`

Queensland Floods Commission of Inquiry

Brisbane River 2011 Flood Event – Flood Frequency Analysis

Final Report by WMAwater
September 2011

Expert Comments by
Erwin Weinmann

RJ Keller & Associates

October 2011

Table of Contents

1 Introduction 3

1.1 Appreciation of terms of reference for WMAwater report 3

1.2. Criteria for assessment of report 4

1.3 Scope and limitations of expert comments 4

2. Flood flow estimates derived by WMAwater 5

2.1 General 5

2.2 1% AEP flood flows for pre-dam conditions 5

2.3 1% AEP flood flows for post-dam conditions 9

2.4 Estimated AEP and ARI of January 2011 flood 11

3. Estimation of 1% AEP flood level profile 12

4. Conclusion 13

References 15

APPENDIX A Design flood estimation – matters for consideration 16

1 Introduction

These expert comments have been prepared to assist Clayton Utz, acting on behalf of Brisbane City Council, with the assessment of the report “Brisbane River 2011 Flood Event – Flood Frequency Analysis, Final Report, September 2011” prepared by WMAwater. This report will be referred to as “WMA (2011)”.

In the following, the basis and scope of the expert comments are further explained.

1.1 Appreciation of terms of reference for WMAwater report

Paragraph 5 of WMA (2011) gives the following terms of reference (TOR):

> “The Commission has requested that Mark Babister of WMAwater undertake the following:
>
> 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.”

It is not known to what extent these TOR have been supplemented by more detailed verbal instructions.

The following comments are relevant for the interpretation of these TOR:

- The term ‘flood frequency analysis’, in the first part of paragraph 1 of the TOR could be narrowly interpreted to mean that the study is restricted to the application of a statistical frequency analysis technique to an appropriate flood data set. However, the remainder of this paragraph makes it clear that a broader interpretation of the first task is appropriate: *the derivation by appropriate methodology of a relationship between flood magnitude (flows and levels) and frequency (expressed as annual exceedance probability – AEP, or average recurrence interval – ARI)*.
- The focus of the study is on estimates of the 1% annual exceedance probability (AEP) flood flows and flood levels at key locations. While this is not explicitly stated, these flood characteristics are understood to relate to the *current (post-dam) conditions of the Brisbane River catchment, river and estuary system*.
- Given the important flood management decisions that will be based on the study outcomes, *the estimated 1% AEP flood flows and flood levels should be as accurate as currently available data and methodology allow* (that is any remaining uncertainty about the adopted ‘best estimate’ should be as small as possible)
- The ‘best estimates’ of flood characteristics to be derived by the study should be *unbiased* (that is there should be no systematic tendency to under- or over-estimate, and any margin of safety to cover for uncertainties should be specified separately, as part of flood risk management measures).

- The reference at the end of paragraph 1 to the "review of the SKM 1% AEP flood profile" is read to imply that the review work should consider both hydrological approaches used in the SKM (2003) report to derive design floods (direct frequency analysis of flood data and simulation of design floods from design rainfalls) as well as the hydraulic modelling used to convert the derived design floods to design flood levels.
- The TOR recognise the *importance of the January 2011 flood as both a source of additional flood data and as a point of reference for flood plain management considerations.*

1.2. Criteria for assessment of report

The comments in the remainder of this report are based on the assessment of the data, methodology and analysis employed in the study against what is considered to represent accepted current practice, as documented in the current version of 'Australian Rainfall and Runoff' (ARR98), supplemented by more recent peer reviewed design information and methodology.

Appendix A to this report provides a summary of matters for consideration in design flood estimation, namely (i) the relationship between (probabilistic) design floods and actual flood events, (ii) the main flood producing and flood modifying factors to be taken account in flood estimation and (iii) the principal hydrologic approaches to design flood estimation. The main points to be taken from this summary are that the actual processes of flood formation and flood modification in the Brisbane River system are very complex, and that, for design flood estimates to be accurate and reliable, they need to be based on methodologies that take adequate account of these complexities and use the full range of flood data available.

It is recognised that the specified scope and available time frame and resources may have imposed limitations on the conduct of the WMAwater study, including the range of methods applied and the sources of data used. However, in these comments*, the assessment is against what is considered to be a desirable standard of rigorousness and completeness for a study whose findings can be expected to have very important and wide ranging implications.*

1.3 Scope and limitations of expert comments

The comments are based on the review of information contained in the following main documents:

- WMAwater (2011): Queensland Floods Commission of Inquiry, Brisbane River 2011 Flood Event – Flood Frequency Analysis Final Report, September 2011.
- SKM (2003): Brisbane River Flood Study – further investigation of flood frequency analysis incorporating dam operations and CRC-FORGE rainfall estimates – Brisbane River, Final Issue, 18 December 2003.
- Independent Review Panel (2003): Report to Brisbane City Council on review of Brisbane River Flood Study, 3 September 2003.
- BCC (2003): Joint Flood Taskforce Report, March 2011.

The comments are based on the information presented in these documents; they address the perceived strengths and limitations of the methodologies applied and compare the results produced by the different studies and reviews.

No additional analysis of basic flood data or information has been undertaken as part of this review.

2. Flood flow estimates derived by WMAwater

2.1 General

The methodology applied by WMAwater for the determination of 1% AEP flood levels in the study area involves three principal steps:

(i) Estimation of 1% AEP design peak flows at Port Office for pre-dam conditions by frequency analysis of peak flows
(ii) Conversion of pre-dam 1% AEP peak flows to post-dam 1% AEP peak flows at Port Office
(iii) Estimation of flood levels in study area for post-dam conditions

The first two steps involve hydrologic analysis techniques and are discussed in Sections 2.2 and 2.3 respectively. The third step involves hydraulic modelling and is discussed separately in Section 3.

2.2 1% AEP flood flows for pre-dam conditions

Data

Flood height data at Port Office
The basic data used to compile a series of maximum annual floods for the period of record are *recorded gauge heights at the Port Office*. Table 2 of WMA (2011) indicates that peak height records at the Port Office site commenced in 1841 but it is unclear how accurate and complete these records are for the early period (paragraph 40 implies that the 1841 flood level is sourced from a plan). Other floods reported for the period between 1824 and 1839 (including the 1825 referred to in the SKM 2003 report) have not been included in the analysis as they were judged to be either not significant or not reliably documented.

Notwithstanding some remaining uncertainties, it appears that the flood frequency analysis for the pre-dam conditions has been based on the most complete record of significant floods in the lower Brisbane River currently available.

To form a homogeneous record for flood frequency analysis, these recorded gauge heights need to be adjusted for the impacts of any significant changes in the conditions of the lower Brisbane River and estuary, notably dredging, river widening and major modifications to flood plain conditions. Section 4.2 of WMA (2011) details the significant changes in river conditions during the period of record, based on documentation in references. The adjustments to flood levels appear to be consistent with those used in BCC flood studies of 1999.

It appears that the adjustments to historical flood levels in the lower Brisbane River to compensate for changes in the conditions of the lower river are based on the most recent information that is readily available. However, as acknowledged in Paragraph 149 of the report, lack of detailed hydraulic modelling of the impacts of historical changes to the bathymetry of the Brisbane River and the possible impacts of storm surges on recorded flood levels, the adjustments are likely to have introduced significant additional uncertainty and possible bias into the 'homogeneous' record of flood heights at the Port Office gauge.

The conversion of these maximum flood heights to peak flows at the Port Office by means of a rating curve (including allowance for the impacts of the dams on recorded flood levels and flows in the period after 1959) is discussed in the next section (Methodology and results).

Peak flow data at other gauging sites
Section 7.1.2 of WMA (2011) discusses the availability of data at other gauging sites and the decision to base the flood frequency analysis on data from the Port Office gauge. The alternative gauges considered are (in downstream direction):

- Lowood/Savages Crossing – located some distance downstream of junction of Lockyer Creek with Brisbane River (1909 to date)
- Mt Crosby Weir – located some distance upstream of junction of Bremer River with Brisbane River (1900-1975)
- Mogill – located immediately downstream of junction of Bremer river with Brisbane River (1965 to date, after construction of Somerset Dam)

In contrast to the Port Office gauge, the rating curves for these three gauges are based directly on concurrent measurements of flood height and flow rate. However, these rating curves still require some degree of extrapolation to the magnitude of the largest observed flood events.

The decision by WMAwater to base the flood frequency analysis on flood height data at the Port Office gauge was based mainly on the fact that the significantly greater record length available at this site would better capture the long term climate variability affecting flood observations. *The discussion in paragraph 115 of WMA (2011) recognises the tradeoff involved between length of record and accuracy of flood data but provides only limited justification for the decision in favour of the longer but more uncertain flood data record at the Port Office.*

Figure 1 below shows a comparison of the pre-dam peakflow estimates for the Port Office site (as used in WMA 2011) and the values used by SKM (2003) for the Savages Crossing site (including simulated peak flows for the events that occurred after construction of the two Dams).

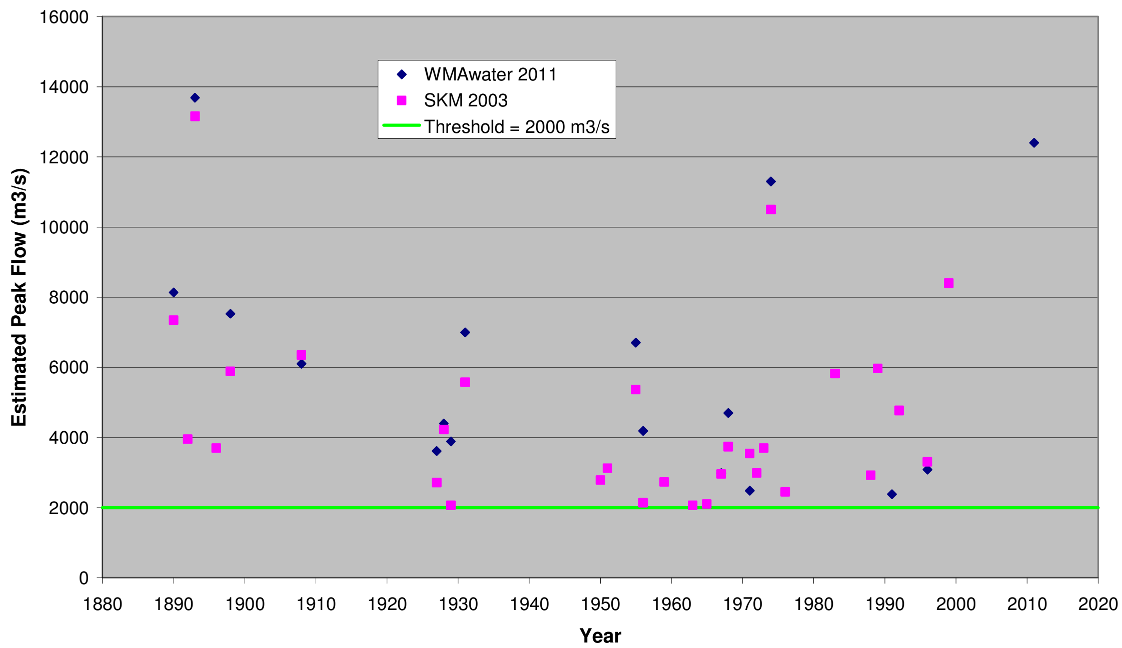

Figure 1 Comparison of annual peak flow data 1890-2011 (pre-dam conditions, flood peaks above threshold of 2000 m^3/s)

The comparison indicates that the estimates for the largest flood events (> 5000 m^3/s) are within about 10 to 20% of each other and thus quite consistent, given the likely influence of a range of factors that introduce variations in flood peaks between the two sites. However, the WMA (2011) pre-dam peak flow series misses some significant flood events which have occurred since the construction of Wivenhoe Dam and have been substantially mitigated by the dam (notably the 1999 event).

It would be highly desirable for any future detailed flood study to use the available flood data from all four sites in accordance with their special merits and limitations. This would allow some checking of flood estimates for consistency and would help to reduce the remaining uncertainty in design flood estimates.

Methodology and results

The main steps in the flood frequency analysis are:

(i) conversion of 'recorded' maximum flood heights to corresponding peak flows by means of a rating curve

(ii) adjustment of estimated flows for post-dam period for flood mitigation effects of Somerset and Wivenhoe Dams

(iii) fitting of a flood frequency curve to the series of adjusted annual maximum flood peaks using a selected probability distribution and fitting technique

(iv) determining confidence limits to express uncertainty in the flood quantile estimates (the flood magnitudes corresponding to selected ARIs or AEPs)

(i) Rating curve at Port Office

While there is anecdotal evidence of some height-discharge measurements at this site (Section 6.3.1), none such observation data was available to construct a rating at the Port Office. The 'best estimate of the high flow rating curve' shown in Figure 8 of WMA (2011) is based on the results presented in previous flood study reports and estimates of the flood height and flow ranges for the 1893, 1974 and 2011 flood events.

The use of a single valued rating curve relationship to convert recorded flood heights to flood peak flows in the range of flood magnitudes of specific interest (flows greater than 2000 m^3/s) involves the important assumption that the variations resulting from different hydrograph shapes and volumes, changing river bathymetry during major flood events and dynamic effects associated with different tidal boundary conditions are relatively minor, and the use of an average rating curve is sufficient.

There is limited information presented in the report to assess the validity of the simplifying assumptions embodied in the rating curve but they can be expected to introduce additional uncertainty into the basic data series used for flood frequency analysis.

(ii) Adjustments for flood mitigation effects of dams

The impacts of Somerset and Wivenhoe Dams on peak flood flows and flood levels in the lower Brisbane River system are discussed in Section 4.3 of WMA (2011), and Figure 3 presents data on the relationship between pre- and post-dam peak flows at the Port Office gauge site. The estimate of the pre-dam equivalent of the January 2011 flood shown in Appendix B (12,400 m^3/s) is consistent with the information presented in Figure 3, but the source of the pre-dam peak flow estimate for the 1974 flood event (11,300 m^3/s) is unclear.

It appears from the information in Appendix B to the WMA (2011) report that the adjustment of 'observed' peak flows for the 1967, 1968, 1971, 1991 and 1996 (and possibly 1974) flood events to pre-dam conditions was not based directly on the information in Figure 3, and Appendix B indicates that the estimated pre-dam flows for these events were sourced from the SKM (1999) report. The WMA (2011) report does not discuss the assumptions made in the SKM report to adjust the 'observed' peak flows to pre-dam conditions, and it is thus difficult to assess the degree of uncertainty (and possible bias) introduced by this step.

(iii) Fitting of flood frequency distribution

The adopted flood frequency analysis method described in Sections 3.3.1 to 3.3.3 of WMA (2011), as implemented in the FLIKE software, is considered to be in accordance with current best practice, as described in the draft of revised Book IV of 'Australian Rainfall and Runoff'. [It is of interest to note that the flood frequency analyses presented in SKM (2003) were also based on application of the FLIKE software.] No specific allowance has been made for differences in accuracy of individual flood peak estimates or for rating curve errors.

The comparison of the fitted flood frequency curves presented in Figures 9 and 10 indicates that the LP3 distribution (Figure 10) provides a better fit to the flood observations, but fails to reflect the apparent flattening of the flood frequency relationship at peak flows above 10,000 m^3/s. *The adopted 1% AEP peak flow estimate of 13,000 m^3/s for the pre-dam conditions appears to be an appropriate 'best estimate', given the flood data series used as basic input*.

(iv) Confidence limits on 1% AEP flood estimate

The confidence limits shown in Figure 10 of WMA (2011) reflect the uncertainty introduced into the flood estimates because of the high degree of natural variability in the flood data (including random errors) and the limited flood record length available for the estimation of the 3 parameters of the selected distribution. The effects of any systematic under- or over-estimation of peak flows for individual flood events (e.g. resulting from errors in adjusted flood heights or rating curve errors) are not included in these fitted confidence limits, nor do the make allowance for uncertainty in selecting the most appropriate theoretical probability distribution (GEV, LP3 or other candidate distribution).

Figure 10 indicates a 90% chance that the true 1% AEP flood peak estimate for pre-dam conditions is between about 10,000 and 22,000 m^3/s but this confidence interval would be wider if allowance was made for other uncertainty factors. In other words, even when the flood data from the largest flood events in a period of record of 170 years at the Port Office are analysed, there remains a substantial degree of uncertainty in the 'best estimate' of the 1% AEP flood peak under pre-dam conditions.

Appraisal of pre-dam flood estimation results

Notwithstanding the considerable degree of uncertainty with the 'best estimate' of the 1% AEP peak flow under pre-dam conditions, the estimate of 13,000 m^3/s produced by the WMA (2011) study is plausible in the light of the largest observed floods over the period of record and broadly consistent with the flood estimates derived by previous studies. Specifically, the 2003 report by the Independent Review Panel gives a peak flow estimate in the range of 10,000 to 14,000 m^3/s for pre-dam conditions at Savages Crossing, based on the flood frequency analyses reported in the SKM (2003) report, and the Review Panel adopted a peak flow estimate in the plausible range of 11,000 to 13,000 m^3/s for pre-dam conditions at the Port Office site[1].

[1] The uncertainty ranges given in the 2003 Review Panel report are labelled as 'plausible bounds'. This relatively narrow confidence interval should be interpreted as only a notional indication of uncertainty around the 'best estimate of 12,000 m^3/s. A formally derived 90% confidence interval about this design flood estimate would be expected to be considerably wider.

Given the large degree of uncertainty with the pre-dam flood estimates at the Port Office site, it would be highly desirable to make use of all available data for large historical flood events (including event rainfall data and flood records from other sites) and to check for consistency between the different sources of information.

2.3 1% AEP flood flows for post-dam conditions

Data

The estimation by WMA (2011) of design peak flows for post-dam conditions is also mainly based on flood data for the Port Office gauge. The actual flood height observations for historical floods are supplemented by results of simulation studies of flood events for pre- and post-dam conditions, apparently mostly sourced from the SKM (2003) report.

Methodology and results

The basic methodology applied by WMA (2011) to account for the flood mitigation effects of the two dams is to use a graphical approach to derive a relationship between pre-dam and post-dam flood peaks at the Port Office site, based on the limited data described above.

Figure 2 of WMA (2011) presents some selected results for the flood mitigation effect of Wivenhoe Dam immediately downstream of the dam, assuming that the dam is at full supply level at the start of the flood event. Figure 3 uses data from a number of sources to represent the flood mitigation effect of the two dams on peak flows at the Port Office. The methodology and assumptions involved in coming up with flood estimates for the pre-and post-dam conditions are not explained in any detail but it appears that most weight is given to pre-and post-dam estimates for the 1893 flood event, derived by SKM (2003), and the January 2011 flood event, derived separately by SKM and WMA.

Finally, the conversion of the 1% AEP peak flood estimate of 13,000 m^3/s for pre-dam conditions to an equivalent post-dam 1% AEP peak flow estimate of 9500 m^3/s was achieved by a single step, described very briefly in paragraph 132 of WMA (2011). These results imply a 27% peak flow attenuation effect of the two dams for the 1% peak flow at the Port Office.

It is considered that the hydrologic basis of this conversion step has not been sufficiently substantiated in the report. Given the complex array of factors that affect the relationship between pre-dam and post-dam flood characteristics in the lower Brisbane River, and the important implications of this conversion step on the 1% AEP flood profile, it should be based on a comprehensive analysis of how the relationship varies in response to different factors, and what can be considered to be a 'typical' degree of attenuation produced by the adopted flood operation of the two dams.

Appraisal of post-dam flood estimation results

The 2003 Review Panel report quotes results from DNRM simulations which indicate that the dams could be expected "to reduce peak flow rates by about 60% on average". It also noted that "the model indicates a January 1974 flood attenuation of nearly 50%, with a peak inflow rate of 10,500 m^3/s and outflow rate of 5,500 m^3/s". The 2003 Review Panel also took into account the results of the RAFTS model simulations by SKM for the pre- and post-dam conditions and concluded that "under post-dam conditions the Panel would expect Q100 flows downstream of Wivenhoe dam to be of the order of 50% of those under pre-dam conditions".

From basic hydrological considerations and experience gathered from other major dam systems, it can be expected that the potential flood attenuation effect (% reduction in peak flow) of Wivenhoe and Somerset Dams is generally largest for small to moderate floods and reduces with increasing flood magnitude (flood volume). However, the large degree of variability in the factors that determine the magnitude and frequency of floods for the post-dam situation (see Table A1 in Appendix A to this report for a summary of these factors) means that the relationship between pre- and post-dam peak flows will be a complex one, characterised by a large degree of scatter around any trend line. The relationship also depends on the assumed operating rules for the dams under major flood conditions.

Figure 2 gives a qualitative indication firstly of the *possible range of attenuation* by the two dams, from no attenuation when a flood is generated essentially in the parts of the catchment below Wivenhoe Dam, to virtually full attenuation when the flood is generated in the parts of the catchment above Wivenhoe Dam and when there is a large storage volume available relative to the flood volume. Secondly the figure shows a narrower *plausible range of attenuation within which most of the flood events could be expected to fall.*

The January 2011 flood appears to lie near the upper end of the plausible spectrum of variation, where the special characteristics of this event resulted in only a modest degree of attenuation. At the other end of the spectrum is the February 1999 flood, which resulted in a substantial inflow to the dams (Appendix D of SKM 2003 shows a simulated pre-dam flood peak flow of 8400 m^3/s at Savages Crossing) but there was only a minor flood recorded below the Dam. The estimated attenuation associated with the January 1974 event lies near the middle of the spectrum[2].

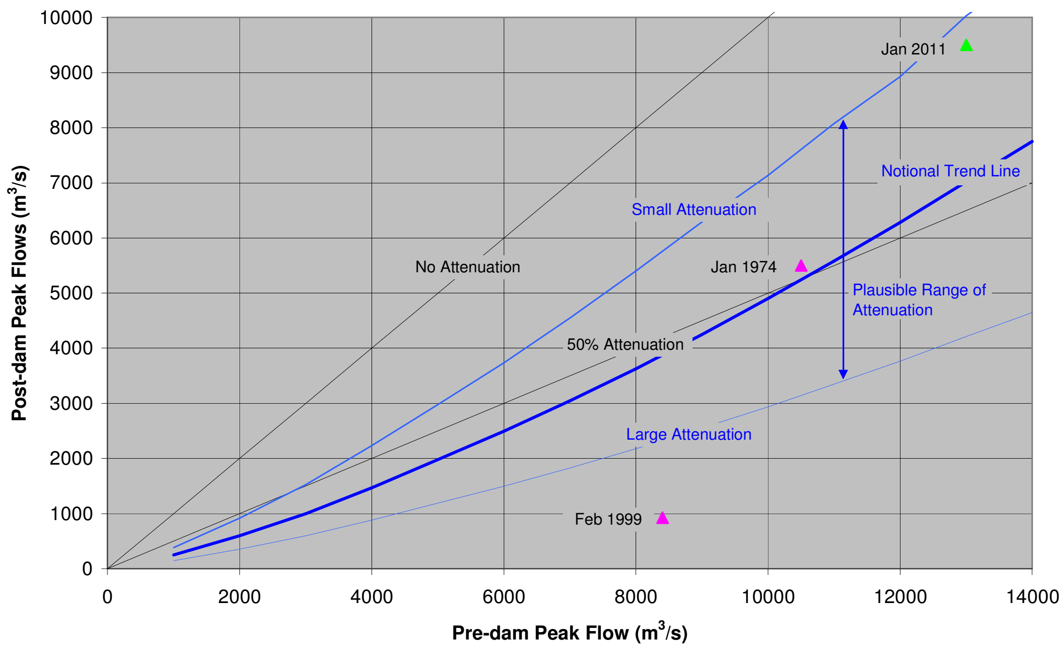

Figure 2 Conceptual diagram illustrating the possible and plausible ranges of flood peak attenuation by Somerset and Wivenhoe Dams

The methodology used in the WMA (2011) report to estimate the post-dam 1% AEP peak flow at the Port Office is based on very few data points which do not properly account for the large degree of variability and estimation uncertainty introduced by variations in storm characteristics and initial catchment/storage conditions. Use of the estimated attenuation effect for the January 2011 flood event as the main basis for determining the post-dam 1%AEP peak flow and corresponding flood level profile is considered to be arbitrary and likely to lead to biased flood estimates. Without confirmation from further analysis, the WMA

[2] In interpreting the estimated attenuation for these historical flood events it needs to be kept in mind that the results for each event are based on a set of specific assumptions which have not been fully documented. The estimated attenuation for the 1974 and 1999 events relates to the Savages Crossing site, while the attenuation for the 2011 event is for the Port Office site.

(2011) peak flow estimate of 9500 m^3/s can therefore not be considered to represent a 'best estimate' of the 1% AEP peak flow for the lower Brisbane River under post-dam conditions.

In my opinion a proper assessment of the likely attenuation effects of the dams on design floods for the lower Brisbane River system needs to be based on simulation modelling studies that examine the effects of likely variations in the key flood producing and flood modifying factors identified in Table A1. The variability effects could be assessed in an approximate fashion by sensitivity analyses, but preferably in a more formal joint probability framework, using Monte Carlo simulation methods. Such an approach would also give a more quantitative indication of the uncertainty in the post-dam design flood estimates.

Alternative estimation approaches

There are also two other approaches available for the estimation of the post-dam flood frequency curve in the lower Brisbane River:

(i) Adjusting each pre-dam annual flood peak recorded at a long-term gauging site, using a simulation model of the flood operation of the two dams to reflect the flood mitigation effects of the two dams, then undertaking a flood frequency analysis of this extended post-dam flood record. Such an adjusted data series for Savages Crossing was provided by DNRM and analysed in the SKM (2003) study as Case 4. However, the results of this analysis were discounted "as the method used [by DNRM] to obtain the adjusted data series was not assessed by SKM".

(ii) Using a design rainfall based approach to estimate the flood frequency curve for pre-and post-dam conditions, based on a well calibrated hydrologic model of the catchment and dam system, combined with a hydraulic river model to route the estimated design flood hydrograph to the point of interest. This approach was applied in the SKM (2003) study, using a calibrated RAFTS model of the Brisbane River catchment to Savages Crossing and a MIKE 11 model to route the flood hydrographs through the river reaches between Savages Crossing and the Port Office. The rainfall-runoff modelling approach adopted in SKM (2003) produced a post-dam 1% AEP flood peak estimate at the Port Office in the range of 5000 to 8000 m^3/s, with an adopted 'best estimate of 6500 m^3/s. It was noted in the 2003 Review Panel report that the flood estimates produced by this approach for the pre-dam conditions were significantly lower than the estimates from flood frequency analysis, and future work was suggested to address any apparent inconsistencies in the results from the two approaches. [Paragraph 138 of WMA (2011) explains this inconsistency by an apparent underestimation of catchment rainfalls (and consequently design rainfalls) in the more elevated parts of the Brisbane River catchment.]

Notwithstanding the limitations in the results obtained by SKM (2003) with the application of the design rainfall based modelling approach, with further development and additional data, and applied in conjunction with flood frequency analysis for additional validation, this approach is considered to have the potential to produce more accurate estimates of design floods in the AEP range from say 2% to 0.5% for the post-dam conditions in the lower Brisbane River.

2.4 Estimated AEP and ARI of January 2011 flood

The data and flood frequency analysis results presented in Figures 9 and 10 of WMA (2011) indicate that *the estimated AEP of an event similar to the January 2011 flood but occurring under pre-dam conditions is of the order of 1%* (equivalent to an ARI of 100 years).

Given the large degree of uncertainty in the estimation of the 1% AEP flood for post-dam conditions and the lack of a complete flood frequency curve for these conditions, it is difficult to assign a reliable AEP estimate to January 2011 flood event. The estimate of 0.83% AEP (120 years ARI) given in paragraph 133 of WMA (2011) indicates that the frequency of the post-dam flood is slightly lower than that of the estimated pre-dam flood. This can be *interpreted to imply that the catchment and storage conditions for this event may have been somewhat more severe than would be expected on average.*

The Joint Flood Taskforce report (2011) recommended the use of the January 2011 event as an interim standard for Brisbane City Council to base its decisions concerning new development and redevelopment. However, it clearly stated that a precautionary approach had been used in coming up with this recommendation which should only apply until the comprehensive flood study it recommended was completed. *This interim recommendation should thus not be interpreted as indicating that the flood flows and levels experienced in the January flood event represent an accurate and unbiased flood estimate for 1% AEP.*

Section 7.2 of the WMA (2011) report gives some information on rainfalls for the Brisbane River catchment, concentrating on a comparison of the 72-hour 1% AEP design rainfall estimates with the Seqwater estimates of 3-day rainfalls in the January 2011 event. The conclusion reached from this analysis is that “on a 72 hour basis the 2011 event upstream of the dam was slightly larger than a 1% AEP event and slightly smaller than a 1% AEP event downstream of the dam” (paragraph 139). *This conclusion appears to be inconsistent with the finding in paragraph 133 but the difference can be explained by the influence of the range of factors that affect the conversion of rainfall inputs to flood outputs, as discussed in Section 2.3 above.*

3. Estimation of 1% AEP flood level profile

The estimation of the 1% AEP flood level profile for the lower Brisbane River relies firstly on the results of the *hydrologic methods for estimating flood flows* and secondly on the *translation of these flood flows to flood levels at points of interest by means of hydraulic modelling*. My particular expertise is mainly in the area of *hydrologic design flood estimation methods and their application in different practical situations.*

My appraisal of the information provided in the WMA (2011) report has concentrated on the hydrologic aspects of the flood study methodology and the flood flow estimation results. My comments on the estimation of the flood level profile for the 1% AEP flood are therefore restricted to aspect that relate to the hydrologic inputs to the flood level determinations and their expected impacts on estimated design flood levels.

As pointed it out in the section on appraisal of post-dam flood estimation results, the 1% peak flood estimate for the Brisbane River reach below Mogill is associated with a large degree of uncertainty that also affects the hydraulic modelling of this design flood event and the flood level results obtained. *The WMA (2011) report does not provide any indication of the impact of this uncertainty in design flood flows on the estimated flood levels, other than stating that a 500 m^3/s reduction in post-dam peak flows would translate into an approximate flood level reduction of 0.5m at Mogill and 0.2 m at the Port Office (paragraph 143).*

It is also important to recognise that the WMA (2011) hydrologic analysis has been restricted to the estimation of peak flows for the pre- and post-dam conditions. The routing of flood flows through the lower reaches of the Brisbane River and the determination of the flood levels associated with these peak flows is also significantly influenced by the assumed hydrograph shape and flood volume associated with each peak flow. The WMA (2011) report does not detail the assumptions made for these flood characteristics or discuss their influence on the calculated flood levels.

4. Conclusion

My appraisal of the flood studies for the Brisbane River reported in WMA (2011) and comparison with information available from other flood study reports supports the following main comments:

1. The terms of reference for the WMA (2011) study appear to have been interpreted too narrowly to ensure that the estimated 1% AEP flood flows and flood levels are as accurate as currently available data and methodology allow, so that they can provide a firm basis for flood risk management decisions with wide ranging implications.
2. The 1% AEP peak flow estimate of 13,000 m^3/s for the Port Office site under pre-dam conditions is considered to be plausible and broadly consistent with estimates obtained by other studies but has a very wide margin of uncertainty associated with it. The WMA (2011) report recognises this uncertainty and suggests additional studies to improve the rating relationship at the Port Office. To reduce this uncertainty, it would be necessary to make use of other sources of data for large historical flood events (including event rainfall data and flood records from other sites) and to check for consistency between the different sources of information.
3. The conversion of pre-dam design peak flows to post-dam peak flow represents a challenging hydrological task, as it has to take account of the likely range of variability of the flood producing and flood modifying factors that affect this conversion. The WMA (2011) report does not demonstrate that this variability has been adequately allowed for in the determination of the post-dam 1% AEP peak flows at the Port Office site. The report does not include any suggestions for future work to address any limitations in the method used for this conversion.
4. The simplifying assumption used in WMA (2011) that the estimated attenuation effect for the January 2011 flood event is representative of typical conditions is considered to have introduced significant (high) bias into the estimated post-dam 1%AEP peak flow and corresponding flood level profile. Without confirmation from further analysis, the WMA (2011) peak flow estimate of 9500 m^3/s can therefore not be considered to represent a 'best estimate' of the 1% AEP peak flow for the lower Brisbane River under post-dam conditions.
5. For a more defensible estimate of the 1% AEP post-dam flood characteristics in the lower Brisbane River it will be necessary to use the combined results of a range of estimation methods based on all the relevant sources of flood data. The methods applied should include rainfall based design flood simulation for the pre- and post-dam conditions.
6. Given the high degree of variability in Brisbane River flood characteristics that can result from widely varying storm rainfall characteristics and initial catchment/storage conditions, it would be desirable to examine to what extent the estimation uncertainty could be reduced by the adoption a joint probability modelling framework (Monte Carlo simulation), as had been suggested in previous studies and reviews.
7. The large degree of uncertainty in the estimated 1% AEP peak flows for the post-dam conditions can be expected to be carried through into the determination of the flood level profile for this design flood event. Given the volume-sensitive nature of the lower Brisbane River system, it would be more appropriate to apply a hydrologic flood estimation method that produces complete flood hydrographs rather than just peak flows as inputs to the hydraulic flood level estimation model.

8. Finally, the outcomes of recent flood studies for the Brisbane River system, including the WMA (2011) study, appear to have been significantly restricted by the limited scope of the studies. Given the importance and wide ranging implications of the flood determinations emanating from the work of The Commission, it is considered essential that any future studies be given enough scope to adequately address the complexities of the Brisbane River flooding situation. The outcomes of these more comprehensive studies would also be helpful in supporting improved decisions on flood operation and management.

References

BCC (2003): Joint Flood Taskforce Report, March 2011.

IEAust (1999): Australian Rainfall and Runoff – A guide to flood estimation (reprinted edition). Institution of Engineers, Australia.

Independent Review Panel (2003): Report to Brisbane City Council on review of Brisbane River Flood Study, 3 September 2003. (As made available by The Commission.)

Kuczera. G. and Franks, S. (2006): Australian Rainfall and Runoff – Book IV – Estimation of Peak Discharge (Draft), Engineers Australia.

SKM (2003): Brisbane River Flood Study – further investigation of flood frequency analysis incorporating dam operations and CRC-FORGE rainfall estimates – Brisbane River, Final Issue, 18 December 2003.

WMAwater (2011): Queensland Floods Commission of Inquiry, Brisbane River 2011 Flood Event – Flood Frequency Analysis Final Report, September 2011.

APPENDIX A
Design flood estimation – matters for consideration

Relationship between design floods and actual flood events

Design flood estimates are probability-based estimates of flood characteristics (flood flows and flood levels) at specified locations (e.g. along a stretch of the Brisbane River) and for a specified set of conditions (e.g. the conditions existing in 2011, expected to remain applicable for the next few years). They reflect the outcomes of complex flood formation processes over the catchment and flood modification processes as the flood wave (or flood hydrograph) travels through the river/floodplain/estuary system. Each actual flood event results from different combinations of these factors within a typical range of variation, resulting in a large degree of variability in flood characteristics (e.g. flood magnitude, duration, 'peakedness'). Design floods should reflect the *'typical characteristics of floods that can be expected to occur at specified frequencies* (ARIs or AEPs).

Causes of floods and main factors affecting flood characteristics

Table A1 illustrates the main factors that affect the formation and modification of floods, and how they are concepualised for the estimation of design floods. While there are other possible causes of floods, for the Brisbane River catchment and the range of flood frequencies of direct interest here, the principal cause of floods is extended heavy rainfall over the catchment. Apart from the duration of a storm rainfall event and the total rainfall depth (average over catchment), the way this total rainfall is distributed in time and how it varies over the different parts of the catchment are also important in determining the resulting flood characteristics. The large range of possible flood modifying factors can significantly increase the degree of variability of flood outputs and adds further complexity to the design flood estimation problem.

Principal approaches to design flood estimation

The two principal approaches are distinguished by the basic data and methodology they use.

Approach 1: Flood frequency analysis (FFA) is based on statistical analysis of *flood characteristic outputs,* generally peak flows.

Strengths:

- based directly on data for flood characteristic at or near the location of interest
- requires few assumptions on how floods have been produced (if catchment and river conditions have remained relatively unchanged)
- allows relatively simple assessment of uncertainty in flood estimates arising from variability in data and limited record length (derivation of confidence limits)

Potential weaknesses:

- needs relatively long data records for reliable estimation of larger design floods (at least 50 years for estimation of 100 year ARI flood, longer for complex systems)
- flood data in record need to be for essentially unchanged conditions or have to be adjusted to a common set of catchment and river conditions
- adjustments to flood data for changes in conditions may introduce significant uncertainties into flood estimates (depending on the reliability of the data and methodologies used for the adjustments)
- extrapolation of fitted flood frequency curves to rarer flood events involves significant uncertainties
- applied mostly for peak flows – in estuarine flooding situations the influence of varying flood hydrograph shapes (flood volumes) and tidal conditions may invalidate the assumption of a one-to-one relationship between flood peak and flood level (as expressed by a rating curve).

Table A1 - Factors to be considered in design flood estimation

	ASPECT	FACTORS TO BE CONSIDERED	EFFECT ON FLOODS	RELEVANCE FOR FLOOD ESTIMATION
CAUSE OF FLOOD	**Catchment Rainfall**	• *Duration of storm event & total event rainfall* • *Distribution in time* • *Distribution in space*	• *Size of flood* • *Relative magnitude & timing of tributary flows*	**Basis for Simulation Modelling of Design Flood Events** **(based on statistical analysis of observed storm rainfall characteristics)**
FLOOD MODIFYING FACTORS (UPSTREAM SYSTEM)	Initial Catchment Conditions	• Catchment wetness • Initial content of dams • Initial condition of floodplains	• Proportion of rain becoming runoff • Flood mitigation potential of storages and floodplains	**Design assumptions on** ***hydrologic*** **flood modifying factors**
	Catchment Modifications	• *Major water storage development (for water supply & flood mitigation)* • Major rural land use changes • Urbanisation (large scale)	• *Reduced and delayed flood peaks downstream of storage* • Increased runoff • Faster flood response	
	River & Floodplain Modifications	• Changes to river & floodplain morphology • Riverside development • River crossings	• Changed flood routing conditions • locally changed flood levels	
FLOOD MODIFYING FACTORS (DOWN-STREAM SYSTEM)	River, Floodplain & Estuary Modifications	• *Changes to river , floodplain& estuary morphology* • Riverside development	• Changed hydraulic conditions • ***Modified rating curve (Port Office)*** • locally changed flood levels	**Design assumptions on** ***hydraulic*** **flood modifying factors**
	Tidal Boundary Conditions	• Astronomical tides • Tidal anomalies (effects of wind, waves, air pressure)	• Tide/flood interactions • ***Modified rating curve (Port Office)*** • Raised flood levels (lower system)	
FLOOD OUTPUTS	**Flood Characteristics**	**Flood flows** at key points (esp. peak flows)	Result of **hydrologic** factors (influenced by hydraulic factors)	**Basis for hydrologic flood frequency analysis**
		Flood levels at sites of interest (max. levels)	Combined result of **hydrologic** & **hydraulic** factors	**Directly observed flood data**

Note: Factors affected by the highest degree of variability are shown *italics*

Approach 2: Rainfall-based design flood estimation by simulation of the flood formation and flood modification processes

Strengths:

- basic probabilistic input: generalised design rainfall data which are based not just on rainfall data from the catchment of interest but also other catchments in the region – this allows more reliable extrapolation to rare events
- rainfall data for historic events are less affected by changes to catchment conditions than flood data
- flexibility to reflect various changes in catchment, storage and river conditions in hydrologic simulation model
- produces complete flood hydrographs – required in volume sensitive systems (where storage and tidal impacts play an important role in determining flood levels)
- can be used in a complementary fashion to flood frequency analysis

Potential weaknesses:

- quality of calibration/validation of simulation models depends on availability of concurrent storm rainfall and flood data for a range of flood events
- available rainfall data may give only an incomplete picture of the actual rainfall variation over the catchment
- requires a range of assumptions on flood modifying factors to ensure that design rainfall inputs are converted to design flood outputs of corresponding ARI or AEP ('probability neutral' conversion)
- quantification of uncertainties (confidence limits) not part of standard procedures (some indication of uncertainty from sensitivity analyses)

To allow best use of all available forms of flood data relevant to a particular catchment system, it is desirable to *use both approaches in a complementary fashion*. Where possible, design flood estimates for the catchment of interest should also be assessed for *consistency/compatibility with design flood estimates for similar catchments in the region*.

Curriculum Vitae

NAME:	**WEINMANN, Peter Erwin**
PRESENT APPOINTMENT:	Adjunct Research Associate of the Department of Civil Engineering, Monash University
CONTACT DETAILS:	[redacted]
QUALIFICATIONS:	• Dipl. Ing. ETH (Zurich), 1969 (Agricultural Engineering & Surveying) • MEngSc (Monash), 1978 (major thesis on "Comparison of Flood Routing Methods for Natural Rivers")
FIELDS OF EXPERTISE:	• Hydrology (flood estimation, yield and low flow studies) • Hydrologic risk assessments (especially dam safety) • Flood risk management • Water resource assessment and planning studies • Design of hydrologic data collection networks
PROFESSIONAL AFFILIATIONS:	• Member, Engineers Australia, Chartered Professional Engineer • Engineers Australia, Revision Committee of 'Australian Rainfall and Runoff' • Editorial Panel, Australian Journal of Water Resources • UNESCO International Hydrology Program, National Committee
AWARDS:	• W H Warren Medal - awarded by Engineers Australia for best paper in Civil Engineering in 1992 (jointly with R J Nathan) • G N Alexander Medal (2002) - awarded for best paper on Hydrology and Water Resources in an Engineers Australia publication (jointly with A Rahman and R G Mein) • C H Munro Orator (Engineers Australia, 2006)
PUBLICATIONS:	Over 60 refereed papers, covering a wide range of topics in the fields of hydrology and water engineering (see list of publications).
CAREER SUMMARY:	• Since 2006: Independent consultant specialising in hydrologic studies and flood risk assessment/management • 1993-2005: Senior Lecturer at Department of Civil Engineering, Monash University (Head of Water/Environmental Group 2002-2004) • 2002-2005: Deputy Director of CRC for Catchment Hydrology (Monash Node) • 1984-1992: Principal Hydrologist, Rural Water Corp., Victoria • 1977-1984: Designing Engineer, State Rivers & Water Supply Commission, Victoria, Flood Plain Management Section • 1970-1977: Engineer/Designing Engineer, State Rivers & Water Supply Commission, Victoria, Major Works - Designs Division
RELEVANT CONSULTING EXPERIENCE (RECENT):	• Brisbane City Council: Member of Joint Flood Taskforce 2011 • Gold Coast City Council: Advice on development of hydrologic models for Gold Coast City catchments (2007-2011) • Snowy Hydro: Peer review of Talbingo Dam flood hydrology (2010/11) • SKM for NSW State Water and ACTEW: Peer review of project on "Estimation of rare design rainfalls for NSW and ACT" • SunWater:: Burdekin Falls Dam, design flood hydrology review (2010) • Department of Water, Western Australia: Peer review of Murray Area flood study – hydrologic assessment (2010) • Glenelg-Hopkins CMA: Review of flood studies for Port Fairy, Warrnambool and Portland catchments (2008-2010) • State Water (NSW): Review of hydrological spillway adequacy assessments of portfolio of 16 State Water dams (2007-2010) • Brisbane City Council: Member of Independent Expert Review Panel for Brisbane River Flood Study (2003)