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seqwater WATER FOR LIFE

January 2011 Flood Event: Report on the operation of Somerset Dam and Wivenhoe Dam

REVIEW OF HYDROLOGICAL ISSUES

- Final A
- 11March 2011

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Executive Summary

In January 2011 unusually severe rainfalls fell on the catchment areas upstream of Wivenhoe and Somerset Dams, resulting in the largest inflows into both dams ever recorded. The outflows from these dams, along with flood flows arising from severe rainfalls in downstream catchments, resulted in severe flooding in the urban areas of Ipswich and Brisbane.

This report provides a review of the hydrological issues of most relevance to the adopted flood procedures, as presented in a report prepared by Seqwater on the January flood event.

The review focuses around addressing four questions of particular interest. The questions considered, and the review outcomes, can be summarised as follows:

- *Is the system used to collect rainfall and stream height data described in the Seqwater Report appropriate to support flood operations decision making in real time?*

  Overall, it is considered that the density and spatial coverage of the data network is comprehensive, though the installation of additional gauges, particularly in the downstream reaches of the catchment, would reduce interpolation uncertainty. A robust approach has been taken with the design and operation of the network, and this is evident in the high availability of the equipment during the event.

- *Is the Real Time Flood Modelling (RTFM) system described in the Seqwater Report appropriate to support flood operations decision making in real time?*

  The ability of the data system to enable the review of tabulated and graphical summaries, investigate apparent anomalies, and prepare data for multiple scenario evaluation are noteworthy features that help ensure the most relevant data are used for forecasting purposes.

  The modelling system is based on a combination of standard and bespoke elements. The configuration and calibration of the flood simulation model, which is the core of the system, is consistent with established practice. The manner in which historic and forecast rainfalls are input to the model is adequate, and the method used to adjust rainfall losses during the event is soundly based on observed data. The model allows for flows associated with earlier rainfalls to be adequately considered, and appropriate steps are taken to help ensure that all inputs are reconciled prior to determining the required gate operations. There is scope for improvement in the simulation framework adopted, though the benefits of such improvements are subject to the availability of more sophisticated (ensemble) rainfall forecasts.

- *The January 2011 Flood Event occurred between 6 January 2011 and 19 January 2011; was adequate data collected during this time to obtain satisfactory results from the RTFM system described in the Seqwater Report, for the purposes of operating Wivenhoe Dam and Somerset Dam?*

  The data system successfully processed over 130 000 packets of data on rainfall and streamflow conditions at different points in the catchment, while losing only around 10% of gauges due to the extreme conditions. This is an outstanding outcome that is testament to the appropriateness of the design and operation of this system.

  Analysis shows that there is generally good agreement between data processed in real time and other independent data available subsequent to the event. It is not possible with the information currently available to comment meaningfully on the accuracy of the streamflow data, though the fact that data from a variety of independent sources could be reconciled in a practical fashion confirms that the recorded data was fit for purpose. Best available information on rainfall forecasts were was used during the event, though these forecasts significantly underestimated the average depths of rain over the most critical three days of importance. At present the skill of the available rainfall forecasts is the primary limitation on the period over which reliable streamflow forecasts can be provided.

- *Does the information contained in Section 8.0 of the Seqwater Report ("Preliminary Assessment of Event Magnitude"), accurately describe the January 2011 Flood Event?*

  The conclusions drawn by Seqwater are considered to be broadly defensible. It is considered that the annual exceedance probability of the rainfalls for the whole dam catchment is around 1 in 100 to 1 in 200, though the annual exceedance probability of the most extreme point rainfalls that occurred in the centre of the Brisbane River catchment is likely to be between 1 in 500 and 1 in 2000. When compared with historical events, flood volumes indicate the volume of the January 2011 event was almost double that of the January 1974 flood, and rivals the February 1893 flood. Peak water levels at gauging stations in the Brisbane River above Wivenhoe Dam were the highest on record. In the Lockyer Valley, peak water levels exceeded the 1974 levels and may well have been larger than those of 1893. A comparison of the recorded peaks, volumes and peak levels at Somerset and Wivenhoe Dams indicate the January 2011 flood event exceeds 1 in 100 AEP.

Contents

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1. Introduction

1.1. Background

Somerset Dam and Wivenhoe Dam are dual-purpose storages that provide urban water supplies to south East Queensland as well as flood mitigation benefits to areas along Brisbane River below Wivenhoe Dam.

In January 2011 unusually severe rainfalls fell on the catchment areas upstream of the dams, resulting in the largest inflows into both dams ever recorded. The outflows from these dams, along with flood flows arising from severe rainfalls in downstream catchments, resulted in severe flooding in the urban areas of Ipswich and Brisbane.

A report was prepared by Seqwater on this flood event (Seqwater, 2011). The Seqwater report presents details of the flood procedures used during the event, the reasons why the adopted procedures were used, and other pertinent information relevant to the severity of the event.

1.2. Purpose of this report

This report provides a review of the hydrological issues of most relevance to the adopted flood procedures, as presented in the report prepared by Seqwater. The review focuses on providing answers to the following questions:

- Is the system used to collect rainfall and stream height data described in the Seqwater Report appropriate to support flood operations decision making in real time?
- Is the Real Time Flood Modelling (RTFM) system described in the Seqwater Report appropriate to support flood operations decision making in real time?
- The January 2011 Flood Event occurred between 6 January 2011 and 19 January 2011; was adequate data collected during this time to obtain satisfactory results from the RTFM system described in the Seqwater Report, for the purposes of operating Wivenhoe Dam and Somerset Dam?
- Does the information contained in Section 8.0 of the Seqwater Report ("Preliminary Assessment of Event Magnitude"), accurately describe the January 2011 Flood Event?

The above questions are addressed in the following four sections.

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1.3. Conduct of the Review

This review was undertaken by Dr Rory Nathan and Peter Hill, and is largely based on review of the five volume report released on 2 March 2011 (Seqwater, 2011). Some supplementary discussions were held with Seqwater staff to get a better understanding of selected aspects of the report. In addition, a visit was made to the flood control centre where the operation of the data capture and modelling system was demonstrated in an interactive fashion.

2. Adequacy of the data collection system

This section addresses the following question:

Is the system used to collect rainfall and stream height data described in the Seqwater Report appropriate to support flood operations decision making in real time?

Seqwater operate a network of 103 rain gauges and 80 river gauges in the Brisbane River catchment. Around one third of these gauges represent conditions in the catchment upstream of the dam, and the remainder are in downstream and/or adjacent catchments. The vast majority of these stations (71 rain and 69 river gauges) provide data into the modelling system in real time to assist with the flood forecasts.

In addition to this data collection system, Seqwater have access to Enviromon radio telemetry data network (operated by the Bureau of Meteorology). This provides access to an extensive network of data recorders located outside the Brisbane River catchment.

There are some notable features to this system, namely:

- it is based on proven technology that is in use by other agencies both here and overseas;
- there are duplicate recorders in the key network gauges;
- there is redundancy in the central data collection servers;
- critical information on water levels in the dams are also read manually;
- the data is reviewed manually prior to operational use to remove extraneous readings; and,
- the system appears to be well maintained, as evidenced by the small proportion of gauges that were not operational during the event.

It would appear that the locations of the rainfall gauges are biased towards the valley floors. This is not uncommon as it is difficult to install and maintain gauges in remote areas at high elevations. While this bias will tend to yield estimates of catchment rainfalls that are lower than actual, in practice this need not lead to the floods being underestimated as the models are generally calibrated to take this bias into account.

From radar imaging available during the event and inferences from the water level data in Wivenhoe Reservoir, it is believed there was substantial rainfall in the vicinity of the reservoir on the morning of 11 January that was not reflected in the telemetered data. It is understood that additional rainfall stations are being installed which will increase the density of rainfall coverage, however there will always be the possibility that significant rainfall may occur between stations. Inevitable gaps in the rainfall networks can be mitigated by incorporating information from weather radar during an event. For example, Figure 2.1 shows the 24 hour rainfall depths to 8:00am on 11 January 2011 estimated from the weather radar operated by the Bureau of Meteorology. This image was captured from the Bureau of Meteorology web site during the event and does not reflect the outcome of any quality control measures and verification against recorded point rainfalls that may have occurred subsequently. The radar image shows the high rainfalls in the vicinity of the Wivenhoe Reservoir that were not captured by the ALERT gauges. Although there still remains uncertainty in radar rainfall estimates, such information (as discussed in Section 8.9 of the Seqwater report) can be used in at least a qualitative manner to help inform the interpolation between point estimates of rainfall.

It is difficult to assess the adequacy of the streamflow ratings on the information presented in Appendix R. No data is presented on the scatter of the individual gauging used to develop the rating relationship, though it is clear from the maximum rating information provided (Appendix R) that considerable extrapolation was required to estimate the maximum flows recorded.

Overall, it is considered that the density and spatial coverage of the data network is comprehensive, though the installation of additional gauges, particularly in the downstream reaches of the catchment, would reduce interpolation uncertainty. A robust approach has been taken with the design and operation of the network, and this is evident in the high availability of the equipment during the event.

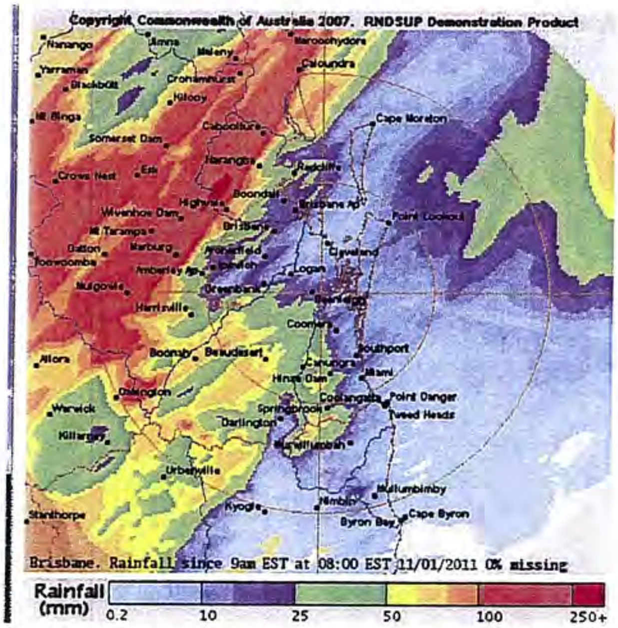

Figure 2.1 Estimates of rainfall totals to 8:00am 11 January 2011 (sourced from www.bom.gov.au during the event).

3. Adequacy of the flood modelling system

This section addresses the following question:

> *Is the Real Time Flood Modelling (RTFM) system described in the Seqwater Report appropriate to support flood operations decision making in real time?*

The modelling system is comprised of two components, namely:

- a data capture system, which automatically collects, filters, and stores rainfall and water level data in real time; and,
- a data modelling system, which in essence converts the observed rainfall data into estimates of flood flows at selected points along the river network.

Comment on these two components is provided in the following two sections.

3.1. Data capture system

The first component – the data capture system – provides the means to utilise the data collected at the 129 ALERT rainfall and streamflow gauges in real time. The system provides the means to rapidly review and analyse an immense body of data, and prepare for input to the modelling system. Data preparation is a very onerous process and outside the domain of flood operations it is usual to spend many days on the careful scrutiny and review of relevant information for even one flood event.

This is a most onerous process and it is clear that considerable thought has been put into the tabulation and graphical functions of the system to allow rapid diagnostic analysis. The ability for the forecast team to review, edit and/or discard data, undertake consistency checks against concurrent and previous information, and prepare inputs for model simulations of different forecast scenarios – all in real time, while handling the cumulative pressures of an extended flood event – is truly impressive.

3.2. Modelling system

The second component of the system – the modelling system – is largely based on modelling concepts used widely across Australia. There are a number of different elements to this modelling system, and salient points relevant to their adequacy are summarised below.

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3.2.1. Data analysis

The data analysis and scenario specification modules represent a pragmatic means to compare, edit, censor, and prepare the real time data for input to the flood simulation model. The ability to review tabulated and graphical summaries, investigate apparent anomalies, and evaluate through the preparation of scenarios, are noteworthy features that help ensure the most relevant data is used for forecasting purposes.

3.2.2. Conceptual basis of flood model

The flood simulation model is based on runoff-routing concepts that have been the mainstay of flood estimation practice in Australia for many years. As such, the calibration, operation and performance of the model would be familiar to experienced flood practitioners. Importantly, the use of the model is consistent with the recommendations of current flood estimation guidelines (Institution of Engineers, 1987).

3.2.3. Model configuration

The model is configured to capture differences in flood response characteristics across homogeneous physiographic regions. The appropriateness of the model routing parameters (ie the parameters that control the size and shape of the flood hydrograph resulting from excess rainfall) adopted for the different regions has not been reviewed for this report, though it is noted that the adopted parameters have been used by different agencies for a number of operational and design purposes over the past 20 years (eg DNR, 1994; Wivenhoe Alliance, 2004). The adopted routing parameters are expected to be invariant with rainfall magnitude, and appropriately the model configuration was not altered during the event. The overall approach to configuration and calibration of the model appears consistent with accepted practice.

3.2.4. Rainfall modelling

Rainfall information captured by the data collection system is input to the flood model to undertake the simulation of the flood generation process. There are two key characteristics of rainfall that need to be specified for each sub-area used in the model, namely:

- the distribution of average rainfall depths spatially across each sub-area, and
- the distribution of rainfall in time over the historic and forecast period.

The distribution of average rainfalls over the sub-areas is based simply on a weighting that reflects the proportion of catchment area covered by the network of available rain gauges. This is a commonly adopted approach, and is best suited to lowland catchments which do not exhibit steep rainfall gradients. However, the adoption of this approach for a catchment with steep topographic gradients where rainfall recorders tend to be located in the valley floors will tend to under-estimate average rainfall depths across the sub-areas. The solution to this problem is not easy, particularly in real-time where there would be little time to undertake (and check) the ability of more sophisticated surface-fitting algorithms to provide more realistic estimates of sub-area rainfalls. The practical means of dealing with the problem, as undertaken by Seqwater, is to resolve any bias in the rainfall estimates through progressive calibration of the loss model during the event, and by closing the water balance at the reservoir itself. Thus while in practice the limitations of the rainfall estimates are adequately accommodated, this represents an opportunity for improvement that would reduce the need for resolving water balance errors in the subsequent steps in the analysis.

The distribution of rainfalls in time for hindcasting (ie for simulating rainfall that has already fallen) is determined by selecting the nearest most relevant rainfall recorder, which is very appropriate.

The distribution of rainfalls for forecasting purposes is based on the application of a single "representative" pattern that is applied to each sub-area. Again, this is a common approach that is adopted even for the provision of design estimates that do not have the added complexity of real-time operation. A potential area of improvement for this aspect is discussed below under "Simulation framework".

3.2.5. Initial loss parameters

Estimates of initial loss (ie the amount of rainfall that seeped into the ground prior to the rise of the flood) is made through correlation with two different, and independent conceptual models of soil water conditions. This is a bespoke process developed by Seqwater that has not been reviewed for this report, but this element is considered to be of minimal importance to the flood characteristics of most interest as the estimates were adjusted at the start of the event to match the observed rise in the recorded flows. The adopted initial loss estimates are consistent with expectations.

3.2.6. Continuing loss parameters

Estimates of continuing loss (ie the amount of rainfall that seeped into the ground during the course of the event) were adjusted progressively during the event by matching model estimates with real-time data. The calibration runs undertaken in real time (as summarised in Appendix S) are reasonable, and the parameters adopted during the event are consistent with expectations. The progressive reduction in continuing loss rates during the event appropriately reflect changes in catchment conditions and are consistent with the physical processes being simulated.

3.2.7. *Baseflow contribution*

The issue of baseflow, while a small proportion of the overall flood, is a rather complex component to consider. Baseflows notionally represent rainfall that seeps more slowly into the river through the soil along the length of the river banks. At the commencement of the flood baseflows are comprised of flows from preceding rainfall events, though as the flood progresses there is increasing contribution from the rainfalls that fell earlier in the same flood, but which seeped slowly into the river through the soil. It thus represents flows from earlier rainfall events, as well as the re-appearance of rainfall which earlier had been previously been treated as initial and continuing losses. Seqwater have developed their own approach to estimating the contribution of baseflow in real time. The conceptual basis of the approach appears reasonable, but no information is presented that allows its parameterisation to be reviewed, or its overall performance to be assessed.

The baseflow contribution presented in Figure 7.2.4 appears to be an unusually small proportion of the total hydrograph volume, but this most likely reflects the fact that the baseflow only represents the contribution from the catchment area that lies below the nearest upstream streamflow gauges. This "partial" baseflow contribution arises as the losses are calibrated progressively during the flood event, and in effect the decreasing loss values adopted for the upstream sub-areas reflect the increasing baseflow contribution from rainfalls that fell on the catchment upstream of the gauge.

In short, the estimation of baseflow in real time is a surprisingly complex task. It is not clear how well the independent estimates correctly capture the partial baseflow contribution of interest, and in essence its estimation is constrained by the need to balance the measured rise in the reservoir with releases and the estimates of total inflow progressively through the event.

3.2.8. *Reservoir routing*

The reservoir routing module included in the modelling system has not been updated to incorporate the changes arising from the 2009 update of the Flood Manual. It was thus necessary to input the reservoir inflows manually into a spreadsheet to undertake the reservoir routing. In theory there is nothing wrong with doing this, but in practice it increases the opportunity for mistakes to be made in the manual processing of the data. There is no evidence that mistakes were made in any of the manual data processing, but in terms of the adequacy of system design, this is an undesirable feature and it would be better to update the routing algorithm in the model to reflect the changed dam configuration. It should also be stated that the level pool routing spreadsheets were not reviewed for this report, but given the need to conserve mass any errors would have been evident over the long period of time that the system has been in use.

3.2.9. *Simulation framework*

The simulation framework adopted for the modelling system is "deterministic". That is, a single simulation is undertaken for a given set of rainfall and model inputs to yield a single set of flood flows. The limitation of this approach is that it does not allow for the expected variations in hydro-meteorological inputs, or their uncertainties, to be incorporated. For example, at present flood forecasts are derived using a single fixed pattern of rainfall that specifies the distribution in both time and space of how rain will occur over the forecast period. In reality there is a great deal of uncertainty about both the depth and the distribution of the forecast rainfalls, and this is not easily reflected in the model forecasts provided. Also, the approach could be extended to allow for uncertainty in major factors of importance, such as the rating curves used to estimate flow rates at the gauging stations.

However, over the last ten years there has been increasing interest in using "stochastic" approaches for practical flood estimation purposes. These approaches are based on multiple model simulations (possibly involving many tens or hundreds of runs for a given rainfall scenario) where all the possible combinations of inputs are considered in a fashion that reflects the likelihood of their occurrence. Thus, rather than assume inputs follow a pre-determined and fixed pattern, the simulation framework allows for variation and uncertainty in the main flood producing factors to be explicitly considered. Monte Carlo approaches are well suited to this type of problem, and the forthcoming revision to the national flood guidelines will be advocating a move to these joint probability approaches.

However, it needs to be stressed that deterministic modelling is the accepted paradigm in current flood estimation practice and is consistent with the current national flood guidelines (Institution of Engineers, Australia, 1987). The limitations associated with deterministic approaches are thus relevant to the vast majority of flood estimates currently undertaken both here and overseas. These reviewers are not aware of any operational flood forecasting system in Australia that currently operates in a stochastic framework. Accordingly, the possibility of moving towards a more stochastic framework should be seen as an opportunity for future improvement, and should not be interpreted as a criticism of current practice.

The availability of ensemble rainfall forecasts (as mentioned in Section 4.5) would provide compelling justification for the development of a stochastic framework. However until such forecasts are available, the benefits to be realised by adoption of a stochastic framework for forecasting purposes are probably of secondary value.

4. Adequacy of event data collection

This question addressed in this section is:

The January 2011 Flood Event occurred between 6 January 2011 and 19 January 2011; was adequate data collected during this time to obtain satisfactory results from the RTFM system described in the Seqwater Report, for the purposes of operating Wivenhoe Dam and Somerset Dam?

The main issues relevant to this question relate the capture of the recorded data, its accuracy, and the nature of the other data available for forecasting purposes. These points are addressed below.

4.1. Data capture

The data capture system has redundancy deliberately designed into it so that key information is still available to the flood operations team in the event of equipment failure. Automatic data recorders have the tendency to operate faithfully until when they are needed, when equipment often then fails due to mechanical and electrical causes associated with the extreme conditions. The fact the system processed over 130 000 packets of data on rainfall and streamflow conditions at different points in the catchment throughout the event, while only losing around 10% of gauges due to the extreme conditions, is rather remarkable.

It is evident that the data capture system provided a comprehensive set of data over the catchment in real time. Indeed, this catchment data set represents the most comprehensive coverage of a severe event known to the authors of this review. The fact that this data set is available at all, let alone was available for analysis in real time during the event, is testament to the appropriateness of the design and operation of this system.

4.2. Recorded Rainfall data

The rainfalls data presented in the Seqwater report were derived from the 129 ALERT rainfall stations in the Brisbane River catchment. This data represents the information available in real-time and hence was used for modelling during the event. Post the event there is the opportunity to compare this operational data with alternate sources of information to check its adequacy and completeness.

The Bureau of Meteorology operates an expansive network of daily read rainfall stations across Australia. This data is generally not available in real-time. It is understood that the Bureau of Meteorology has yet to complete the process of reviewing and checking the rainfall data recorded during the event, however daily totals from a number of sites are available on their public web site.

Generally the daily read gauges are not at the same location as the ALERT stations. In order to compare the data, daily read gauges located within two km of the ALERT stations were identified. The total rainfall recorded at each pair of sites was then compared for the eight days to 13 January 2011.

Figure 4.1 below shows that there is generally good agreement in the rainfall totals at the pairs of stations. There appears to be a small bias with the daily read values approximately 10% higher than the ALERT values. The reason for this relatively small bias was not explored but could possibly be attributed to the tendency for the ALERT gauges in the lower rainfall portions of the catchment. However, give the close proximity of the station pairs the difference it is speculated that the most likely reason for the bias might be due to differences in standard installation details (such as distance from the ground and exposure of the site).

The generally good agreement between the ALERT and daily read data confirms that the ALERT data is appropriate to support flood operations decision making in real time. In real time the tendency of the ALERT data to slightly underestimate the rainfall totals when compared to the daily gauges is compensated by the progressive calibration of the loss model during the event, and by closing the water balance at the reservoir itself.

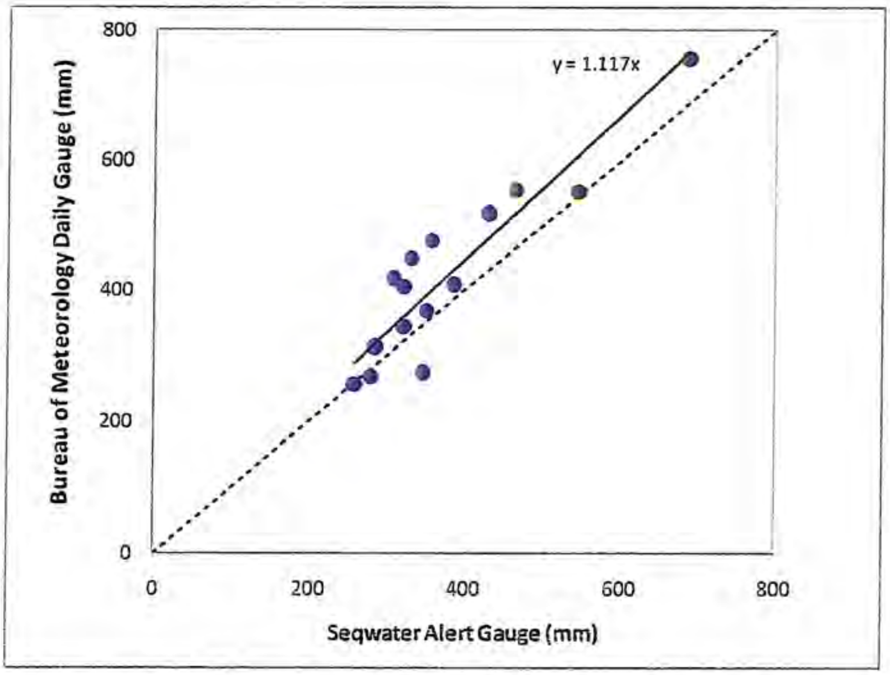

Figure 4.1 Comparison of eight day rainfall totals recorded by Seqwater and Bureau of Meteorology gauges to 13 January 2011.

4.3. Recorded Streamflow data

While it is not possible to comment meaningfully on the accuracy of the streamflow data without access to additional information on the quality of the gauge ratings, it is worth noting that the streamflow data must have been reasonably fit for purpose for:

- The flood event model was able to be calibrated to the recorded streamflows using loss parameters within the range of expected values, where it was not necessary to adjust the routing parameters;
- It was possible to resolve inconsistencies between routed recorded streamflows and total inflows to the reservoir with reasonable ease – successfully closing the water balance at Wivenhoe Dam represents a single "point of truth" that integrates a variety of information from independent sources.

4.4. Recorded Reservoir Levels

It is clearly important that accurate information is available on reservoir levels as this is a primary input to decisions on gate operation. There are two automatic recorders on Wivenhoe Dam, as well as a manual gauge board. For the majority of the event the two sources of data yielded similar readings, however as discussed in the report (Section 6.5) the automatic recorder provided anomalous readings for a period of time around the peak of the event on January 11th. While the behaviour of the recorders under these extreme conditions suggests the need for review of the design (or at least location) of the recorders, the availability of the manual gauge board readings reinforced the value of the redundancy built into the system.

Some focus is given in the report (Section 8.9) to the high intensity rainfalls that were inferred to fall on the reservoir in the early hours of January 11th. The analysis presented in quite plausible (see also next section), however this inference is heavily based on the assumption that the reservoir levels accurately reflect the change in volume of impounded water. It should be noted, however, that this analysis is confounded by uncertainty in some other key factors, namely:

- the paucity of rainfall gauges in the lower reaches of the Wivenhoe Dam catchment;
- the bathymetry data collected for Wivenhoe Reservoir that determines the relationship between reservoir level and impounded volume;
- the accuracy of the rating curves in the upstream reservoirs; and,
- the representativeness of the gauge board readings to the estimation of reservoir outflows under such extreme flow conditions.

The important point here is not whether the inference presented in the Seqwater report is correct, but rather to note that the information available to the operators *during the event* was sufficient for them to recognise that there was a discrepancy; furthermore, having noted this discrepancy, the flood operations team undertook an analysis that, even with the benefit of hindsight, looks plausible, and which *allowed pragmatic corrections* to be made to close the water balance and to continue with their flood management activities.

The cause of this discrepancy at the height of the reservoir rise can be analysed as required with the processed information available subsequent to the event: the notable point is that the operators had sufficient independent sources of information available to them during the event that enabled them to resolve the inconsistency. The exact source of this inconsistency remains a moot point. The fact that the operators identified the problem, and correctly allowed for it in their operations, provide good evidence that the monitoring and analysis system was operationally robust.

4.5. Forecast Rainfalls

The Bureau of Meteorology provides a range of quantitative forecasts that were used by Seqwater progressively through the event. The primary products of most use to forecasting rainfalls for the specific dam catchments of interest include:

- 24-hour Quantitative Precipitation Forecasts; and
- 3-day and 5-day ACCESS forecasts.

The performance of the 24 hour catchment average Quantitative Precipitation Forecasts provided by the Bureau of Meteorology is illustrated graphically in Figure 4.2. It is seen that the forecasts leading into the first and second major flood peaks (morning of the 9th and afternoon of the 10th) were around one third the actual. The forecast following the second peak (on the 11th) were around twice the actual.

In terms of spatial accuracy, it is seen in Figure 4.3 (from Seqwater Appendix J) that the 24 hour forecast made at 9am on the 10th does indicate very heavy rainfall over the Stanley catchment and in the immediate vicinity of Wivenhoe Dam. However the 24 hour forecasts for 9am on the 11th does not pick up the heavy rain in the immediate vicinity of Wivenhoe (which supports the inference discussed in the previous section regarding the sharp rise in reservoir level).

The plots of the flood forecasts (for the scenarios with and without rainfall) provided in Appendix A of the Seqwater report clearly reflect the impact of these rainfall forecasts on flood prediction.

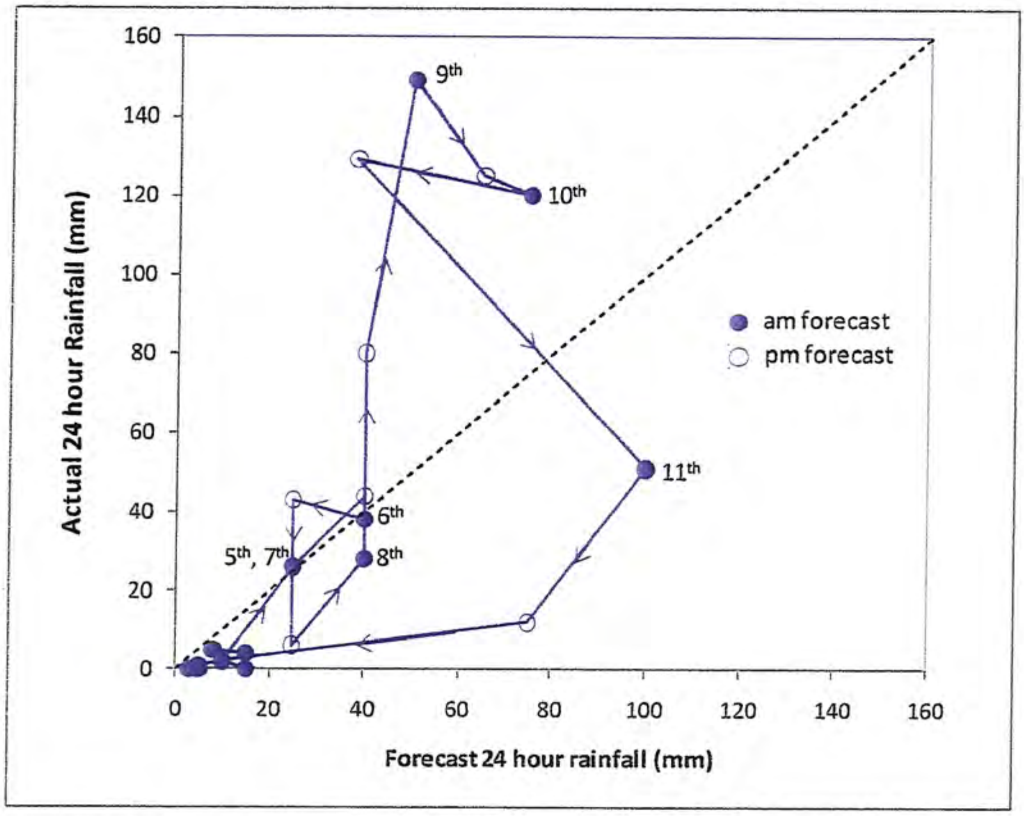

Figure 4.2 Progressive comparison of 24 hour catchment average Quantitative Precipitation Forecasts versus actual values.

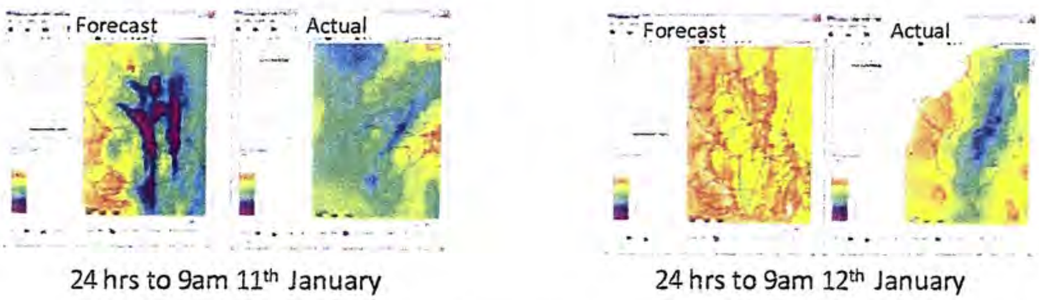

Figure 4.3 Progressive comparison of forecast versus actual 24 hour spatial rainfall distribution.

The performance of the 3-day and 5-day forecasts based on the ACCESS model is also discussed in the Seqwater report. The ACCESS model was jointly developed by the Bureau of Meteorology and the CSIRO, and incorporates modelling components developed by leading overseas climate agencies. A plot of the information provided is shown in Figure 4.3, which clearly illustrates the persistent underestimation of the larger catchment rainfalls in the period prior to the major flood peaks.

Figure 4.3 also highlights two features of particular interest:

- The difference between the 3-day and 5-day ACCESS forecasts is negligible throughout the event, which indicates that the rainfall was always expected to fall predominately within a 72-hour period; and,
- The successive forecasts fluctuate around a mean trend prediction by an alternating divergence of around 30% – there is little apparent persistence between successive forecasts which is not consistent with physical reasoning.

ACCESS is a sophisticated physically-based simulation model of the climate and earth system that represents the best available science in climate prediction. Its forecasting skill has been shown to be superior to the Bureau's previous operational global and regional models (Bureau of Meteorology, 2010). These reviewers are not qualified to provide meaningful comment on the efficacy of the ACCESS modelling system, but it seems reasonable to speculate that the poor forecast skill during the event reflects extreme weather conditions that lie outside the normal operating bounds for which model performance can be relied upon. Given the inherent uncertainty in providing forecasts of extreme conditions it seems sensible that in the future consideration be given to providing ensemble forecasts; these schemes are based on multiple numerical predictions which reflect different likelihoods of initial conditions. Such forecasts could be incorporated into a stochastic modelling framework as discussed in Section 3.2.9 of this report.

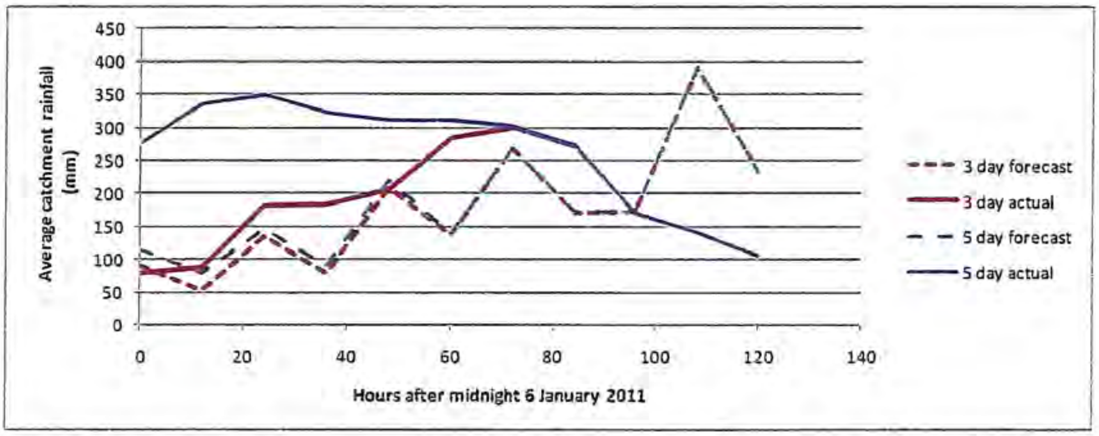

Figure 4.3 Progressive comparison of forecast versus actual 3-day and 5-day rainfall totals.

4.6. Forecast Streamflows

The ability of the modelling system to adequately forecast streamflows is dependent on the adequacy of the flood model, and on the quality of the recorded and forecast inputs. The adequacy of the flood modelling system is discussed in Section 3.2, and the quality of the forecast inputs is discussed above.

The performance of the streamflow forecast is illustrated by reference to two periods of inflows to Wivenhoe Dam (excluding releases from Somerset):

- Run 21, undertaken Sunday 9th January at 7pm
- Run 35, undertaken Tuesday 11th January at 4 am.

With respect to Run 21, the model predicted an inflow peak of around 8,800 m^3/s, which is only about 5% lower than the computed peak (Table in Section 9 of the Seqwater report); the timing of the peak was correctly forecast to be some 12 hours later. It is assumed that the forecast was made using the 24 hour rainfall forecast that was around 50% lower than what actually occurred.

With respect to Run 35, the model predicted the second inflow peak of around 6,000 m^3/s, which is around 55% lower than the computed peak; the timing of the peak was forecast to be some 14 hours later, which is a little later than what actually occurred. It is worth noting that the streamflow forecast was made when the previous 24 hour rainfall forecast was around 30% less than what actually occurred.

It is hard to see how these forecasts could be improved upon. In both cases the streamflow gauges further upstream in the catchment had only just commenced to rise again after the previous flood recession. The model is integrating the upstream flows that were recorded and routing them downstream to the reservoir, and there is insufficient forecast rainfall to magnify the flood response.

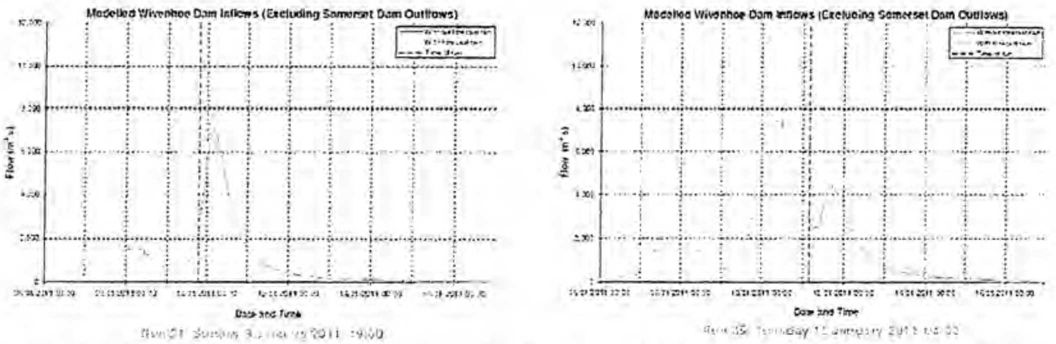

Figure 4.4 Forecast streamflows undertaken at 7pm on the 9th and 4am on the 11th January.

5. Assessment of event severity

This section addresses the following question:

Does the information contained in Section 8.0 of the Seqwater Report ("Preliminary Assessment of Event Magnitude"), accurately describe the January 2011 Flood Event?

The assessment of event severity is based on a number of different sources of evidence, namely the comparison of:

- rainfall depths with existing rainfall intensity frequency information;
- flood volumes and flood levels with historical maxima;
- flood peaks with flood frequency information; and,
- flood peaks and volume with "design flood" information.

These assessments are briefly addressed in the sections below.

5.1. Rainfall Frequency Assessment

The approach presented in the Seqwater report to assess the severity of the event rainfall is to compare the rainfall depths with rainfall intensity frequency information. This information is readily available across the whole of Australia, and provides a standard means to assess the probability that a given rainfall depth will be exceeded in a given period of time.

While this represents a most useful means of assessment, it is worth making the following points:

- Exceedance probabilities are computed for rainfalls occurring at a point and not for a specified area – while analysis of point rainfalls provides a useful indicator of event severity, it is the behaviour of rainfalls over the whole catchment area that is of most relevance to floods;
- Exceedance probabilities are computed for durations ranging from 1 hour to 120 hours – short duration rainfalls are relevant to flash flooding that might occur in a local catchment, it is only storm durations of between 24 to 72 hours that are of most relevance to dam operations;
- Estimates of exceedance probabilities rarer than 1 in 100 for storm durations less than 24 hours are considerably more uncertain than for storm durations of 24 hours and longer; and,
- The rarer the exceedance probability the greater its uncertainty, where the credible limit of extrapolation for durations of 24 hours and longer is around 1 in 2000.

Taking into consideration the above points, the best overall assessment of event severity given the information presented is considered to be a regional assessment of the exceedance probabilities of the longer duration events. To this end, Figure 5.1 was prepared using the CRC-FORGE information presented in the Seqwater report.

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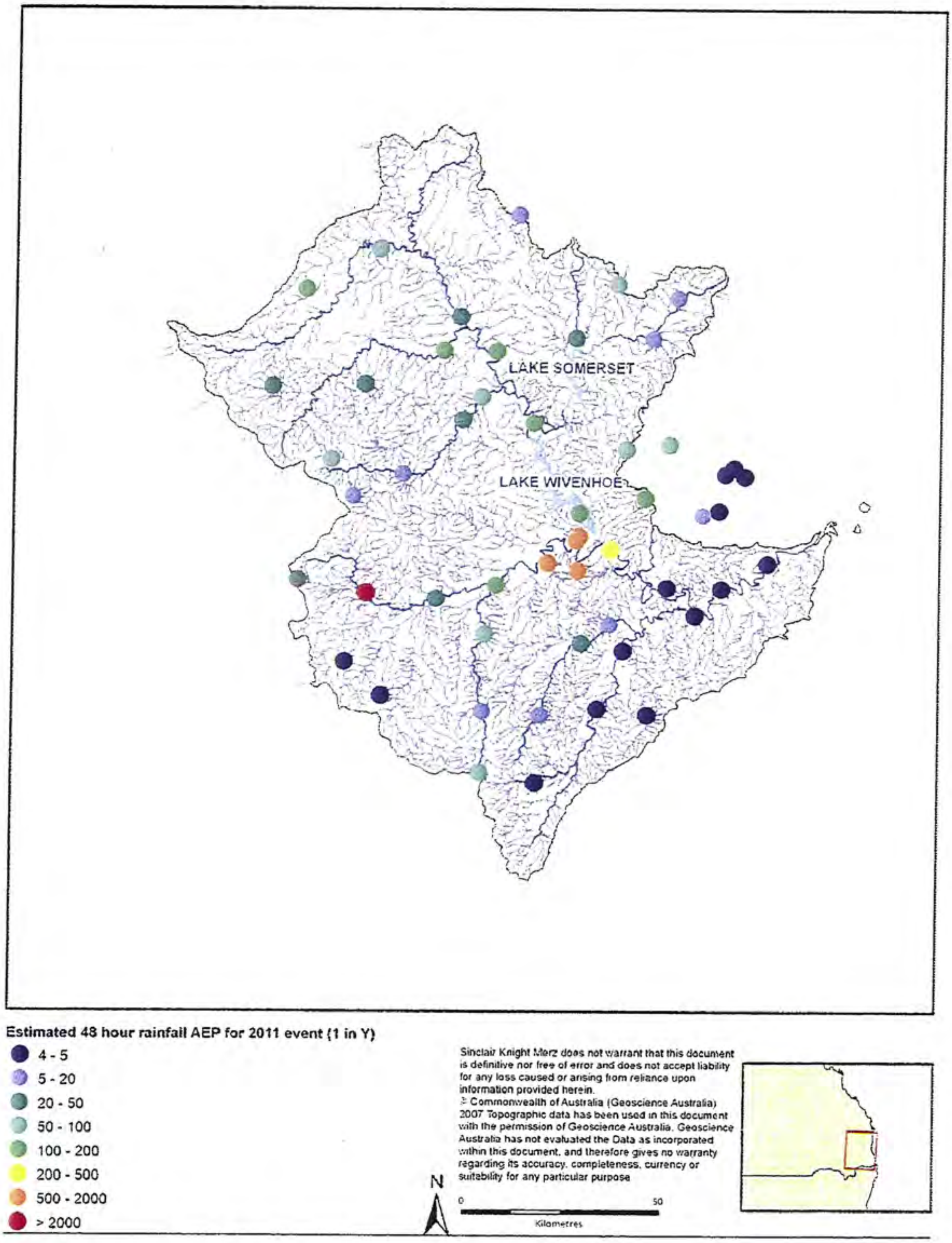

Figure 5.1 Spatial analysis of exceedance probabilities of 48 hour rainfalls.

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On the basis of Figure 5.1 it may be inferred that:

- The most extreme point rainfalls occurred in the centre of the Brisbane River catchment, in the areas immediately below Wivenhoe Dam – the annual exceedance probability of these rainfalls are between 1 in 500 and 1 in 2000;
- The annual exceedance probability of point rainfalls varies between around 1 in 20 at the upper reaches of the catchment above Wivenhoe Dam, to beyond 1 in 100^{+} in the lower reaches; and,
- The most intense region of localised rainfall occurred in the headwaters of the Lockyer Valley.

The above information is consistent with the exceedance probabilities of the catchment average rainfalls presented in Figure 8.4.2 of the Seqwater report (as derived using CRC-FORGE information). On this basis, it seems reasonable to assume that the annual exceedance probability of the catchment average rainfalls upstream of Wivenhoe Dam is between 1 in 100 and 1 in 200.

5.2. Flood Maxima

The information presented in Section 8.5 of the Seqwater report indicates that the volume of the January 2011 flood is similar to the volume of the 1893 flood, and is almost double the volume of the 1974 flood. Information on the 1893 flood must necessarily be of poorer quality than that available today (certainly the changed hydraulic conditions of the lower reaches of the Brisbane River confound attempts to estimated flood characteristics from flood levels, as reported in Brisbane City Council, 1999), and the presence of the dams prevents direct comparison with historic flood levels recorded at Brisbane. Further, the information in Section 8.6 also makes it clear that for many gauging stations the peak levels reached in January were the highest ever recorded.

It would thus appear reasonable to assess the January event as being amongst the largest floods to have occurred in the (approximately) 170 years of historic record. It is not possible to state whether or not this is the largest flood event to have ever occurred; indeed since it is the *combination* of flood peak and volume that is of most importance to maximum flood levels in the dam, it is not straightforward to identify the flood characteristics of most importance, as these are heavily dependent on the configuration and operation of the dam outlet works.

5.3. Flood Frequency Assessment

Flood frequency analysis is presented for two sites in the upper reaches of the Brisbane River catchment. This analysis is based on a limited period of record at only two locations, and no information is available on the uncertainty associated with extrapolation of the rating curve. It can be concluded, however, that the estimated rarity of the floods is consistent with the inferences based on rainfall frequency.

5.4. Comparison with Design Flood Information

"Design floods" provide information on the relationship between the magnitude of a specific flood characteristic (such as the peak) and the annual probability that it is exceeded. It is certainly of interest to compare historical events with such design flood information, though there are a number of factors that potentially undermine the validity of any conclusions drawn. Suffice to state here that the focus of deriving extreme design floods is generally on the derivation of floods relevant to the safety of the dam, and these are heavily dependent on estimates of Probable Maximum Precipitation; without careful review of the methods employed by Wivenhoe Alliance (2004) it is difficult to assess the defensibility of flood estimates with annual exceedance probabilities in the range of most interest to this event. Of particular concern here is the defensibility of comparisons with design floods derived from rainfall bursts of specific different durations, the assumptions made concerning antecedent conditions, and the joint treatment of factors that influence the transformation of rainfalls into floods for exceedance probabilities around the credible limit of extrapolation.

From the information provided, the annual exceedance probability of the January 2011 event estimated using the design flood information is between 1 in 1000 and 1 in 2000, depending on the flood characteristic assumed to be of most importance. It is noted that this is rather rarer than the exceedance probabilities of the upstream rainfalls would suggest. While it is possible that the combination of antecedent conditions and other factors might result in a flood with a significantly lower exceedance probability than the concomitant rainfall, given the concerns noted above any such inference should be viewed with caution until more detailed analysis can be undertaken.

5.5. Overall Assessment of Severity

The Seqwater report summarises the conclusions drawn on the basis of their analyses. The conclusions drawn by Seqwater are considered to be broadly defensible, where in the opinion of these reviewers emphasis should be given to the following:

- The most extreme point rainfalls occurred in the centre of the Brisbane River catchment, in the areas immediately below Wivenhoe Dam – the annual exceedance probability of these rainfalls are between 1 in 200 and 1 in 500;
- The annual exceedance probability of point rainfalls varies between around 1 in 20 at the upper reaches of the catchment above Wivenhoe Dam, to beyond 1 in 100$^+$ in the lower reaches;
- The annual exceedance probability of the catchment average rainfalls upstream of Wivenhoe Dam is between 1 in 100 and 1 in 200 (on the basis of CRC-FORGE information);
- When compared with historical events, flood volumes indicate the volume of the January 2011 event was almost double that of the January 1974 flood, and rivals the February 1893 flood;

- Peak water levels at gauging stations in the Brisbane River above Wivenhoe Dam were the highest on record. In the Lockyer Valley, peak water levels exceeded the 1974 levels and may well have been larger than those of 1893; and,
- A comparison of the recorded peaks, volumes and peak levels at Somerset and Wivenhoe Dams indicate that the January 2011 flood event easily exceeds 1 in 100 AEP.

6. References

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