Brisbane River 2011 Flood Event - Flood Frequency Analysis

REVIEW OF REPORT BY WMAwater

- Final A
- 28 September 2011

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1. Introduction

1. This report was prepared at the request of the Queensland Floods Commission of Inquiry. It provides a review of the report prepared by WMAwater (2011) that investigates the "Q100" flood along the lower reaches of the Brisbane River and the probability of the 2011 flood event.

2. For simplicity the term "Q100" is adopted throughout this report to denote the flood that has a 1 in 100 (or 1%) chance of being exceeded in any one year[1].

3. The scope of the report prepared by WMAwater was to provide estimates of:
    - the Q100 flood line on the basis of information and reports that existed prior to the 2010/2011 floods;
    - the Q100 flood line as it stands now, taking into account the data from the January 2011 event; and,
    - the severity of the January 2011 flood along different points on the Brisbane River expressed in terms of its annual exceedance probability (ie, the chance that it might be exceeded in any one year).

4. It needs to be recognised that the above scope represents a most difficult task, particularly as the investigation was undertaken in a very limited timeframe and without the involvement of the two key agencies concerned (namely, Seqwater and Brisbane City Council). In essence the scope requires WMAwater to resolve some vexed issues that have been the focus of a number of detailed investigations and independent reviews over the past three decades. It is thus inevitable that any conclusions drawn from such an investigation will be open to argument and be vulnerable to criticism. In short, this is a complex problem that is subject to considerable investigative constraints: it must be expected that any conclusions drawn are subject to the appropriate caveats, and would be superseded by the more detailed investigations contained in Recommendation 2.12 of the Interim Report prepared by the Queensland Floods Commission of Inquiry (2011).

5. This report should be read in conjunction with the report prepared by WMAwater (2011), but the main points are made in a fashion that should avoid the need for detailed cross-referencing.

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[1] The Q100 flood is more correctly referred to as the "1 in 100 AEP" or "1% AEP" flood, where AEP denotes the "annual exceedance probability" of the event. This flood is also referred to colloquially as the "100 year flood", which is a misleading term that does not correctly capture the notion that the event has a 1 in 100 chance of being exceeded in any one year.

6. It should be noted that the author of this report has been involved in a number of previous investigations relevant to the subject of this review, namely:
   - preliminary risk assessment of Wivenhoe, Somerset and North Pine Dams, commissioned by the (then) South East Queensland Water Board, as reported in Sinclair Knight Merz and Hydro Consulting Hydro Electric Corporation (March, 2000);
   - hydrological investigations into flood behaviour for the lower Brisbane River commissioned by the Brisbane City Council, as reported in SKM (2003);
   - review of hydrological issues relevant to the January 2011 event commissioned by Seqwater, as reported in SKM (2011[a]); and,
   - provision of advice to Seqwater on an ad-hoc basis since January 2011.

7. A summary of the qualifications and experience of the author of this report is provided in Section 2. An overall appraisal of the WMAwater report is presented in Section 3, and more detailed matters relating to the frequency analyses are discussed in Sections 4 and 5. Conclusions and recommendations arising from this review are presented in Section 6.

2. Qualifications and Experience of Reviewer

8. This report was prepared by Dr Rory Nathan, who is currently the General Manager Technology and Practice, and the Practice Leader for Hydrology, with Sinclair Knight Merz (SKM).

9. Dr Nathan holds the following academic qualifications:
   - Bachelor of Engineering (Agriculture) from the University of Melbourne (1980)
   - Master of Science (in Engineering Hydrology) from the University of London (1985)
   - Diploma of Imperial College, University of London (1985)
   - Doctor of Philosophy, University of Melbourne (1990)

10. He has the following professional affiliations:
    - Fellow, Institution of Engineers, Australia
    - Australian Representative, Floods Committee, International Committee on Large Dams
    - Member Hydrology Sub-committee, NSW Dams Safety Committee
    - Honorary Fellow, Department. Civil Engineering, Monash University
    - Past Honorary Fellow, Dept. Civil and Environmental Engineering, University of Melbourne

11. Dr Nathan has over thirty years experience in various organisations in Australia and overseas, covering academia, the public service, and private industry. Of particular relevance to the subject of this review, he was the lead author of the current Australian guidelines for the estimation of large to extreme floods (Nathan and Weinmann, 1999), and was a co-author of the current guidelines on the selection of acceptable flood capacity for dams (ANCOLD, 2000). He is also on the Engineers Australia's Technical Steering Committee for the ongoing revision of the general guidelines for design flood estimation. He has worked on numerous projects concerned with the assessment of flood risk across Australia, in every State and Territory. He has been contracted by the majority of major dam owning and other water resource agencies in Australia to provide consulting and advisory services, independent technical review, and participation in expert panels in formal flood risk assessment processes. He has also been contracted by several U.S. agencies to provide input to the development of flood estimation practice and related guidelines on the characterisation of flood risk.

12. He has published over 150 research papers on engineering hydrology in refereed journals, books, and conference proceedings, and has won several national and international awards for his contribution to professional practice, including:
    - Named as member of *Top 100 Most Influential Engineers* in Australia, 2009;
    - *National Civil Engineer of the Year*, awarded by the Institution of Engineers, 2000;

- Three-times awarded Engineers Australia’s *W.H. Warren Medal* for the best paper in Civil Engineering (1992, 1998, and 2005);
- American Society Civil Engineering Journal of Irrigation and Drainage Engineering *Best Research Paper Award* (1997); and,
- *G.N. Alexander Medal* (1998) for the best paper in Hydrology and Water Resources, awarded by Engineers Australia.

13. A more detailed curriculum vitae is provided in Appendix B.

3. Overall Appraisal

14. The following briefly reviews the approach taken by WMAwater to address the scope of investigations as provided by the Queensland Floods Commission of Inquiry. The comments provided below are grouped according to the report sections adopted by WMAwater, and more detailed matters relating to the frequency analyses and assessment of event severity are discussed in Sections 4 and 5 of this report.

15. Section 3 of the WMAwater report presents background material on the context for the Q100 and the salient issues involved in its estimation. This material is well supported by the relevant guidelines and provides a useful overview of the issues involved.

16. Section 4 of the WMAwater provides a concise distillation of material relating to the history of flooding and river engineering works along the Brisbane River since early European settlement. The summary is well targeted to the needs of the investigation, though the information presented on the flood mitigation performance of Wivenhoe dam is based on a selective mix of historical and simulated analyses. This has important implications as noted in paragraph 19 below and in the following Section 4.

17. Section 5 of the WMAwater summarises the outcomes of the flood investigations previously undertaken for the catchment. The information is presented in a manner that emphasises the chronology of the estimates, and little analysis is provided on the differences in hydrologic assumptions, information content, and methodology that is associated with the different estimates. Such analysis would highlight the nature of the supporting evidence, and would clarify the extent to which the changes are due to re-examination of historical data, changes in methodology and operating assumptions, and/or the role of subjective judgement used in the investigations. In other words, while the discussion provides a comprehensive summary of how estimates have changed over time, it does not constitute a critical review that sheds light on the hydrological rationale for the changing estimates of Q100 over time. As discussed in Section 4 of this report, the nature of the factors that influence the flood estimates under "no-dam" conditions have changed little in comparison with those under current conditions where the mitigating impacts of Somerset and Wivenhoe Dams are considered.

18. Section 6 of the WMAwater report discusses the general issues involved in determining a rating curve, as well as a number of specific issues that confound the derivation of flows from flood level information at the Port Office. Determination of reliable rating curves over the period of available flood level information is a tractable problem, but its solution does require relevant bathymetric and tidal information, and careful hydraulic analysis. The rating curve derived by WMAwater makes good use of available information and is consistent with other analyses; the only point of minor disagreement relates to the averaging of rating curve

information over the lower range of discharges. The lower end of the curve is well defined by the constant release of 3500 m^3/s from Wivenhoe Dam made by Seqwater in January 2011 (SKM, 2011[b]); the artificial nature of these flow conditions are well suited to the derivation of the lower end of the rating curve and should be given high weight compared to other evidence.

19. Section 7 of the WMAwater report presents the substantial analyses used to derive the revised estimate of the Q100. Comment on the key issues arising from this is provided in the next section of this report, but in terms of overall appraisal it is suffice to note here that:

    - the broad approach used to undertake the frequency analysis using historical maxima is appropriate;
    - there is reasonably strong justification for the Q100 estimate under "no-dam" conditions as it is largely supported by observations over a 170 year period; but,
    - the justification presented for the Q100 estimate under current conditions is based on an assumption that reduces the operational complexity of Wivenhoe Dam and the associated joint probability issues to a single fixed reduction factor – the analysis involves a somewhat circular argument and relies heavily on the information contained in a single event, and as such, the estimate provided by WMAwater is not considered defensible; and accordingly,
    - the estimates of the Q100 flood levels along the Brisbane River are not supported – the primary reason for this view is because the Q100 flow estimates are not defensible, but it is also noted that more current information on debris marks has not been used.

20. Section 8 of the WMAwater report provides the conclusions of their investigations. As indicated in the preceding paragraph the conclusion drawn regarding the Q100 estimate under "no-dam" conditions is accepted, and the Q100 estimate relevant to current conditions is not. The recommendations made concerning the need to model the Port Office gauge with a hydrodynamic model are supported, but the lack of discussion (and associated recommendations) around the limitations inherent in the treatment of Wivenhoe Dam operations and the associated joint probability issues is considered a significant omission.

4. Flood Frequency Analysis

4.1. Overview

21. The approach adopted by WMAwater to derive an estimate of the Q100 event based on information available prior to 2011 may be summarised as follows:

    a) The Port Office gauge was selected on the basis of relevance and length of record.
    b) Historical *flood levels* prior to 1917 were adjusted to account for dredging works, and the *flow peak* for the 1974 event was adjusted (upwards) to represent "no-dam" conditions.
    c) A statistical distribution was fitted to the historical flood maxima and used to estimate the "no-dam" Q100.
    d) A single factor was applied to the "no-dam" Q100 estimate to derive an estimate of the Q100 under current conditions.

22. The above approach was repeated using data obtained from the January 2011 event (where in step *b* the flow peak for the 2011 event was adjusted upwards to represent "no-dam" conditions), and the Q100 estimates were recalculated to determine the impact of the recent floods.

23. The above steps involve varying degrees of subjective judgement and are underpinned by different levels of supporting evidence. These differences impact markedly on the defensibility of each successive step, as discussed below.

4.2. Adjustments to Historical Flow Estimates

24. *Adjustment of historical flood levels prior to 1917*. The estimates of flood peaks for the events prior to 1917 are largely based on estimates provided by City Design (1999[a]), where the highest events were revised in line with a rating curve derived from the hydraulic modelling[2]. These adjustments attempt to take account of the river engineering works that had taken place, as summarised by WMAwater. The rationale for this adjustment is clear, though it is recognised that the bathymetric information on which the estimates are based is uncertain. The sensitivity testing undertaken by WMAwater would suggest that the adjustments are "probably appropriate".

25. *Impact of Revised Rating Curve*. It would appear that WMAwater revised the flood estimates provided by City Design (1999[a,b]) for the highest historic events on the basis of their revised

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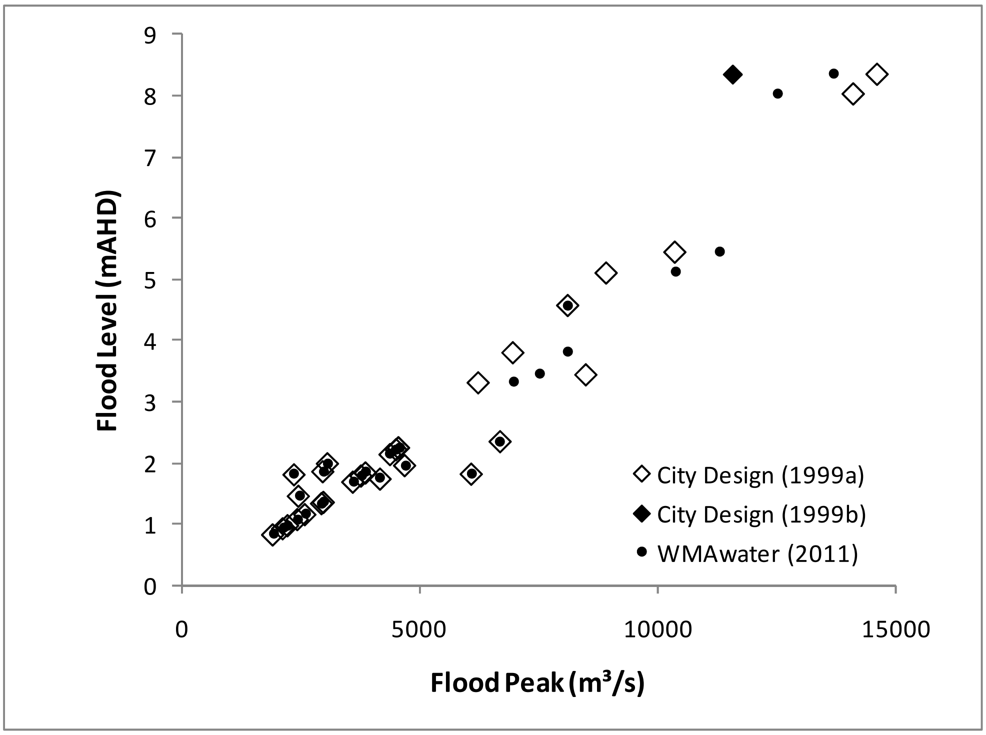
[2] Appendix B of the WMAwater report incorrectly states that the adjusted flood level data was obtained from "SKM June 1999 report" – this citation should read City Design (1999[a]). It is also noted that WMAwater also replaced the 1931 flood level estimated by City Designs (6245 m^3/s) with their own estimate (7000 m^3/s).

rating curve. The difference between the two sets of flood estimates is illustrated in Figure 1. With the information provided it is not possible to comment meaningfully on the appropriateness of the new flood estimates, other than to speculate that the hydraulic modelling approach used by WMAwater is likely to be more defensible than that available to City Designs in 1999. The point of the Figure 1 is to illustrate the influence of this step in their analysis, where at the high flow end the difference in the best estimate of flows is in the order of ~1000-2000 m^3/s.



- **Figure 1. Difference in estimates of historical floods derived by WMAwater and City Designs.**

26. *Derivation of "No-dam" estimate of 1974 peak flow*. No information is provided by WMAwater regarding the means by which the estimate of flow at the Port Office gauge was adjusted upwards to represent "pre-Somerset dam" conditions. Various estimates could be derived from earlier work that are within 1000 m^3/s of the adopted value of 11300 m^3/s (eg Hegerty and Weeks, 1985; SKM, 1998; City Designs, 1999; SKM, 2003) and it is unclear from the text what adjustments were made to account for the revised rating curve and for the removal of Somerset Dam.

27. *Derivation of "No-dam" estimate of 2011 peak flow*. Similarly, no information is provided by WMAwater regarding the means by which the estimate of flow at the Port Office gauge (~9600 m^3/s) was adjusted upwards to represent "no-dam" conditions (12400 m^3/s). It is

assumed that this was achieved using hydrologic inputs and hydraulic model provided by SKM (2011[c]), but adopting different assumptions in some fashion. It should be noted that the estimate derived by SKM (13400 m^3/s) was higher than that adopted by WMAwater, though without further information it is difficult to comment on the relative merits of the WMAwater estimate.

4.3. Frequency Analysis for “No-dam” Conditions

28. WMAwater used the FLIKE software developed by Kuczera (2001) to fit two different statistical distributions to the set of “no-dam” flood peaks. The conceptual nature of the statistical approach adopted (Bayesian maximum likelihood fitted to a censored historical series) represents best practice and is fully supported.

29. It is noted that the difference in estimates of the “no-dam” Q100 arising from choice of the distribution adopted for the full period of record is around 1600 m^3/s, or around 12% of the adopted estimate. This uncertainty reflects the “unknowable” nature of the distribution that governs the distribution of floods, and is additional to the uncertainty arising from the sample of historic maxima considered. It should also be noted that this uncertainty does not reflect the uncertainty inherent in the estimates of the flood maxima, as discussed above in paragraphs 24 to 27.

30. The nature of these uncertainties are common to all such investigations, and the preceding point is made to illustrate that, even if we assumed that we had 171 accurate observations of annual maximum floods, and that they represented a homogeneous sample, estimation of the Q100 is inherently an uncertain business. A reasonable estimate of the uncertainty of the “no-dam” Q100, even with these 171 years of observations, is around 30% to 40% of the adopted value.

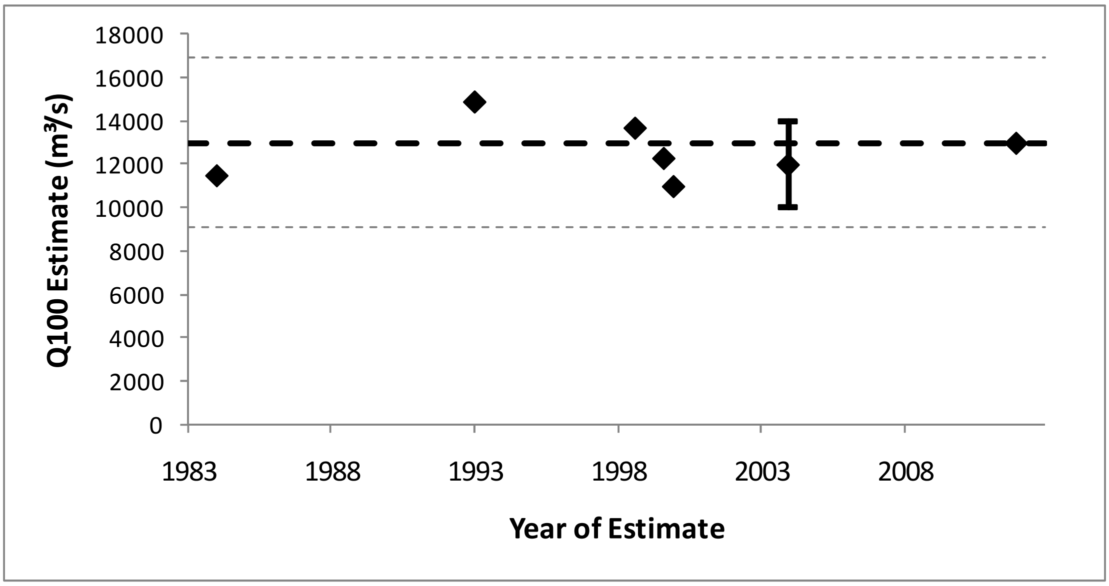
31. On the basis of the information presented by WMAwater, it is considered that 13000 m^3/s represents a reasonable estimate of the “no-dam” Q100.

32. WMAwater make the point that their estimate of 13 000 m^3/s is consistent with the “more recent” flood frequency estimates provided by SKM (1998) and City Design (1999[a]). This is a slightly curious observation to make, for it is noteworthy that this estimate is similar to *all* previous estimates of the Q100 in studies cited by WMAwater. The term “similar” is used here to denote a range of values that lie well within the notional (but optimistic) band of uncertainty of ±30%. The relevant estimates of interest are summarised in Table 1, and illustrated in Figure 2.

- **Table 1: Summary of estimates of the "no-dam" Q100.**

Estimate of Q100 (m^3/s)	Year Derived	Source
11500	1984	Weeks (1984) (also cited by Greer, 1992)
14910	1993	Dept. Natural Resources (1993)
13700	1998	SKM (1998)
12300	Jun 1999	City Design (1999[a])
11000	Dec 1999	City Design (1999[a])
12000	2003[1]	SKM (2003); Mein et al. (2003) Indicative uncertainty: 10000 – 14000 m^3/s
13000	2011	WMAwater

[1] See paragraph 33 for details.



- **Figure 2. Chronology of estimates of the "no-dam" Q100 (where the bold dashed line denotes the estimate made by WMAwater, and the notional associated band of uncertainty is shown by the narrow dashed lines).**

33. It is not clear why WMAwater did not critically review the extensive flood frequency analysis undertaken by SKM (2003). It represents the most recent investigations into the characterisation of flood risk along the lower Brisbane River, and the findings of the study were independently reviewed and endorsed by an independent panel (Mein et al, 2003). The study used a similar statistical approach as adopted by WMAwater, but reinforced the statistical inference by use of information from a number of other gauges. The SKM (2003) investigations focused on flood observations derived for Savages Crossing, which has a catchment area around 25% less than the Port Office gauge. While historical evidence (eg

City Design, 1999[b]) suggests that the peak flows along the lower Brisbane River tend to remain approximately constant (as noted by WMAwater, paragraph 97), evidence based on general Australian flood extremes (eg Nathan et al, 1994; Malone, 2011) suggests that peak discharges (for the larger catchment areas of interest) vary in a non-linear manner that is proportional to the ratio of the catchment areas raised to the power of 0.62. Thus, a Q100 estimate derived for Savages Crossing might be transposed to the Port Office under "no-dam" conditions by application of a factor that might vary between 1.0 and 1.20 (where greater weight should be applied to the lower figure on the basis of site-specific information). The SKM (2003) study concluded that the "no-dam" Q100 was likely to be between 10000 m^3/s and 14000 m^3/s, with a best estimate being 12000 m^3/s. If some account were made for the difference in catchment area between the two sites, the corresponding estimate at the Port Office gauge might be between 12000 m^3/s and 14300 m^3/s. This range neatly brackets the estimate derived by WMAwater, but given the additional weight that should be given to catchment-specific behaviour, it is concluded that the WMAwater estimate is around 5% higher than the estimate derived by SKM (2003).

34. This level of agreement between the SKM (2003) and WMAwater results is particularly important as they *were derived using largely independent data sets*. That is, using two separate sets of data representing long-term flood behaviour, both studies yielded similar estimates of the "no-dam" Q100. Such independent corroboration increases the level of confidence in the best estimate adopted. (The two studies do, however, diverge when it comes to the estimate of the Q100 for current conditions, and this is discussed in the following section.)

35. The information presented in Table 1 and Figure 2 actually illustrates an important point: the estimates of "no-dam" Q100 have changed little over the past 30 years because the underlying information from which they are derived is from a long period of observations that spans 170 years. The estimates of the "no-dam" Q100 are thus *statistically robust* as there is reasonably good evidence for the natural variability of flood behaviour in this catchment. Further efforts to refine the flood observations using better bathymetry data and hydraulic modelling will serve to reduce the band of uncertainty, but the "best estimate" is unlikely to change in a material fashion.

4.4. Estimation of the Q100 for Current Conditions

36. The reasonable consistency that is evident for estimates of the Q100 under "no-dam" conditions is not present when the corresponding timeline of estimates for "current" conditions are compared. This point is made quite strongly in the WMAwater report, and the reasons for this are worth exploring.

37. The difference between estimates of the Q100 under “no-dam” and “current” conditions is the mitigating effects afforded by the presence of Somerset and Wivenhoe Dams. These dams have considerable potential to reduce flood peaks for rainfall events that occur in the upper half of the Brisbane River catchment, but obviously have no ability to control floods from rainfalls that fall downstream of their location. Their potential for flood mitigation decreases as the magnitude of the flood increases, and this is in part dependent on the manner in which Wivenhoe Dam is operated. The ability of the dams to reduce peak levels at the Port Office is dependent on a number of key factors, namely:

- The average depth of the rainfall and the nature of the antecedent conditions;
- The location of the most intense areas of rainfall (ie, the spatial patterns of rainfall);
- The manner in which rainfall intensity varies during the event (ie rainfall temporal patterns);
- How the storm moves across the catchment during the event;
- The influence of tidal conditions on flood levels;
- The flood storage available in the dams just prior to the onset of the event; and,
- Operating procedures used to release stored floodwaters from the dams.

38. It should be recognised that all but the last two factors influence flood magnitude under either “no-dam” or “current” conditions. These factors are *stochastic* in that they depend on the capricious variability of Mother Nature, whereas the last two factors are (to different degrees) determined by human intervention.

39. There is an infinite manner in which the different stochastic factors may combine to result in a flood, and for this reason the longer the period of record the more confidence we have in our ability to characterise expected flood behaviour. As discussed in the preceding section, we have reasonable confidence in our estimate of Q100 under “no-dam” conditions as we have 170 years of observations to help us.

40. However, the introduction of the dams completely alters the manner in which these stochastic factors combine to yield a flood. The presence of the dams markedly heightens the sensitivity of the flood magnitude to these natural stochastic influences. For example, under natural conditions it makes little difference whether or not the most intense part of the storm is located over the exact centre of the catchment, or a small way upstream or downstream of it. However, with a dam in place, such a difference might mean that the bulk of the flood is impounded by the dam, or the flood might rise downstream of it. Examples of this variability may be seen in the spatial patterns associated with past major events, as reproduced in Appendix B from information presented in SKM (2003; 2011[a]). These plots show for example that the rainfall in the January 1893 event was largely restricted to the area above Somerset Dam, but in January 1974 it would have fallen below both dams. Thus, even if the

average catchment rainfall depth had been the same, the resulting peak flow at the Port Office would have been markedly different.

41. In short, the introduction of dams into the system vastly increases the complexity and uncertainty of flood behaviour as experienced by residents of Brisbane. While the availability of 170 years of record allows us to characterise flood risk with some degree of certainty, we need considerably more sophisticated tools to estimate this with the dams in place. Indeed, the historical information available to us that is relevant to "current" conditions (ie since the upgrade to Wivenhoe Dam in 2003) is in fact contained in a single event, in January 2011. With care, the historical information contained in a small number of events might be altered to represent current conditions, but by comparison with the information content that supports the estimate of the "no-dam" Q100, this is a miserably small data set to examine.

42. Given the foregoing, it is seen that the uncertainty surrounding the estimate of the Q100 for "current" conditions is inherently greater than that for "no-dam" conditions. Any estimate of the Q100 for current conditions is necessarily subject to simplifying assumptions, each of which will reflect the changing nature of what is "current". That is, the estimates will change according to the size of dam, the governing operating rules, and the nature of the design information that was thought to be most relevant at the time. It is thus to be expected that estimates of the Q100 for "current" conditions will be more volatile than those for "no-dam" conditions, and that these will vary over time as conditions change. It is for this reason that the only defensible way of estimating flood risk for current conditions is to analyse the joint probabilities in an explicit manner using such techniques as Monte-Carlo simulation, as recommended by SKM (2003) and Mein et al. (2003), and more recently by the Joint Flood Task Force (2011) and in the Interim Report prepared by the Queensland Floods Commission of Inquiry (2011).

43. The foregoing provides a broader context for commenting on the method used by WMAwater to estimate the Q100 under current conditions. WMAwater (as described in paragraph 32 of their report) converted the "no-dam" estimate of the Q100 to "current" conditions by the simple application of a single factor (0.73). In essence, this factor is intended to account for all the stochastic complexity as described in the preceding paragraphs. WMAwater make the under-stated comment that the "2011 data provides the only real data point on the performance of the dam". It is for this reason that the Q100 estimate is sensitive to consideration of the 2011 event, whereas that for "no-dam" conditions is not. No further comment is made concerning the limitations of their approach, and no recommendations are made concerning the need for improving this aspect of their inference.

44. By this means, WMAwater estimate the Q100 for current conditions to be 9500 m^3/s. This estimate is almost 50% higher than the estimate derived by SKM (2003), despite the fact that

the corresponding estimates derived by WMAwater and SKM for "no-dam" conditions are similar. It should be noted that the SKM (2003) estimate is derived using a model to simulate the operating procedures of the two dams, and a hydraulic model to route the outflows down to the Port Office. The inputs reflecting the stochastic behaviour of the system were conditioned to be consistent with the "no-dam" flood conditions, where the impacts associated with dam operations were handled by deterministic modelling.

45. The estimate derived by SKM (2003) was endorsed by an independent review panel established for the purpose. Both SKM and the independent review panel acknowledge the limitations of the adopted approach, and as a consequence both parties separately recommended the need for a more rigorous approach based on explicit joint probability procedures.

46. WMAwater's estimate of "current" flood risk is heavily dependent on the results of a single flood event. Apart from the statistical sampling limitations involved, the simplicity of this approach introduces a degree of circularity in their argument. As noted above, the flood mitigation potential of the dams decreases as the magnitude of the flood increases. If the January 2011 flood is more representative of an event with an annual exceedance probability of 1 in 200, then it would be expected that a factor lower than 0.73 should be used, and thus the resulting estimate of the Q100 would be lower. The assumption that the characteristics of the January 2011 event are directly relevant to the Q100 biases the outcome in a very selective fashion. Giving more weight to the other evidence presented in Figure 3 of their report would alleviate this problem, but again the size of the sample compared to the nature of the stochastic influences does not provide compelling justification for the adopted approach.

47. In summary, it is considered that the approach taken by WMAwater does not give adequate consideration to the stochastic factors that influence the conversion of the "no-dam" estimate of the Q100 to "current" conditions. While it might be expected that the January 2011 event might result in an upwards revision of the Q100 estimates as derived in 2003, no compelling evidence to this effect has been presented.

5. Assessment of Event Severity

48. On the basis of their derived Q100 estimate for current conditions, WMAwater estimate that the 2011 event has an annual exceedance probability of 1 in 120. The exceedance probability is precisely stated given the large uncertainty inherent in its estimation. Following from the discussion presented in the preceding section, this author does not agree with either the inferred accuracy or the magnitude of this assessment.

49. WMAwater present supporting evidence in the form of rainfalls. It is not stated how the rainfall estimates provided in Table 12 of the WMAwater report were derived. Any estimate of total catchment rainfall is heavily dependent on the number and quality of the rainfall gauges used, and the manner in which the surface fitting procedures account for the influence in topography. It is thus not possible to comment on the validity of the catchment rainfall totals presented. It is noted that only gauges operated by the Bureau of Meteorology were used, and that there are other gauges (eg ALERT) that could be used to refine the estimate. It is not clear why a range of areal reduction factors were considered as this can be calculated – from Table 4-1 of SKM (2003) it may be inferred that the 3-day areal reduction factor relevant to the catchment is 0.86.

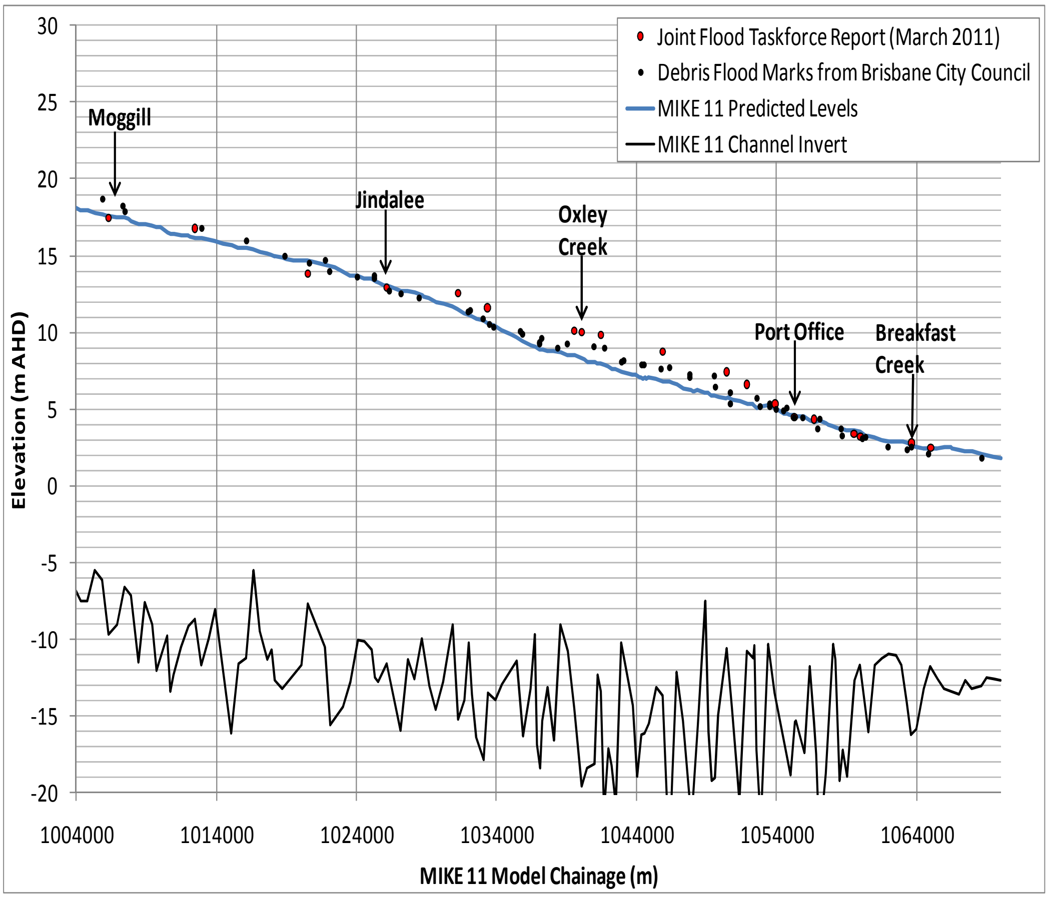
50. SKM (2011[a]) undertook an analysis of event rainfall data and concluded that the annual exceedance probability of the rainfalls for the whole dam catchment was around 1 in 100 to 1 in 200, though the annual exceedance probability of the most extreme point rainfalls that occurred in the centre of the Brisbane River catchment was likely to be between 1 in 500 and 1 in 2000. This interpretation suggests that the event rainfalls were rarer than that concluded by WMAwater, but it is fair to say that neither analysis was rigorously undertaken and there is no strong evidence to support one view over the other. To this author's knowledge no careful analysis of catchment rainfalls has yet been published that utilises all available data in a manner that takes account of the topographical gradients involved.

51. As discussed in the preceding section and noted by WMAwater, the exceedance probability of the rainfall event can only give a general indication of the severity of a flood event. This is particularly the case for Brisbane River, where the spatial and temporal characteristics of the rainfall can influence flood severity downstream of the dams in a manner that may be quite differentiated from the causative rainfall.

52. Analysis of estimates of the January 2011 flood under "no-dam" conditions would suggest that this was an event with an annual exceedance probability of around 1 in 100, but again this does not reflect the true flood risk as it stands under current conditions.

53. WMAwater present a flood profile on the basis of their estimate of Q100 under current conditions at the Port Office. This flood profile is then used to make inferences regarding the severity of the event at different locations down Brisbane River. Given that this author does not agree with the estimate of the Q100 then it follows that the assessment of severity as presented is also not endorsed. There are, however, a couple of additional minor points regarding this assessment that are worth noting, as discussed below:

- WMAwater did not use the MIKE-11 model (version 2) developed by SKM as it is stated that the model underestimates peak levels by up to 1.8 m between Jindalee and the Port Office. It is noted that WMAwater did not have access to the SKM report that accompanies version 2 of the model (SKM, 2011c), as this (and other) limitations of the modelling were noted and discussed. This particular limitation did not impact on the results reported, and thus this aspect was not refined within the timeframe available.
- It should also be noted that the maximum underestimation of water levels along this reach is actually about half that indicated by WMAwater. The reason for this discrepancy is that WMAwater relied upon interim flood levels referenced by the Joint Flood Taskforce (2011), which are flagged as requiring verification. The discrepancy between these interim values and recorded data may be discerned from the information presented in Figure 6-6 of SKM (2011[b]) and in Figure 6-7 of SKM (2011[c]). A plot illustrating model performance against flood debris data obtained by Brisbane City Council is shown in Figure 3. It should be noted that these debris marks provide only an approximate indication of flood level, but that at the confluence with Oxley Creek these indicators are consistent with recorded data.
- Finally, it the WMAwater report states that the MIKE11 model was adjusted to match the surveyed flood levels, but no details of how this adjustment was undertaken nor the physical basis for this adjustment is provided. It is thus not clear on what basis the comparisons with the derived Q100 level are provided.



- **Figure 3. January 2011 peak level profile versus observed debris flood marks provided by Brisbane City Council.**

6. Conclusions and Recommendations

54. The scope of the investigations addressed by WMAwater relates to some vexed issues that have been the focus of a number of detailed investigations and independent reviews over the past three decades. It is understood that WMAwater had limited time to undertake their investigation, and it is appropriate that any conclusions drawn are subject to the appropriate caveats.

55. On the basis of the material presented by WMAwater it is this author's opinion that:

  - the broad approach used to undertake the frequency analysis using historical flood maxima is appropriate;
  - there is reasonably strong justification for the Q100 estimate of 13000 m^3/s under "no-dam" conditions as this analysis makes use of flood behaviour observed over a 170 year period;
  - the method used to convert the estimate of "no-dam" Q100 to current conditions is overly simplistic and involves a somewhat circular argument that relies heavily on information contained in a single event;
  - the estimate of Q100 for current conditions is accordingly not supported; and,
  - as a consequence the Q100 flood level estimates along the Brisbane River are also not supported.

56. The estimate of the Q100 under current conditions is inherently more uncertain than the estimate of Q100 under "no-dam" conditions. It is considered that the only defensible way of estimating flood risk for current conditions is to analyse the joint probabilities in an explicit manner using such techniques as Monte-Carlo simulation.

57. This author agrees with the recommendations for improving the rating relationship at the Port Office gauge made by WMAwater, but it is recommended that higher priority be given to the application of more rigorous (joint probability) hydrological methods that reflect current operating procedures to allow the flood risk downstream of the dams to be characterised with confidence.

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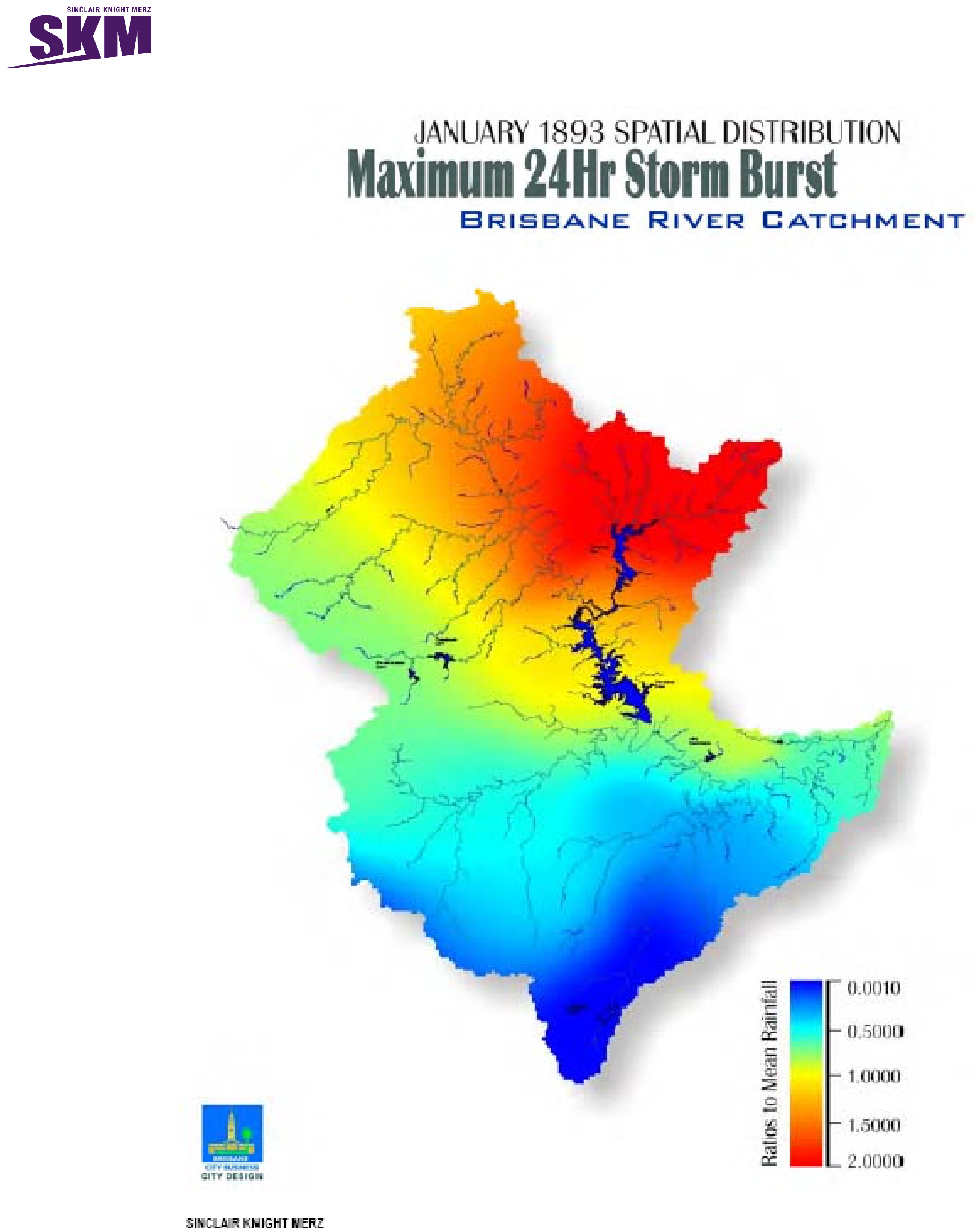
Appendix A – Spatial Patterns from Historic Events



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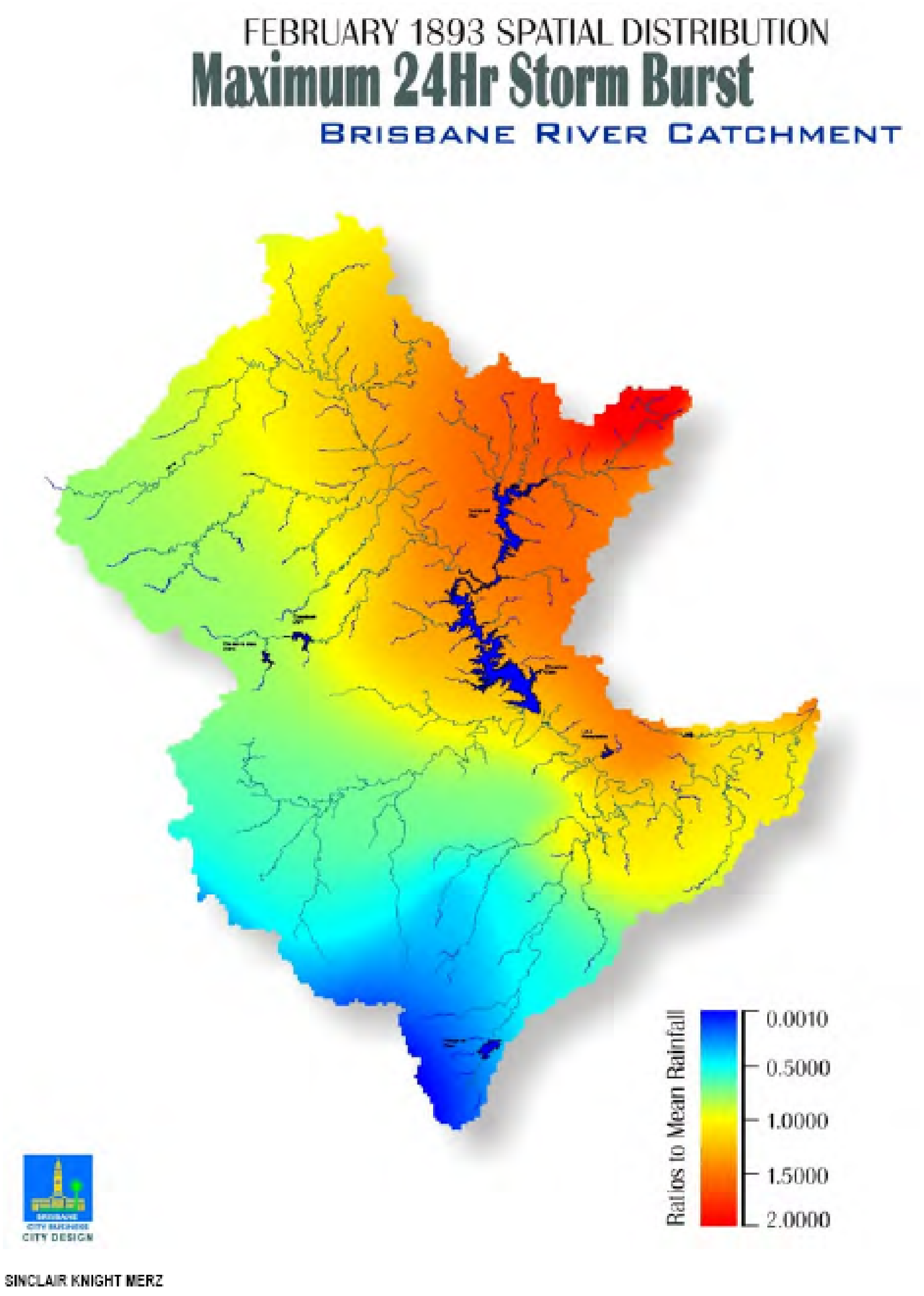

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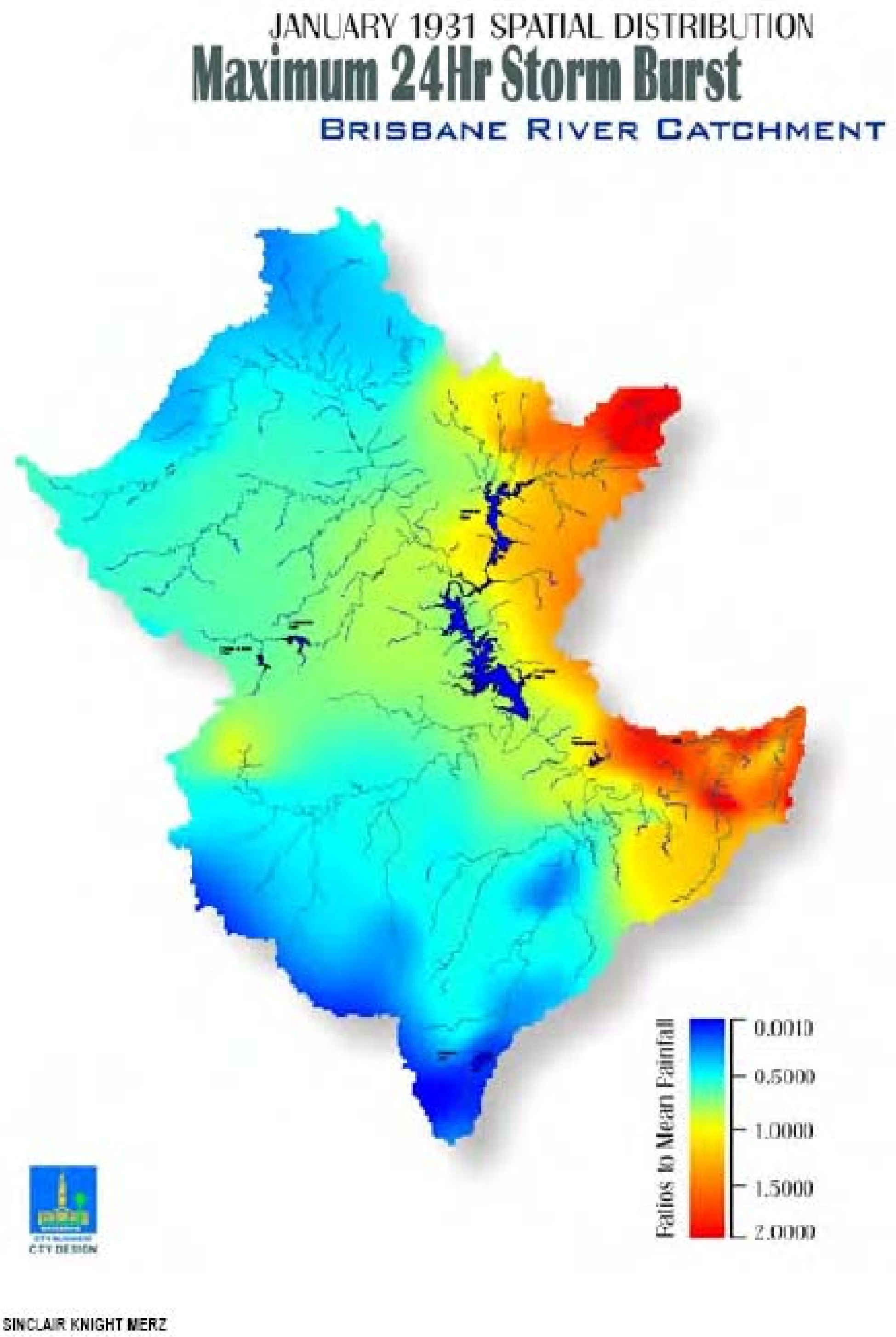

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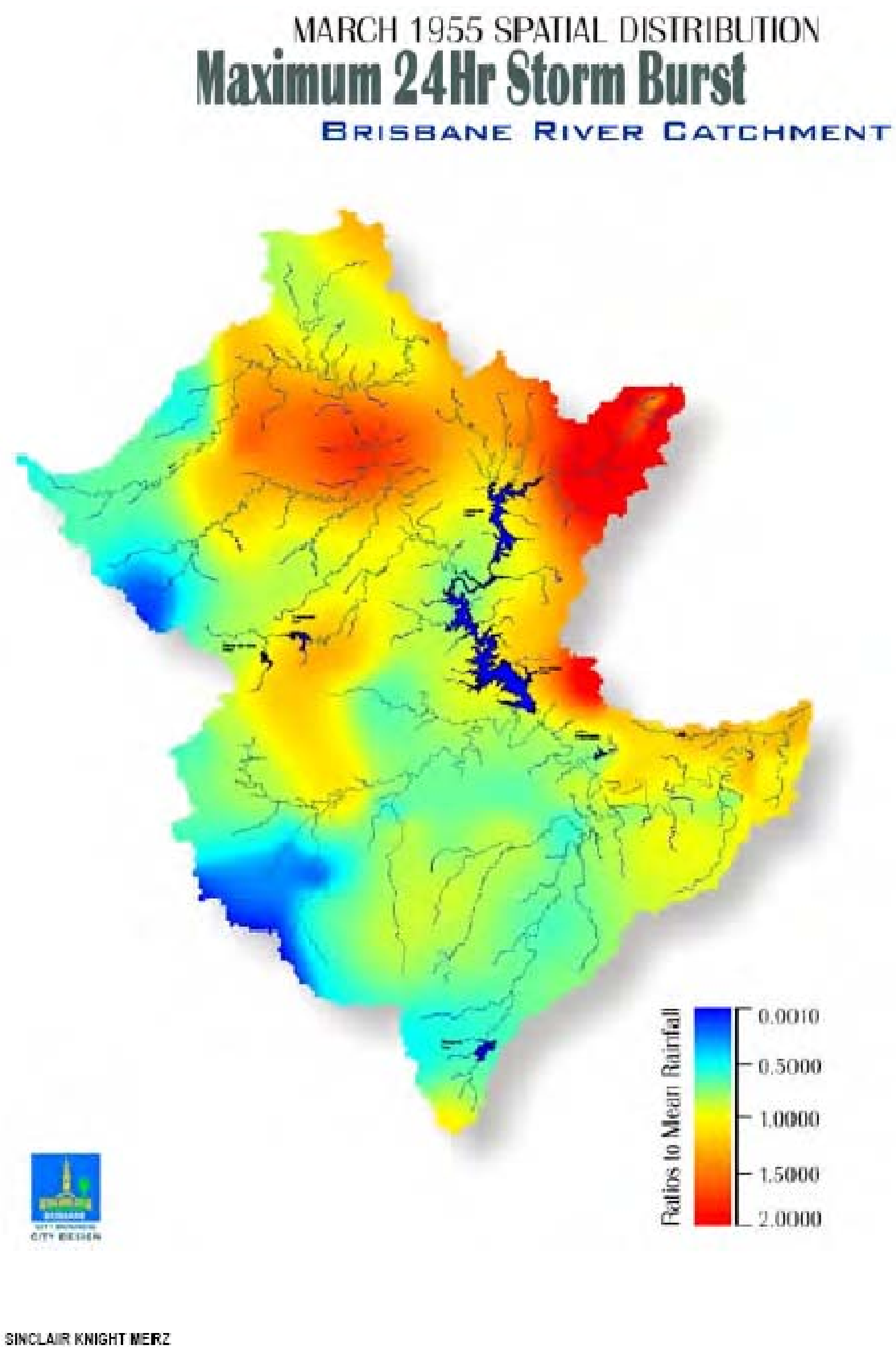

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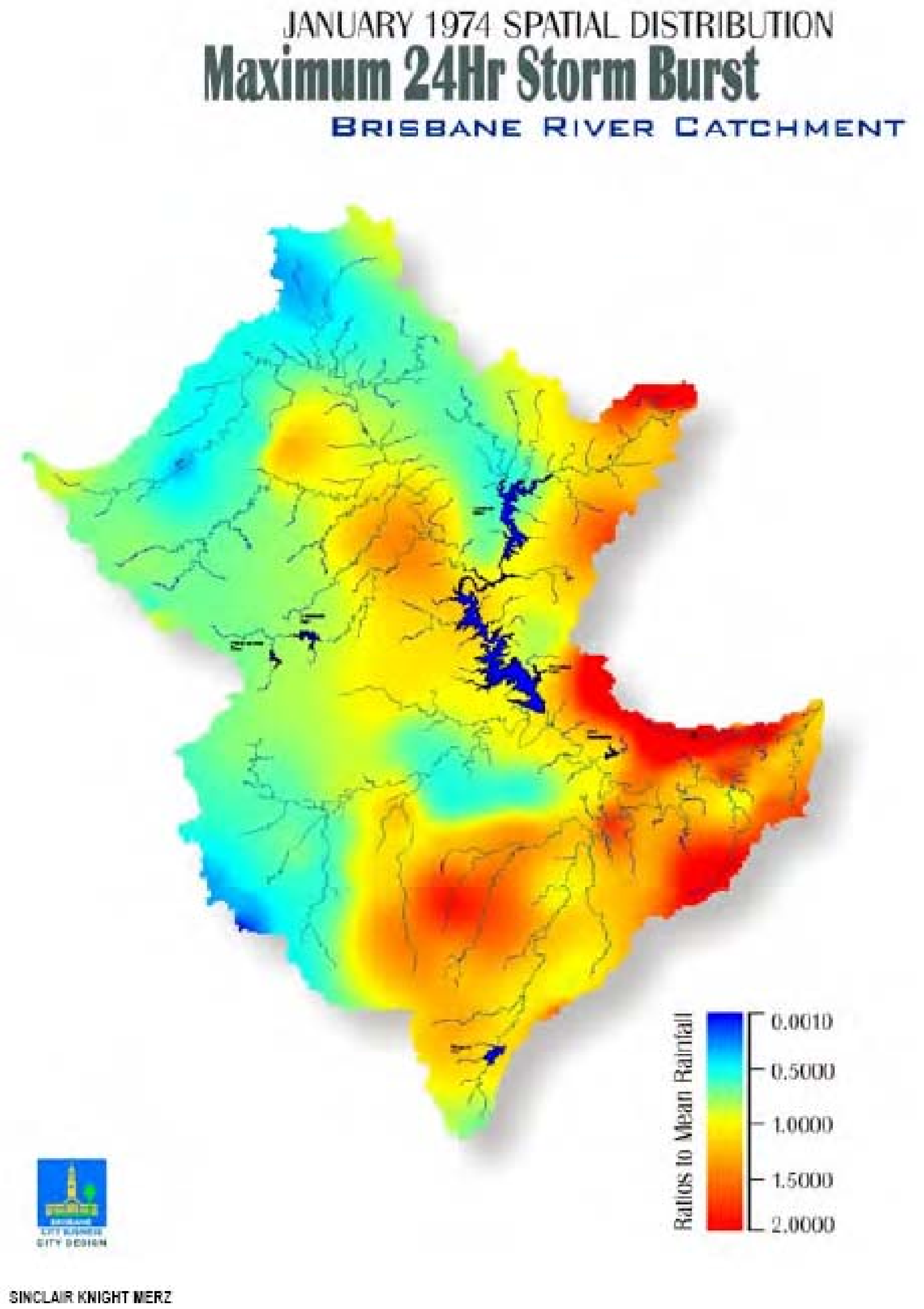

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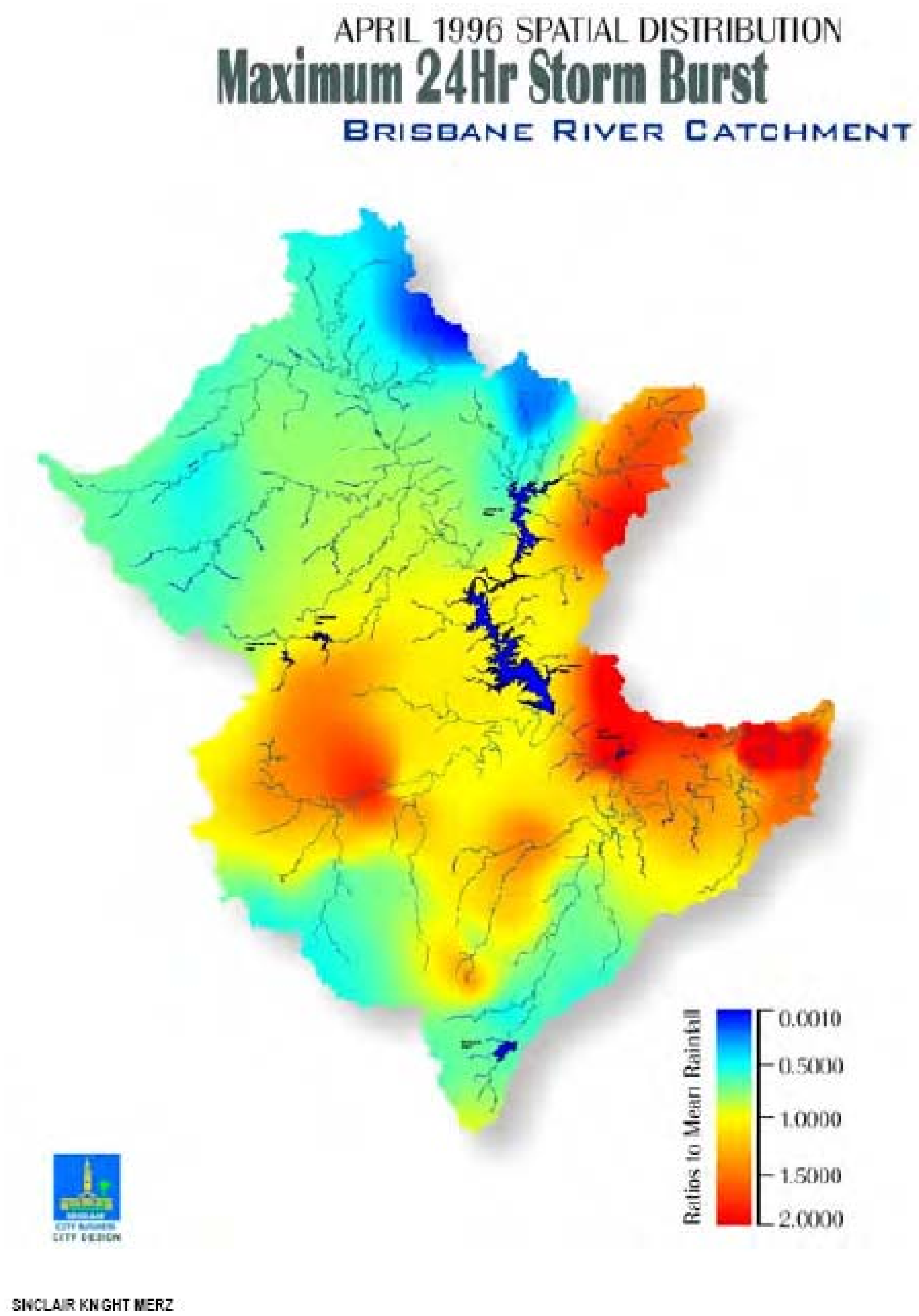

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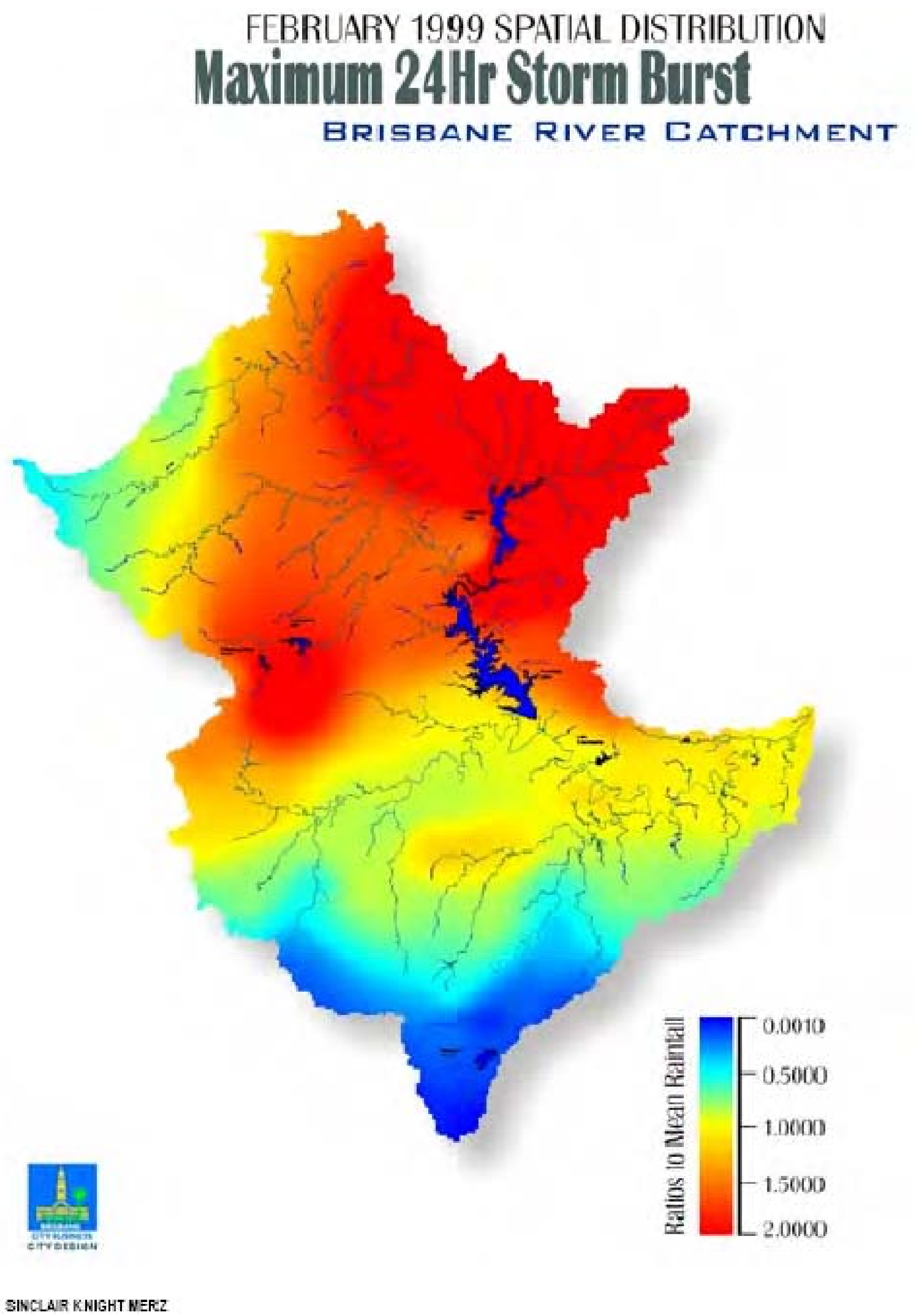

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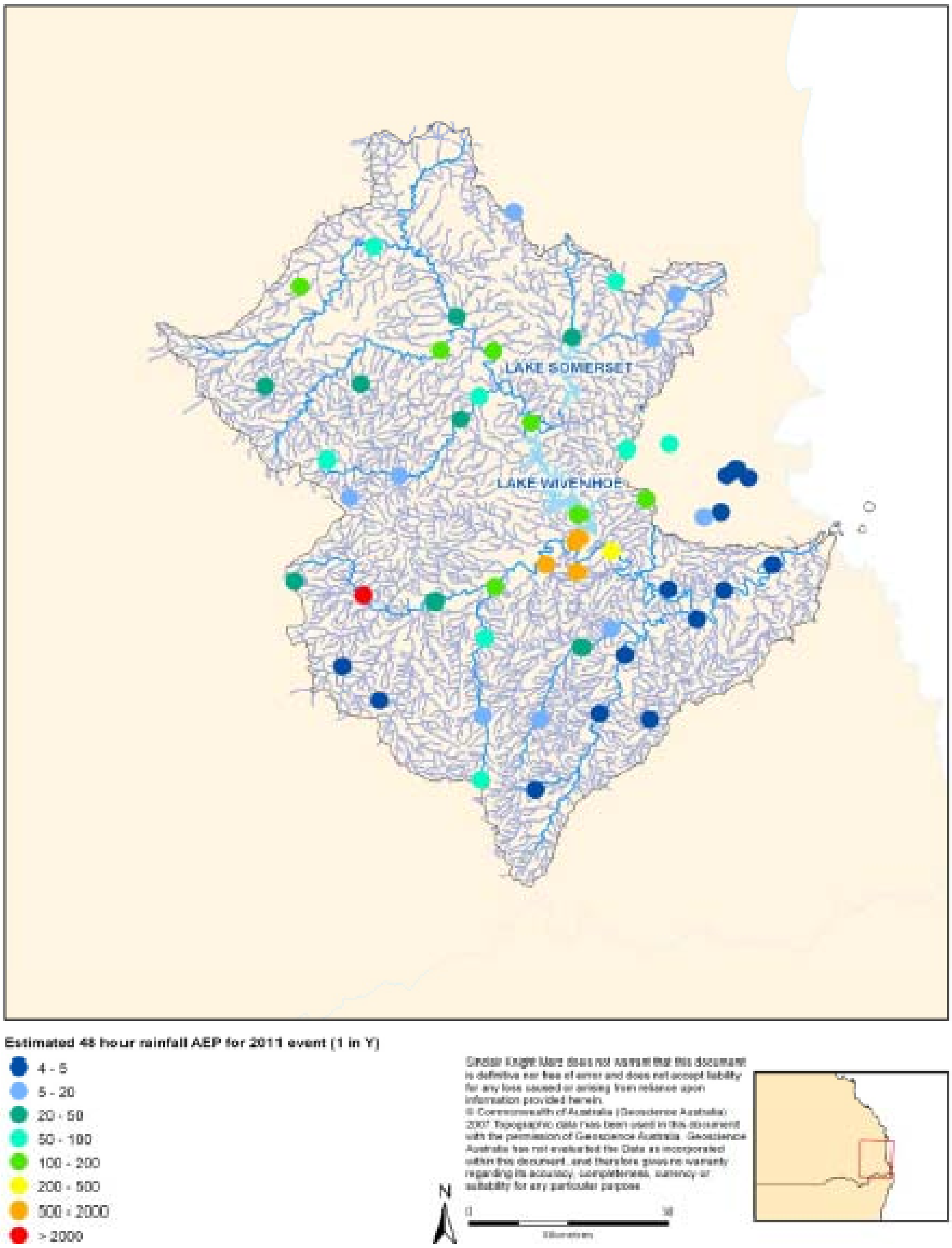

Spatial variation in exceedance probabilities of 48 hour rainfalls recorded in January 2011.

Reproduced from SKM (2011[a])

Appendix B – Curriculum Vitae for Dr Rory Nathan

Curriculum Vitae

Dr Rory Nathan
Practice Leader Hydrology

Qualifications

- B.E.(Agr), University of Melbourne, 1980
- M.Sc., D.I.C., University of London, 1984
- Ph.D., University of Melbourne, 1990

Affiliations

- Fellow, Institution of Engineers, Australia
- Australian Representative, Floods Committee, International Committee on Large Dams
- Member Hydrology Sub-committee, NSW Dams Safety Council
- Honorary Fellow, Department. Civil Engineering., Monash University
- Past Honorary Fellow, Dept. Civil and Environmental Engin., University of Melbourne

Awards

- Named as member of "Top 100 Most Influential Engineers" in Australia, 2009
- National Civil Engineer of the Year, awarded by the Institution of Engineers, 2000
- W.H. Warren Medal (1992, 1998, and 2005) for the best paper in Civil Engineering (national award by the Engineers Australia).
- ASCE Journal of Irrigation and Drainage Engineering Best Research Paper Award (1997)
- G.N. Alexander Medal (1998) for the best paper in Hydrology and Water Resources, (national award by the Engineers Australia)
- Best presentation of a technical paper at the Hydrology & Water Resources Conf. (1993)
- ACEA Award of Excellence (1998).
- Victorian Engineering Excellence Award (2003).

Fields of Special Competence

Dr Rory Nathan has around 30 years experience in engineering hydrology in both the academic and consulting fields. He is actively involved in a number of research projects under the auspices of Engineers Australia and with the University of Melbourne. While he has generally worked in areas of flood estimation, hydrological processes, regionalisation, and catchment hydrology, he has developed specialist skills in the following areas:

- Estimation of extreme hydrologic events (floods and low flows)
- Characterisation of risk for dam safety
- Hydrologic estimation in ungauged catchments
- Regionalisation of hydrologic information
- Characterisation of flow regimes for environmental flows
- Modelling and simulation of hydrologic processes
- Hydrologic model development and application

Relevant experience

- Convenor and senior author of the national guidelines for the estimation of large to extreme floods published by the Institution of Engineers Australia.

SKM

- Contracted by the U.S. Bureau of Reclamation to provide input to the development of guidelines on the characterisation of hydrologic inputs for risk analysis
- Contracted by the U.S. Army Corps of Engineers to help formulate research directions to be undertaken in the area of hydrologic risk using federal agency funding
- Contracted by the Murray Darling Basin Commission to oversee and review the flood risk assessment of Hume Dam being undertaken by NSW State Water (and SMEC).
- Member of panel undertaking risk review of the Dam Safety Program for Western Australia's South-West Irrigation Dams
- Member, Expert Review Panel for the Preliminary Risk Assessment of the portfolio of dams owned by the Hydro-Electric Authority, Tasmania
- Member, Expert Review Panel for the Preliminary Risk Assessment of Somerset, Wivenhoe, and North Pine Dams owned by the South East Queensland Water Board
- Member, Expert Review Panel for the upgrading of Rosslynne Dam owned by the Southern Rural Water
- Project Manager consequence assessment and risk characterisation of Dartmouth Dam (Goulburn-Murray Water)
- Project Director for the consequence assessment and risk characterisation of Hume Dam (DLWC, NSW)
- Variously Project Manager and Project Director for the estimation of hydrologic loads, risk characterisation, and consequence assessment of several dams owned by Goulburn-Murray Water (and its predecessor the Rural Water Corporation); Dartmouth, Eildon, Cairn-Curran, Nillhacootie, Laanacoorie, Mokoan, Waranga, Buffalo, Fyans, Bellfield, Rocklands,
- The estimation of hydrologic loads and review of spillway adequacy for many major water storages owned by the (then) Rural Water Corporation (Eildon, Dartmouth, Laanacoorie, Wartook, Bellfield, Fyans, Waranga, Lonsdale, Rocklands, Pine, Taylors, Cairn-Curran, Tullaroop, Upper Coliban, Lauriston, Malmsbury, Buffalo, and Pykes Creek).
- Responsible for event tree development and risk characterisation of hydrologic inputs to the Preliminary Risk Assessment of all dams owned by the Snowy Mountain Hydro-Electric Authority.
- Responsible for the derivation and characterisation of hydrologic and hydraulic inputs to the Preliminary Risk Assessment of all dams owned by South Australia Water.
- Use of quantitative risk analysis for evaluation of floodplain development options for AMP
- Provision of advice to ACTEW/AGL on how to best account for climatic variability in the development of options for their future water supply options (ongoing)
- Assessment of the vulnerability to climate change and variability for the water resources of the Fitzroy River
- Project Director for the consequence assessment of four major dams owned by the Dept. of Land and Water Conservation, NSW (Blowering, Burrinjuck, Split Rock and Keepit)
- Project Director for the consequence assessment and risk characterisation of the Kiewa Hydroelectric Scheme (Southern Hydro)
- Expert reviewer of extreme event hydrologic studies undertaken by Melbourne Water (Upper Yarra and Devils Bend reservoirs)
- The estimation of hydrologic loads and review of spillway adequacy for O'Shannassy Reservoir (Melbourne Water).

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