial task of the rating curve review process was to compile and review available data at each of the major gauges within the catchment and to classify the flood gauges according to their proposed priority of usage. The gauges were assessed in terms of: singularity of control (having a direct and consistent relationship between gauge level and stream flow); the significance of the gauge to the hydrologic modelling; the availability and reliability of calibration data at the site; and the length and quality of flood record at the site. Using these criteria, gauges were classed as either primary or secondary, with the method and detail of analysis applied to each classification discussed below.

Gauge rating curves form the link between recorded flood levels and discharge at the gauge. The data used to develop these ratings can be obtained by a variety of methods, including:

- Flow gauging – An estimate of discharge obtained from physically measured flow properties corresponding to measured water levels. Flow measurements may be obtained by a number of different methods, but are typically based on measured flow velocity and cross-section area. Accuracy of the flow estimate can therefore vary significantly depending on the data capture method. Nevertheless, flow gauging is the only method that provides simultaneous flow and level measurement, and is thus independent of numerical modelling. Except in rare circumstances, flow gauging data is typically only available for low to mid-range flows.
- Reverse reservoir routing – The Brisbane River catchment contains several reservoirs, of which six have been considered by Seqwater to have an influence on flood behaviour. These include the major Wivenhoe and Somerset Dams and the smaller Moogerah, Cressbrook Creek, Lake Manchester and Perseverance Dams. These reservoirs generally have well-defined relationships between reservoir level, volume and outflow from which inflows into the reservoir can be estimated by back analysis of the continuity equation.
- Hydraulic modelling – Hydraulic models calculate water level for a known discharge. The reliability is dependent on how well the numerical model can represent the actual physical flow conditions. Confidence in the hydraulic model predictions can be improved by calibrating the model to flow gauging or other data.
- Hydrologic modelling – Hydrologic models estimate discharge based on recorded rainfall data that can then be matched to recorded stream levels. Results of the hydrologic model are influenced by multiple factors, which include the model parameters, assumed losses and rainfall data that may vary significantly across the catchment and not be captured reliably by the rainfall gauges. Additionally, because this method is wholly dependent on the output of the hydrologic model, using rating curves derived in this manner to calibrate the hydrologic model can lead to a circular reasoning, and must therefore be treated with caution. Nevertheless, hydrologic modelling can be used to evaluate consistency between gauges within a catchment, and greater confidence can be placed if the catchment model can be well calibrated to a nearby reliable gauge. Hydrologic modelling is particularly useful to evaluate consistency between upstream and downstream gauges. As with the hydraulic model, the results can be calibrated to flow gauging data and used to extrapolate the rating to higher discharges, however this extrapolation is based on the catchment-wide properties and empirical formulations inherent in

the hydrologic model rather than the more realistic and specific local site conditions of a hydraulic model.

- Correlation of gauge data – Provided that the additional contributing catchment between the gauges is small, gauges in close proximity can be correlated to allow flows from a well-documented site to be translated to a less data rich site, or to potentially identify discrepancies or outliers in the data.

The methods above are listed in order of perceived reliability, and thus the order of priority used when determining or reviewing reliability of the gauge ratings. It should be noted that no one method is considered completely reliable, and that the highest confidence can only be reached by comparison of and achieving consistency between all the available data.

5.2.2 Selection and treatment of Brisbane River gauge ratings

Primary gauges were considered to be of high importance for the hydrologic modelling. Eight gauges were given this classification as listed in Table 5-1, including at least one gauge in each of the seven catchments to provide a reliable control for the URBS model calibration. In addition to the review of existing data and ratings, a detailed hydraulic assessment of the rating curve was conducted for the primary gauges. With the exception of the lower Brisbane River gauges downstream of Wivenhoe Dam, this entailed development of an independent two-dimensional hydraulic model of the gauge site. Where recorded stream gauge level and flow measurement were available, the hydraulic models were calibrated to match this data and then used to extend the rating curve to levels/flows in excess of the largest observed flood at the site.

Secondary gauges were considered to be those for which a reliable rating curve is desirable, but not essential for the hydrologic model calibration, or limited by availability of data or other factors adversely affecting development of a reliable rating. Preliminary analysis of secondary gauge ratings was initially limited to review of existing data, including flow gauging data, gauge ratings, and hydrologic model results. This data was assessed to identify the range and reliability of the existing rating. Once calibration of the hydrologic models had been undertaken, the secondary ratings were subsequently reviewed. Figure 5-1 shows the treatment of a secondary gauge rating at Gregors Creek, including available stream flow gauging's and hydrologic model results, as well as previous ratings adopted for the gauge by DNRM and Seqwater. This data was reviewed and assimilated to adopt a final consistent set of ratings for the catchments.

Ratings have been developed for the five main gauge locations in the Lower Brisbane River (Savages Crossing, Mt Crosby, Moggill, Centenary Bridge and Brisbane City) using results from a two-dimensional TUFLOW model of the lower Brisbane River developed by BCC CPO on behalf of DSDIP during 2014 for use as a disaster management tool (DMT) (BCC, 2014b).

The DMT model results identify that much of the lower Brisbane River between Wivenhoe and Brisbane City is subject to noticeable dynamic effects (e.g. hysteresis) that become increasingly more pronounced with flood magnitude and with distance downstream. The ratings derived from the DMT model were compared to available calibration data at each site, including flow measurements, steady-state Wivenhoe releases and the Hydrologic Assessment's hydrologic model results.

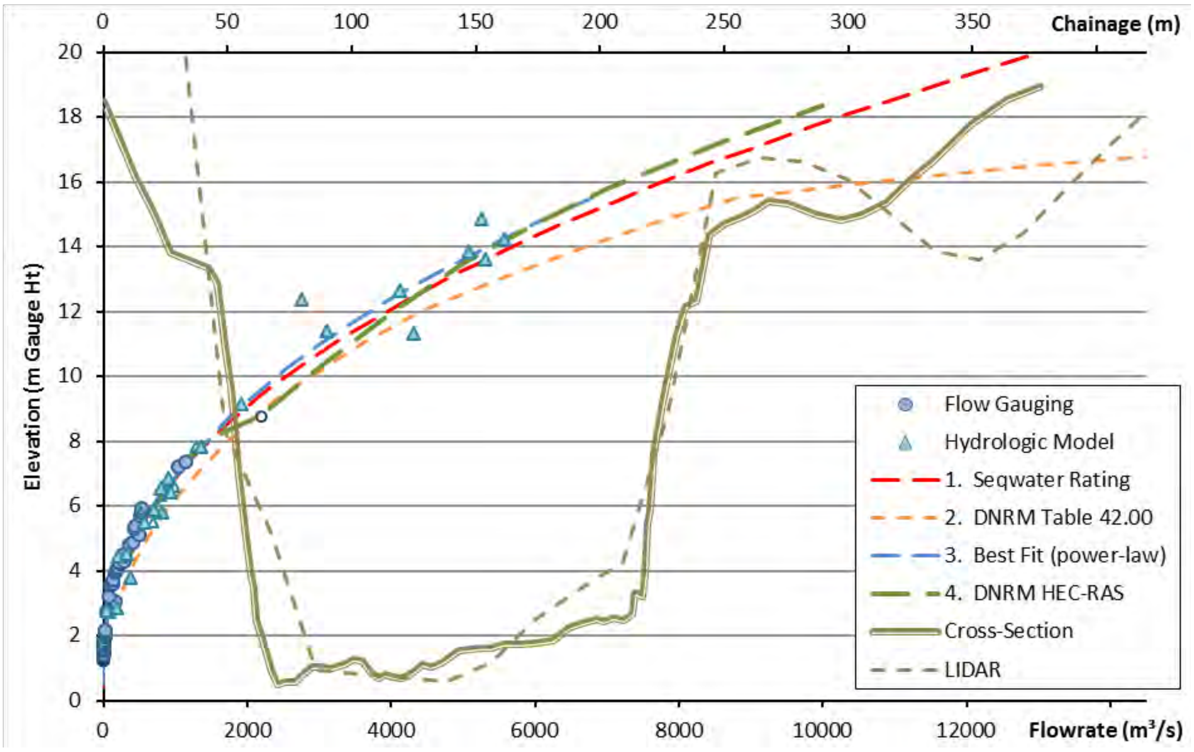


Figure 5-1 Rating Comparison – Brisbane River @ Gregors Creek (full range)

Table 5-1 Brisbane River gauge ratings reviewed as part of BRCFS

Catchment	Primary Gauge Sites	Secondary Gauge sites
Stanley River to Somerset	Stanley River at Woodford	Stanley River at Peachester Kilcoy Creek at Mt Kilcoy
Brisbane River to Wivenhoe	Brisbane River at Linville	Brisbane River at Gregors Creek Brisbane River at Caboonbah Brisbane River at Middle Creek
Lockyer Creek to O'Reilly's Weir	Lockyer Creek at Glenore Grove	Lockyer Creek at Gatton Lockyer Creek at Gatton Weir Lockyer Creek Helidon Laidley Creek at Warrego Hwy
Bremer River to Walloon	Bremer River at Walloon	Bremer River at Adams Bridge Bremer River at Rosewood
Warrill Creek to Amberley	Warrill Creek at Amberley	Warrill Creek at Junction Weir
Purga Creek to Loamside	Purga Creek at Loamside	Purga Creek at Peak Crossing
Lower Brisbane River	Brisbane River at Mt Crosby Weir Brisbane River Centenary Bridge Brisbane River at Savages Crossing Brisbane River at Moggill Brisbane River at Brisbane City	

Hydrologic model and flood frequency results were also compared to ensure as much as possible consistency between the gauge ratings along the river. The resulting ratings are therefore consistent with the current hydrologic modelling, but it is important to recognise that the only independent point of truthing in the high flow ratings is the flow gauging undertaken at Centenary Bridge, and that the uncertainty increases with distance from this site as storage attenuation and other effects may not be properly represented in the current hydrologic models.

5.3 Types of Hydrologic Models

Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle that are used to simulate the hydrological processes of interest. In flood modelling, the primary interest is to simulate the process of rainfall running off a catchment and being transported (routed) as a flood hydrograph down the creek or river. Two major types of hydrologic models can be distinguished:

- Process-Based Models. These models aim to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated. These models can be subdivided into single-event models (e.g. a single flood) and continuous simulation models (e.g. long-term simulation for months/years).
- Conceptual Models. These models are based on data and use mathematical and statistical concepts to transform a certain input (for instance rainfall) to the model output (for instance runoff). Commonly used techniques are regression, transfer functions, neural networks and system identification. These models are known as conceptual hydrology models.

Process models and conceptual models can be used for either deterministic simulation or stochastic simulation. Deterministic simulation is conducted using a fixed set of inputs to obtain a single output value, (e.g. a hydrograph at a location of interest). Stochastic analysis is performed using multiple simulations with inputs sampled from probability distributions of the input parameters which produces multiple outputs.

5.3.1 Runoff-routing Models

For flood hydrology assessment runoff-routing conceptual models are typically used. They are deterministic single event hydrologic models that represent the storage effects of a catchment by a series of linked conceptual storages. An input representing rainfall excess is routed through the model to provide an output that represents the resulting surface runoff hydrograph. These types of models are used to estimate flood flow hydrographs at nominated locations within the catchment based upon rainfall inputs.

The hydrologic model application adopted for this assessment is the URBS hydrological model (Carroll, 2012a). URBS is a semi-distributed runoff-routing networked model of sub-catchments based on centroidal inflows. URBS can be run in a mode which describes catchment and channel storage routing behaviour separately.

This arrangement allows the model to represent non-uniform rainfall across the catchment such as is necessary for historical event calibration. The node-link concept of a semi-distributed model also means that it is possible to obtain output flow hydrographs at multiple locations in the catchment which is valuable for historical event calibration and for obtaining design flood simulation results at multiple locations.

Design flood estimates were derived using the URBS hydrological model of the Brisbane River catchment as developed by Seqwater (2013b). This model was modified during the course of the BRCFS to better suit the objectives of the study.

Seqwater divided the Brisbane River catchment into seven distinct sub-catchment models based on review of topography, drainage patterns, and major dam locations. Seqwater also considered the key locations of interest for operation of the flood mitigation dams in the catchment and the best use of available data including water level gauges. These seven catchments were further divided into sub-areas to provide adequate delineation of the storage and channel routing characteristics of each catchment.

Refer to Figure 5-2 for the sub-catchment layout adopted.

5.3.2 Simplified Dam Operations Model

Somerset and Wivenhoe Dams are multi-purpose storages that provide urban water supplies (including drinking water) to South East Queensland, as well as flood mitigation benefits to areas below Wivenhoe Dam. The dams are equipped with gates (either on the spillway as at Wivenhoe Dam, or as sluices through the dam as at Somerset Dam), which allow the release of flood water to be varied in accordance with prescribed operational procedures.

In addition to the main gated spillway at Wivenhoe Dam there is an auxiliary spillway that was constructed in 2005 as part of an upgrade to improve flood adequacy of this storage. The auxiliary spillway consists of a three bay fuse plug spillway located on the right abutment. The various fuse plug embankments are triggered at different lake levels during rare to extreme flood events. The main spillway gates are intended to be fully opened prior to the initiation of the fuse plug embankments.

A Dam Operations Module was developed as part of the study to represent the effect that Wivenhoe and Somerset Dams have on flood flows that pass through the system under a ‘with-dam’ condition.

The Dam Operations Module is a reservoir simulation model based upon the Loss of Communications (LOC) emergency flood operation procedure described in the Flood Manual. This procedure is outlined in the Manual of Operation Procedures for Flood Mitigation at Wivenhoe Dam and Somerset Dam Revision 11 (Seqwater, 2013a). The Dam Operations Module is incorporated into the Delft-FEWS Model Framework (Werner et al., 2013) by using the Real Time Control (RTC) Tools software. Delft-FEWS is a component-based modelling framework that incorporates a wide range of general data handling utilities and open interfaces to many hydrological and hydraulic models that are commonly used around the world, including the URBS hydrological model and RTC tools for reservoir modelling.

Under a LOC operating procedure the decision making process is only dependent on lake levels with no regard to downstream flows. Appropriate radial gate openings at Wivenhoe Dam are determined by following the radial gate operating sequence as set out in the Flood Manual.

The BRCFS flood hydrology simulation of the decision making process at Somerset Dam (which flows into Wivenhoe Dam) takes into consideration the behaviour in Lake Wivenhoe. This is achieved using a process documented in the Revision 11 Flood Manual whereby an *'interaction diagram*' is used to compare lake levels in Somerset and Wivenhoe Dams at a given time. The diagram is used to decide if more floodwater should be stored in Somerset Dam or if the floodwater should be released into Wivenhoe Dam. This approach aims to balance flood storage between the dams, however the crest gates are not operated at Somerset Dam so achieving a balance is not always possible in some floods. The use of the LOC procedure, on average, results in slightly '*conservative*' estimates of peak downstream flow in the Mid Brisbane River and Lower Brisbane River when compared with the operations procedure that are used when the operations are directed from the Flood Operation Centre documented in the Flood Manual. The downstream peak flows are in the order of 5 to 10% higher on average using the LOC procedure. This means the derived AEP peak flows for the 'with-dams condition' scenario will likely be conservative.

The other dams included in the URBS hydrologic model, namely Moogerah, Lake Manchester, Perseverance and Cressbrook Creek Dams, have fixed crest spillways and are not subject to manual operations. As such, they are not included in the simplified dam operations model.

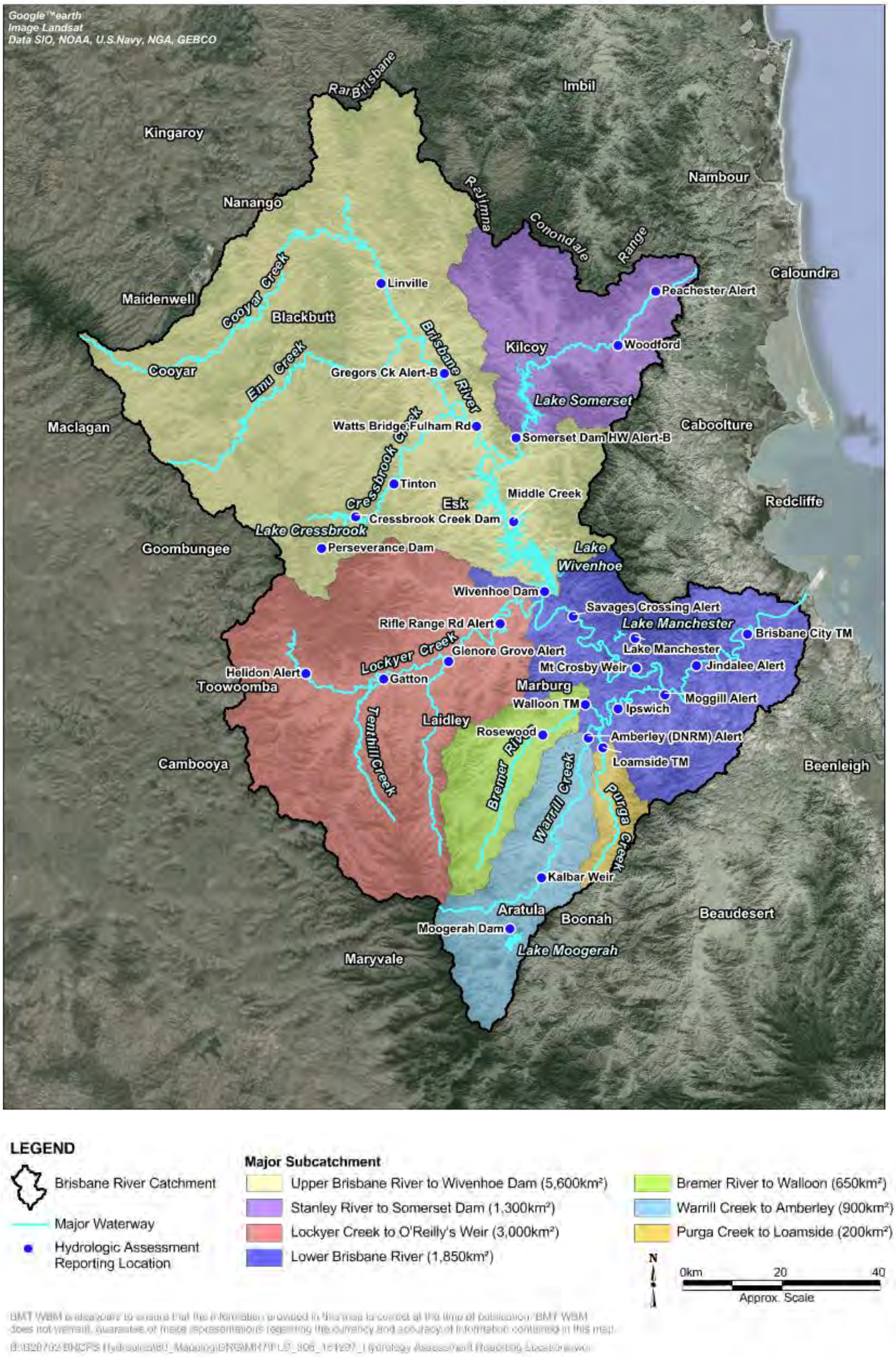


Figure 5-2 Brisbane River Catchment – Sub-Catchments and Hydrology Assessment Reporting Locations

5.4 Calibration to Historical Events

As mentioned in Section 5.3.1, hydrologic modelling for the BRCFS was undertaken using an URBS model initially developed by Seqwater (2013b). Review of this model was required as the purposes of the BRCFS investigation are different from those for which the model was developed. In particular, it was necessary for the URBS model to be able to appropriately model a broader range of event magnitudes, from small to extreme events.

A review of the rating curves generated by Seqwater, DNRM, BoM and other sources was also undertaken as part of the BRCFS (see Section 5.2).

As a result of these reviews, modification and subsequent re-calibration of the URBS model was undertaken. The calibration process resulted in a single set of model parameters that achieve a reasonable calibration across a wide range of flood event types and magnitudes as summarised in the following sections.

5.4.1 Available Historical Events

Calibration of the URBS models is conducted by performing runoff routing of recorded historical rainfall events and adjusting the rainfall loss and flood routing parameters to best represent observed river flow characteristics recorded during those events. As part of the original calibration process conducted by Seqwater (2013b), the models were calibrated using recorded rainfall and stream gauge data from 38 historical flood events that occurred between 1955 and 2013, with verification to a further 10 events between 1893 and 1947. The recalibration for the BRCFS focussed on the five recent events of January 1974, May 1996, February 1999, January 2011 and January 2013, whilst verification was undertaken to the 43 remaining events used by Seqwater.

5.4.2 Re-calibration Approach and Outcome

Following a detailed review, the URBS models were updated with revised stream gauge ratings, and a number of changes to the model schematisation made to ensure that it best represented flow characteristics in particular areas of interest. The most significant changes to the models were:

- Modification of the routing of the lower Lockyer Creek floodplain downstream of Glenore Grove to include the main channel and three separate bypass locations. In this area the main channel is perched (the river banks are higher than the surrounding floodplain) and breakout flows travel across the floodplain by a different route and at a different speed to the main channel. This behaviour was estimated by observing the timing of flood peaks between Glenore Grove and Savages Crossing.
- Adjustment of the routing parameters for the main Brisbane River channel downstream of Wivenhoe by applying a reach length scaling factor to reduce the routing time to match observed travel times between the main stream gauges (Wivenhoe, Savages Crossing, Mt Crosby Weir, Moggill, Centenary Bridge and Brisbane City). Additional storage was provided at key locations using storage-discharge relationships directly related to physical properties of the river and floodplain and determined by combining level-volume relationships taken from the DTM with level-flow relationships estimated from the main gauge rating.

The adopted calibration process was relatively similar to the methodology developed by Seqwater. Availability and reliability of stream gauge data was reviewed to identify primary and secondary calibration points, with the primary (more reliable) locations used to guide selection of calibration parameters and the secondary (less reliable) locations used for review and confirmation. The primary and secondary calibration points were generally aligned with those from the rating curve review process.

Model parameters for each of the seven sub-catchment models were adjusted to obtain a best fit of the recorded data at the primary calibration sites. Typically this involved using the URBS routing parameters (alpha and beta) to adjust the timing and shape of the hydrograph and rainfall losses (initial and continuing) to match the observed flood peak. The calibration performance at other gauges was reviewed to confirm that an acceptable match was achieved. This procedure was conducted independently for each of the five main calibration events. Due to the differing nature of the events, the optimisation procedure tended to produce slightly different parameters for each event.

Performance of the calibration was assessed using ranking and weighting criteria developed by Seqwater (2013b) that considered quantitative measures of the flood hydrograph calibration as well as a qualitative assessment of the quality of data and magnitude of the flood event. Five performance criteria were assessed, including the ratio of peak flows, the ratio of cumulative flow volume and the Nash-Sutcliffe value (a measurement of the match of the hydrograph shape and timing), as well as an overall assessment of the magnitude of the flood event and the availability and reliability of the calibration data. These criteria were then used to weight the parameters for each event calibration to derive a single set of parameters for each model.

Once a single reconciled set of parameters was obtained, the model performance was verified using the recommended parameters for all 48 available historical events, including the five selected calibration events, the remaining 33 post 1955 events and 10 pre-1955 events that include the 1893 record flood in the Brisbane River.

The outcome of the recalibration process is a set of calibrated hydrologic models based on the compilation of numerous events at multiple locations.

The recalibration process has generally seen either an improved or equivalent quality of calibration for all catchments when compared to the previous Seqwater calibration. The changes can generally be attributed to revision of the stream gauge rating curves and changes to the schematisation of the models.

Comparison of modelled and estimated (rated) peak flow rates and volumes at each gauge site indicates a good correlation between the modelled and estimated values, with no obvious flowrate related bias.

5.5 Hydrologic Assessment Methodologies

5.5.1 Approaches Investigated

The Hydrologic Assessment investigated multiple alternative methods for estimating design floods throughout the Brisbane River catchment. The techniques considered include:

- Flood Frequency Analysis (FFA)
- Design Event Approach (DEA)
- Monte Carlo Simulation (MCS) method.

FFA methods derive statistics of peak flows and flow volumes directly from observed flow records, whereas the DEA and MCS methods both rely on rainfall statistics in combination with a hydrologic model to compute peak flows and flow volumes at locations of interest.

The DEA is a well-established, traditional rainfall-based method documented in Australian Rainfall and Runoff (Engineers Australia, 1987) that 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 a peak flood flow is AEP neutral).

The MCS method removes many of the assumptions and limitations common to DEA methodologies through the use of correlations between contributing variables. Applying the MCS method involves statistically generating or running thousands of flood events.

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 flood mitigation 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 three methods were applied to estimate design flood flows throughout the 13,500km^2 catchment of the Brisbane River for two different scenarios: ‘no-dams’ and ‘with-dams’ conditions.

5.5.2 Scenarios (No-Dams, With-Dams)

Two dam scenarios have been investigated by the Hydrologic Assessment; referred to as ‘with-dams condition’ and ‘no-dams condition’. These catchment conditions reflect the catchment response with/without the influence of existing major dams and their reservoirs represented in their 2013 configuration respectively. The dams referred to are the major water storages that exist within the catchment (Perseverance, Cressbrook Creek, Lake Manchester, Somerset, Wivenhoe and Moogerah Dams). The scenarios do not consider any of the other minor dams within the catchment as the smaller dams have minimal influence on riverine flooding at the required flood assessment locations. The dams included are summarised in Table 5-2.

Table 5-2 With-Dam Condition Reservoirs

Reservoir	Year Completed	Water Supply Capacity at FSL (ML)	Flood Mitigation Capacity (ML)	Surface Area (ha)
Lake Manchester	1916	25,690	0	281
Somerset Dam	1953	379,000	524,000	4,350
Moogerah Dam	1961	83,700	0	827
Perseverence Dam	1965	30,140	0	220
Cressbrook Creek Dam	1983	81,840	0	517
Wivenhoe Dam	1985	1,165,000	1,970,000	10,800
Total		**1,755,370**	**2,494,000**	**16,995**

Moogerah, Lake Manchester, Perseverance and Cressbrook Dams are modelled in the URBS hydrological model as level pool storages with fixed crest spillway relationships. The storage representation and associated relationships are consistent with the description contained in the Brisbane River Flood Models, Seqwater (2013). No alterations have been made to the URBS model with respect to these four dams.

Somerset Dam and Wivenhoe Dam were represented by use of the RTC Tool in the MCS Framework because of the interaction of the dam operations during flood events (see Section 5.2.2).

The 'no-dams condition' models have been modified to remove all representation of the dams, including storage details and reduced reach length factors for drowned reaches. The catchment data has also been adjusted to remove the effect of impervious areas associated with the reservoirs. The design flood modelling for the 'no-dams condition' is not considered a pre-development scenario; as it represents the current catchment conditions simply with the major dams removed.

5.5.3 Design Event Approach (DEA)

The DEA is a rainfall based design peak flow and hydrograph estimation methodology. The methodology was recommended in Australian Rainfall and Runoff (ARR) (Engineers Australia, 1987) and is used widely by practitioners. The DEA uses one probabilistic input, that is the rainfall depth, for a given Annual Exceedance Probability (AEP) and duration.

Rainfall data is based on IFD relationships discussed in Section 4.1.

Rainfall depths are modified by subtracting losses to allow for storage and infiltration. A standard initial and constant continuing loss model was adopted. Typical losses were selected for the design events based on experience and comparison with other methods including FFA and MCS. Although design event losses are not directly relatable to specific historical events the magnitude of losses observed for the calibration events were used as an indicative guide to suitable losses for each catchment.

In accordance with the ARR methodology a single temporal pattern has been applied across the entire catchment for each event and for each duration. Temporal patterns for events up to and including the 1 in 100 AEP were based on standard 1987 ARR temporal patterns, with the Brisbane River catchment situated within Zone 3. The PMP temporal pattern was determined using methodologies described in the GTSMR or GSDM Guidebook (BoM, 2003a). Temporal patterns for the intermediate range of flood magnitudes were interpolated using normalised curves of the cumulative temporal patterns. This approach was adopted to avoid anomalies between flood magnitudes within the transition.

In estimating peak design flows for a specified location and AEP, design rainfalls for a number of durations are routed through a rainfall runoff-routing model. The duration that yields the largest peak flow rate is deemed the critical duration and its associated peak flow rate and hydrograph are used for subsequent hydrologic and hydraulic analyses. The main shortcomings of this methodology are that:

- It is assumed that the design peak flow for a specified AEP is associated with a design critical duration rainfall event of the same AEP with fixed hydrologic inputs.
- The temporal pattern and point rainfall AEP are assumed to be uniform over the entire catchment which does not reflect the temporal and spatial variability inherent in real storm events, particularly for large or complex catchments.
- The hydrologic inputs are fixed and assumed to be probability neutral.

5.5.4 Flood Frequency Analysis (FFA)

FFA of the Brisbane River catchment stream gauges involves compilation and statistical analysis of historical flow data. This flow data has been collected from multiple sources, including stream gauge and URBS hydrologic modelling, and reliability of the data can vary significantly. Stream gauges record water level and the resulting flow estimates are dependent on the both the accuracy of the level measurement and the reliability of the flow rating curve, which may vary as site conditions change.

The URBS model provides a method of estimating flow data for selected historical flood events based on rainfall records. The flow estimates are therefore dependent on the accuracy of the rainfall data, which varies across the catchment, and the calibration of the model. Nevertheless, the results can provide useful information, particularly if the model can be calibrated against other gauges. Additionally, the hydrologic record at a number of the sites has been affected by construction of dams, and this effect must be removed to provide a homogenous sample representing ‘no-dam conditions’.

The assessment methodology was developed to use current best practice techniques and taking advantage of automated Bayesian fitting techniques implemented in the FLIKE flood frequency analysis software developed by the University of Newcastle. The initial stage of the methodology required the collection and review of available flow data from all sources. Reliable FFA requires three criteria to be satisfied:

- The gauge site must have a reasonable period of uninterrupted record, as the amount of confidence in the statistical analysis increases with the length of the sample period.
- The record must be homogeneous. It must consistently identify all floods (above a certain magnitude) within the period of record, and if parts of the record are influenced by dams or other changes in catchment properties then this influence must be removed.
- The flow estimates themselves must be reliable through the use of a reliable rating curve or other flow estimation method.

Ten gauge locations throughout the catchment were considered to have a good combination of characteristics suitable for a reliable FFA.

For sites where the stream flow data has been influenced by upstream dams, 'no-dams conditions' peak flow estimates were obtained by calibrating the hydrologic models (with dams) to match the recorded flood peaks, then removing the dams from the models and running with the same parameters to estimate the flood conditions that would have occurred if the dams were not present.

The annual peak flow records were assessed to identify and filter outliers and errors from the gauge records and/or extend or supplement the at-site data record using historical and/or translated flood records where appropriate to make optimum use of the available data.

An initial FFA was conducted for each of the gauge sites considered to be most reliable. Analysis was conducted using both the Log-Pearson III and GEV probability distributions, two of the most common probability functions applied for FFA in Australia. Analysis at the Brisbane River catchment sites identified that in most situations the Log-Pearson III distribution provided a better overall representation of the data set, as well as being relatively consistent with the DEA and MCS methodologies.

Regional analysis techniques that draw upon better gauge records from nearby and/or hydrologically similar sites can help improve results derived at a location where the historically monitored information is inadequate for FFA, or may result in improvements in terms of consistency (between the locations), robustness and reliability. Due to the unavailability of other methods (e.g. the new ARR Project 5 Regional Analysis Tool) at the time the BRCFS was conducted, an alternate approach loosely based on the Index Flood Method was adopted for the BRCFS analysis as follows.

- An unbiased FFA of a range of primary gauges considered to have reliable record length and flow estimates was undertaken.
- The frequency distribution parameters (skew and standard deviation) were analysed to determine if consistent catchment-wide values or trends could be identified.
- These catchment values were then returned back into the site analyses as Gaussian prior distribution parameters used with the Bayesian inference method adopted by the FLIKE flood frequency analysis software.

5.5.5 Monte Carlo Simulation (MCS)

MCS is a method for calculating probabilities in the field of numerical computing. In the MCS approach for the Brisbane River catchment, a large number of potential events is simulated with the combination of a hydrologic model and a reservoir simulation model. Exceedance probabilities of peak discharges and flow volumes at key river locations are derived from the model simulation results. The method has the advantage over FFA and DEA approaches in that it explicitly considers the natural variability of all relevant physical processes that contribute to flood events. A practical disadvantage is that it is generally more complex to implement and that it requires longer simulation times.

The main challenge in the MCS approach is to generate realistic and representative potential flood events. This means the potential events should correctly account for probabilities of occurrence of factors contributing to flood flows such as rainfall (depth, duration, spatial and temporal patterns), antecedent moisture conditions, initial reservoir volumes and ocean water levels. Furthermore, the likelihood of combined occurrences (correlations) of these factors needs to be taken into account. The generated events then need to be simulated within a model capable of representing the relevant physical processes in the catchment during flood events.

The computation scheme shown in Figure 5-3 provides a broad outline of the MCS framework, which consists of the following three components:

(1) Pre-processing: a combination of advanced statistical techniques to generate a large set of realistic and representative synthetic flood events. These events are characterised by rainfall, initial losses, initial reservoir volumes and ocean water levels.

(2) Processing: simulation of the synthetic events with a combination of a hydrologic model (URBS) and a reservoir simulation model (RTC tools) to obtain peak discharges and flow volumes at each location of interest.

(3) Post-processing: statistical techniques to combine the results of (1) and (2) to derive design peak flows, flow volumes and hydrographs for a range of AEPs across the entire Brisbane River system.

The computational procedure in Figure 5-3 is carried out separately for each river location/gauge of interest. The scheme is applied for a Total Probability Theorem (TPT) based sampling method (Rahman et al, 2002), but other sampling schemes can be implemented as well.

As part of component (1), stochastically generated estimates of variations in rainfall in both space and time were used. This data was provided for use in the BRCFS by Seqwater with the associated methodology described in SKM (2013). A world-leading multiplicative-random cascade approach or STEPS (Short Term Ensemble Prediction System) was applied that utilised radar data on 9 events resulting in 600 space-time patterns. A further 60 space-time patterns were derived specifically for the BRCFS using an additional event in January 2013 (Jacobs, 2014). These data were used in the MCS to provide more realistic representations of spatial and temporal variability of storm rainfall throughout the entire Brisbane River catchment.

The stochastic space-time rainfall patterns are used in the MCS framework for rainfall events with an AEP of less than 1 in 2,000. These stochastically generated space-time patterns were used in both the Hydrologic Assessment and also in the derivation of the ensemble of hydrographs required for the Hydrology/Hydraulics Interface.

The MCS framework adopts the same hydrologic model configuration that was adopted for the simulation of the DEA. This includes the use of the URBS runoff-routing model, a reservoir simulation model for Wivenhoe and Somerset Dams and an initial loss/continuing loss model to determine runoff from rainfall. Furthermore, the same total burst event rainfall depth statistics were implemented. However, stochastic space-time patterns were utilised in lieu of the BoM temporal patterns for frequently occurring events.

The MCS model for the BRCFS was implemented in Delft-FEWS.

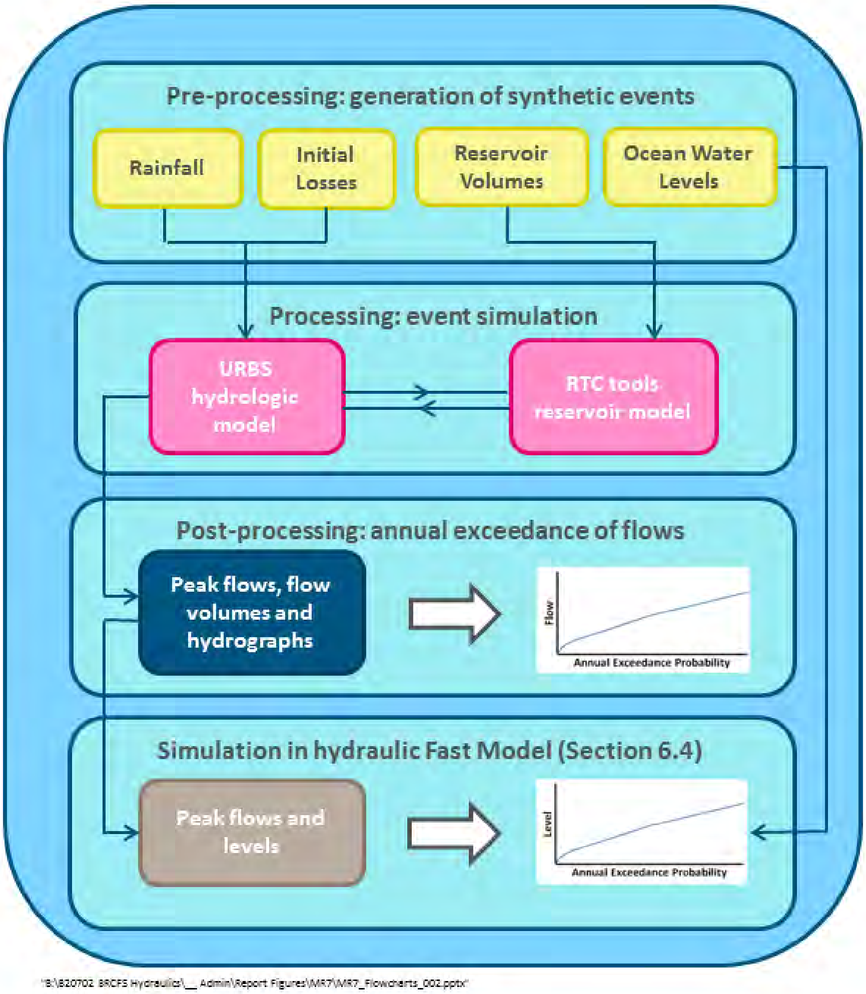


Figure 5-3 Computational steps of the Monte Carlo Simulation framework

5.6 Design Peak Flow Assessments – With and No Dams

5.6.1 Reconciliation Process

A reconciliation process was undertaken in order to assimilate the design flood estimates from the various methods that were applied (FFA, DEA and MCS). The main objective of this process is to determine, for each location of interest and each annual exceedance probability, which of the three methods is expected to provide the most reliable design flow estimate.

Significant effort was spent on obtaining mutual consistency in results for the three methods and on the validation of the methods using data records. Furthermore, estimated design flows were verified extensively for mutual consistency between results of different locations.

When reconciling the available design flood estimates it is important to recognise the strengths and limitations of each method. For example, provided sufficient records exist, FFA is often considered most reliable for frequent flood events, but extrapolation to large and rare events can be strongly influenced by the presence (or lack of) extreme events in the data record.

For the ‘no-dams’ condition, the reconciled design flows for the majority of the locations are based on a combination of:

- Empirical estimates from rated flows for frequent events or high values of AEP
- FFA results for frequent to large events or intermediate values of AEP
- MCS results for large to extreme events or low values of AEP.

To reconcile between the estimates obtained from the three independent techniques, ranges or bounds of AEP were adopted to distinguish which techniques were most appropriate. For example, FFA estimates were considered most reliable for ‘high’ (i.e. 1 in 2 to 1 in 10 AEP ranges), whereas the DEA and MCS approaches were considered more appropriate for the ‘intermediate’ and ‘low’ ranges. The choice of bounds between the ‘high’, ‘intermediate’ and ‘low’ range of AEPs differed per location.

For locations for which limited or no (reliable) data on peak discharges were available and, hence, no FFA results, the reconciled design flows for the high and intermediate range of AEP values were based on data and FFA results of nearby stations.

The choice of bounds between the ‘high’, ‘intermediate’ and ‘low’ range of AEPs differed per location. Refer to Figure 5-4 for an example of the comparison of estimates for the three approaches and the reconciled estimates for the location at Savages Crossing for the no-dams condition.

The top plot shows results for peaks, the bottom plot shows results for volumes. In this example, the bound between ‘high’ and ‘intermediate’ was 1 in 5 AEP and the bound between ‘intermediate and ‘low’ was 1 in 50 AEP. So, for AEPs > 1 in 5 AEP the empirical estimates were selected; for AEPs< 1 in 50 the MCS estimates were selected and for AEPs between 1 in 5 and 1 in 50 the FFA estimates were selected.

FFA of stream gauge records for the ‘with-dams’ condition is considered to be of limited benefit, particularly for the locations on the Brisbane River downstream of Wivenhoe as:

- Consistent post-dam data record length is limited (approximately 30 years)
- The data will not fit a known statistical distribution
- Data is influenced by dam operations and is therefore not fully homogeneous.

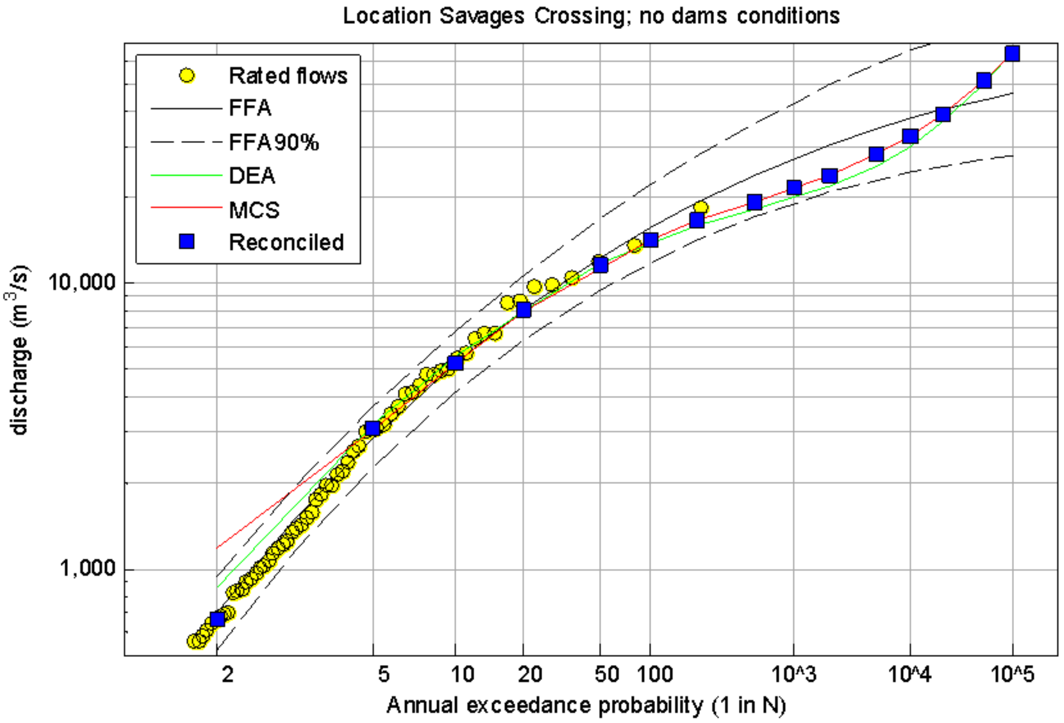
Because of these issues, traditional FFA methods, including calculation of a probability distribution and the subsequent fitting of confidence limits cannot be conducted.

For the 'with-dams' condition, the reconciled design flows for these locations are therefore based on a combination of:

- Empirical estimates from rated flows for (very) frequent events or high values of AEP
- MCS results for frequent events to extreme events or intermediate to low values of AEP.

Figure 5-5 provides an example of the comparison of estimates for the two approaches for the location at Savages Crossing for the 'with-dams' condition. The top plot shows results for peaks, the bottom plot shows results for volumes.

The reconciled 'with-dams' estimates were successfully validated for spatial consistency by comparing plots of peak flow versus catchment area and (peak flow/catchment area) versus catchment area.



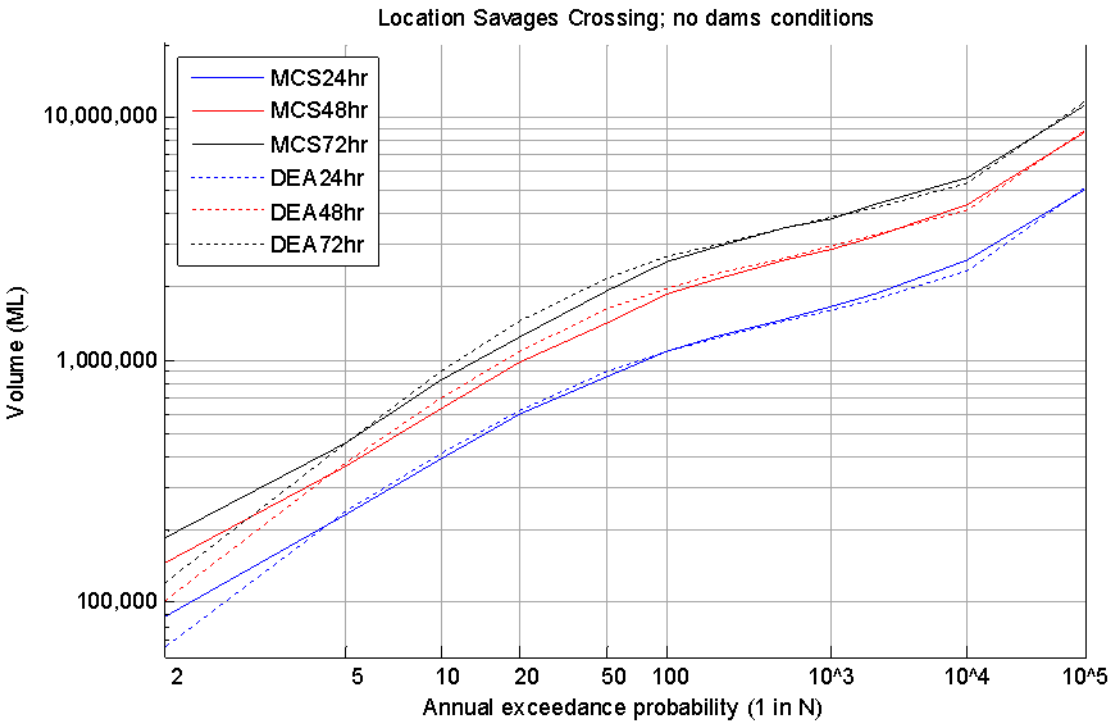
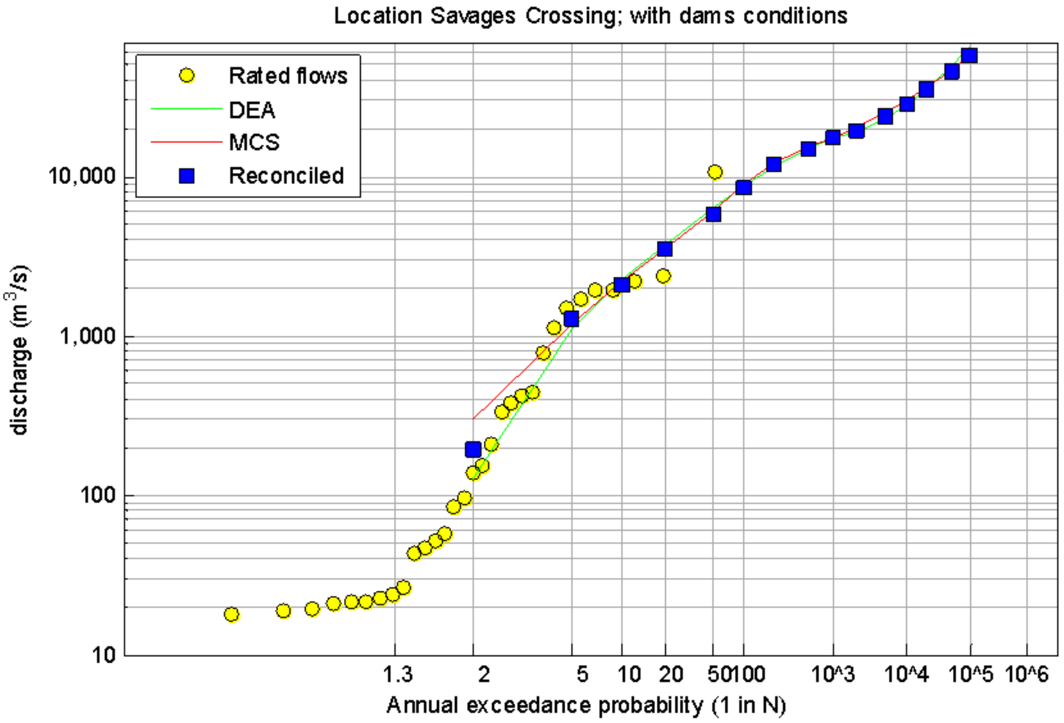


Figure 5-4 Design peak flows and flow volumes at location Savages Crossing as derived with the three methods; 'no-dams conditions'



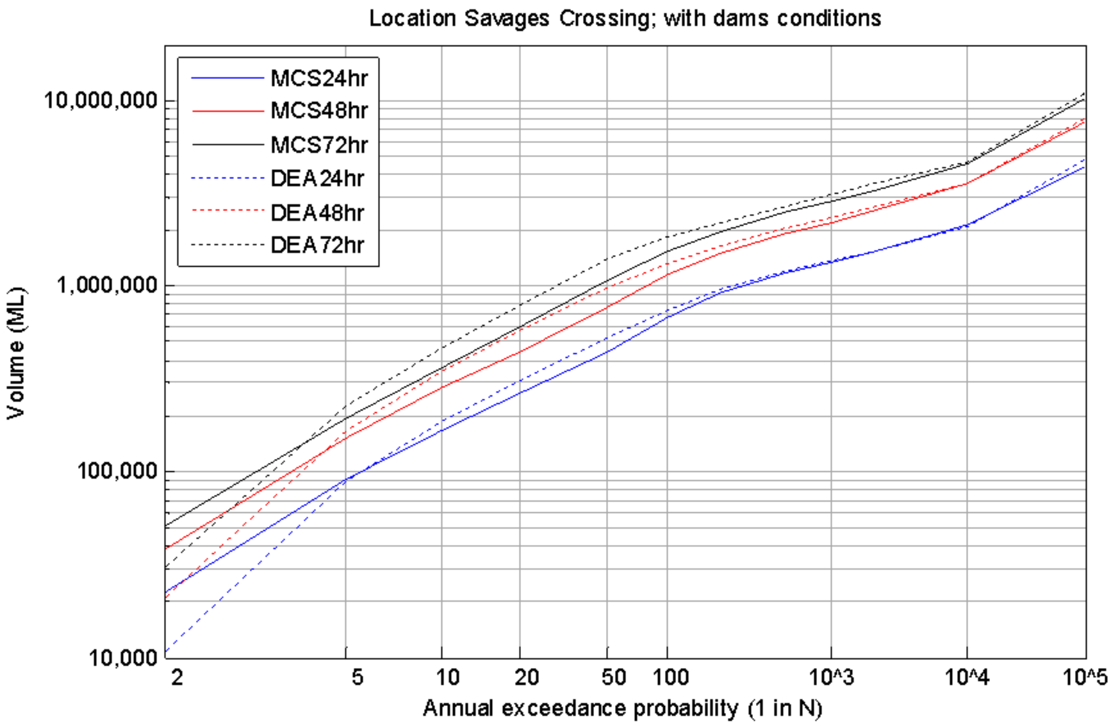


Figure 5-5 Design peak flows and flow volumes at location Savages crossing as derived with the two methods; 'with-dams conditions'.

5.6.2 Peak Flow Estimates

The reconciled and recommended estimates for the nominated locations within the Brisbane River Catchment for the design peak flow estimates are summarised in Table 5-3 and Table 5-4 for the 'no-dams' conditions and 'with-dams' conditions respectively.

It is observed that the existence of the dams result in the following reduction in 1 in 100 AEP peak flows:

- Nearly 50% at Somerset Dam and Wivenhoe Dam
- Between 29% and 41% at locations along the Brisbane River downstream of Wivenhoe Dam
- 8% in the peak Bremer River flow at Ipswich, due to the influence of Moogerah Dam.

Typically the operation of Somerset and Wivenhoe Dam in accordance with the Flood Manual results in a reduction in peak flow of around 30% downstream of Wivenhoe Dam. However, it is important to note that the reduction in peak flow is not uniform in every flood and is highly dependent on the rainfall patterns upstream and downstream of the dams. In some floods the reduction in the peak flow will be significantly less than 30% and other floods could be significantly more. The mitigation of peak flow extends over the full flood frequency range, although it diminishes for larger events. It should be recognised that for releases from Wivenhoe Dam that are in excess of 28,000 m^3/s (the maximum capacity of the main and auxiliary spillways), it is assumed that Wivenhoe Dam will not fail even though the dam will be overtopped by these larger events. This is a non-conservative assumption and so the estimates in excess of this value downstream of Wivenhoe Dam should be treated with caution.

The estimates for Ipswich are based only upon flows emanating from the Bremer River catchment, and therefore do not necessarily reflect the effects of the Brisbane River. Reference should be made to the Hydraulic Assessment for updated estimates due to the complex interaction of hydraulic effects at this location.

5.6.3 Critical Storm Durations

In the MCS approach, several burst durations have been considered. For a given location and AEP, the duration that results in the highest design flow is referred to as the 'critical duration'. Frequency curves for all locations were derived for eight storm durations, ranging from 3 hours to 168 hours depending on the catchment area.

For 'no-dams' conditions, the following was observed:

- Burst durations of 3 hours and 6 hours are never critical, except in some cases for PMP conditions.
- For AEPs of 1 in 2 and 1 in 5, longer durations are generally more critical. This is due to the fact that short duration / high AEP events have a relatively low rainfall depth. A large proportion of the rainfall does not reach the river system for these events due to rainfall losses.
- For catchments < 1,000 km^2, critical durations are in the range of 12-24 hours.
- For catchments between 1,000 km^2 and 5,000 km^2, critical durations are in the range of 18-48 hours.

- For catchments between 5,000 km^2 and 10,000 km^2, critical durations are in the range of 36-72 hours.
- For catchments >10,000 km^2, critical durations are in the range of 48-96 hours.

For ‘with-dams’ conditions, the following was observed:

- Critical durations are generally higher than critical durations for ‘no dams’ conditions
- Burst durations of 120 hours are in a substantial number of cases critical.

The last observation raises the question if durations above 120 hours should have been considered in the MCS simulation runs. Therefore, a sensitivity analysis was carried out in which results were compared of two TPT runs: a run in which burst durations up to 120 hours were considered and a run in which burst durations up to 168 hours were considered. The comparison shows that the influence of the larger durations on the frequency curves is negligible. The applied upper limit in the current study for considered burst durations of 120 hours is therefore considered acceptable.

5.6.4 Flood Volume Estimates

Flow volumes for different durations can be derived directly from the hydrographs that are produced with the MCS and DEA approaches for both conditions. Subsequently, frequency curves can be derived in the same manner as frequency curves are derived for peak discharges.

Mutual differences between design flow volumes of the various methods for the ‘no-dams condition’ are consistent with the mutual differences observed for design peak flows.

Similarly, DEA and MCS flow volumes for the ‘with-dams condition’ are generally in good agreement.

5.6.5 Limitations

It needs to be recognised that a significant degree of uncertainty remains with the derived design flood flows, particularly for the range of rare to extreme events. For example the extreme peak flow estimates below Wivenhoe Dam in excess of 28,000 m^3/s (the current available release capacity of the dam) rely on the fact that the existing embankment will not fail. The hydrologic models have also only been calibrated to events that have peak flows of 16,000 m^3/s in the Lower Brisbane River.

More frequently occurring flood peak flows (such as the 1 in 2 AEP flood) should also be treated with some caution due to the variability of these estimates as evidenced by the wide scatter of MCS results. These results are very sensitive to the adopted contributing factors and should be regarded as indicative estimates. However, some greater reliance can be placed on estimates for locations where there is consistency between the three independent methods.

It was not possible to reconcile the design flood estimates for some locations such as the Bremer, Warrill and Purga Creek catchments. This is because of the inconsistency between FFA and the rainfall based approaches due to a possible underestimation of the underlying design rainfall Intensity-Frequency-Duration (IFD) data.

Less confidence can also be placed in the Lockyer Creek catchment estimates due to higher uncertainty in the high stage rating of these sites which occurs when flow exceeds the main channel capacity when it spills into the extensive floodplain.

Overall, the estimates derived from the MCS exhibit wide variability, which is a reflection of the variation in contributing factors such as rainfall depth, rainfall spatial distribution, rainfall temporal distribution, and antecedent catchment conditions, which includes catchment wetness (rainfall loss rates) and initial reservoir levels.

5.7 Hydrologic and Hydraulic Modelling Interfacing

The simulated flows generated within the MCS framework were used as input for hydraulic modelling. In order to do so, the MCS framework had to be adapted so as to generate flow hydrographs at around 100 locations for input to the hydraulic modelling. These flows were agreed in consultation with the TWG and IPEs from both the Hydrologic and Hydraulic Assessments to be based on the MCS settings for the Brisbane City output location.

The URBS hydrologic model used by the MCS was adapted to provide flow hydrographs for the inflow boundaries being used for the hydraulic modelling. Quality control checks were carried out to verify that the changes did not affect the MCS hydrologic calculations.

A total of 11,340 MC flood events were generated using the MCS framework (Aurecon, 2015b) to provide input to the hydraulic modelling. Each hydrologic simulation was carried out with the combination of the URBS runoff-routing model and a reservoir model for simulating the operation of Wivenhoe and Somerset dams. The 11,340 events is 9 x 60 x 21 being the combination of:

- 9 rainfall burst durations: 12, 18, 24, 36, 48, 72, 96, 120 and 168 hours.
- 60 different classes of area-average rainfall depth, corresponding to 60 pre-defined AEP values ranging from 0.8 to the AEP of the probable maximum flood (PMF).
- 21 simulations per combination of burst duration and rainfall depth, each with different statistically generated combinations of different starting reservoir volumes, rainfall initial losses, ocean water levels and spatio-temporal rainfall patterns.

The 9 burst durations were selected with the aim to cover the whole range of durations that are considered relevant for the focus area of the hydraulics phase. Values of rainfall depth where derived from rainfall statistics which, for each burst duration, describe a one-to-one relation between AEP and rainfall depth.

For each simulated event, the output of the combined hydrologic and reservoir modelling consists of hourly discharge time series (240 hours, or ten days, in total) at each boundary location of the river network resulting in delivery of around 1.1 million hydrographs. Meta-data was also provided for each flood event that included: event ID; burst duration; area-average rainfall depth and associated AEP; initial losses and continuing losses per sub-catchment; initial reservoir volumes for the six modelled reservoirs; and derived peak flows and flow volumes at key locations.

Table 5-3 Peak Flow (m^3/s) versus AEP - Reconciled No-dams Condition Peak Flows[5]

Location	Catchment Area (km^2)	AEP (1 in N)													
		2	5	10	20	50	100	200	500	1,000	2,000	10,000	100,000	PMP DF	AEP of PMP
Linville	2,005	150	710	1,300	1,900	2,900	3,700	4,200	4,800	5,400	6,000	7,900	13,700	21,400	500,000
Gregors Creek	3,885	330	1,400	2,500	3,700	5,300	6,500	7,400	8,800	9,700	10,800	14,500	26,300	36,300	260,000
Fulham Vale	3,975	370	1,700	2,700	4,000	5,400	6,400	7,400	8,800	9,700	11,100	14,700	26,600	34,500	250,000
Peachester	104	120	300	420	540	680	780	870	980	1,100	1,200	1,400	1,900	2,600	9,710,000
Woodford	250	210	510	750	1,000	1,300	1,500	1,700	2,000	2,200	2,500	3,200	4,300	6,000	4,070,000
Somerset Dam	1,335	540	1,400	2,200	3,000	3,900	4,600	5,200	6,100	6,700	7,400	9,500	13,400	18,300	750,000
Tinton	420	37	210	390	590	840	1,100	1,200	1,400	1,600	1,800	2,400	3,400	6,000	2,360,000
Middle Creek	6,710	670	2,400	4,500	6,600	9,000	10,900	12,400	14,600	16,500	18,800	25,200	57,800	65,700	150,000
Wivenhoe Dam	7,020	670	2,400	4,600	6,800	9,300	11,200	12,800	15,100	16,800	19,000	25,000	49,200	54,800	140,000
Helidon	270	73	230	400	590	800	960	1,100	1,300	1,500	1,700	2,200	3,400	6,700	2,840,000
Gatton	1,550	89	410	830	1,300	2,300	3,100	3,700	4,400	5,000	5,600	7,900	13,600	24,000	650,000
Glenore Grove	2,230	99	570	1,200	2,000	3,200	4,000	4,900	5,800	6,500	7,400	10,400	18,300	27,700	460,000
Savages Crossing	10,180	670	3,100	5,200	8,100	11,600	14,300	16,600	19,100	21,500	23,900	32,600	63,800	63,800	100,000
Mount Crosby	10,600	830	3,100	5,400	8,100	11,400	13,800	16,100	18,800	21,300	23,400	32,400	N/A	62,600	90,000
Walloon	620	260	680	1,100	1,300	1,600	1,900	2,200	2,500	2,800	3,100	4,000	5,500	8,700	1,570,000
Kalbar Weir	470	200	590	950	1,200	1,600	1,700	1,800	2,100	2,300	2,600	3,400	4,600	7,600	2,180,000
Amberley	920	230	630	1,000	1,400	2,000	2,200	2,400	2,800	3,000	3,400	4,500	6,400	9,980	1,110,000
Loamside	215	65	210	310	390	490	580	670	780	870	980	1,200	1,700	2,800	4,770,000
Ipswich	1,850	440	1,400	2,100	2,700	3,500	3,900	4,400	5,200	5,800	6,500	8,800	13,200	18,400	540,000
Moggill	12,600	1,100	3,800	6,400	9,300	12,300	14,600	17,000	19,900	23,000	25,900	35,800	N/A	64,400	80,000
Centenary Bridge	12,915	1,100	3,700	6,200	9,000	11,800	14,000	16,400	19,300	22,300	25,300	35,500	N/A	64,900	80,000
Brisbane	13,570	1,100	3,700	6,200	8,900	11,800	13,900	16,300	19,100	22,000	25,000	34,600	N/A	62,800	80,000

[5] Note: the 1 in 100,000 AEP peak flow is only provided for locations for which the AEP of the PMP is below 1 in 100,000
Note 2: The AEP of the PMP is dependent upon catchment area

Table 5-4 Peak Flows (m^3/s) versus AEP - Reconciled With-dams Condition Peak Flows[6]

Location	AEP (1 in N)													
	2	5	10	20	50	100	200	500	1,000	2,000	10,000	100,000	PMP DF	AEP of PMP
Somerset Dam	0	800	1,300	1,800	2,200	2,500	3,000	3,300	3,600	4,000	5,400	10,700	20,900	750,000
Wivenhoe Dam	0	470	930	1,700	3,300	6,300	8,800	10,300	12,500	12,900	21,200	35,800	43,700	140,000
Savages Crossing	190	1,300	2,100	3,500	5,800	8,500	11,800	15,000	17,500	19,500	29,000	56,900	56,900	100,000
Mount Crosby	200	1,300	2,200	3,600	6,000	8,600	11,700	14,800	17,100	19,700	27,200	N/A	55,500	90,000
Ipswich	390	1,300	2,000	2,500	3,300	3,600	4,000	5,000	5,600	6,000	8,300	12,000	16,700	540,000
Moggill	630	2,100	3,300	4,800	7,300	10,200	12,400	15,700	18,000	20,400	29,300	N/A	57,600	80,000
Centenary Bridge	640	2,100	3,300	4,800	7,100	9,900	11,900	15,000	17,700	19,900	28,500	N/A	55,900	80,000
Brisbane	700	2,200	3,300	4,800	7,100	9,900	12,000	14,900	17,500	19,700	27,600	N/A	53,800	80,000

Note 1: Estimates shown in red are above 28,000m^3/s which exceed the maximum release capacity of Wivenhoe Dam. These estimates should be treated with caution.
Note 2: The estimates shown in blue for Somerset Dam should also be regarded with caution as they represent the flows associated with the design floods specific to Wivenhoe Dam.
Note 3: The AEP adopted in the Hydraulics Assessment is a notional 1 in 100,000 AEP event based upon the application of the MC method to the levels. This should not be confused with the AEP of the PMP which is based upon the catchment area versus AEP relationship defined in Book 8 of ARR

[6] Note: the 1 in 100,000 AEP peak flows is only provided for locations for which the AEP of the PMP is below 1 in 100,000

6 Hydraulic Models and Selection of AEP Ensembles

The BRCFS Hydraulic Assessment developed and calibrated an integrated suite of hydraulic models, which were used to select and simulate MC events to define flood behaviour, peak flood level surfaces and other key outputs across the study area. This section summarises the approach taken in producing the hydraulic models and selecting the AEP design floods.

6.1 Sources of Flooding

Flooding may be attributable to a number of sources and/or mechanisms including:

- Overtopping the banks of rivers, creeks or other drainage channels.
- Overland (exceedance) flow resulting from:
    - heavy rainfall exceeding the ability of the surface to infiltrate the water; or
    - the rate of surface water runoff exceeding the ability of an urban drainage network to capture or convey the flow and which can be exacerbated by blockage.
- Tidal/ Storm surge flooding caused by elevated ocean levels that propagates into low lying river catchments.
- Flooding from groundwater due to a raised water table following prolonged rainfall.
- Failure of infrastructure such as dams or water mains.

Often, a flood event is a combination of two or more of these mechanisms. For example elevated river levels may restrict the outfalls of piped drainage networks limiting the ability of those networks to convey flow. If river levels continue to rise then river water can propagate back up piped networks and surcharge out of connecting drains. This is sometimes managed through use of back flow devices (flap gates) installed on pipe outlets that only permit flow in one direction.

The BRCFS is concerned with flooding from the main branches of the Brisbane River downstream of Wivenhoe Dam, the lower sections of Bremer River including Warrill and Purga Creeks, and the lower areas of Lockyer Creek. The floodplains are included to the extent that inundation caused by elevated river levels extend fully into the low lying areas of Brisbane River tributaries. This is often referred to as backwater flooding and includes the inundation of numerous smaller side tributaries.

A distinction is drawn between Brisbane River riverine flooding and localised flooding. Localised flooding is caused by rainfall within a tributary's catchment and is a different flooding mechanism to riverine flooding. 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 riverine flooding that slowly and steadily rises as the Brisbane River rises.

Localised flooding is not considered as part of the BRCFS and reference should be made to local authorities for further guidance.

6.2 Types and Objectives of Hydraulic Models

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 one-dimensional (1D) hydraulic model with a target run time of 15 minutes or less per simulation as specified in the ITO. 1D models use the most simplified form of the free-surface fluid flow equations and are quick to compute by today's standards. The Fast Model's primary purpose is to simulate thousands of Monte Carlo (MC) flood events (hence the need for a quick compute time). Outputs from these events were used to determine AEP flood levels at locations downstream of Wivenhoe Dam.

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. The Detailed Model primarily uses the two-dimensional (2D) form of the free-surface fluid flow equations, which are significantly more accurate in reproducing complex flow effects (such as occurs in the Brisbane River) than the 1D form, but take significantly longer to compute. The Detailed Model is used for producing flood maps and 3D surfaces of flood levels, depths, velocities and hydraulic hazard (a measure of the hazard of deep and/or fast flowing water).

The development of the Fast and Detailed Models followed a three staged approach:

- Update and utilise the existing Disaster Management Tool (DMT) and utilise the updated DMT (UDMT) to inform the development of the Fast and Detailed Models.
- Development and calibration of the Fast Model was carried out first due to the much quicker simulation times and need to use the model for the peak flood level MCS assessment.
- Development and calibration of the Detailed Model with fine-tuning of the Fast Model calibration and schematisation prior to the MCS assessment.

A description of the three resulting hydraulic models and how these models are used to meet the study objectives is provided below.

6.2.1 Updated Disaster Management Tool (UDMT)

The Disaster Management Tool (DMT) was developed by Brisbane City Council (City Projects Office) for the then Department of State Development Infrastructure and Planning (DSDIP), and was finalised in June 2014 (BCC, 2014b) as an interim tool developed to derive flood mapping for disaster management purposes. The DMT is a 2D hydraulic model based on the TUFLOW software using the high powered computing capability of graphic cards to achieve rapid run times. Of note is the TUFLOW software solution of the 2D equations used for the DMT modelling is of a simpler form than that used for the Detailed Model, plus key functionality required for the level of detail sought for the Detailed Model was also not available for the graphic card implementation.

Use was made of the DMT model for informing the build of the Fast Model, particularly with regard to out of bank flow paths and floodplain inundation. To achieve this, the DMT model was updated with revised inflows from the Hydrologic Assessment, refined land use categorisation and other datasets that had become available since the DMT model completion such as bathymetry survey. To ensure the updates had not adversely affected the DMT model calibration, the updated DMT

(UDMT) was simulated for the 1974, 2011 and 2013 events, with the results remaining comparable to the original model.

A key use of the UDMT was to simulate hypothetical extreme flood events by scaling the 1974 event inflows by up to a factor of eight. This allowed for the identification of extreme flow breakouts and overland flow paths to be identified, which helped inform the Fast Model development.

6.2.2 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 Hydraulic Assessment ITO. Its primary purpose, as stipulated by the ITO, is to simulate 500 MC 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.

The Fast Model is based on the TUFLOW software using 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 channels hydraulic conveyance properties are based on cross-sections, which are extracted from digital elevation models, principally the DMT DEM and bathymetry datasets (see Section 4).

The nodes 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 DMT DEM.

Main river structures such as bridges and floodplain structures such as underpasses or large culverts through embankments are represented in the model.

The schematisation of the channels and nodes, particularly in the floodplains is informed by the UDMT model. Figure 6-1 provides an example of the model schematisation in the lower floodplain of Lockyer Creek with the hydraulic hazard mapping from the UDMT shown in the background.

The Fast Model included over 2,300 channels with a run time of around 4 minutes for an 8 day flood on a standard single CPU core.

6.2.3 Detailed Model

The Detailed Model is a 1D/2D hydraulic model based on the TUFLOW software 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. 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 hazard for regional planning purposes.
- Use the model into the future to quantify the impacts or changes in flood levels, depths and velocities and 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 is predominately a 2D model using a 30m square 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 30m resolution was considered too coarse to represent the in-bank topography. Checks on the suitability of the 30 m grid were undertaken which included comparisons of results to those derived using a 20 m grid. The 30 m grid resolution of the Detailed Model is endorsed by the IPE as meeting the requirements of the ITO.

The topography is based on the DMT DEM and 2014 LiDAR data, supplemented with bathymetry datasets and improved with model breaklines to represent linear features such as road and rail embankments.

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. This includes stormwater pipes in the inner Brisbane area which have the potential to convey backflow from the river into low lying areas behind the river banks. For design simulations, backflow prevention devices were not included.

An example of Detailed Model output taken during model calibration is illustrated in Figure 6-2 for the Tennyson reach downstream of the Indooroopilly Bridge.

6.3 Calibration to Historical Events

6.3.1 Introduction

To ensure that hydraulic models are sufficiently representing the flood behaviour, calibration and verification of models are undertaken. This is achieved using a range of historical flood events for which there is a good range and quality of recorded data including river level hydrographs, flow gaugings and recorded peak flood levels.

Calibration involves simulating the events and adjusting model parameters such as the Manning's n surface roughness coefficients until the model matches well with recorded data. Verification involves checking the calibrated model against additional events with no further adjustments to parameters. A joint calibration of hydrologic and hydraulic models was not carried out due to the separation of the Hydrologic and Hydraulic Assessments, however, to ensure consistency between the models was a requirement of the hydrologic/hydraulic interfacing tasks as discussed in Section 3.3.

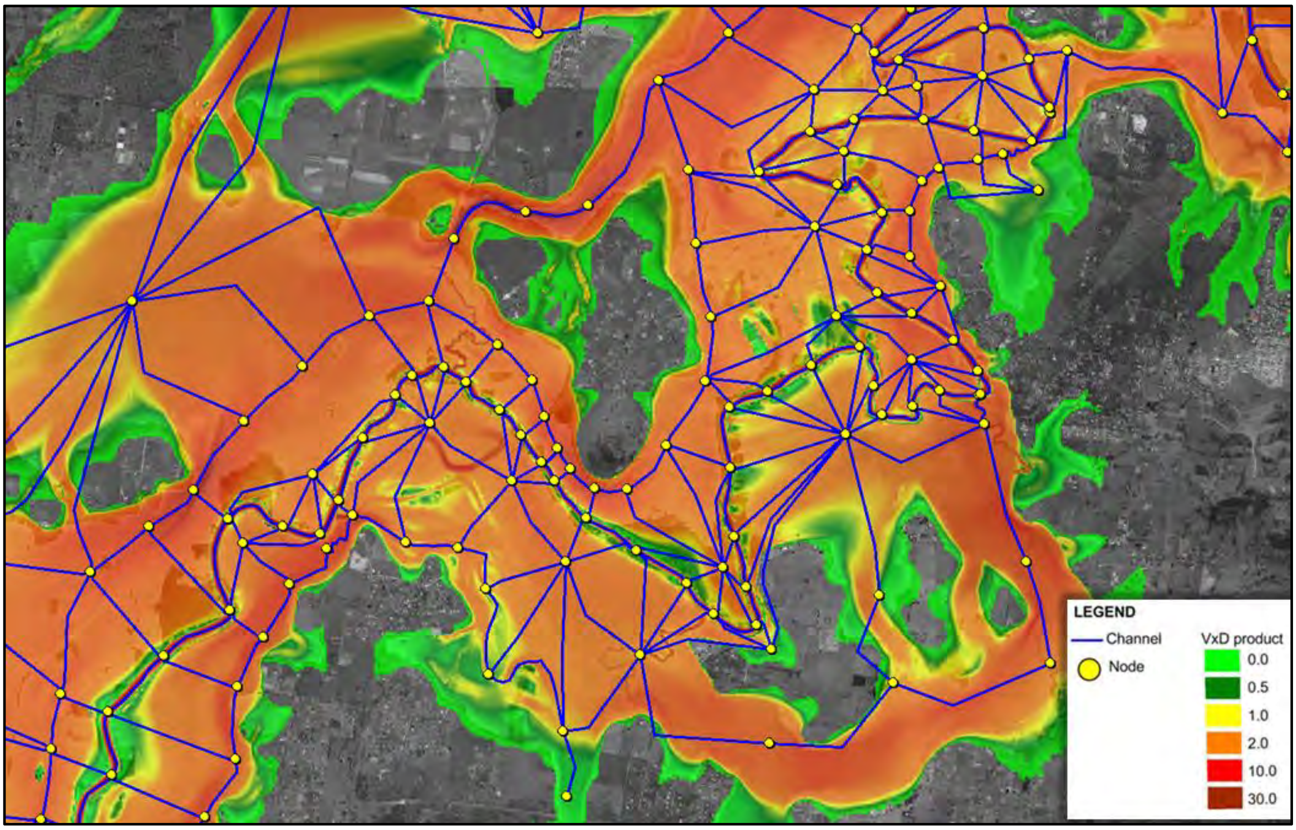


Figure 6-1 Fast Model Schematisation using UDMT Hazard Output: Lockyer Creek near Mt Tarampa

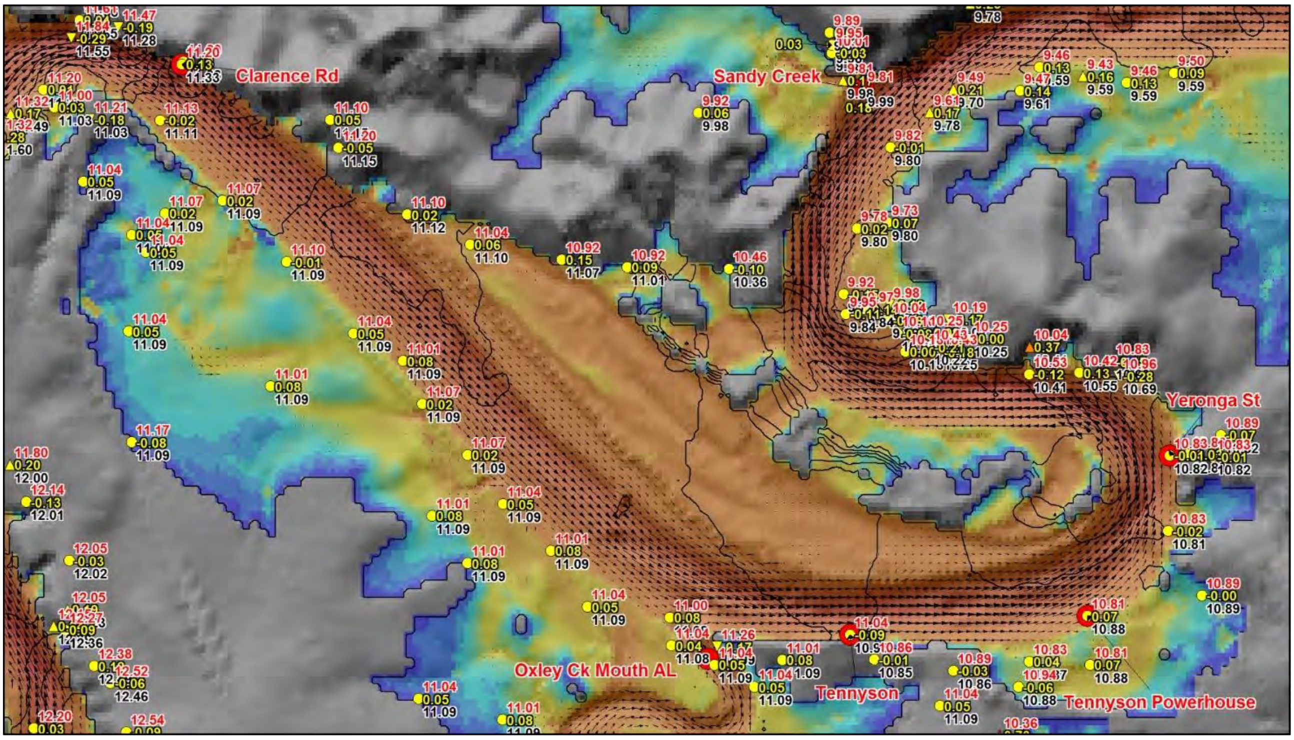


Figure 6-2 Example of Detailed Model Hydraulic Modelling for the 1974 Flood Verification: Tennyson

(Modelled Levels shown in black font with the 1974 flood levels in red font. Yellow font is the difference.)

6.3.2 Calibration Approach

Five historical events were utilised in the hydraulic modelling calibration/verification process, namely those of 1974, 1996, 1999, 2011 and 2013. Of these, the events of 1974 and 2011 were the most significant flood events in recent history for the metropolitan areas of Brisbane and Ipswich.

The focus of the Fast Model calibration was on the model's performance at the river and creek water level gauges, any flow recordings, and the flood marks along the river and creek banks. The Detailed Model calibration had the same focus but with the addition of overbank (floodplain) calibration data.

Accuracy tolerances specified in the Hydraulic Assessment ITO were used to guide the level of calibration required, recognising that calibration data such as flood elevation marks also have a degree of uncertainty.

Data specific edits were made to the models when simulating particular events. For example, a number of bridges such as the Go Between Bridge and Goodwill Bridge were not present in some of the modelled events (in this case 1974, 1996 and 1999). Likewise some features such as backflow prevention devices in and around Brisbane CBD were installed following the 2011 flood event and so are only included for the simulated 2013 event.

The calibration approach for both Fast and Detailed Models was similar and follows these steps:

- Undertake a tidal 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
- Proof the model against a range of extreme synthetic flood events.

A key finding during the Hydraulic Assessment was the need to incorporate additional form (energy) losses at locations such as sharp bends or rock outcrops to achieve a desirable calibration across multiple events with a single set of calibration parameters. 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. Energy losses that result from these obstructions are more closely approximated by the energy (form) loss equation, rather than the Manning's equation, which represents the roughness of the bed.

Typically the losses applied in the Detailed Model are around 20% of the equivalent values applied in the 1D Fast Model as the full 2D equations inherently model energy losses associated with flow being forced to change direction and speed. A loss is still required however, particularly at locations where strong three-dimensional effects are likely or the obstructions are of similar or smaller size than the 2D grid spacing.

For each model the calibration resulted in a single set of parameter values (Manning's n and form loss) for that model. The calibration parameters were derived through thousands of simulations testing different combinations of parameters, whilst remaining consistent with Brisbane River's physical characteristics. Importantly, the final parameters are in agreement with industry standard values, and the same set of parameters produces a reproduction of all five historical events across all flow regimes ranging from tidal flows to the major floods of 1974 and 2011.

6.3.3 Calibration Outputs

Calibration output is presented as a series of hydrograph plots, long sections, tables and mapping of flood extents. The mapping includes comparison of recorded flood levels with modelled levels. Example output is provided in Figure 6-3 to Figure 6-5 for the January 2011 event. Figure 6-6 shows examples of calibration point mapping to flood marks for both the 2011 and 1974 events. Table 6-1 shows the comparison between the calibration/verification events to the recorded data for Brisbane City, Ipswich, Lowood and Moggill.

The Fast and Detailed Model calibrations were endorsed by the IPE as suitable for the objectives of the BRCFS.

Table 6-1 Fast and Detailed Model Calibration to Levels at Key Locations

	Peak Water Level (mAHD)											
	Lowood			Ipswich at David Trumpy Bridge			Moggill			Brisbane City		
	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

6.3.4 Hydraulic Model Calibration 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.

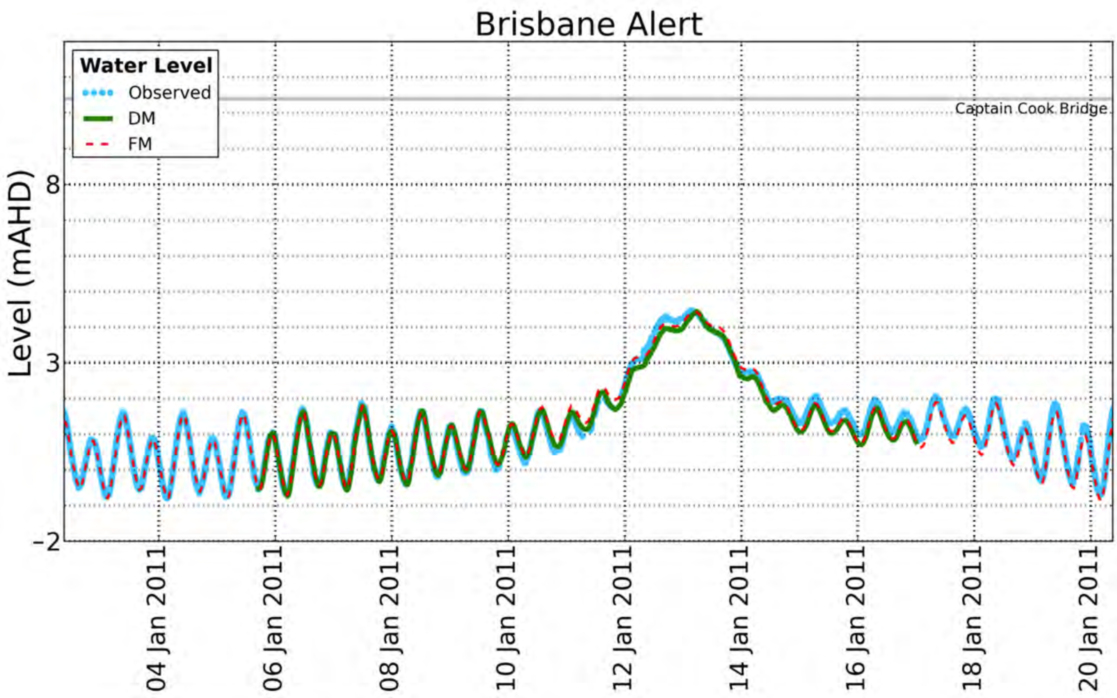


Figure 6-3 2011 Event at Brisbane City Gauge – Fast and Detailed Model vs Observed

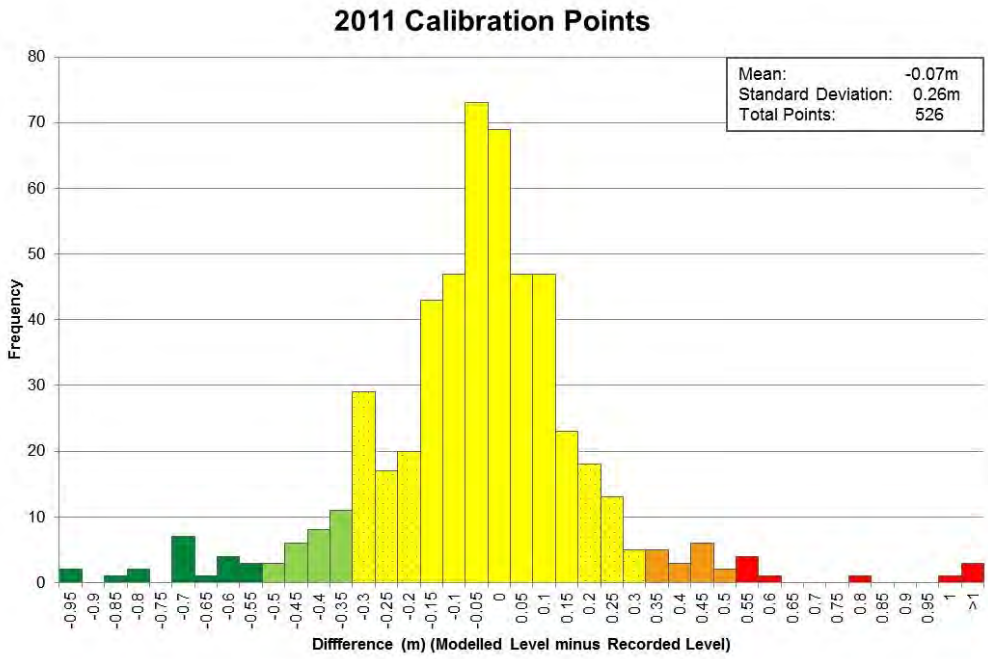


Figure 6-4 2011 Detailed Model Calibration - Statistical Assessment of Differences between Observed & Modelled Peak Flood Levels

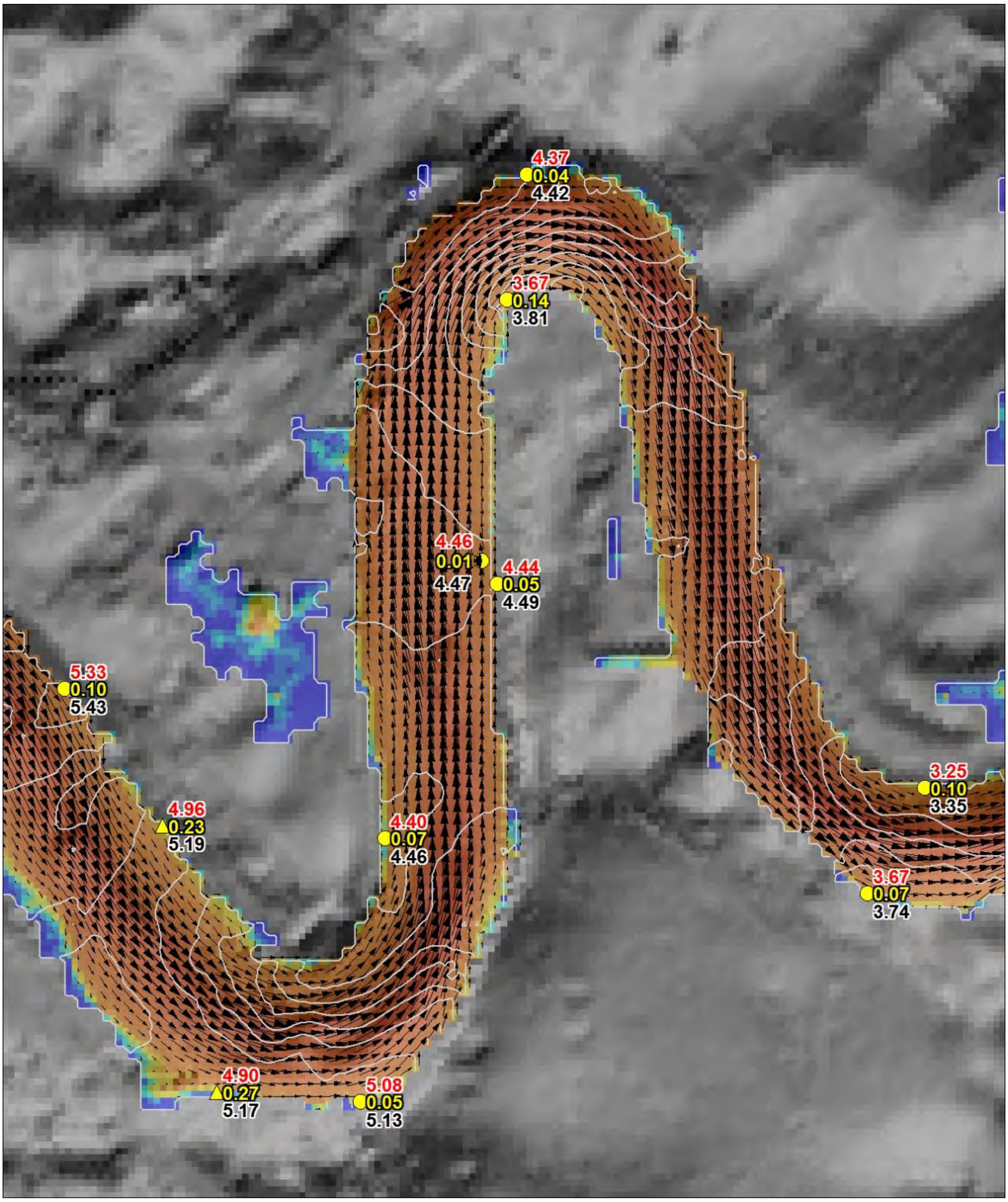


Figure 6-5 Reproduction of Superelevation at Story Bridge Bend – 2011 Flood

(Red font for surveyed level, black font for modelled level and yellow font for modelled minus surveyed)
(Water level contours at 0.1m intervals)

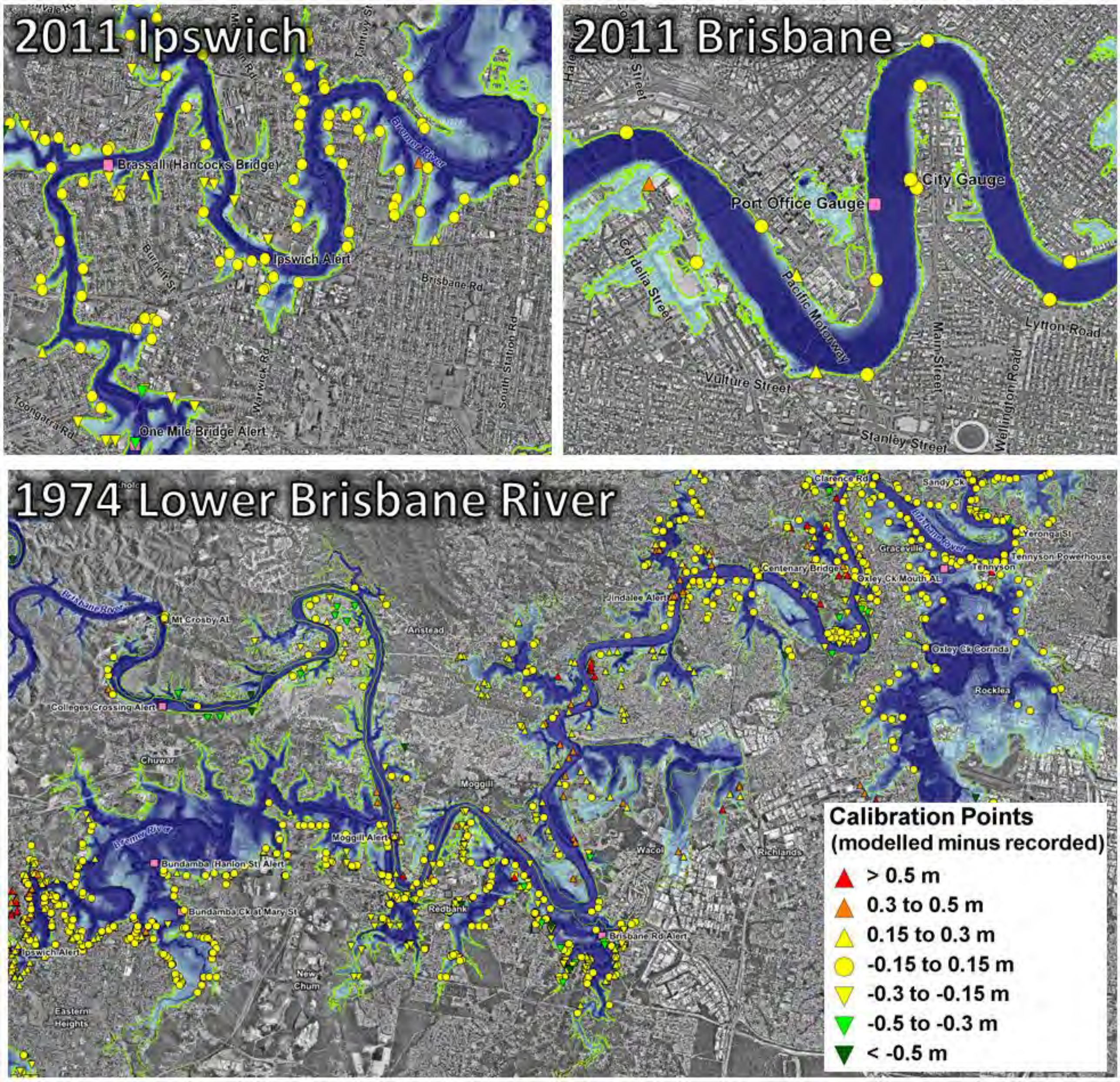


Figure 6-6 Examples of Calibration Mapping to Recorded Flood Marks

6.3.5 Rating Curve Cross Checks

Additional cross checking of model performance was undertaken by comparing the Fast and Detailed Model stage-discharge relationships at key locations, with the operational rating curves used by Seqwater and those derived by the Hydrologic Assessment. Where available, stream gauging measurements were also shown and compared. The comparisons showed consistency between Fast and Detailed Models results, the rating curves and gaugings if available, thereby demonstrating consistency between the hydrologic and hydraulic modelling.

Figure 6-7 presents an example of a comparison for Savages Crossing on the Brisbane River, a key location where consistency between hydrologic and hydraulic modelling should be evident. The Hydrologic rating curves are shown as light and dark blue circles, field measurements as yellow circles and the Fast and Detailed Model results as alternating red and green symbols respectively with a different symbol for each event.

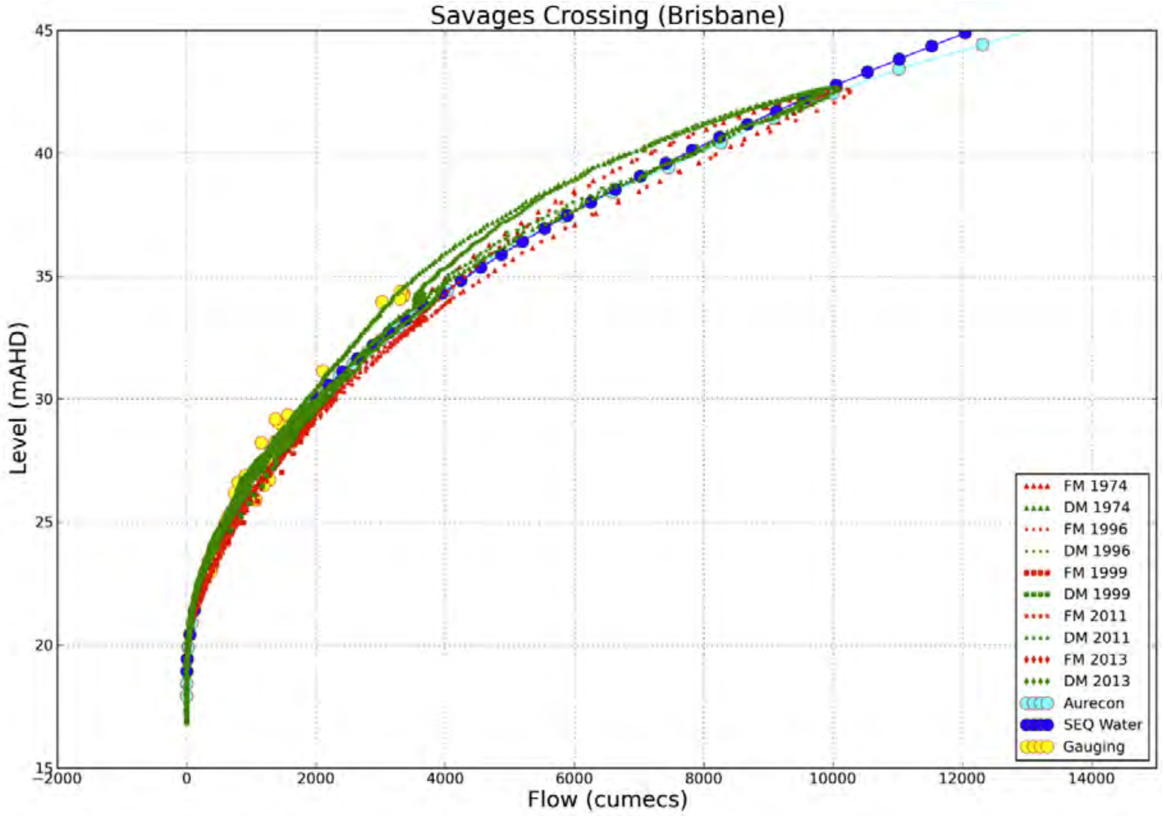


Figure 6-7 Comparison of Hydraulic Modelling with Rating Curves at Savages Crossing

6.4 Derivation of AEP Ensembles

6.4.1 Overview

For the purposes of the BRCFS an AEP ensemble is the term given to a subset of MC events that, as a group, are representative of the AEP peak flood levels at the 28 Hydraulic Assessment Reporting Locations defined along the main waterways in the study area. The selection process for the ensembles follows three stages:

(1) **Stage 1:** Simulation of the 11,340[7] Hydrologic Assessment MC events through the calibrated Fast Model retaining peak water levels and flows for each event at each Reporting Location.

(2) **Stage 2:** Undertaking a flood level frequency analysis of the 11,340 MC 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 MC events to form AEP ensembles. The maximum levels from each ensemble 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.

Eleven (11) AEP ensembles were derived based on Table 1 in the Hydraulic Assessment's ITO (DILGP, 2014), which is reproduced in Table 6-2 below. This includes the 1 in 100,000 AEP flood as this is considered the rarest event that can be estimated in a consistent and defensible manner across all sites in the study area.

Table 6-2 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] The Hydrologic Assessment considered 60 AEPs per event duration with 21 simulations performed per AEP. Thus the Hydrologic Assessment simulated 1,260 MC 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 1,260) MC events.

6.4.2 Fast Model Monte Carlo Simulations

The 11,340 MC events were simulated through the Fast Model with peak water levels and peak flows at each Reporting Location tracked at every computational timestep. A range of statistical analyses was used to check for any numerical inconsistencies causing unreliable output. For example results were flagged for review should an unusually large change in water level and/or flow over one computational timestep occur.

Fundamental checks were also made on model performance such as checking the model mass error was within standard bounds.

6.4.3 Annual Exceedance Probability (AEP) Analysis

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

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.

Results of the analysis are presented as peak AEP levels at Reporting Locations. A graphical example of this is shown below in Figure 6-8 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 6-8) does not represent the flood behaviour from any single event, and it cannot be expected that any single flood will conform to this profile.

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 and is a key location for requiring consistency between the Hydrologic and Hydraulic Assessments.

The comparison between the two sets of results is shown in Figure 6-9, from which it is seen that there is a satisfactory level of agreement between the results.

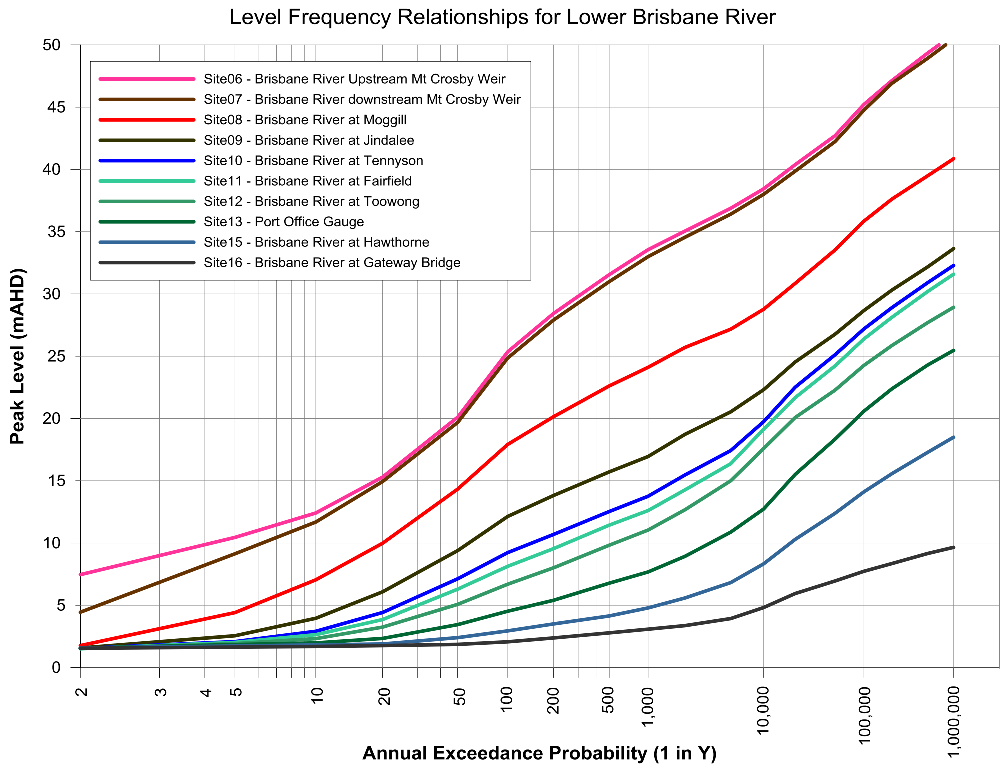


Figure 6-8 Derived Level Frequency Relationships for Sites along the Lower Reaches of the Brisbane River

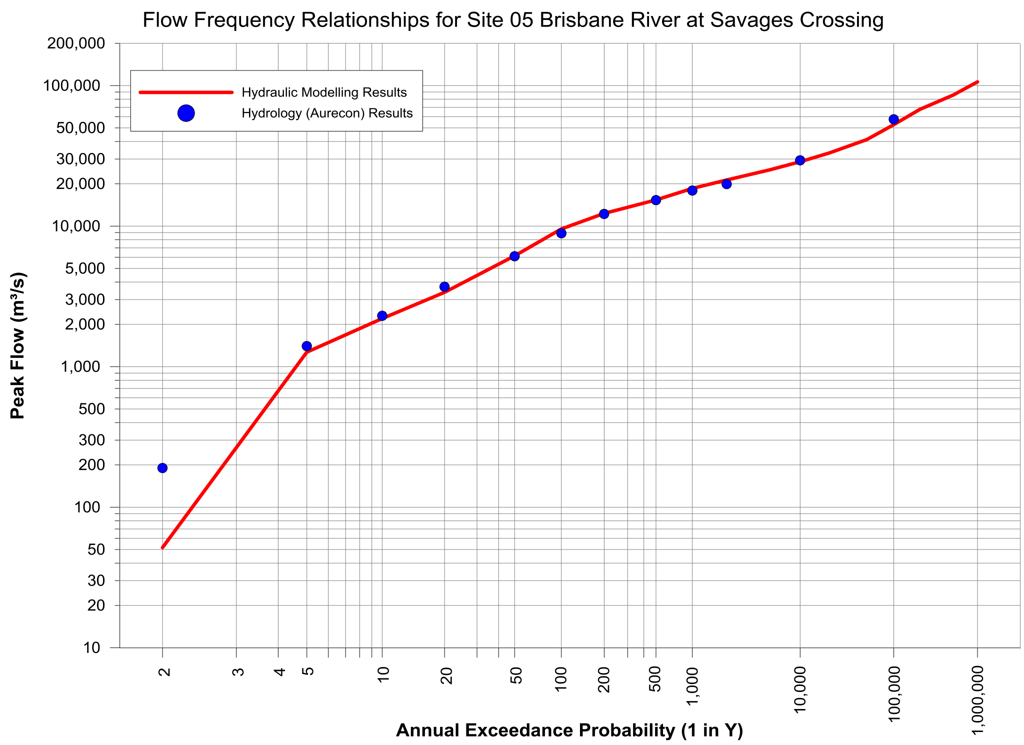


Figure 6-9 Comparison of Flood Frequency Relationships based on Results Obtained from the Hydrologic and Hydraulic Assessments

6.4.4 Selection of Fast Model AEP Ensembles

MC events forming ensembles are selected based on peak water levels. For each AEP ensemble the AEP flood level surface is calculated as the maximum of the ensemble's peak flood levels, sometimes referred to as the maximum of the maximums.

A selection process was followed based around peak flood levels being within an acceptable tolerance of the AEP level, referred to as the Critical Event Tolerance (CET). 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. The process is summarised in Figure 6-10.

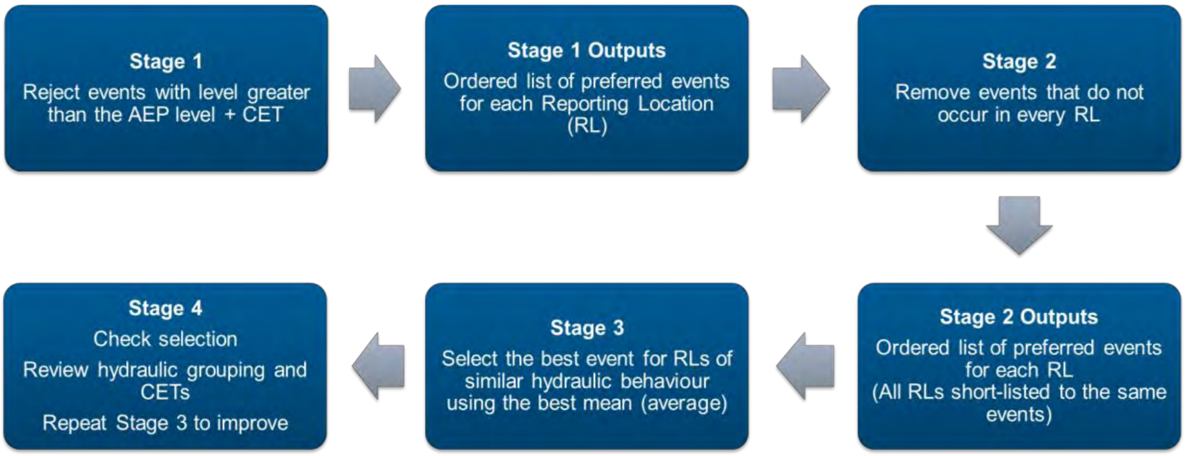


Figure 6-10 Flow Chart of MC Event Selection Methodology

6.5 AEP Ensembles

A finalised set of 60 MC events to represent the 11 AEP ensembles was derived as presented in Table 6-3.

Figure 6-11 shows an example of the 1 in 100 AEP ensemble at Moggill. The 1 in 100 AEP ensemble is comprised of five Monte Carlo events. At Moggill the event with ID '120_0776' results in the highest water level (although two events give similar but slightly lower peak levels). At other locations within the Brisbane River catchment one of the other four events may result in the highest level.

Table 6-3 Events in each AEP Ensemble after Fine-Tuning Selection using Detailed Model

AEP	% AEP	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**

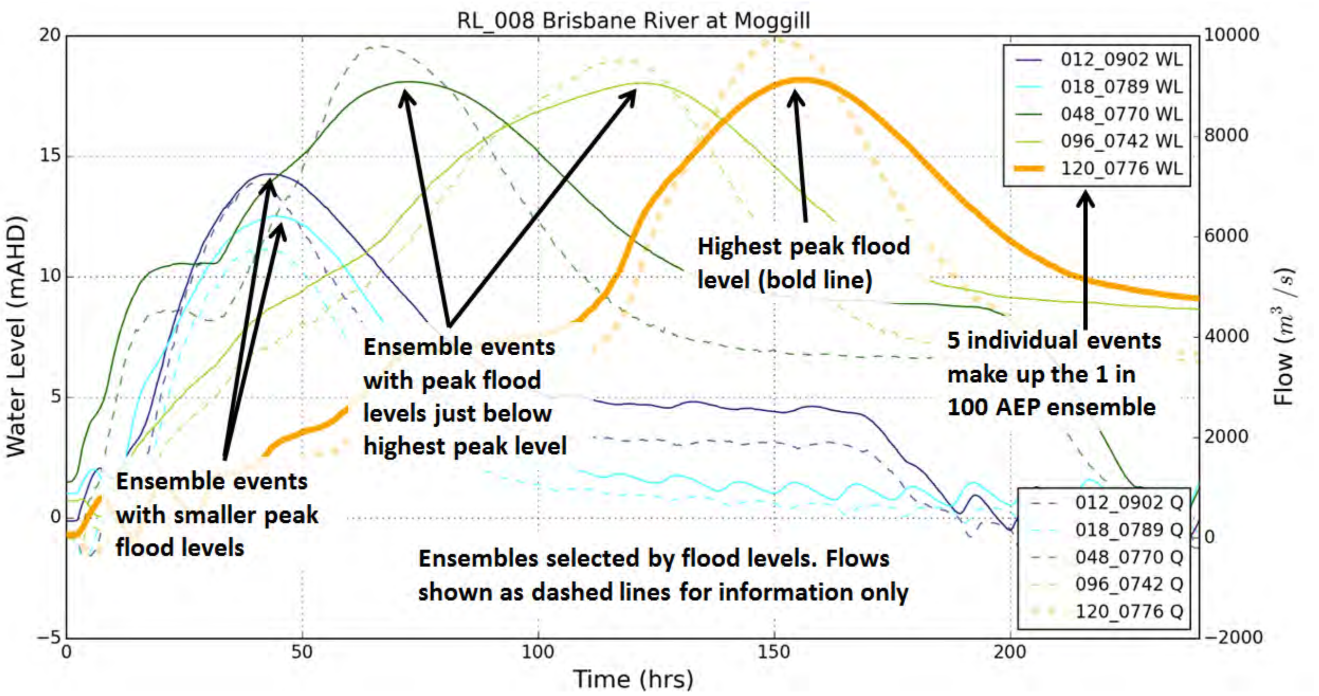


Figure 6-11 Example of an Ensemble (1 in 100 AEP at Moggill)

7 Design Riverine Flood Results

7.1 Overview

The 60 MC events that make up the 11 AEP ensembles were simulated through 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, i.e. for peak flood levels, depths, velocities and DxV (hydraulic hazard), unless otherwise specified. Table 7-1 provides a summary of the AEP design flood levels and flows at Lowood, Ipswich, Moggill and Brisbane CBD. The Fast Model and Detailed Model results for the 60 MC events were compared and showed satisfactory agreement.

It is noted that due to the different techniques utilised for hydrologic and hydraulic modelling, the flows produced by these two methods can differ. Where the hydrologic modelling interfaces with the hydraulic modelling, the flows are the same. However, progressing downstream hydraulic models are more accurate in calculating the propagation speed and distribution of flood waters down the river, creeks and onto the floodplains. Therefore, greater differences in flows may occur the further the distance from the hydrologic/hydraulic interface.

A schematic containing selected AEP ensemble peak levels relative to the river bed levels and the significant historical events of 1893, 1974 and 2011 is shown for Ipswich and Brisbane in Figure 7-1 and Figure 7-2 respectively.

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

- In the lower reaches of Lockyer Creek floodplain, the 1 in 100 AEP flood level is comparable to both the 1974 and 2011 although is higher in some places (typically 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 level is lower than both the 1974 and 2011 floods (e.g. at Lowood it is approximately 0.8m to 1.0m lower than both 1974 and 2011 events).
- Near Ipswich CBD the 1 in 100 AEP flood level 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 level is typically 0.1m to 0.3m higher than the 2011 flood. In the Brisbane CBD region, the 1 in 100 AEP level is similar or up to 0.2m higher than 2011, and around 1.0m lower than the 1974 flood.
- Downstream from the Gateway Motorway, the 1 in 100 AEP flood level is similar to the peak level resulting from the storm surge experienced in the January 2013 event, which was higher than that experienced during 2011 and 1974 floods.

The 1 in 200 AEP flood level 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.

Table 7-1 Summary of Peak Design Flood Levels and Flows at Lowood, Ipswich, Brisbane and Moggill

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.

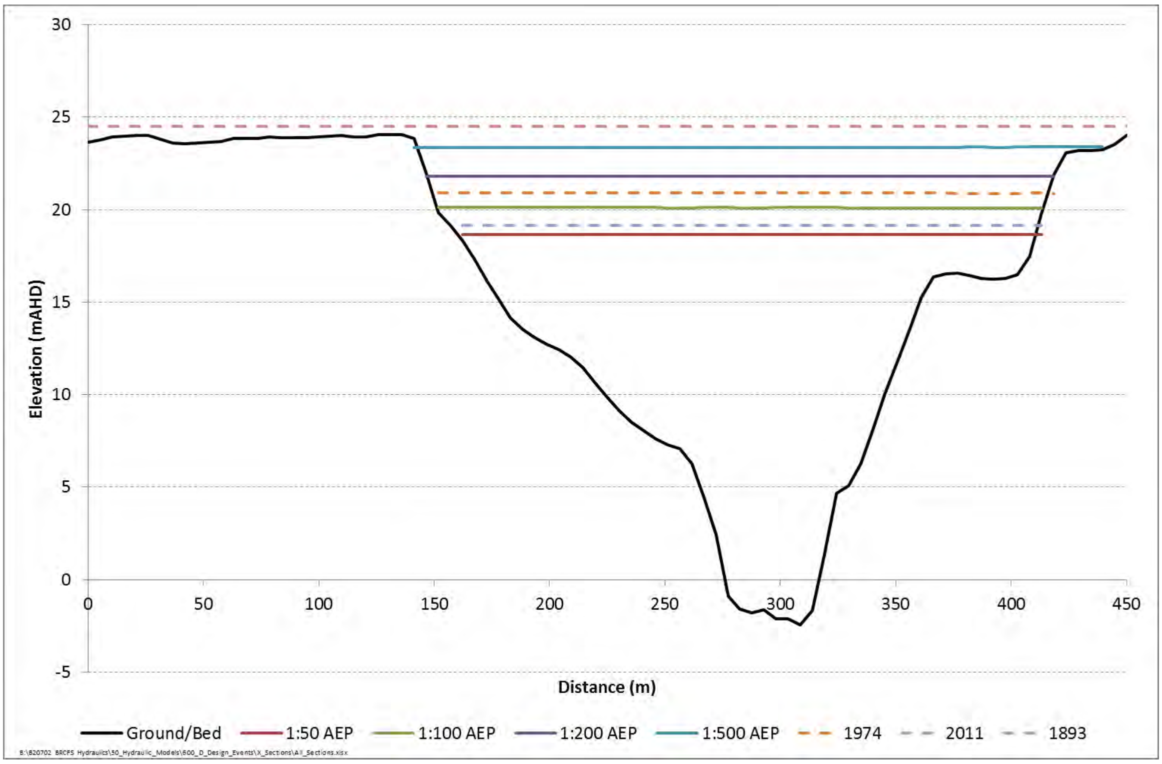


Figure 7-1 Ipswich CBD Design and Historic Flood Levels

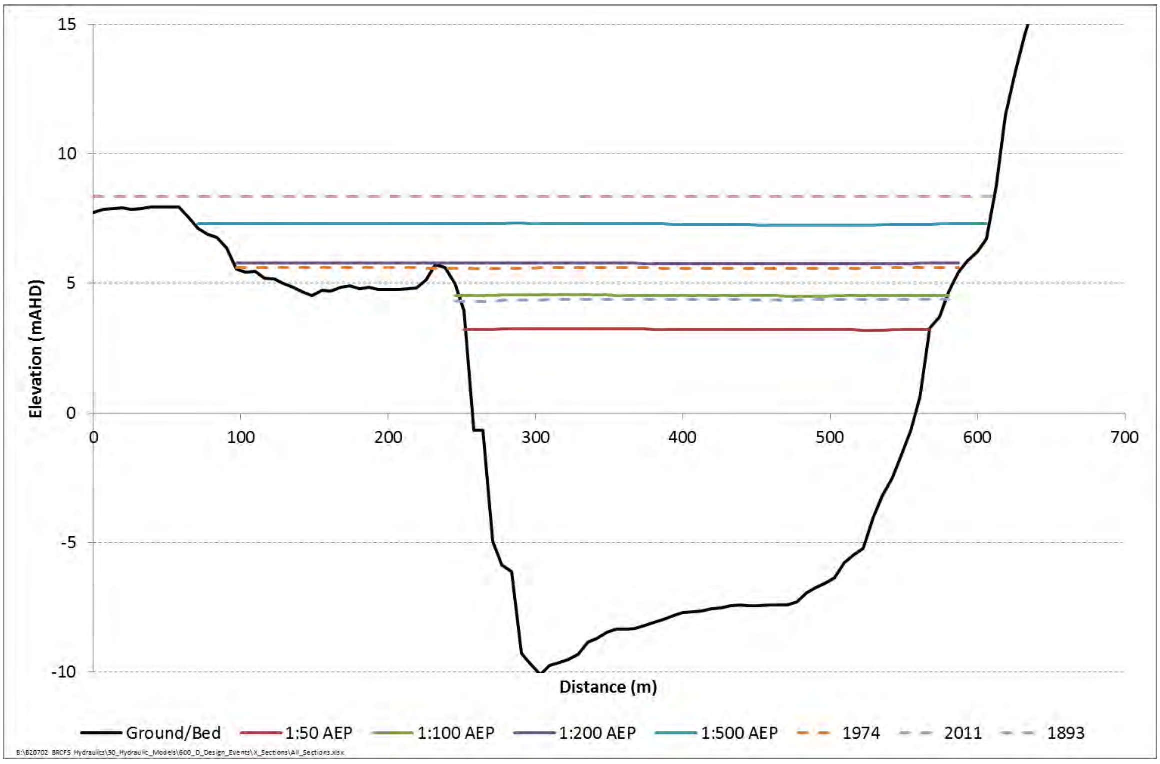


Figure 7-2 Brisbane CBD (City Gauge) Design and Historic Flood Levels

7.2 Mapping

The Hydraulic Assessment provides peak outputs across the assessment area digitally for all AEP floods. Drawings are divided into AEP floods and then further divided into five regions with one A3 page per region. A key sheet identifying the regions is provided in Map 1.

Four model outputs are presented as follows; with examples shown in Figure 7-3.

- Peak Water Surface Levels – the flood extent is shown with 1m interval contours giving peak level to mAHD. Examples provided in this report (Map 2 to Map 6) showing the 1 in 100 AEP mapping additionally including intermediate 0.5m contour intervals.
- Peak Flood Depth Maps – blue shaded mapping indicating five intervals of flood depth.
- Peak Flood Velocity Maps – multi-colour shaded mapping with six intervals of velocity.
- Peak Depth x Velocity (DxV or Hydraulic Hazard) Maps – multi-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 yellow dashed line showing the ‘extreme flood’ extent, nominally taken as 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 Hydraulic 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 flood is included in the A3 Map Addendum at the end of this report (see Map 2 to Map 21).

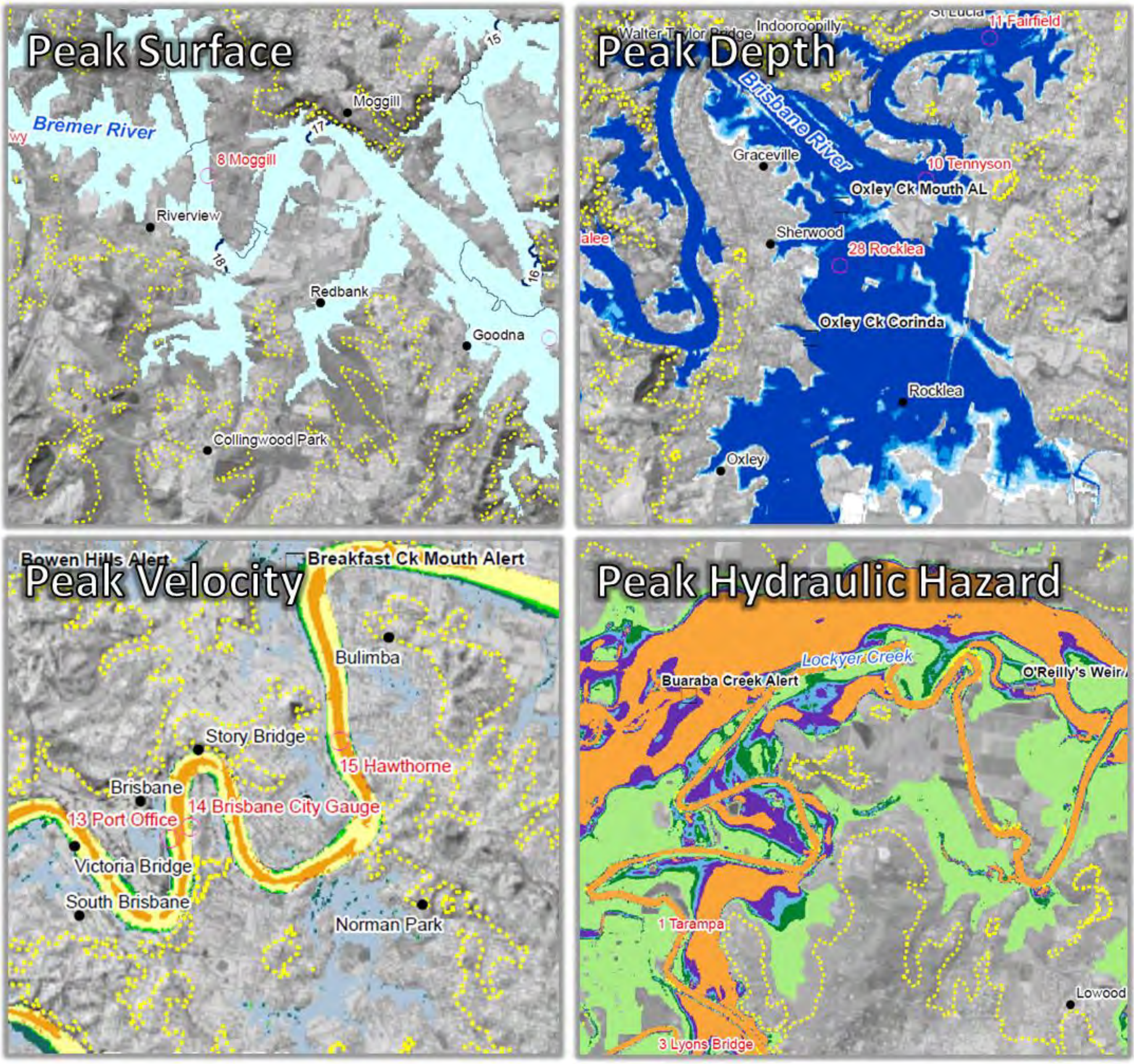


Figure 7-3 Example Map Output for the 1 in 100 AEP Flood

7.3 Hydrographs

Plot output for the modelling includes:

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

An example time series plot for Brisbane City Gauge is shown in Figure 7-4 for the 1 in 100 AEP ensemble. It contains both water levels (WL) and flows (Q). All five MC events that comprise the 1 in 100 AEP ensemble are included on the plot labelled with a unique event identifier. A thick line is used to indicate that individual MC event that results in the highest peak flood level at the location.

It can be seen that in this case, three MC events give peak levels close to the maximum peak of 4.5 mAHD but the events differ in their timing and in the rate of rise. Therefore, the individual MC event within an ensemble that results in the highest flood level at any given location for that ensemble may not be the event that exhibits the fastest rate of rise or longest duration of inundation at that location.

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 MC events. Whether or not a rate of rise estimated by one of these three options is suitable is dependent upon the accuracy required.

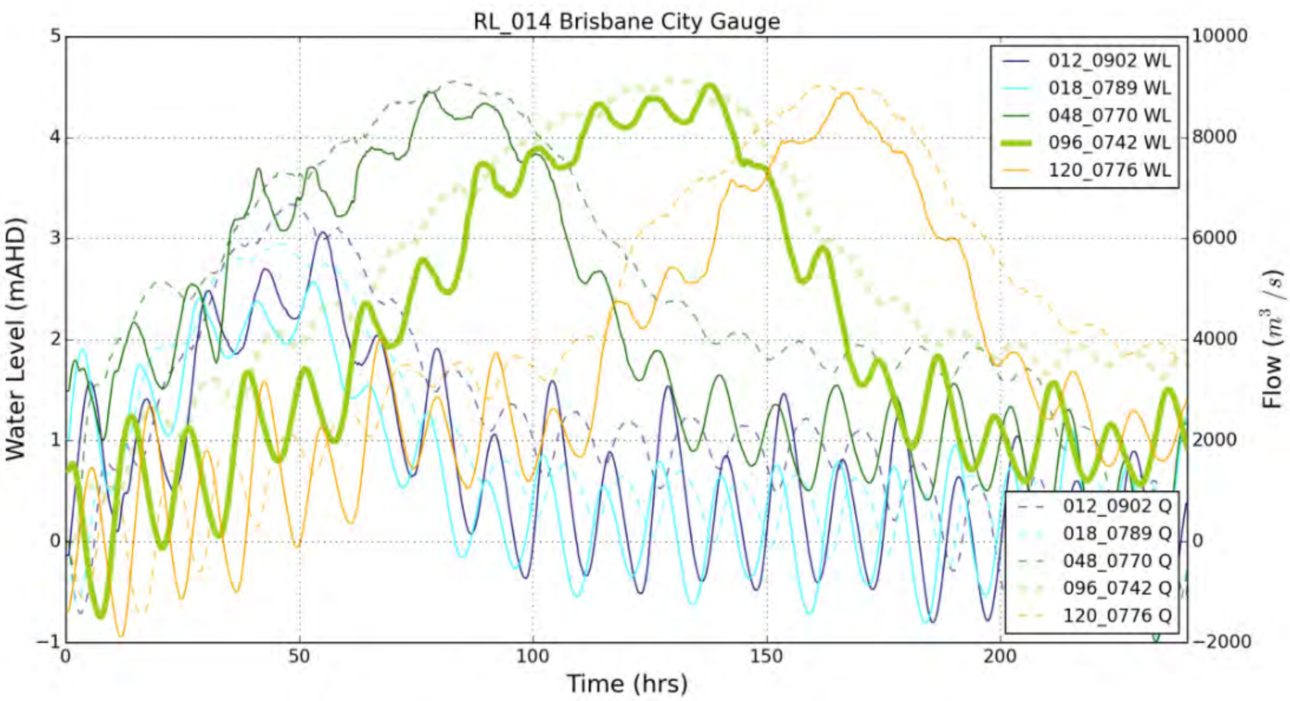


Figure 7-4 Hydrograph (Stage and Flow) at Brisbane City Gauge for the 1 in 100 AEP Ensemble (5 Events)

7.4 Backflow Prevention Devices

Following the 2011 event, a programme began to fit a number of large drainage pipes in inner Brisbane with backwater prevention devices, which are designed to prevent river water backing up into low-lying areas. Such devices do not provide protection for all floods for the following reasons:

- The device may fail - the device becomes blocked or unable to fully close.
- The river bank is breached or overtopped - major riverine floods can still overtop river banks when flood levels in the river are high enough.

As it is not possible to eliminate all flood risk for the reasons outlined above, it was assumed (in agreement with the TWG) that no backflow prevention devices were fitted to the stormwater pipes or trunk drainage systems, for the design flood modelling.

Mapped output may therefore show flooding in areas for which backflow prevention devices would otherwise provide protection. In this regard, the mapping can be considered conservative in these areas.

7.5 Rating Curve Reconciliation

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.

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.

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. In lieu of these factors, a single rating curve per site was not produced using hydraulic model results. Instead, the results from the hydraulic modelling are presented along with the effects of any looping or hysteresis as this can be used to help inform agencies of the sensitivity and uncertainty when adopting a single rating curve at a hydraulically complex site.

For ten nominated sites a rating review has been undertaken and contrasted to a review of the Hydrologic Assessment rating curves. The review concluded that the Hydrologic Assessment rating curves are commensurate with the hydraulic modelling stage-discharge relationships within the bounds of data inaccuracies, modelling uncertainties, hysteresis effects, and variations in hydraulic behaviour of the different calibration events. On this basis it was agreed and endorsed by the IPE that there was no justifiable benefit in seeking to further refine the hydrologic and hydraulic modelling calibrations.

Contrasting examples are shown below for the rating curves at two nominated sites: Savages Crossing on the Brisbane River (Figure 7-5); a relatively consistent rating at a site not subject to any notable backwater influences, and at Amberley on Warrill Creek (Figure 7-6); a site subject to backwater influences from the Brisbane River during extreme events. The 'Operational (2013)' rating curves are those developed by Seqwater as part of model calibration (Seqwater 2013b) to inform real time flow forecasting for dam operations[8].

It is to be noted that different models (e.g. the hydrologic model and the Fast and Detailed hydraulic models) have varying abilities to represent the complex and variable looping characteristics of rating curves. The hydraulic models with their ability to reproduce variations in hydraulic gradients as the flood rises and falls, and to take into account more accurately the effects of backwater, are considered significantly more accurate in this regard.

Differences between the Fast Model and the Detailed Model are primarily the consequence of the Fast Model's substantially more simplistic geometrical representation of the river and floodplains, as well as the more simplistic assumptions adopted in the 1D hydraulic equations used by the Fast Model.

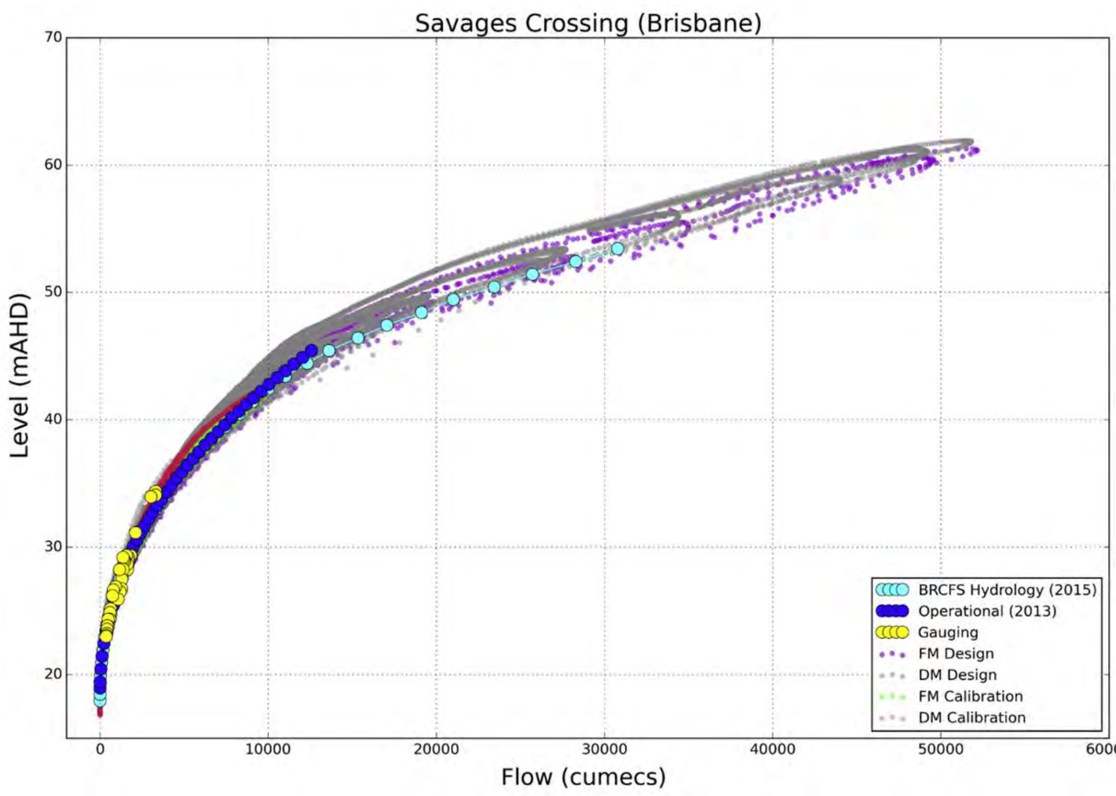


Figure 7-5 Rating Curves at Savages Crossing, Brisbane River

[8] The 'Operational 2013' rating curves are valid at the time of report prepared by Seqwater. Seqwater continue to review and revise rating curves as required and the operational rating curves presented in this study may not necessarily be current.

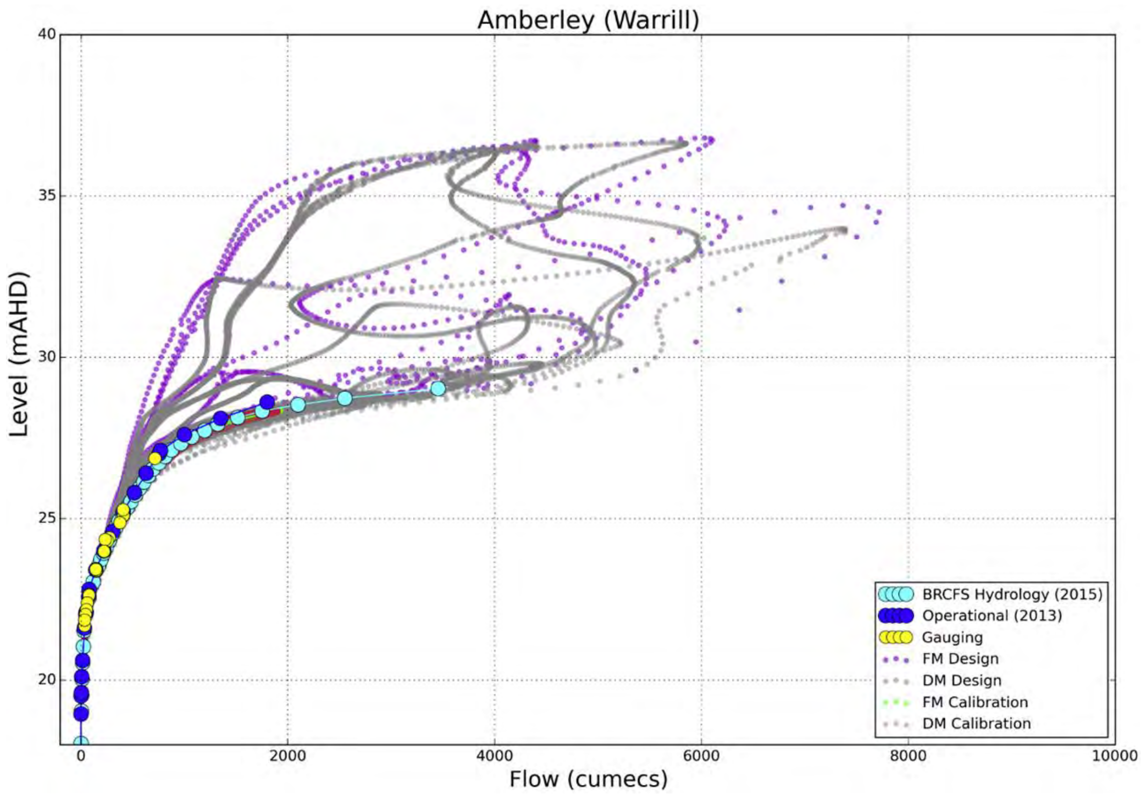


Figure 7-6 Rating Curves at Amberley, Warrill Creek

8 Sensitivity Analysis

8.1 Introduction

Sensitivity scenarios have been simulated to ascertain the sensitivity of the Base Case 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.

It is important to clarify that when the sensitivity scenarios are simulated using pre-selected AEP ensembles, the flood modelling outputs represent the impacts on only those individual ensemble events. The sensitivity scenarios do not produce equivalent AEP peak flood levels for that scenario and must be regarded as indicative only.

In general, four categories of sensitivity test have been undertaken as follows:

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

8.2 With and No Dams

A ‘no dams’ scenario, in which the influence of the major storages of Wivenhoe, Somerset, Cressbrook, Perseverence, Manchester and Moogerah Dams was removed, was compared to a ‘with dams’ scenario. This was undertaken for the five calibration events 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[9]. This allows for a ‘like for like’ comparison of the dams’ influences on the five calibration events.

Table 8-1 presents 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 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 2.0m in Brisbane and 2.8m at Ipswich for the model conditions simulated.

[9] 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.

Table 8-1 No Dams: Brisbane City Gauge

Event	No Dams* (mAHD)	With Dams** (mAHD)	Change due to Dams (m)
Brisbane City Gauge			
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
Ipswich CBD			
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

* 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

8.3 Climate Change

Climate change sensitivity scenarios examined the impacts of climate change (storm rainfall characteristics and sea level rise) on design flood levels. Both mid and high range climate predictions were assessed. Table 8-2 summarises the climate change parameters that have been adopted for sensitivity analysis as specified in the ITO.

Table 8-2 Parameters used in the BRCFS Climate Change Sensitivity

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

Four Climate Change scenarios are modelled based on combinations of the parameters given in Table 8-2 as follows:

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

Results from these scenarios are derived for 1 in 5, 20, 100 and 10,000 AEPs. Peak level results at Brisbane and Ipswich CBDs are graphically presented using bar charts in Figure 8-1.

Figure 8-1 shows that scenarios CC1 and CC3, which only have a sea level rise change, have a diminishing impact upstream from the ocean (with negligible change at Ipswich) and with increasing magnitude of flood event (negligible influence in Brisbane for the 1 in 10,000 AEP flood).

For much of the Brisbane River, the CC2 scenario (0.3m rise in sea level and 10% increase in rainfall intensity) produces similar peak levels to the Base Case 1 in 200 AEP flood levels. The CC4 scenario (0.8m rise in sea level and 20% increase in rainfall intensity) produces peak levels around 2.5m above Base Case 1 in 100 AEP levels for Brisbane CBD. For parts of the lower Bremer, peak levels for this scenario are around 3.8m higher.

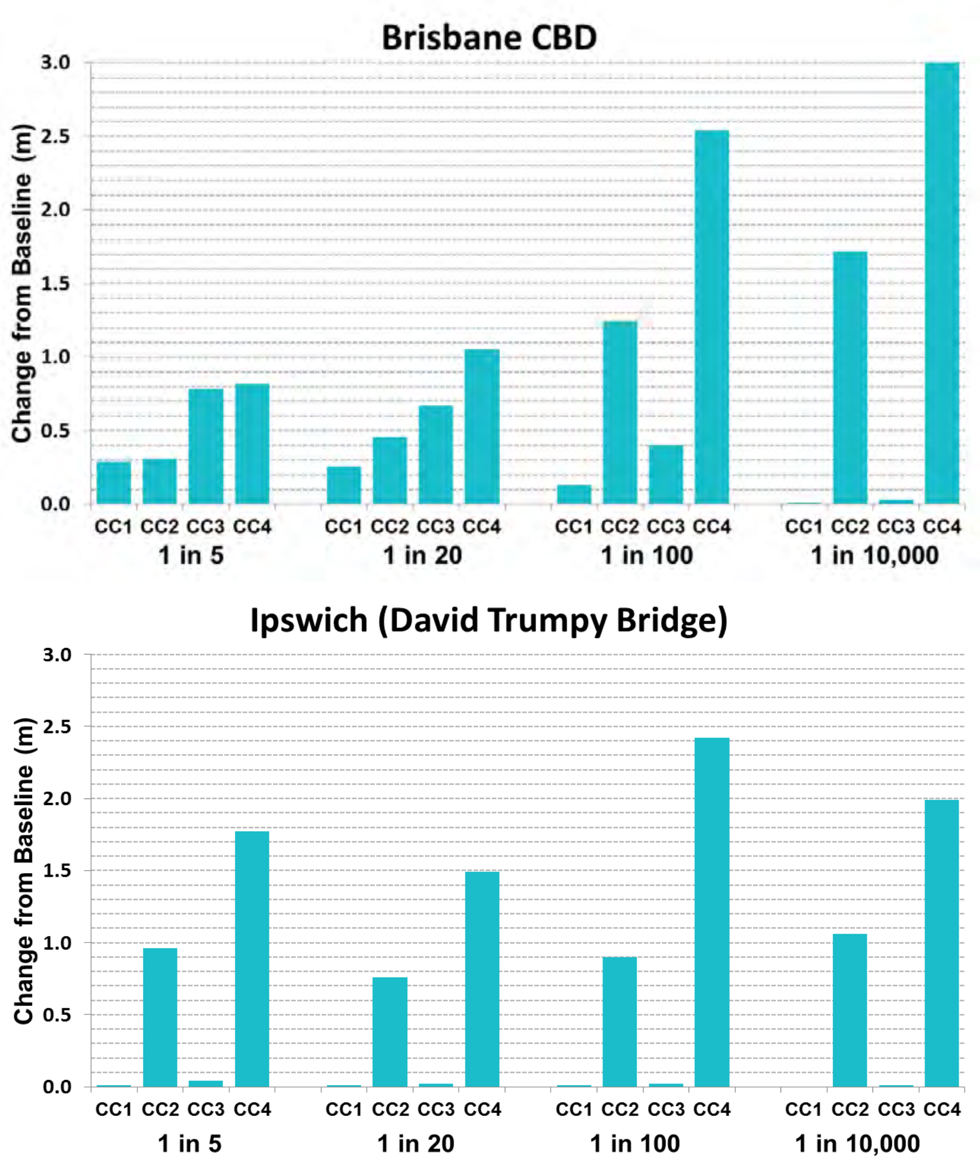


Figure 8-1 Change in Peak Flood Level under Climate Change Sensitivity Scenarios

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

8.4 Bed Level Change

The Detailed Model has been used to gain an understanding of the sensitivity on modelled peak flood levels to potential changes in channel geometry caused by sediment movement. The adopted approach relates a change in bed level to a desired change in channel conveyance.

A ±20% conveyance change was taken as appropriate for the upper and lower bounds of the assessment resulting in two scenarios:

- BL1: 20% increase in conveyance (decrease in bed level) resulting in approximately 38 million cubic metres of bed material removed. This equates to an average 2m decrease in bed level.
- BL2: 20% decrease in conveyance (increase in bed level) resulting in approximately 41 million cubic metres of bed material added. This equates to an average 2m increase in bed level.

The changes to bed level are 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.

Figure 8-2 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 peak level is also shown. The decrease in bed level lowers peak 1 in 100 AEP flood levels at Brisbane CBD by around 0.7m. Although there are no changes to bed level along the Bremer River, the peak level at Ipswich CBD decreases by around 0.3m 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 1m. An increase in peak flood level of 0.5m 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.

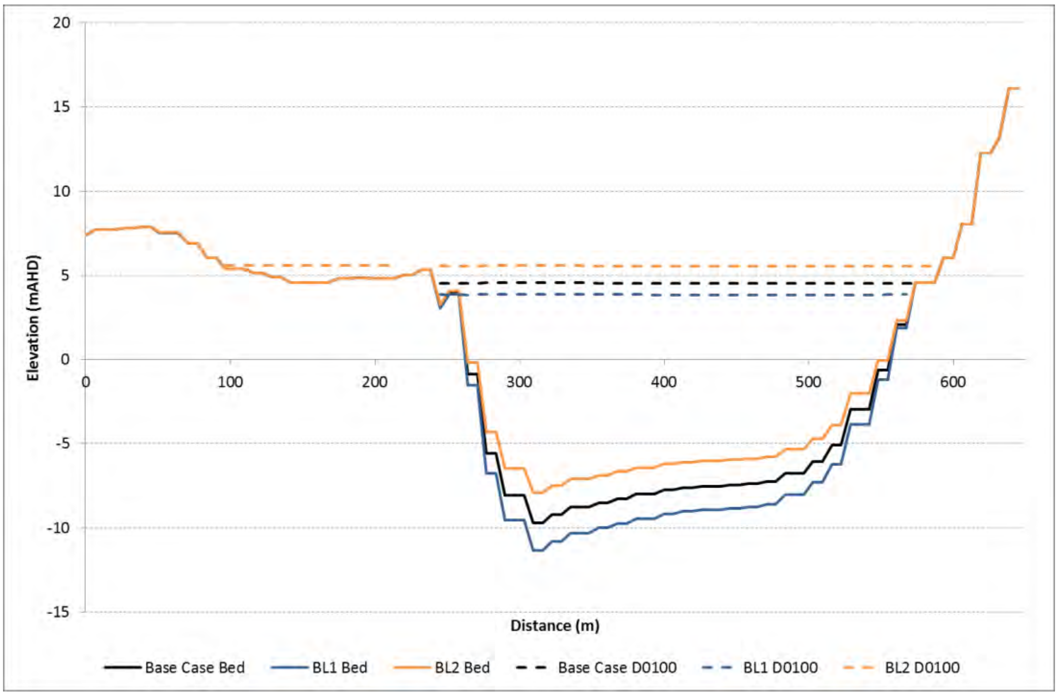


Figure 8-2 Brisbane CBD: Bed Level Sensitivity, 1 in 100 AEP Flood

8.5 Future Floodplain

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 floodplain. This sensitivity test simulates a hypothetical ultimate development scenario across the Brisbane City Council (BCC) and Ipswich City Council (ICC) local government areas.

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 floods. 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 and the results obtained can therefore be considered excessive and beyond the bounds of reality.

In all AEP floods modelled for this scenario (1 in 100, 200, 500 and 10,000 AEPs) 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. The effect is more pronounced for the larger events considered. Table 8-3 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 on flows. Modelled peak levels are predicted to be around 2m lower at the City Gauge in Brisbane CBD.

Table 8-3 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

9 How BRCFS Addresses QFCoI Recommendation 2.2

The Queensland Floods Commission of Inquiry (QFCoI) was established in January 2011 to undertake a detailed investigation into the events of the 2010/2011 floods across Queensland. The Commission's brief was to make recommendations for the improvement of preparation and planning for future floods and natural disaster emergency response, including any necessary legislative change.

The QFCoI Final Report[10] was issued in March 2012 and contained 177 recommendations covering a broad range of flood related issues. Recommendation 2.2 set out the need to complete a flood study of the Brisbane River catchment and identified components that should be addressed within the study. Descriptions of the components and how the BRCFS addressed each one are presented in Table 9-1. Colour shading indicates whether the component relates to the Hydrologic Assessment (blue), Hydraulic Assessment (pink) or both (yellow). Table 9-1 summarises how each component has been addressed within the BRCFS.

Table 9-1 BRCFS Treatment of QFCoI Recommendation 2.2 Components

QFCoI Recommendation 2.2 Component	BRCFS Treatment
Be comprehensive in terms of methodologies applied and use of different methodologies to corroborate results	Use of FFA, DEA and MCS approaches in the Hydrologic Assessment including reconciliation of methods. Use of Fast and Detailed Models in the Hydraulic Assessment, detailed calibration and reconciliation between models and Hydrologic Assessment. Exhaustive TWG and IPE reviews.
Collate, and create where appropriate: -rainfall data -stream flow data -tide levels -inundation levels and extents -data on the operation of Wivenhoe and Somerset dams -river channel and floodplain characteristics including topography, bathymetry, development and survey data	Collation of historic rainfall, stream flow, tidal data, historic flood data, dam operations, topographic, bathymetric and hydraulic structure data. Generation of synthetic rainfall data for design flood purposes.
Determine correlation between any of the above data sets	Correlations between random variables such as the spatial and temporal pattern of rainfall and correlation between rainfall and reservoir volumes or ocean water levels undertaken within the Hydrologic Assessment.
Produce suitable hydrologic models run in a MC framework, taking account of variability in factors such as: -spatial and temporal rainfall patterns -saturation of the catchment -initial water levels in dams -effect of operating procedures -physical limitations on the operation of the dams - tidal conditions	Development and calibration of the URBS hydrologic model then simulated in a MCS framework. The MCS framework takes account of the variability in the listed factors.

[10] Queensland Floods Commission of Inquiry, Final Report, QFCOI, Brisbane, March 2012.

QFCoI Recommendation 2.2 Component	BRCFS Treatment
- closely occurring rainfall events	
Validate hydrologic models to ensure they reproduce: -observed hydrograph attenuation -probability distributions of observed values for total flood volume and peak flow -timing of major tributary flows -observed flood behaviour under no dams conditions and current conditions	Calibration of the hydrologic model to five events with validation to a further 43 events. 'No dams' and 'with dams' (current) conditions assessed.
Produce a suitable hydraulic model or models that : -are able to determine flood heights, extents of inundation, velocities, rate of rise and duration of inundation for floods of different probabilities -are able to deal with movement of sediment and changes in river beds during floods -are able to assess historical changes to river bathymetry -are able to be run in a short time to allow detailed calibration and assessment work -characterise the backwater effect at the confluence of the Brisbane and Bremer rivers and other confluences as appropriate	'Fast' and 'Detailed' models developed. Both models can be used for determination of flood heights, velocities, rate of rise and duration of inundation for small to extreme flood events. Detailed model can additionally be used for mapping flood extents. In agreement with the TWG and IPE the Detailed Model was used to gain an understanding of the sensitivity of modelled peak flows and peak levels to changes in channel geometry (bathymetry) rather than perform morphological (dynamic change in river bed levels) modelling due to lack of bed level change data. Model run times are suitable for facilitating a Detailed Model calibration and further assessment. Models calibrated/validated to five historical flood events and tested for extreme hypothetical flood events. Backwater effects of the Brisbane River (downstream of Wivenhoe Dam) on all tributaries are fully accounted for.
Analyse joint probability of floods occurring in the Brisbane and Bremer rivers (and any other pair of rivers if considered appropriate)	Accounted for through the MCS methodology that encompasses thousands of resulting flood combinations.
Be iterative and obtain short-term estimate of the characteristics of floods of different probabilities in all significant locations in the catchment (at least Brisbane City, Ipswich City and at Wivenhoe Dam) in order to determine the priorities for the rest of the study.	The DMT study (BCC CPO, BCC 2014b) carried out before the Hydraulic Assessment provided this insight, which was subsequently utilised for the Hydrologic and Hydraulic Assessments. The Hydrologic and Hydraulic Assessments were delivered in multiple stages with each stage assessed on its own merits and priorities established for the subsequent stages.

10 Study Limitations and Uncertainties

This BRCFS represents the most comprehensive hydrologic and hydraulic modelling assessment 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 previous regional scale hydraulic assessments undertaken.

However, all modelling contains limitations as modelling is a simplification of the physical process it is representing. Therefore, the future use of the BRCFS hydrologic and hydraulic models and associated numerical analyses and methods, needs to take into account the assumptions, limitations and constraints, so as to correctly interpret the outcomes and outputs, and to appropriately apply and use the models into the future.

The following points summarise the main limitations and uncertainties, focussing on the final study outputs. This summary list is not exhaustive and reference should be made to the relevant BRCFS technical reports (see Section 12) for details on modelling limitations and uncertainties.

- Assessment of the hydrologic modelling flood peak estimates indicates that wide confidence limits are expected for most locations for the more frequently occurring events (1 in 2 AEP to 1 in 20 AEP). The uncertainty increases with increasing flood magnitude and it needs to be recognised that a significant degree of uncertainty exists with the derived flood frequency curves, particularly for the range of large to extreme events. However, greater reliance is placed on estimates for locations where consistency exists between the FFA, DEA and MCS methods. Despite this uncertainty, the hydrologic modelling is significantly more comprehensive than any previous studies of the Brisbane River catchment and has substantially reduced the high degree of uncertainty in flood peak estimates downstream of Wivenhoe Dam that existed prior to the BRCFS.
- Hydrologic modelling locations that are considered the most unreliable include the Bremer River catchment locations of Walloon, Amberley and Loamside, where there are inconsistencies between FFA and the rainfall based approaches due to a possible underestimation of the underlying design rainfall data. Less confidence can also be placed in the Lockyer Creek catchment location estimates due to higher uncertainty in the high stage rating of these sites, which occurs when flow exceeds the main channel capacity and spills into the floodplain.
- Hydraulic modelling outputs are for riverine flooding, not local flooding, and must be interpreted as such. Riverine flooding in the context of this study is flooding due to elevated levels in the Brisbane and Bremer Rivers, and in the lower Lockyer, Warrill and Purga Creeks, as covered by the modelling. Flooding in side tributaries is only represented insofar as being caused by the elevated riverine levels. Recommendations on handling flood mapping from local and riverine flooding are provided in the Hydraulic Assessment reporting.
- Other than for tidal regions, the Detailed Model has had limited calibration for very small flood events (less than 2,000m^3/s peak flow) and flood events greater than the major floods of 1974 and 2011 (greater than 15,000m^3/s peak flow). Events outside the range of the calibration event magnitudes are more uncertain.

- The derivation of design flood levels from the hydraulic models for each AEP was established using the MCS statistical method at 28 locations (the Hydraulic Assessment Reporting Locations) along the main rivers and creeks. Outside the area covered by these Reporting Locations, the AEP level estimates may have less accuracy than AEP level estimates at Reporting Locations.
- The Detailed Model is designed for regional flood mapping, planning and development control, and should only be used for modelling features that have a measureable influence on Brisbane River riverine flooding. The model is not designed for assessing flood impacts from individual property scale works. However, it is suitable for determining riverine AEP flood levels at the property scale noting any limitations on the mapping.
- The Detailed Model assumes that no backflow prevention devices are fitted to the stormwater pipes or trunk drainage systems for the Base Case modelling. This will result in a conservative (worst case) modelled riverine flood level and extent in those areas that are typically protected by the backflow prevention devices.

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). It is understood that this matter is being addressed by the Queensland Government in conjunction with the local governments, with DSITI as the data custodian.

Whilst the Hydraulic Assessment is a highly comprehensive detailed investigation, the models represent a point in time and the current situation can change. Triggers for revisiting or reworking will depend on the significance of change to the study outcomes which will need to be assessed accordingly. Such triggers could include major flood events, improvements to design rainfalls, increased certainty on the effects of climate change, significant advancements in modelling techniques and major civil works such as large dams or extensive levee work.

11 Conclusions

The BRCFS Hydrologic and Hydraulic Assessments have conducted through a wide-ranging and thorough approach using the latest proven and established techniques, innovation through the use of the Monte Carlo Simulation (MCS) statistical method and modelling that has been subject to a robust calibration to historical flood events of varying magnitude. By taking this wide-ranging and thorough approach in scope, along with an exceptionally high level of technical review via the Technical Working Group (TWG) and Independent Panel of Experts (IPE), the BRCFS is the most complex and comprehensive flood study undertaken of the Brisbane River catchment and most likely, undertaken in Australia to-date.

The key outcomes from the BRCFS Hydrologic and Hydraulic Assessments are:

- Consolidated stream flow rating curves that are reconciled and endorsed by the hydraulic modelling.
- Calibrated hydrologic models for the purpose of deriving floods from design rainfall events and which cover the entire Brisbane River Catchment providing flow hydrographs for input to the hydraulic modelling.
- A simplified Wivenhoe and Somerset Dam operations model integrated with the hydrologic modelling.
- A statistical framework for deriving design flood flow estimates using the MCS method with a data set covering more than 230,000 statistically derived flood events across the entire catchment.
- The “Fast Model”, a hydraulic model that simulates a flood event in around 5 minutes, and accurately reproduces the flood wave along the main waterways below Wivenhoe Dam.
- The “Detailed Model”, a hydraulic model that uses world leading software and technology to produce a high resolution, accurate reproduction of Brisbane River flood characteristics.
- Successful calibration and verification of the hydrologic and hydraulic models to the historical events of 1974, 1996, 1999, 2011, 2013 and tidal only conditions, using in each model a single set of industry standard parameters for that model.
- Statistical analysis of 11,340 statistically derived events using the Fast Model to derive interim AEP peak flood levels at 28 locations below Wivenhoe Dam using the MCS method.
- Selection of a set of 60 MC events from the 11,340 MC events that produce peak levels at the 28 locations that match the derived interim AEP flood levels. The 60 MC events form 11 AEP ensembles ranging from the 1 in 2 to the 1 in 100,000 AEP. Each AEP is an ensemble of 4 to 7 MC events.
- Simulation of the 60 MC events through the Detailed Model to produce high resolution maps of peak flood levels, depths, velocities and hydraulic hazard (a measure used for evaluating the flood risk). Other outputs include tables of peak levels and flows, and charts in a variety of formats.

- Sensitivity tests using the Detailed Model to provide indicative estimates on changes to flood behaviour resulting from: (a) a hypothetical future floodplain development case; (b) climate change; (c) Brisbane River bed level changes; and (d) the effect of major dams on historical flood events.

The BRCFS is the most comprehensive, up-to-date and accurate assessment of Brisbane River riverine flooding for AEPs ranging from 1 in 2 to 1 in 100,000. The latest available data was used to develop hydrologic and hydraulic models, and these models were validated by calibrating and verifying their results against well documented historical floods and tidal conditions. Industry leading techniques were used to derive AEP design floods 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 BRCFS.

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12.1 BRCFS Technical Report References

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- **Hydrologic Milestone Report 3:** Hydrologic Model Recalibration Report, May 2015.
- **Hydrologic Milestone Report 4:** Assessment of Implications of Climate Change on Flood Estimation, May 2015.
- **Hydrologic Milestone Report 5:** Dam Operations Module Implementation Report, May 2015.
- **Hydrologic Milestone Report 6:** Flood Frequency Analysis Report, May 2015.
- **Hydrologic Milestone Report 7:** Design Event Approach Report, May 2015.
- **Hydrologic Milestone Report 8:** Monte Carlo Simulation Report, May 2015.
- **Hydrologic Milestone Report 9:** Reconciled and Recommended Flood Frequency Estimates Report, May 2015.
- **Hydrologic Milestone Report 10:** Draft Final Hydrology Report, May 2015.
- **Hydrologic Milestone Report 11:** Final Hydrology Handover Report, May 2015.

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- **Hydraulic Milestone Report 1**: Data Review and Modelling Methodology, Draft Final, October 2014.
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- **Hydraulic Milestone Report 3**: Detailed Model Development and Calibration, Draft Final, September 2015.
- **Hydraulic Milestone Report 4**: Fast Model Results and Design Events Selection, Draft Final, August 2016.
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Appendix A IPE Endorsement

Independent Panel of Experts for the Brisbane River Catchment Flood Study
Review of the BRCFS Technical Summary Report (MR7 Report)

Introduction

The MR7 report by BMT-WBM and Aurecon Consortium summarises the work carried out in the hydrology and hydraulics phases of the Brisbane River Catchment Flood Study (BRCFS). The outputs of the hydrology phase were presented in ten reports labelled MR1 to MR10. Each aspect of this work was reviewed by a three-member team that formed the Independent Panel of Experts (IPE). Similarly the outputs of the hydraulics phase, consisting of reports MR1 to MR6, were reviewed by a three-member Independent Panel of Experts. Two members of the IPE were common to each phase. The IPE terms of reference were not to just review the completed work but to also provide independent technical advice to the project.

During each phase of the project the IPE have attended a series of workshops where approaches were outlined, interim findings presented and final results discussed. The IPE have also reviewed the technical aspects of each draft report and, while this is not a core part of the IPE terms of reference, some feedback has been provided on editorial and presentational aspects.

This review of the MR7 report first addresses the question if the approaches adopted in the hydrologic and hydraulic assessments, as summarised in the report, have been appropriate and sufficient to address the BRCFS objectives. It then discusses the results obtained and any limitations and qualifications that need to be kept in mind when applying the study outputs. The review also comments on whether the MR7 report is appropriately targeted at the intended audience and clear in its reporting of methods, results and guidance on the use of the study outputs.

Overall study approach

As clearly outlined in the report, for the BRCFS to achieve its objectives, the hydrologic and hydraulic assessments had to be in depth, and they required the development and application of state-of-the-art analytical and modelling methods to deal adequately with the complexity and variability of flooding in the Brisbane River catchment.

Flooding on the Brisbane River catchment is particularly complex because:

- large floods can be generated by a range of different storm mechanisms that produce very different rainfall distributions and types of floods
- Wivenhoe and Somerset dams play a significant flood mitigation role and their construction and operation has altered the natural flooding regime
- there are complex interactions between flooding in the Brisbane River and its lower tributaries
- much of the Brisbane River is deeply incised and hydraulically quite steep with unusually high velocities and little over bank storage
- significant natural flood storage areas are present in the Lockyer Creek, Bremer River and lower Brisbane River tributaries.

To adequately deal with these requirements and complexities, the selected overall study approach had to involve the following key steps, and their documentation in the MR7 report is as indicated in italics:

1. Developing a clear understanding of the special features of the Brisbane River catchment and the key factors influencing flooding – *Chapter 2 Brisbane River Catchment.*

2. Collation and quality control of all relevant flood data and related information –*Chapter 4 Data Collection and Collation*, with additional material on checking of rating curves in *Sections 5.7 and 7.5*.
3. Developing and calibrating hydrologic models to represent the response of the different Brisbane River sub-catchments to heavy rainfalls and the flood mitigation impacts of dams – *Sections 5.2 Types and Objectives of Catchment Modelling, and 5.4 Calibration to Historical Events.*
4. Applying traditional analytical and modelling methods to derive hydrologic design flood estimates – *Sections 5.5.3 Design Event Approach and 5.5.4 Flood Frequency Analysis.*
5. Developing and applying a hydrologic modelling framework that more fully captures the range variability of contributing factors beyond what is directly reflected in the flood observations – *Section 5.5.5 Monte Carlo Simulation.*
6. Combining estimates from a range of hydrologic design flood estimation methods to make maximum use of all the relevant data/information, applying a systematic reconciliation approach to resolve potential discrepancies between results from different methods – *Section 5.6 Design Peak Flow Assessments – With and No Dams.*
7. Integrating the hydrologic and hydraulic modelling phases by carrying the Monte Carlo simulation through to the hydraulic modelling – *Section 5.8 Hydrologic and Hydraulic Model Interfacing.*
8. Selecting appropriate hydraulic modelling systems for the different study phases (UDMT, Fast Model and Detailed Model) – *Section 6.2 Types and Objectives of Hydraulic Models.*
9. Calibrating the Fast Model and the Detailed Model to ensure that they provide a realistic representation of the floodplain hydraulics of the Brisbane River and its lower tributaries– *Section 6.3 Calibration to Historical Events.*
10. Analysing the numerous Monte Carlo Simulation outputs and condensing them to a representative set of event ensembles for running through the Detailed Hydraulic Model – *Sections 6.4 and 6.5 Design Event Ensembles.*
11. Running the Design Event Ensembles through the Detailed Hydraulic Model to derive the required study outputs: peak design flood levels at key locations and maps of flood levels, flood depths, flood extents, flood velocities and hydraulic hazard – *Chapter 7 Design Riverine Flood Results.*
12. Analysing and clearly documenting the sensitivity of study results to hypothetical changes in the catchment that may occur due to direct human interference, geomorphic or climatic processes. – *Chapter 8 Sensitivity Analysis.*

The IPE considers that this overall study approach has been well matched to the requirements of the BRCFS and, within the constraints of the information currently available, has been able to deal appropriately with the complexities of the flooding situation in the Brisbane River catchment.

The MR7 report can only provide a brief summary of the methods adopted in each step of the overall approach and the extensive work involved; more detailed documentation has been provided in the milestone reports prepared progressively during the conduct of the hydrologic and hydraulic assessments. The IPE also notes that a number of the steps involved significant development and testing of novel methods.

Limitations and qualifications

In earlier review reports on the Hydrologic Assessment the IPE has raised a number of issues that required clarification as part of the Hydraulic Assessment. The following comments indicate to what extent the IPE considers these issues as having been resolved by subsequent work:

1. Bremer River tributaries:
   - Uncertainty in rating curves for gauges on Bremer River and tributaries (backwater effects during larger floods):

     Rating curve reviews based on all information including the Detailed Model results indicated that the rating curves at these locations are reasonable for flows up to the largest available for calibration. However, for larger flow hysteresis occurs and the effects vary depending on the nature of each flood event.
   - Unresolved discrepancies in reconciliation process, probably due to underestimation of the design rainfalls used in the DEA and MCS methods:

     Anticipated new information on design rainfalls is not available at the time of this report.
2. Lockyer Creek:
   - Uncertainty in rating curves for flood events affected by backwater from Wivenhoe releases:

     The hydraulic modelling has shown that there are no significant hysteresis effects, even for extreme events, but the accuracy of the rating curve is uncertain for flows that extend on to the floodplain.
   - Lack of survey info on creek bathymetry:

     The in-bank topography at the gauge site remains uncertain since it is based on LiDAR.
3. Lower Brisbane River
   - Uncertainty in rating curves due to flood storage areas and backwater effects:

     Review of rating curves on the Lower Brisbane River at Savages Crossing, Mt Crosby Weir, and Moggill showed good matching between the rating curves derived from the hydrology studies and the rising limbs of the stage-discharge relationships from the Detailed Model. Revision or refinement of the associated Hydrologic Assessment work is not considered warranted.

     As stated in the last para, p 47, Section 5.7.1 " Hydrologic model and flood frequency results were also compared to ensure as much as possible consistency between the gauge ratings along the river. The resultant ratings are therefore consistent with the current hydrologic modelling, but it is important to recognise that the only independent point of truthing in the high flow ratings is the flow gauging undertaken at Centenary Bridge.
   - Uncertainty in the amount of extra storage used in URBS to represent the floodplain of the Lower Brisbane River reaches (particularly for very large events):

     This has been resolved as the upstream inputs from URBS have been routed through the hydraulic models (rather than through URBS).

     [The operational URBS model used by Seqwater may need adjustment based on hydraulic modelling results.]

It is also clear that some results are affected by sources of uncertainty related to the complex flood hydrology and hydraulics of the Brisbane River catchment and the relatively short flood history, which particularly affect the flood estimates for rare to extreme events. Reducing these uncertainties remains a task for future research, based on the availability of additional rainfall and flood data for the Brisbane River catchment.

The IPE recognises that resolution of the following issues is clearly outside the scope of this study:

- Lockyer Creek flooding upstream of backwater influence from Brisbane River
- Local creek flooding in Lower Brisbane River area and upper parts of Bremer River tributaries

Throughout all of the hydraulics phase of BRCFS, the IPE was kept fully informed on the details of the hydraulic modelling and of its application. Any suggestion made by the IPE for minor improvement or revision was acted on satisfactorily. Each of the individual Final reports, MR1-MR6 was reviewed closely by the IPE and was endorsed by it.

The Future of the BRCFS

Because of Australia's relatively short flood record each new large flood event on a large catchment will lead to increased understanding of flood behaviour. Despite this limitation the BRCFS is expected to be a reliable basis for flood planning for a considerable period of time. The techniques adopted are leading edge and are consistent with best practice recommended in Australian Rainfall and Runoff 2016. More importantly the studies have made best use of all available data and demonstrated that the techniques adopted reproduce at site flood frequency analysis. When an approach can be validated against observed floods and at site flood frequency analysis at multiple sites it demonstrates that the modelling approach is robust and reproducing the key processes. This also removes the need to update the modelling for recent minor changes to design rainfall released by the Bureau of Meteorology in late November 2016.

Conclusions

The BRCFS has been carried out in two phases; the hydrology phase and the hydraulics phase. Throughout each phase the relevant IPE has been kept fully informed on the details of the methodologies of the developing study and on the results being generated. This has been achieved through the IPE participation in all of the Workshops where discussions of the methodologies and results took place and through detailed review of each of the ten reports MR1-MR10 produced during the hydrology phase and of each of the six reports MR1-MR6 produced during the hydraulics phase.

Any recommendations and suggestions for minor improvements/changes made by the IPE were taken into account in the production of each final report. Each of the individual Final reports, hydrology MR1-MR10 and hydraulics MR1-MR6 was reviewed closely by the relevant IPE and was endorsed by it.

The techniques adopted in the BRCFS are leading edge and are consistent with best practice recommended in Australian Rainfall and Runoff 2016. More importantly the studies have made best use of all available data and demonstrated that the techniques adopted reproduce at site flood frequency analysis. The BRCFS is expected to be a reliable basis for flood planning in the Brisbane River catchment for a considerable period of time ahead.

17 November 2016

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Appendix B BRCFS – List of Committees

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Hydrologic Assessment

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- Mark Babister
- Emeritus Professor Colin Apelt OAM

Hydraulic Assessment

- Mark Babister (Chair)
- Emeritus Professor Colin Apelt OAM
- Dr John Macintosh

Technical Working Group

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- Evan Caswell
- James Charalambous
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BoM

- Chris MacGeorge (to Oct 2016)
- Paul Birch (from Oct 2016)

DEWS

- Russell Cuerel

DSITI

- John Ruffini

ICC

- Tony Dileo (to Jul 2014)
- Hoy Sung Yau

LVRC

- Quentin Underwood

Seqwater

- Terry Malone (to Nov 2014)
- Lindsay Millard
- Michel Raymond

SRC

- Tony Jacobs

Steering Committee

BCC

- Mark Tinnion (BCC) (from June 2015)
- Saul Martinez (BCC) (from July 2015)
- Ellen Davidge (BCC) (to June 2015)

DNRM

- Lyall Hinrichsen (Chair, Steering Committee)
- Leanne Barbeler (from Sept 2015)
- Mandy Downes (from Sept 2016)

DEHP

- John Lane (from Sept 2015)

DEWS

- Richard Priman

DILGP

- Susan M Nightingale (DILGP) (from April 2016)
- Dean Misso (DILGP) (to August 2013)
- Mark Saunders (DILGP) (to April 2016)
- Lynn Sawtell (DILGP) (to June 2015)

DSITI

- John Ruffini

ICC

- Bryce Hines (from June 2014)
- Tony Dileo (to June 2014)
- Nick Vass-Bowen (to June 2014)

LVRC

- Quentin Underwood

QRA

- Graeme Milligan (from June 2016)

Seqwater

- Rob Drury

SRC

- Tony Jacobs

Project Team

DNRM

- Saji Joseph
- Dr Pushpa Onta
- Dr Wai-Tong Wong

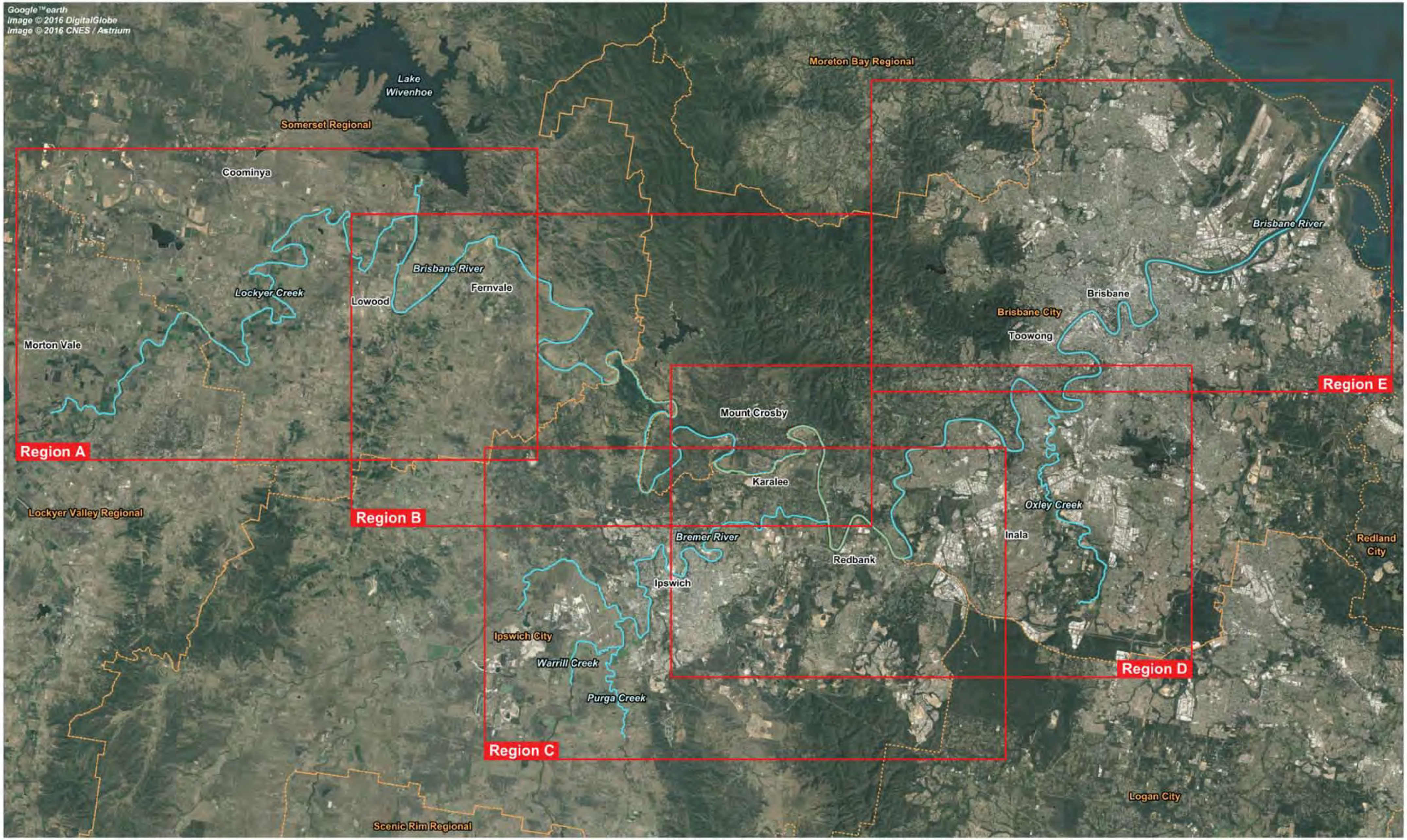
DILGP

- Con de Groot (to May 2016)
- Dr Roger Brewster (to June 2016)

QRA

- Dr Roger Brewster (from July 2016)
- Greg Scroope (from June 2016)

Map Addendum



LEGEND

Major Waterway

Local Government Area Boundary

Title:

Key Sheet for Design Flood Mapping

Map 1

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N

0km 5 10

Approx. Scale

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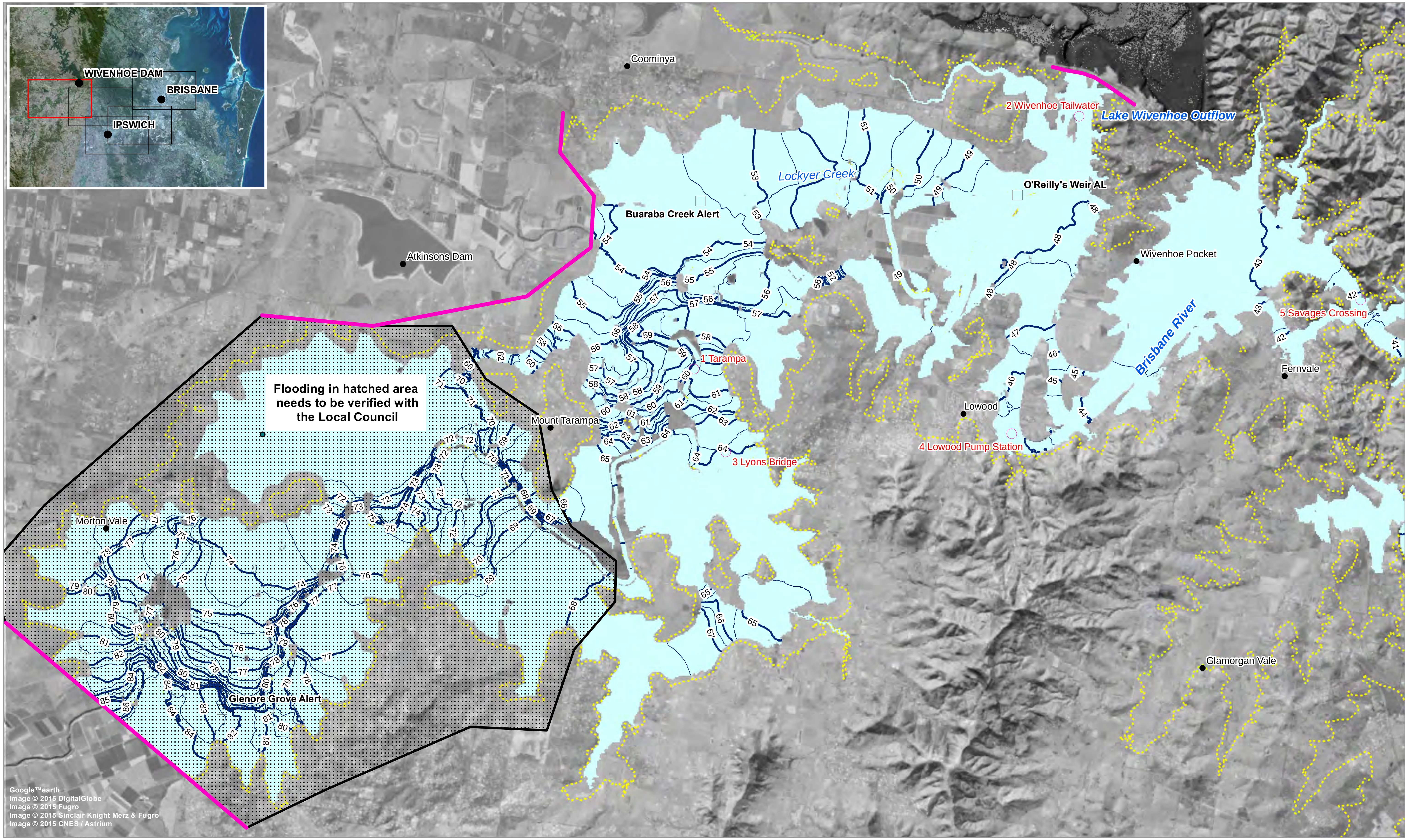

LEGEND

- Riverine Flood Extent
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling
  Refer to Councils for local flooding beyond limit
- 30 — 1.0m Flood Level Contour*
- Intermediate 0.5m Contour
- Gauging Station
- Hydraulic Assessment Reporting Location

**Flood Contour Vertical Datum is the Australian Height Datum (AHD, 1971)*

Brisbane River Catchment Flood Study
Study Partners

Queensland Government

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Lockyer Valley Regional Council
Somerset Regional Council
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Peak Water Surface Level Maps - 1 in 100 AEP Region A

Map 2
(MR5,Drawing 5)

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0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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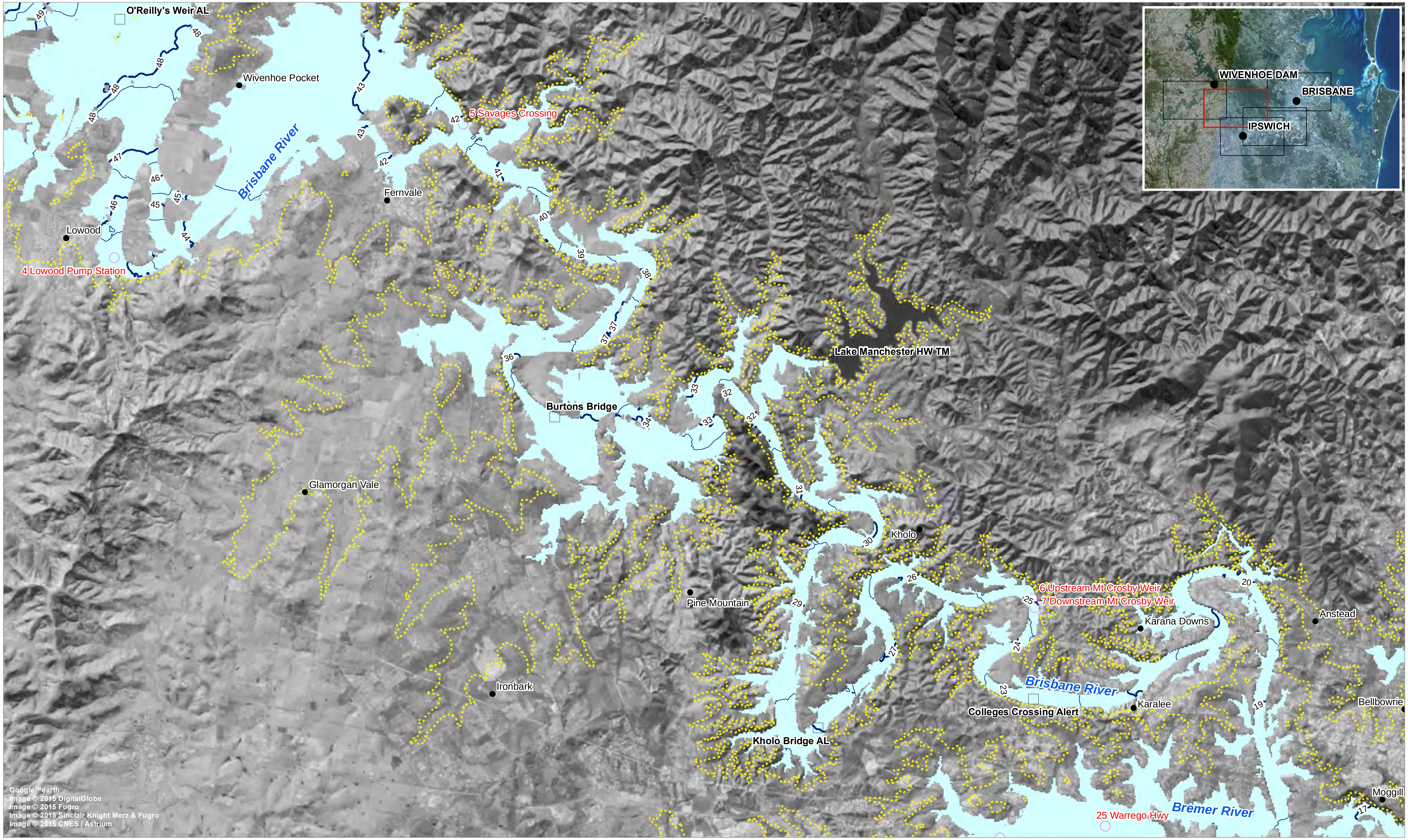

LEGEND

- Riverine Flood Extent
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling *Refer to Councils for local flooding beyond limit*
- 30 1.0m Flood Level Contour*
- Intermediate 0.5m Contour
- Gauging Station
- Hydraulic Assessment Reporting Location

**Flood Contour Vertical Datum is the Australian Height Datum (AHD, 1971)*

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Peak Water Surface Level Maps - 1 in 100 AEP Region B

Map 3
(MR5,Drawing 6)

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0 1.5 3 4.5
Kilometers
Map Grid of Australia 1994, Zone 56

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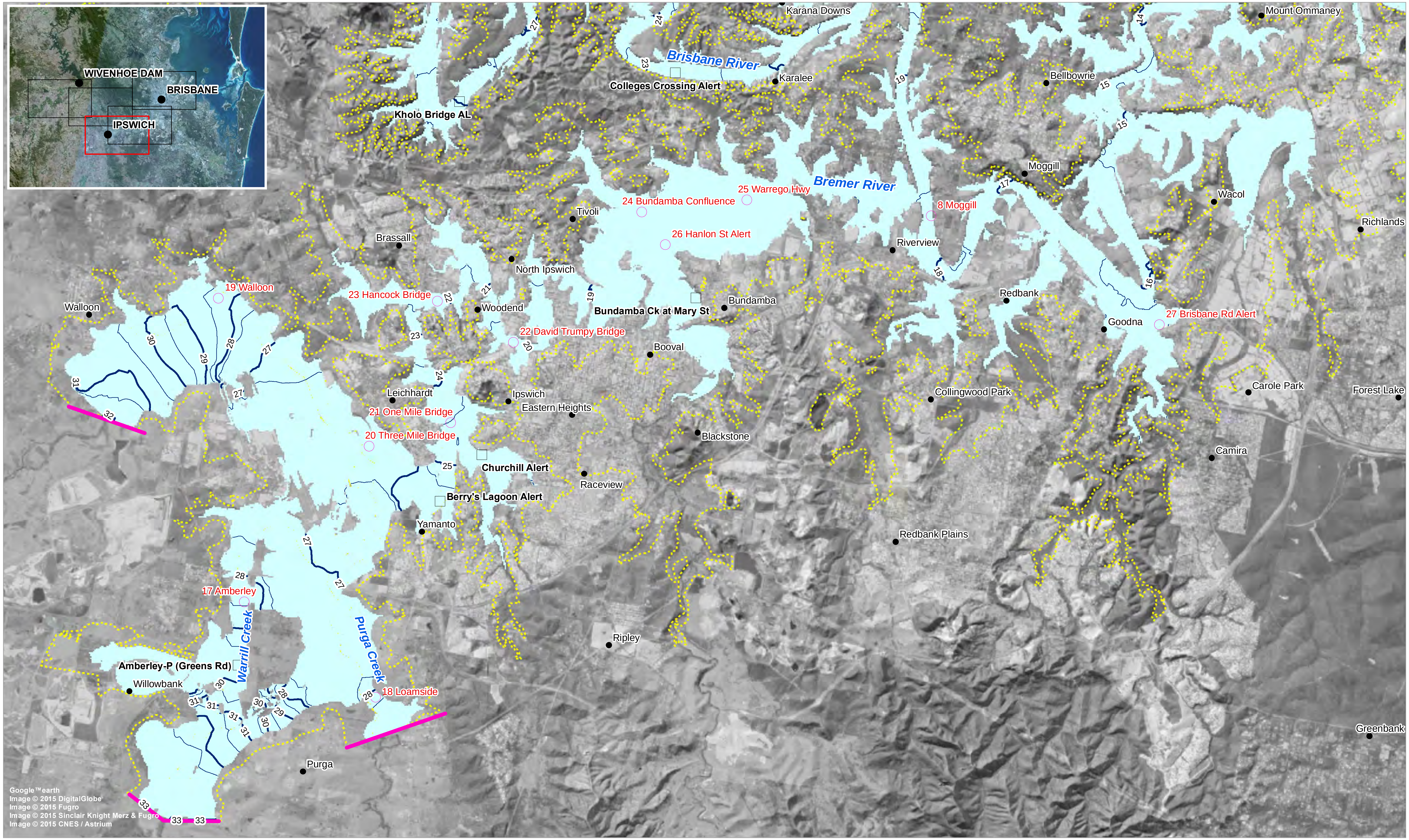

LEGEND

- Riverine Flood Extent
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling *Refer to Councils for local flooding beyond limit*
- 30 1.0m Flood Level Contour*
- Intermediate 0.5m Contour
- Gauging Station
- Hydraulic Assessment Reporting Location

**Flood Contour Vertical Datum is the Australian Height Datum (AHD, 1971)*

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Peak Water Surface Level Maps - 1 in 100 AEP Region C

Map 4
(MR5,Drawing 7)

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0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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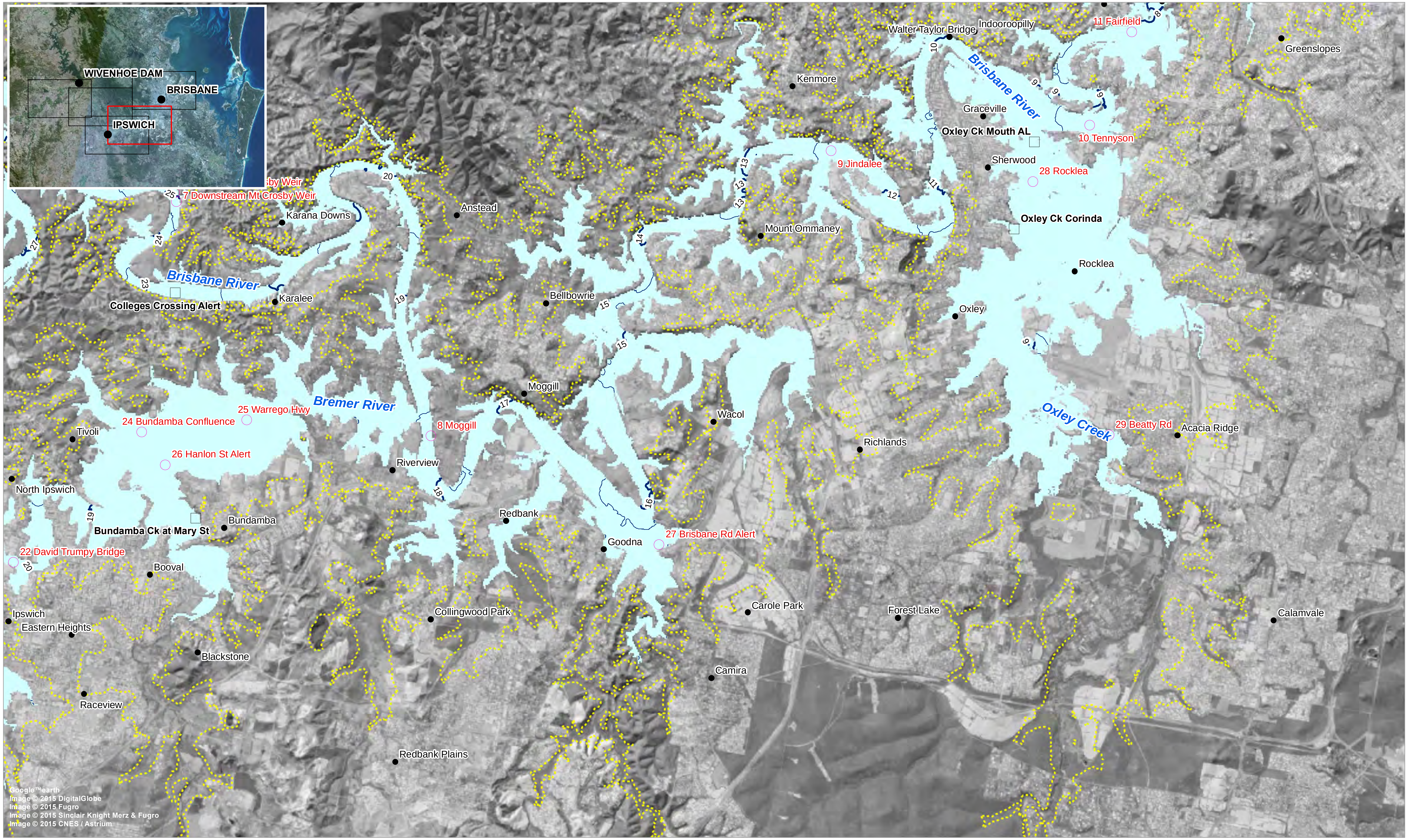

LEGEND

Riverine Flood Extent

Extreme Flood (notional 1 in 100,000 AEP)

Limit of Detailed Modelling *Refer to Councils for local flooding beyond limit*

30 1.0m Flood Level Contour*

Intermediate 0.5m Contour

Gauging Station

Hydraulic Assessment Reporting Location

**Flood Contour Vertical Datum is the Australian Height Datum (AHD, 1971)*

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Peak Water Surface Level Maps - 1 in 100 AEP Region D

Map 5
(MR5,Drawing 8)

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0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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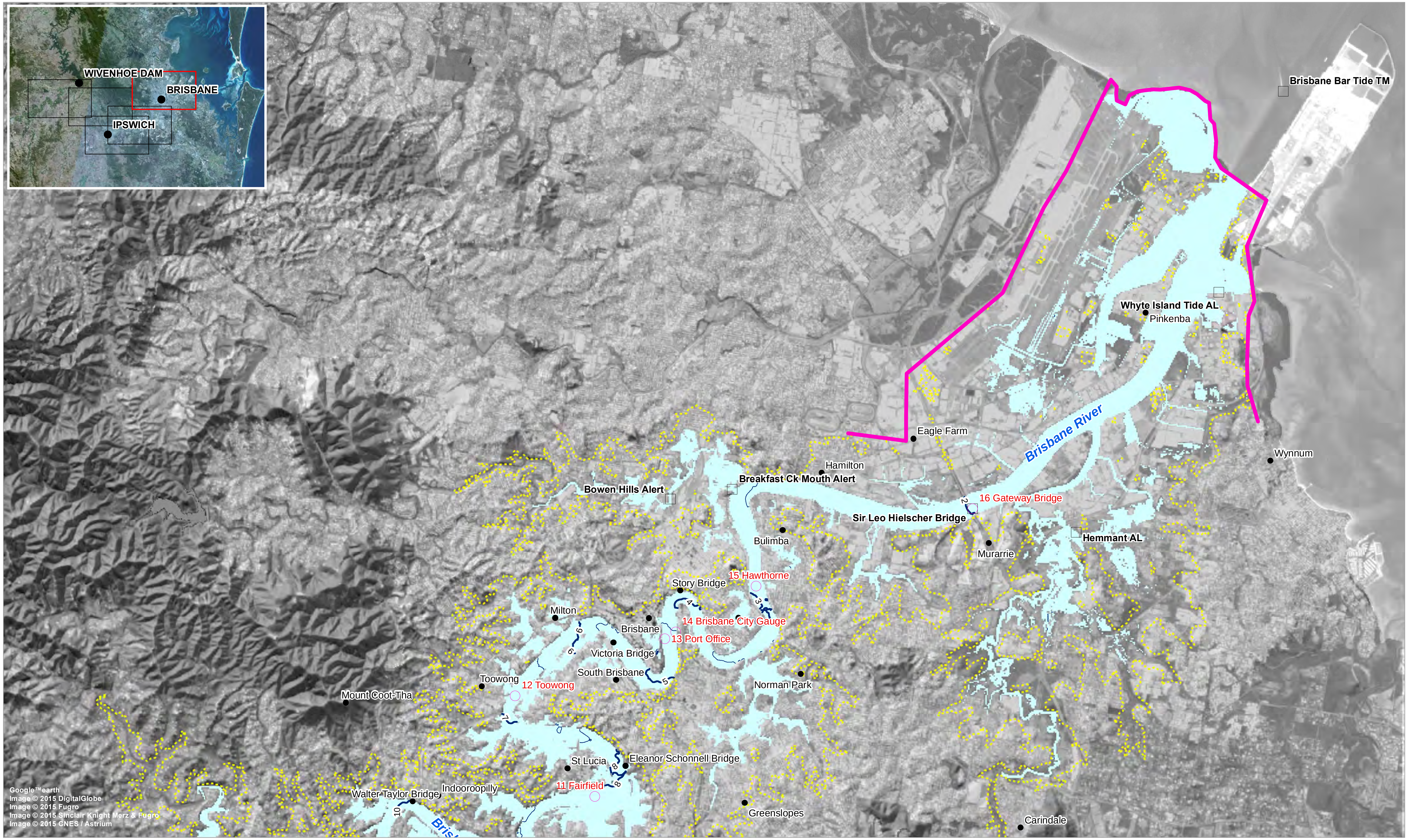

LEGEND

- Riverine Flood Extent
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling
  Refer to Councils for local flooding beyond limit
- 30 1.0m Flood Level Contour*
- Intermediate 0.5m Contour
- Gauging Station
- Hydraulic Assessment Reporting Location

**Flood Contour Vertical Datum is the Australian Height Datum (AHD, 1971)*

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Peak Water Surface Level Maps - 1 in 100 AEP Region E

Map 6
(MR5,Drawing 9)

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0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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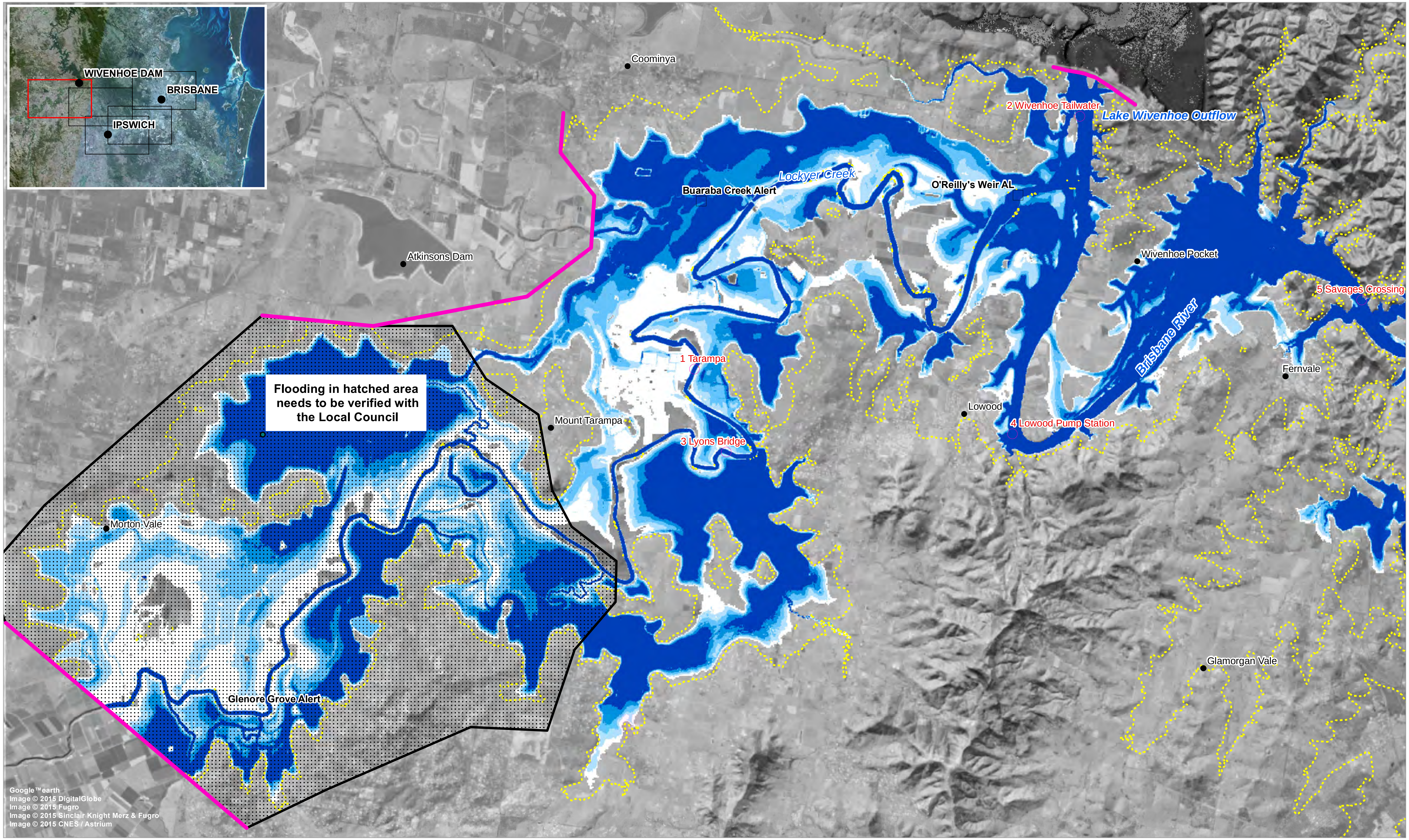

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

Brisbane River Catchment Flood Study

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Peak Flood Depth Maps - 1 in 100 AEP Region A

Map 7 (MR5,Drawing 10)

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0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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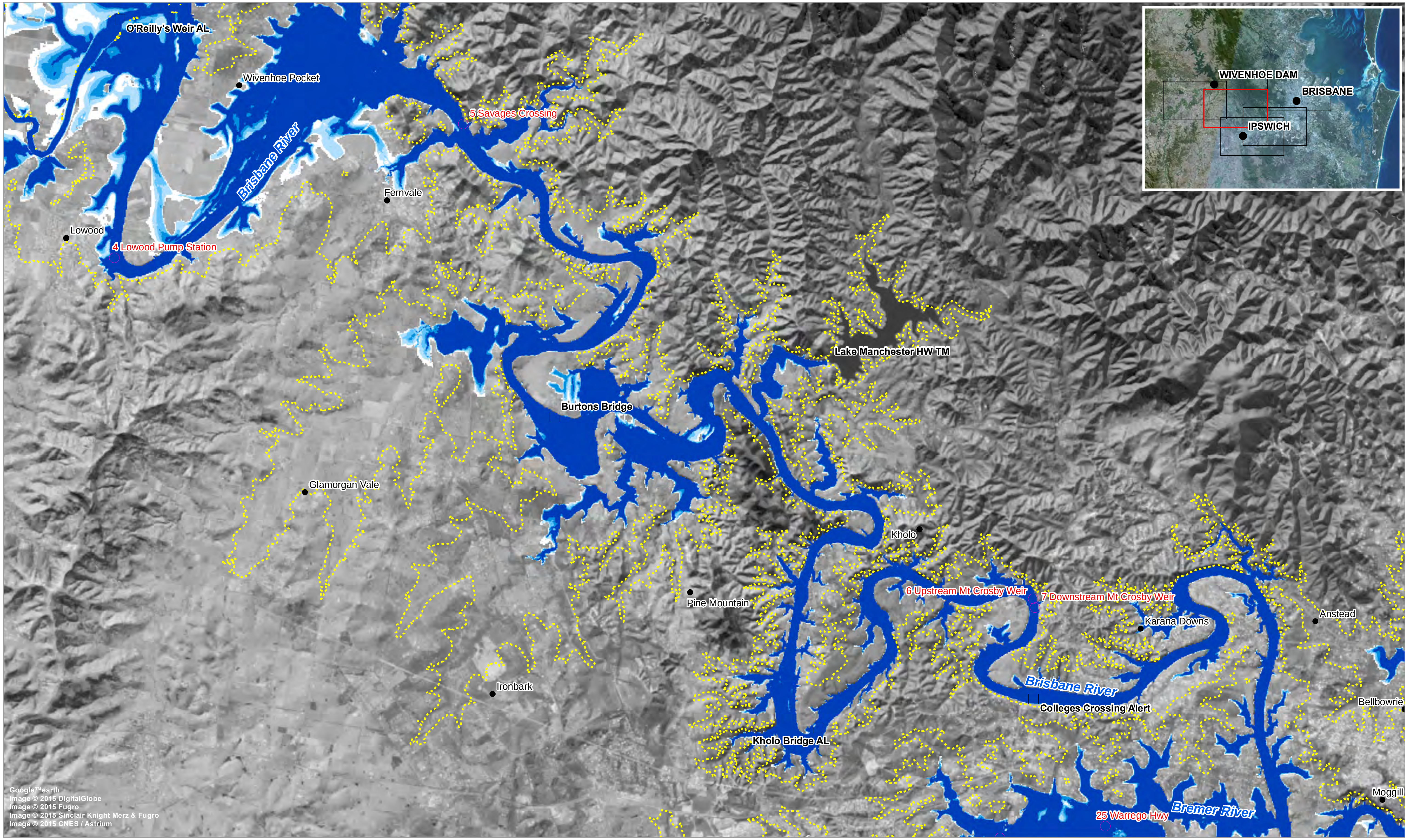

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

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Peak Flood Depth Maps - 1 in 100 AEP Region B

Map 8
(MR5,Drawing 11)

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0 1.5 3 4.5
Kilometers

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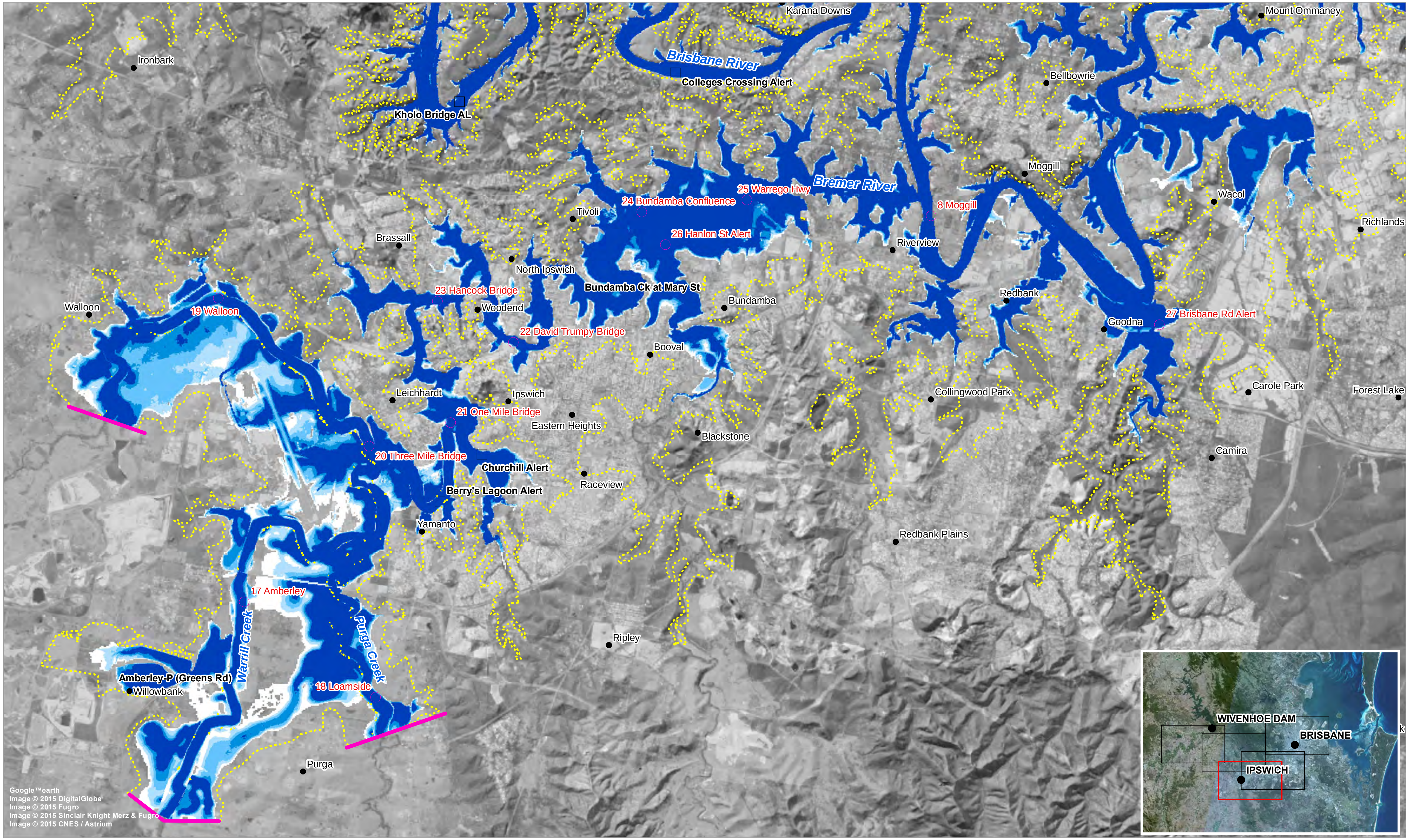

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

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Study Partners

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Peak Flood Depth Maps - 1 in 100 AEP Region C

Map 9
(MR5,Drawing 12)

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0 1.5 3 4.5
Kilometers

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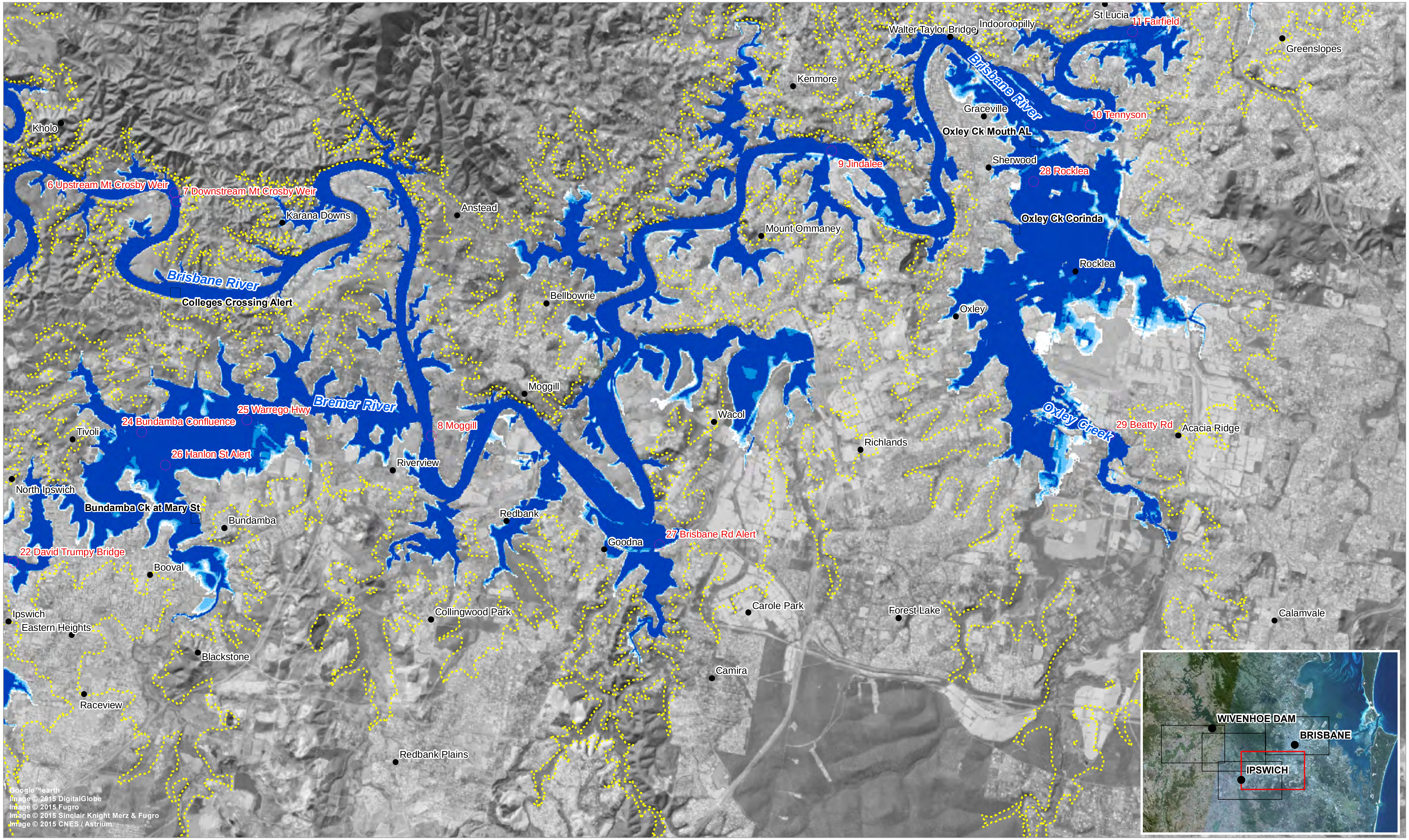

Google™earth
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Image © 2015 CNES / Astrium

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

Brisbane River Catchment Flood Study
Study Partners

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Peak Flood Depth Maps - 1 in 100 AEP Region D

Map 10
(MR5,Drawing 13)

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0 1.5 3 4.5
Kilometers

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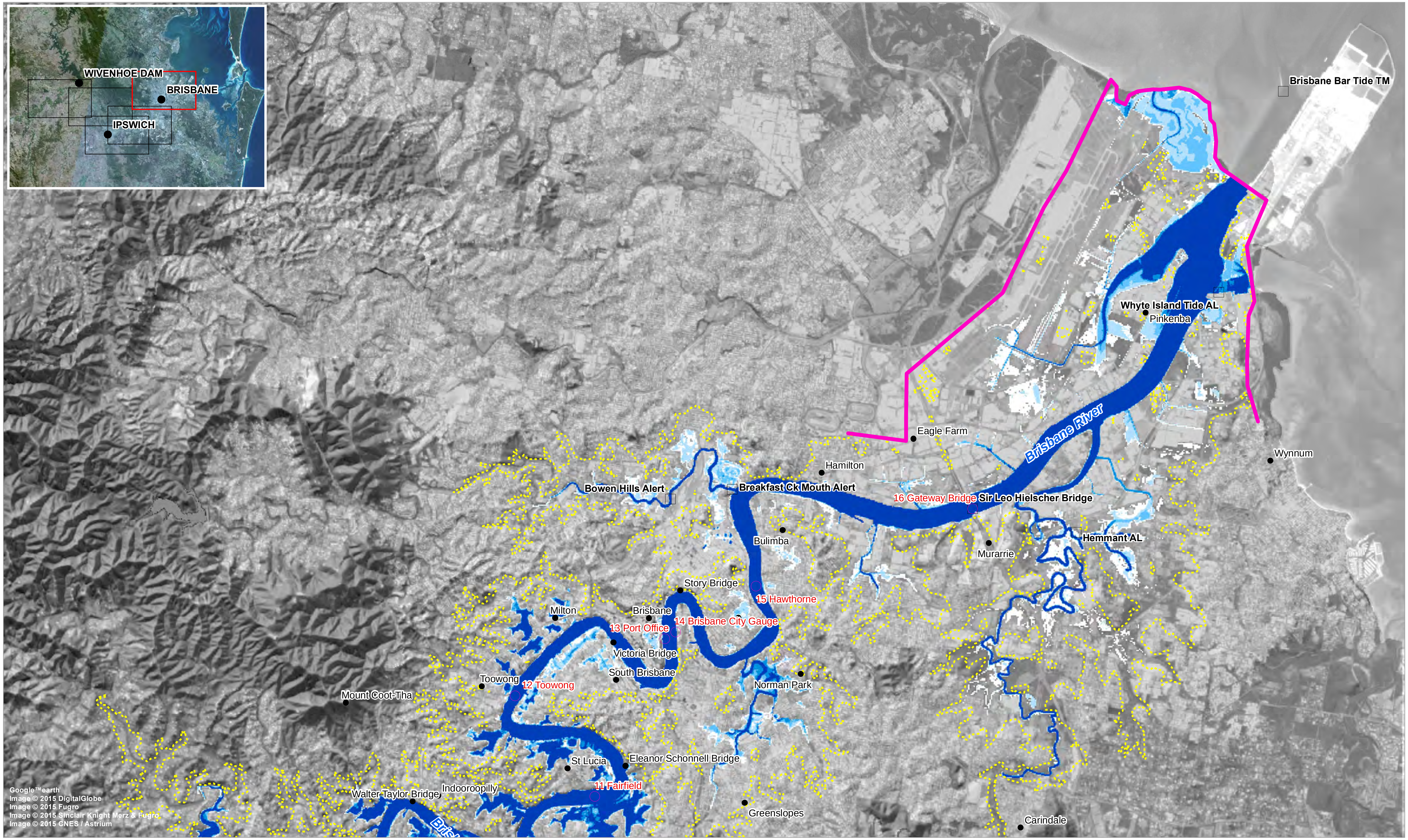

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- >2

Brisbane River Catchment Flood Study

Study Partners

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Peak Flood Depth Maps - 1 in 100 AEP Region E

Map 11
(MR5,Drawing 14)

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0 1.5 3 4.5
Kilometers

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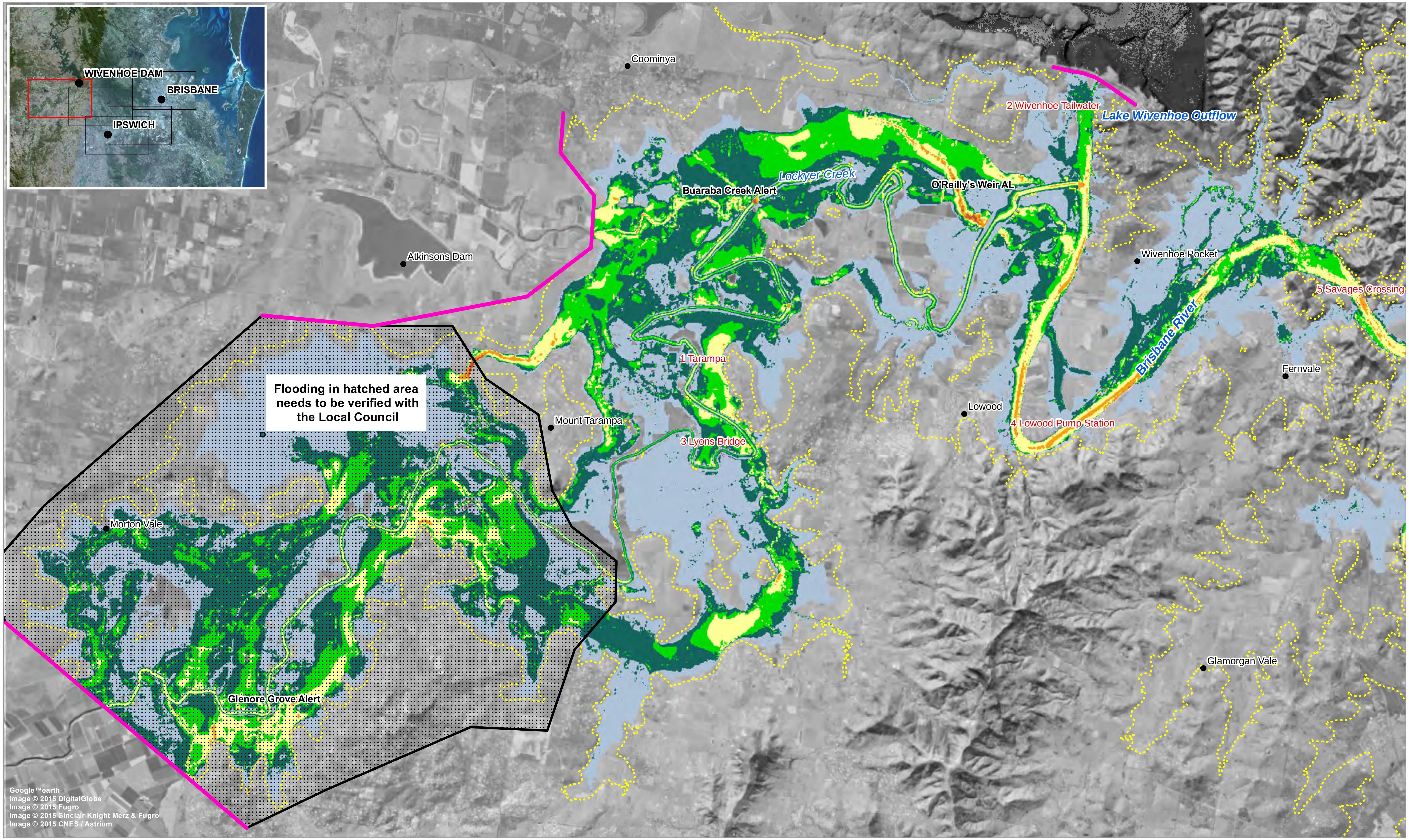

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 3.0
- 3.0 - 5.0
- >5.0

Brisbane River Catchment Flood Study

Study Partners

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Peak Flood Velocity Maps - 1 in 100 AEP Region A

0 1.5 3 4.5

Kilometers

Map Grid of Australia 1994, Zone 56

Map 12
(MR5,Drawing 15)

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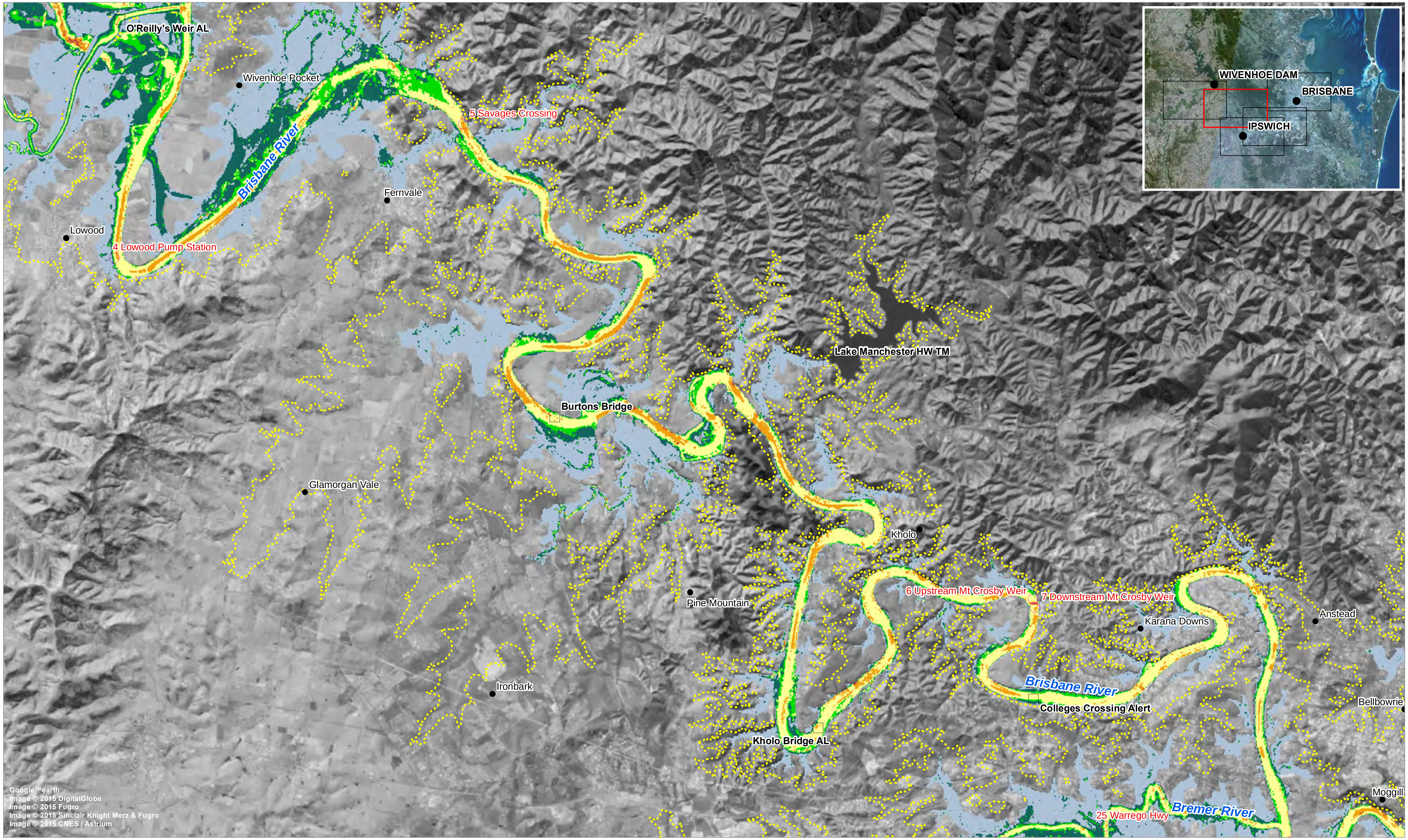

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 3.0
- 3.0 - 5.0
- >5.0

Brisbane River Catchment Flood Study

Study Partners

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Peak Flood Velocity Maps - 1 in 100 AEP Region B

Map 13
(MR5,Drawing 16)

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0 1.5 3 4.5
Kilometers

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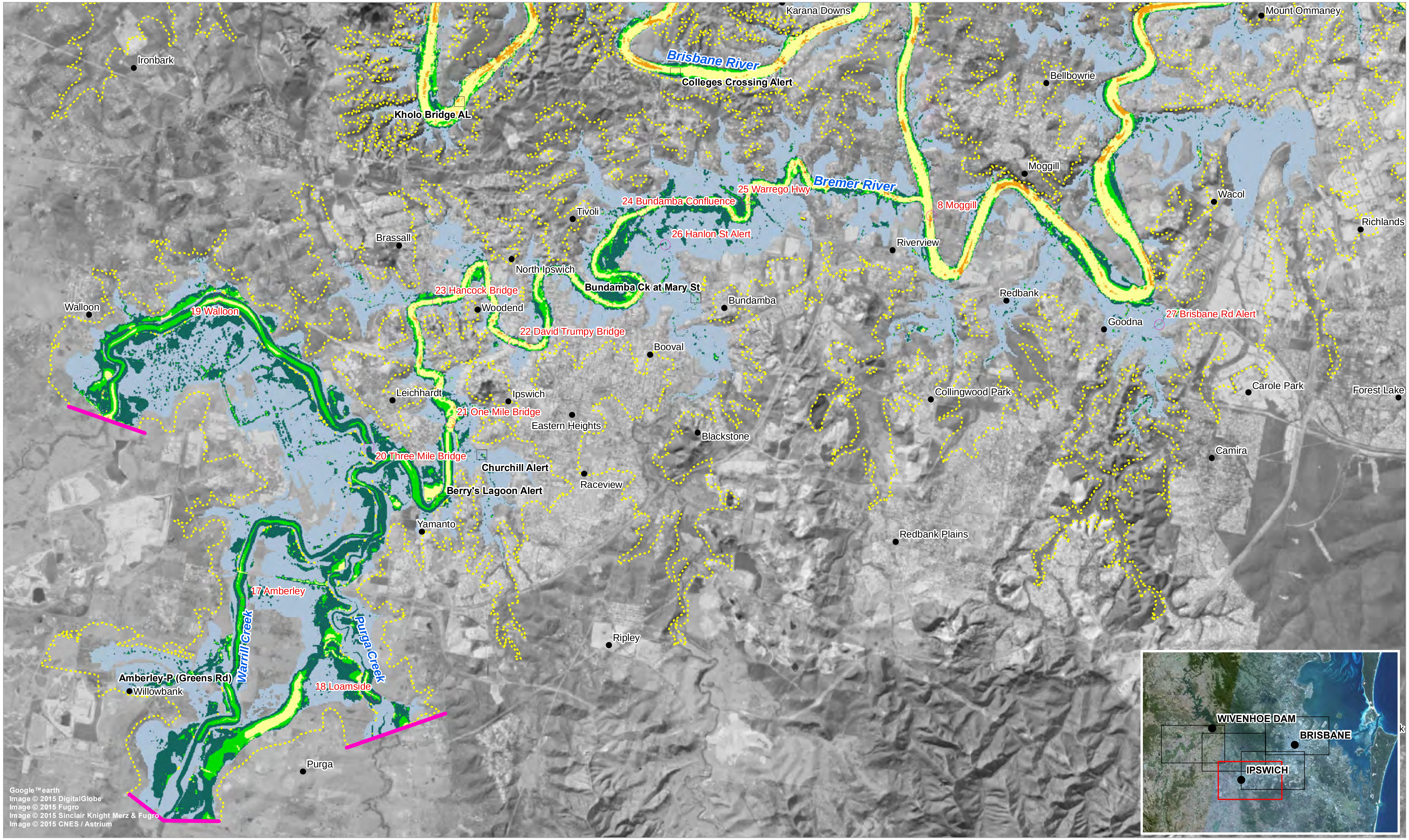

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling
  Refer to Councils for local flooding beyond limit

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 3.0
- 3.0 - 5.0
- >5.0

Brisbane River Catchment Flood Study
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Peak Flood Velocity Maps - 1 in 100 AEP Region C

Map 14
(MR5,Drawing 17)

Feb. 2017

0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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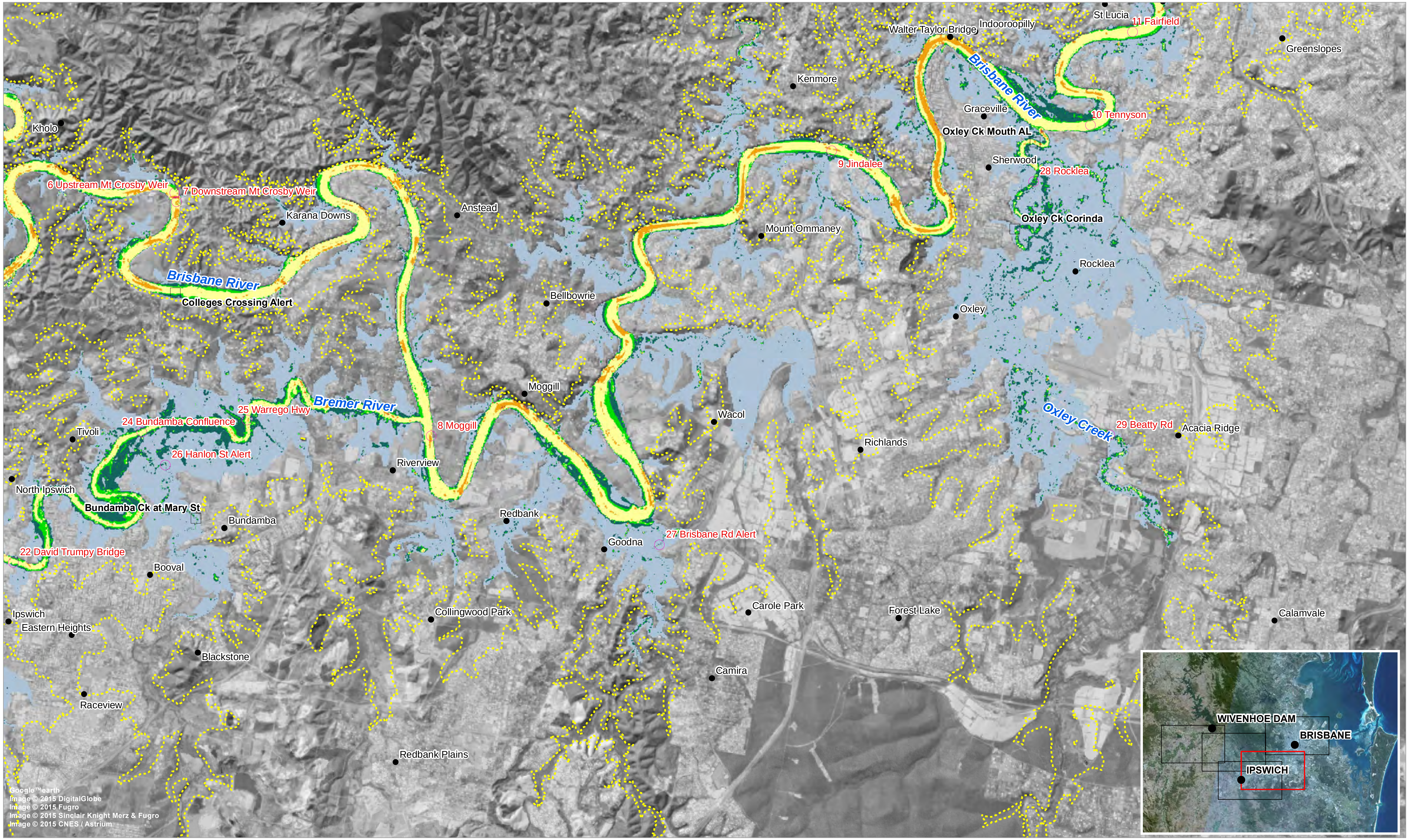

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Velocity (m/s)
0 - 0.5
0.5 - 1
1.0 - 1.5
1.5 - 3.0
3.0 - 5.0
>5.0

Brisbane River Catchment Flood Study

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Peak Flood Velocity Maps - 1 in 100 AEP Region D

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0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

Map 15
(MR5,Drawing 18)

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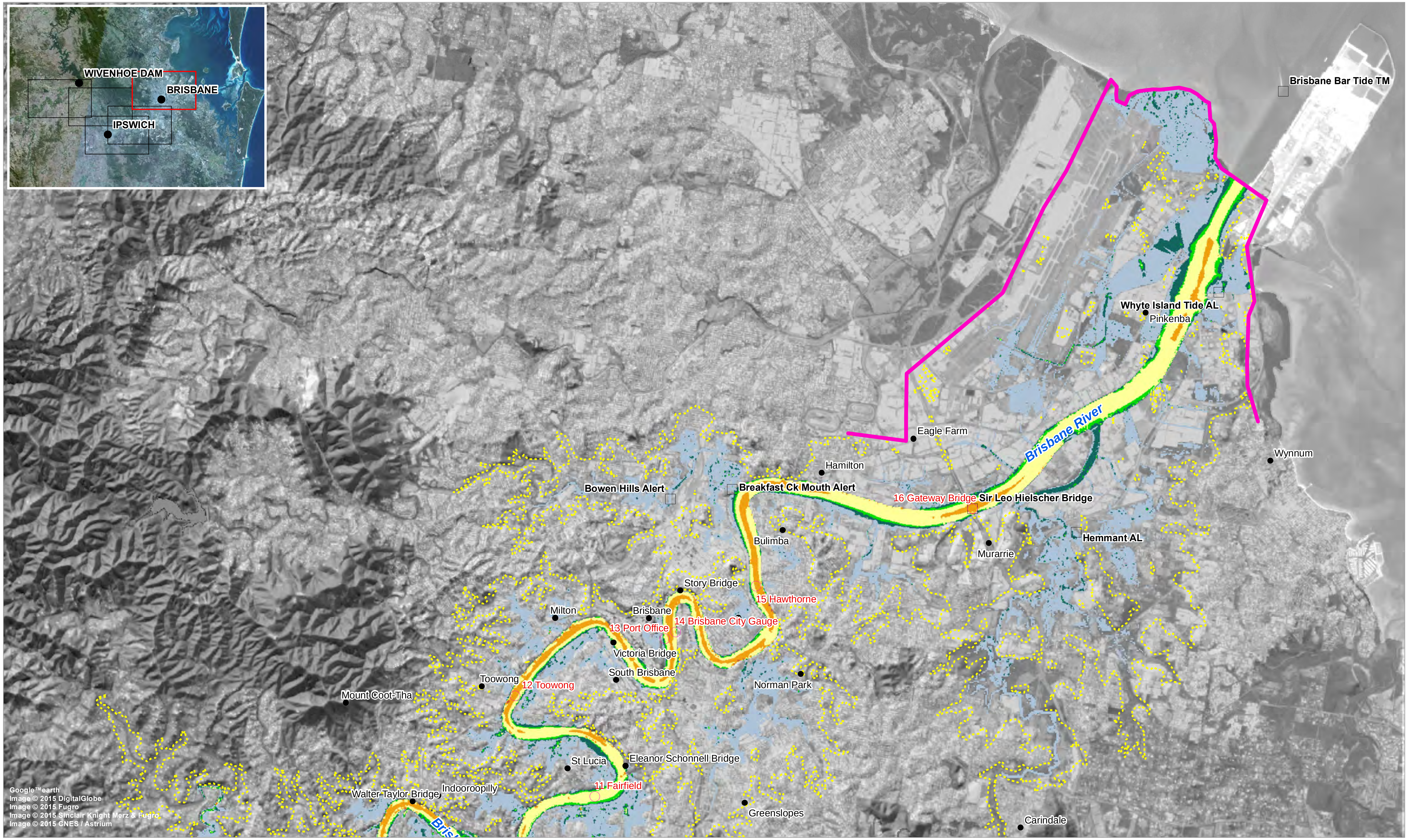

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Velocity (m/s)

- 0 - 0.5
- 0.5 - 1
- 1.0 - 1.5
- 1.5 - 3.0
- 3.0 - 5.0
- >5.0

Brisbane River Catchment Flood Study

Study Partners

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Peak Flood Velocity Maps - 1 in 100 AEP Region E

Map 16
(MR5,Drawing 19)

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0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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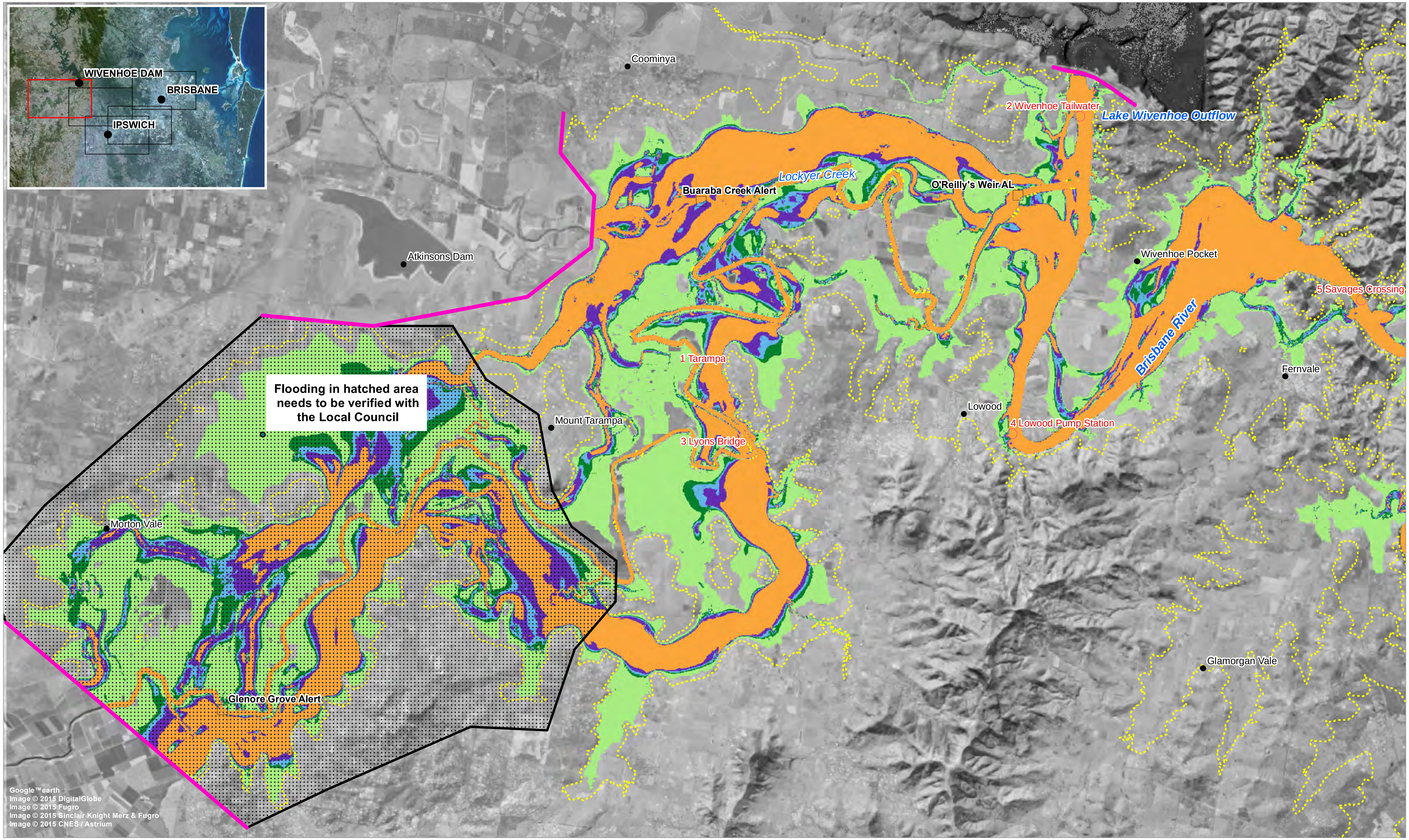

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth x Velocity (m^2 /s)

- 0 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.2
- >1.2

Brisbane River Catchment Flood Study

Study Partners

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Peak Depth x Velocity (Hydraulic Hazard) Maps - 1 in 100 AEP Region A

Map 17
(MR5,Drawing 20)

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0 1.5 3 4.5
Kilometers

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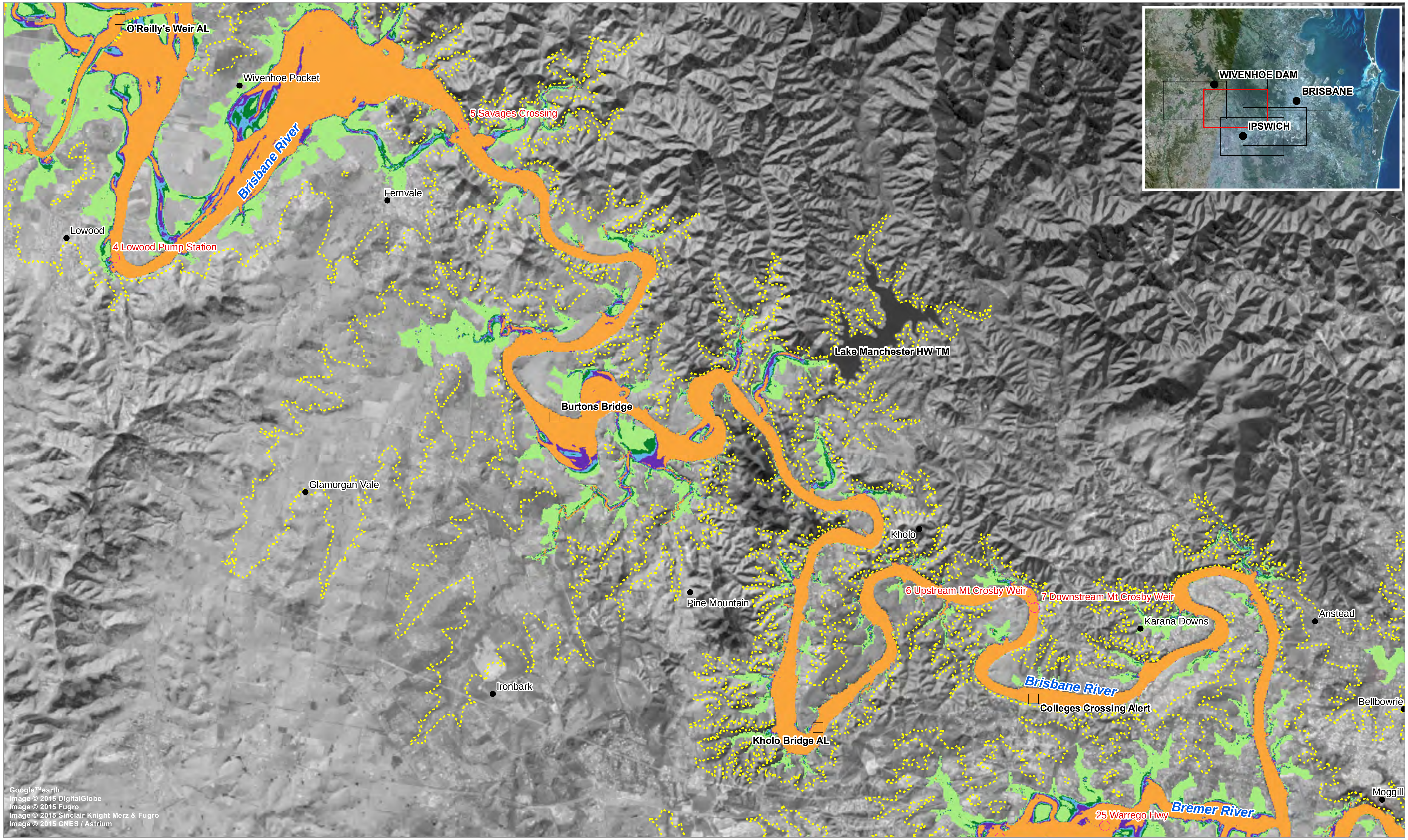

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth x Velocity (m^2 /s)

- 0 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.2
- >1.2

Brisbane River Catchment Flood Study

Study Partners

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Somerset Regional Council
Seqwater

Peak Depth x Velocity (Hydraulic Hazard) Maps - 1 in 100 AEP Region B

Map 18
(MR5,Drawing 21)

Feb. 2017

0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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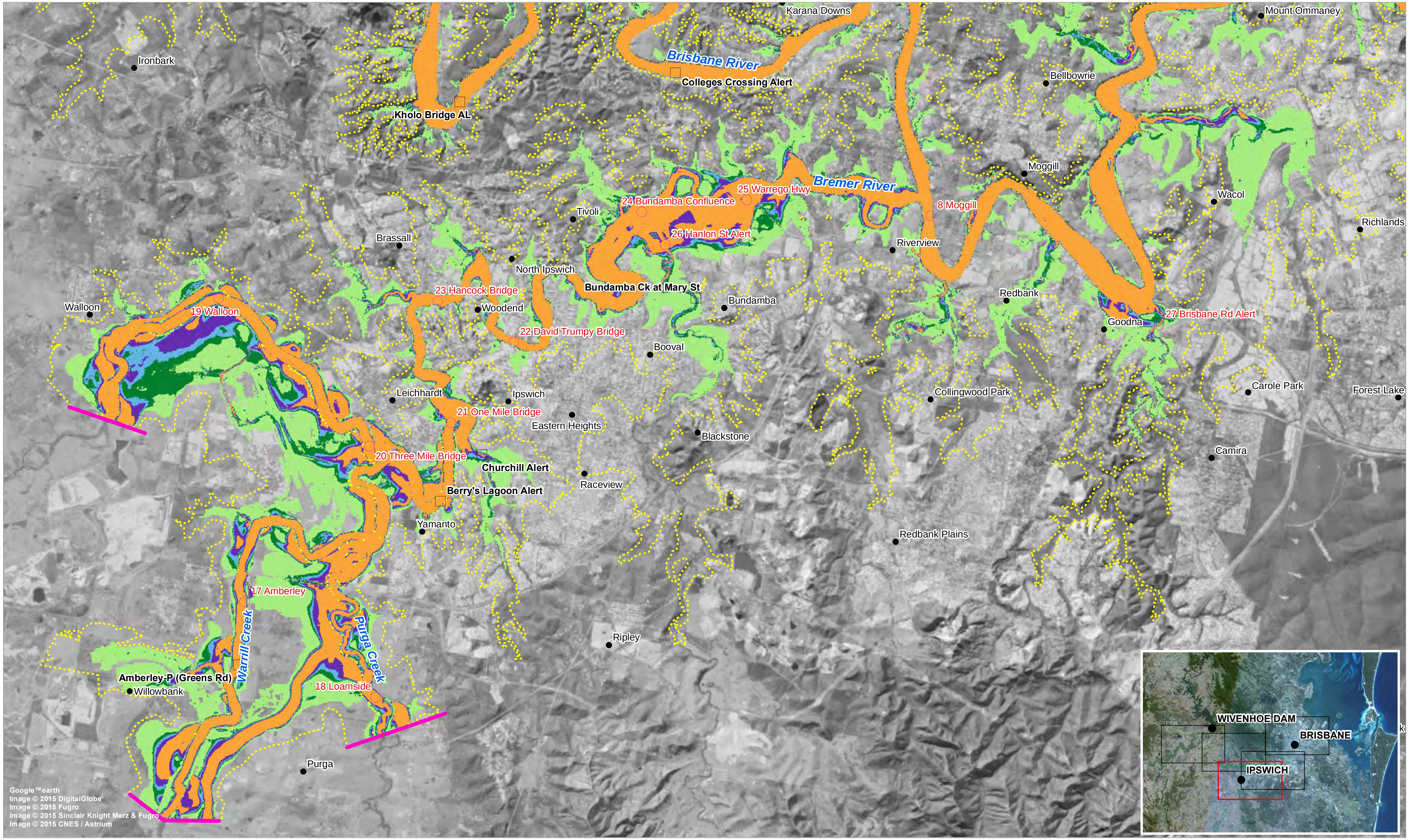
Filepath : B:\B20702 BRCFS Hydraulics\60_Mapping\MXD\MXD_OUTPUT\MR7\D0100\MR7-Map-18.mxd



LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth x Velocity (m^2/s)

- 0 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.2
- >1.2

Brisbane River Catchment Flood Study

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Peak Depth x Velocity (Hydraulic Hazard) Maps - 1 in 100 AEP Region C

Map 19
(MR5,Drawing 22)

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0 1.5 3 4.5
Kilometers

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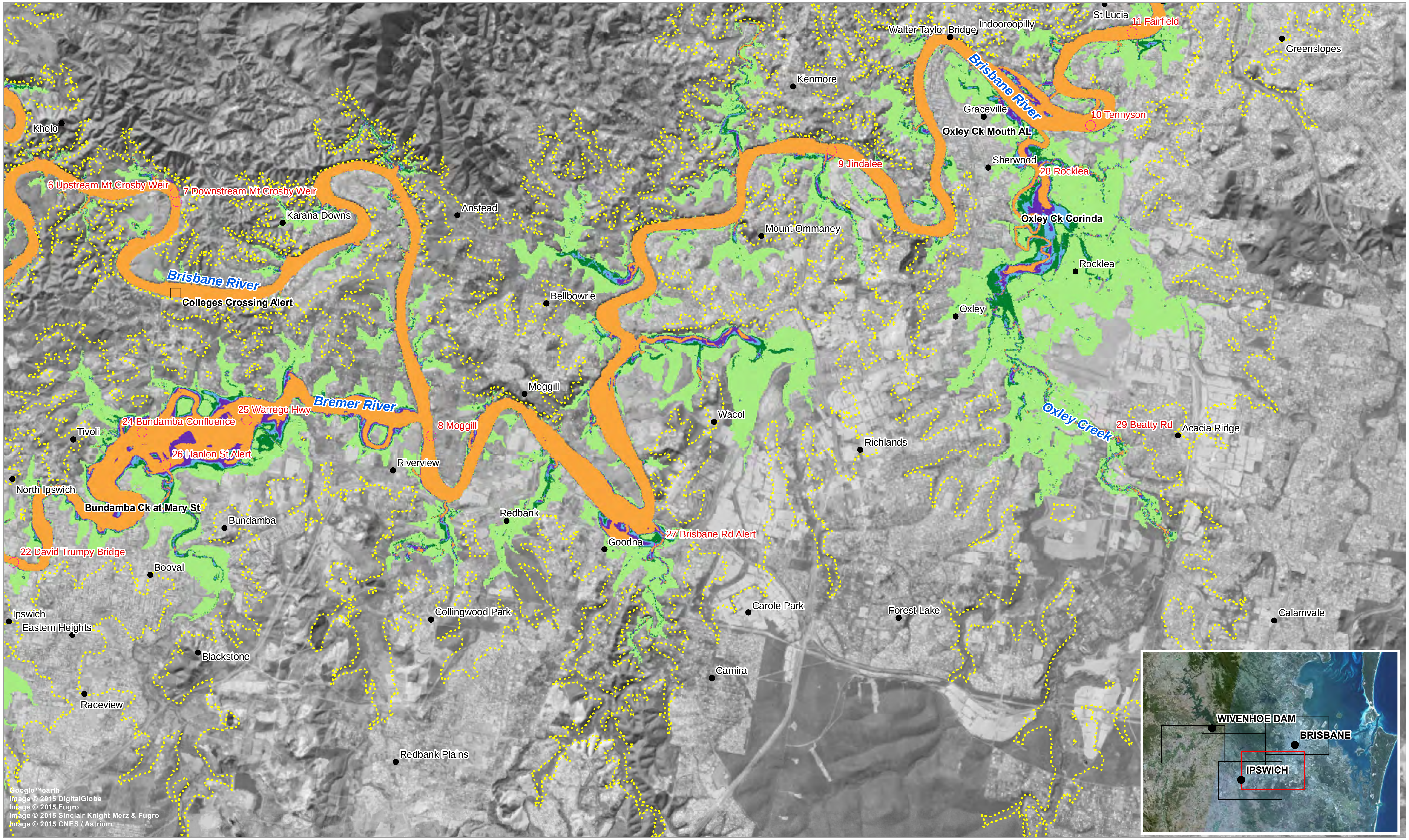

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth x Velocity (m^2 /s)

- 0 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.2
- >1.2

Brisbane River Catchment Flood Study
Study Partners

Queensland Government

Brisbane City Council
Ipswich City Council
Lockyer Valley Regional Council
Somerset Regional Council
Seqwater

Peak Depth x Velocity (Hydraulic Hazard) Maps - 1 in 100 AEP Region D

Map 20
(MR5,Drawing 23)

Feb. 2017

0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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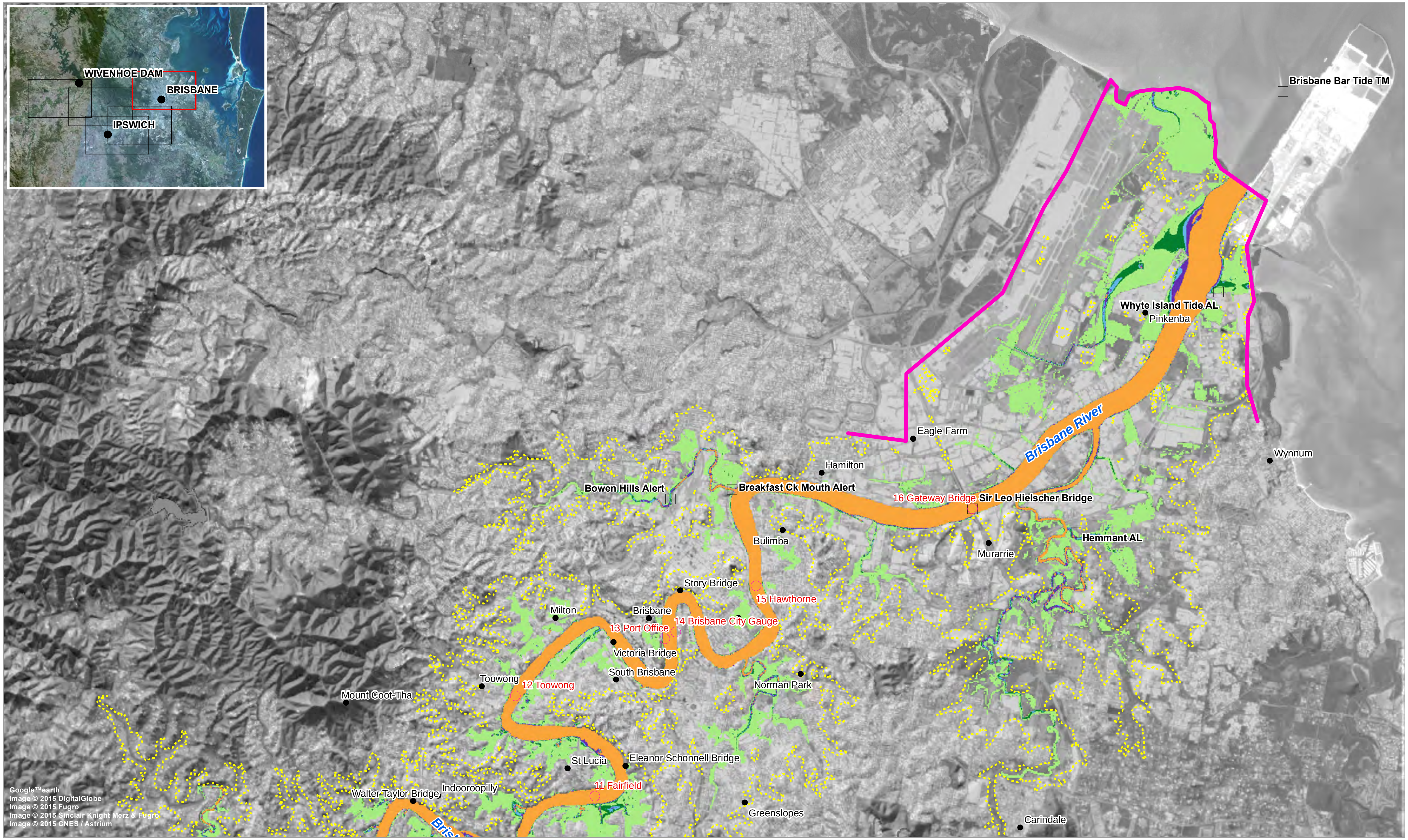

LEGEND

- Gauging Station
- Hydraulic Assessment Reporting Location
- Extreme Flood (notional 1 in 100,000 AEP)
- Limit of Detailed Modelling

Refer to Councils for local flooding beyond limit

Depth x Velocity (m^2 /s)

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Brisbane River Catchment Flood Study
Study Partners

Queensland Government

Brisbane City Council
Ipswich City Council
Lockyer Valley Regional Council
Somerset Regional Council
Seqwater

Peak Depth x Velocity (Hydraulic Hazard) Maps - 1 in 100 AEP Region E

Map 21
(MR5,Drawing 24)

Feb. 2017

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

0 1.5 3 4.5
Kilometers

Map Grid of Australia 1994, Zone 56

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