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ASSESSING FLOOD RISKS IN THE CITY OF DUBBO, AUSTRALIA

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ABSTRACT

In 2012 a draft flood study was undertaken to define the nature and extent of flooding and flood hazards for a range of design floods in the City of Dubbo which is located on the banks of the Macquarie River in central New South Wales, Australia. The study area included the floodplains of the Macquarie River and the lower Talbragar River located around 6 km north of Dubbo. Located upstream of Dubbo, the major Burrendong Dam was commissioned in 1965 and it has affected the flood behaviour of the Macquarie River downstream of the dam. In May 2015 additional assessments were undertaken including the review of 44 rating tables, flow gaugings and flood frequency analysis at Station 421001 Macquarie River at Dubbo. These assessments are described. Five Pre-Dam and Post-Dam annual peak flow scenarios were assembled and subjected to Bayesian flood frequency analysis The outcomes of the additional assessments ,which were subject to peer review are outlined and the updated assessment of flooding and flood hazards for a range of design floods in the City of Dubbo are overviewed. It is concluded that the additional assessments should increase the confidence of the community when adopting the updated flood study for the City of Dubbo.

Keywords: Rating tables, flow gauging, Bayesian flood frequency analysis

1 INTRODUCTION

In 2012 a draft flood study was undertaken to define the nature and extent of flooding and flood hazards for a range of design floods in the City of Dubbo which is located on the banks of the Macquarie River in central New South Wales, Australia. The study area included the floodplains of the Macquarie River and the lower Talbragar River located around 6 km north of Dubbo. Located upstream of Dubbo, the major Burrendong Dam (refer Figure 1) was commissioned in 1965 and it has affected the flood behaviour of the Macquarie River downstream of the dam. These assessments were described in part as follows (Cardno, 2012):

> *This flood study uses data from a number of previous studies. However, by using the latest 2-dimensional hydrodynamic modelling techniques and comprehensive aerial laser survey data it is considered to be more complete and reliable than previous investigations.*
>
> *Estimation of flood discharges was undertaken by a combination of flood frequency analysis and hydrological modelling. Flood frequency analysis was undertaken for the Macquarie River at Dubbo, for the post-Burrendong Dam scenario. Burrendong Dam was commissioned in 1965 and it has affected the flood behaviour of the Macquarie River, so that analyses of pre-1965 data are not directly relevant. The flood frequency analysis was updated to included stream gauging data up until 2006, and estimates of the magnitude of flood peaks for design rainfall events were updated.*
>
> *Estimates of flood discharges for the Talbragar River, and for the minor tributaries within the study area, were derived using rainfall-runoff modelling. In the case of the Talbragar River the modelling was based on modelling undertaken for a previous study (Rust-PPK, 1995).*
>
> *The other major component of the study was the establishment, calibration and running of a 2-dimensional hydrodynamic model for the study area. This model was developed using aerial laser survey (ALS) data provided by Dubbo City Council for the city area. The model covers approximately 194 square kilometres and contains over 2 million cells. The cell size varied with a finer grid being used in the Dubbo CBD.*
>
> *The hydrodynamic model was calibrated against observed flood levels from a flood in August 1990. Good agreement was obtained, with most of the calculated flood levels being generally within ±0.1 metre of the observed level.*
>
> *The hydrodynamic model was also adjusted back to historical conditions and run to represent the February 1955 flood. Only limited data are available for this event and the accuracy of some of the flood*

level observations is uncertain. However, it is considered that the model satisfactorily reproduced the major features of the flood.

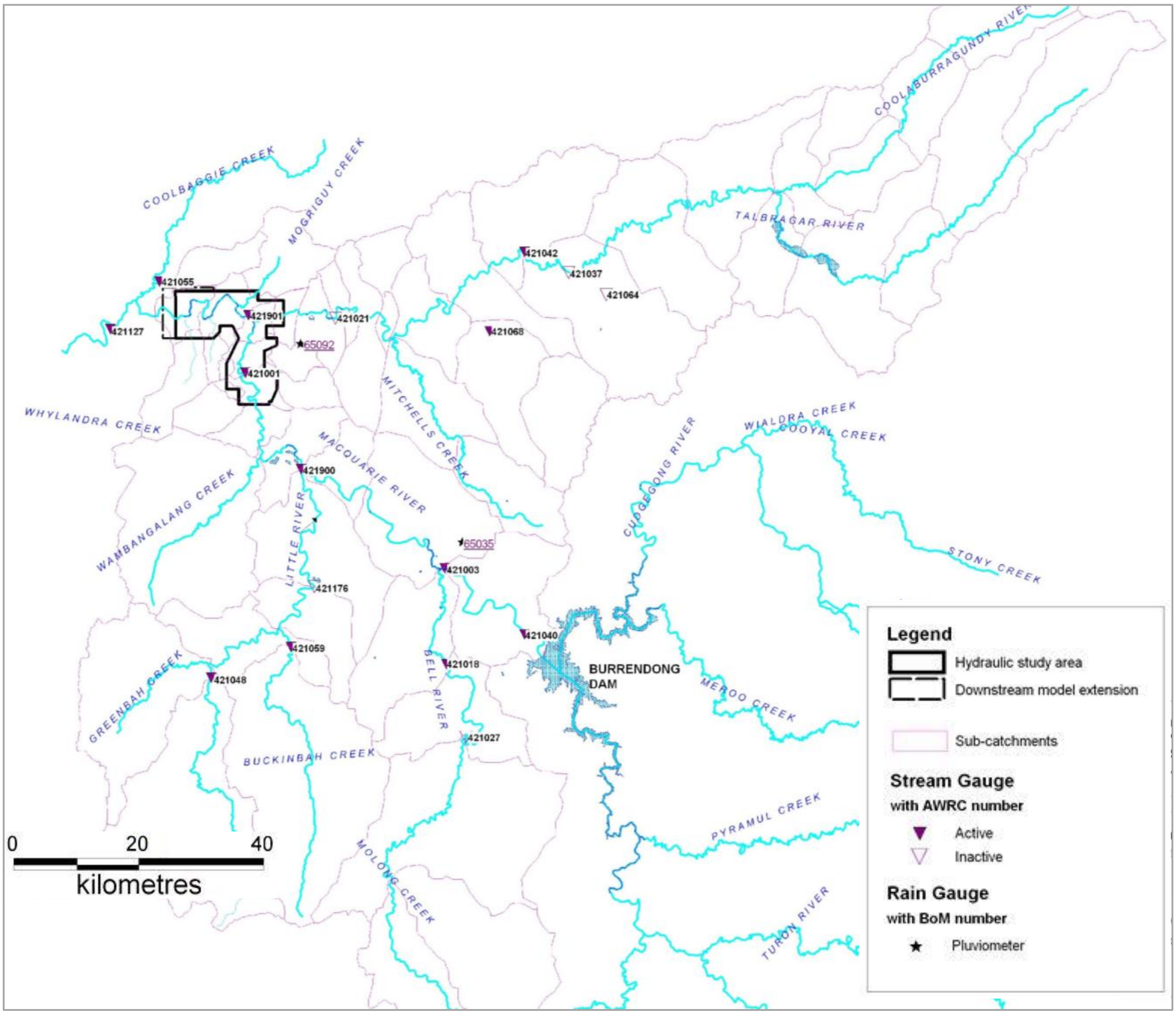

Figure 1. Rivers and Creeks flowing to the Study Area (after Cardno, 2012)

The calibrated model was then used to update flood level predictions for a range of flood level predictions for design rainfall events with Annual Exceedance Probabilities (AEP's) of 0.5%, 1%, 2%, 5% and 10%, as well as for selected extreme flood cases.

Historical evidence indicates that the flood behaviour in the study area depends on the relative timing of flows in the Macquarie River and Talbragar River. Accordingly, the sensitivity of the flood results to this timing was examined by running different design event scenarios based on interpretation of the historical observations.

There is insufficient meteorological data to allow a comprehensive statistical analysis of the joint probabilities of different storm events. Instead, a practical approach has been adopted to the joint probability issue by assuming that during a large storm, a lesser storm will occur on the other catchment. For example, a 1% AEP storm on the Macquarie River catchment has been combined with a 5% AEP storm on the Talbragar River catchment. This assumption is reasonably consistent with the limited historical data. For smaller floods, of the order of 10% AEP, it is considered more likely that the flood-producing rains may cover both the Talbragar and Macquarie-below-Burrendong catchments. It is also more likely that floods will be stored at Burrendong Dam, so that there would be no flood outflow. For such floods it has been assumed that the flood events will encompass both the Talbragar and Macquarie-below-Burrendong catchments.

Design flood levels have been listed at a large number of selected locations within the area covered by the hydrodynamic model. Flood levels at other locations can be derived either by interrogation of the model, or by linear interpolation if the model is not available.

Depending on the flood scenario, in particular the relative timing of the Macquarie and Talbragar flood peaks, flood levels at the Dubbo gauge can differ by over one metre for a given AEP. The recommended approach to setting design flood levels for planning purposes is to use an 'envelope' approach, taking the higher of the two levels at each location for the scenarios with a given AEP such as 1% AEP. A listing of 'envelope' 1% AEP levels plus 0.5 m freeboard has been prepared to provide this information. This wide range will also have an influence on the approach which is adopted by SES to flood management. The consequence of these results is that, in addition to the Dubbo PS gauge, other flood intelligence such as rainfall and flooding reports from the Talbragar River catchment, should be used to determine which scenario is likely to apply in any flood event.

2 FLOOD FREQUENCY ANALYSIS

In May 2015 additional assessments were undertaken including the review of 44 rating tables, flow gaugings and flood frequency analysis at Station 421001 Macquarie River at Dubbo. These assessments are overviewed as follows.
As described in Cardno, 2012:

Over 100 years of flood data are available from the composite record at Dubbo, represented by the Pumping Station (Town) Gauge No. 421001. Additional data are also available for some of the gauging stations on the Macquarie River and its tributaries. However, the focus of this study is on Dubbo and its immediate surrounds, and updating of flood frequency analyses at other gauging stations was outside the scope of this Study.

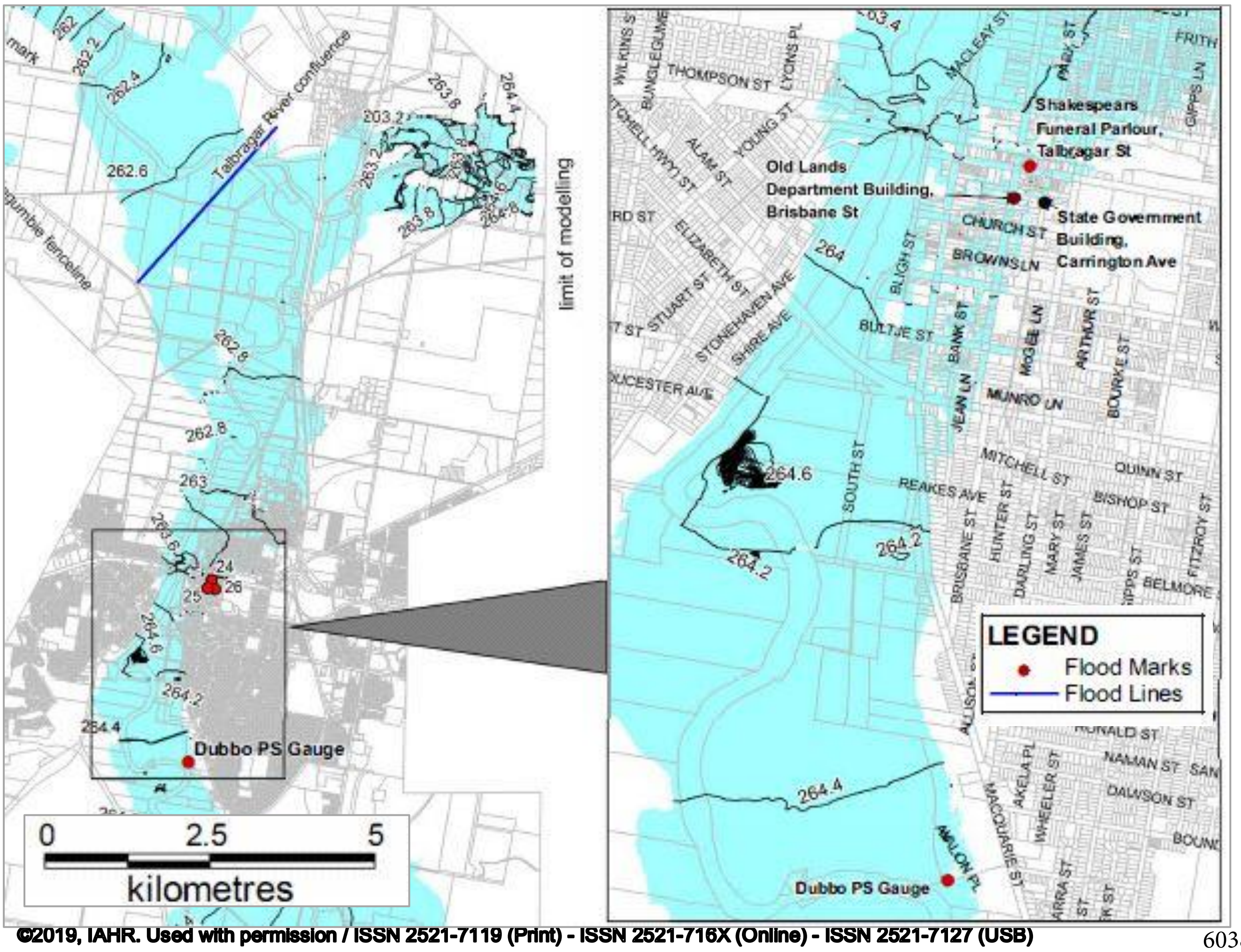

Figure 2. Location of Dubbo Pumping Station (PS) Gauge No. 421001 and estimated 1955 Flood Extent and Levels (m AHD). (after Cardno, 2019)

2.1 2007 Flood Frequency Analysis

As described in Cardno, 2012:

A flood frequency analysis for the Macquarie River at Dubbo was previously undertaken for the 1988 Dubbo Flood Study Report DWR, (1988). Because the completion of Burrendong Dam has had a significant effect on flood behaviour, the analysis was done by routing the recorded floods through the Dam using the Department's adopted gate operation procedures.

An additional 29 years of post-dam data are now available at the Dubbo Pumping Station (PS) gauge, more than doubling the available data for the post-dam scenario. Accordingly it was decided to update the flood frequency flood frequency analyses. Details of the update are given in Appendix C (refer Cardno, 2012).

Significant floods have occurred in the Macquarie River upstream of Burrendong Dam, for example that of August 1998, but they have not necessarily caused flooding downstream of the dam.

The additional flood frequency analysis has led to revision of the estimated frequency of the historical floods, and also to a revision of the estimated Macquarie River discharge for floods of specified AEP.

The flood frequency analysis reported in Cardno, 2012 included gauge data at Station 421001 Macquarie River at Dubbo available up to and including 2006.

2.2 2015 Flood Frequency Analysis

Based on the occurrence of a major flood in December 2010 and additional available data, the flood frequency analysis was updated to include the additional eight years 2007 to 2014 in the annual series of peak gauge levels and flows for Dubbo. As described in Section 3.2 of the Discussion Paper attached in Appendix C of Cardno, 2019, the aims of the 2016 assessments at the gauge at Station 421001 Macquarie River at Dubbo included to:

- Update flood frequency analysis of flows to include readings from 2007 – 2014 inclusive; and
- Quantify sensitivity of peak flows to the rating table.

Flood frequency analysis was not undertaken for the Talbragar River but instead design hydrographs were based on hydrological modelling.

A separate flood frequency analysis was undertaken using the Bayesian approach (FLIKE) which was proposed in Chapter 2 At-Site Flood Frequency Analysis of draft Book 3 Peak Discharge Estimation of the updated version of Australian Rainfall & Runoff. Three censoring scenarios were adopted as follows:

- Scenario E0 – No censoring;
- Scenario E1 – One occurrence in previous 95 years greater than a threshold flow; and
- Scenario E3 – Three occurrences in previous 95 years greater than a threshold flow.

The FLIKE flood frequency flows are compared with the design peak discharges adopted at the Dubbo Pump Station gauge (refer Table 4(b) in the 2012 Cardno report) in Table 1.

Table 1 Comparison of 2015 Post-Dam Flood Frequency Flows and
2012 Revised Design Flows at the gauge at Station 421001 Macquarie River at Dubbo

AEP	2015 FLIKE Post-Dam Scenario			Cardno, 2012
(1 in X)	E0	E1	E3	Table 4(b) & Table C.2
10	784	773	822	820
20	1,329	1,314	1,431	1,360
50	2,524	2,503	2,816	2,500
100	3,980	3,959	4,564	3,820

200	6,158	6,147	7,263	5,700

It was concluded that (refer Section 3.2, Appendix C of Cardno, 2019):

- *Extending the period of record from 2006 to 2014 slightly increased the estimated 100 yr ARI peak flow under Post-Dam conditions (based on LPIII analysis using the 2007 rating table);*
- *The adoption of the 2013 rating table lowers the flood frequency curve;*
- *The ARR2015 FLIKE assessment gave curves which were slightly higher than the ARR1999 LPIII analysis;*
- *The ARR1999 LPIII analysis of the extended annual record (based on the 2007 rating table) is very similar to the ARR2015 FLIKE analysis of the extended annual record (based on the 2013 rating table);*
- *In relation to the ARR2015 FLIKE analyses the rating table has a greater impact on the estimated 100 yr ARI peak flow than the inclusion of 1 or 3 synthetic historical exceedances;*
- *The 100 yr ARI design peak inflow adopted in the 2012 study is slightly lower than the range of 100 yr ARI peak flows estimated under Scenarios E0, E1 and E3 but is well within the confidence limits;*
- *The 200 yr ARI design peak flow adopted in the 2012 study is lower than the range of 100 yr ARI peak flows estimated under Scenarios E0, E1 and E3 but is well within the confidence limits.*

2.3 2016 Flood Frequency Analysis

A peer review of the 2015 flood frequency analysis resulted in a further review of rating tables, flow gaugings and the flood frequency analysis at the gauge at Station 421001 Macquarie River at Dubbo.

2.3.1 Rating Tables

The review found that 44 rating tables were applied at the Station 421001 Macquarie River at Dubbo gauge over various periods. Rating Table 1 also applied to the period 1885 – 1900. Figure 3 compares rating curves Nos. 1, 10, 13, 175.01 and 200 to give an indication how the rating curves at the gauge have varied over time.

For the maximum gauge height of 9.12 m recorded in 1886 and depending on the selected rating table, the calculated peak discharge at the gauge would vary from 768 m^3/s up to 1,642 m^3/s. It was also clear that there was a step change in the estimated peak flow from Rating Table 12 (1 July 1943) onwards.

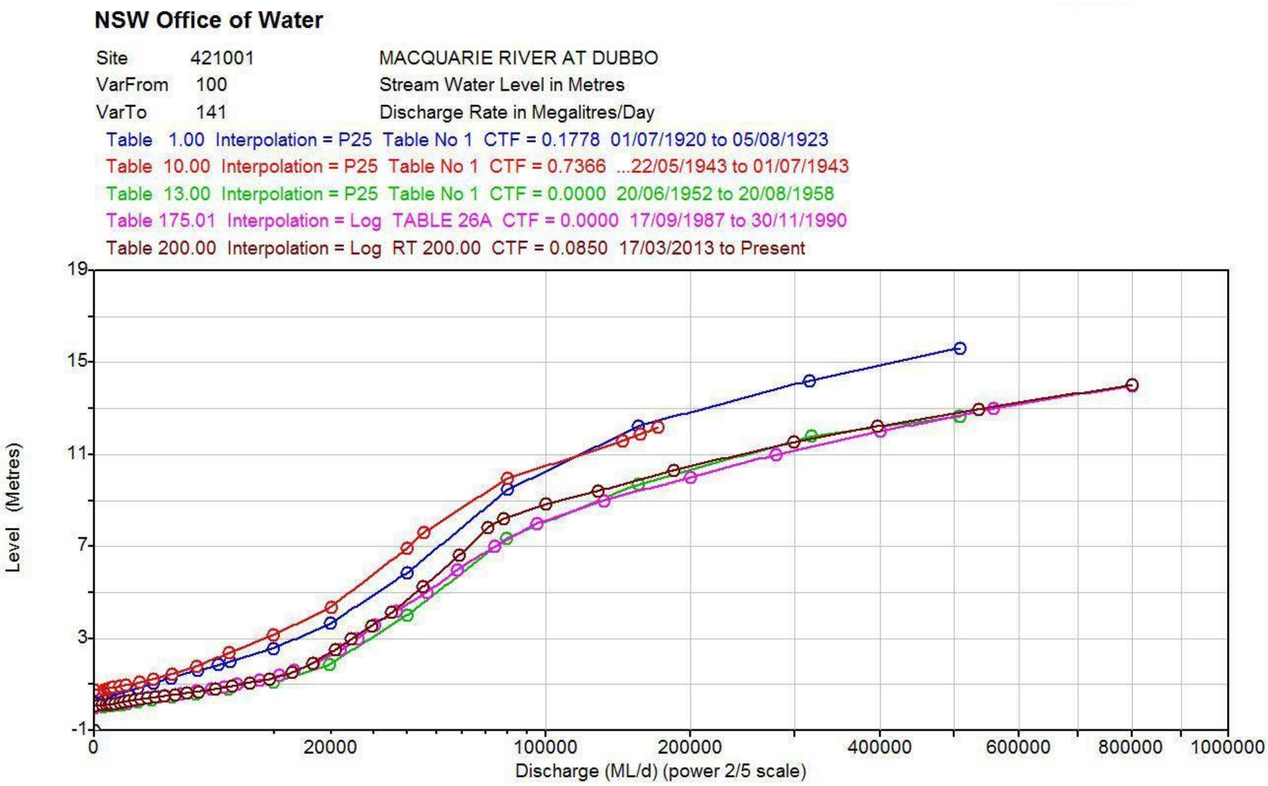

Figure 3. Comparison of Rating Curves. 1, 10, 13, 175.01 and 200 at Station 421001 Macquarie River at Dubbo

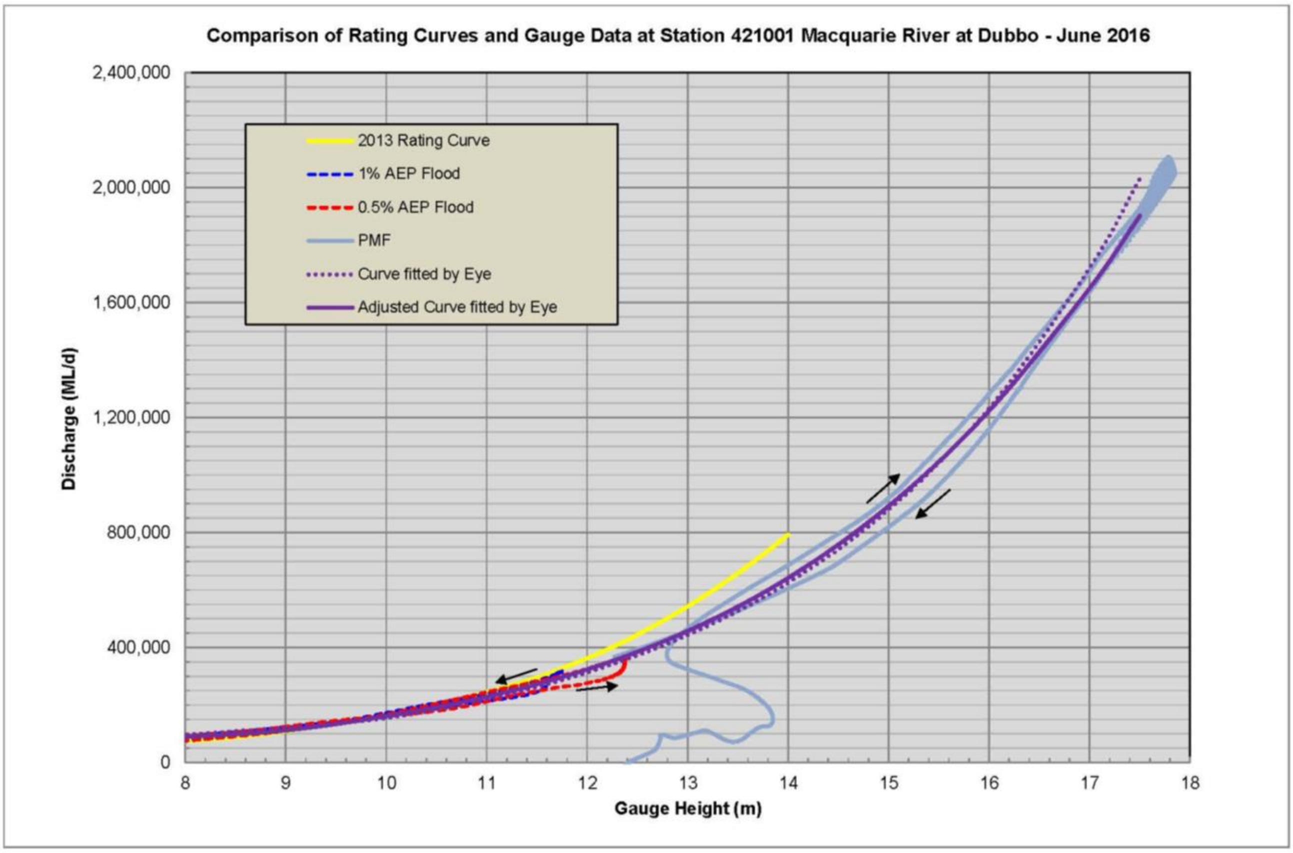

Figure 4. Comparison of 2013 Rating Curve (No. 200) and stage-discharge variations during 1% AEP flood, 0.5% AEP flood and Probable Maximum Flood (PMF) simulations.

The results of hydraulic modelling of the Macquarie River and its floodplain over a range of flood events can be also used to create a stage-discharge rating curve at the gauge at Station 421001 Macquarie River at Dubbo. Figure 4 compares Rating Curve No. 200 with the rising and falling limbs of the 1% AEP flood, 0.5% AEP flood and PMF simulations.

Curves fitted by eye to the hydraulic modelling results are also plotted. The first curve by eye was fitted in late March 2016. The adjusted curve by eye was fitted in June 2016. The adjustment is primarily in the higher stages > 16 m gauge height. The direction of the rising and falling limb of the 0.5% AEP and PMF is also indicated.

2.3.2 Flood Frequency Analysis

A number of Pre-Dam and Post-Dam annual peak flow scenarios were assembled as follows:

Pre-Dam Scenarios (PR1, PR2, PR3, PR4, PR5)

- PR1 The annual peak flows are based on the applicable rating table for each year. Where multiple tables operated in a year then the lowest estimated peak flow was adopted.
- PR2 The annual peak flows are based on the applicable rating table for each year. Where multiple tables operated in a year then the highest estimated peak flow was adopted.
- PR3 It was determined that in the 2007 assessment the Pre-Dam peak flows were obtained from Rating Table 100. These annual peak flows were obtained from Rating Table 100 without any censoring of low values
- PR4 These annual peak flows were obtained from the current rating table (Rating Table 200) without any censoring of low values
- PR5 The annual peak flow were obtained by applying the rating curve fitted by eye to the modelling results

Post-Dam Scenarios (PO1, PO2, PO3, PO4, PO5)

PO1 The annual peak flows are based on the applicable rating table for each year. Where multiple tables operated in a year then the lowest estimated peak flow was adopted.
PO2 The annual peak flows are based on the applicable rating table for each year. Where multiple tables operated in a year then the highest estimated peak flow was adopted.
PO3 It was determined that in the 2007 assessment the Post-Dam peak flows were obtained from Rating Table 175.01. These annual peak flows were obtained from Rating Table 175.01 without any adjustments to peak flows eg. August 1990
PO4 These annual peak flows were obtained from the current rating table (Rating Table 200) without any adjustments to peak flows eg. August 1990
PO5 The annual peak flow were obtained by applying the rating curve fitted by eye to the modelling results)

A further scenario was added:

PO4A This scenario is based on Scenario PO4 data except the peak flow for 1990 was increased to 2,320 m^3/s based on the gauged flow of 2,177 m3/s at a gauge height close to but lower than the maximum recorded gauge height.

A FLIKE assessment of each of the various PR and PO annual peak flow scenarios was undertaken. The PR4 and POA4 FFAs were also correlated to calculate the equivalent Post-Dam peak flows for the three highest flow events prior to 1965 and an analysis of the PO4A annual peak flows based on three censoring scenarios was undertaken.

Based on their review of the results of the assessment of three censoring scenarios a Peer Reviewer confirmed the suitability of E0 for use.

The peak flows estimated by flood frequency analyses undertaken in 2007, 2015 and 2016 at the gauge at Station 421001 Macquarie River at Dubbo are given in Table 2.

Table 2 Comparison of 2015, 2016 Post-Dam Flood Frequency Flows and 2012 Revised Design Flows at the gauge at Station 421001 Macquarie River at Dubbo.

AEP		Cardno, 2012	FLIKE Post-Dam FFA	
(1 in X)	(%)	Table 4(b) & Table C.2	2015 E0	2016 (PO4A) E0
10	10%	820	784	790
20	5%	1,360	1,329	1,343
50	2%	2,500	2,524	2,557
100	1%	3,820	3,980	4,037
200	0.50%	5,700	6,158	6,255

3 2018 DESIGN FLOODS

3.1 Hydrology

Based on the outcome of the 2016 flood frequency analysis adjusted peak design inflows to the Macquarie River were adopted. The peak design inflows to the lower reach of the Talbragar River were as adopted in Cardno, 2012.

In August 2016 the peak flows reported in the 2012 report, the peak inflows (in m^3/s) obtained from the 2016 TUFLOW model and the PO4A peak flows were compared. The primary issue of concern was the peak inflow adopted in the 2012 for the 0.5% AEP flood which was 1,000 m^3/s lower than the peak flow obtained from the flood frequency analysis. Consequently, increasing the peak flow from 4,700 m^3/s to 6,255 m^3/s increased the Macquarie River flood levels by around 1 m.

Advice was provided to Dubbo Regional Council in relation to the issues of concern in September 2016 (refer Figure 5). In relation to the 0.5% AEP flood it was proposed to adjust the peak inflow to give a 0.5% AEP flood level at the t the gauge at Station 421001 Macquarie River at Dubbo which should be comparable to the gauge height predicted by the adopted flood frequency analysis (the adjusted peak inflow would be around 5,300 m^{3}/s).

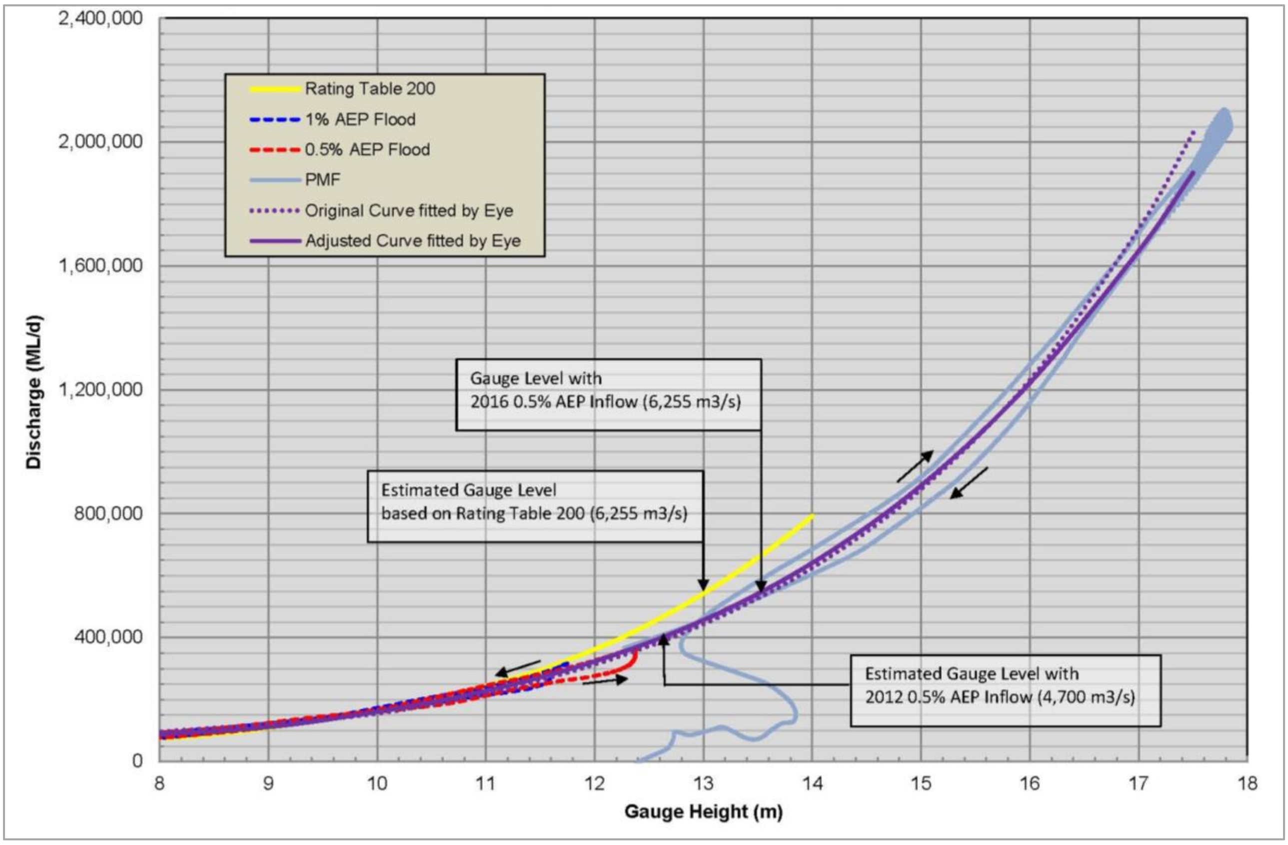

Figure 5. Comparison of Rating Curves and Gauge Data at Station 421001 Macquarie River at Dubbo

In October 2016 the Peer Reviewer advised, in part, that while it would be intellectually interesting to resolve this difference between the two estimates and that the pragmatic decision to adjust the flow was supported given there were no practical consequences.

The peak inflows to the Macquarie River adopted in the 2012 and 2018 assessments are compared to the peak inflows flood obtained from the 2007 and 2016 flood frequency analyses in Table 3. The changes in peak inflows in comparison to the peak inflows adopted in the 2012 floodplain model for the 10% AEP, 5% AEP, 2% AEP, 1% and 0.5% AEP Macquarie River floods were -31%, -1%, +2%, +6% and +13% respectively. The Talbragar River inflows remaining unchanged from the 2012 study.

Table 3. Comparison of Adopted Peak Design Inflows for the Macquarie River and the Talbragar River

AEP		Macquarie River				Talbragar River
(1 in X)	(%)	Cardno, 2012 Table 4(b) & Table C.2	2012 TUFLOW Model	2016 PO4A EO FFA	2018 TUFLOW Model	2012 & 2018 TUFLOW Models
10	10%	820	1,142	790	790	1,819
20	5%	1,360	1,360	1,343	1,343	2,473
50	2%	2,500	2,500	2,557	2,557	3,214
100	1%	3,820	3,820	4,037	4,037	4,011
200	0.50%	5,700	4,700	6,255	5,300†	4,881

† *The 0.5% AEP peak inflow was adjusted to give a 0.5% AEP flood level at the gauge at Station 421001 Macquarie River at Dubbo which should be comparable to the gauge height predicted by the adopted flood frequency analysis*

The peak design inflows for the Talbragar River adopted in the 2012 and 2018 assessments are also given in Table 3 for comparison to the Macquarie River peak design inflows.

3.2 Hydraulics

As discussed in Cardno, 2012, two scenarios were modelled for the 5%, 2%, 1% and 0.5% AEP floods. The first represents the case where Macquarie River flooding is dominant, while the second represents a Talbragar River-dominant flood. A single scenario was modelled for the 10% AEP flood.

It was found that there is an overall reduction in the estimated 10% AEP flood levels in comparison to the levels reported in 2012. This reduction is attributed to the difference in the Macquarie River peak flow adopted in the 2012 and 2018 TUFLOW models and the modification of the floodplain model on the lower Talbragar River floodplain as a result of the validation of the floodplain model with the December 2010 flood.

Likewise, the modification of the floodplain model on the lower Talbragar River floodplain was the main source of lowering of the 5% AEP and 2% AEP levels design flood levels in comparison to the 5% AEP and 2% AEP levels reported in 2012 along a substantial reach of the Macquarie River and Talbragar River.

While the modification of the floodplain model on the lower Talbragar River floodplain lowered the 1% AEP and 0.5 % flood levels to a degree in the Talbragar River (in comparison to the levels reported in 2012), the 1% AEP design flood levels along substantial reaches of the Macquarie River and the 0.5% AEP design flood levels completely along the Macquarie River have increased (in comparison to the levels reported in 2012).

Three extreme flood cases were modelled, as selected by Council. For Macquarie River, they are:-

- 'Sunny Day' Burrendong Dam failure
- PMF with no Burrendong Dam failure
- PMF with Burrendong Dam failure

The 10th, 25th, 50th, 75th and 90th percentile differences between the extreme flood levels estimated in 2018 and reported in 2012 are as follows.

	Sunny Day Dambreak	PMF without Dambreak	PMF with Dambreak
Percentile	Difference (cm) (2018-2012)	Difference (cm) (2018-2012)	Difference (cm) (2018-2012)
10%	-5	0	-28
25%	-2	4	-16
50%	1	11	-7
75%	36	46	68
90%	98	75	147

These flood level differences give an indication of the potential impact of probable maximum flood in the Macquarie River and on substantial areas of Dubbo as well as the adverse impacts of failure of Burrendong Dam on a sunny day (no rainfall) or under extreme weather conditions.

4 CONCLUSIONS

In 2012 a draft flood study was undertaken to define the nature and extent of flooding and flood hazards for a range of design floods in the City of Dubbo. In May 2015 additional assessments were undertaken including the review of 44 rating tables, flow gaugings and flood frequency analysis at Station 421001 Macquarie River at Dubbo. Five Pre-Dam and Post-Dam annual peak flow scenarios were assembled and subjected to Bayesian flood frequency analysis. The outcomes of the additional assessments were peer reviewed. It is concluded that the additional assessments should increase the confidence of the community when adopting the updated flood study for the City of Dubbo.

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