Review of Brisbane River 2011 Flood Frequency Analysis

PREPARED FOR

QLD Flood Commission of Inquiry

September 2011

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CIVIL, ENVIRONMENTAL AND MINING

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Executive Summary

This document is a review of the report WMA (2011a) regarding flood frequency analysis of the Brisbane River. The report is herein referred to as the WMA report or as WMA without citing the year. The scope of work requested of Mark Babister by the Queensland Flood Commission of Inquiry was to:

1. Conduct a flood frequency analysis and determine the 1% AEP flood level for key locations on the Brisbane River ... using information available prior to the January 2011 event ... This work should include a review of the SKM 1% AEP flood profile.
2. Repeat task 1 with the 2011 event included in the historical dataset.
3. Using results of task 1 and 2 determine the ARI and AEP of the January 2011 floods at particular points along the Brisbane River and Bremer River.

Addressing Task 2, the WMA report concludes that the post-dam best estimate of the Brisbane River is 9500 m^3s^{-1}, which is based on a pre-dam best estimate of 13000 m^3s^{-1}. The methodology in obtaining both estimates seems justified. Furthermore, the pre-dam best estimate is consistent with earlier estimates, most notably the SKM (2003) best estimate of 12000 m^3s^{-1} ± 2000 m^3s^{-1}. Both flood frequency assessments have given detailed reasoning and used best-practice Bayesian techniques to obtain their estimates. The upward revision of 1000 m^3s^{-1} from the SKM estimate is minor given the uncertainty range and relative orders of accuracy involved. This difference can largely be attributed to the 2011 event and minor differences in methodology. The post-dam estimate of 9500 m^3s^{-1} is higher than the SKM (2003) estimate of 6500 m^3s^{-1} and largely relies on insight obtained from the 2011 flood to suggest the dams had less impact in the region of high flows than the 50% reduction estimate used in the investigations of SKM (2003).[1]

Addressing Task 1, it is the reviewer's interpretation that the task requires a critique of the data and methodologies used prior to the 2011 event rather than an analysis on the influence of 1 data point. The report offers a flow estimate of 9000 m^3s^{-1} using only data available prior to 2011, but the reviewer considers that the authors have implicitly used knowledge of the 2011 event in their argument for a different pre-dam to post-dam conversion of the flow (paragraph 132 and Figure 3). Nonetheless, the report goes a long way towards explaining discrepancies between their estimate and earlier estimates. Reasons offered include (i) confirmation by the 2011 event that early settlement flood estimates are plausible (ii) recent understanding of climate variability (iii) well-known discrepancies between flow-based and rainfall based techniques attributed to few rainfall records in the 1800s and to poor areal rainfall estimates (iv) uncertainty in the stage-discharge relationship (v) lack of large floods to validate the Wivenhoe dam and (vi) significant scatter in the pre-dam to post-dam flow conversion. The report concludes by emphasizing uncertainties in the stage-discharge relationship, but the reviewer feels that greater emphasis should be given to the scatter in the pre-dam to post-dam conversion. This is the largest differentiating factor between the WMA estimate and that recommended by SKM (2003). This point relates strongly to "joint probability" issues which are thorny obstacles in reliable flood estimation (relevant examples include flow peak with flow volume, and the joint distribution of rainfall over multiple catchments). These issues can only be addressed with detailed Monte Carlo assessment, which was a key recommendation of the SKM report (2003, page 48).

Regarding Task 3, this is the matter of applying a hydraulic model to the estimate 1% AEP flow. The hydraulic model is well documented in other reports and is not considered a main obstacle in coming up with flood design levels (as compared to the hydrological issues involved). Following from an upward revision of the 1% AEP flow, the authors note higher design levels ranging from 1m at the Port Office gauge to approximately 3m in the reaches approaching Moggill gauge.

[1] The expert review panel (2003), on SKM reports, advised 6000 m^3s^{-1}. Only SKM (2003) is referenced for brevity.

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1. Introduction

The scope of work requested by the Queensland Flood Commission of Inquiry to Mark Babister of WMA water was to:

1. Conduct a flood frequency analysis and determine the 1% AEP flood level for key locations on the Brisbane River below its junction with the Bremer River and on the Bremer River in the vicinity of Ipswich using information available prior to the January 2011 event. This work should be used to determine 1% AEP flood levels at up to 8 key locations in the Brisbane and Bremer Rivers and to produce 1% AEP flood profiles. This work should include a review of the SKM 1% AEP flood profile.
2. Repeat Task 1 with the 2011 event included in the historical dataset.
3. Using results of Task 1 and 2 determine the ARI and AEP of the January 2011 floods at particular points along the Brisbane River and Bremer River.

The requested work involves the flood frequency technique such that the overall method required to complete all three tasks is one and the same. The simplest and most ideal case for a flood frequency analysis is that a long record of gauged flows exist, that the catchment has not undergone significant changes in time and that the rate of flooding is relatively constant between differing periods. In this situation the annual maximum series assumes a statistical similarity so that an appropriate probability distribution may be fitted and the Q100 design flow[2] directly inferred. While the Brisbane River does have a long timeseries suited to this method, there are a number of complications in meeting the requirements for statistical similarity. This review will discuss these matters in separate sections by tracing through the main steps of a flood frequency analysis:

- Select annual maximums and homogenize them to reflect equivalent catchment conditions ('pre-dam')
- Perform the flood frequency analysis to obtain the Q100 estimate of pre-dam flow,
- Convert the pre-dam Q100 estimate to a flow estimate of current conditions ('post-dam')
- Use of the post-dam Q100 flow with a hydraulic model to obtain flood level estimates

Since the commission of Wivenhoe dam in 1984, the estimation of Q100 flows for the assessment of downstream flood planning has been contentious, with best estimate flows ranging between 5510 m^3s^{-1} and 9560 m^3s^{-1} and design levels ranging from 3.16 mAHD to 5.34 mAHD (summarised in Table 5, Figure 6 and Figure 7 of the WMA report). The WMA report, as with preceding reports, documents the history of these estimates and the considerations given over time to resolve known discrepancies. There are a number of related issues at the centre of debate:

1. The higher rate and magnitude of floods in the 1800s and the attendant reliability of their observation.
2. Discrepancies between streamflow based techniques (flood frequency analysis) and rainfall based techniques (e.g. design storm rainfall).
3. Converting measured heights to equivalent representative flows, i.e. the reliability of the stage-discharge curve (incl. correction factors for dredging, sediment build up, channel widening, etc.)

[2] Q100 is a design flow that will be exceeded 1% of the time in a *long run* average (1% AEP, annual exceedence probability). It is synonymous with the term 100 year ARI (average recurrence interval). While it is the 1% AEP flood height at any given point that is of interest, the design methodology requires the 1% AEP flow be defined and that 1% AEP heights are subsequently obtained from this flow.

4. The method for converting "pre-dam" flows to "post-dam" flows (and vice versa)
5. The use of deterministic rainfall methods (current standard practice) versus newer stochastic approaches, i.e. Monte Carlo (being proposed in current revision of Australian Rainfall & Runoff guidelines)

It is necessary, therefore, that the WMA report provide plausible explanations that reconcile these issues to accompany their best estimate of the Q100 flow. In brief, the explanations offered by the WMA report, listed in corresponding order, are:

1. A higher rate of flooding between centuries is plausible. They cite recent research into the influence of Interdecadal Pacific Oscillation as an example. (§3.3.5)
2. The density of rain gauges is sparse in the period of the 1800s (§7.2) and that, assuming it to be a genuinely wetter period, rainfall-based methods over-represent the more recent drier part of the record. Another factor is the use of biased (low) areal rainfall averages since rain gauges are not placed in regions of steeper terrain that coincide with higher rainfall.
3. The stage-discharge relationship is inherently less certain in the region of interest (large floods) but the 2011 floods offer a greater understanding of this relationship (§6). Improved understanding of this relationship is cited as a future means for reducing uncertainty in the Q100 estimate (§8.1).
4. The conversion of pre-dam to post-dam estimates for pre-dam flows above 8000 m^3s^{-1} has been poorly understood and overestimated the performance of Wivenhoe dam (Figures 2 to 5). This is perhaps the single biggest reason offered to explain the discrepancy in Q100 estimates (paragraph 134).
5. This issue is not highlighted in the WMA report, though the SKM (2003) report repeatedly cites this issue (page 6, 36, 37, 41, 42, 46, 48). In the reviewer's opinion this issue assumes central importance in its ability to explain issue 4.

While the WMA report offers satisfactory explanations on all of these issues, it does not place suitable emphasis on the 4th issue, even though this is the most significant factor explaining a difference in Q100 estimates between 6500 m^3s^{-1} (SKM, 2003) and 9500 m^3s^{-1} (WMA). In the reviewer's opinion, the most significant insight of the report is found in Figures 2 to 5 but the discussion in §4.3 and §7.1.7 is brief and deserves a fuller treatment. The emphasis on stage-discharge relationship in the conclusions, while valid, should not outweigh the issue of pre-dam to post-dam conversion and Monte Carlo methods.

A further matter addressed in this review is the role of hind-sight estimates of Q100 and the scope of work implied by Task 1. The WMA report cites a Q100 flow of 9000 m^3s^{-1} excluding all January 2011 flood information, but the reviewer feels the authors have used implicit knowledge of January 2011 in arguing for a different pre-dam to post-dam conversion than SKM (2003). The reviewer speculates that the intended question to be answered is why there might have been a discrepancy between pre-2011 and post-2011 estimates and how this can be reasonably explained.

2. Selection and homogenisation of annual maximums

There history of the discrepancy between the flow based and rainfall based techniques in estimating the Q100 has been well documented. The choice is either to assume the large floods in the 1800s are less reliable (or unreliable) or provide explanations as to why the rainfall based techniques are biased low. The WMA report suggests that the 2011 flood gives credibility to the observations of large floods in the early settlement of Brisbane (§8, paragraph 145). The authors offer detailed background on these early estimates in addition to explanations that might explain the discrepancy between rainfall and flow based techniques.

In an earlier review, Professor Mein (1998, §5) suggested that either the weather was genuinely more extreme in this period or that the flood observations in the 1800s on the Brisbane River should be regarded with suspicion (with endorsement for the latter). As a defence of the former scenario, the authors highlight the existence of climatic variability in §3.3.5, that given periods of a flood record spanning multiple decades can be biased toward either higher or lower flood values. The presentation of Figure 1 is only qualitative and it supports this assertion a little, but the reference to Kiem *et al.* (2003) provides a better and quantitative support for this observation. This reference demonstrates a regional flood frequency using 40 sites across NSW showing markedly different flood distributions between the +ve and -ve phases of the Interdecadal Pacific Oscillation (IPO) up to the 100 year ARI. To the reviewer's knowledge there are no quantitative studies of IPO phases of flooding for the Brisbane region anywhere close to 1% AEP events. The reviewer expects this would be difficult to establish for the Brisbane River record because analysis of the IPO in the 1800s would need to rely on plaeo-reconstructions which do not have the same temporal resolution as the post-1900 reconstructions (see Verdon and Franks, 2006). Nonetheless, it is plausible that natural climatic cycles can lead to multiple larger or more frequent floods in one epoch, followed by smaller or fewer floods in the subsequent epoch.

The report by City Design (1999, §5.1) addressed the concerns of the quality of flow estimates in the 1800s by detailing the methods used to account for the effects of river dredging and blockage of the river mouth. They conclude these flows can be reliably included in the flood frequency analysis and go on to obtain a pre-dam Q100 estimate of 12,300 m^3s^{-1}. WMA (§4, §6) have also chosen to include these observations (notably 1841, 1844, 1890, 1893, 1898) and further to the June 1999 report they provide a detailed account of the height estimates and the history of changes in the river such as dredging works. The authors also discuss the effect of dams on the flow estimates at the Port Office gauge. This discussion is largely concerned with the impact of Somerset Dam on the 1974 event and the impact of Somerset and Wivenhoe on the 2011 event. All these factors are drawn upon in §6.3.2 to construct a stage-discharge curve for the Port Office gauge that is also supported by information from existing stage-discharge curves and hydraulic modelling to test the dredging assumptions of the 1893 event. In this way the adopted flows are suggested to represent flows that would occur under pre-dam conditions for identical river section properties. Appendix B of the WMA report summarises the adopted homogenized flow estimates. Many of the lower flows are identical to the June 1999 report (Table 1) and a summary of changes in the larger flows is given here.

Table 1 Differences in adopted flows due to different stage-discharge relationship

Year	City Design, 1999 (m^3s^{-1})	WMA (m^3s^{-1})
1841	14100	12534
1844	8924	10410
1890	6972	8132
1893	14600	13690
1898	8500	7528
1931	6245	7000
1974	10364	11300
2011	n/a	12400

While the suggested revision of flows based on the WMA stage-discharge curve is justified by the reasoning offered in §4 and §6, a further reason is that the pre-dam Q100 estimate derived by WMA (13000 m^3s^{-1}) is not significantly different from the estimate of 12,300 m^3s^{-1} made by the June 1999 report or the SKM (2003) estimate of 12000 m^3s^{-1} ± 2000 m^3s^{-1} (a point noted by the authors in §8, paragraph 145).

The authors stress the need to improve the stage-discharge relationship (§8.1), which is a valid emphasis as this will help reduce uncertainty in the flood estimate, but it is the reviewer's opinion that this is not the most important emphasis. This issue of uncertainty in the pre-dam Q100 estimate and in the stage-discharge relationship is pursued further in the following section concerning the flood frequency analysis.

3. Flood frequency analysis

Numerous flood frequency studies have been performed on the Brisbane River and these are summarised in §5. Whereas earlier methods used rudimentary "fit by eye" techniques, WMA (and also SKM, 2003) have used a more advanced Bayesian technique (FLIKE, Kuczera, 1999) that has numerous advantages including the ability to (i) incorporate prior or regional information (ii) incorporate stage-discharge uncertainty (iii) assess parametric uncertainty and (iv) allow for thresholded values (censoring).

Whereas SKM (2003) used a regional approach that incorporated prior information, WMA have adopted a frequency analysis solely for the Port Office gauge. Both methods have their merits, and the contrast is not of interest here since they derive similar pre-dam estimates. WMA have adopted a threshold of 2000 m^3s^{-1} (based on Figure 8) so that tidally effected values below this threshold can be incorporated into the method without needing to specify their exact value. For the full record there are 141 values below this threshold and the 30 values above this threshold are listed in Appendix B.[3] The authors considered two common distributions the GEV and LP3 distribution and 4 different scenarios: (i) full record, 1841-2011 (ii) full record omitting the 2011 event, 1841-2010 (iii) partial record matching the Lowood/Savages period, 1908-2011 (iv) Lowood/Savages period omitting the 2011 event, 1908-2010.

The reviewer has repeated this analysis using the same software. It is important to stress the methodology used by WMA and the overall recommendation of a 13,000 m^3s^{-1} pre-dam Q100 are not being drawn into question. If anything the variation on analyses presented here further confirms the 13,000 m^3s^{-1} estimate.

[3] Note: 31 values are inadvertently listed in Appendix B, but the 1843 maximum is below the threshold

The method suggested here is nonetheless recommended as it will result in lower estimate uncertainty estimates and offers a suggestion on the relative influence of stage-discharge curve uncertainty.

The LP3 and GEV are standard 3-parameter distributions used in flood frequency analysis and the use of both distributions provides a comparative check of the methodology. Reviewing the fitted distributions, the reviewer's opinion is that the LP3 gives slightly poorer fits. Furthermore, with technical reasoning outlined in Appendix A of this report, the reviewer considers the 2-parameter Gumbel distribution (simplified from the GEV) to offer a comparable fit, with the chief benefit being a reduction in uncertainty due to one less parameter. The reviewer also recommends that the expected probability of the Q100 quantile is quoted in preference to the Q100 obtained from best expected parameters (assumed usage of WMA)[4]. The results of this analysis are presented in Table 2. Comparing these results to those presented for the GEV in Table 10 of WMA the estimates here are slightly higher due to the usage of the expected probability of the Q100 statistic[3] and the 90% uncertainty limits are smaller due to the use of the Gumbel distribution (limits of WMA Q100 GEV estimate inferred from Figure 9 as being 10,000 m^3s^{-1} to 20,000 m^3s^{-1}). From Table 2 the best estimate is on the order of 13,000 m^3s^{-1} ± 3000 m^3s^{-1} and the influence of the 2011 data point on this estimate is on the order of 500 m^3s^{-1} lower and corresponds well with earlier estimates prior to January 2011 (City Design, 1999; SKM, 2003). The 1908-2011 estimate is of a similar magnitude to the 1841-2010 estimate, but the uncertainty limits are much larger. The 1908-2010 estimate is on the order of 2000 m^3s^{-1} lower and is more sensitive to the removal of the 2011 event as there is less data in this series.

Table 2 Estimates of Q100 flow (m^3s^{-1}) from different scenarios using the Gumbel distribution. 4 different time periods are considered and the effect of stage-discharge curve errors is nominally demonstrated. 90% limits are supplied in brackets.

Year	Gumbel, No Rating Error	Gumbel Rating Error N(1,0.2) above 8000 m^3s^{-1}
1841-2011	13177 (9834,16661)	13351 (9886,16968)
1841-2010	12403 (9225,15688)	12522 (9271,15927)
1908-2011	12384 (7950, 17407)	12430 (7953,17505)
1908-2010	10597 (6803,14958)	10620 (6811, 15007)

Note: The exact values from a large sample (5,000,000) have been provided for sake of reproducibility, but given the magnitude of the values and nature of the estimation they should not be considered more specific than say the nearest 500 m^3s^{-1}.

The reviewer also notes that the FLIKE software provides facility to incorporate incremental errors in the stage-discharge relationship. A further test was done using the Gumbel distribution and allowing for normally distributed incremental errors in the stage-discharge curve (mean = 1, std. dev. = 0.2) for flows above 8000 m^3s^{-1}. These figures have not been determined from detailed consideration of information used in the construction of the stage-discharge curve and they are solely provided for their demonstrative purpose. Table 2 summarises the results of these repeated analyses. It can be seen that there is negligible difference in the best estimate after taking into consideration the orders of accuracy. The upper uncertainty limit is higher, but again this does not seem to be by a significant amount. The scenarios beginning in 1841 are more sensitive to the stage-discharge curve error as they have more events above

[4] The former corresponds to an actual best estimate of the Q100 statistic (the average of Q100s made over many parameter combinations), while the latter refers to the Q100 obtained when applying a single set of parameters (even though they are the "best" individual parameters). The Q100 obtained from the best estimate parameters will be close to, but not coincident with the true best estimate of the Q100 statistic.

the adopted 8000 m^3s^{-1} threshold and the 1908-2010 is the least influenced as only the 1974 event is above this threshold.

A comparison of the GEV and Gumbel distributions is provided in Figure 1 as it highlights the reduction in uncertainty and the similarity of best estimate flows for AEPs between 20% and 1%. In brief, the estimate of 13,000 m^3s^{-1} provided by WMA is confirmed here and its upwards revision from earlier estimates, based on Table 2, can be attributed to the influence of the 2011 event. It is recommended that the estimate is quoted with 90% confidence as 13,000 ± 3000 m^3s^{-1}. Table 2 demonstrates a method for explicitly allowing for uncertainty in the stage-discharge curve, but it is unclear whether the demonstrated values are appropriate and so the estimates are qualitative only. Nonetheless, this demonstration strengthens the reviewer's opinion that the estimation methodology is not as sensitive to the stage-discharge curve uncertainty as to other components.

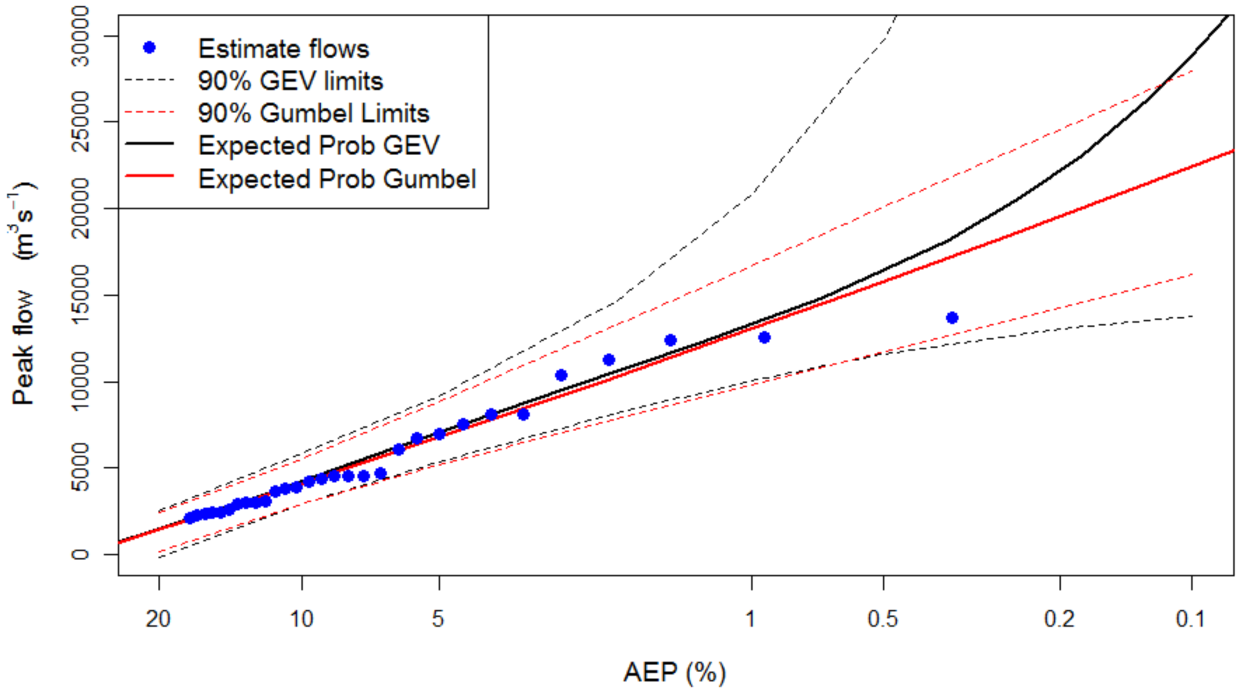

Figure 1 Comparison of GEV and Gumbel fits to 1841-2011 Brisbane River Flood data

4. Pre-dam to post-dam conversion

The previous section has highlighted that the pre-dam estimate provided by WMA is similar to earlier estimates, notably SKM (2003). However, the SKM (2003) post-dam best estimate is 6500 m^3s^{-1} whereas WMA suggest 9500 m^3s^{-1} is a better estimate. The assumption by WMA of a different pre-dam to post-dam conversion than SKM (2003) is based around Figure 3 of the WMA report. This figure summarises (i) extensive modelling undertaken by SKM involving a sensitivity analysis of spatial variation and temporal variation in the rainfall patterns, (ii) estimates derived using the CRC-FORGE method, (iii) the 1974 and 1893 historical events considered by SKM and (iv) the 2011 event. Very little discussion is given of the graph even though it contains a large degree of information. The challenge presented by Figure 3 is that estimates based on the CRC-FORGE and variation in rainfall patterns are supposed to represent 1% AEP estimates. However, these techniques only generate a scatter of pre-dam flow estimates in the range 7000-

10000 m^3s^{-1} whereas flood frequency analyses suggest a Q100 pre-dam estimate of 12,000 ± 2000 m^3s^{-1}. In determining a pre-2011 estimate of the post-dam Q100 flow the authors present a dashed line from the top end of this scatter (which also includes the 1974 event) up to the estimated flow of the 1893 event. Using this line the authors are able to convert the pre-dam Q100 of 13,000 m^3s^{-1} to 9000 m^3s^{-1} without explicitly using knowledge of the 2011 event (§7.1.6 para. 132). In the accompanying discussion the authors readily acknowledge that the 2011 event "provides the only real data point on the performance of the dam" and using the two actual estimates of the 2011 event (SKM 2011, §7, pg. 55, and WMA 2011b, pg. 3 respectively) estimates the post-dam Q100 flow to be 9,500 m^3s^{-1}. The only prior point in the region of high flows is the 1893 estimate, which was considered in the SKM report (2003, pg. 29) to be of questionable reliability (where the consideration was not in isolation but also included attempts to reconcile their method with the lower rainfall estimates and with the inherent scatter in the data underlying Figure 3). Therefore while an estimate of 9000 m^3s^{-1} could well be derived without knowledge of the 2011 event, it places disproportionate confidence in the reliability of the 1893 estimate (implicitly backed up by knowledge of the 2011 event).

The WMA report highlights the considerable scatter and sparseness of existing estimates of the dam's influence (§4.3, para. 63). The authors cite the example that "two floods could have a similar peak inflow and very different volumes and hydrograph shapes". This is very true. Consider for example that if the 2011 event did not have a second peak, the dams would not have required releases and there would be a different factor representing the attenuation of the dam for the same peak inflow. This observation of the joint nature of flood peaks and flood volumes is then countered with "there is however reasonable correlation of volume and peak flow". While true, this statement underplays the degree of difficulty implied by this scatter and seems at odds with the suggested zones of influence of the dam being depicted in Figures 3 to 5. With these zones of influence the authors are trying to highlight that the scatter in the dam's performance is not necessarily linear and likely departs from the assumed 50% line. It is because of a lack of understanding (at high pre-dam flows) and the considerable scatter in the pre-dam to post-dam relationship that a hindsight estimate can recommend a post-dam Q100 of 9,500 m^3s^{-1} where the previous best estimate based on the general scatter and other underlying issues in the data assumed a 50% reduction that gives 6500 m^3s^{-1}.

The conversion of pre-dam flow estimates to post-dam flow estimates is a complex function of the spatial and temporal patterns of rainfall. These patterns lead to the joint occurrence of flood volumes and peaks, but they also lead to other joint probability issues. For example, a rain event that lands exclusively below the Wivenhoe, or in the Lockyer or Bremer systems, will not be intercepted by the dams and so will undergo 0% attenuation. The same amount of rainfall falling in the catchment exclusively above the Wivenhoe may well undergo 100% attenuation. These types of problem are referred to as a joint-probability problems and they present a significant challenge to hydrologic design methods. Other types of joint probability problems include the initial reservoir level at the start of the storm (resolved previously, see §4.3, para. 61), the joint effect of tidal anomalies and freshwater flooding on flood levels in the lower reaches (less relevant to this report).

The chief issue with the overall flood frequency analysis is not with the fitting of distributions to selected data points, rather to the complication of the dams: dam response is volume dependent, but traditional flood frequency analysis is peak-based. There is significant scatter in the conversion of pre-dam to post-dam estimates and the relationship in Figure 3 is not well understood for the higher flows. One of the main recommendations of SKM (2003, pg. 48) was to implement a more exhaustive assessment of this scatter via a Monte Carlo approach. However, there is considerable challenge in implementing this method, since the discrepancy between rainfall–based and runoff-based techniques remains. The WMA report (§7.2) suggests two reasons why the rainfall methods are biased low. The first is that if the 1800s genuinely produced larger floods, then we do not have suitably dense rainfall networks in this period to have captured the events. In other words, the period which we have dense rainfall networks for is postulated to be a drier period. While this explanation is possible it is not clear to the reviewer how it could be tested or how rainfall scaling factors could be reliably estimated with correct long-term frequency in order to overcome this issue. The second reason offered by the authors is that areal averages of rainfall have been underestimated owing to the inhibited pattern of gauges in regions of steep terrain so that they do not capture the most intense parts of a storm. It is not clear whether this observation would account for the entire discrepancy between flow based and rainfall based estimates, but it at least has the benefit that it can be quantified more readily with attention to spatial interpolation algorithms and covariate elevation data. Even if these issues were overcome, it is a non-trivial exercise to generate the spatial patterns for a Monte Carlo estimate. While Monte Carlo estimation techniques are mature to the point of being included in the latest revision of Australian Rainfall and Runoff, the methods for simulating spatial rainfall data are complicated and remain less developed in engineering research and less tested in engineering practice.

5. Obtaining flood level estimates

This review is primarily concerned with the hydrologic aspects of the WMA report. Having obtained the Q100 post-dam estimate of 9500 m^3s^{-1}, the Mike 11 model was used to obtain the 1% AEP flood level estimates and the January 2011 flood level estimates for all lengths of the Brisbane River up to the Moggill gauge. Revisions of this model are documented in WMA (2011b) and SKM (2011). The authors note that while the model matched the January 2011 observations at Moggill, Jindalee and the Port Office well, discrepancies of up to 1.8m were observed at other locations recorded in the 2011 Joint Task Force report. The authors therefore calibrated the model to this data and used it to obtain the flood levels corresponding to the 1% AEP. As a technical matter, more information would have been appreciated on how the calibration of Figure 13 was achieved or whether this can be found in other reports. For example, what are the roughness values in the main channel and flood plain? Comparing the existing 1% AEP levels to the updated estimates (Figure 12), a difference of approximately 1m is seen at the Port Office gauge, at 3 km upstream the difference is approximately 2 m, at 10 km upstream the difference is 2.5 m, at 25 km upstream the difference is 3 m. Based on the frequency analysis, the 2011 event has an approximate ARI of 120 years (0.83% AEP) and the flood levels vary up to 0.5 m above the 1% AEP level in the upper reaches.

6. Conclusions

The estimation of design levels on the Brisbane River contains many complications and sources of uncertainty. The WMA report is concerned with the methodology of flood frequency analysis, which, in its most straightforward mode, is the fitting of a distribution to a set of statistically similar flood peaks. While this method is traditionally focused on streamflow, it seems that the methodology cannot be easily divorced from rainfall-based analyses because of the need to convert the pre-dam flow estimates coming out of the flood frequency analysis back into post-dam estimates that can be used to obtain the design levels for current conditions.

Over the successive reports on the Brisbane River there has been a discrepancy between the flow-based estimates and the rainfall-based estimates which existing studies have struggled to reconcile. This is in part due to the peculiar occurrence of more frequent and larger floods in the 1800s, where only 1 comparable flood exists in the 1900s. As suspicion has been cast over the accuracy of flood estimates in the 1800s, more emphasis has typically been placed on verifying the assumptions that underpin the rainfall analysis. With the occurrence of the 2011 flood, the WMA report places a renewed confidence in the credibility of flood estimates in the 1800s and offers detailed reasoning to establish the reliability of their estimation. In doing so they offer several reasons to support the plausibility of numerous large floods in the 1800s and to justify their perception that rainfall –based estimates are biased low. The first reason they offer is that there is a recent and growing understanding that flood peaks can be modulated by climatic oscillations spanning multiple decades. On this basis, the irregular rate and magnitude of flooding is more conceivable. They further suggest that, if this claim is proven true, then the lack of rainfall observations spanning the 1800s means that estimates of large rainfalls from the 1900s are biased towards a relatively drier period. While these explanations are plausible, it should be stressed that they remain quantitatively unverified for the Brisbane region (and verification is a non-trivial task). The other reason they offer to potentially explain the low bias in rainfall estimates is that rain gauges do not adequately sample higher rainfall areas that naturally occur in less accessible and steeper terrains. This suggestion is more amenable to being verified.

After detailed consideration the pre-dam Q100 estimate of 13,000 m^3s^{-1} ± 3000 m^3s^{-1} is robust and it agrees with earlier flood frequency estimates. The authors highlight the inherent uncertainty in the stage-discharge relationship, but it is suggested here that while this emphasis is valid, a better understanding of the pre-dam to post-dam conversion of flows is of equal, if not greater significance. As a hindsight exercise the existence of the 2011 flood along with the 1974 and 1893 floods is sufficient to establish the conversion of pre-dam estimates from the flood frequency technique to post-dam estimates (without recourse to rainfall based methods). WMA suggest the best post-dam estimate is 9,500 m^3s^{-1}, and this seems reasonable given the methodology they have followed. However, attempting to apply this conversion without knowledge of the 2011 event, whether explicit or implicit, is considerably more challenging and represents the issue facing the authors of the SKM report (2003) who determined an estimate of 6500 m^3s^{-1}. As a main recommendation the authors of this earlier report recommended a (rainfall based) Monte Carlo analysis as the best means for overcoming this limitation. This recommendation is repeated here as the zones of influence suggested by WMA in Figures 3 to 5 are still subject to uncertainty. However, correct implementation of this technique would face several challenges including the convincing simulation of spatial rainfall patterns and the outstanding issue that rainfall based estimates have yielded lower flow estimates.

References

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Appendix A

Inspecting Figure 9 and Figure 10 of the WMA report it seems that the upper uncertainty bound extends to the vicinity of 20,000 m^3s^{-1}, which seems high. The GEV distribution has the following distribution function

$$F(x;\mu,\sigma,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

Where μ is the location parameter, σ is the scale parameter and ξ is the shape parameter. When the skewness is zero (or otherwise not significantly different from zero), the 3-parameter GEV distribution becomes the 2-parameter Gumbel distribution.

$$F(x;\mu,\sigma,0) = \exp\left\{-\exp\left(\frac{-(x-\mu)}{\sigma}\right)\right\}$$

The benefit of having one less parameter is a reduction in the uncertainty estimate (as the skewness parameter need not be estimated, but is fixed to have the pre-determined value of 0). Qualitatively this decision can be determined by inspecting any (lack of) curvature in the fitted GEV distribution. Quantitatively it can be made by assessing the distribution of the estimated skewness parameter (supplied by the FLIKE software of Kuczera, 1999). If the 95% limits of this distribution contain the value 0, then the skewness cannot be statistically distinguished from 0. In other words, a Gumbel distribution is suitable. Figure A1 shows this observation to hold for the 1841-2011 Port Office record (though perhaps a GEV with fixed skewness parameter at 0.1 would perform just as well or could be argued for on the basis of prior knowledge).

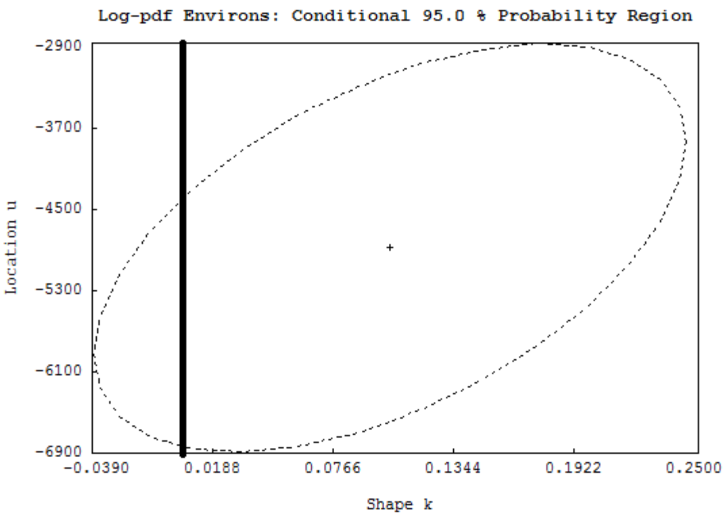

Figure A1 Distribution of GEV shape and location parameters for 1841-2011 data. Best estimate of shape parameter is 0.1, but the 95% confidence interval shows it is not statistically different from 0

It is important to note that this is a statistical observation and that other reasons may apply for retaining the skewness parameter. The most notable is for the extrapolation of estimates beyond the largest observed value. In this instance, the presence of the 1841 and 1893 events as indicated in Figure 9 show that the Q100 is within the interpolation region so that this simplification is justified.