Review of

BRISBANE RIVER FLOOD STUDY

Report to Brisbane City Council

Independent Review Panel

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Executive Summary

This review was commissioned by the Brisbane City Council, so as to obtain independent and expert advice as to 'whether the August 2003 estimates of the Q100 flow and level at the Brisbane Port Office are reasonable'. [Q100 designates the peak discharge that can be expected to be equalled or exceeded once every 100 years on average].

In the conduct of the review, the Panel had two presentation/discussion sessions with representatives of the prime consultant (Sinclair Knight Merz), City Design, and the Department of Natural Resources and Mines (one session). Two draft reports (SKM, dated 8 and 28 August 2003, respectively) with the latest estimates of the Q100 values were the key documents.

It should be stated at the outset that the estimation of Q100 for a catchment of this size (nearly 14000 sq. km) is a challenging task. The extreme variability of rainfall, the change in catchment response due to the construction of dams, and the variable conditions in the tidal section of the river, are some of the factors which complicate the application of 'standard' flood methodologies. The advent of new techniques for flood frequency analysis and for extreme rainfall estimates, together with much improved hydraulic routing methods for estuaries, has added much to the technologies now available for flood estimation.

The Panel:

(i) have reviewed the methodology used by SKM to determine the Q100 river flow and level

(ii) believe that the appropriate technical processes have been followed in this study

(iii) based on the evidence available to it, is of the view that, for the Brisbane Port Office, the best current estimates for

- the Q100 flow is 6000 m^3/s
- the Q100 level is 3.3 m AHD

There is an inevitable degree of uncertainty in any estimates of this kind; in this case, heightened by the variable influence of the Somerset and Wivenhoe Dams on different storm events on the Brisbane River Catchment. A quite plausible range for the Q100 flow is 5000 to 7000 m^3/s and for the Q100 level, 2.8 to 3.8 m AHD. It seems certain that the position of the best estimates in the respective ranges can be more precisely determined, and the width of these ranges could be significantly reduced, with further investigation as outlined in Section 5.2 of this report.

The Panel notes that the current 'best estimates' of Q100 and the corresponding flood level at the Port Office provide a sufficient basis for a decision on whether the currently adopted flood levels are broadly acceptable. However, for general flood risk assessments and risk-based flood management decisions, more refined flood frequency estimates will ultimately be required.

Acknowledgment

The provision of material from representatives of the Brisbane City Council, City Design, Department of Natural Resources and Mines, and Sinclair Knight Merz greatly helped the Panel in the conduct of this review. It is a pleasure to acknowledge the high level of cooperation accorded to the Panel by these organisations in responses to questions and requests for information. In doing so, it is important to stress that the Panel has reached its conclusions independently, based on its own interpretations of the material supplied to it.

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1. Introduction

1.1 Purpose of report.

The Brisbane City Council (BCC) appointed a Review Panel in July 2003 to provide independent advice to, and make expert assessment of, a study being conducted by Sinclair Knight Merz (SKM) on design flood flows and levels in the Brisbane River. This report provides the Panel's determination as to whether the SKM estimates of the Q100 flow and level (ie. those likely to be equalled or exceeded on an average once in 100 years) are reasonable.

1.2 Background

A number of studies have been carried out in recent years to estimate the risk of flooding of areas of Brisbane from the Brisbane River. Given the size and complexity of the catchment, exacerbated by tidal effects in the downstream river reaches, the task is a challenging one; it is not surprising that there has been considerable variability in the design estimates of both flow and level. These are documented in the "Chronology of Events" prepared by Council (Appendix 1).

There have been major advances in the last five years in the methodology used to estimate extreme floods from rainfall, including design data that was not previously available for large catchments. The 2003 SKM Study was commissioned to provide an updated estimate of design flood with the new technologies, with the Panel providing an independent review role (see Appendix for Terms of Reference). The Panel met with the consultants and others for progress presentations on 31 July and 14 August 2003, and received draft copies of the relevant sections of the SKM report on 22 August.

1.3 Guide to this report

This review begins with a general overview of what can be termed best practice in flood hydrology (Chapter 2). It then highlights the particular characteristics of the catchment and estuarine zone of the Brisbane River which affect flood flows and levels (Chapter 3). Chapter 4 gives the Panel's assessment of the methodology used in the most recent Brisbane Flood Study (SKM, 2003 (a) and (b)), with comments on the results obtained. The Conclusion (Chapter 5) provides a statement as the most likely value of the Q100 flood and level at the Port Office in Brisbane, and the uncertainty that exists in these estimates. Recommendations for the work required to reduce this remaining uncertainty are included.

2. Design flood estimation – aims and best practice methodology

2.1 Introduction

Design flood estimation is not a simple process of following clearly defined standards and guidelines but it involves a considerable degree of judgement by the investigator. Before assessing the different studies and comparing their results, it is therefore useful to discuss more broadly what design flood estimation aims to achieve, what methods are available to achieve these aims and what issues are involved in applying the methods.

This section starts by explaining the aims of design flood estimation and introducing the most important principles and technical terms used in design flood estimation. The introductory description of best practice methodology is divided into three parts: flood frequency analysis, rainfall-based approaches for estimating design flood flows and hydraulic methods for converting design flood flows to design flood levels. The section concludes with a discussion of uncertainty in design flood estimates and its implications.

2.2 Aims and principles of design flood estimation

Flooding is a natural part of the flow regime of the Brisbane River and its tributaries. Its major cause is heavy storm rainfall over parts or all of the Brisbane River catchment. The nature and magnitude of flooding resulting from heavy storms depends also on catchment conditions, with the worst floods occurring when a heavy rainfall occurs over an already wet catchment. Major land use changes in the catchment have the potential to modify the flood response to storm rainfall, as do major storage developments such as the construction of Somerset and Wivenhoe Dams. For planning and floodplain management, design flood estimation must therefore relate to the *current or expected future catchment conditions*.

The distribution of flood events over time is almost random; there is no clearly discernible or predictable pattern of how flood flow periods occur. Similarly, the magnitude of flood events also varies randomly. It is therefore not possible to predict the actual occurrence of the next flood but only to estimate the *average flood frequency,* expressed as the average number of years between occurrences of floods of a given magnitude and referred to as the Average Recurrence Interval (or ARI). The aim of design flood estimation is to establish the *flood frequency curve* for a site of interest, or the relationship between flood magnitude and flood frequency.

The observations from *historic flood events* provide the main source of information for design flood estimation. Because of the great variability of climate and catchment conditions producing floods, each observed flood event differs from the next one with respect to one or several flood characteristics. For the purpose of flood management and design it is therefore necessary to define representative flood events which reflect the most likely combinations of the different flood characteristics for different magnitudes of events. These *defined flood events (DFE)* or *design flood events* are derived from historic flood data by means of statistical frequency analysis or by hydrologic modelling methods.

For a particular flood event, the maximum flood levels reached at different locations along the river are the characteristics of most direct interest to floodplain management. However, these are closely related to the peak flows experienced at those locations, which lend themselves better to frequency analysis. Design flood estimation therefore involves two steps. In the first step, *hydrologic* estimation methods are applied to estimate *design flood flows*, specifically peak flow rates for given ARIs, expressed in m^3/s. In the case of the Brisbane River Flood Study, the design flow of specific interest is Q100, the estimated peak flood flow with an ARI of 100 years. In the second step, *hydraulic* methods are then applied to convert the design flood flows to *design flood levels*. In the case of the lower Brisbane River, which is subject to tidal influences, there is no unique relationship between flood flows and flood levels, and a set of representative design conditions have to be assumed in the hydraulic analysis.

The methods applied in design flood estimation should follow best practice guidelines, to the extent that these have been formulated and are applicable to a specific situation. In Australia, the adopted guidelines for design flood estimation are documented in 'Australian Rainfall and Runoff – a Guide to Design Flood Estimation' (ARR, IEAust, 1999). These guidelines are not prescriptive, and in more complex flood estimation situations such as the Brisbane River catchment, they allow for a substantial degree of subjective interpretation by the designer, based on experience and professional judgement.

While designers and decision makers generally require a "best estimate" of the flood magnitude for a given ARI, it must be recognised that usually such estimates involve a considerable degree of uncertainty which may need to be allowed for in the decision making process. An indicative range of uncertainty is provided by confidence limits around the best estimate.

A range of different methods is available to the designer for both the hydrologic and hydraulic analysis components. In each specific case, the selection of the most appropriate method depends on the amount and quality of the data available, the particular characteristics of the catchment and the intended use and importance of the flood estimates. In situations where the design flood estimates are used to support decisions with far-reaching consequences, the approach should make best use of all relevant sources of data and information, and comparative analysis using a number of methods would be desirable. In the case of the Brisbane River Flood Study, the various investigators have followed two main approaches in the hydrologic analysis:

- frequency analysis of flood events extracted from streamflow records, and
- hydrologic modelling approaches to derive simulated design flood events from design rainfall events.

In the following, these two approaches are described in more detail.

2.3 Frequency analysis of observed flood data

The expected frequency of floods of different magnitudes can be assessed by a statistical frequency analysis of observed flood events. For this purpose, a series of annual maximum flood events is extracted from an essentially complete record of streamflow data at a stream gauging station that has operated over a sufficiently long period of time. For this analysis to be meaningful, the data in the flood series have to reasonably satisfy the following basic assumptions:

- the occurrence of flood events is *random* and the events used in the analysis are *independent* of each other
- the events in the flood series are *homogeneous* (from the same population of events), *stationary* (free of any significant time trend) and *consistent* (not affected by any changes in the methods of measuring the data)
- the flood data being analysed are *representative* of the flood conditions of interest

In considering these assumptions it must be recognised that flood flows are not directly observed, but are estimated from observed water levels at the gauging site by means of a rating curve. The rating curve is established from flow velocity measurements (gaugings) for different flow magnitudes, but often the range of gaugings does not extend to the largest observed floods. Flood flow estimates for these larger events thus need to be based on extrapolated rating curves and are of lower accuracy.

Where the flood data do not readily satisfy some of the basic assumptions of statistical frequency analysis, because of changed catchment conditions or different methods of observation, adjustments need to be applied to some data points to render the series more homogeneous. In some cases, additional data on large historical floods may also be available, but these are generally based on less accurate forms of flood observations. Decisions on the use of adjusted and possibly lower quality data involve a trade-off between the benefit of potentially useful additional information and the danger of contaminating a reliable data series with "noise" from lower quality data.

Another potentially useful source of flood data is from other stream gauging stations in the same catchment or from stations in neighbouring catchments that have similar flood characteristics. If the flood data from these stations, after some form of standardisation, satisfy the assumption of homogeneity, they can be combined to undertake a regional flood frequency analysis. Again the balance between additional information and noise introduced by regional data needs to be carefully assessed.

For each data series to be analysed, a theoretical probability distribution is fitted which should reflect the characteristics of the empirical flood frequency distribution defined by the observed floods. The fitted distribution can then be used to estimate flood magnitudes over the full range of ARIs of interest; this often involves some degree of extrapolation beyond the range of observed floods. Many different probability distributions and parameter estimation methods are available for this fitting process, but only a relatively small number of these are used in standard Australian practice. In more complex flood estimation situations, such as the Brisbane River catchment, the choice of distribution and parameter estimation method can have a significant bearing on the resulting design flood estimates.

In practice, the dilemma involved in the selection of the most appropriate data set and analysis method from a range of alternatives is often addressed by undertaking flood frequency analyses for a number of different flood series using a range of methods. The results of these analyses are then carefully evaluated, and the estimates considered to be most plausible and reliable selected as a design basis.

Since the preparation of the current version of the Australian guidelines on flood frequency analysis (ARR, IEAust, 1999), which were originally published in 1987, a number of important developments in flood frequency analysis methodology have taken place. In addition to the Log-Pearson 3 (LP3) distribution recommended in ARR, a range of other generalised distributions are now available for fitting, and the traditional product moment method for determining distribution parameters has been supplemented by the more robust L-moment and LH-moment methods. Bayesian methods of flood frequency analysis (Kuczera, 1999) allow different weights to be assigned to different forms of flood data, so that their influence on the final design flood estimate reflects the different levels of information content. These newer developments not only provide analysts with more powerful and flexible tools for flood frequency analysis, they also give a clearer indication of the uncertainties in design flood estimates (see Section 2.6). The guidelines on flood frequency analysis in Book IV of ARR (IEAust, 1999) are currently being revised, and the revision team has indicated that these newer developments will form an integral part of the new guidelines.

2.4 Rainfall-based approaches

Since floods are generally produced by heavy rainfall, an alternative to flood frequency analysis is to focus the attention on storm rainfalls and their transformation to flood events. Rainfall-based approaches overcome the lack of direct flood observations for the conditions of interest by incorporating knowledge of physical hydrologic and hydraulic processes into models that simulate how floods are generated. Because of the complex nature and high degree of temporal and spatial variability of processes, the models are forced to adopt a simplified, conceptual representation of the catchment and the governing processes. To the extent that the model structure reflects the key catchment characteristics, and the model parameters can be validated against observations, the models provide a reliable and flexible tool to derive design floods for a significantly broader range of conditions than is directly reflected in the observed flood data. However, the reliability of the design flood estimates reduces with increasing degree of extrapolation beyond the range of direct observations.

The basic input to flood estimation models is design rainfall data for the specific catchment and the ARI of interest. The most important design rainfall characteristics for storms of different durations are the average rainfall intensity over the catchment, and the likely distribution of rainfall in time and space. These design rainfall characteristics have been derived from analysis of data from many rainfall stations in a region and are available from design rainfall databases (e.g. ARR99, CRC-FORGE). The different design rainfall characteristics are combined to define a design storm event for a given rainfall duration and ARI.

Design storm events provide the basic probability input to the procedure. The "design event approach" adopted in Australia assumes that the 100-year ARI flood is produced by a 100-year design storm event. For this assumption to be satisfied, all intermediate steps in the transformation of design rainfall to design flood need to be effected in a "probability-neutral" fashion; this means that parameters such as rainfall losses, initial storage contents and other flood modifying factors need to be selected in such a way that they are not biasing the probability of the simulated design flood.

The selection of a representative design storm and associated other design assumptions should be supported by the analysis of catchment-specific data, but in a catchment as large and complex as the Brisbane River catchment, the selection of these design inputs may still involve a considerable degree of professional judgement. In such situations it is desirable to check the appropriateness of the assumptions made by applying the model first to reproduce floods for catchment conditions for which reliable results of flood frequency analysis are available. In the case of the lower Brisbane River under current conditions, special complexity is introduced into the modelling process by the presence of Somerset and Wivenhoe Dams and their operation under flood conditions. It is therefore advisable to apply the hydrologic model to the pre-dam situation first and validate the results against the results of flood frequency analysis for pre-dam conditions.

2.5 Converting design flood flows to design flood levels

Hydraulic calculations are necessary to determine the design flood levels associated with a design flood. These calculations take account of the flow carrying capacity of the river channel and of the resistance to flow, including boundary shear and energy losses due to channel bends, bridges and other obstructions. The effects of tributary streams and of over-bank flooding must also be taken into account.

An appropriate water level must be specified at the downstream end of the river system. This is often referred to as the tailwater level.

The flood travels down the river system as a flood wave and it is modified as it progresses. The changes in the flood wave must be calculated correctly to establish the peak flood levels at different locations along the river.

In current practice, the hydraulic calculations are carried out with a computer software system that takes full account of the dynamics of the flood wave. This is described as the 'hydraulic model'. A number of well established hydraulic model systems are in use currently. The MIKE11 system was used by SKM and the RUBICON system was used by DNRM for the Brisbane River Flood Studies. Each of these hydraulic models is well established and is consistent with current best practice.

It is essential for the hydraulic model to be calibrated before it can be used to calculate design flood levels. In the process of calibration, the model is made to reproduce the observed flood levels for one or more historic floods for which sufficient data have been measured. This is achieved by adjusting the resistance and energy loss parameters in the model until satisfactory agreement is obtained between the flood levels calculated with the hydraulic model and the measured flood data.

2.6 Uncertainty

While designers and decision makers generally require a single valued "best estimate" of the design flood magnitude for a given ARI, it must be recognised that, by necessity, design flood estimates involve a considerable degree of uncertainty which may need to be allowed for in the decision making process.

A substantial degree of uncertainty in flood frequency estimates is inherent from the high degree of variability of hydrologic factors producing floods and the limited sample available from the total population of floods. Additional uncertainty may arise from the following sources of error in the basic data and in the methods of design flood estimation:

- systematic errors and inconsistencies in the basic rainfall and water level observations at gauging sites (e.g. for early historical data and very large events)
- uncertainty in the rating curves used to convert water level observations to flow estimates (particularly for large floods and for sites affected by tidal influences)
- errors introduced by the adjustment of flood data for the effects of changes in hydrologic and hydraulic catchment conditions (e.g. dams and changes to lower Brisbane River cross-sections)
- uncertainty in the choice of the correct model (distribution) for flood frequency analysis and in the estimation of its parameters
- uncertainty introduced by simplified representation of catchment characteristics in hydrologic models and estimation of model parameters

The confidence limits around the 'best estimates' obtained from flood frequency analysis give an indication of how some of these uncertainties affect the resulting design flood estimates, but they generally do not reflect all the uncertainty factors involved in the flood estimation process.

While the band of uncertainty around the 'best estimate' of a design flood may be so large that the decisions made using a lower bound estimate or an upper bound estimate would be substantially different, it should also be recognised that the adopted standards for floodplain management allow for some degree of uncertainty. In situations of unavoidable large uncertainty, consistency of approach in terms of current-best-practice may become the overriding consideration in determining the design basis.

3. The Brisbane River - particular issues for design flood estimation

3.1 Introduction

Chapter 2 set out to explain flood estimation techniques in general. For a specific catchment, it is important to choose techniques suitable for the task in hand, as well as to identify the features that will have a bearing on the flood response.

In the case of the Brisbane River, its large area is of considerable import. Its land-use has changed over the period of record. There are two very large water supply dams that are also operated so as to mitigate floods. In the lower reaches of the Brisbane River, the ocean levels affect flood levels. These aspects are each discussed further in respective sections below, followed by a discussion of the available data of relevance for a flood study.

3.2 Size of catchment

ARR99 defines any catchment that commands an area in excess of 1,000km^2 as being 'large'. The Brisbane River commands a catchment area of approximately 14,000km^2 and clearly sits within the large catchment category.

The variability of rainfall over the catchment is a key influence on floods in the Brisbane River. Differentials in excess of 1,000mm have been observed within the catchment for historical events. Similar gradients are also evident in design rainfall estimates by CRC FORGE estimates of design rainfalls.

Investigations by SKM (2003 (a)), for example, have found that spatial variability in rainfall distribution about the catchment alone can be responsible for variability in design discharges of the order of ±2,000m^3/s under 1% AEP design rainfall conditions. The problem is exacerbated when large dams exist on the catchment, and when rainfall may be centred above or below the dams

Variability of rainfall temporal pattern over the catchment is an added complication, but of lesser importance than spatial variability.

3.3 Catchment characteristics

Within any catchment, runoff response to rainfall is largely controlled by characteristics that fall into the following three general categories: Topography (draining system structure, catchment area, grades etc); Land classification (land use, soil type, vegetation etc); Waterway capacity (conveyance and storage).

These characteristics serve to dictate a catchment's response to rainfall, that is, the depth of rainfall that reports as runoff, the rate of runoff, and its duration of occurrence.

In many instances it is not necessary to explicitly account for key catchment characteristics in detail, as their influences can be adequately defined within a simplified scope of modelling parameters that are determined through a process of calibration against historical records.

Characteristics within the Brisbane River catchment have been continually changing, primarily as a result of progressive settlement and development. These changes will have had an effect on runoff characteristics (flood flow rates and levels), but one considered small in relation to the impact of the large dams, Wivenhoe and Somerset.

Investigations by both BCC and SKM have assumed that the only change in catchment characteristic of importance has been the construction of these dams. Under the circumstances this assumption is considered reasonable, given that most other key catchment characteristics can be considered to have largely remained unchanged over the years. It is noted that although development of the major regional centres of Brisbane and Ipswich Cities will have resulted in substantial change to local runoff characteristics, the overall impact on Brisbane River flooding is expected to be relatively small on account of the relatively small area of the overall catchment occupied. Catchment change has therefore been presented with respect to two scenarios: "No Dams"; and "With Dams".

3.4 Position and size of major storages

As noted previously, there are two major dams located within the catchment that provide both water supply and flood attenuation service:

- Wivenhoe Dam:
  - Completed: 1985
  - Water supply storage capacity: 1,150,000ML (approximately)
  - Regulated temporary flood storage capacity: 1,450,000ML (approximately)
  - Location: Brisbane River upstream from confluence with Bremer River
  - Catchment: approx. 7,000km^2

- Somerset Dam:
  - Completed: 1959
  - Water supply storage capacity: 370,000ML (approximately)
  - Regulated temporary flood storage capacity: 524,000ML (approximately)
  - Location: Stanley River upstream from confluence with Brisbane River

[information extracted from SKM 2003 (b)]

Clearly, the amount of flood storage is these dams is very significant relative to the design runoff volumes, so the correct simulation of these dams (and their operation during events) is of paramount importance.

3.5 Effect of tides and storm surge on flood levels

Brisbane River remains tidally affected up to around Colledge's Crossing, or approximately 86km upstream from its mouth in Moreton Bay. Mean High Water Spring Tide (MHWS) in the bay is at approximately 0.9mAHD. The potential for storm surge effect in the bay is relatively significant (BCC, Discrepancy in Predicted Flow Rate in Brisbane River, undated):

- MHWS 0.9mAHD
- January 1974 Storm Surge: 1.6mAHD
- May 1996 Storm Surge: 2.8mAHD

Sensitivity investigations undertaken by BCC to assess the likely effect of bay water levels on flood levels at Brisbane Port Office found the following:

- It appears the tidal and storm surge fluctuations can account for approximately a ±2m range in bay levels (ie –0.9mAHD to +2.8mAHD).
- The effects of tidal and/or storm surge influences in the bay diminish as discharges increase:
  - ±2m at zero flow;
  - ±0.8m at around 5,000 m^3/s;
  - ±0.5m at around 10,000 m^3/s (close to BCC estimate of January 1974 flow); and
  - nil (ie. completely drown out) at discharges greater than approximately 14,000 m^3/s.

The stage discharge curve was computed using the calibrated Mike11 Model developed in the 1998 and 2000 flood studies. It was compared with the Bureau of Meteorology data and found to be different. The Bureau of Meteorology discharge-stage information was derived to suit the Bureau of Meteorology flood forecasting model and has not yet been adequately verified.

Forensic investigations by BCC have also attempted to quantify the likely effect of historic dredging and excavation works about the entrance of the river. This work was undertaken to aid with their adjustment historic flood level estimates for an alternative FFA of flood data at river gauge stations to the downstream of Colledge's Crossing.:

- Removal of a bar at the mouth of Brisbane River in around 1864 is estimated to have resulted in lowering "large" flood levels at Port Office by approximately 0.4m;
- Dredging about the port in around 1917 is estimated to have resulted in lowering "small" floods by approximately 1.5m, with little effect on "large" floods. (According to the Bureau of Meteorology, this lowering should be only 0.6 m.)

3.6 Data available

A considerable amount of rainfall and stream flow data is available, and has been accessed in the conduct of the various investigations by BCC, SKM, BOM and DNRM.

Key data sources include:

- AEP 1 in 100 Rainfall Depths, Temporal and Spatial Patterns, Areal Reduction Factors for the Brisbane River Catchment CRC FORGE analysis undertaken by DNRM.
- Long-term daily rainfall totals from a significant number (around 130) of stations through the catchment.
- Daily stage height data and rating curves, utilised by SKM:
    - Brisbane River @ Savages Crossing (143001) – 72 years
    - Warrill Creek @ Amberley (143108) – 40 years
    - Lockyer Creek @ Lyons Bridge (143210) – 22 years
    - Lockyer Creek @ O'Reilly's Weir (143207) – 53 years
  - Daily stage height data and rating curves (calibration), utilised by BCC:
    - Brisbane River @ Brisbane Port Office – data from 1841
    - Brisbane River @ Moggill – data from 1893
    - Brisbane River @ Mt Crosby – data from 1864
    - Brisbane River @ Lowood – data from 1890
- Historic flood levels and estimated flow rates at Lowood, 1893 and 1825
- Peak annual flow series data for Savages Crossing (1890-2000) for assessed adjustments "No Dams" and "With Dams" scenarios.

It is also understood that relatively detailed waterway cross-sectional / bathymetry information is available for Brisbane River from around Moggill Gauge to the entrance.

4. Evaluation of recent studies

4.1 Introduction

Chapters 3 & 4 set out the current best-practice methodology for flood estimation, and the characteristics of the Brisbane River catchment that need special consideration. They thus provide the context for the review of the techniques adopted for, and the results from, the SKM 2003 study.

This chapter looks first at the flood frequency analysis of the flows at Savages crossing (Sect. 4.2), then at the results for the same location (pre-dams) obtained using the rainfall-based method (4.3), before comparing the two (4.4). It then considers the simulation of the catchment response to large storms with the Wivenhoe and Somerset Dams in place, as used to estimate the current Q100 for the Port Office (4.5). The conversion of this design flow to a design level is examined next (4.6). The chapter concludes with consideration of the uncertainty in the estimates (4.7), and a statement of the Panel's views on the recommended values of flood level at the Port Office (4.8).

4.2 Flood frequency analyses (pre-dam)

Among the several stream gauging stations located along the Brisbane River between Wivenhoe Dam and the Brisbane Port Office, the combined record from the gauges at Savages Crossing, Lowood and Vernor (from here on referred to as Savages Crossing) provides the longest record of high quality flood data, and has therefore been adopted by SKM as the key site for flood frequency analysis.

Four different flood data sets have been prepared for the Savages Crossing site and have been used for separate flood frequency analyses by SKM. Data Sets 1 to 3 relate to the pre-dam situation, while Data Set 4 attempts to represent the current situation with Somerset and Wivenhoe Dams providing a substantial degree of flood mitigation for the lower Brisbane River. The continuous record period represented by these data sets varies from 42 to 111 years, with the historical record period extended in some cases to include the large flood of January 1893, and in one case also the similarly large flood thought to have occurred in 1825.

For the *pre-dam* situation, the SKM draft report presents the results from a total of 12 different cases analysed to assess the sensitivity of the Q100 estimates to variations in the following factors:

- Inclusion or omission of January 1893 and 1825 historical floods
- Extension of recorded flood data set by inclusion of the following additional periods:
    - from 1890 to 1909 (extended by DNRM using IQQM model)
    - from 1959 to 1982 (with and without DNRM adjustment for impact of Somerset Dam)
    - from 1983 to 2000 (with DNRM adjustment for impact of Wivenhoe Dam)
- Inclusion or omission of information from regional flood frequency analysis
- Fitting of Generalised Pareto (GP) or Log-Pearson 3 (LP3) distribution

- Application of FLIKE or GetDat flood frequency analysis packages which use different parameter estimation methods

The Q100 estimates obtained from these 12 separate analyses varied from 6,700 m^3/s to 15,700 m^3/s, with the most plausible range given by SKM as 10,000 to 14,000 m^3/s. Based on the results of the two most plausible cases, SKM adopt the 'best estimate' of Q100 as 12,000 m^3/s.

The Panel considers the flood frequency analysis approach taken by SKM to be appropriate and agrees with the conclusion that the 'best estimate' of Q100 for the pre-dam case at Savages Crossing is approximately 12,000 m^3/s. While the 90% confidence limits around the best-case distributions are somewhat wider, the plausible range of uncertainty for the Q100 estimate is about 10,000 to 14,000 m^3/s.

Additional flood frequency analysis work was also undertaken by City Design for a range of sites between Savages Crossing and Brisbane Port Office. For each site, available information from various sources was combined to derive a most plausible rating curve for the full range of flood magnitudes of interest. While this work is not as rigorous in terms of the quality and consistency of the data used and the methods of frequency analysis applied, it nevertheless provides useful confirmation of the SKM estimates. City Design's 'best estimate' of Q100 at Savages Crossing for the pre-dam case is 10,800 m^3/s.

Based on these results, it is of interest to note that, in the absence of Somerset Dam, the January 1974 storm would have produced about a 70-year flood at Savages Crossing, while the January 1893 flood is estimated as having an ARI of 100 to 150 years.

4.3 Rainfall-based flood estimates (pre-dam)

To estimate the runoff generated by rain falling on the catchment, SKM used the RAFTS runoff routing model. They had calibrated this model satisfactorily during previous studies on the catchment of the Brisbane River, so that further calibration effort was considered unnecessary. The Panel were willing to accept the adequacy of the calibrated RAFTS model without specific review.

Design values of 10 mm initial loss and 1 mm/h continuing loss, distributed uniformly over the catchment, were used to estimate the Q100 event. The Panel considers these values acceptable for an extreme event on the Brisbane River catchment. (The assumption of zero losses would increase the Q100 estimate by about 15%).

As explained in Sect. 3.2, a particular challenge for design flood estimation on large catchments is the appropriate depth and variability of rainfall to use in the calculation. SKM adopted the recent CRC-FORGE work to get the average depth for each storm duration – with appropriate areal reduction factors (Sect. 3.6). The Panel endorse this.

The critical storm durations of 30 h at Savages Crossing and 72 h at Moggill/Port Office seem reasonable, and accord with other studies. Representative patterns in accordance with ARR (IEAust, 1998) were adopted. To assess sensitivity to temporal patterns, five patterns were applied to the catchment average CRC Forge rainfall 48 hour storm duration. The RAFTS model was used with nil losses. At Savages Crossing and at the Port Office, the ARR standard temporal pattern produced the smallest peak flows. The largest peak flows at these locations were produced by the 1974 historic temporal patterns, these being larger than the ARR peaks by 15% at Savages Crossing and by 10% at the Port Office.

Spatial distribution is a factor which can have a significant effect (especially for the post-dams case – Section 4.5). The Panel suggested using patterns from a number of large storms on the catchment, and SKM have done this for seven events. The result gives an approximate indication of the influence of spatial pattern on flood peaks of the 100 year ARI event (8000 to 11500 m^3/s, pre-dam case at Savages Crossing). The median value (of about 10000 m^3/s) is an appropriate vale for comparison with the flood frequency study (see next section).

4.4 Comparison of FFA and rainfall-based estimates (pre-dam)

The comparison of results from frequency analysis and rainfall-based estimates is a form of check undertaken to assess the degree of consistency in the results using different data sources, methods and assumptions. In the evaluation of the comparative results, allowance has to be made for the different degrees of reliability attached to the estimates from different approaches.

The most recent SKM studies produced the following Q100 estimates for the pre-dam situation at Savages Crossing:

Table 4.1 Summary of Q100 estimates at Savages Crossing (pre-dam conditions)

Method	**Q100 estimates [m^3/s]**		
	Best Estimate	**Plausible Range**	
		Lower Bound	**Upper Bound**
Flood Frequency Analysis	12,000	10,000	14,000
RAFTS Modelling	10,000	8,000	11,500

The comparison indicates that, while the plausible ranges of estimates from the two approaches overlap to some degree, the RAFTS modelling produces estimates that are significantly lower.

In the Panel's judgement, the flood frequency analysis estimates are based on relatively long streamflow records at a number of sites, and while there is considerable doubt on the reliability of large floods at individual sites, there is sufficient confirming information from flood observations at other sites to lend credence to the adopted Q100 estimate.

For the rainfall-based estimates, the design rainfall depths used to define design storms for the catchment are also based on the analysis of a large database of long-term rainfall records from many stations within and around the catchment. However, the RAFTS model converting these design rainfalls to design storms requires many assumptions regarding model parameters and secondary design inputs, such as spatial/temporal patterns of design rainfall and losses, and their variation with storm magnitude. The uncertainty involved in these assumptions may introduce bias into the estimation of the 100-year flood from a 100-year storm rainfall depth.

The Panel therefore considers that the pre-dam Q100 estimate at Savages Crossing from RAFTS modelling estimate may be low by 10 to 20%. It would be desirable to assess, if the tendency for underestimation of peak flows also affects the estimate of flood volumes associated with Q100 in a similar fashion, as the post-dam flood peaks at Brisbane are largely determined by the inflow volumes to the dams. However, at this stage the information available does not allow this to be confirmed.

The expected tendency for underestimation in the rainfall-based approach should be taken into account when the RAFTS model is used to estimate design floods for the lower Brisbane River catchment under post-dam conditions.

4.5 Calculation of the post-dam flood discharges

Both the Somerset and Wivenhoe storages are capable of significantly modifying flood flows from their commanded catchments. The amount of flood attenuation that can be achieved by the structures is dependent upon a range of conditions, including:

- The antecedent storage inventory
- The volume and duration of the flood inflow hydrograph
- The rate of controlled discharge from the storage.

Under flood conditions both storages are operated in accordance with predefined rules controlling discharge to the downstream waterway. It is understood that these rules have been established with the objective of mitigating the potential impact of flooding on downstream communities and infrastructure. These rules are relatively complex and are not amenable to simplification.

In consideration of the significant impact that Wivenhoe and Somerset Dams can potentially have on the timing and magnitude of downstream flood flows it is necessary that proper account be taken of dam operation in any hydrological assessment. To this end, DNRM have established a hydrological model of the Brisbane River catchment for the purpose of simulating the expected performance of dam operation. It is understood that the model functions on a continuous simulation basis and utilised historical time series rainfall data to simulate an associated time series of waterway and dam flows. Although DNRM have made available the outputs from this model, no other details have been documented. This being the case, the Panel cannot comment on the efficacy of the model.

Review of historical dam routing results from the DNRM model for the period 1890 to 2000 has indicated that it should be possible to operate the dams to reduce peak flood flow rates by about 60% on average. It is interesting to note that the model indicates a January 1974 flood attenuation of nearly 50%, with a peak inflow rate of 10,500m^3/s and outflow rate of 5,500m^3/s.

Flood frequency analysis by SKM of the DNRM dam routing time series showed that standard frequency distributions, such as the *Generalised Pareto* and *Log Pearson*

Type III, do not fit the data well. It is expected that this occurrence is largely due to the highly modified and non-linear nature of the flood hydrograph transformation by the dams. The Panel therefore considers the Q100 estimate from this analysis to be unreliable and not suitable as a basis for checking the results of hydrologic modelling for the post-dam case.

Hydrological modelling of the catchment has also been undertaken by SKM. This work has used the RAFTS program to undertake the basic rainfall-runoff-routing process, and a program from DNRM to simulate the routing of flow hydrographs (generated using RAFTS in this instance) through the Somerset and Wivenhoe storages under post-dam scenario conditions. SKM used the models to generate design flood flow rates from synthetically generated design storm events – in this case 1 in 100 AEP design CRC FORGE rainfall events.

The SKM application of the RAFTS hydrological model was used to both make estimates of:

- Design Q100 flow rates at Savages Crossing under both pre- and post-dam conditions
- Typical variability in Q100 flow rates that might reasonably be attributed to differences in the spatial distribution of rainfall across the catchment during the course of the driving storm event.

As noted above, SKM used the CRC FORGE method to establish the design 1 in 100 AEP storm event - comprising total rainfall depth, temporal and spatial rainfall distributions, and associated areal reduction factors. Typical "real event" spatial distributions for rainfall were also extracted from 7 historical storms events of significance. No specific criterion was applied to the selection of events, other than that the data was readily available for utilisation within the relatively limited time constraints afforded by the scope of current investigations.

It is noted that CRC FORGE rainfall was applied to the 7 historical spatial distributions, and not the actual rainfall associated with the event. This approach satisfied the investigation objective that was to sample the typical variability in runoff flow rates as might be produced by different spatial distributions of rainfall under both pre- and post-dams development scenarios.

Outcomes of SKM investigations are summarised in the following tabulation. In reviewing this information it should be noted that the base estimate is derived from RAFTS modelling using the CRC FORGE rainfall spatial distribution (eg 9,600 m^3/s at Savages Crossing for the pre-dams case). An indication of plausible range was obtained from calculation of the difference between the median valuation of the seven historical spatial distributions, and the second highest and second lowest bounding values (ie values at rank positions 2 and 6, with the median being at rank position 4). These ranges were then superimposed upon the RAFTS based estimates to give the plausible ranges listed in Table 4.2.

Table 4.2 RAFTS based Pre- and Post-Dam Q100 flow estimates (m^3/s) with indication of plausible range of variability

Location	Pre-Dams			Post-Dams			Reduction (%)
	RAFTS Q100	Plausible Bound		RAFTS Q100	Plausible Bound		
		Lower	Upper		Lower	Upper	
Savages Crossing	9,600	8,100	10,800	5,400	3,900	6,600	40
Moggill	10,100	9,500	10,800	5,000	4,200	6,000	50
Port Office	10,100	9,500	10,800	5,000	4,200	6,000	50

Review of the above outcomes indicates:

- The pre-dams best estimate of peak discharge at Savages Crossing (9,600 m^3/s) is 20% lower than that derived by SKM using FFA (see Section 4.2). This being the case it is probable that the estimate of post-dams peak discharge is also low.
- The variability indicated by analysis of historical spatial rainfall distributions appears to be generally consistent with that concluded by SKM on the basis of FFA work. This may be taken to indicate that the noted variance is probably physically realistic.
- Variability in post-dam flow estimates is significant, being of the order of 40% of the design base discharge value.
- The attenuated peak flood flow rate factors are generally consistent with that reflected in the source DNRM data.
- There appears to be little attenuation of flood flow rates between Moggill and Port Office. This characteristic is totally consistent with independent observations as reported by BCC.
- Savages Crossing peak discharges are of the same order as those further downstream.

The issue of variance between FFA and RAFTS model results has not yet been fully addressed by SKM. Nevertheless, SKM have investigated the sensitivity of estimated Q100 flow rates to assumed loss rates. The key outcome of this sensitivity appraisal was that the noted variance could not be fully explained by the influence of assumed rainfall losses. The cause for this variance warrants further investigation.

SKM also undertook investigations to assess the effect of antecedent dam storage inventory levels on the attenuation of flood flow rate. Analyses using antecedent inventories of 50% and 75% full supply volume indicated significant impact. However, prior analysis by BCC of the likelihood of the occurrence of antecedent drawdown was small, and that a FSL assumption is justified.

As a check on design flows, SKM used the RAFTS model to simulate the 1893 and 1974 historical flood events with both dams in place and with dam operating procedures applied. The peak flow calculated at the Port Office for the 1974 flood event was 6800 m^3/s. It is difficult to relate this result with those obtained from systematic study of 1 in 100 AEP rainfall events discussed above.

The Panel considers that flow estimates based on flood frequency analyses (Section 4.2) presents a fair assessment of *Best Estimates* under pre-dam conditions (ie Q100 of 12,000m^3/s with a plausible range between 10,000m^3/s and 14,000m^3/s). As noted above, RAFTS flow estimates are considered low, around 20% under pre-dam conditions. Under post-dam conditions the Panel would expect Q100 flows downstream of Wivenhoe dam to be of the order of 50% of those under pre-dam (as found by RAFTS, Table 4.3) – that is, 50% of 12,000m^3/s, or 6,000m^3/s.

In consideration of the above, the Panel considers that Q100 flow values presented in Table 4.3 below presents a fair and reasonable assessment of Q100 flow rates for design purposes – *on the basis of information currently made available to the Panel.*

Table 4.3 Panel Recommended Pre- and Post-Dam Q100 flow estimates (m^3/s) with indication of plausible range of variability

Location	Pre-Dams			Post-Dams		
	Q100	Plausible Bound		Q100	Plausible Bound	
		Lower	Upper		Lower	Upper
Savages Crossing	12,000	10,000	14,000	6,000	4,000	8,000
Moggill	12,000	11,000	13,000	6,000	5,000	7,000
Port Office	12,000	11,000	13,000	6,000	5,000	7,000

4.6 Estimation of design flood levels

Flood levels along the Brisbane River were calculated with the MIKE11 hydraulic model. The model extends upstream from the Brisbane bar to approximately 15km downstream from Savages Crossing. The inflow hydrograph at the upstream end was provided from a RAFTS hydrological model that has its output approximately 2 km upstream from the end of the MIKE11 model. The DNRM dam operations have been applied in producing this hydrograph and it includes Lockyer Creek flows. Downstream from this point, there are approximately 150 inflow locations in the MIKE11 model. At the downstream end the water level was set at MHWS (0.92 m AHD) and held constant throughout the entire flood simulation.

The MIKE11 hydraulic model that was developed for the Ipswich Rivers Flood Studies was used to calculate design flood levels in the Brisbane River. The Panel has not examined the calibration of the model. SKM reports that the calibration at the Port Office and at Moggill is considered good but that calibration has not been done at other locations along the Brisbane River within Brisbane City. Consequently, flood levels estimated for locations other than at the Port Office and at Moggill must be treated with care. It is noted also that the need to extrapolate the rating curves causes some uncertainty in the calibration of the hydraulic model, because of the uncertainty that attaches to the estimates of the flows of large floods used in calibration.

The hydraulic model was run with input flows calculated from CRC Forge rainfall estimates, spatially distributed with areal reduction factors, for the 1% AEP design rainfall, for seven durations. The critical duration was 72 hours and, for this case, the peak flow calculated at the Port Office is 5060 m^3/s and the peak flood level is 2.68 m AHD.

The peak flow at the Port Office calculated with the hydraulic model is similar to that calculated with the RAFTS model (5,000 m^3/s, Section 4.5). However, the Panel considers that the values of Q100 estimated from RAFTS modelling may be low by 10 to 20% (see Sections 4.4, 4.5) and it has formed the opinion that the current best estimate for the Q100 flow at the Port Office is 6,000 m^3/s, as explained in section 4.8. It follows that the flood level, 2.68 m AHD, may be low and it would be desirable to calculate the flood level corresponding to a peak flow of 6,000 m^3/s. From simple interpolation in an approximate rating based on the MIKE11 results in the 2003 SKM study, the flood level for this flow is estimated at 3.3 m AHD.

The use of a constant water level at MHWS at the downstream end of the hydraulic model is consistent with what was adopted for the original Brisbane River Study. This may appear to result in slightly high estimates of flood levels in the tidally affected reaches of the river. However, the flood hydrograph is of long duration and the flow in the tidal reaches will be very close to the peak for a time interval similar to or greater than the interval between low tide and high tide. Therefore, the use of a constant water level at MHWS may not be conservative. It is known also that storm surges are often associated with the severe large weather patterns that produce large flood events. The Panel considers that a Monte Carlo analysis to examine the joint probabilities of flow rates and tide levels, including influences of storm surges, is required to resolve this issue.

4.7 Sources of remaining uncertainty

Rating curve extrapolation

At all of the flow gauging stations the maximum gauged flow is substantially smaller than the maximum estimated flow. For example, at Savages the maximum gauged flow is of order 30 - 45% of the estimated 1974 peak flow (SKM, 2003 (b)). Extrapolation of the rating curve to such an extent is a source of considerable uncertainty in the estimates of the larger flows that influence the FFA in the range of the Q100.

The need to extrapolate the rating curves also causes uncertainty in the calibration of the hydraulic model, because of the uncertainty that attaches to the estimates of the flows of large floods used in the calibration.

Unfortunately, little can be done to reduce these uncertainties until gaugings can be obtained during larger flood events.

Spatial and temporal pattern variability

The results obtained with seven historical spatial distributions of rainfall in the hydrological modelling show that the estimate of Q100 is substantially affected by the spatial distribution used. At Savages, the pre-dams estimates of Q100 ranged from 11507 to 8005 m^3/s and the post-dams estimates ranged from 7847 to 5279 m^3/s (SKM, 2003 (a)).

The results from a limited assessment of the effects of different temporal patterns for the pre-dam case showed variations in peak flows of 15% at Savages Crossing and of 10% at the Port Office.

Larger estimates of Q100 may result from spatial and temporal patterns of rainfall other than those modelled. This question could be resolved by a full Monte Carlo analysis.

Correlation of losses with storm occurrence

In the hydrological modelling the initial loss was set at 10mm and the continuing loss at 1.0mm/hr (SKM, 2003 (a)). These losses are within the ranges that are considered reasonable for eastern Queensland. It has been stated that 'A Q100 event … generally occurs in a season of wet winters and high rainfall summers' (BCC, 1999). This has provided the basis for the use of relatively low losses in the hydrological modelling. Nevertheless, this has not been examined rigorously. Further, it is uncertain whether pre-event wetting of the catchment prior to large storm events may result in even smaller losses and larger peak flows.

These issues would be clarified by a correlation analysis of pre-event catchment soil moisture levels with storm occurrences.

Correlation of pre-event dam levels with storm occurrence

The set of post-dams estimates of flows downstream from Wivenhoe dam were calculated with the assumption that the dam was at FSL, RL 67.0 m AHD, in all cases. Sensitivity tests showed that the estimated peak flow at the Port Office Gauge is reduced by about 13% if Wivenhoe dam is 75% full with SWL at RL 64.0 m AHD at the start of the flood event (SKM, 2003 (a)). Data sets are available that would enable a correlation analysis to establish the most likely pre-event dam level.

Calibration of hydraulic model

The MIKE11 hydraulic model that was developed for the Ipswich Rivers Flood Studies was used to calculate design flood levels in the Brisbane River. The model calibration at the Port Office and at Moggill is considered good but it has not been calibrated at other locations along the Brisbane River within Brisbane City. The model should be calibrated throughout the length of the river within Brisbane City to provide good estimates of flood levels throughout.

4.8 Best estimates of the 100 year ARI at the Port Office

As noted in previous section, the spatial distribution of the design storm used to calculate the Q100 is critical. For this reason, the Panel requested SKM to calculate Q100 estimates using the spatial distributions from seven historical large storms. The range of Q100 for the Port Office was 3400 to 7121 m^3/s. The Panel considers this to be an extreme range, it is unlikely to be a fair indication of the likely uncertainty of the Q100 flood flow.

If the outermost two are 'dropped', the range reduces to 5000 to 6800 m^3/s, with the median being 5900 m^3/s (SKM, 2003(a), Table 7). After rounding these values in recognition of their approximate nature, the Panel regard 6000 m^3/s as the best current estimate of the Q100 flow-rate, with 5000 m^3/s being the lower estimate of Q100, and 7000 m^3/s being the upper. [As noted in the Conclusion, further work is needed to refine the position of this estimate in the range, and to reduce the size of the range itself]

The Q100 level calculated at the Port Office with the hydraulic model is 2.68 m AHD. However, the flow associated with this level is 5060 m^3/s, while the Panel regard 6000 m^3/s as the best current estimate of the Q100 flow. The best estimate of the Q100 level corresponding to this flow is 3.3 m AHD, with 2.8 and 3.8 m AHD being the levels corresponding to the lower and upper estimates of flow.

5. Conclusion

5.1 Panel findings

The estimation of Q100 for a catchment of this size (13570 sq. km) is a challenging task. The extreme variability of rainfall, the change in catchment response due to the construction of dams, and the variable conditions in the tidal section of the river, are some of the factors which complicate the application of 'standard' flood methodologies. The advent of new techniques for flood frequency analysis and for extreme rainfall estimates, together with much improved hydraulic routing methods for estuaries, has added much to the technologies now available for flood estimation. The Panel notes that the further studies done by SKM, in conjunction with City Design, took advantage of these new techniques.

With respect to its Terms of Reference, the Panel:

(i) have reviewed the methodology used by SKM to determine the Q100 river flow and level;

(ii) believe that the appropriate technical processes have been followed in this study;

(iii) based on the evidence available, is of the view that, for the Brisbane Port Office, the best current estimates for
  - the Q100 flow is 6000 m^3/s
  - the Q100 level is 3.3 m AHD

There is an inevitable degree of uncertainty in any estimates of this kind. The Panel believes the possible range for flow to be 5000 to 7000 m^3/s; for level to be 2.8 to 3.8 m AHD.

The Panel notes that the current 'best estimates' of Q100 and of the corresponding flood level at the Port Office, provide a sufficient basis for a decision on whether the currently adopted flood levels are broadly acceptable. However, for general flood risk assessments and risk-based flood management decisions, more refined flood frequency estimates will ultimately be required.

5.2 Recommendations for Further Work

a) The SKM 2003 study has demonstrated the very significant effect of assumed storm variability on the estimated post-dams flows at the Port Office. The Panel believes that this variability could be reduced if a similar study was conducted, but using Monte Carlo methodology to simulate the possible combinations of storm temporal and spatial patterns (instead of seven observed storms). Such a study could also properly estimate and account for the correlations between event occurrence, losses and reservoir drawdown (instead of using fixed average values). The Panel strongly recommends that such a study be done as Council moves towards a risk-based approach to flood management.

b) More confidence would be engendered in the results if there was a better match between the flood frequency analysis of observed data and the estimates obtained from the rainfall-based RAFTS model. The current variance of around 20% is not desirable. Given the importance of runoff volume in a situation involving large dams, the Panel recommend that:

(i) Calibration of the RAFTS model be re-visited with the view to reducing the variance with FFA outcomes to within acceptable bounds.
(ii) Frequency analysis of event volumes be carried out, and compared with runoff volumes predicted by the RAFTS model from design rainfalls of corresponding frequency.

c) The MIKE11 model of the Brisbane River should be calibrated throughout the length of the river within Brisbane City to provide good estimates of flood levels throughout.

d) Consideration should be given to including the effect of tidal variation on flood levels in the estuarine zone. This would involve a Monte Carlo type analysis to examine the joint probabilities of flow-rates and tide height.

e) The DNRM model for simulating the expected operation and effect of Wivenhoe and Somerset Dams on flood flows, and associated data, should be independently reviewed when the DNRM final report is made available.

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6. References

BCC (1999) Report, Further Investigations for the Brisbane River Flood Study (Draft), December 1999.

IEAust (1999) Australian Rainfall and Runoff – A Guide to Flood Estimation, (Reprinted Edition), Institution of Engineers, Australia, Barton ACT.

Kuczera, G. (1999) Comprehensive at-site flood frequency analysis using Monte Carlo Bayesian inference, Water Resources Research, 35(5), 1551-1558.

SKM (2003(a)) Report, Further Investigations of Hydrology & Hydraulics Incorporating Dam Operations and CRC Forge Rainfall Estimated (Draft), 28 August 2003.

SKM (2003(b)) Report, Flood Frequency Analysis of Brisbane River (Draft), 8 August 2003.

Appendix – Terms of Reference and Chronology of Events
(Documents from Brisbane City Council)

TERMS OF REFERENCE

for

Brisbane River Flood Study

Independent Expert Review Panel

Background

A chronology of events to date has been included at the end of this document. It outlines the work undertaken so far to determine the Q100 Brisbane River flood level. The Brisbane City Plan 2000 uses the Q100 as the key input in the determination of development control levels adjacent to the river. The Q100 currently used is based on a study that was completed about the same time as Wivenhoe Dam was constructed. This 1984 figure of 6,800 m^3/s has been used as the basis for setting development control levels for nearly twenty years.

Council commenced extensive work into hydrologic and hydraulic aspects of the catchment after the 1993 DNR study indicated that the Q100 flow at the Brisbane Port Office may be as high as 9,380 m^3/s. The 1998 study undertaken for Council by SKM recommended a Q100 of 9,560 m^3/s. In June and December 1999 BCC's City Design produced draft reports that recommended Q100's of 8,600 m^3/s and 8,000 m^3/s respectively.

Preliminary results from the 2003 DNRM study on flows in the Brisbane River indicate a Q100 of 6,000-7,000 m^3/s at the Brisbane Port Office. BCC is undertaking further work to assess the results of the various methods.

BCC and SKM are now using updated information (including the DNRM results) to review the flood frequency analysis and determine the revised Q100 flood level at the Brisbane Port Office.

Even if the Q100 changes from 6,800 m^3/s, it is likely that the Development Control Level will remain the same as is currently used in the Brisbane City Plan.

Role

The role of this expert panel is to determine whether the August 2003 estimates of Q100 flow and level at the Brisbane Port Office are reasonable.

Objectives

1. Review the methodology that has been used to calculate estimates of Q100 river flow (1998 – 2003)
2. Ensure that the appropriate technical process has been followed for the 2003 Q100 river flow / level at the Brisbane Port Office.
3. If required, provide specific recommendations on further work be undertaken
4. Assess the suitability of the 2003 Q100 river flow / level for design purposes..

Outcome sought

It is expected that the expert panel will produce a report providing opinions, recommendations and advice on the technical process followed and the estimated Q100 river flow / level at the Brisbane Port Office

Membership of Panel

- Professor **Russell Mein** (Chair) – Experience: Former CEO of CRC for Catchment Hydrology and former Chairman of ARR Advisory Panel
- Professor **Colin Apelt** – Experience: Former Head of the Department of Civil Engineering, University of Queensland
- Dr **John Macintosh** – Experience: Chairman Engineers Australia National Committee on Water Engineering, and Director / Principal Water Engineer with consultants Water Solutions Pty Ltd
- **Erwin Weinmann** – Experience: Deputy Director CRC for Catchment Hydrology (Monash Node), Senior Lecturer in water subjects at Monash University and Co-author of Book VI (Estimation of Large and Extreme Floods)

Responsibilities of Members

- To read briefing materials provided prior to meetings.
- To attend and participate in meetings of the expert panel.
- To assess and report on the methodology and process used to determine the Q100 flow / level at the Brisbane Port Office.

Timing

It is initially anticipated that there will be two meetings of the expert panel:

- Thursday 31 July – to review the work done to date and agree on the process to finalise the Q100.
- Mid August – to consider the findings of the Q100 investigation and to critically assess the Q100 determined at the Brisbane Port Office

The objective is to deliver a brief report to the Manager Water Resources outlining the findings by 25 August 2003.

Brisbane River Flood Study
Chronology of Events

1984 Reports for Brisbane City Council and Water Resources Commission. Q100 river flow set at 6,800 m^3/s (or cubic metres per second). This flow was used as the basis for flood levels for development control level.

1993 DNR study undertaken for the (now) South East Queensland Water Corporation to examine operating rules for the dam. The study determined that Q100 flow was 9,380 m^3/s. The report recommended that further work be undertaken to determine areal reduction factors. DNR consider this flow volume was seen as an overestimation as it was not specifically produced for the Q100 event in Brisbane. This prompted Council to re-examine flood levels in the river and led to commissioning the SKM report, which commenced in November1996.

1998 Model developed and draft SKM report received by Council, proposing Q100 flow of 9,560 m^3/s.

1998 Report and results reviewed by Council officers who determined that this flow was based on assumptions that equated to a lower probability of flooding than the Q100. This resulted in Council commissioning Professor Russell Mein, eminent hydrologist, to undertake an independent review of the work to date.

1998 December, received Professor Mein's review of the draft SKM report. This review stated;

> The overall approach for the hydrologic component of the study ... is appropriate. However ... conservative assumptions in key input variables point to the likelihood

that the magnitude of the Q100 obtained in this Study is an over-estimate." Professor Mein made six recommendations for work needed to address the issues of concern.

1999 June, draft review by City Design. Note that this revised downwards the Q100 flow to 8,600 m3/s as a result of the additional analysis–a reduction of 10% on the SKM report (This draft report did not fully address Professor Mein's review recommendations). This is the report referred to by the Courier Mail in its stories on flooding which appeared in the newspaper from 24 June 2003 to 5 July 2003.

1999 December, review by City Design. This draft report entitled "Further Investigations for the Brisbane River Flood Study" was to fully incorporate Professor Mein's recommendations and revised the Q100 flood discharge down again to 8,000 m^3/s as the analysis was refined. It should be noted that this report again did not fully address Professor Mein's peer review analysis.

2000 January to September, review of all these reports, discussions with external stakeholders, including South East Queensland Water Corporation, Department of Natural Resources, Bureau of Meteorology. Council continued to review the draft June and December reports as the peer review recommendations had not been fully addressed.

2000 October, Brisbane River Flood Study Technical Workshop held. Purpose – to ensure that the definitive flood study report would be technically rigorous and adopt an approach / methodology that is consistent with the current practices, using the latest available information. Participants included Professor Mein, BCC Waterways and City Design, Department of Natural Resources, Bureau of Meteorology, South East Queensland Water Corporation, Institution of Engineers National Committee on Water Engineering and Ipswich City Council.

Action plan arising from October workshop identifies FORGE Study being undertaken by DNR for SEQ Water Corporation. At this time, the continuous simulation study was due to be finalised by December 2000 and was consistent with Professor Mein's comments, as well as the current approach by the CRC for Catchment Hydrology.

Preliminary results showed the DNR Q100 level as closer to the BCC 1984 study than the 1992 DNR study, which reinforced our position on the over-estimation of the Q100 flood flows. The workshop concluded that the FORGE work being done would need to be taken into account. In addition, the workshop suggested that we take into account the areal reduction factors, which it was estimated may produce a 20% reduction in total rainfall at the Brisbane Port Office gauge.

Since 2000 Council has been in contact with DNRM every few months to check on the progress of the report. Officers of DNRM have consistently reassured us as to the probability of the Q100 flow figure being close to, or at the level of the 1984 Q100 figure.

Council has been taking other actions as well, for example, raising community awareness of flooding issues with tools such:

- Council's flood information system which predicts flood levels in the river during major flood events,
- Upgraded system which will automate and improve the accuracy of Q100 on individual properties,
- Fact sheets and articles in publications and information on Council's website.

On Friday 27 June 2003 BCC received preliminary advice from DNRM that the Q100 flood flows at the Brisbane Port Office would be between 6,000 and 7,000 m^3/s. This affirmed that the preliminary estimate from early reports was likely to be an over-estimate. This is consistent with their advice from the October 2000 workshop and from contacts with DNRM since then.

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City Design - Flood Modelling Services

RECALIBRATION OF THE MIKE11 HYDRAULIC MODEL AND DETERMINATION OF THE 1 IN 100 AEP FLOOD LEVELS

- Final Report
- 05/02/2004

- Final Report
- 05/02/04

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Executive Summary

In June 1998 SKM developed a MIKE11 hydraulic model as part of the Brisbane River Flood Study for Brisbane City Council. This model was then used as a base model for the model developed for the Ipswich Rivers Flood Studies (SKM 2000). During the Ipswich Study, many additional rivers and creeks were added to the hydraulic model.

These additional rivers/creeks changed the Brisbane River routing characteristics, consequently the model needed to be re-calibrated. Re-calibration was only performed within the Ipswich City Council boundary.

Further work was therefore required to re-calibrate the hydraulic model within the Brisbane City boundary. The purpose of this report is to present the findings of the re-calibration of the Brisbane River model.

The 1974 and 1955 flood events were used to calibrate the hydraulic model. These events were chosen because they provide an adequate calibration envelope so that the 1 in 100 year design event can be accurately modelled.

Calibration was generally achieved to within the general specification tolerances.

A design 1 in 100 AEP event was run based on a flow of 6000 m^3/s at the Brisbane Port Office Gauge. This corresponds to the 'best guess' report by the expert panel (IRP 2003).

1. Introduction

The purpose of this report is to present the findings of the re-calibration of the Brisbane River Hydraulic Model. This model was calibrated using the 1974 and 1955 flood events.

The Calibration process involved

- Updating and re-running the 1955 RAFTS Model
- Re-calibrating the 1955 RAFTS Model (loss rates only)
- Extraction of hydrographs from the 1955 RAFTS model and input into MIKE11
- Extraction of hydrographs from the 1974 RAFTS model and input into MIKE11
- Adjusting roughness values in the 1974 and 1955 MIKE11 model. Iterating until the best match between predicted water levels and recorded water levels was achieved.

The 1974 and 1955 events were chosen because there is reliable historical flood level data for flood events. The flows for these events in the subject reach of the river are approximately 10 000 m^3/s (1974) and 4400 m^3/s (1955). This provides an envelope in which the design event can be accurately predicted. A design 1 in 100 AEP event was run based on a flow of 6000 m^3/s at the Brisbane Port Office Gauge. This corresponds to the ‘best guess’ report by the expert panel (IRP 2003).

2. Hydrology

2.1 General

A RAFTS hydrologic model was developed as part of the Brisbane River Flood Study (SKM 1998). This study required that hydrologic model calibration/verification be undertaken for a total of 8 historical flood events. These events are presented in **Table 1**.

- **Table 1 Brisbane River Flood Study Calibration/Verification Events**

Calibration Events	Verification Events
January 1974	February 1931
June 1983	March 1955
Late April 1989	July 1973
May 1996	Early April 1989

In June 2000, the Ipswich Rivers Flood Studies (SKM 2000) was completed. All rivers within the study area fell within the Brisbane River Catchment and thus the Brisbane River RAFTS model was used as a basis of the Studies. Sub-catchment areas were refined in order to better represent the river network within the study area and therefore model re-calibration had to be undertaken. The re-calibration was performed on 4 events for the Ipswich Rivers Flood Studies. These calibration events are presented in **Table 2**.

- **Table 2 Ipswich River Flood Studies Calibration Events**

Calibration Events
January 1974
June 1983
Late April 1989
May 1996

Verification events were not re-run for the Ipswich River Flood Studies.

For this investigation, it was considered that the 1974 and 1955 historical flood events would provide the best calibration range for the 1 in 100 AEP flood event. It was therefore necessary to rerun the 1974 and 1955 historical flood events and extract the hydrographs for use in the MIKE11 hydraulic model.

2.2 1974 Historical Flood Event

The 1974 event was originally modelled using RAFTS as part of the Brisbane River Flood Study (SKM 1998). As part of the Ipswich Rivers Flood Studies (SKM 2000) the Brisbane River RAFTS model was updated and re-calibrated. Re-calibration of the 1974 hydrologic model was not required. A comparison of the RAFTS predicted hydrographs and recorded hydrographs for the 1974 flood event have been provided in Appendix A. These hydrographs have been directly taken from the Ipswich Rivers Flood Studies Report (SKM 2000).

2.3 1955 Historical Flood Event

The 1995 event was not re-run as part of the Ipswich Rivers Flood Studies and subsequently the 1955 had to be run through the updated Brisbane River RAFTS model. As a result, loss rates reported in the Brisbane River Flood Study Report (SKM 1998) were adjusted to provide a better calibration. **Table 3** presents the adopted loss rates.

- **Table 3 Rainfall Losses March 1955 calibration**

Catchment Location	New Model Initial Loss	New Model Continuing Loss	Old Model Initial Loss	Old Model Continuing Loss
Brisbane	100	2.5	100	2.5
Bremer	50	1.5	50	1.5
Lockyer	90	1.8	85	2.5
Somerset	130	2.5	130	2.5
Wivenhoe	60	2.0	20	1.8

A comparison of the RAFTS predicted hydrographs and recorded hydrographs for the 1955 flood event have been provided in **Appendix A**. The magnitude of the discharge was matched for the key locations. Generally a good match was achieved however the timing of the peak discharge predicted by the RAFTS model for the Vernor gauging station was earlier than that of the recorded hydrograph. One possible explanation for the delay in the recorded hydrograph at Vernor Gauge is the storage of runoff by Somerset Dam. Although the dam was not completed, some storage was available. This storage could have resulted in delaying flows from the upstream portion of the catchment. This explanation would seem reasonable as the remainder of the hydrographs provide good agreement with timing.

The only catchment parameters adjusted for the 1955 event were loss rates. Various loss regimes were trialed in order to match the timing of the hydrograph at Vernor Gauge. The adopted loss regime presented in **Table 3** provides the best overall match.

3. Hydraulic Model Calibration

3.1 General

The hydraulic model MIKE developed for the Brisbane River Flood Study (SKM 1998) was used as a base model for the model developed for the Ipswich Rivers Flood Studies (SKM 2000). During the Ipswich Study, many additional rivers and creeks were added to the hydraulic model.

These additional rivers/creeks changed the Brisbane River routing characteristics, consequently the model needed to be re-calibrated. Re-calibration was only performed within the Ipswich City Council boundary, and therefore further work was required to re-calibrate the hydraulic model within the Brisbane City boundary.

Generally, the upper reach of the Brisbane River from MIKE11 model chainage BNE 964km to BNE 990 km consists of mainly open grassed and treed floodplains with severe meanders at various locations. Rural properties are located at various levels along this reach.

The reach of the Brisbane river from MIKE11 model chainage BNE 990 km to BNE 1040 km consists of mainly open grassed and treed floodplains with severe meanders at various locations. Residential properties are located at various intervals and levels along this reach. These residential properties could be described as low density areas.

From chainage BNE 1040 km to BNE 1070 km the reach could be described as medium to high density residential areas which include the inner city area. The general shape of the river could be described as severely meandering.

The lower reach of the Brisbane River from BNE 1070 km to BNE 10788.66 km is relatively uniform with no major bends. Industry and residential properties line the banks along with mangrove swamps close to the river outlet.

The hydraulic model used for this assessment extends outside the Brisbane City Boundary however for completeness all results have been provided. Chainage 967.41 kms and downstream fall within the Brisbane City Boundary.

Model calibration involves the selection of appropriate model schematisatisation and model parameters in order to match simulated and recorded water levels and discharges. This involves an iterative process and the careful selection of roughness parameters which reflect channel and floodplain conditions and an accurate description of flow movement.

3.2 Channel Roughness

Channel roughness values (Mannings ‘n’) selected were initially based on site visits, examination of aerial photographs and past experience from other flood studies. In order to achieve a reasonable match between recorded and predicted flood levels, roughness values were modified in some locations to better reflect the hydraulic behaviour of the flood.

The model has been re-calibrated against the 1974 and 1955 flood events. This was achieved by matching the water levels predicted by the MIKE11 hydraulic model with actual recorded data by altering the channel roughness values in the MIKE11 model.

The hydraulic model was first calibrated for the 1974 event. The same roughness values were then used for the 1955 event. The figure in **Appendix C** compares the roughness parameters used in the previous model and that of the new model.

Generally, acceptable calibration is considered to be achieved when predicted levels are within general calibration tolerances of 150 mm of maximum height records. 100 mm of continuous flood level records and 200 mm of other sources of flood levels.

3.3 January 1974 Flood Event

The January 1974 flood event was the largest flood event that has occurred in the Brisbane River System in recent times. This event was considered to be the primary calibration event because a large amount of recorded flood level information was available.

At the time of this flood Wivenhoe dam had not been constructed and this enabled good calibration of the discharge hydrographs to be achieved. The Merivale Bridge was not constructed until 1975 and therefore not modelled for the 1974 calibration.

3.4 March 1955 Flood Event

The 1955 flood event commenced on the 26 March 1955 and was the third largest recorded flood event last century. The event continued over a period of three days. Although Somerset Dam was not fully completed for the 1955 its storage had been constructed. At the time of the flood, the only structures on the Brisbane River downstream of Mt Crosby weir were Indooroopilly Bridge, William Jolly Bridge, Victoria Bridge and the Story Bridge.

The adopted tailwater level at the Western Inner Bar for this event was 1.3 m AHD which is consistent with the tailwater adopted for the Brisbane River Flood Study (SKM 1998).

4. Results

For gauging stations with continuous records it was possible to compare the recorded hydrograph with hydrographs predicted by the model. For the 1974 event, predicted and recorded hydrographs generally good agreement (Refer **Appendix B**).

For the 1955 event, the peak water levels for the predicted hydrographs generally matched the peak of the recorded hydrographs. The timing for predicted hydrographs occurs earlier than the recorded hydrograph, this appears to be caused by the same problem that affected the RAFTS hydrographs already mentioned in **section 2.3.** The hydrographs for the Port Office Gauge did not match, however it appears that there are errors in the recorded hydrograph, as it is not consistent with the rest of the hydrographs.

For both events the recorded spot levels varied significantly depending on whether the level was taken on the outside or inside of the bend. The predicted levels outside the maximum allowable tolerance of 0.2m were checked and in most cases were deemed to be likely due to superelevation at bends or incorrect recorded level information. This was primarily decided by looking at surrounding levels and identifying outliers in the recorded levels.

In some reaches of the Brisbane River, higher than expected roughness values were required to achieve calibration. After checking the locations where high values were required, it was found that high roughness values corresponded to bends in the river. A plot of bend locations and corresponding roughness are presented in **Appendix C.**

4.1 Flood Levels

Table 4 & 5 outline the peak flood levels predicted by the model at the gauging stations for both the 1974 and 1955 flood events. A complete record can be found in **Appendix D.** For the 1974 event, predicted flood levels were generally within 100mm of the recorded levels at continuous flood level gauges.

- **Table 4 Peak Flood Levels 1974**

Chainage	Predicted Flood Level	Recorded Flood Level		Difference
		Left Bank	Right Bank	
Mt. Crosby Weir (43003A)	26.81	26.74		0.07
Mt. Crosby (040142/040818)	26.75	26.83		-0.08
Moggill Gauge	19.91	19.93	20.04	-0.08
Goodna Hospital Gauge	18.44		18.43	0.01
Mt Ommaney Gauge	14.67	14.55	14.58	0.10
Darra Wharf Gauge	13.52	13.36	13.79	-0.05

Sherwood Gauge	12.43		12.52	-0.09
Clarence Road Gauge	11.14		11.20	-0.06
Oxley Creek Gauge	11.15		11.01	0.14
King Authur Terrace Gauge	11.11		11.04	0.07
Tennyson Power House Gauge	10.93		10.83	0.10
Yeronga Street Gauge	10.77		10.83	-0.06
Sandy Creek Gauge	9.81		9.81	0.00
Dutton Park Cemetery Gauge	9.50		9.57	-0.08
Highgate Hill Gauge	8.29		8.36	-0.07
St Lucia Ferry Gauge	8.15		8.09	0.06
Montague Road Gauge	6.46		6.56	-0.10
Port Office Gauge	5.28	4.95	5.44	0.09
Newstead Park Gauge	2.88	2.60	3.30	-0.07
Cresent Road Gauge	2.61	2.63	2.63	-0.02
Cairncross Dock Gauge	2.47		2.49	-0.02
Bulimba Power House Gauge	1.83		1.90	-0.07
Western Inner Bar Gauge	1.55		1.55	-0.01

Predicted flood levels for the 1955 event were generally within 150 mm of the recorded levels. Water Levels toward the lower end of the Brisbane River were higher in the Mike11 model than the recorded levels; this could be a result of

- less development along the river bank than the 1974 case
- changes in river bathymetry due to erosion sedimentation and or dredging
- for this event only the Story, Victoria, William Jolly and Indooroopilly bridges had been constructed.
- for this event the majority of gauging stations were only manually read as opposed to automatic readings for the 1974 flood

Nevertheless a good calibration was achieved for the 1974 event and a reasonable calibration was achieved for the 1955 event. The 1974 event is considered to be the primary calibration event because it better reflects current river conditions and because more historical data is available.

▪ **Table 5 Peak Flood Levels 1955**

Chainage	Predicted Flood Level	Recorded Flood Level	Difference
Clarence Road Gauge	5.30	5.56	-0.26
King Authur Terrace Gauge	5.18	5.10	0.08
Yeronga Street Gauge	4.98	4.95	0.03
Sandy Creek Gauge	4.41	4.65	-0.25
Dutton Park Cemetery Gauge	4.22	4.12	0.09
Highgate Hill Gauge	3.62	3.82	-0.20
Port Office Gauge	2.50	2.28	0.22
Newstead Park Gauge	1.72	1.75	-0.03
Western Inner Bar Gauge	1.30	1.30	0.00

4.2 Peak Flows

Predicted discharges for the Port Office Gauge were 9979 m^3/s (1974) and 4364 m^3/s (1955). A complete record of peak flows predicted by the model can be found in **Appendix D.**

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5. Design Event Modelling

5.1 Background

In October 2003 a review was undertaken of the Brisbane River catchment hydrology. As part of this review, it was decided that the design 1 in 100 AEP event would be based on a flow of 6000 m^3/s at the Brisbane Port Office Gauge. This corresponds to the 'best guess' report by the expert panel (IRP 2003).

Because no events that corresponded to 6000 m^3/s at the Port Office Gauge had previously been modelled, it was decided that a CRC FORGE event (modelled as part of the SKM 2003 review) would be used as a base model for the 1 in 100 AEP design event. Hydrographs for the CRC-FORGE event would be scaled accordingly to give a discharge of 6000 m^3/s at the Port Office Gauge.

The 1% AEP CRC-FORGE event is spatially distributed with areal reduction factors using a standard AR&R (1987) temporal pattern. It was run using the 'Post Dams' case with a critical duration of 72 hours (Refer Brisbane River Flood Study Review, SKM, Oct 2003). The discharges predicted by this event are presented in **Table 6**. It should be noted that these discharges were calculated before the model was fully calibrated.

- **Table 6 CRC-FORGE event – RAFTS Model – Discharges**

Gauge Location	Chainage	Discharge
Savages crossing	Ch 948270 m	5368 m^3/s
Moggill	Ch 1006300 m	5043 m^3/s
Port Office	Ch 1055690 m	5044 m^3/s

This CRC-FORGE event was chosen because it was the only event that gave a reasonably consistent discharge throughout the Brisbane River.

5.2 Results

Hydrographs were extracted from the RAFTS model and input into the calibrated MIKE 11 model. This produced a peak at the Port Office Gauge discharge of 5273 m^3/s (refer **Table 7**).

- **Table 7 CRC-FORGE event – MIKE 11 Model – Discharges**

Gauge Location	Chainage	Discharge
Savages crossing	Ch 948270 m	5084 m^3/s
Moggill	Ch 1006300 m	5298 m^3/s
Port Office	Ch 1055690 m	5273 m^3/s

The difference between the values in **Table 6** and **Table 7** are the result of routing affects.

The expert review panel (IRP 2003) recommended a discharge of 6 000 m^3/s at the Port Office Gauge for the 1% AEP event. During the work SKM undertook there was no RAFTS run that produced this flow and hence a factored event was derived.

To achieve the desired discharge at the Port Office Gauge, all the input hydrographs were scaled up by a factor of 1.117 (ie 6000m^3/s / 5273m^3/s = 1.117) and the MIKE 11 model re-run. The resulting discharge at the Port Office Gauge was 5971 m^3/s (refer **Table 8**). This is only 0.5% less then 6000 m^3/s and therefore considered acceptable. A full record of discharges is presented in **Appendix E.**

- **Table 8 CRC-FORGE event – MIKE 11 Model – Discharges (with scaled up hydrographs)**

Gauge Location	Chainage	Discharge
Savages crossing	Ch 948270 m	5775 m^3/s
Moggill	Ch 1006300 m	6011 m^3/s
Port Office	Ch 1055690 m	5971 m^3/s

Flood levels for the 1 in 100 year AEP event are outlined in **Table 9,** a full record of flood levels are presented in **Appendix E.**

- **Table 9 CRC-FORGE event – MIKE 11 Model – Flood Levels (with scaled up hydrographs)**

Gauge Location	Chainage	Level
Savages crossing	Ch 948270 m	39.34 m
Moggill	Ch 1006300 m	14.36 m
Port Office	Ch 1055690 m	3.16 m

Bibliography

Sinclair Knight Merz (1998) *Brisbane River Flood Study*, report for Brisbane City Council, June 1998.

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Sinclair Knight Merz (2003) *Brisbane River Flood Study – Further Investigation of Flood Frequency Analysis Incorporating Dam Operations and CRC-FORGE Rainfall Estimates-Brisbane River*, Report for Brisbane City Council, December 2003.

Independent Review Panel (2003) *Review of Brisbane River Flood Study*, Report for Brisbane City Council, September 2003.

Appendix A Hydrological Hydrograph Comparison

1974 Historical Event Comparison

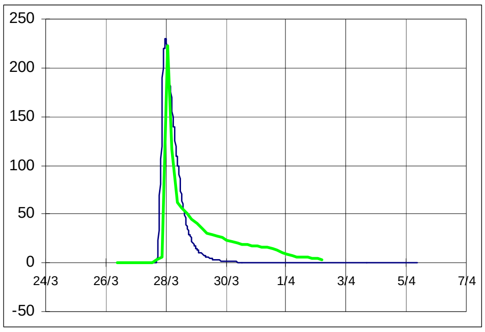
1974 Historical Event Comparison

1974 Historical Event Comparison

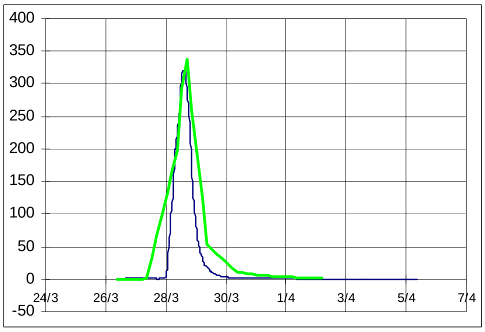
1974 Historical Event Comparison

1955 Historical Event Comparison

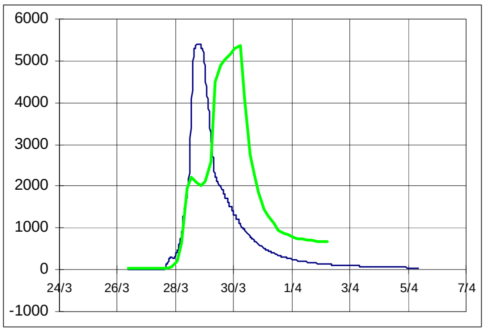
143203A Lockyer Creek AMTD 99.5
HEL-OUT Helidon Predicted
-------- DISCHARGE (m^3/S) Recorded



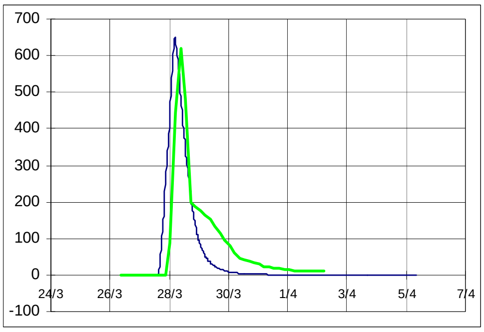
143102A Warrill Creek AMTD 50.9
KAL-OUT Kalbar Predicted
-------- DISCHARGE (m^3/S) Recorded



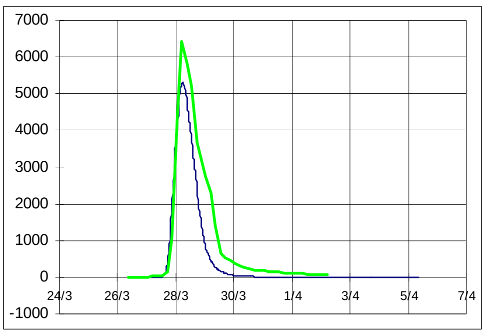
143001B Brisbane River AMTD 140.1
SAV11 Vernor Predicted
-------- DISCHARGE (m^3/S) Recorded



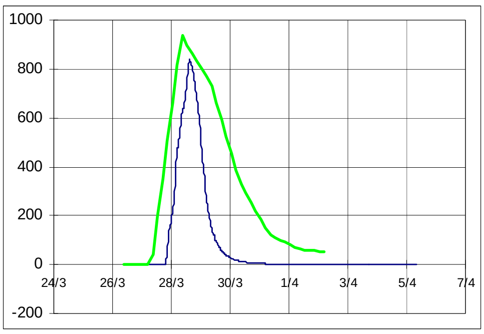
143204A Lockyer Creek AMTD 62.0
LYO+ Wilsons Weir Predicted
-------- DISCHARGE (m^3/S) Recorded



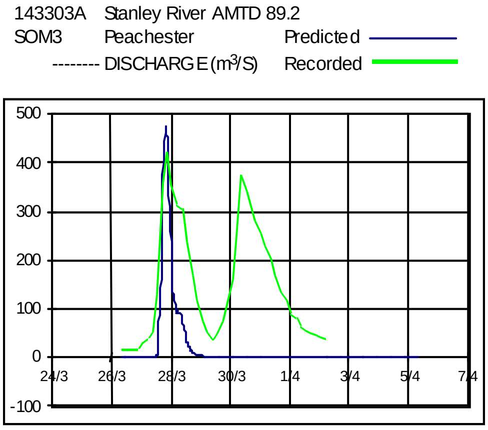
143005A Brisbane River AMTD 230.9
WIV8 Watts Bridge Predicted
-------- DISCHARGE (m^3/S) Recorded



143206A Lockyer Creek AMTD 36.4
LYO-OUT Brightview Weir Predicted
-------- DISCHARGE (m^3/S) Recorded

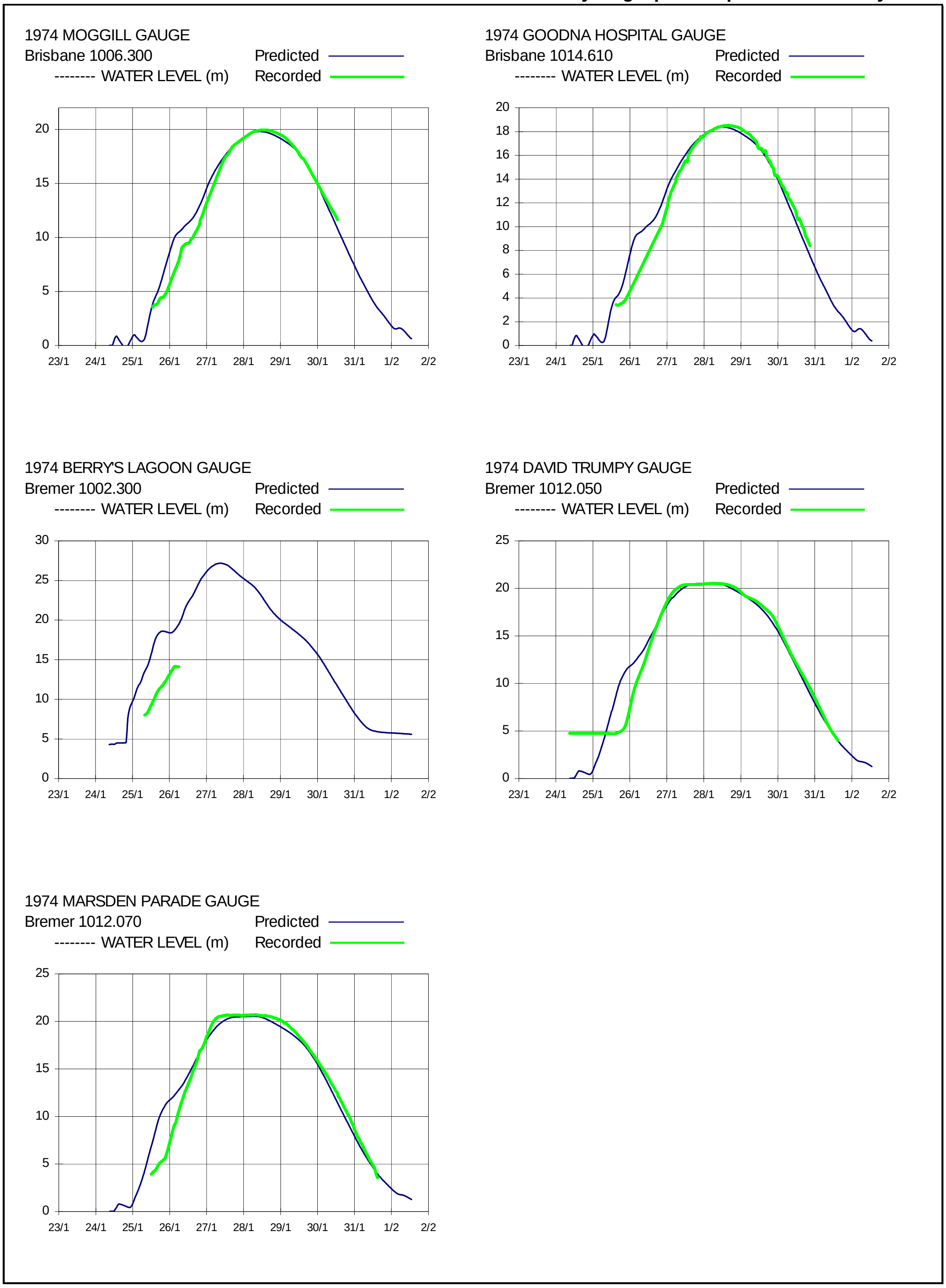


1955 Historical Event Comparison

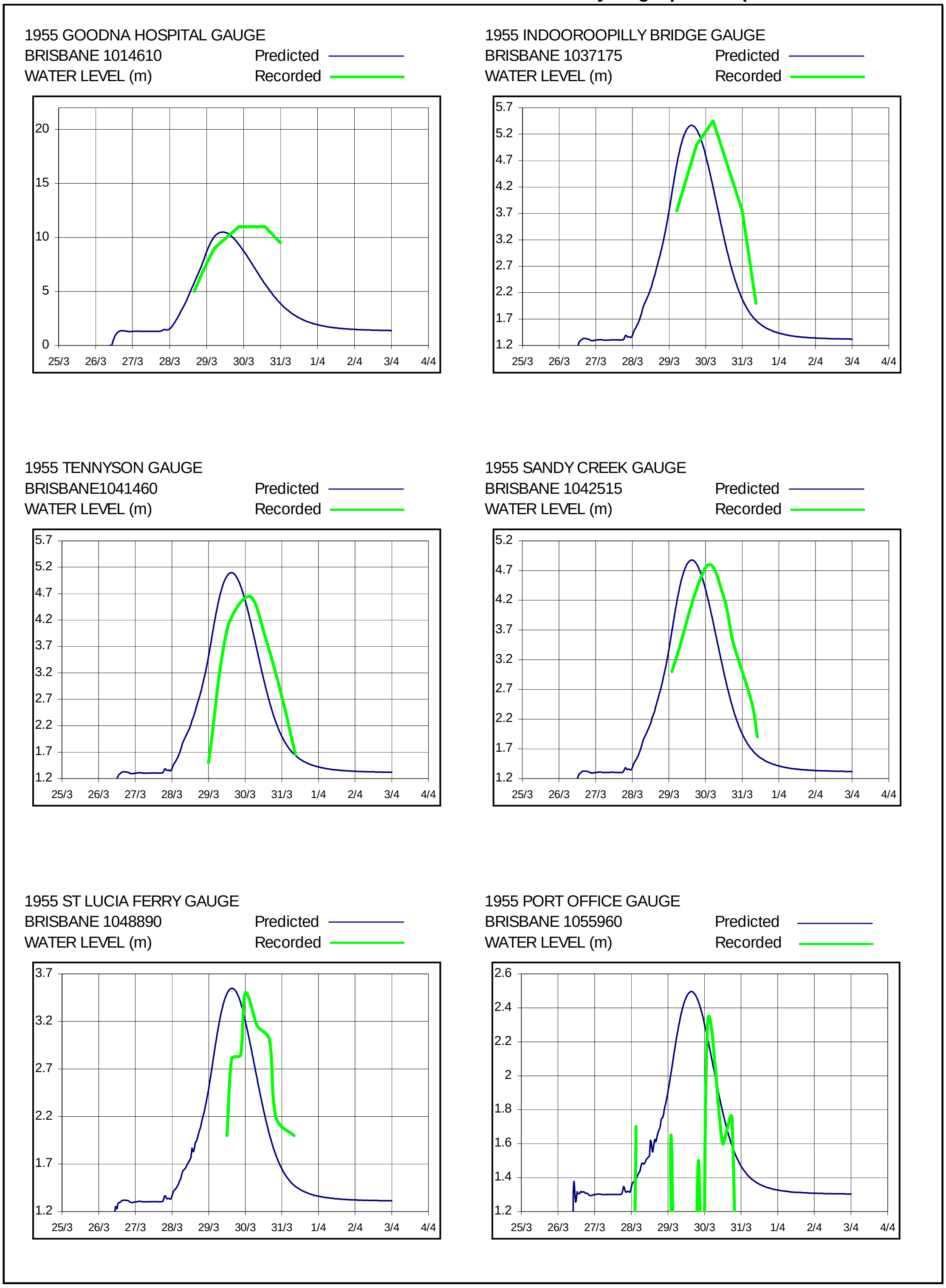


Appendix B Hydraulic Hydrograph Comparison

Predicted & Recorded Hydrograph Comparison - January 1974

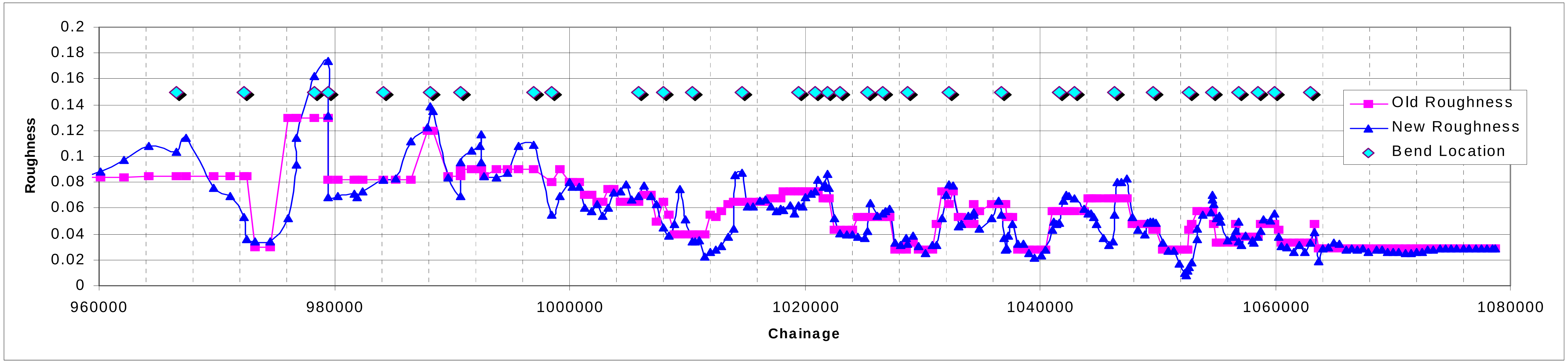


Predicted & Recorded Hydrograph Comparison - March 1955



Appendix C Roughness Parameters

Comparison of Roughness Values for New Model and Previous Model



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Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference		Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference
931570	0.084	0.086	0.002		980330	0.082	0.069	-0.013
933670	0.084	0.086	0.002		981660	0.082	0.071	-0.011
934270	0.084	0.086	0.002		981960	0.082	0.069	-0.013
934620	0.084	0.086	0.002		982460	0.082	0.073	-0.009
936070	0.084	0.086	0.002		984160	0.082	0.082	0.000
936820	0.084	0.086	0.002		985260	0.082	0.083	0.001
939770	0.084	0.086	0.002		986480	0.082	0.112	0.030
942320	0.084	0.086	0.002		987960	0.120	0.123	0.003
943570	0.084	0.086	0.002		988160	0.120	0.139	0.019
944120	0.084	0.086	0.002		988360	0.120	0.135	0.015
945570	0.084	0.086	0.002		989700	0.085	0.084	-0.001
947170	0.084	0.086	0.002		990700	0.085	0.070	-0.015
950270	0.084	0.086	0.002		990760	0.090	0.095	0.005
952320	0.084	0.086	0.002		991710	0.090	0.105	0.015
953870	0.084	0.086	0.002		992420	0.090	0.108	0.018
954920	0.084	0.086	0.002		992450	0.090	0.117	0.027
955970	0.084	0.086	0.002		992470	0.090	0.095	0.005
958770	0.084	0.086	0.002		992670	0.085	0.085	0.000
960170	0.084	0.088	0.004		993760	0.090	0.084	-0.006
962070	0.084	0.097	0.013		994760	0.090	0.087	-0.003
964170	0.085	0.108	0.023		995690	0.090	0.108	0.018
966610	0.085	0.104	0.019		996980	0.090	0.109	0.019
967410	0.085	0.115	0.030		998460	0.080	0.055	-0.025
969790	0.085	0.075	-0.010		999160	0.090	0.069	-0.021
971160	0.085	0.070	-0.015		1000000	0.080	0.081	0.001
972260	0.085	0.053	-0.032		1000285	0.080	0.077	-0.003
972600	0.085	0.036	-0.049		1000775	0.080	0.077	-0.003
973260	0.030	0.034	0.004		1001315	0.070	0.061	-0.009
974580	0.030	0.034	0.004		1001865	0.070	0.057	-0.013
976020	0.130	0.052	-0.078		1002350	0.065	0.063	-0.002
976750	0.130	0.094	-0.036		1002785	0.065	0.054	-0.011
976750	0.130	0.114	-0.016		1003275	0.075	0.060	-0.015
978280	0.130	0.162	0.032		1003775	0.075	0.072	-0.003
979507	0.130	0.174	0.044		1004300	0.065	0.073	0.008
979513	0.130	0.132	0.002		1004810	0.065	0.078	0.013
979530	0.082	0.069	-0.013		1005325	0.065	0.067	0.002

Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference		Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference
1005870	0.065	0.070	0.005		1021539	0.068	0.076	0.008
1006300	0.070	0.078	0.008		1021715	0.068	0.078	0.010
1006910	0.070	0.069	-0.001		1021895	0.068	0.086	0.018
1007410	0.050	0.063	0.013		1022105	0.068	0.075	0.007
1007920	0.065	0.045	-0.020		1022575	0.043	0.052	0.009
1008445	0.055	0.039	-0.016		1023040	0.043	0.041	-0.002
1008925	0.040	0.048	0.008		1023570	0.043	0.040	-0.003
1009400	0.040	0.075	0.035		1024080	0.043	0.040	-0.003
1009820	0.040	0.052	0.012		1024563	0.053	0.037	-0.016
1010490	0.040	0.034	-0.006		1025070	0.053	0.037	-0.016
1010725	0.040	0.034	-0.006		1025360	0.053	0.042	-0.011
1010980	0.040	0.035	-0.005		1025590	0.053	0.064	0.011
1011510	0.040	0.022	-0.018		1026170	0.053	0.054	0.001
1011980	0.055	0.026	-0.029		1026680	0.053	0.056	0.003
1012475	0.053	0.028	-0.025		1026900	0.053	0.058	0.005
1012935	0.058	0.031	-0.027		1027160	0.053	0.059	0.006
1013445	0.063	0.038	-0.025		1027680	0.028	0.033	0.005
1013920	0.065	0.044	-0.021		1028180	0.028	0.031	0.003
1014110	0.065	0.086	0.021		1028680	0.028	0.037	0.009
1014610	0.065	0.088	0.023		1028760	0.033	0.032	-0.001
1015090	0.065	0.061	-0.004		1029200	0.033	0.039	0.006
1015560	0.065	0.062	-0.003		1029680	0.028	0.031	0.003
1016140	0.065	0.066	0.001		1030220	0.028	0.025	-0.003
1016640	0.065	0.067	0.002		1030870	0.028	0.032	0.004
1017130	0.068	0.061	-0.007		1031260	0.048	0.031	-0.017
1017610	0.068	0.058	-0.010		1031700	0.073	0.052	-0.021
1017920	0.068	0.060	-0.008		1031995	0.073	0.071	-0.002
1018200	0.073	0.058	-0.015		1032230	0.063	0.078	0.015
1018725	0.073	0.062	-0.011		1032585	0.073	0.077	0.004
1019095	0.073	0.056	-0.017		1033080	0.053	0.046	-0.007
1019490	0.073	0.062	-0.011		1033370	0.053	0.048	-0.005
1019865	0.073	0.061	-0.012		1033900	0.048	0.054	0.006
1020115	0.073	0.068	-0.005		1034370	0.048	0.055	0.007
1020525	0.073	0.071	-0.002		1034414	0.063	0.056	-0.007
1020830	0.073	0.073	0.000		1034890	0.058	0.044	-0.014
1021095	0.073	0.082	0.009		1035900	0.063	0.052	-0.011

SKM

Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference		Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference
1036460	0.063	0.066	0.003		1049120	0.048	0.049	0.001
1036770	0.063	0.055	-0.008		1049370	0.048	0.050	0.002
1036915	0.063	0.037	-0.026		1049590	0.043	0.049	0.006
1037090	0.063	0.028	-0.035		1049870	0.043	0.049	0.006
1037175	0.053	0.028	-0.025		1050430	0.028	0.033	0.005
1037285	0.053	0.039	-0.014		1050860	0.028	0.027	-0.001
1037625	0.053	0.048	-0.005		1051360	0.028	0.027	-0.001
1038085	0.028	0.032	0.004		1051895	0.028	0.017	-0.011
1038600	0.028	0.033	0.005		1052310	0.028	0.010	-0.018
1039100	0.028	0.025	-0.003		1052390	0.028	0.008	-0.020
1039565	0.028	0.022	-0.006		1052595	0.028	0.012	-0.016
1040090	0.028	0.024	-0.004		1052640	0.043	0.014	-0.029
1040490	0.028	0.028	0.000		1052865	0.048	0.018	-0.030
1041010	0.058	0.044	-0.014		1053320	0.058	0.036	-0.022
1041230	0.058	0.050	-0.008		1053385	0.058	0.044	-0.014
1041460	0.058	0.048	-0.010		1053900	0.058	0.055	-0.003
1041700	0.058	0.049	-0.009		1054490	0.058	0.057	-0.001
1041960	0.058	0.065	0.007		1054640	0.058	0.066	0.008
1042235	0.058	0.070	0.012		1054680	0.058	0.071	0.013
1042515	0.058	0.069	0.011		1054760	0.048	0.063	0.015
1042910	0.058	0.068	0.010		1054970	0.033	0.052	0.019
1043725	0.058	0.059	0.001		1055280	0.033	0.054	0.021
1044060	0.068	0.056	-0.012		1055420	0.033	0.049	0.016
1044340	0.068	0.056	-0.012		1055960	0.033	0.035	0.002
1044605	0.068	0.053	-0.015		1056400	0.033	0.038	0.005
1044860	0.068	0.048	-0.020		1056695	0.048	0.042	-0.006
1045400	0.068	0.037	-0.031		1056865	0.038	0.050	0.012
1045885	0.068	0.031	-0.037		1056950	0.038	0.034	-0.004
1046180	0.068	0.034	-0.034		1057090	0.038	0.032	-0.006
1046340	0.068	0.055	-0.013		1057530	0.038	0.039	0.001
1046580	0.068	0.080	0.012		1058040	0.038	0.035	-0.003
1046900	0.068	0.080	0.012		1058230	0.038	0.034	-0.004
1047350	0.068	0.083	0.015		1058530	0.038	0.037	-0.001
1047915	0.048	0.053	0.005		1058735	0.048	0.042	-0.006
1048375	0.048	0.043	-0.005		1059035	0.048	0.051	0.003
1048890	0.048	0.040	-0.008		1059540	0.048	0.051	0.003

SKM

Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference		Chainage [m]	Roughness (Previous Model)	Roughness (New Model)	Difference
1059990	0.048	0.056	0.008		1069535	0.029	0.026	-0.003
1060345	0.043	0.038	-0.005		1070025	0.029	0.026	-0.003
1060535	0.033	0.031	-0.002		1070530	0.029	0.026	-0.003
1061015	0.033	0.030	-0.003		1071040	0.029	0.025	-0.004
1061530	0.033	0.026	-0.007		1071520	0.029	0.025	-0.004
1062020	0.033	0.032	-0.001		1072015	0.029	0.026	-0.003
1062535	0.033	0.026	-0.007		1072515	0.029	0.027	-0.002
1062940	0.033	0.033	0.000		1072995	0.029	0.028	-0.001
1063310	0.048	0.042	-0.006		1073485	0.029	0.028	-0.001
1063645	0.029	0.019	-0.010		1074000	0.029	0.029	0.000
1064000	0.029	0.029	0.000		1074460	0.029	0.029	0.000
1064490	0.029	0.029	0.000		1074985	0.029	0.029	0.000
1065010	0.029	0.033	0.004		1075480	0.029	0.029	0.000
1065503	0.029	0.032	0.003		1076000	0.029	0.029	0.000
1065990	0.029	0.028	-0.001		1076495	0.029	0.029	0.000
1066505	0.029	0.029	0.000		1077010	0.029	0.029	0.000
1067020	0.029	0.028	-0.001		1077510	0.029	0.029	0.000
1067485	0.029	0.029	0.000		1078040	0.029	0.029	0.000
1067965	0.029	0.026	-0.003		1078525	0.029	0.029	0.000
1068660	0.029	0.028	-0.001		1078660	0.029	0.029	0.000
1069045	0.029	0.028	-0.001					

Appendix D MIKE11 Results

Figure D-2a Flood Calibration Profile - January 1974
Brisbane River

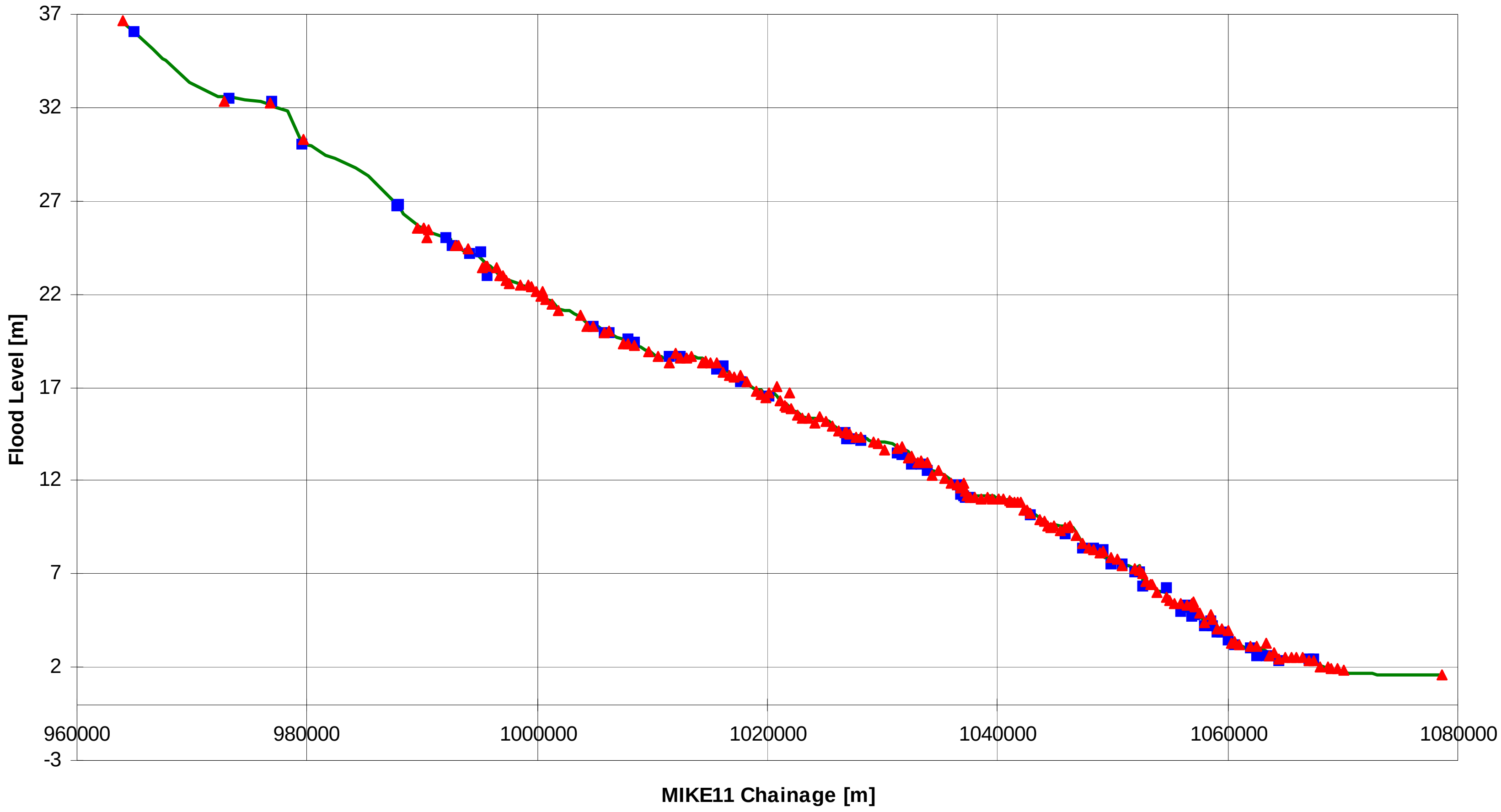
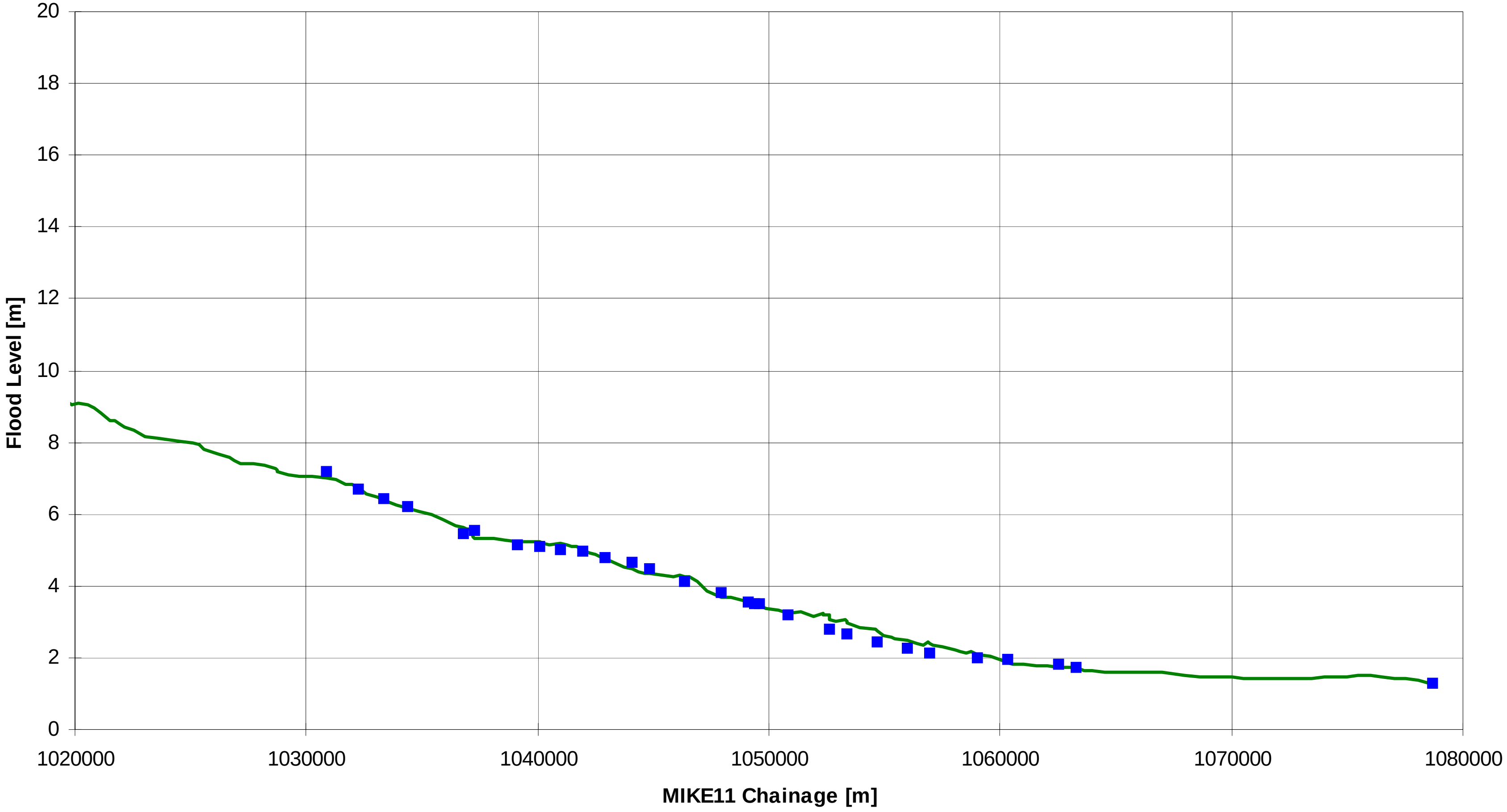


Figure D-2a Flood Calibration Profile - March 1955
Brisbane River



Appendix E DESIGN EVENT Results

Joint Flood Taskforce Report
March 2011

This document has been approved on behalf of the Joint Flood Taskforce by

Name	Professor Colin Apelt		
Position	Joint Food Taskforce Chair		
Signature	Original Signed by Colin Apelt	Date	8 March 2011

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Executive Summary

In January 2011, Brisbane experienced the second-highest flood of the last 100 years, after January 1974. There was major flooding through most of the Brisbane River catchment, most severely in the Lockyer and Bremer catchments where numerous flood height records were set. The flooding caused substantial loss of life in the Lockyer Valley and thousands of properties were inundated in metropolitan Brisbane, Ipswich and elsewhere.

Joint Flood Taskforce Brief

As with any such event, questions about flood control levels are raised. Given that the flood control levels are theoretical, it is prudent to review them in light of an actual event to assess the reliability of the present theoretical model. To this end a Joint Flood Taskforce (JFTF) was established to report within 30 days, which it has done, on the following three questions.

- How does the January 2011 flood event compare to the Q100 as presently defined and Brisbane City Council's Defined Flood Event?
- Does Q100, as it is currently described, remain the best estimate of a 1 in 100 year event?
- Accordingly, what standard should be used to enable new development and redevelopment to proceed with confidence and certainty?

Findings of Joint Flood Taskforce

In answering these questions the JFTF has focussed on river flooding only. Creek flooding and the impact of Storm Surge are considered to be outside the scope for this review. The JFTF was limited by the data and modelling available and that could be made available. Further the answers provided stress their interim nature given a number of other reviews that are currently underway. These reviews include "Queensland Floods Commission of Inquiry" and Council's Flood Response Review Board.

How does the January 2011 flood event compare to the Q100 as currently defined and Brisbane City Council's Defined Flood Event (DFE)?

In the flood event experienced, the heaviest rains were inland on the western fringe of the Brisbane River catchment and on the Great Dividing Range. Over the Brisbane River catchment as a whole, based on rainfall captured by the BoM's Enviromon rain gauges, the estimated average 5-day rainfall is 322mm, with the major sub-catchments of Wivenhoe Dam, Bremer River and Lockyer Creek receiving 370mm, 223mm and 268mm respectively.

Given the pattern of rainfall, the Brisbane River received significant flows from the upstream catchments of the Lockyer and Bremer. The flow down the upper Brisbane River (above the Lockyer Creek) and Stanley River were mitigated by Wivenhoe Dam. However Brisbane felt the full force of the flows down the Lockyer and Bremer Rivers. As a result of the rainfall, Brisbane experienced a significant river flood. During this flood event, the rainfall over much of Brisbane was not sufficient to cause any significant creek flooding from local runoff. However, creeks that are tributaries of the Brisbane River were flooded deeply in their lower reaches by water backing up from the River.

Based on examination of the rainfall patterns of a number of previous Brisbane River floods, it is concluded that the Brisbane catchment experienced a significant rainfall event with a rain pattern that was different from that experienced in 1974. Full details of the rainfall magnitudes were not available at the date of this Report. However back calculation from recorded releases from Wivenhoe and the record of water level in the dam suggest significantly more flood producing rainfall occurred than indicated by the presently available rainfall data. The calculated dam inflow hydrographs show two inflow peaks, the first of the magnitude of 1974 and the second 36 hours later of greater magnitude than 1974. The level recorded at Savages Crossing was higher than in 1974. Flood inflow volumes to Wivenhoe as calculated from the known releases from Wivenhoe dam and the recorded water levels in the dam total 2,650 GL, as compared to a total of 1,410 GL for that location in 1974 and 2,744 GL in February 1893.

On balance the JFTF considers that the flood runoff resulting from the major rainfall event of January 2011 was greater than the 1974 event but not as great as the 1893 event.

All of the peak flood levels recorded in January 2011 by the gauges along the Brisbane River were higher than the existing Defined Flood Level, ie. the level previously calculated for the 1974 flood event mitigated by Wivenhoe Dam. Therefore, taking into account this fact together with its assessment of the rainfall event, the JFTF considers that the January 2011 flood event was larger than the Brisbane City Council's Defined Flood Event.

The Q100 as presently defined is, in general, a slightly lesser flood than the Defined Flood Event. Therefore the JFTF considers that the January 2011 flood event was larger than the Q100 as presently defined.

Much more detailed work is required to accurately identify the probability of this event for Brisbane. The information needed and the work required to complete this analysis are summarised in the Recommendations below.

Does Q100, as it is currently described, remain the best estimate of a 1 in 100 year event?

The term, Q100, can be misunderstood. Some people mistakenly believe a 1 in 100 year flood will only occur once every 100 years on average. However, Q100 is a probability-based design flood event, aimed to reflect *typical combinations of flood producing and flood modifying factors* which act together to produce a flood event that has a 1 in 100 chance in any one year (or an average recurrence interval of 100 years) of being equalled or exceeded at a specific location of interest. It is a theoretical flood model used to inform planning and policy.

The January 2011 flood has brought a significant amount of new data and information on the nature of flooding in the Brisbane River and about the factors contributing to very large flood events in this catchment. Significant work is required to review Brisbane's Q100 in the light of this new information. This work could not be completed given the data available to the JFTF report, some of which is still being collected.

In light of the available information about the 2011 flood event, the JFTF considers that it is essential that the current Q100 is reviewed. It is not possible to predict the outcome of such review but it is considered more likely than not that this review will lead to an increase in the magnitude of the Q100 and increases in associated flood levels.

Accordingly, what standard should be used to enable new development and redevelopment to proceed with confidence and certainty?

To answer this question five (5) scenarios have been evaluated. These scenarios are:

- Current Q100 (3.3m at City Gauge)
- Current Defined Flood Level, DFL (3.7m AHD at City Gauge)
- January 2011 Flood Event (4.46m AHD at City Gauge)
- 1974 without Wivenhoe Dam (5.45 m AHD at City Gauge)
- 1893 without Somerset and Wivenhoe Dams (8.35m AHD at City Gauge)

On balance, the JFTF believes that, in the absence of results of a detailed flood study review, a precautionary approach should be adopted. Therefore, it considers that the actual January 2011 flood event, as observed during the event, should be used as the **interim** standard on which Brisbane City Council bases its decisions concerning habitable floor levels for new development and should be a consideration for habitable floor levels for redevelopment of existing properties. Wherever the existing DFL is higher than the January 2011 flood event, the existing higher flood level should prevail.

The JFTF notes that, in regions where the interim standard will be applied, the degree of immunity from flood risk will vary with location. This is because the January 2011 flood event is an actual event and will have variable tidal influences along the tidal reach. Consequently variable probabilities will apply along this reach.

The recommendation of an **interim** development standard refers to land use types that are currently assessed against a DFE in the City Plan. This currently excludes industrial development however this should be considered through the current City Plan review.

Further the DFE and resulting flood regulation lines are considered only part of a flood risk management framework for a community. The approach to flood risk management for Brisbane needs to consider a broader range of initiatives if it is to effectively manage flood risk for the City. Flood risk management requires that the consequences of floods be investigated for a range of flood events up to and including the PMF. For land use planning, flood levels as well as flood flows corresponding to specific probabilities must be considered. This approach must include identification of the benefits of the management of risk, rather than seeing it as all cost.

Recommendations of Joint Flood Taskforce

It is recommended,

That the actual January 2011 flood event, as observed during the event, be used as the **interim** standard, on which Brisbane City Council bases its decisions concerning new development and redevelopment, with the essential condition that, wherever a higher level has been set as the current DFL, the higher level must apply; and that this interim standard apply until conclusion of the Commission of Inquiry and the comprehensive flood study recommended below is completed.

That all data relating to the January 2011 flood event be gathered from all sources and archived so that further analysis can make use of all data available.

That the bathymetry (river bed and banks) of the Brisbane River and its tributaries and the characteristics of the bed material from Wivenhoe dam to the mouth be measured as soon as possible.

That a comprehensive flood study be commissioned to review flood flows and levels within the Brisbane River catchment making full use of the data relating to the January 2011 flood event.

That the effects of morphological (river bed level and cross section) changes due to sediment erosion and deposition during flood events be studied for a range of flood magnitudes to determine their effects on flood levels.

That consideration be given to whether a Monte Carlo approach to the flood risk for the Brisbane Catchment is feasible and, if yes, whether it should be carried out and which influencing factors should be included in the Monte Carlo approach. This may include consideration whether two or more types of rainfall events should be built into the statistical analysis for theoretical floods. (In a Monte Carlo analysis the influencing input factors such as rainfall patterns, storm tracks, catchment conditions, tide and storm surge are sampled, either randomly or in accordance with their joint probabilities, to select a large number of different combinations of inputs for simulation with a catchment modelling system to develop many alternative predictions of flood events. These predictions are then analysed statistically to estimate their exceedance probabilities).

That a complete Flood Risk Management analysis for the area of Brisbane affected by flooding by Brisbane River and its tributaries be carried out. It is essential to move from the Q100 mentality and to adopt a risk management approach inline with National Flood Risk Advisory Group (NFRAG) and other relevant guidelines. The risk management approach would require a detailed assessment of the benefits and costs of a full range of flood mitigation options.

1.0 Purpose and Scope of the Report

1.1 Purpose

On the 11 February 2011 the JFTF was established by the Brisbane City Council. Ipswich City Council were then invited to participate in accordance with the Terms of Reference as given in Appendix A. Ipswich City Council chose to adopt an observer status, providing technical input and were not an approval entity. An outcome of the JFTF required by the TOR was the response to the following questions.

1. How does the January 20011 flood event compare to the Q100 as presently defined and Brisbane City Council's Defined Flood Event (DFE)?
2. Does Q100, as it is currently described, remain the best estimate of a 1 in 100 year event?
3. Accordingly, what standard should be used to enable new development and redevelopment to proceed with confidence and certainty?

A Technical Reference Group and an Industry Reference Group were established at the same time, as detailed in the TOR, to provide input to the work of the core JFTF. The role of the Technical Reference Group was focussed essentially on the first two questions while the role of the Industry Reference Group was critical in the response to the third question.

This report provides the response of the JFTF to the TOR including its answers to the three questions.

1.2 Approach

To provide the context for this work, the flood history of the Brisbane River is summarised including the event of January 2011. An overview the catchment in which Brisbane is situated is provided including major dams with their impacts.

Brisbane's Q100 and DFE control levels for Brisbane are discussed as are their role as development standards. The January 2011 event is then compared to the current Q100 event and the current DFE and the appropriateness of the current Q100 is examined.

Five potential DFEs are examined. These scenarios are:

- Current Q100 (3.3m AHD at City Gauge)
- Current Defined Flood Level, DFL (3.7m AHD at City Gauge)
- January 2011 Flood Event (4.46m AHD at City Gauge)
- 1974 without Wivenhoe Dam (5.45 m AHD at City Gauge)
- 1893 without Somerset and Wivenhoe Dams (8.35m AHD at City Gauge)

The effectiveness and impacts of each option are discussed and a conclusion reached as to their suitability from both a hydrological and planning perspective.

1.3 Limitations

This report only considers river flooding within Brisbane. Flooding in the Bremer River is not examined, neither is creek flooding and nor is the impact of storm surge or climate change.

The State government's "Queensland Floods Commission of Inquiry" will consider and make recommendations relating to any long term planning changes. However, this will not be available for some time. This report aims to provide certainty to Brisbane's community by providing interim guidance on flood levels and controls. The focus of this report is the next 1 to 2 years. As a result, longer term impacts such as changing sea levels and variations in rainfall patterns and other consequences of climate change are not considered.

Given the interim nature of the report, there are limitations on the data that could be collected, flood modelling that could be completed and the economic analysis that could be completed for the analysis of benefit and cost. Therefore recommendations are made for future work to increase the robustness of the recommendations or revise them if necessary.

Finally, the appropriateness of the Wivenhoe Dam operation procedures and potential improvements in these procedures are a consideration for the State's Judicial Commission. This report assumes Dams were operated inline with current legislated operating procedures. Consequently, Wivenhoe Dam operation is not considered.

2.0 Background

2.1 Flood Risk Management

2.1.1 Introduction

Flood risk is the potential for people or property to suffer damage from flooding. Flood risk at a location depends upon the frequency of flooding at different levels and the associated consequences to the community.

The object of flood risk management is to reduce a community's flood risk to acceptable levels, either by reducing exposure to flooding or by reducing the vulnerability of people and property to flooding. This involves trading off the economic, social and environmental costs of flooding against the benefits of allowing a broad range of activities to take place on the floodplain. Such trade-off decisions need to be made in a proper risk management framework, based on firstly assessing the probabilities and consequences of flooding at different levels of severity, and then considering the benefits and costs of a range of flood risk management options. The benefits of flood risk management options can be expressed in terms of the reduction in expected flood damages, environmental, social and economic, while the costs include the cost of implementing the flood risk management measures as well as associated opportunity costs.

In a broader sense, flood risk management also includes flood response and flood recovery actions but in the context of this report the focus is on the *prevention aspects* of flood risk management.

2.1.2 Flood risk management principles and guidelines

In Australia, flood risk management is guided by principles, policies and guidelines established at the national, state and local government levels. At the national level, the National Flood Risk Advisory Group (NFRAG) has been established to follow up on COAG reform commitments, including the development of National Flood Risk Management Guidelines (see AJEM, 2008). The national guidelines developed by NFRAG describe the vision for flood risk management as:

> "Floodplains are managed for the long term benefit of the local and wider community such that hazards to people and damages to property and infrastructure are minimised and environmental values are protected."
> (AJEM, 2008)

The Queensland State Planning Policy 1/03 : Mitigating the Adverse Impacts of Flood, Bushfire and Landslide 1.0 (SPP, 2003) and the associated guideline State Planning Policy 1/03 Guideline: Mitigating the Impacts of Flood, Bushfire and Landslide 1.0, which form the basis for development decisions in relation to floods and other natural hazards, are consistent with the flood risk management framework outlined in 'Floodplain Management in Australia – Best Practice Principles and Guidelines (SCARM, 2000).

2.1.3 Flood risk management options

The range of flood mitigation options available to reduce the exposure of a community to flooding or its vulnerability to flood risk includes the following main groups:

(i) *Land use planning and development controls* (including building regulations) to exclude development from the most hazardous parts of the floodplain and ensure that exposure to flooding and flood damage are minimised for development in fringe areas of the floodplain.
(ii) *Other non-structural measures* such as developing flood warning systems, improving community awareness and readiness by community education on the nature and impacts of flooding.
(iii) *Major structural flood mitigation works* to reduce the frequency of flooding above a given level (e.g. flood control storages) or the extent of flooding (e.g. levees) – these options can be employed to reduce the flood risk to *existing development* in the flood plain
(iv) *Flood proofing measures* to reduce the exposure of property to flood damage (e.g. raising of house floors, flood barriers, use of flood resistant building materials),

This report only concentrates on benefits derived directly or indirectly from the first group, with other potential flood risk management options to be considered as part of a more comprehensive future study. The specific focus of the report is on land use planning and development controls through setting of *defined flood levels for planning and building purposes* in the areas affected by Brisbane River flooding.

2.1.4 Residual flood risk

Flood risk management options are designed to reduce the flood risk for flood events up to a design flood (and the associated defined flood level). There is still a chance of the defined flood level being exceeded by larger floods; this is referred to as '*residual flood risk*'. The larger the average recurrence interval selected for the defined flood event (and thus the higher the defined flood level), the lower the residual flood risk. As an example, if the Q100 is adopted as the defined flood level, then the residual flood risk will consist of the consequences associated with all the floods larger than the Q100 event, weighted by the probability of their occurrence. While floods much larger than the January 2011 event may occur, their low probability of occurrence means that, in the determination of residual flood damages, they will be given a much lower weight than flood events which occur relatively frequently.

2.1.5 Conclusion

Flood Risk Management is a best practice approach and if adopted will provide a framework to mitigate damage from flooding for all properties at risk from flood. No matter what flood DFE is in place it should be considered as only integral part of the Flood Risk Management framework which needs to be complemented with other flood risk controls as outlined in section 2.1.3

2.2 Details of the river flood event of January 2011

In January 2011, Brisbane experienced the second-highest flood of the last 100 years, after January 1974. There was major flooding through most of the Brisbane River catchment, most severely in the Lockyer and Bremer catchments where numerous flood height records were set. The flooding caused substantial loss of life in the Lockyer Valley and thousands of properties were inundated in metropolitan Brisbane, Ipswich and elsewhere.

2.2.1 Rainfall

For the 2011 event, the heaviest rains were inland on the western fringe of the Brisbane River catchment and on the Great Dividing Range. Recorded gauge levels for this event, show Brisbane's peak three-day rainfall was 166 mm, while the peak one-day total was 110 mm.

Over the Brisbane River catchment as a whole, based on rainfall captured by the BoM's Enviromon rain gauges, the estimated average 5-day rainfall is 322mm, with the major sub-catchments of Wivenhoe Dam, Bremer River and Lockyer Creek receiving 370mm, 223mm and 268mm respectively.

However back-calculation from recorded releases from Wivenhoe and the record of water level in the dam suggest significantly more flood producing rainfall occurred. The calculated dam inflow hydrographs show two peaks, the first of the magnitude of 1974 and the second of greater magnitude than 1974, 36 hours later. The peak level recorded at Savages Crossing was higher than in 1974 but not as great as estimated for the 1893 event. Estimated flood volume inflows to Wivenhoe as calculated from the known Wivenhoe dam releases and the recorded water levels in the dam total 2,650 GL as compared to a total of 1,410 GL for that location in 1974 and 2,744 GL in February 1893

It is thought that the coverage of the existing rain gauge network[1] was insufficient to accurately capture the variation in rainfall intensities for this event. This is supported by evidence from radar imaging which suggested significant falls not recorded in rain gauges. For example, there were large falls observed over Wivenhoe Dam that would not be captured by any rain gauge. To obtain a greater understanding of the total rainfall received, work is required to analyse the recorded radar imaging of the event.

Insufficient rainfall data exist for a comprehensive assessment of the 1893 event. However, the available station data indicate that peak rainfalls in the region during the 1893 event were much heavier than those during either the 1974 or 2011 events. Crohamhurst, in the Glasshouse Mountains inland from the Sunshine Coast, received 907.0 mm on 3 February 1893, which remains an Australian daily record, whilst three-day totals included 1715.0 mm at Mooloolah and 1680 mm at Crohamhurst.

On balance the JFTF considers that the flood runoff caused by the rainfall event of January 2011 was greater than the 1974 event but not as great as the 1893 event.

2.2.2 Flood resulting from Rainfall

In 2011 Brisbane experienced a significant river flood. Given the pattern of rainfall, the Brisbane River received significant flows from the upstream catchments of the Lockyer and Bremer. The flow down the upper Brisbane River above Wivenhoe Dam and Stanley River was mitigated by Wivenhoe Dam. However, Brisbane felt the full force of the flows down Locker Creek and Bremer River. As a result of the rainfall, Brisbane experienced a significant river flood.

The flooding caused thousands of properties to be inundated in metropolitan Brisbane. It should be noted that the pattern of rainfall experienced caused little to no creek flooding within Brisbane, though creeks were flooded by backwater from the river.

It is reported that the flood levels recorded at Savages Crossing were higher than in 1974.
DERM reported the peak level recorded at Savages Crossing was 24.167m AHD at 03.40 am on 12 January 2011, somewhat higher than the peak level of 23.767m AHD in the 1974 flood. The corresponding discharge based on the extrapolated rating curve was 6900 cumecs. It has been suggested that the extrapolated rating curve may have underestimated the actual flow rate. Nevertheless the discharge of 6900 cumecs is larger than that for the current DFE.

The peak height at the Brisbane Port Office gauge of 4.46 m was less than that in 1974[2]. The flood level in Brisbane in January 2011 was reduced by the mitigating effect of Wivenhoe Dam.

Measurements of flood levels for January 2011 have been based on marks on buildings where available, rather than on debris marks. Levels vary across the river by substantial

[1] The existing rain gauge network is made up mostly of gauges owned by BOM and Seqwater.
[2] There are two gauges at/near the Port Office. The “Port Office gauge” is at the end of Edward Street on the true left side of the river. There is also an ‘Alert’ gauge on the true right side a little downstream from the Thornton Street ferry pier

amounts – up to 0.4m at bends; the water surface is curved generally because of the effects of super-elevation at the outsides and of local reduction at the insides of bends, as well as the tendency for the water to be higher towards the centre of a fast flowing river than near the banks. All the measured flood levels are higher than the Defined Flood Levels and these correspond to the levels calculated for a flood with the characteristics of the 1974 flood after the reducing effects of Wivenhoe Dam.

2.2.3 Outstanding Information Required for Description of 2011 Event

A number of important items required for a complete description of the January 2011 event are not available at the time of writing this report. These include the following:

- BoM is still assembling and checking the rainfall data.
- DERM gauged the flow at Jindalee Bridge with Acoustic Doppler instrumentation – this data is still awaited.
- There is a strong suspicion that the extrapolated part of the DERM rating curve for the gauging station at Savages Crossing is inaccurate causing some underestimates of flows of order 20% or more.
- The bathymetry of the river, from Wivenhoe Dam to the mouth of the river, may have changed substantially and it needs to be measured as soon as possible. There was very extensive erosion of the Lockyer and there is a strong suspicion that much of this was deposited in the Brisbane River. There are suggestions that this may be part of the reason for the apparent "discrepancy" in the differences between the DFLs and 2011 levels upstream from the Tennyson Tennis Centre – further upstream the differences are similar in magnitude but, in some reaches, they decrease before increasing again. However, there are substantial differences in the shapes of the hydrographs for the different flood events and this could be a major contributor.
- The accuracy of the stage/volume relationship for Wivenhoe dam storage needs to be checked.

2.2.4 Comparison of January 2011 with Present DFE

As stated above in 2.2.1, the JFTF considers that the flood runoff caused by the rainfall event of January 2011 was greater than the 1974 event. Further, as noted above in 2.2.2, all the measured flood levels for the January flood event are higher than the levels calculated for a flood with the characteristics of the 1974 flood after mitigation by the effects of Wivenhoe Dam and these latter levels are the presently Defined Flood Levels (DFLs) for areas where the river flooding causes the highest level of flooding.

Consequently, despite the lack of complete data at this time, the JFTF has concluded that the January 2011 flood event, as actually experienced, was larger than a flood similar to that of 1974 after mitigation by Wivenhoe, and therefore larger than the Council's presently defined DFE.

2.3 River Flood history

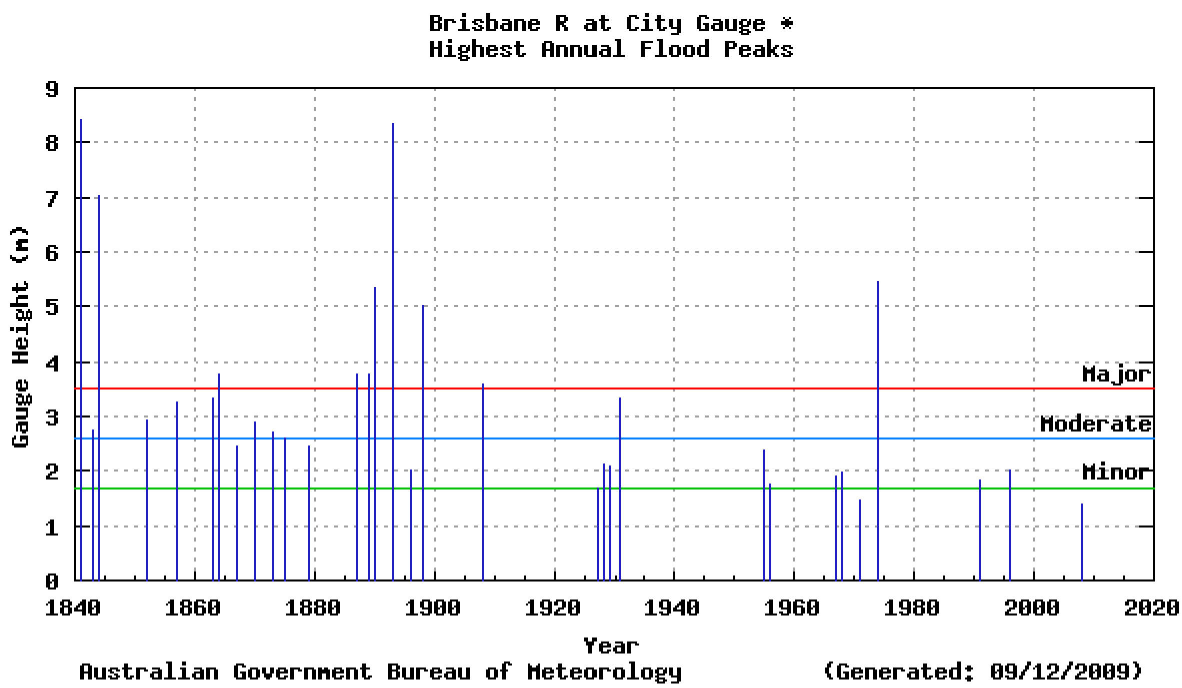
Flood records held by the Bureau of Meteorology and the state extend back as far as the 1840's for Brisbane. These records show Brisbane is a city built on the flood plain of a river with a history of flooding. While flood peaks are referenced to the Brisbane Port Office gauge in Brisbane City, the flood levels reached upstream are significantly higher. The Figure below shows the history of the highest annual flood peaks recorded at the

City Gauge between 1840 and December 2009 (so it does not include the January 2011 flood). In that period, Brisbane experienced 10 Major, 8 Moderate and 12 Minor flood events. The descriptions of Major, Moderate and Minor as used by the Bureau of Meteorology are given in the Glossary. The table below shows flood levels on the Brisbane River for a selected number of river flood events.

Table 1: Selected Flood events

River Height Station (m AHD)	Feb 1893	Feb 1931	Jan 1974	Jan 2011
Gatton	16.33	n/a	14.63	n/a
Mt Crosby	32.00	21.78	26.74	n/a
Ipswich	24.50	15.50	20.70	19.25
Moggill	24.50	15.40	19.93	17.48
Jindalee	17.90	9.60	14.10	12.91
Brisbane City	8.35	3.32	5.45	4.46

The floods of 1841 and 1893 reached over 8 m AHD in Brisbane City. This represents a depth of approximately 6.5 m above the highest tide level. Since 1893 the largest flood in the Brisbane - Bremer systems was in 1974. In Brisbane the 1974 flood rose to a height of 5.45 m at Brisbane Port Office gauge while Ipswich reached a height of 20.7 m. As the Brisbane River flooded it backed up the Bremer River resulting in 4 to 5 days of record heights in Ipswich. Seqwater has been quoted in the media as saying the 1974 flood saw a river flow rate of 9,500 cubic metres of water per second. Note that the Jan 2011 flood (4.46m at City Gauge) is not included in the graph below, which was prepared in 2009 by the Bureau of Meteorology.



2.4 The Brisbane River Catchment

2.4.1 Geographical Characteristics

The Brisbane River is a large catchment of 14,000 km^2. Numerous creek systems feed the Bremer and Brisbane rivers. Rainfall across the catchment varies for any single event with differences of 1,000mm been observed values in the catchment for historic events.

2.4.2 Catchment Characteristics

Runoff is largely controlled by topography (draining system structure, catchment area, grades, etc.), land classification (land use, soil type, vegetation etc.) waterway capacity (conveyance and storage) and antecedent soil moisture content. These characteristics dictate the catchment's response to rainfall. This includes the depth, rate, and duration of runoff.

In the Brisbane catchment, these characteristics have changed significantly since the 1893 events due to progressive settlement and development. This development included two large dams that provide temporary flood storage within the catchment. As a result the catchment's response to rainfall has changed significantly since 1893 and continues to change.

Furthermore, the generation of runoff and hence the development of a flood hydrograph is influenced by the characteristics of an individual storm event. The characteristics include the storm intensity, the spatial and temporal patterns of rainfall, and the movement of the storm over the catchment

2.4.3 Flood Mitigation Dams

Two large dams provide temporary flood storage in the catchment, Wivenhoe and Somerset dams. Both dams are upstream of where the Lockyer Creek and the Bremer River joins the Brisbane River. As such where the rain event is centred within this large catchment and how it moves over it determines their effectiveness as a flood mitigation measure for any event.

Table 2: Major Dams

Dam	Wivenhoe	Somerset
Completed	1985	*1959*
Water supply Storage (GL)	1,150	370
Temporary Flood Storage	1,450	524
Location	Brisbane River Upstream of Lockyer & Bremer	Stanley River upstream of Brisbane River
Catchment (km^2)	7,000 including Somerset Dam	1,330
Reservoir surface area (km^2)	107.5	42.1

While Wivenhoe and Somerset dams are capable of significantly reducing Brisbane River events, they have limited mitigating effect on the Bremer River acting only to reduce the downstream level of the Bremer River as it enters the Brisbane River.

2.4.4 Creeks

As mentioned above, this report does not consider creek flooding. It is the opinion of the review group that given the power of the flow in the Brisbane River during flood any creek flooding will have limited impact on the flood levels seen along the river. The more likely scenario is that the Brisbane River will back up any creek causing greater localised flooding or creek flooding. Given this the increased creek flooding is outside the scope of this report but should be considered as part of a more comprehensive flooding review such as the update of the Lord Mayor's Taskforce on Suburban Flooding.

2.4.5 Tide and Storm Surge

The Brisbane River is tidal for approximately 86km from its mouth to around Colleges Crossing. Mean High Water Spring Tide in the bay is approximately 0.927 m AHD. Highest Astronomical Tide is 1.487 m AHD.

Storm tide risk in the bay is significant. The storm tide level on January 1974 was approximately 1.6m AHD while in May 1996 the storm tide level was around 2.8m AHD. It appears that tide and storm surge can account for approximately +/- 2 m range in the bay. However, the probability of the largest observed storm tide level coinciding with a flood of the magnitude of the January 2011 event is significantly less than 1 in 100.

2.5 Flood control levels in Brisbane

2.5.1 Differences between Design Events and Actual Events

Before any comparative information is presented it is important to understand the difference between actual observed flood events and probability-based design flood event such as Q100.

The flood event experienced in January 2011 is an *actual observed flood event*. It is *one of many possible events* from a large population of flood events that have occurred or could occur in the Brisbane River catchment from a combination of meteorological, hydrological and hydraulic factors. Observations on these factors during actual flood events are the main source of data and information for the derivation of probabilistic design flood events such as the Q100.

The term, Q100, can be misunderstood. Some people believe a 1 in 100 year flood will only occur once every 100 years on average. Rather, Q100 is a probability-based design flood event, aimed to reflect *typical combinations of flood producing and flood modifying factors* which act together to produce a flood event at a specific location of interest that has a 1 in 100 chance of being equalled or exceeded in any one year (1% annual exceedance probability – AEP); it is described as having an average recurrence interval (ARI) of 100 years. It is a theoretical flood model used to inform planning and policy.

Flood event characteristics of interest for flood management considerations are the peak flow, flood event volume and flood duration, and the resulting flood levels at specific locations. Best estimates of Q100, or similar probability-based design floods, together with information on the bounds of uncertainty attached to these estimates, form the basis for the selection of the DFE for a specific location.

As such, any actual flood event will vary in some degree from the theoretical flood model. This is particularly an issue for a large catchment such as the Brisbane-Bremer catchment. In such large catchments there is a greater chance that actual events will have variables that exceed the range used in developing the theoretical flood model.

2.5.2 Q 100 for Brisbane

For Brisbane the Q100 for river flood has a history of calculation and review based on specific events. The current Q100 for Brisbane was last estimated in 2003 as a peak flow of 6,000 cumecs (with uncertainty bounds of ± 1000 cumecs) and a corresponding flood level of 3.3 m AHD at Brisbane's Port Office gauge (with uncertainty bounds of ±. 0.5 m)

2.5.3 Defined Flood Event (DFE) and Defined Flood Level (DFL) for Brisbane

DFL is the level above Australian Height Datum (AHD)[3] that Council requires habitable floors to be built above to provide protection against floods up to the magnitude of the DFE. DFL is based on the flood levels that are estimated in the DFE. It is a planning control to avoid people building habitable floor levels in locations or at heights that carry greater risk of flooding than that protected against by the DFL. The Brisbane City Plan also requires an additional 500mm of "freeboard" to be added to allow for a factor of safety, uncertainties and localised effects. It should be noted that in unusual circumstances Queensland's performance based planning system under the Sustainable Planning Act 2009 can allow alternate solutions other than set floor levels to be considered.

It is desired that the floor levels of commercial and industrial developments meet or exceed the DFL; however an applicant may use a risk management approach if adopting the DFL leads to undesirable outcomes. Although this may be worthy of some reconsideration, it is beyond the scope of the TOR for the Joint Flood Taskforce.

The State Planning Policy 1/03 states the Queensland Government's default position is that the 1% Annual Exceedance Probability (AEP) flood or Q100 is generally suitable as the DFE for a Local Government. However, there is a provision to allow a Local Government to define the DFE as higher than the Q100.

Brisbane City Council has defined the DFE to be higher than the Q100 due to previous experience with river flooding (1974 floods). Brisbane City Council uses a flow of 6,800 cumecs as its DFE with a resulting level of 3.7 m AHD at Brisbane's Port Office gauge as its DFL. This was first set in 1978 and was reconfirmed in 2003.

[3] AHD - Australian Height Datum - is the national surface level datum corresponding approximately to mean sea level. Levels measured relative to this datum are given as "m AHD

2.5.4 The role DFE and DFL in development

DFE and the resulting DFL are fundamental in setting levels for development. Levels for a development are set from the DFL though they vary with building classification and use (eg. habitable or non-habitable). The DFL reflects the slope of the flood profile and thus increases in level progressively as one moves upstream from the Port Office.

Levels set for development include a 'freeboard' margin which allows for uncertainties in the hydrologic and hydraulic models to determine design flood flows and corresponding flood levels, as well as a range of factors which may raise the flood levels locally. The freeboard margin may vary for different locations and types of development.

3.0 How January 2011 Flood compares to Q 100

As discussed above in 2.4.1, before any comparative information is presented it is important to understand the difference between actual observed flood events and probability-based design flood event such as Q100. The flood event experienced in January 2011 is an *actual observed flood event*. It is *one sample from many possible events* that have occurred or could occur in the Brisbane River catchment from the combination of meteorological, hydrological and hydraulic factors. Observations on these factors during actual flood events are the main source of data and information for the derivation of probabilistic design flood events such as the Q100. Q100 is a theoretical statistical estimate of flood characteristics used to inform planning and policy.

3.1 Runoff

On balance the JFTF considers that the flood runoff resulting from the major rainfall event of January 2011 was greater than the 1974 event but not as great as the 1893 event. One likely contributing factor is the nearly complete saturation of the ground resulting from the long period of rainfall preceding the flood event.

Two large rainfall events, separated by 36 hours were recorded. Further analysis of the rainfall is required to confirm that the January 2011 event was rarer than the Q100 design event. However, this analysis can be undertaken only after the BoM have collated and checked the rainfall data.

3.2 Antecedent catchment conditions

The Q100 calculation assumes 10 mm initial loss and 1 mm/h continuing loss, uniformly distributed over whole catchment. This reflects a relatively saturated state of the catchment at the start of a 72-hour design storm and the resulting flood event. In the months leading up to January 2011, sustained rainfall was experienced across the catchment resulting in a saturated catchment. It is possible that the initial loss and continuing loss were less than those assumed in the Q100 calculation.

In the Q100 calculation the initial reservoir volume was assumed to be 100 percent of its water supply storage with the corresponding level of 67.0m AHD (the "F.S.L.")
The conditions at the beginning of the Jan 2011 flood were similar. The dam level was at 67.0m AHD on 2nd February 2011 and had risen slightly to 67.3m AHD on 6th February.

3.3 Inflows to Wivenhoe Dam

Flood volumes for Q100 for various rainfall durations are given in Table 4-7 of SKM 2003. The 72-hour volume is 2180 GL.

The total flood inflow volume to Wivenhoe dam during the Jan 2011 flood event was estimated to be 2,650 GL. This estimated inflow volume exceeds the available flood storage in the Dam of 1450 GL.

3.4 Flood Routing Effect of Storages

The 2003 review of Q100 estimated that there was a reduction of about 50% in peak flows between pre-dam and post-dam estimates of Q100 in Brisbane. This reduction arose from the attenuation effect of the estimated available flood storage in the dams. A comparison of the magnitude and effectiveness (attenuation capacity) of the available flood storage between the Q100 and the January 2011 event needs to be assessed in future work.

Currently the mitigating effect of the dams in the 2011 flood is not available. The operation of Wivenhoe dam is outside the Terms of Reference of the JFTF and it is expected that it will be one of the matters examined by the State Commission of Enquiry. It is necessary that this mitigating effect is assessed in future work.

3.5 Relative timing of flood contributions from different parts of the Catchment

The twin rainfall events separated by 36 hrs created nearly coincident peaks at the confluence of Lockyer Creek. The timing of peak discharge from the dam was separated by only a relatively small time interval from the arrival of the peak flow from the Lockyer at its junction with the Brisbane River. The design parameters used in design Q100 modelling does not consider coincident peaks.

3.6 Interaction with Tides and Storm Surge

The flood of January 2011 peak was influenced by a high tide of 0.46 m AHD at 3.13am on the 13 January. In the Q100 design model the downstream control used was a level at the mouth of the Brisbane River corresponding to Mean High Water Spring Tide (MWHS), 0.9m AHD ("the tailwater level").

3.7 Resulting Flood Levels Q100 versus January 2011 Flood Levels

Table 3: Level Difference- Q100 Vs January 2011 Flood

Selected Locations	Jan 2011 Flood Approx. Level (m AHD) #	Q100 Design Level (m AHD)	Difference between 2011 and Q100 (m)	DFE Design Level- DFL (m AHD)	Difference between 2011 and DFL (m)
Brett's Wharf	2.48	1.63	0.85	2.05	0.43
Mouth Breakfast Creek	2.80	1.80	1.00	2.05	0.75
Powerhouse	3.20	2.35	0.85	2.80	0.4
New Farm Park	3.41	2.40	1.1	3.10	0.31
Story Bridge	4.35	3.00	1.35	3.66	0.69
City Gauge	4.46	3.30	1.36	3.70	0.76
SouthBank	5.35	3.70	1.65	4.30	1.05
Park Road	6.63	4.31	2.32	5.11	1.52
West End Ferry	7.42	4.92	2.50	5.79	1.64
Fairfield	8.72	5.97	2.75	6.78	1.94
Tennyson Tennis Centre	9.84	7.00	2.84	7.79	2.05
Mouth Oxley Creek	10.0	7.12	2.88	7.99	2.01
Graceville (Low Side)	10.10	7.18	2.92	8.05	2.05
Sherwood Arboretum	11.61	8.44	3.17	9.51	2.10
Seventeen Mile Rocks	12.57	9.24	3.33	10.30	2.27
Centenary Bridge	12.91	9.51	3.40	10.80	2.11
Westlake	13.80	10.30	3.50	11.88	1.92
Goodna Creek	16.79	13.30	3.49	15.20	1.59
Moggill Ferry	17.48	14.00	3.48	15.90	1.58
Karana Downs	22.98	19.31	3.67	21.10	1.88

Jan 2011 level subject to final verification

3.8 Comparison of January 2011 with Present Q100

Despite the lack of complete data at this time the JFTF has concluded that the January 2011 flood event was larger than the Q100 as presently defined.

4.0 Q100 Reviewed

4.1 Basis of current Q100 estimate

4.1.1 Overview

Q100 refers to the peak flow rate at a specific location that has a 1 in 100 chance of being equalled or exceeded in any one year (1% annual exceedance probability – AEP) or an average recurrence interval (ARI) of 100 years. There are many alternative characteristics of flood hydrographs that are important in risk management of flood events and for the selection of the DFE at a specific location. These characteristics include the peak flood flow, the peak flood level, the rate of rise in the flood hydrograph, the flood volume among many others.

From the perspective of land use planning, it is usually the peak flood level that is of interest and hence it is the peak flood level quantiles (the levels that correspond to given annual exceedance probabilities) that are desired from the design flood process. In many flood situations, estimation of the peak flood level quantile is achievable by estimation of the peak flood flow quantile. This occurs as a result of the peak flood level being dominated only by the peak flood flow. However, in many estuarine situations, the peak flood level is the result of interaction between coastal and ocean processes and the flood flow. In these situations, there is a need to consider the joint probability between flood flows and ocean conditions in determining the peak flood level quantile.

For the Brisbane River, peak flood levels in the upstream sections of the catchment would be flow dominated while the peak flood levels in downstream sections of the catchment require consideration of the joint probability between flood flows and ocean conditions.

The estimation of Q100 (and flood characteristics for other probabilistic design floods) is based on the application of a range of hydrological methods and tools, using all the available storm rainfall and flood data that are directly relevant to the area of interest. In the particular case of the Brisbane River design flood estimates, the approach adopted in 2003 used the best elements of two methods: statistical flood frequency analysis and simulation modelling of design flood events, with subsequent reconciliation of the results obtained by the individual methods (SKM, 2003; Independent Review Panel Report, 2003). The steps involved in the estimation process can be briefly described as follows.

Flood frequency analysis (FFA)
This is generally the most direct method for estimating peak flows (or flood volumes), using recorded flood data from many previous flood events of different magnitudes. FFA can be reliably applied where long-term flood records are available and where catchment conditions have remained essentially unchanged over the period of record. In the Brisbane River catchment this applies to flood data from most of the tributaries but for the lower Brisbane River the construction of dams means that pre-dam and post-dam conditions need to be analysed separately. The period of record since the completion of Wivenhoe Dam is quite short and insufficient to allow reliable estimation of Q100 for post-dam conditions. Furthermore, the increased urbanisation downstream of the dam has the potential to modify the flow-probability relationship for the more frequent floods (i.e. the Q2 to Q10 flows).

Rainfall-runoff modelling of design flood events
In this method the processes that convert probability-based design rainfall events to design flood events (hydrographs) of corresponding probability are simulated by means of a rainfall-runoff model of the catchment. This process requires assumptions about typical combinations of flood producing/modifying factors to define design storms and their conversion to flood events of given AEP or ARI (e.g. Q100). Modelling has the advantage that it is quite flexible in allowing different catchment conditions to be

simulated. Specifically, the flood mitigation impacts of dams (i.e. the modification of the inflow hydrograph to an attenuated outflow hydrograph) can be modelled quite accurately. However, in the case of a dam spillway that is controlled by flood gates, this also requires assumptions on how the dam is operated during flood conditions.

It is worth noting that the probability based design rainfalls refer to the most intense portion of a storm event. Hence the parameters used in the design modelling process usually are selected with knowledge of this constraint. Where flood volume is an important aspect of the design flood hydrograph, techniques for inclusion of pre and post peak burst rainfall are available; these techniques have been developed since the publication of the last edition of ARR and therefore are not included in the current document.

Reconciliation of flood estimates from different methods
The approach adopted in the Brisbane River flood studies (SKM, 2003) then combines the strengths of the two estimation methods by using FFA results to verify the model outputs for the pre-dam situation and then applying a modified version of the model (which simulates the effects of the dams) with probability based design storm inputs to derive peak flows and flood hydrographs for the post-dam condition.

4.1.2 Brief summary of flood studies to produce 2003 estimate of Q100

Only a brief summary is given here of the flood studies that were carried out in 2003 to produce the current estimate of Q100; more details are presented in Appendix B. The complete description of the studies and the recommendations drawn from them are given in the SKM (2003) report and the Independent Review Panel Report (2003).

The SKM (2003) study included a broad range of *flood frequency analyses* for a number of sites within the Brisbane River catchment but focussed specifically on the estimation of Q100 at Savages Crossing for the pre-dam conditions. This was based on recorded flood peak data at this site for the period from 1909 to 1958 (prior to completion of Somerset Dam), extension of flood peak data (by DNRM) to cover the period from 1890 to 1909, simulated pre-dam flood peaks for the period from 1959 to 2000 (from modelling studies by DNRM), as well as a regional flood frequency analysis using flood data from Brisbane River tributaries with adequate flood record lengths.
The *rainfall-runoff model* adopted in the SKM (2003) study is the RAFTS runoff routing model, which had earlier been developed by BCC and calibrated in a previous study. The key inputs to the model and assumptions for the estimation of Q100 are listed in Appendix B. Here it is noted that a 72-hour design storm was used, with rainfall distributed over the catchment according to the typical variation of design rainfall intensities and that the design losses assumed were 10 mm initial loss and 1 mm/h continuing loss, uniformly distributed over whole catchment; these losses reflect a relatively saturated state of the catchment at the start of a flood event

For the post-dam situation it was assumed that Wivenhoe dam was at FSL (RL 67.0 m AHD) at the start of the flood event and that the dam was operated according to operational rules incorporated into the WIVOPS simulation program, provided at that time by DNRM.

The Independent Review Panel noted the relatively wide band of uncertainty about the Q100 estimates from both methods. Taking into account all aspects of the study it recommended that the Q100 (peak flood) values shown in Table 4. be adopted.

Table 4: Recommended Pre- and Post-Dam Q100 flow estimates (m3/s) with indication of plausible range of variability (from Independent Review Panel Report, 2003 and SKM, 2003)

Location	Pre-Dams			Post-Dams		
	Q100	Plausible Bound		Q100	Plausible Bound	
		Lower	Upper		Lower	Upper
Savages Crossing	12,000	10,000	14,000	6,000	4,000	8,000
Moggill	12,000	11,000	13,000	6,000	5,000	7,000
Port Office	12,000	11,000	13,000	6,000	5,000	7,000

4.1.3 Summary

The final outcome from the Independent Review Panel Report (2003), drawing on the SKM 2003 flood study, was the conclusion that, for a flood with 1% annual exceedance probability, the best current (i.e. 2003) estimates are a Q100 flow of 6000 m3/s at the Brisbane Port Office and a corresponding flood level of 3.3 m AHD. It is very important to stress the inevitable degree of uncertainty in estimates of this kind. The Panel considered the possible range for Q100 at this location to be 5000 to 7000 m3/s and the associated range of levels to be 2.8 to 3.8 m AHD.

4.2 Critical factors in estimating Q100

4.2.1 Flood frequency analysis

The Q100 estimate for the pre-dam situation from FFA, as discussed in 4.1.2, is affected by a number of sources of uncertainty. The most basic factor relates to the rating curve that is used to convert the observed flood levels at the gauging site to flood flow estimates. As the flow magnitudes of floods for which gaugings have been undertaken are significantly smaller than the largest observed floods, the estimation of peak flows for these larger floods relies on the uncertain extrapolation of rating curves.

The largest floods in the Brisbane River catchment are likely to have resulted from different combinations of flood producing factors than the more frequent events. The statistical methods for fitting flood frequency distributions use data from the whole range of flood magnitudes, and the relatively few observations of large floods may be insufficient to define the shape of the flood frequency curve in the range of large to rare events, resulting in wide uncertainty bounds for the Q100. While some of the analyses have tried to overcome these limitations by extending the record to the floods of the 1890s and by adjusting recorded post-dam floods for the flood mitigating impacts of the dams, these steps introduce additional uncertainty in the basic data used for flood frequency analysis and may thus provide only limited additional information.

Additional flood gauging information collected during the January 2011 flood event may help to redefine rating curves in the extrapolated range and thus reduce the influence of this source of uncertainty on flood estimates. An additional very large observed event has also the potential to reduce uncertainty in the extrapolation of flood frequency curve, but uncertainty in the conversion of post-dam peak flows to pre-dam peak flows still remains.

4.2.2 Rainfall-runoff modelling

The key uncertainty factors in the derivation of Q100 from rainfall-runoff modelling are:

- The spatial pattern of rainfall and the storm movement over the catchment which can be considered typical for producing the flood characteristics of the Q100 in Brisbane under post-dam conditions
- The typical temporal pattern of rainfall associated with a design storm of 100 years ARI
- The typical depth of rainfall that occurs in the period prior to the peak burst of rainfall
- The antecedent conditions (rainfall losses) that would be typical for a Q100 event
- The expected initial level of the storages at the beginning of the design flood event and the spillway operation during the event

The flood data and information collected during the January 2011 event can be expected to provide additional insight into the appropriateness of the assumptions made in the 2003 studies, which could lead to a revision of some of these assumptions. However, only part of this data is available at present.

When it becomes available, the additional information on the above five flood producing/modifying factors available from observations of the January 2011 event should be used to assess the sensitivity of the rainfall-runoff model results to key assumptions, and to consider if some of the assumptions made in the 2003 studies should be revised

In principle, it would also be possible to use the rainfall and flood observations from the January 2011 flood event to check the rainfall-runoff model calibration/validation. This is outside the scope of this interim assessment but should form part of future more detailed studies.

4.2.3 Revision of best estimate of Q100

The analysis of the currently available data from the January 2011 has led to the following observations relevant to a possible revision of assumptions made in the determination of Q100:

- There are additional factors to be considered when defining a 'design storm' and a 'design flood event' that produces design flood levels of corresponding probability in Brisbane.
- The key additional factors include the special characteristics of the temporal rainfall pattern (longer duration, double peak) and spatial distribution of rainfall that tend to be critical for the post-dam flooding situation in Brisbane.
- Both of these factors are highly variable and the Jan 2011 flood indicated a different range of variation than previously assumed.
- The assumed losses in the derivation of the current Q100 event may be higher than what can typically be expected during rare storm events.

- A detailed study of the joint probability of the various flood producing factors (using Monte Carlo simulation) will be necessary to determine the typical combinations of factors that are likely to produce a Q100 event for Brisbane.
- For the determination of flood levels in Brisbane associated with the Q100 event, the joint probability of river flooding, tidal influences and creek flooding will also need to be considered.
- A revised Q100 estimate from a detailed study and the resulting flood levels in Brisbane will still have a significant band of uncertainty associated with them.
- Even without such a detailed study it is clear that any review/revision of Q100 should allow for the special factors experienced during the Jan 2011 flood event which point to an increase in estimated design flood peaks and design flood levels downstream of Wivenhoe Dam compared to the current Q100 event and the DFE.
- In the absence of results of detailed studies a precautionary approach should be adopted in the revision of previous Q100 estimates as an interim measure.

These observations support the following conclusions on the likely direction and magnitude of a revision to the current Q100 for the Brisbane River:

- The flood hydrograph reaching Brisbane during the Jan 2011 event can be interpreted as providing a likely upper bound estimate of the revised Q100 flood estimate for Brisbane and is thus consistent with a precautionary approach.

4.2.4 Flood level considerations

Estimation of a design flood level can be considered to comprise two components; namely estimation of the design flow and, secondly, the conversion of the design flow to a design level at a specific site. Typical approaches for conversion of flows to levels include

- Rating curve;
- Hydrodynamic model.

The use of a rating curve assumes a unique relationship between flow and level. While this approach is applicable for many situations, it is unlikely to be appropriate for the Brisbane River in the tidal region. The 2003 studies recognised this limitation and therefore used the second approach.

The basis of the use of a hydrodynamic model to convert flood flows to flood levels is the numerical solution of the unsteady flow equations for flow over surfaces. There are many factors influencing the local transformation of flow to level with the more important of these being

- Energy gradient – in general, the steeper the energy gradient, the larger the flow rate. Hence, the same flood flow can result in different flood levels due to different energy gradients which may occur during the rising and falling stages of a flood hydrograph or for different types of flood events.
- Floodplain representation – there is a need to represent the floodplain in a digital form either as a cross section or as a DTM. This digital representation is assumed to be representative of the catchment characteristics. If the calibrated model is capable of reproducing historical events, then it is assumed that the

representation is adequate for the purpose. The 2003 studies used a calibrated Mike-11 model.
- Hydrograph volume – the third parameter is the hydrograph volume. There are two components to the hydrograph volume which are the volume arising from the runoff generated by the rainfall prior to the peak burst and the runoff volume generated from the peak burst of rainfall. It is the former volume which can be important in the transformation of flood flows into flood levels as this prior volume can pre-fill the floodplain thereby reducing the energy gradient and hence increasing the flood level for a given flood flow.
- The bathymetry of the river channels – it is likely this has changed in the Brisbane River and in its major tributaries, possibly substantially, since it was last measured.

Of the four components noted above, it is considered that the flood volume is the most important consideration. The flood hydrograph volume for the January 2011 flood event was far greater than that for the Q100 design hydrograph. The design event was based on a flow dominant problem and not one where volume is a major issue. This greater volume will result in filling of the floodplain prior to arrival of the peak flow thereby limiting the available floodplain storage for attenuation of the flood hydrograph. Hence design flood levels calculated for the same peak flow as for the January 2011 flood event are likely to be biased low in the design event in the regions where floodplain storage was assumed to be available.

The peak ocean level during the Jan 2011 event was 0.46 m AHD compared with the level of 0.9 m AHD used for the design event. This means that, in the downstream reaches, the Jan 2011 levels will be lower than in a design event for the same flow rate but with an ocean level of 0.9 m AHD. In downstream reaches influenced by the ocean levels, there is no direct relationship between flow rates and flood levels.

4.2.5 Unknown Information Required for New Estimate of Q100

Before a new estimate for Q100 can be developed it will be necessary for the following information to be obtained.
- BoM is still assembling the rainfall data for Jan 2011
- There is strong suspicion that the extrapolated rating curve for the gauging station at Savages Crossing (owned by DERM) is seriously inaccurate causing underestimates of flows of order 20% or more.
- BoM is finding that large floods often have intense localised rainfall events. These are not adequately recorded by the existing rain gauge network and they may be missed completely.
- BoM suspects that it may be necessary to increase substantially the estimates of peak flows for the 1893 floods, for 1974 and for 2011 because of the previous matter and also because some of the rainfall data is for relatively long periods – up to daily rainfall – and this misses out on high intensity shorter periods within the event.
- There is some belief that the 2011 rainfall event was greater than that in 1974 but this requires clarification when the complete data is available. However there is clear evidence that the runoff volumes were greater than those in 1974 and if

Wivenhoe dam had not been present it is possible that the peak flow and peak levels would have been greater than that in 1974.

4.3 Conclusion

On the basis of the data currently available, the flood levels experienced during the Jan 2011 flood event provide an indication of the levels that may be expected from a revised Q100 event. However, varying tidal influences and creek contributions mean that the probability associated with these levels may be different at different locations.

The January 2011 flood has brought a significant amount of new data and information on the nature of flooding in the Brisbane River and about the factors contributing to very large flood events in this catchment. Significant work is required to review Q100 for the Brisbane River in the light of this new information. This work could not be completed given the data available to the JFTF, some of which is still being collected as detailed in 4.2.5.

In light of the available information it is clear that the current Q100 needs to be reviewed. It is more likely than not that this review will raise the Q100 upwards.

On balance, the JFTF believes that, in the absence of results of a detailed flood study review, a precautionary approach should be adopted. Therefore, it considers that the actual January 2011 flood event, as observed during the event, should be used as the **interim** standard on which Brisbane City Council bases its decisions concerning habitable floor levels for new development and should be a consideration for habitable floor levels for redevelopment of existing properties. Wherever the existing DFL is higher than the January 2011 flood event, the existing higher flood level should prevail.

5.0 Benefits and Cost of New Defined Flood Event

For understanding the consequences of a new DFE, five (5) alternate DFL scenarios have been qualitatively compared. These scenarios are:

- Current Q100 (3.3m at City Gauge)
- Current Defined Flood Level (3.7m AHD at City Gauge)
- January 2011 Flood Event (4.46m AHD at City Gauge)
- 1974 without Wivenhoe Dam (5.45 m AHD at City Gauge)
- 1893 without Somerset and Wivenhoe Dams (8.35m AHD at City Gauge)

Section 6 of this report then draws conclusions on the overall benefits and consequences of changing the Brisbane River flood standard, for each of the scenarios.

5.1 Flood Risk Management Benefits

5.1.1 Nature of Flood Risk Management Benefits

The benefits of different flood risk management strategies are measured by their potential to reduce expected future flood damages and other flood impacts (including risk of injury and loss of life) compared to a base case. In the Brisbane River flooding context considered here, the benefits of various *defined flood event scenarios* are expressed as marginal benefit in comparison with the flood damage costs and flood impacts associated with the *current DFE* (the 'do nothing' option).

The estimation of the expected future flood damages/impacts has to take into account the full range of possible flood events, weighted by their annual exceedance probability. The benefits of a higher DFE (and associated higher defined flood levels) are then measured by the reduction in residual flood damages (the flood damages that are not avoided by the adoption of a specific DFE).

The types of benefits may include:

(i) Reduction in trauma to the community associated with the occurrence of a flood event that exceeds the adopted habitable flood standard and consequential loss of valued possessions. This is a result of development being more resilient to flood damage. This benefit will accrue over the long term as development and redevelopment occurs. It is generally accepted that as the DFE increases in height, the reduction in trauma to the community would reduce, over a period of time.

(ii) Existing development – gradual reduction of flood damage potential as habitable floor levels are raised through redevelopment of existing buildings. It must be noted this is a long term benefit and depends on the rate of redevelopment and refurbishment of existing building stock. Similar to trauma reduction, higher DFE's will lead to a reduction in flood damage potential.

(iii) Future development – reduction in residual flood damage cost in areas subject to the new flood level regulations. This effect provides benefits from the commencement of a new flood standard and continues to accrue as new development comes on line ie. it is a long term benefit

(iv) Reduced cost of flood response and flood recovery measures when an event that exceeds the current DFE occurs. This benefit occurs over the long term through the overall accrual of higher flood protection afforded to people, buildings and infrastructure through development and redevelopment.

These benefits associated with setting defined flood levels for planning and building purposes can be enhanced by other flood risk management measures that raise public awareness of the flood risk, helping the affected community to reduce its exposure to flood risk by preventative measures, flood warning systems, flood mitigation and improved flood resilience. Through the Lord Mayor's Task Force on Suburban Flooding, Council has initiated many such measures since 2005.

5.2 Flood Risk Management Costs

In determining costs of alternate DFE scenarios a descriptive methodology has been used as described below.

5.2.1 Impact Assessment Descriptors

To best determine how these costs can be assessed, three key descriptors have been developed. The criteria are listed below and shown in more detail in Appendix B.

1. Urban Fabric – the impact upon infrastructure and development costs to deliver the desired urban growth patterns for Brisbane ie. the SEQ Regional Plan and CityShape 2026.

2. Social Fabric – the number of people affected, impacts upon their built environment, community facilities, amenity and the amount of change they will be required to manage in their day to day lives. For example, where a property owner's home was not previously included with the DFE, once included there may be consequences for insurance, the value of the dwelling and even community facilities may no longer be able to be located close by.
3. Economic Fabric – relates primarily to the impacts upon businesses such as property development through development costs to achieve flood resilience. Changes in flood standards can also impact upon the decisions about locations of commercial operations that may have higher levels of flood risk e.g. private schools, manufacturing industry with low ability to relocate expensive machinery quickly at a time of flood.

5.2.2 Limitations of Methodology

Given the data available for this investigation, there are known impacts which were not possible to consider. Some of these are listed below, but there may be others:

- Precise knowledge of cost to each property
- Property market response.
- Housing affordability
- Development costs
- Social wellbeing and health

Additionally, habitable floor level information was not available for the various scenarios, so inundation of part or all of a property was used as a proxy in Section 5.3.3.

5.3 Assessment of Individual Criteria

Where data was available it has been used in the following assessment of impacts. Where data was not available, impact has been classified from "low" to "extreme" with reference to the descriptors in Section 5.2.1.

5.3.1 Impact on growth centres & corridors

Significant planning has been undertaken in Brisbane City through Neighbourhood Planning to deliver the CityShape 2026 and support SEQ Regional Plan 2009-2031 growth framework and housing targets. This section aims to give an indication of the potential magnitude of impact of the various DFE scenarios on these planning initiatives.

The growth corridors and centres listed in the table below are those which could be physically affected by some form of inundation from one or more of the various DFE scenarios.

Table 5: Possible consequence of DFL scenarios on growth centres and corridors

DFE Scenario	Current Q100	Current DFE	Jan 2011	5.45m (1974)	8.35m (1893)
Albion	Low	Minor	Medium	High	Extreme
Eastern Corridor	Low	Low	Low	Minor	Medium
City Centre	Low	Low	Minor	Medium	Extreme
South Brisbane Riverside	Low	Low	Medium	High	Extreme
Woolloongabba	Low	Low	Low	Low	Minor
Milton	Low	Low	Medium	High	Extreme
Towong-Taringa	Low	Low	Minor	High	High
South West Rail Corridor	Low	Low	Medium	Medium	High
Overall Impact	Low	Low	Minor	Medium	High

5.3.2 Transport Network

Brisbane and Ipswich are to a large degree established areas with much of the transport network already in place. The consequences of new DFEs are the ability of the transport network to improve its flood immunity without significant impacts on the surrounding area in terms of amenity or functionality with other parts of the network. On this basis the consequence has been assessed subjectively on a number of elements of the transport network.

Table 6: Transport Network Consequences

DFE Scenario	Current Q100	Current DFE	Jan 2011	5.45m (1974)	8.35m (1893)
Local Roads	Minor	Medium	High	High	Extreme
Arterial Roads	Low	Low	Minor	Medium	Medium
Rail Network	Low	Low	Low	Minor	Medium
Overall Impact	Low	Minor	Medium	High	Extreme

5.3.3 Additional number of properties within DFE area

For the purpose of this exercise, properties within the DFE area are defined as those properties situated on land that shows any level of inundation during the peak of these selected flood event scenarios. Where land parcels are held together these are counted as one property. For multi-unit residential development the total number of units on that property has been counted, as they all are affected in some way, if not from direct inundation. For example, a community title development with 150 individual dwelling units may have received flood waters in its basement, though no flooding of habitable areas within any of the individual units may have occurred. In some instances, the flooding impact would have been immaterial, affecting vacant land only.

For residential properties it would have been preferable to compare the number of dwellings that would receive inundation of the habitable floor level, but this information was not available.

Table 7: Numbers of properties within DFE area

DFE Scenario	Current Q100	Current DFE	Jan 2011	5.45m (1974)	8.35m# (1893)	Jan 2011-Current DFE
Commercial	1,171	1,178	2,759	2,907	n/a	1,581
Industrial	783	1,589	2,000	2,482	n/a	411
Community	24	34	46	48	n/a	12
Multi-Unit Residential	6,814	10,756	15,834	18,025	n/a	5,078
Single Dwelling Residential	4,666	7,543	10,228	12,306	n/a	2,685
Total	13,445	21,100	30,867	35,768	n/a	9,767

This measure is not available at this time.

5.3.4 Impact on streetscapes

In determining the impact on residential streetscapes, the additional depth of inundation for each DFE scenario, compared to the current DFE is shown in Table 10. In many areas, such as Fairfield and Rocklea, the existing level of inundation currently causes difficulties with achieving house design under 8.5m. The additional consequence is dealing with the amenity issues of bulk and scale in the local setting of isolated houses over 8.5m. Therefore the assessment of this measure also factors in this consequence.

To assess this impact it is considered a typical two (2) storey houses of timber and tin construction may be between 7.5 and 8.3 m in height (including 0.5m flood freeboard).

Since a large proportion of these types of houses affected during the January 2011 event are located between West End/Milton and Graceville, the average relative difference in level between Park Road and Graceville has been used. The reason for this is the effect of a rise at the City Gauge is magnified upstream. This effect is shown in the comparison of river heights in Table 8.

Table 8: Height difference of DFE scenarios from current DFE and impact on residential design.

DFE Scenario	Q100	Current DFE	Jan 2011	5.45m (1974)	8.35m (1893)
Height Difference to DFL at Park Road	-0.8	0.00	1.52	2.01	5.59
Height Difference to DFL m at Graceville	-0.87	0.00	2.05	2.75	6.73
Average Difference	-0.84	0.00	1.79	2.38	6.16
Relative Impact	Low	Nil	Medium	High	Extreme

The effective interface of a use and the street is a key factor in achieving street activation and amenity. As the height difference between the street and active building uses increases, safety, activation and amenity become harder to successfully achieve. While small differences can be accommodated, greater increases may only be accommodated by graduated design and potentially flood resistant uses.

Many inner city commercial streetscapes are situated between Teneriffe and West End, including the lower city centre and Southbank. As the majority of new development is currently occurring from the City to West End, the difference between the current DFE and the scenario DFEs at the City Gauge and West End Ferry are used as a guide to average consequence as seen in Table 9.

Table 9: Height difference (m) of DFE scenarios from current DFE and impact on streetscape

DFE Scenario	Q100	Current DFE	Jan 2011	5.45m (1974)	8.35m (1893)
Height Difference to DFE Scenario Level m at City Gauge	-0.4	0.00	0.76	1.75	4.76
Height Difference to DFE Scenario Level m at West End Ferry	-0.87	0.00	1.64	2.16	5.90
Average Difference	-0.64	0.00	1.20	1.96	5.33
Relative Impact	Low	Nil	Medium	High	Extreme

5.3.5 Impact on community infrastructure

Community infrastructure such as medical facilities, schools and the like are particularly susceptible to flood risk and many received some level of inundation during the January 2011 event. For comparative purposes, Table 10 shows the number of community facilities that would receive some level of inundation at the various scenarios.

Table 10: Potential impact on community infrastructure – medical & schools

DFE Scenario Event	Q100	Current DFE	Jan2011	5.45m (1974)	8.35m (1893)#
Facilities Affected	24	34	46	49	n/a
Relative impact	Low	Low	Minor	Medium	High

Information not available at this point of time however it is considered the impact is likely to be at least high.

5.3.7 Industry and commercial development

The principal industrial area affected by the January 2011 event is at Rocklea. This is an established area which reuses or rebuilds sites. Much of the area is under the current DFE and consequently risk management solutions are often required to manage the impacts of flooding on individual sites. As the DFE is not applied to development applications for industrial uses, in-depth investigation of the impacts on industry is considered outside the scope of the Terms of Reference. It is hoped however that property and business owners in these areas will choose to manage their own flood risk, possibly using a new DFE as a guide. Table 11 shows the height difference between the current DFE and the various scenarios at Rocklea.

Table 11: DFE comparisons at Rocklea

DFE Scenario	Q100	Current DFE	Jan2 011	1974	1893
Relative Difference in DFL scenarios compared to current DFL at Rocklea (m)	-087	0.0	2.05	2.99	7.05
Relative impact	Low	Nil	High	High	Extreme

Commercial development along the River is concentrated generally between the CBD and Toowong/West End. The impact on these activities will be measured by its ability to adapt to a new DFE over time. This may be through built form/design changes and/or risk and disaster management approaches, such as locating essential building services out of basements and in upper parts of buildings. As the change in DFE increases the process of adaptation becomes more challenging. Therefore, as flood restrictions on built form increase, flexibility in design decreases with potential adverse impact on building utility and costs. There is however a positive benefit over the long term as commercial precincts would become more flood resilient. The difference in level from City Gauge to West End Ferry has been used for comparison. The impact is then applied as per the discussion above, as shown below in Table 13.

Table 12: DFE comparisons in several commercial areas

Flood Scenario	Current Q100	DFE	Jan 2011	5.45m (1974)	8.35m (1893)
Height Difference to DFE Scenario Level m at City Gauge	-0.4	0.00	0.76	1.75	4.76
Height Difference to DFE Scenario Level m at West End Ferry	-0.87	0.00	1.63	2.16	5.9
Average Difference m	-0.64	0.00	1.20	1.96	5.33
Relative Impact	Low	Nil	Medium	High	Extreme

6.0 Discussion of DFE Scenarios

In the limited time available, the assessment of the benefits and costs of the different options could only be undertaken in a qualitative way but it is important that a full flood risk management study should be undertaken as soon as possible.

6.1 Current Q100 of 3.3m AHD at City Gauge

As can be seen from the tables throughout Section 5, the current Q100 is a theoretical flood level that is below the current DFE. Given the research undertaken into the January 2011 flood event and the advice of the expert hydrologists, it is not advisable to reduce the current DFE for the Brisbane River. Due to a lack of available information, the JFTF was unable to redefine the Q100 for the River in the time frame available although this work clearly needs to be done. Adopting the current Q100 as a new DFE would have a negative benefit in terms of improving Brisbane's flood risk management.

6.2 Current DFE of 3.7m AHD at City Gauge

The current DFE is a theoretical event that has been in place for the Brisbane River since 1978. The January 2011 flood was significantly higher than the current DFE (0.76m at the City Gauge), encompassing an estimated 9,767 additional properties.

This height difference is amplified as the distance from the river mouth increases (with some local variations), demonstrated by a height difference of approximately 2.05m at Rocklea and Graceville. Given the recommendations of the expert hydrologists, maintaining the current DFE as an interim development standard would not change the current flood risk and damage profile of the city and is not recommended.

6.3 January 2011 Flood Event Level of 4.46m AHD at City Gauge

As can be seen by looking at the history of Brisbane River annual flood peaks dating back to 1840 (refer to Section 2.3), this event of 4.46m at the City Gauge is very significant. Prior to the January 2011 flood event, only 6 other events have exceeded 4m at the City Gauge since the 1840s. All of these events occurred prior to the construction of Wivenhoe Dam.

The effect of changing an interim DFE to the 2011 flood level has been assessed against the impact on the urban, social and economic fabric as defined in Section 5.2.1. Where possible the effect has been quantified. The overall impact has been assessed as Minor to Medium, with significant benefits for flood risk management accruing over time, as redevelopment and new development occurs.

Due to the limited time available, accurate financial cost implications of this option were not able to be quantified. One notable feature is that if the DFE was to move to such a level, there would be a significant impact on those communities affected by the change. Predominant matters are building heights in the suburbs upstream of West End and difficulty in maintaining streetscape in some local areas with a risk management approach. It does however set the City on a path for achieving a long term outcome of proportions approaching a medium value of flood risk management benefit. It also provides greater protection against a possible trend of more frequent large flood events.

6.4 1974 Flood level of 5.45 m AHD at City Gauge

As a comparison, the pre-Wivenhoe Dam 1974 flood event was assessed. It was used because the level was already modelled making it possible to draw the comparisons to other events undertaken in Section 5.

DFE of this level would have a High consequence on the city's urban, social and economic fabric. It would be difficult for many areas to develop properly with land sterilisation for certain uses locally, a real prospect. It would also have an impact on house raising options with this becoming an unrealistic option in many locations such as Rocklea where the habitable floor level would increase by an estimated 2.99m. In addition to the practicalities of achieving habitable floor levels above this height, detrimental impacts on both residential and commercial streetscapes would result.

At this level, some reconsideration of land uses may be necessary. Notably however the overall impact on growth centres and community facilities is limited, though transport networks will suffer. Long term flood risk and damage profile of the city is likely to be significantly reduced but the costs would outweigh the benefits.

6.5 1893 Flood Level of 8.35m AHD at City Gauge

This level was assessed to provide a feeling for what an extreme event may do. In summary, a DFE of such a magnitude would require a complete reappraisal of how the city is planned, its transport network security and location of community facilities, however long term flood risk and damage profile of the city would likely be highly reduced.

7.0 Conclusion

How does the January 2011 flood event compare to the Q100 as currently defined and Brisbane City Council's Defined Flood Event (DFE)?

In the flood event experienced, the heaviest rains were inland on the western fringe of the Brisbane River catchment and on the Great Dividing Range. Over the Brisbane River catchment as a whole, based on rainfall captured by BoM's Enviromon rain gauges, the estimated average 5-day rainfall is 322mm, with the major sub-catchments of Wivenhoe Dam, Bremer River and Lockyer Creek receiving 370mm, 223mm and 268mm respectively.

Given the pattern of rainfall, the Brisbane River received significant flows from the upstream catchments of the Lockyer and Bremer. The flow down the upper Brisbane River (above the Lockyer Creek) and Stanley River were mitigated by Wivenhoe Dam. However Brisbane felt the full force of the flows down the Lockyer and Bremer Rivers. As a result of the rainfall, Brisbane experienced a significant river flood.

Based on examination of the rainfall patterns of a number of previous Brisbane River floods, it is concluded that the Brisbane catchment experienced a significant rainfall event with a rain pattern that was different from that experienced in 1974. Full details of the rainfall magnitudes were not available at the date of this Report. However back calculations from recorded releases from Wivenhoe and the record of water level in the dam suggest significantly more flood producing rainfall occurred than indicated by the presently available rainfall data. The calculated dam inflow hydrographs show two peaks, the first of the magnitude of 1974 and the second of greater magnitude than 1974, 36 hours later. The level recorded at Savages Crossing was higher than in 1974. Flood inflow volumes to Wivenhoe as calculated from the known releases from Wivenhoe dam and the recorded water levels in the dam total 2,650 GL as compared to a total of 1,410 GL for that location in 1974 and 2,744 GL in February 1893.

On balance the JFTF considers that the flood runoff resulting from the major rainfall event of January 2011 was greater than the 1974 event but not as great as the 1893 event.

All of the peak flood levels recorded in January 2011 by the gauges along the Brisbane River were higher than the existing Defined Flood Levels, ie. levels previously calculated for the 1974 flood event mitigated by Wivenhoe Dam. Therefore, taking into account this fact together with its assessment of the rainfall event, the JFTF considers that the January 2011 flood event was larger than the Brisbane City Council's Defined Flood Event.

The Q100 as presently defined is, in general, a slightly lesser flood than the Defined Flood Event. Therefore the JFTF considers that the January 2011 flood event was larger than the Q100 as presently defined.

Much more detailed work is required to accurately identify the probability of this event for Brisbane.

Does Q100, as it is currently described, remain the best estimate of a 1 in 100 year event?

Q100 is a theoretical flood model used to inform planning and policy. This probability-based design flood event aims to reflect typical combinations of flood producing and flood modifying factors which act together to produce a flood event that has a 1 in 100 chance in any one year of occurring at a specific location of interest.

The January 2011 flood has brought a significant amount of new data and information on the nature of flooding in the Brisbane River and about the factors contributing to very large flood events in this catchment. Significant work is required to review Brisbane's Q100 in the light of this new information. This work could not be completed given the data available to the JFTF report, some of which is still being collected.

In light of the available information about the 2011 flood event, the JFTF considers that it is essential that the current Q100 is reviewed. It is not possible to predict the outcome of such review but it is considered more likely than not that this review will lead to an increase in the magnitude of the Q100 and increases in associated flood levels.

Accordingly, what standard should be used to enable new development and redevelopment to proceed with confidence and certainty?

To answer this question five(5) scenarios have been evaluated. These scenarios are:

- Current Q100 (3.3m at City Gauge)
- Current Defined Flood Level,DFL (3.7m AHD at City Gauge)
- January 2011 Flood Event (4.46m AHD at City Gauge)
- 1974 without Wivenhoe Dam (5.45 m AHD at City Gauge)
- 1893 without Somerset and Wivenhoe Dams (8.35m AHD at City Gauge)

On balance, the JFTF believes that, in the absence of results of a detailed flood study review, a precautionary approach should be adopted. Therefore, it considers that the actual January 2011 flood event, as observed during the event, should be used as the **interim** standard on which Brisbane City Council bases its decisions concerning habitable floor levels for new development and should be a consideration for habitable floor levels for redevelopment of existing properties. Wherever the existing DFL is higher than the January 2011 flood event, the existing higher flood level should prevail.

The JFTF notes that, in regions where the interim standard will be applied, the degree of immunity from flood risk will vary with location. This is because the January 2011 flood event is an actual event and will have variable tidal influences along the tidal reach. Consequently variable probabilities will apply along this reach.

The recommendation of a new development standard refers to land use types that are currently assessed against a DFE in the City Plan. This currently excludes industrial development however this should be considered through the current City Plan review.

Further the DFE and resulting flood regulation lines are considered only part of a flood risk management framework for a community. The approach to flood risk management for Brisbane needs to consider a broader range of initiatives if it is to effectively manage flood risk for the City. Flood risk management requires that the consequences of floods be investigated for a range of flood events up to and including the PMF. For land use planning, flood levels as well as flood flows corresponding to specific probabilities must be considered. This approach must include identification of the benefits of the management of risk, rather than seeing it as all cost.

8.0 Recommendations

It is recommended,

That the actual January 2011 flood event, as observed during the event, be used as the **interim** standard, on which Brisbane City Council bases its decisions concerning new development and redevelopment, with the essential condition that, wherever a higher level has been set as the current DFL, the higher level must apply; and that this interim standard apply until conclusion of the Commission of Inquiry and the comprehensive flood study recommended below is completed.

That all data relating to the January 2011 flood event be gathered from all sources and archived so that further analysis can make use of all data available.

That the bathymetry (river bed and banks) of the Brisbane River and its tributaries and the characteristics of the bed material from Wivenhoe dam to the mouth be measured as soon as possible.

That a comprehensive flood study be commissioned to review flood flows and levels within the Brisbane River catchment making full use of the data relating to the January 2011 flood event.

That the effects of morphological (river bed level and cross section) changes due to sediment erosion and deposition during flood events be studied for a range of flood magnitudes to determine their effects on flood levels.

That consideration be given to whether a Monte Carlo approach to the flood risk for the Brisbane Catchment is feasible and, if yes, whether it should be carried out and which influencing factors should be included in the Monte Carlo approach. This may include consideration whether two or more types of rainfall events should be built into the statistical analysis for theoretical floods. (In a Monte Carlo analysis the influencing input factors such as rainfall patterns, storm tracks, catchment conditions, tide and storm surge are sampled, either randomly or in accordance with their joint probabilities, to select a large number of different combinations of inputs for simulation with a catchment modelling system to develop many alternative predictions of flood events.

These predictions are then analysed statistically to estimate their exceedance probabilities).

That a complete Flood Risk Management analysis for the area of Brisbane affected by flooding by Brisbane River and its tributaries be carried out. It is essential to move from the Q100 mentality and to adopt a risk management approach in line with National Flood Risk Advisory Group (NFRAG) and other relevant guidelines. The risk management approach would require a detailed assessment of the benefits and costs of a full range of flood mitigation options.

Appendix A: Terms of Reference

Joint Flood Taskforce

TERMS OF REFERENCE (TOR)

Document Change History

Document Control Sheet

Contact for enquiries and proposed changes. If you have any questions regarding this document or if you have a suggestion for improvements, please contact:

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Version History

Version	Author	Issue Purpose	Date
V 1.0	Andrew Chesterman	First Release Draft	1 February 2011
V 2.0	Andrew Chesterman	Addition of JTF – Technical Reference Group	2 February 2011
V 3.0	Caitlin Kinsella	Minor Updates, including changes to membership names, and end-date.	10 February 2011
V4.0	Caitlin Kinsella	Updates from Cr Cooper's office.	10 February 2011
V5.0	Caitlin Kinsella	Final updates from Cr Cooper's office.	10 February 2011

Project Owner Approval

The following officers have **approved** this document.

Name ______________________________

Position ______________________________

Signature ______________________________ Date ____________

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Document Purpose

The purpose of this document is to clearly define the Terms of Reference (TOR) for a Brisbane City Council/Ipswich City Council Joint Flood Taskforce.

Role of the Joint Flood taskforce

Brisbane City Council, in partnership with Ipswich City Council will form a Joint Flood Taskforce to investigate the January 2011 flooding events. The Taskforce will recommend interim flood immunity standards and development guidelines to manage redevelopment of flood affected properties and new development activity within the Brisbane River floodplain.

Operation of Joint Flood taskforce

The Taskforce will utilise available information to make its recommendations on the questions posed in 3.3 *Outcomes of the Joint Flood Taskforce*

The Taskforce shall provide recommendations to the Lord Mayor's Recovery Task Group by **Thursday 10 March**.

Relationship to State Commission of Inquiry

The Joint Flood Taskforce does not form part of the State's Commission of Inquiry.

The recommendations of the Joint Flood Taskforce are interim and their application may be validated or varied dependant on the outcome of the State's Commission of Inquiry. The recommendations of the Joint Flood Taskforce will be provided to the Commission of Inquiry and Flood Response Review Board.

Relationship to Lord Mayor's Flood Response Review Board and Lord mayor's Recovery Task Group (LMRTG)

The Lord Mayor has established an independent Flood Response Review Board. This Board will review the effectiveness of Council's response and disaster management arrangements, the impact of planning regulations in flood affected areas and the effectiveness of public warnings and advice, as well as the effectiveness of storm water and flood prevention infrastructure, and failure of river-based infrastructure. This Board will report in May 2011 to the Lord Mayor and the LMRTG. The progressive minutes and final recommendations of the Joint Flood Taskforce will be provided to the Lord Mayor's Flood Response Review Board.

The LMRTG, and the Town Planning Recovery Sub-Committee, will oversee the Joint Flood Taskforce and implement its recommendations on an interim basis.

Outcomes of the joint flood taskforce

The primary goal of the Taskforce is to provide expert advice and develop interim recommendations guiding development and redevelopment in Brisbane and Ipswich.

Key questions the Taskforce will need to answer are:

1. How does the January 2011 flood event compare to the Q100 as presently defined and BCC's Defined Flood Event?
2. Does Q100, as it is currently described, remain the best estimate of a 1 in 100 year event?
3. Accordingly, what standard should be used to enable new development and redevelopment to proceed with confidence and certainty?

Membership – Joint Flood Taskforce

The proposed Joint Flood Taskforce shall be comprised of:

- Chair - Emeritus Professor Colin Apelt
- Shane Hackett – Acting Manager Water Resources Branch, Brisbane City Council
- Quinton Underwood – Senior Engineer, Hydraulics, Ipswich City Council
- Erwin Weinmann - Experience: Senior Lecturer in water subjects at Monash University, Former Deputy Director CRC for Catchment Hydrology (Monash Node), and Co-author of Book VI (Estimation of Large and Extreme Floods)
- Professor James Ball - University of Technology Sydney

Membership – Technical Reference Group

In addition to the Joint Flood Taskforce, a Technical Reference Group will be established for the Taskforce to interface with as required.

It is expected the Joint Flood Taskforce would establish smaller expert technical working groups for input into the recommendations (formed from amongst the members of the Technical Reference Group).

Internal

- Kerry Doss – Manager City Planning
- Andrea Kenafake – Manager Development Assessment
- Richard Sivell – Manager Major Development
- Don Carroll – Group Manager Water – City Design
- Ken Morris – Principal Engineer Flood Management – City Design
- Bevan Lynch – Chair Urban Futures Brisbane

External (subject to confirmation)

- Water CRC, Canberra
- BMT
- Bureau of Meteorology
- Department of Infrastructure and Planning
- Department of Environment and Resource Management
- SEQ Water Grid Manager
- SEQ Water

Membership- Industry reference Group

The Taskforce will establish, consult and advise an Industry Reference Group on the proceedings of the taskforce. The Industry Reference Group will have the opportunity to provide comment and advice to the Taskforce on the release of their interim recommendations.

The Industry Reference Group will provide external advice on the needs of industry to respond to the flood in terms of redevelopment and new development standards. The group will also provide industry perspective on the potential impact of the implementation of new standards on practicality, affordability and implantation needs.

The proposed Industry Reference Group will comprise;

- Chair - Bevan Lynch – Urban Futures Brisbane
- BDO Kendalls - Mark Gray
- Commonwealth Bank - Leon Allen
- MIRVAC - Matthew Wallace
- Pradella - Brett Lentz
- UDIA – Brian Stewart
- HIA - Mike Roberts
- Property Council of Australia – Justin Goddard
- Lend Lease - Guy Gibson
- Insurance Council of Australia – Robert Wheaton
- UDIA - Brian Stewart (replacement for Martin Zaltron)
- PIA – Audra Caler
- Master Plumbers – Ernie Kratschrier
- AIA President - Peter Skinner

- BDA – Matthew Miller
- UDAL - Andrew Hammonds
- Others tbc

Role of the Joint Taskforce members

The Joint Flood taskforce Chairman will be responsible for day to day decision making within the scope of the Terms of Reference and be responsible for decision making where;

- Any significant variation to scope.
- Any change in schedule that will have an impact on delivery
- Any significant issues or risks which they are not able to deal with.

If the designated Chair is not available, then the BCC Manager Water Resources will act as proxy. The acting Chair will be responsible for convening and conducting that meeting. The Acting Chair is responsible for informing the Chair as to the salient points/decisions raised or agreed to at that meeting.

Administration

Agenda

All agenda items for each Taskforce meeting must be forwarded to the Joint Flood Taskforce secretariat by C.O.B. 2 working days prior to the next scheduled meeting.

The agenda, with attached meeting papers will be distributed at least 1 working day prior to the next scheduled meeting. The Chair has the right to refuse to list an item on the formal agenda, but members may raise an item under ‘Other Business’ if necessary and as time permits.

Minutes & Meeting Papers

The minutes of each Taskforce will be prepared by the Joint Flood Taskforce secretariat. The secretariat will be supported by Brisbane City Council’s Water Resources Branch.

Meeting Agendas will include:

- Minutes and actions from previous meeting
- Update from the last Meeting
- Update on progress of the activities
- Key upcoming events, activities, changes
- Any Other Business
- Action summary and next meeting date

Action items arising from the meeting minutes will be forwarded to the relevant Divisional Manager and Taskforce member within two working days following each meeting.

Frequency of Meetings

Meetings are held weekly or at the determination of the Chair.

Proxies to Meetings

Members of the Taskforce will only have a proxy in exceptional circumstances. Where an extended period of absence is anticipated or known, a proxy shall be nominated with the approval of the Chairman.

The nominated proxy shall have voting rights at the attended meeting. The nominated proxy shall provide relevant comments/feedback to the Taskforce member they are representing of the salient points from the meetings they have attended

Quorum Requirements

The Taskforce members are key advisors to the Chair in their decision making capacity, however all decisions lie with the Chair.

A minimum of 4 Taskforce members is required for the meeting to be recognised as an authorised meeting and for the recommendations or resolutions to be valid.

Review Timetable

TBC

Appendix B: Details of Flood Studies that produced the 2003 Estimate of Q100

B.1 Results of flood frequency analyses

The SKM (2003) study included a broad range of flood frequency analyses for a number of sites within the Brisbane River catchment but focussed specifically on the estimation of Q100 at Savages Crossing for the pre-dam conditions. This was based on recorded flood peak data at this site for the period from 1909 to 1958 (prior to completion of Somerset Dam), extension of flood peak data (by DNRM) to cover the period from 1890 to 1909, simulated pre-dam flood peaks for the period from 1959 to 2000 (from modelling studies by DNRM), as well as a regional flood frequency analysis using flood data from Brisbane River tributaries with adequate flood record lengths.

The Q100 estimate from flood frequency analysis for the pre-dam situation is given in Table B1, together with nominal upper and lower bounds.

Table B1: Summary of Q100 estimates from FFA at Savages Crossing – pre-dam conditions (from Review Panel Report, 2003 and SKM, 2003)

Method	**Q100 estimates [m^3/s]**		
	Best Estimate	**Plausible Range**	
		Lower Bound	**Upper Bound**
Flood Frequency Analysis	12,000	10,000	14,000

B.2 Results of rainfall-runoff modelling

A number of different rainfall-runoff models of the Brisbane River catchment have been developed for a range of purposes. The model adopted by SKM is the RAFTS runoff routing model, which had earlier been developed by BCC and calibrated in a previous study.

The key inputs to the model and assumptions for the estimation of Q100 for the pre-dam situation are:

- Design rainfall depths for an ARI of 100 years and for a range of durations (adopted average rainfall depth over catchment = 308 mm, based on CRC-FORGE design rainfalls for a critical duration of 72-hours, with allowance for an areal reduction factor)
- Rainfall temporal pattern – standard ARR87 temporal pattern for this location, duration and ARI applied over whole catchment (with a sensitivity analysis of temporal patterns based on 4 other patterns)
- Rainfall spatial pattern – based on the spatial variation of CRC-FORGE point design rainfall estimates (with a sensitivity analysis of spatial patterns based on rainfall distributions experience during 7 historical storms); storm assumed to be stationary over the catchment
- Design losses – 10 mm initial loss and 1 mm/h continuing loss, uniformly distributed over whole catchment – these losses reflect a relatively saturated state of the catchment at the start of a flood event

For the post-dam situation two further inputs/assumptions were necessary:

- Initial state of storages – assumed to be at FSL (RL 67.0 m AHD) at the start of the flood event
- Flood operation of dams – Wivenhoe assumed to be operated according to operational rules incorporated into WIVOPS simulation program

The best estimates of Q100 for the pre-dam and post-dam situation at three key locations are given in Table B2, together with nominal upper and lower bounds.

Table B2: RAFTS based Pre- and Post-Dam Q100 flow estimates (m3/s) with indication of plausible range of variability (from Review Panel report, 2003, and SKM, 2003)

Location	Pre-Dams			Post-Dams			Reduction (%)
	RAFTS Q100	Plausible Bound		RAFTS Q100	Plausible Bound		
		Lower	Upper		Lower	Upper	
Savages Crossing	9,600	8,100	10,800	5,400	3,900	6,600	60
Moggill	10,100	9,500	10,800	5,000	4,200	6,000	50
Port Office	10,100	9,500	10,800	5,000	4,200	6,000	50

B.3 Adopted Q100 estimate and uncertainty bounds

The Review Panel noted the relatively wide band of uncertainty about the Q100 estimates from both methods but considered that the pre-dam flood peak estimates at Savages Crossing derived by flood frequency analysis were more reliable than the RAFTS model-based estimates, which involved a range of additional assumptions. The post-dam estimates from RAFTS modelling were thus adjusted accordingly to give the recommended Q100 (peak flood) values shown in Table B3.

Table B3: Recommended Pre- and Post-Dam Q100 flow estimates (m3/s) with indication of plausible range of variability (from Review Panel Report, 2003 and SKM, 2003)

Location	Pre-Dams			Post-Dams		
	Q100	Plausible Bound		Q100	Plausible Bound	
		Lower	Upper		Lower	Upper
Savages Crossing	12,000	10,000	14,000	6,000	4,000	8,000
Moggill	12,000	11,000	13,000	6,000	5,000	7,000
Port Office	12,000	11,000	13,000	6,000	5,000	7,000

Glossary

ARI- Average Recurrence Interval - the expectation (or average over many occurrences) of the interval (years) between flood events with a similar magnitude

AEP – Average Exceedance Probability, the likelihood of occurrence of a flood of given size or larger in any one year, usually expressed as a percentage

AHD - Australian Height Datum - is the national surface level datum corresponding approximately to mean sea level. Levels measured relative to this datum are given as "m AHD".

Bathymetry – Bed levels and cross sectional dimensions of a river channel

COAG – The Council of Australian Governments

CRC-FORGE- Cooperative Research Centre Focussed Rainfall Growth Estimation. The CRC-FORGE method is a regional analytical method for point rainfall estimates of low Average Exceedance Probability (AEP) from data records on average less than 100 years duration. The method is a development of the FORGE method (UK) by the Cooperative Research Centre for Catchment Hydrology

DFE - Defined Flood Event - The flood event from which defined flood levels are developed and ultimately the flood control lines for development

DFL- Defined Flood Level- The flood level resulting from the Defined Flood Event

DMT- Divisional Management Team

Environmon – a network of rain gauges owned by BoM

Flood hydrograph- Expresses peak flow, flood event volume and flood duration in a graph.

Flood quantiles – the values of a flood characteristic (peak flow, flood volume, flood level at a site) that correspond to specified ARIs

Freeboard – a margin above a defined flood level set to provide a factor of safety for uncertainties in flood level estimates and localised flood effects

Mike-11- A computer program for simulation of channel flows using one dimensional equations

Monte Carlo methods (or Monte Carlo experiments) - a class of computational algorithms that rely on repeated random sampling to compute their results. With respect to catchment simulation, the influencing factors are sampled (either randomly or in accordance with their joint probabilities) for simulation with a catchment modelling system to develop alternative predictions. These predictions are then analysed statistically to estimate their exceedance probabilities

Minor, Moderate and Major flooding- as defined by BoM:

- minor flooding: causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.
- moderate flooding: low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.
- major flooding: appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

NFRAG- National Flood Risk Advisory Group

PMF- Probable Maximum Flood-

Q100- the peak flow rate at a specific location that has a 1 in 100 chance of being equalled or exceeded in any one year (1% annual exceedance probability – AEP; or an average recurrence interval (ARI) of 100 years).

SCARM - the Standing Committee on Agriculture and Resource Management, a committee of the Agriculture and Resource Council of Australia and New Zealand (ARMCANZ)

RAFTS - an acronym for a catchment simulation model - River And Flow Training System

Rating Curve - a rating curve is used to convert a recorded flood level at a gauging station to the equivalent discharge at the gauging station.

WIVOPS- Wivenhoe Dam Operations Systems

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SPP (2003). State Planning Policy 1/03 - Mitigating the Adverse Impacts of Flood, Bushfire and Landslide (and associated Guideline). Queensland Department of Local Government and Planning, Department of Emergency Services.

Brisbane River Flood Study

FURTHER INVESTIGATIONS OF HYDROLOGY & HYDRAULICS INCORPORATING DAM OPERATIONS AND CRC FORGE RAINFALL ESTIMATES

- Further Investigations
- Draft
- 29 Aug 2003

Brisbane River Flood Study

FURTHER INVESTIGATIONS OF HYDROLOGY INCORPORATING DAM OPERATIONS AND CRC FORGE RAINFALL ESTIMATES

- Draft
- 29 Aug 2003

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Contents

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1. Executive Summary

The Brisbane River Catchment is approximately 13500 km^2 and includes Wivenhoe and Somerset Dams. The catchment area upstream of these dams is approximately 7000 km^2 and therefore there is potential for flood mitigation to areas below the dams. The potential for flood mitigation is dependent on the following factors:

- Dam Operating Procedures.
- Dam levels at the start of a flood event.
- Spatial and Temporal Patterns.

The most appropriate way assess the above factors is by Monte Carlo Analysis however given the restrictions on time, this analysis was not able to be undertaken. To account for the above factors, sensitivity analysis was undertaken separately for spatial patterns, temporal patterns and starting water levels in the dams. Investigation of dam operations was not undertaken as part of this study.

The Department of Natural Resources and Mines (DNRM) provided 1%AEP CRC Forge rainfall estimates. These estimates included Areal Reduction Factors (ARF) which accounts for spatial distribution of rainfall over a catchment. ARF's were not available for catchments of this size when the previous Brisbane River Flood Study (SKM 1998) was undertaken.

CRC Rainfall depths were input into the RAFTS hydrological model (SKM 2000) for pre-dams conditions, and a series of spatial patterns were modelled. A range of peak flows were determined at Savages Crossing and these varied between 8000 m^3/s and 11500 m^3/s.

The median peak flow produced by the RAFTS model for the range of spatial patterns using a standard temporal pattern was approximately 10000 m^3/s using an Initial Loss (IL) of 10 mm and a Continuing Loss (CL) of 1.0 mm/hr. The flood frequency estimate was determined to be 12000 m^3/s (SKM 2003).

Using a catchment average 48 hour CRC Forge rainfall depth (ARF applied), the RAFTS model was then re-run using various temporal patterns for predams conditions. When zero losses were applied, the range of flows was between 12000 m^3/s and 13800 m^3/s.

This shows that by using a combination of spatial and temporal patterns, reconciliation between the FFA estimate and the RAFTS estimate could be achieved.

The CRC Forge estimates for various spatial patterns with a standard AR&R temporal pattern were run through the DNRM Dam Operations model. This model predicts an outflow hydrograph from Wivenhoe Dam. The Wivenhoe Dam outflow hydrograph was then input into the RAFTS model and peak flow estimates were calculated at Savages Crossing. Peak flows ranged approximately from 3000 m^3/s to 8000 m^3/s. The median value of the spatial pattern for post dams conditions was estimated to be 6200 m^3/s.

A temporal pattern sensitivity analysis for post dam conditions was not undertaken.

Using the 1% AEP 72 hour storm with standard temporal patterns and an IL of 10 mm and CL of 1.0 mm/hr, a dam starting water level sensitivity analysis was undertaken. If the dam is assumed full at the start of the event, the peak flow at Savages Crossing was estimated to be 5400 m^3/s. If the dam was assumed to be at 75% full, the peak flow at Savages Crossing was reduced to 3500 m^3/s.

The main objective of the report was to determine 1% peak flows and flood levels at the Port Office. To do this, the MIKE11 hydraulic model (SKM 2000) was used to account for routing effects from Savages Crossing to the Port Office. The flows predicted by MIKE11 compared well to the flows predicted by RAFTS at the Port Office. A rating curve from the hydraulic model was used to predict flood levels at the Port Office.

Based on the current level of investigation, it is difficult to provide a single estimate of the 1% AEP flood event at Port Office. **Table 1** provides a range of estimates with a 'best estimate' upper estimate and lower estimate.

- **Table 1 Range of Estimates at Moggill and the Port Office for the 1% AEP Flood**

Condition	Peak Flow (m^3/s)	Peak Flood Level (m AHD)
Lower Estimate	5000	2.76
Best Estimate	6500	3.51
Upper Estimate	8000	4.41

As a check of the peak flows predicted by the design events, two historical flood events were run through the RAFTS model. The 1893 and 1974 flood events were run through the RAFTS model for the pre and post dam conditions. For post dam conditions, the estimated peak flow at the Port Office for the 1893 and 1974 flood events were 9500 m^3/s and 6800 m^3/s respectively. Flood flows predicted for the 1893 flood event are outside the range presented in **Table 1**. While this is of some concern, the reliability of the measured historical data for this event is questionable.

Conversely, the predicted post dam peak flow for the 1974 flood event matches well with the 'best estimate flow. Measured historical data for this flood is much more reliable and a reasonable amount of confidence can be placed on the estimate.

The peak flows presented in this report are less than those predicted in the Brisbane River Flood Study (SKM 1998). The primary reasons for the reduction in peak flows are due to:

- Introduction CRC Forge Rainfall depths with Areal Reduction Factors.
- Better representation of Dam Operating Procedures.
- More reliable streamflow data.

It is recommended that the following actions be undertaken:

- Undertake a Monte Carlo Analysis
- Re-calibrate the Ipswich Rivers MIKE 11 hydraulic model within the Brisbane City Council Boundary.

2. Introduction

The introduction of CRC Forge Rainfall estimates for Queensland requires that further investigations be undertaken to determine potential impacts along the lower reach of the Brisbane River within the bounds of Brisbane City.

Furthermore, there have been modifications to Operation Procedures for Wivenhoe and Somerset Dams since the initial Brisbane River Flood Study Report (Sinclair Knight Merz, June 1998) was completed and inclusion of the latest procedures will be included in this investigation.

After a number of meetings with Council Officers, the following methodology was adopted:

- Review previous reports, CRC Forge rainfall estimates and historical streamflow data.
- Undertake a Regional Flood Frequency Analysis (pre dams).
- Undertake hydrologic modelling (pre dams).
- Undertake hydrologic modelling (dams in place).
- Analyse catchment sensitivity using various temporal patterns.
- Undertake a check with historical flood events.
- Undertake hydraulic modelling
- Reporting and documentation.

As part of the review process, an external Expert Review Panel was formed to comment on the methodology and to review the outcomes of this investigation. The findings of this panel will be presented in a separate report.

3. Hydrological Modelling

Hydrologic Modelling was undertaken to determine flows within the lower reach of the Brisbane River with Wivenhoe Dam and Somerset Dam in place. The RAFTS hydrological model developed for the Ipswich Rivers Flood Studies was used for this investigation. The Ipswich River Flood Studies RAFTS model is based on the original Brisbane River Flood Study RAFTS model.

Unless otherwise stated, the parameter set used for the RAFTS modelling was as follows.

- Initial Loss Rate (IL) = 10 mm
- Continuing Loss (CL) = 1.0 mm/h
- All model runs were undertaken for the 1% AEP flood event only.

3.1 Assumptions

- The Ipswich Rivers Flood Studies (SKM 2000) RAFTS model was used for the investigation.
- The Department of Natural Resources and Mines (DNRM 2003) Wivenhoe and Somerset Dam Operations Model was used to determine Dam outflows.

3.2 Methodology

The following Methodology describes the process that was used to determine 1% AEP flood flows at Moggill and the Port Office.

- Remove Wivenhoe Dam and Somerset Dam from the RAFTS model
- Input CRC FORGE Rainfalls in the RAFTS model using various historical rainfall distributions.
- Run the RAFTS hydrologic model (pre-dams) for the 1% AEP flood event for a series of duration's spatial and temporal patterns to determine the critical duration storm.
- Inflow hydrographs were then extracted from the RAFTS model and input into the NRM Dam Operations Model.
- The NRM Dam operations model was then run and an outflow hydrograph from Wivenhoe Dam was generated.
- Upstream of Wivenhoe Dam was removed from the RAFTS model and the outflow hydrograph generated by the NRM dam operations model was used at this location.
- The RAFTS model was then re-run to determine 1% AEP flows at Moggill and the Port Office Gauge.
- A sensitivity analysis was then performed to using Wivenhoe and Somerset Dam operating procedures assuming different starting water levels in Wivenhoe and Somerset Dams at the start of the flood event.

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3.3 Pre Dams RAFTS Modelling

The object of the pre dams modelling was to achieve reconciliation between the Flood Frequency Estimates and the flow estimates produced by RAFTS. CRC Forge rainfall estimates were input into the RAFTS model using various spatial distributions. A sensitivity analysis was also undertaken to determine affects that temporal patterns have on peak flows.

3.3.1 CRC Rainfall Estimates – Standard CRC Forge Distribution

CRC Forge Rainfall Estimates for varying duration's were input into the model with Areal Reduction Factors (ARF) applied. **Table 2 CRC Forge Rainfall Depths for Brisbane River Catchment with Applied Areal Reduction Factors** – 1%AEP presents the rainfalls and ARF's used.

- **Table 2 CRC Forge Rainfall Depths for Brisbane River Catchment with Applied Areal Reduction Factors – 1%AEP**

	24 Hour (mm)	30 Hour (mm)	36 Hour (mm)	48 Hour (mm)	72 Hour (mm)	96 Hour (mm)	120 Hour (mm)
CRC Forge Rainfall	247	268	285	317	358	385	402
CRC Forge Rainfall with ARF applied	188	209	229	263	308	338	358

The CRC Forge rainfall estimates were spatially distributed across the catchment. Maps of the 24 hour spatial pattern are presented in **Appendix A**. Standard Temporal Patterns were then applied and the RAFTS model was run for a range of durations. An Initial Loss of 10 mm and a Continuing Loss of 1.0 mm/hr was adopted.

The CRC Forge rainfall estimates with ARF's applied are presented in **Table 3 Peak Flows for CRC Forge Spatially Distributed with Areal Reduction Factors for 1% AEP Flood – Pre-dams**.

- **Table 3 Peak Flows for CRC Forge Spatially Distributed with Areal Reduction Factors for 1% AEP Flood – Pre-dams**

Location	24 Hour (m^3/s)	30 Hour (m^3/s)	36 Hour (m^3/s)	48 Hour (m^3/s)	72 Hour (m^3/s)	96 Hour (m^3/s)	120 Hour (m^3/s)
Savages Crossing	8387	**9607**	8379	8626	9192	8128	8384
Moggill	7607	9015	7588	8004	**10101**	9180	9446
Port Office	7608	9015	7589	8005	**10106**	9190	9463

Note: - **Bold values indicate the critical duration at each location**
- **Flows at Moggill and Port Office should be considered indicative only.**

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3.3.2 Spatial Pattern Sensitivity

To determine the impact of spatial patterns, seven historical spatial patterns were assessed. The 24 hour rainfall spatial pattern for each historical event were determined and a ratio was applied to rainfall depth until the catchment average rainfall depth matched the CRC Forge Rainfall Depths (ARF applied) for each duration.

The seven historical spatial patterns assessed are:

- January 1893 – most of the rainfall occurred on the north-west portion of the catchment upstream of Wivenhoe and Somerset Dams.
- February1893 – the majority of the rainfall fell on the eastern half of the catchment.
- January 1931 – high rainfalls occurred along the eastern catchment boundary
- March 1955 – high rainfalls were experienced upstream of Wivenhoe dams on the Brisbane and Stanley Rivers.
- January 1974 – this event produced high rainfalls along the eastern boundary and Lower Brisbane Catchment.
- April 1996 – rainfalls produce were high in the Lockyer and Lower Brisbane Catchments.
- February 1999 – high rainfalls fell upstream of Wivenhoe Dam.

Maps of each of the above historical spatial patterns are presented in **Appendix A**.

Each of the historical spatial patterns were applied with standard temporal patterns (AR&R 1987). RAFTS was then run (pre-dams) with an Initial Loss (IL) of 10 mm and a Continuing Loss (CL) of 1.0 mm/h was applied.

Peak flows are presented in **Table 4 Pre- dams 1% AEP Peak Flows for Historical Spatial Distribution**. Note that for all spatial distributions the 30 hour flood is the critical duration storm at Savages Crossing and the 72 hour flood is the critical duration at Moggill and Port Office. Flows presented at Moggill and the Port Office in **Table 4** should be considered indicative only. More accurate flows will be determined during the hydraulic modelling.

- **Table 4 Pre- dams 1% AEP Peak Flows for Historical Spatial Distributions.**

Spatial Distribution	Savages Crossing (m^3/s)	Moggill (m^3/s)	Port Office (m^3/s)
January 1893	11507	10196	10198
February 1893	10062	**9501**	**9504**
January 1931	8543	8026	8030
March 1955	**10046**	9619	9623
January 1974	8005	9112	9117
April 1996	8621	8917	8922
February 1999	11205	10197	10200

Note: - Bold values indicate the median flow at each location
- Flows at Moggill and Port Office should be considered indicative only.

A full listing of peak discharges at Savages Crossing, Moggill and Port Office are present in **Appendix B**.

3.3.3 Temporal Pattern Sensitivity

To assess the sensitivity of the catchment with respect to temporal patterns, a series of patterns were applied for the catchment average CRC Forge Rainfall 48 hour storm duration. An I.L of 0 mm and a C.L of 0 mm/hr was applied.

The temporal patterns assess are as follows:

- AVM – Mark Pearse
- 1972 – This is a back loaded temporal pattern extracted from the January 1972 flood event.
- 1974 – A mid loaded temporal pattern extracted from the January 1974 flood event.
- 1975 – This is a front loaded temporal pattern extracted from the December 1975 flood event.
- AR&R 1987 – Standard temporal pattern outlined in Australian Rainfall and Runoff.

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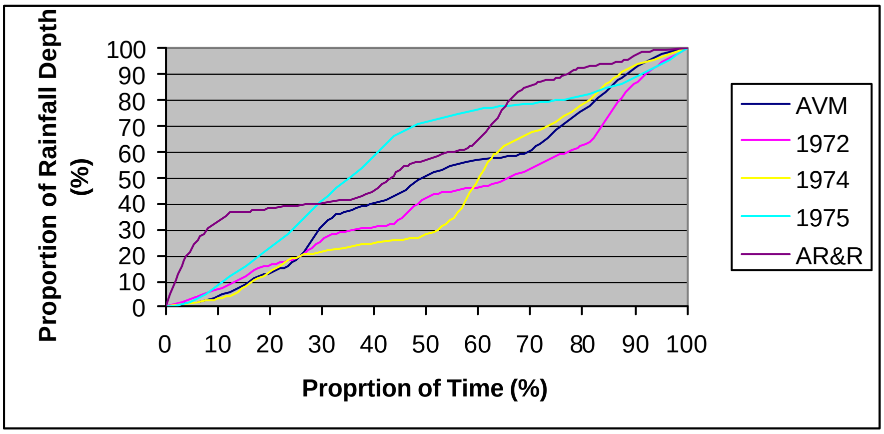
- **Figure 1 Temporal Patterns for the 1% AEP 48 Hour Storm Event**



The resulting peak flow estimates using the temporal patterns described above are presented in **Table 5 48 Hour Temporal Pattern Sensitivity.**

- **Table 5 48 Hour Temporal Pattern Sensitivity**

	48 hour Temporal Pattern				
Location	**AR&R**	**AVM**	**1972**	**1974**	**1975**
Savages Crossing	11967	12635	12858	13864	13032
Moggill	12817	13464	13287	14115	13634
Port Office	12817	13464	13287	14115	13634

3.3.4 Discussion

Table 4 and **Table 5** show that spatial and temporal patterns have a significant affect on peak flows. Given the size of the catchment and the variability that spatial and temporal patterns have on peak flows, it is evident that a Monte Carlo Analysis would be appropriate. A Monte Carlo Analysis was not possible within specified time frame for this report and therefore the sensitivity analyses was undertaken to investigate potential effects of this phenomenon.

The pre-dams historical spatial distributions produce peak flows at Savages Crossing that range from 11500 m^3/s to 8000 m^3/s with the median peak flow being 10046 m^3/s. The estimated peak flow at savages using the CRC Forge Spatial Pattern was estimated to be 9607 m^3/s.

If an IL of 0 mm and CL of 0 mm/h is applied to the CRC Forge 30 hour storm (critical at Savages Crossing), the peak flow from the RAFTS model was predicted to be 11278 m^3/s. It should be noted that the 'best estimate' of peak flow at Savages Crossing from the Flood Frequency Analysis was estimated to be 12000 m^3/s. This means that the RAFTS peak flow estimates and the FFA

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estimates cannot be reconciled unless ARF's are increased or spatial and temporal patterns are combined.

3.4 Post Dams RAFTS Modelling

Inflows to Somerset Dam and Wivenhoe Dam and outflows at Lockyer Creek and Bremer River were extracted from the pre-dams RAFTS model results and run through the DNRM Dam Operations Model. These inflows were based on the outputs presented in **Appendix B** and included an IL of 10 mm and CL of 1.0 mm/hour.

The outflow volume from Wivenhoe Dam produced by the DNRM Dam Operations model was compared to the total inflow volume into Wivenhoe and Somerset Dams. The comparison found good consistency between the volumes.

Outflow hydrographs at Wivenhoe Dam were determined using the DNRM Dam Operations model and then used in RAFTS for the CRC Forge and historical spatial patterns to determine flows at Savages Crossing, Moggill and Port Office.

3.4.1 CRC Rainfall Estimates – Standard CRC Forge Distribution

The parameters described in **Section 3.3.1** were used for the Post Dams RAFTS modelling.

The CRC Forge rainfall estimates with ARF's applied are presented in **Table 6 Peak Flows for CRC Forge Spatially Distributed with Areal Reduction Factors for 1% AEP Flood – Post Dams**.

- **Table 6 Peak Flows for CRC Forge Spatially Distributed with Areal Reduction Factors for 1% AEP Flood – Post Dams**

Location	24 Hour (m^3/s)	30 Hour (m^3/s)	36 Hour (m^3/s)	48 Hour (m^3/s)	72 Hour (m^3/s)	96 Hour (m^3/s)	120 Hour (m^3/s)
Savages Crossing	2069	3356	2186	2399	**5368**	2335	2502
Moggill	3017	3690	2999	3302	**5043**	3811	3990
Port Office	3020	3691	3001	3305	**5044**	4073	4177

Note: - Bold values indicate the critical duration at each location
- Flows at Moggill and Port Office should be considered indicative only.

3.4.2 Spatial Pattern Sensitivity

The parameters described in **Section 3.3.2** were used for the Post Dams RAFTS modelling. Peak flows are presented in **Table 7 Post Dams 1% AEP Peak Flows for Historical Spatial Distributions**. Note that the critical duration storm at Savages Crossing, Moggill and Port Office range from 72 to 120 hours for Post Dam Conditions. Flows presented at Moggill and the Port Office in **Table 7** should be considered indicative only. More accurate flows will be determined during the hydraulic modelling.

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- **Table 7 Post Dams 1% AEP Peak Flows for Historical Spatial Distributions**

Spatial Distribution	Savages Crossing (m^3/s)	Moggill (m^3/s)	Port Office (m^3/s)
January 1893	7847 (120hr)	7120 (120hr)	7121 (120hr)
February 1893	6568 (120hr)	5850 (120hr)	**5851** (120hr)
January 1931	3279 (120hr)	3218 (120hr)	3411(120hr)
March 1955	**6241** (72hr)	5709 (72 hr)	5710 (72hr)
January 1974	4771 (96hr)	**5841** (96hr)	5852 (96hr)
April 1996	4162 (72hr)	5019 (72hr)	5035 (96hr)
February 1999	7431 (120hr)	6819 (120hr)	6819 (120)

Note: **- (120hr) denotes the critical storm duration**
- Bold values indicate the median flow at each location
-Flows at Moggill and Port Office should be considered indicative only.

3.4.3 Dam Sensitivity

Full supply level of Wivenhoe Dam is at RL 67.0 m AHD and has a storage capacity of 1,165E6 m^3 of storage. The crest level of Wivenhoe Dam is at RL 79 m AHD with a corresponding storage capacity of 2,934E6 m^3. The maximum flood mitigation volume of Wivenhoe Dam is 1,769E6 m^3.

It is unlikely that Dam Operators would ever allow this amount of flood storage volume to be used as Wivenhoe Dam is an earth fill dam and overtopping is likely to cause dam failure.

The catchment area above Wivenhoe Dam is approximately 7,080 km^2. Assuming no losses, the total runoff volume for the 1% AEP flood (average CRC Forge rainfalls with ARF applied) for durations ranging from 24 hours to 120 hours are presented in **Table 8 Flood Runoff Volumes for the 1% AEP above Wivenhoe Dam**.

- **Table 8 Flood Runoff Volumes for the 1% AEP above Wivenhoe Dam**

Storm Duration (hours)	CRC Rainfall Depth wit ARF Applied (mm)	Runoff Volume ($m^3 \times 10^6$)
24	188	1331
30	209	1480
36	229	1621
48	263	1862
72	308	2180
96	338	2393
120	358	2534

Table 8 shows that if Wivenhoe Dam is at FSL, the 1%AEP 36 hour flood runoff volume can be fully stored between FSL and Crest Level without release. For 1%AEP events with longer

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durations, Wivenhoe Dam would have to be lower than FSL to store the entire flood runoff volume before the crest level is over, topped (no releases).

Given current operational procedure, it is unlikely that no releases would occur during a flood event, particularly if Wivenhoe Dam is at FSL at the start of the flood event. To determine the impacts starting water level have on flood flows downstream, a number of sensitivity runs have been done for the 1% AEP 72 hour storm. Dam Starting Water Levels (SWL) have been assumed at 75% full and 50% full with current Operating Procedures.

Peak flows assuming different Wivenhoe Dam starting water levels are presented in **Table 9 Dam Starting Water Levels Sensitivity Analysis for the 1% AEP 72 Hour Storm**.

- **Table 9 Dam Starting Water Levels Sensitivity Analysis for the 1% AEP 72 Hour Storm**

Location	FSL - RL 67 m AHD (m^3/s)	SWL 75% - RL 64 m AHD (m^3/s)	SWL 50% - RL 60 m AHD (m^3/s)
Savages Crossing	5368	3486	3334
Moggill	5043	4376	4376
Port Office	5044	4402	4402

Note: - Flows at Moggill and Port Office should be considered indicative only.

Table 10 shows that the reduction in flow is approximately 13% at the Port Office Gauge between the dam being at FSL and 75% full. It is interesting to note that flows do not change significantly between the 75% and 50% starting water levels.

3.4.4 1893 and 1974 Historical Flood Events

As a check on design flows, the 1893 and 1974 historical flood events were input into the RAFTS model and flows at Savages Crossing were reconciled with measured estimates. Wivenhoe and Somerset Dams were then input into the model and operating procedures were applied.

The resulting Post Dam flows are presented in **Table 11 Predicted Post Dam Flows for the 1893 and 1974 Historical Flood Events**.

- **Table 11 Predicted Post Dam Flows for the 1893 and 1974 Historical Flood Events**

	1893 (IL = 0 and CL = 0.5mm/h)		1974 (IL =0mm and CL = 2.5mm/h)	
Location	No Dams (m^3/s)	Som and Wiv in Place (m^3/s)	Somerset in Place (m^3/s)	Som and Wiv in Place (m^3/s)
Savages Crossing	13258	9563	7554	3882
Moggill	13856	9517	9850	6639
Port Office	13869	9519	9874	6801

Table 11 shows that the peak flows for the historical events at the Port Office are above the 1%AEP CRC Forge Estimate (5044 m^3/s), and the median spatial pattern estimate of 5851 m^3/s.

There are many uncertainties associated with the 1893 event however more confidence can be placed in the predicted 1974 flow estimate. The 1974 peak flow is within the range of flows predicted by varying spatial distributions whereas the 1893 flood is outside the predicted range.

3.4.5 Discussion

The variability of flows predicted for the post-dams catchment is further affected by the introduction of Wivenhoe and Somerset Dams. This further suggests that Monte Carlo Analysis would be an appropriate way to investigate the complexities of Dams, spatial and temporal patterns to obtain the best estimate of the 1%AEP flood event.

The CRC Forge spatially distributed peak flow at Savages Crossing was estimated to be 5368 m^3/s for the post dams case. The historical spatial distributions produce peak flows at Savages Crossing that range from 7847 m^3/s to 3279 m^3/s with the median peak flow being 6241 m^3/s.

Based on the preceding information it is difficult to specify a single estimate for the 1% AEP flood at the Port Office. Given the current information, the 'best estimate' of peak flow at the Port Office would be 6500 m^3/s with an upper and lower limit of 8000 m^3/s and 5000 m^3/s respectively.

It is recommended that Monte Carlo Analysis be undertaken as there many uncertainties associated with the above best estimate.

The peak flows presented in this report are less than those predicted in the Brisbane River Flood Study (SKM 1998). The primary reasons are that the DNRM Dam operations model was provided allowing an accurate representation of release procedures. The previous study (SKM 1998), assumed emergency operating procedures which minimise the mitigation affects that Wivenhoe and Somerset Dams have on the lower Brisbane River.

Derivation of the Areal Reduction Factors as part of CRC Forge estimates since the 1998 study have also had an impact on the flows estimates. For catchments of this size, ARF's were not available in 1998.

Another factor is that the reliability of the streamflow at Moggill and Port Office is questionable as these gauges are height read gauges and tidal effects make it difficult to derive reliable rating curves at these locations. In the 1998 study, the emphasis was to match Flood Frequency Estimates at Moggill and the Port Office. After discussions with DNRM, it was concluded that the most appropriate location to reconcile flows between rainfall based methods and flood frequency estimates was at Savages Crossing. For this investigation the focus was placed on Savages Crossing.

4. Hydraulic Modelling

The MIKE11 hydraulic model developed for the Ipswich Rivers Flood Studies was used to determine peak flood levels at the Port Office Gauge. It should be noted that this model is an extension of the Brisbane River Flood Study MIKE11 hydraulic model and that the model was re-calibrated as part of the Ipswich Rivers Flood Studies work.

While the calibration at the Moggill and Port Office is good, other sections of the reach within Brisbane City has not been calibrated, as the main focus was to calibrate the model within the Ipswich City Boundary. For the purposes of this investigation this model will provide good flood level estimates at Moggill and Port Office, however care should be taken when flood level estimates are derived in other areas of Brisbane City.

4.1 Assumptions

- Hydraulic modelling was undertaken assuming MHWS tide at the Brisbane Bar.

4.2 MIKE11 Modelling

The Ipswich Rivers Flood Studies MIKE11 hydraulic model was used for the assessment. This model routes flows from the Brisbane Bar to approximately 10km downstream of Savages Crossing. The model also includes Bremer River and other smaller tributaries which accounts for most of the major tributaries in the downstream reaches of the Brisbane River. The hydraulic modelling was undertaken for the 1% AEP spatially distributed over the catchment. Duration's ranging from 24 to 120 hours were assessed.

4.3 Results

The peak Discharges and Flood Levels for at Moggill and Port Office are presented in **Table 12 1% AEP Peak Flood Levels and Flows for the CRC Forge Spatial Distributed Rainfall**.

- **Table 12 1% AEP Peak Flood Levels and Flows for the CRC Forge Spatial Distributed Rainfall**

	Moggill		Port Office	
Duration (hours)	Q (m^3/s)	WL (m AHD)	Q (m^3/s)	WL (m AHD)
24	3269	9.41	3337	1.79
30	4117	11.27	4047	2.15
36	3317	9.61	3331	1.79
48	3647	10.36	3717	2.00
72	**5195**	**13.24**	**5059**	**2.68**
96	4103	11.54	4472	2.42
120	4231	11.77	4853	2.48

Note: - Bold values indicate the critical duration at each location

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4.4 Discussion

Table 6 and **Table 12** show that there is good consistency between the peak flows estimated by RAFTS and the peak flows estimated by MIKE 11 at the Port Office. Some confidence can therefore be taken in using RAFTS flow outputs and rating curves produced by MIKE11 at the Port Office.

Using the 'best estimate and upper and lower limits of peak flows at the Port Office presented in **Section 3.4.5**, a rating curve was used to predict flood levels at the Port Office for the 1%AEP flood event. Peak flood levels and corresponding flows are presented in **Table 13 Peak Flood Level and Peak Flow Estimates for the 1%AEP Flood Event at Port Office.**.

- **Table 13 Peak Flood Level and Peak Flow Estimates for the 1%AEP Flood Event at Port Office.**

Condition	Peak Flow (m^3/s)	Peak Flood Level (m AHD)
Lower Estimate	5000	2.76
Best Estimate	6500	3.51
Upper Estimate	8000	4.41

Note that these estimates should be considered indicative because the actual tide level may vary for an actual flood event. The levels presented in the above table are based on a Mean High Water Spring Tide (0.918) at the Brisbane Bar.

5. References

Department of Natural Resources & Mines - CRC Forge Rainfall Estimates 2003

Department of Natural Resources & Mines - Wivenhoe and Somerset Dams Operational Mode 2003

Brisbane River Flood Study - Sinclair Knight Merz June 1998

Ipswich Rivers Flood Studies - Sinclair Knight Merz July 2000

Australian Rainfall and Runoff - A guide to Flood Estimation Volume 2 IEAust 1988

Appendix A Historical Spatial Distributions

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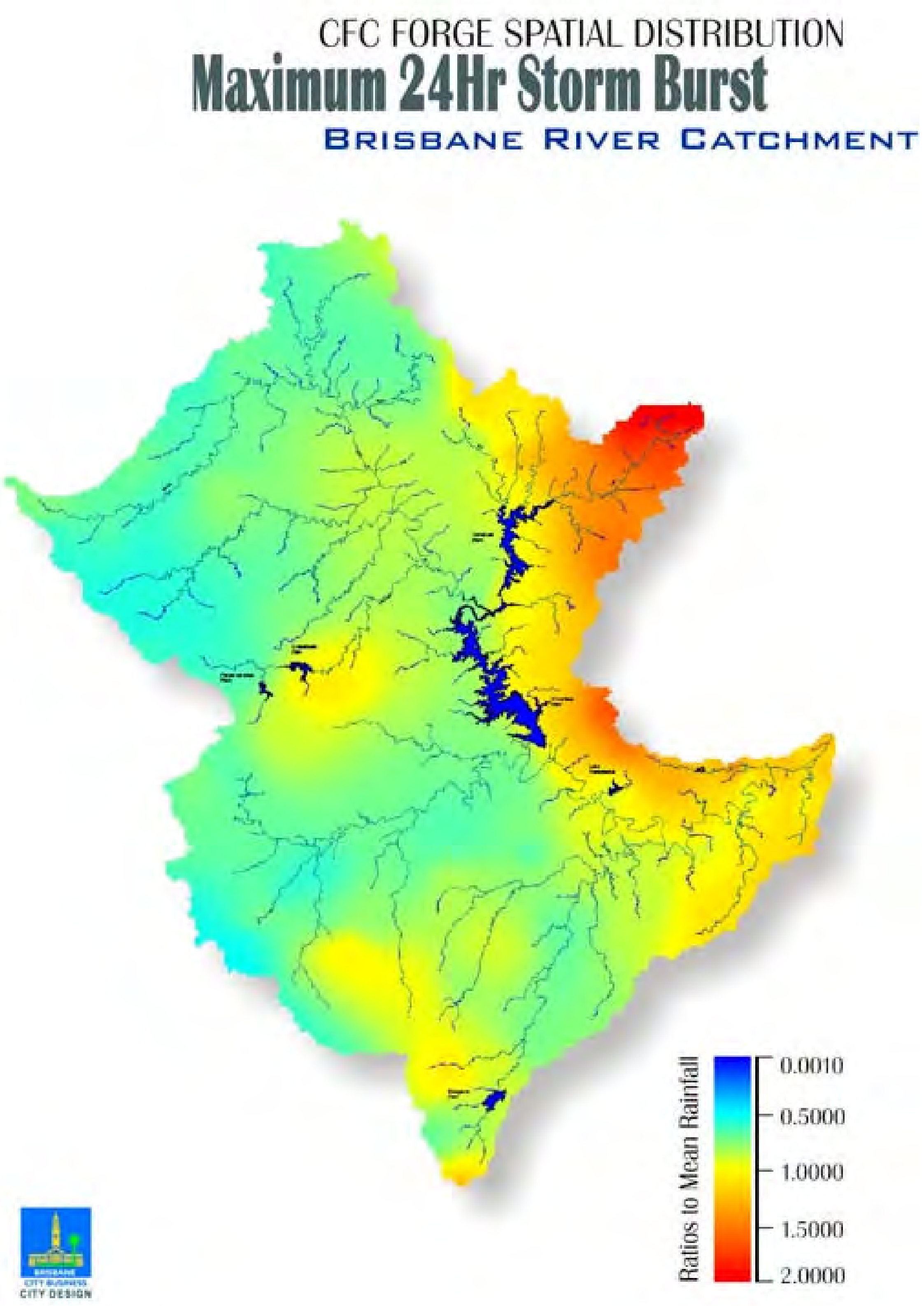
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Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
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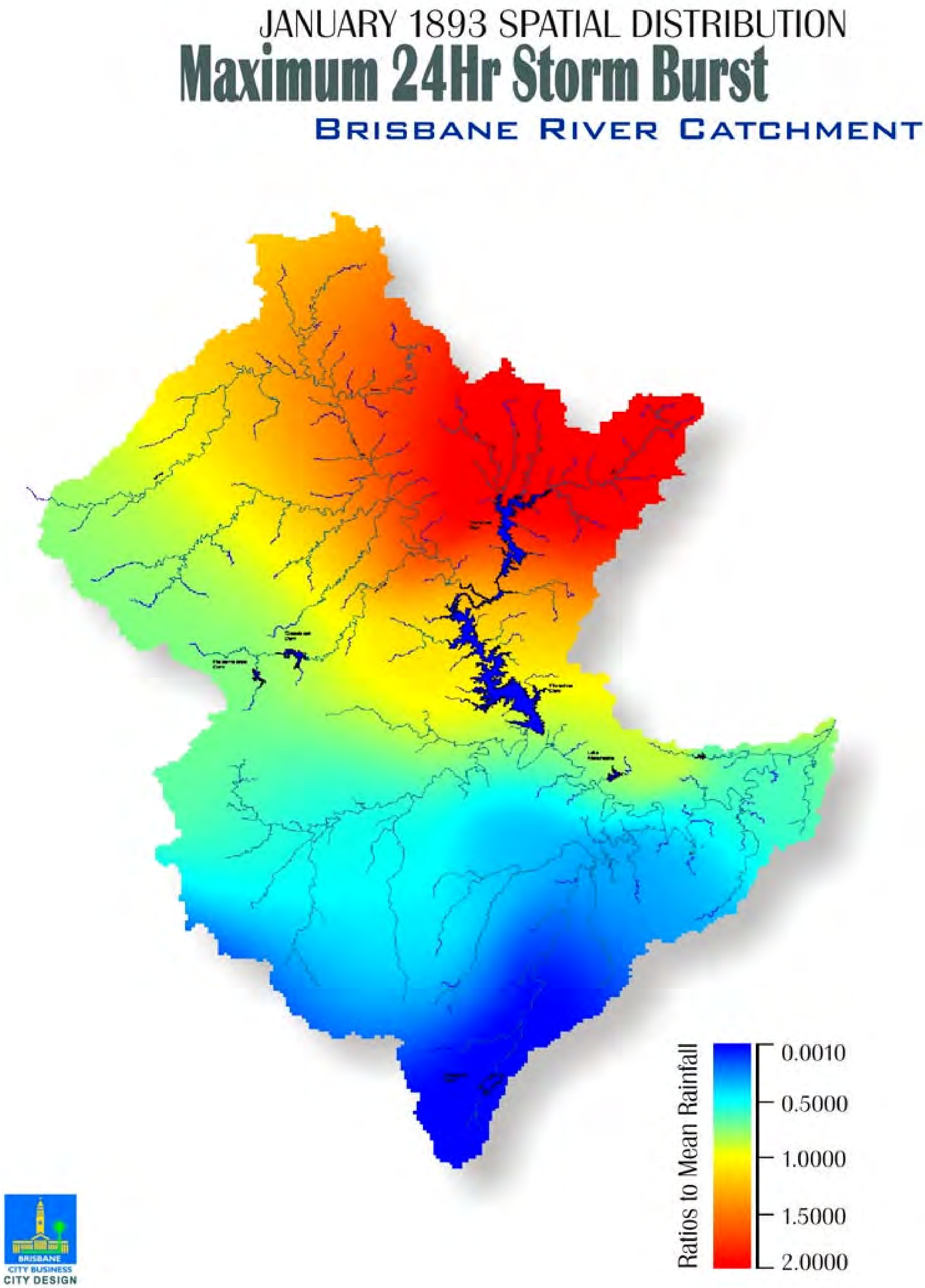
1.5000
2.0000
BRISBANE CITY BUSINESS CITY DESIGN

SKM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Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
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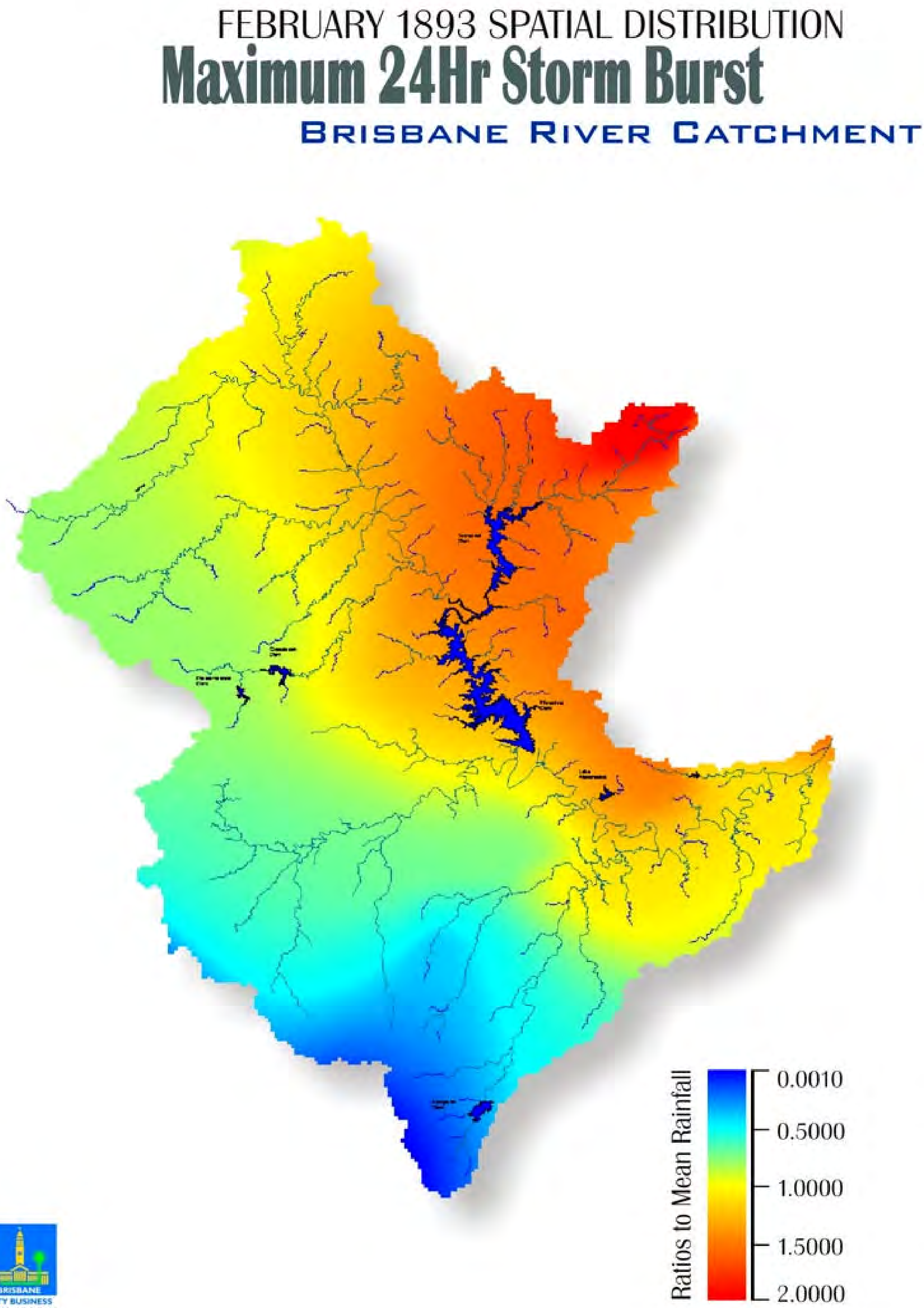
0.5000
1.0000
1.5000
2.0000
BRISBANE
CITY BUSINESS
CITY DESIGN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Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
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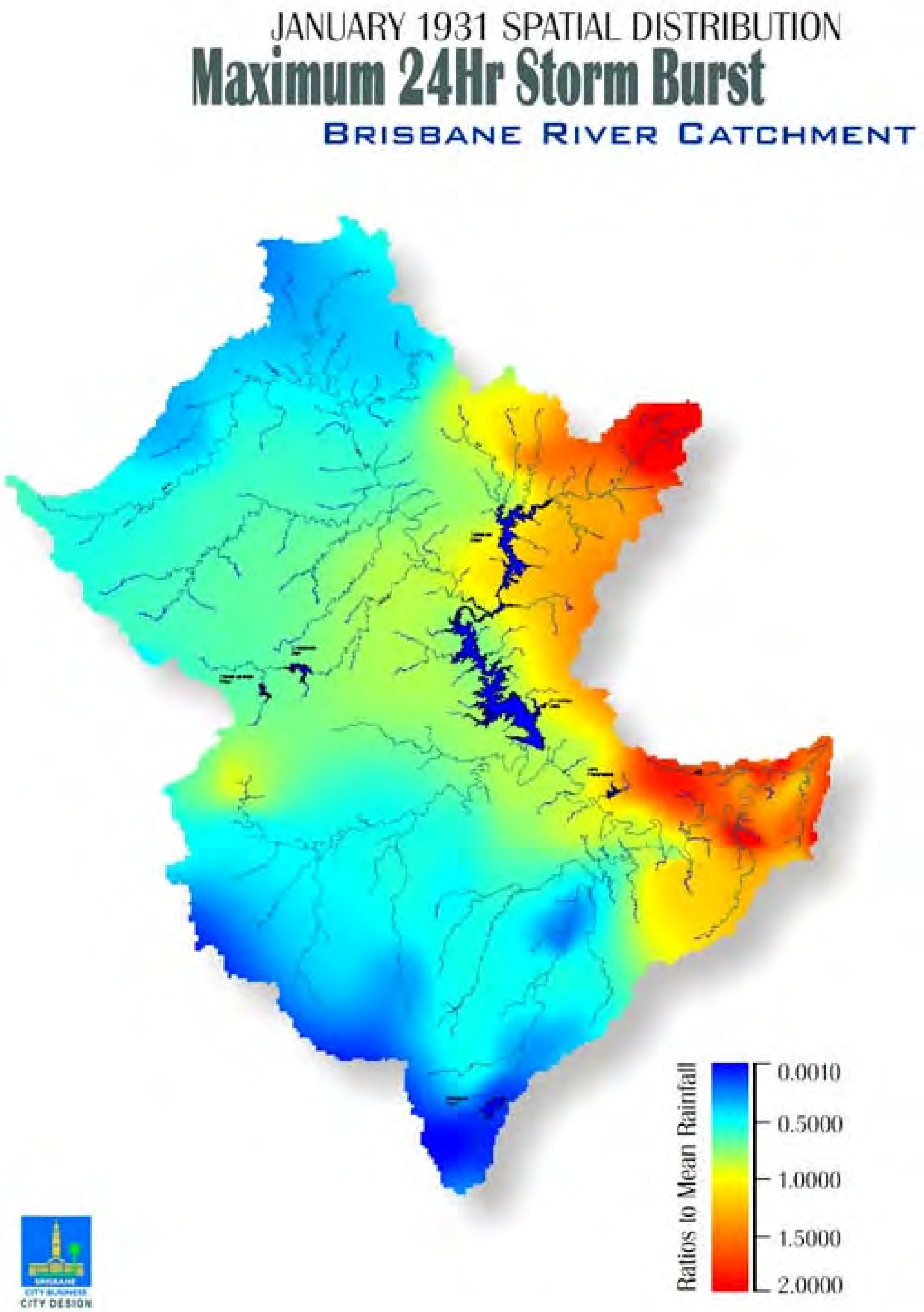
2.0000

SKM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Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
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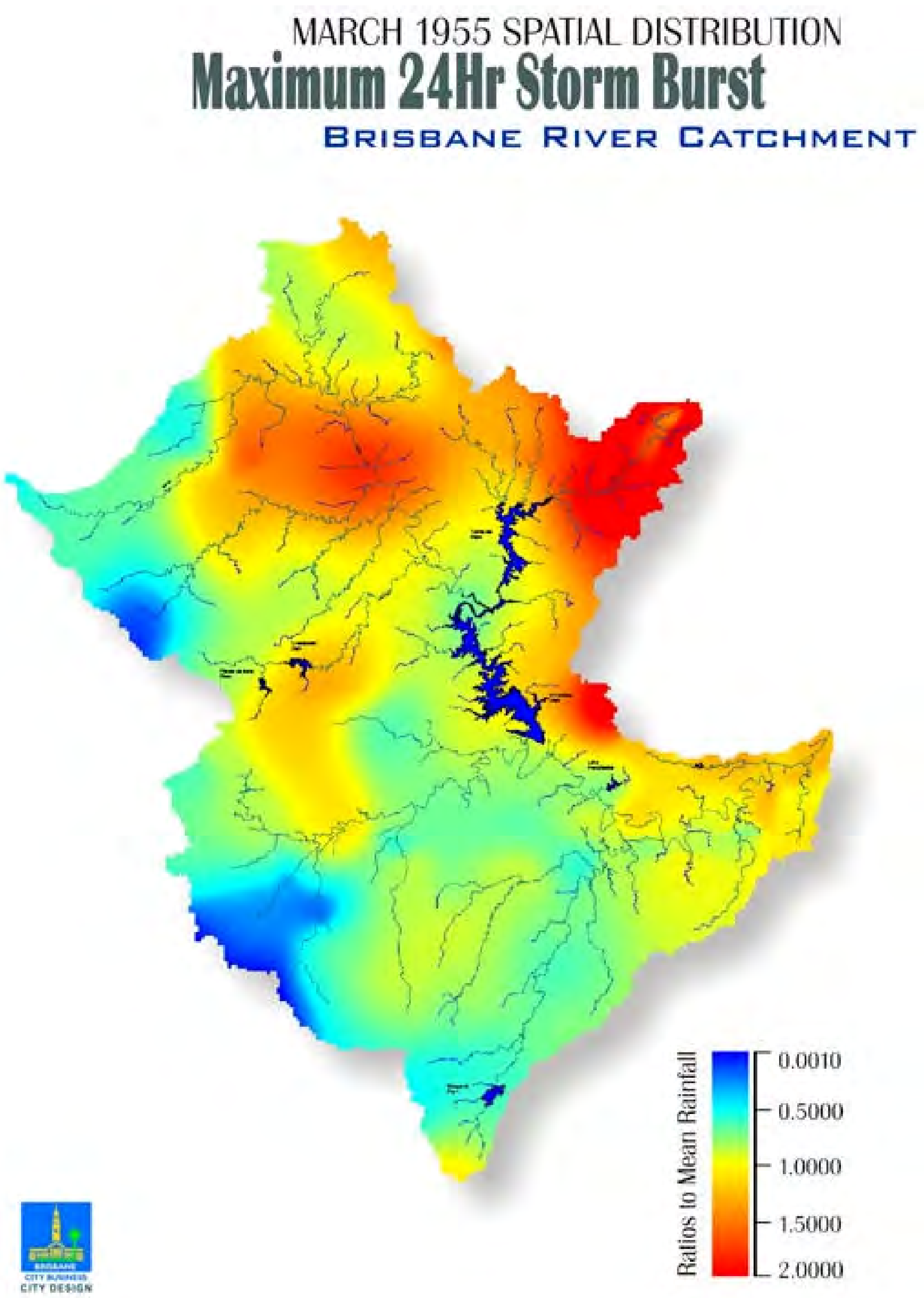
CITY DESIGN


MARCH 1955 SPATIAL DISTRIBUTION
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BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
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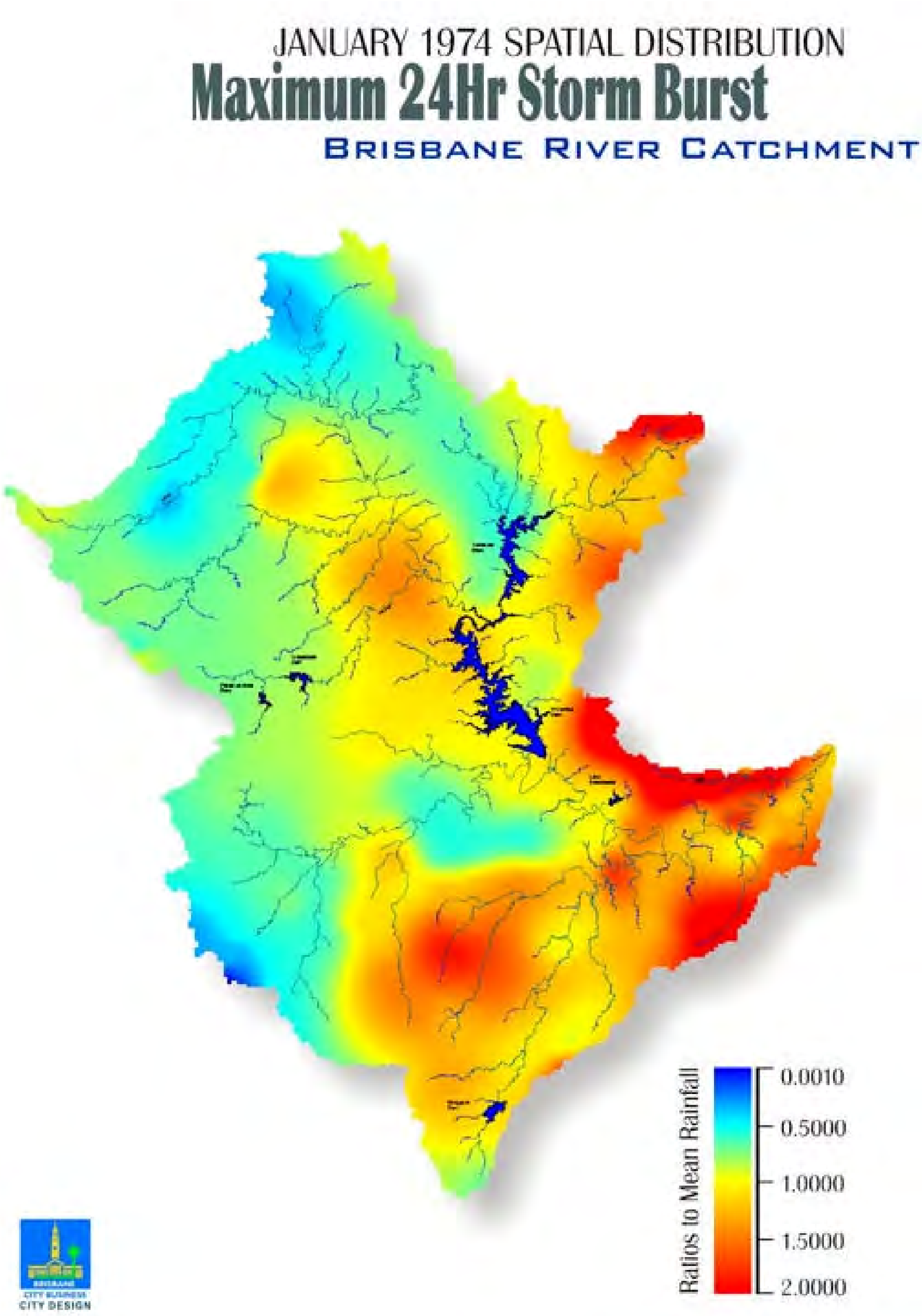
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BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
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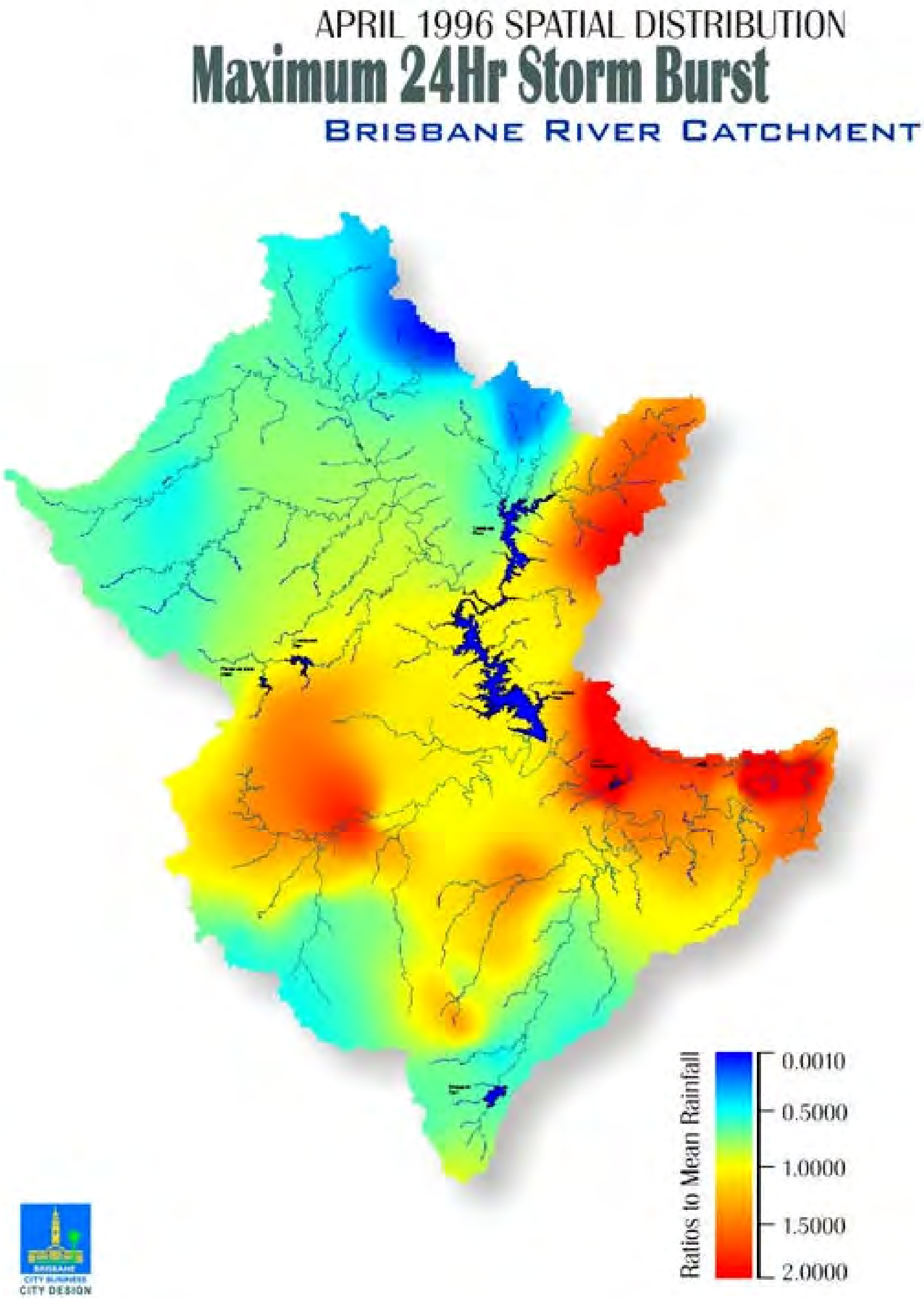
CITY DESIGN

SKM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Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
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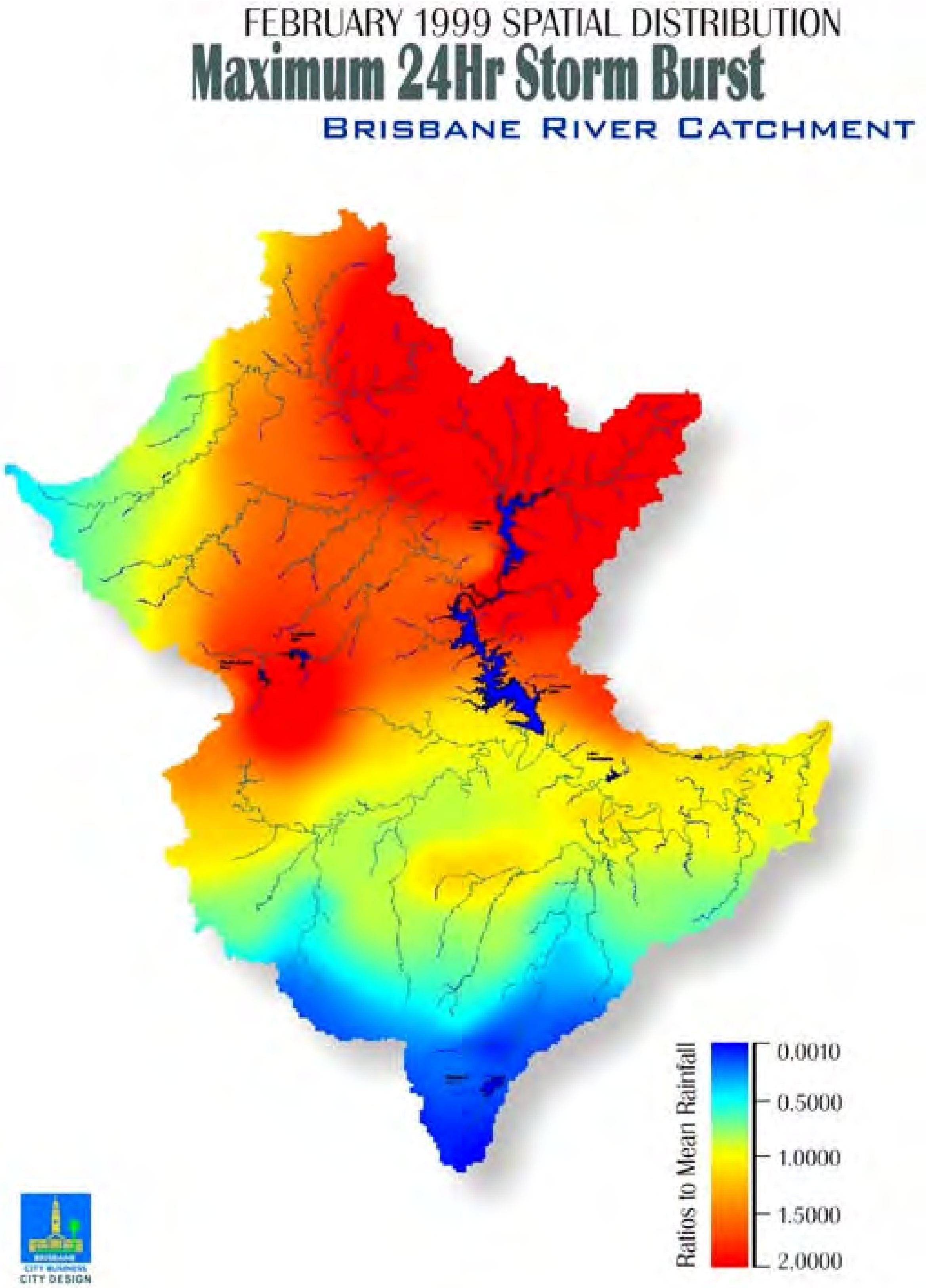
BRISBANE CITY BUSINESS CITY DESIGN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Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
0.0010
0.5000
1.0000
1.5000
2.0000
CITY DESIGN

Appendix B Pre and Post Dam RAFTS Model Results

BRISBANE FLOOD STUDY - RESULTS
NO DAMS

	DURATION	SAV-OUT	POG-OUT	JIN###
JAN 1893	24	9861	7927	7927
	30	**11507**	9793	9792
	36	9810	7932	7932
	48	10238	8535	8534
	72	10911	**10198**	**10196**
	96	9774	9394	9392
	120	10074	9641	9639
FEB 1893	24	8698	7502	7502
	30	**10062**	8789	8788
	36	8682	7512	7512
	48	9012	7866	7865
	72	9634	**9504**	**9501**
	96	8568	8636	8632
	120	8804	8904	8898
JAN 1931	24	7505	6745	6745
	30	**8543**	7648	7648
	36	7476	6776	6775
	48	7712	7191	7190
	72	8183	**8030**	**8026**
	96	7140	7610	7514
	120	7360	7713	7630
MAR 1955	24	8671	7537	7536
	30	**10046**	8925	8925
	36	8689	7554	7553
	48	8955	7916	7915
	72	9563	**9623**	**9619**
	96	8376	8750	8745
	120	8635	9002	8997
JAN 1974	24	7058	7203	7202
	30	**8005**	8049	8046
	36	7049	7073	7072
	48	7227	7528	7527
	72	7714	**9117**	**9112**
	96	6729	8161	8154
	120	6879	8454	8432
APR 1996	24	7531	7068	7067
	30	**8621**	7966	7966
	36	7549	7079	7078
	48	7748	7427	7425
	72	8287	**8922**	**8917**
	96	7184	8043	8034
	120	7399	8182	8170
FEB 1999	24	9631	7884	7884
	30	**11205**	9708	9708
	36	9578	7894	7893
	48	9981	8444	8443
	72	10642	**10200**	**10197**
	96	9512	9387	9384
	120	9809	9629	9626

BRISBANE FLOOD STUDY - RESULTS
WITH DAMS

	DURATION	SAV-OUT	POG-OUT	JIN###
JAN 1893	24	3026	2909	2909
	30	6008	4705	4705
	36	3474	3284	3284
	48	5366	3880	3880
	72	7323	6699	6699
	96	7596	6892	6892
	120	**7847**	**7121**	**7120**
FEB 1893	24	1877	2070	2061
	30	3818	3449	3449
	36	1935	2211	2203
	48	3471	3148	3148
	72	6197	5615	5615
	96	6310	5596	5595
	120	**6568**	**5851**	**5850**
JAN 1931	24	1872	2319	2051
	30	1926	3314	2708
	36	1884	2836	2452
	48	1758	2580	2382
	72	3079	3968	3146
	96	3170	3383	2940
	120	**3279**	**3411**	**3218**
MAR 1955	24	1925	2350	2345
	30	3524	3433	3433
	36	2063	2544	2541
	48	3272	3013	3013
	72	**6241**	**5710**	**5709**
	96	5926	5340	5339
	120	6151	5585	5584
JAN 1974	24	1753	3326	3324
	30	2467	3989	3987
	36	1871	3350	3279
	48	1943	3633	3627
	72	3307	4965	4418
	96	**4771**	**5852**	**5841**
	120	2911	3662	3656
APR 1996	24	3554	3400	3399
	30	4067	4138	4137
	36	3535	3260	3260
	48	3605	3691	3690
	72	**4162**	**5035**	**5019**
	96	3492	4417	4378
	120	3509	4663	4571
FEB 1999	24	3424	2887	2886
	30	5789	4442	4442
	36	3575	3147	3150
	48	4604	3495	3494
	72	6879	6448	6447
	96	7217	6624	6623
	120	**7431**	**6819**	**6819**

Flood Frequency Analysis for Brisbane River Catchment Summary Report

FLOOD FREQUENCY ANALYSIS OF BRISBANE RIVER

- Draft
- 8/08/2003

Flood Frequency Analysis of Brisbane River

FLOOD FREQUENCY ANALYSIS OF BRISBANE RIVER

- Draft
- 8/08/2003

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B	pdf	pdf	Barry Ball (BCC)

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Document version:	Draft B
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1. Introduction

1.1 Background

An Expert Panel has been appointed to review the flood studies undertaken for the Brisbane River in SE Queensland, with particular emphasis on the flood flows and associated levels in the lower reaches including Brisbane City.

Sinclair Knight Merz was approached to assist the Expert Panel with their review. The primary tasks for SKM were to:

- Undertake flood frequency analysis, and to
- Update the rainfall – runoff modelling results

The details of the tasks are presented in Appendix A.

1.2 Scope of Report

The subject of this report covers the first two points in Appendix A, namely to,

1) Collect and Collate Data. This task involves the collection of stream gauge information and discussions with hydrographers from various Stream Gauge Authorities to determine the reliability of readings at individual Gauging Stations. The amount of time available will dictate the degree to which the quality of the annual maxima can be assessed, and any caveats on the remaining uncertainty will be noted in the report.
2) Undertake a regional and at-site flood frequency analyses (FFA) for the Brisbane River Catchment under 'No Dams' conditions for selected sites.

This report gives an assessment of the flood frequency analysis undertaken with the available data.

The report has been prepared for expert reviewers and familiarity with the flood frequency techniques adopted, such as regional analysis and Bayesian techniques, is assumed.

2. Sources of Data

Gauging station data were obtained from the Department of Natural Resources and Mining (NRM) and the Commonwealth Bureau of Meteorology (BOM). Data of various typed was collected, including:

- recorded water elevation above the gauge datum,
- flow data estimated from a rating relationship and
- rating tables

were obtained. In some instances the data had been processed in some additional manner as discussed below.

A number of reports on large flood events and the analysis thereof have also been made available.

2.1 Selection of Data for Analysis

2.1.1 Department of Natural Resources and Mining Data

There are two sources of data from NRM:

- Recorded water elevation data and associated flow estimates
- Estimates of “no dams” flood peaks at Savages Crossing that adjusted to exclude the influence of the dam(s) where appropriate.
- Estimates of “no dams” flood peaks at Savages Crossing that adjusted to exclude the influence of the dam(s) where appropriate

Both data sets have been analysed without assessment as to the method of obtaining the peak flow rates. That is the data sets were taken “as provided.”

A significant amount of recorded data was not selected for the reasons discussed in relation to the BoM data below.

2.1.2 Bureau of Meteorology Data

Stations from the BoM have generally been omitted at this stage for a number of reasons. The reason for each site being omitted is stated in Appendix C (along with other sources of gauged data). The primary reasons for omission were:

- short record length,
- small catchment area, and/or
- uncertainty in the rating curve.

The latter reason included either very low gauged flow or the rating curve had been changed to a “calibration curve” for use in real time flood forecasting. It may be possible to include some of this flow data for future analysis when questions regarding the adjustment made to the calibration curves have been resolved.

Elevation data for a number of sites of direct interest to this study, such as Moggill (40545), Brisbane City (40690) and the Port Office (040690) were also obtained.

3. Flood Frequency Analyses

3.1 Introduction

The Expert Panel requested that SKM undertake flood frequency analysis of the available data and come up with a best estimate of the likely 1 in 100 annual exceedance probability (AEP) peak flow rate at Savages Crossing. This peak flow rate is also referred to as the Q100 event. An estimate of the Q100 for the "no dams" case (ie peak flow that would occur if the dams were not present) was requested with an indication of the sensitivity of the estimate to the various sources of uncertainty leading to a plausible range for the Q100 estimate.

The sources of data have been documented in Section 2.

The sources of uncertainty that could affect the Q100 estimate at Savages Crossing include:

- Adjustment of data for the influence of the dams
- Uncertainty in the rating curves that relate recorded river level to flow rate
- The magnitude of historic data (especially 1893 and 1825)
- The period of record associated with the historic data
- Choice of distribution
- Selection of parameters for the distribution
- Method of including historical data

NRM provided a series of data (1890 – 2000) that was adjusted so as to represent the peak flow rates expected if Somerset and Wivenhoe dams had existed over the entire period. A frequency analysis of this data was also undertaken.

Frequency analysis was undertaken using a range of at-site and regional methods. The main benefit of adopting a regional approach to flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (e.g. at Savages Crossing 45% of the peak flows lie beyond the maximum rating) then the regional information provides useful information on the appropriateness of the at-site estimates.

Regional information was incorporated in the Bayesian analysis of flood peaks that is performed by FLIKE. The regional information was incorporated into the Bayesian analysis as prior frequency distributions of the parameters of the Generalised Pareto distribution. The regional method is reported in Appendix D.

The analyses to determine the "best" estimate from flood frequency analysis and a plausible range is summarised in Table 3.1. FLIKE was used to derive quantile estimates for Cases 1 and 2, but due to difficulties with the data sets an SKM program *GetDat* was used to assess Cases 3 and 4. The *GetDat* program is based on Hosking and Wallis' L-Moments routines, and includes Monte-Carlo simulation for estimation of confidence limits. No prior or regional information was assessed in Cases 3 and 4.

The results of these analyses are recorded with selected frequency distributions in the Sections 3.2 - 3.5 and the results summarised in Table 3.7.

Table 3.1 Summary of flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)

	Continuous Record	Historic Data (m^3/s)	Historic Period	Distribution	Model for fitting distribn	Prior Informn (regional)	Main Objective
Case 1 Pre -Wivenhoe and Somerset							
1A	1909-1951	Excluded	1909-1951	GP	FLIKE	Excluded	Assess the continuous record of Savages Crossing Data that is unaffected by large dams
1B	1909-1951	1893 (Qp=13000)	1847-1951	GP	FLIKE	Excluded	As for 1A except includes the best estimate of the 1893 historic peak
1C	1909-1951	1893 (Qp=13000)	1847-1951	GP	FLIKE	Included	As for 1B except includes regional information
1D	1909-1951	1825 (Qp=13200) 1893 (Qp=13200	1825-1951	GP	FLIKE	Excluded	As for 1B with the addition of the historical event of circa 1825 (diary notes from early explorers with heights in the order of the 1893 event)
1E	1909-1951	1893	1847-1951	LPIII	FLIKE	Excluded	Test the difference re LPIII distribution instead of GP
1F	1909-1951	1893 (Qp=14500)	1847-1951	GP	FLIKE	Included	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable higher estimate)
1G	1909-1951	1893 (Qp=12000)	1847-1951	GP	FLIKE	Included	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable lower estimate)
1H	1909-1951	1893 (Qp=13000)	1847-1951	LPIII	ARR87 incl historic data	Excluded	Determine Q100 using ARR87 method for including historical data.

Case 2 **Pre Wivenhoe, no adjustments made for Somerset**							
2A	1909-1982	Excluded	1909-1982	GP	FLIKE	Included	Test inclusion of additional 31 years of record.
2B	1909-1982	1893	1847-1982	GP	FLIKE	Included	As for 2A plus historic data. Indicate sensitivity to effect of Somerset on Q100 estimate
Case 3 **"No Dams" based on NRM adjusted estimates**							
3A	1890-2000	Excluded	1890-2000	GP	GetDat	Excluded	Assess Q100 from “no dams” adjusted data series produced by NRM.
3B	1890-2000	Excluded	1890-2000	LPIII	GetDat	Excluded	Assess impact of LPIII as an alternative distribution for this series.
Case 4 **"Dams" based on NRM estimates**							
4A	1909-2000	Excluded	1890-2000	GP	GetDat	Excluded	Assess the impact of dams on Q100 at Savages Crossing based on NRM’s assessment of flows if dams had been in place for the historic period of record.
4B	1909-2000	Excluded	1890-2000	LPIII	GetDat	Excluded	Assess impact of LPIII as an alternative distribution for this series.

SKM

3.2 Analysis of Pre-Somerset and Pre-Wivenhoe Data

The data set for these runs was the NRM unadjusted gauge data (1909-1951) supplemented by historical data as noted in the table below.

The Case 1 analyses investigate the primary sources of uncertainty in the data apart from adjustments for the influence of the dams.

The results are tabulated with comments in Table 3.2 with specific influence on curves plotted in Figures 3.1 – 3.3 so that the influence of specific assumptions can be compared graphically..

Table 3.2 Summary of Case 1 flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)

	Continuous Record	Historic Data (m³/s)	Historic Period	Distbn	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 1 Pre -Wivenhoe and Somerset								
1A	1909-1951	No	1909-1951	GP	No	6 690	Assess the continuous record of Savages Crossing Data that is unaffected by large dams	Ignores all information in the fifty years of data post Somerset (and post-Wivenhoe) dam and the historic 1893 event. Also excludes prior information from regional analysis
1B	1909-1951	1893 (Qp=13000)	1847-1951	GP	No	14 070	As for 1A except includes the best estimate of the 1893 historic peak	By excluding the data post Somerset dam the frequency of the 1893 event is overestimated, consequently the Q100 estimate is judged to be conservative..

	Continuous Record	Historic Data (m³/s)	Historic Period	Distbn	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
1C	1909-1951	1893 (Qp=13000)	1847-1951	GP	Yes	11 970	As for 1B except includes regional information	The regional information has a significant influence on the Q100 estimate and partially compensates for the impact of the frequency of the 1893 event in 1B. Note similarity of Q100 estimate to that for 2B where the unadjusted post-Somerset but pre-Wivenhoe data was included.
1D	1909-1951	1825(Qp=13200) 1893 (Qp=13200	1825-1951	GP	No	15 690	As for 1B with the addition of the historical event of circa 1825 (diary notes from early explorers with heights in the order of the 1893 event)	The plotting position of this event is outside the 90% confidence interval. Hence the magnitude is highly questionable and should be excluded from consideration.
1E	1909-1951	1893	1847-1951	LPIII	No	13 720	Test the difference re LPIII distribution instead of GP	Relatively minor difference to 1B (the equivalent data fitted with the Generalised Pareto distribution)
1F	1909-1951	1893 (Qp=14500)	1847-1951	GP	Yes	12 660	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable higher estimate)	Magnitude taken from P Baddiley "not unreasonable" estimate of 1893 peak. Q100 at Savages Crossing is influenced but not overly sensitive.

	Continuous Record	Historic Data (m^3/s)	Historic Period	Distbn	Prior Info (regional)	Q100 Estimate at Savages Crossing (m^3/s)	Main Objective	Comments
1G	1909-1951	1893 (Qp=12000)	1847-1951	GP	Yes	11 560	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable lower estimate)	Magnitude taken from P Baddiley URBS modelling calibrated to 1974, daily temporal pattern and cont loss of 2.5mm/hr. Q100 at Savages Crossing is influenced but reasonably insensitive.
1H	1909-1951	1893 (Qp=13000)	1847-1951	LPIII (ARR87 incl historic data)	No	7667	Determine Q100 using ARR87 method for including historical data.	This method gives a significantly lower Q100 for Savages Crossing. Note: the ARR87 method gives a Q100 of 6179m^3/s if the historical data is excluded.

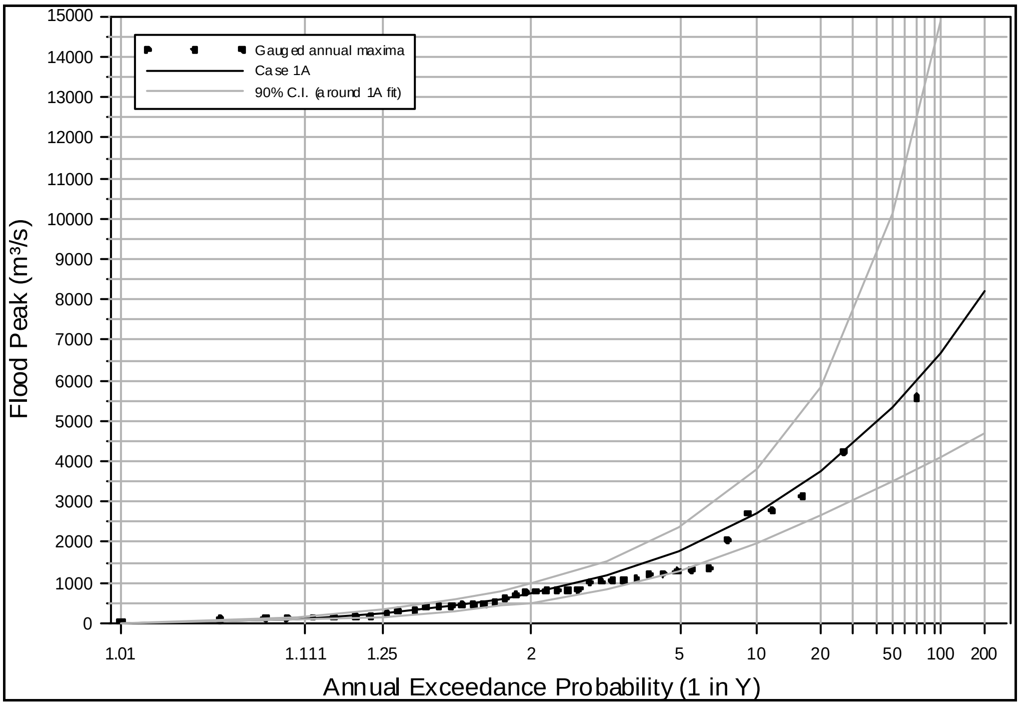

Figure 3.1 Generalised Pareto Distribution fitted to the 1909-1951 pre dams data at Savages Crossing.

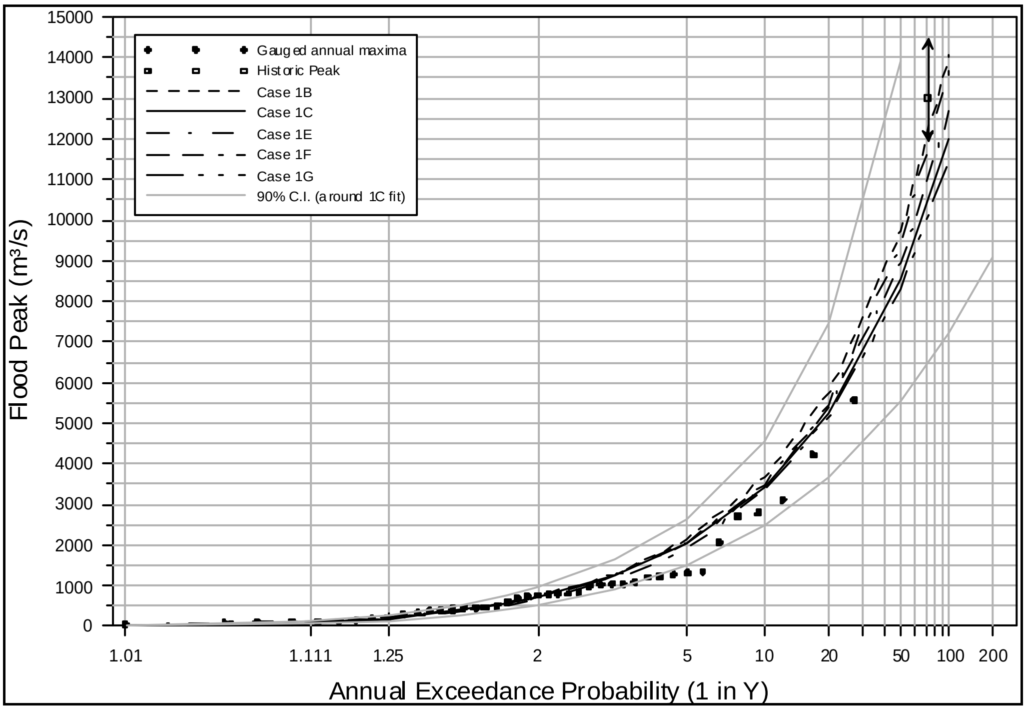

Figure 3.2 Comparisons of variations in flood frequency for various assumptions on pre-dams data for Savages Crossing.

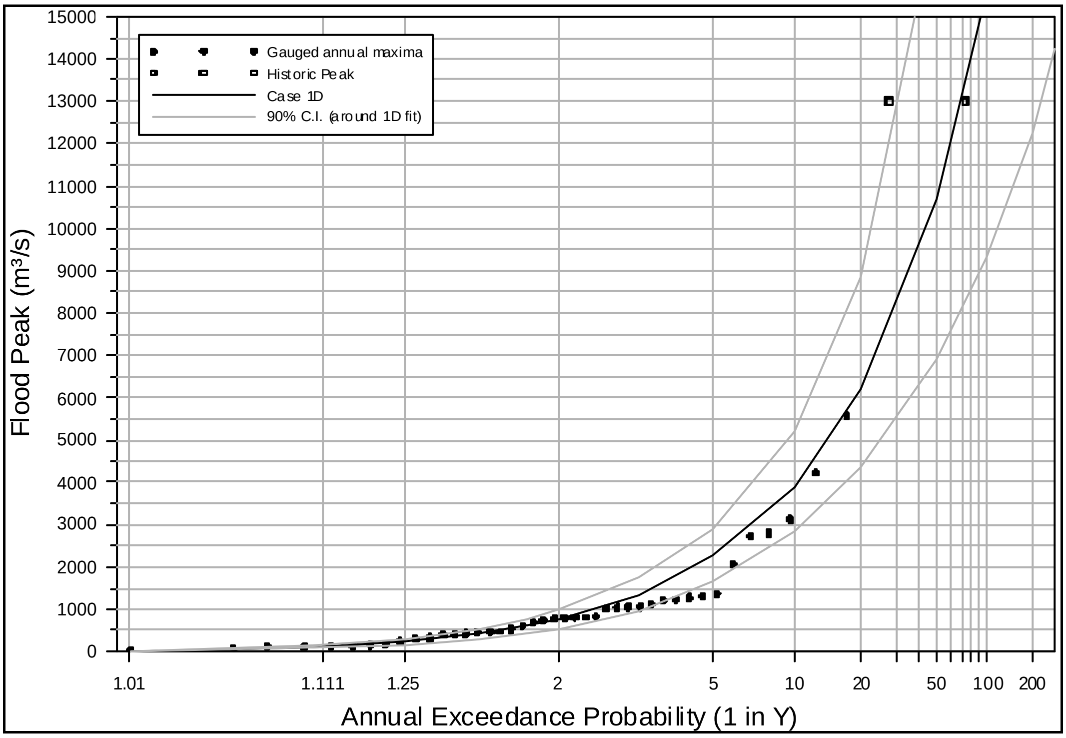

Figure 3.3 Assessment of the inclusion of a 1925 estimate of a flood possibly of the same magnitude as the 1893 event.

SKM

3.3 Case 2: Analysis of Pre-Wivenhoe Data With No Correction for Somerset Dam

These analyses were based on gauged flows up to 1982, with no corrections made for the influence of Somerset Dam.

Table 3.3 Summary of Case 1 flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)

	Continuous Record	Historic Data (m^3/s)	Historic Period	Distbn	Prior Info (regional)	Q100 Estimate at Savages Crossing (m^3/s)	Main Objective	Comments
Case 2 **Pre Wivenhoe, no adjustments made for Somerset**								
2A	1909-1982	No	1909-1982	GP	Yes	7 870	Test inclusion of additional 31 years of record.	Q100 increases (note record includes 1974 event) but excludes the historic data including the flood of record (1893) so Q100 is underestimated.
2B	1909-1982	1893	1847-1982	GP	Yes	11 500	As for 2A plus historic data. Indicate sensitivity to effect of Somerset on Q100 estimate	Inclusion of historic data is very important (cf 2A). Q100 estimate is not overly sensitive to the influence of Somerset in the record (at least prior to Wivenhoe dam) Q100 estimate at Savages Crossing is likely to be greater than Q100 estimate here as data has *not* been adjusted for effect of Somerset dam. Refer to 3a for analysis of data adjusted for dams. Consistent with 1C and 3A Q100 estimates.

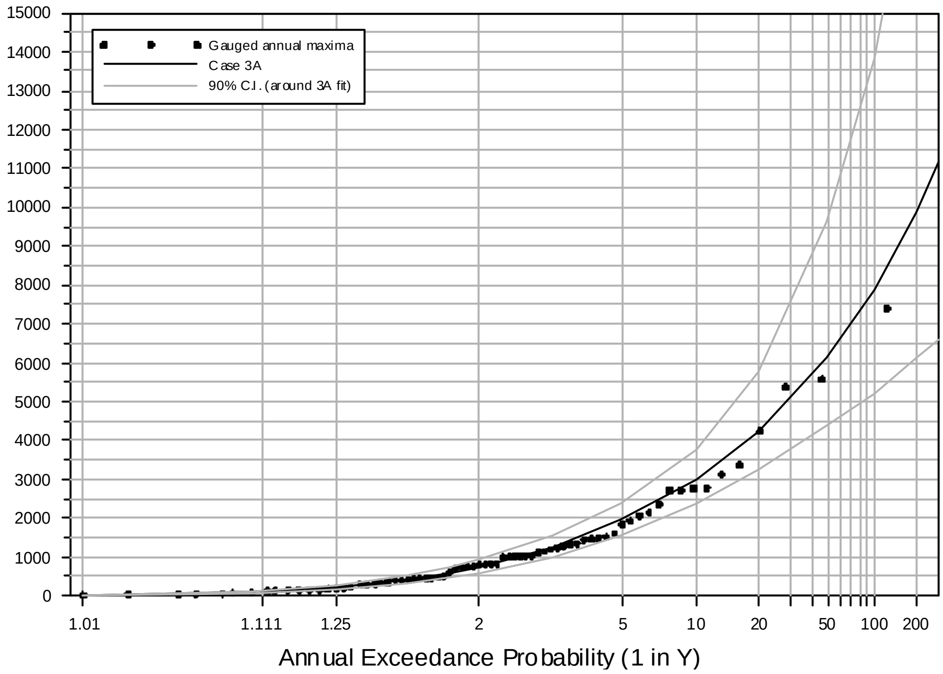

Figure 3.4 Assessment of the pre-Wivenhoe gauged data without 1893 event.

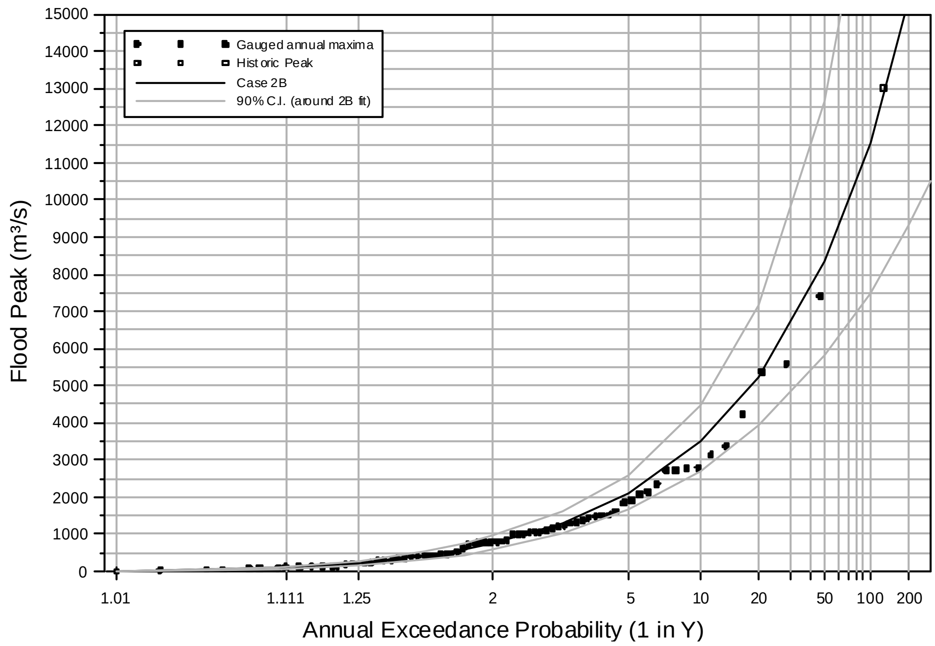

Figure 3.5 Assessment of the pre-Wivenhoe gauged data with 1893 event..

3.4 Analysis of “No Dams” Data Estimated by NRM

Note effect of Somerset is highly variable depending on the operation. NRM has indicated that they have spent significant resources assessing the effect of Somerset on the flood series. The data series has been provided without documentation as to the method used to adjust the data. SKM has taken this series and analysed the statistics without investigation of derivation.

Table 3.4 Summary of Case 3 flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)

	Continuous Record	Historic Data (m³/s)	Historic Period	Distbn	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 3 **"No Dams" based on NRM adjusted estimates**								
3A	1890-2000	No	1890-2000	GP	No	11 900	Assess Q100 from "no dams" adjusted data series produced by NRM.	Q100 estimate is consistent with 1C and 2B. Note: method used to obtain adjusted data series not assessed by SKM.
3B	1890-2000	No	1890-2000	LPIII	No	13 150	Assess impact of LPIII as an alternative distribution for this series.	Q100 is more sensitive to choice of distribution for this data set than observed between 1B and 1E above.

SKM

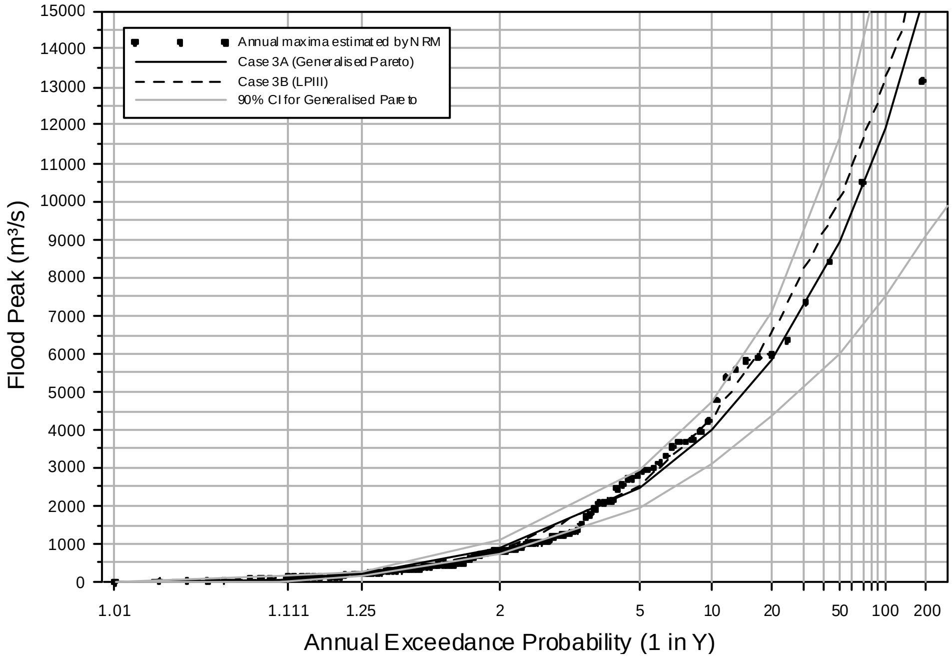

Figure 3.6 Assessment of the "no –dams" annual maxima series provided by NRM using both GP and LPIII distributions.

3.5 Analysis of Post-Dam Data Estimated by NRM

These analyses were based on "post-dam" data set provided by NRM. As with the analyses reported in Section 3.4, no assessment of the manner in which this data set was derived was undertaken.

Table 3.5 Summary of Case 4: Post Dam Data - flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)

	Continuous Record	Historic Data (m³/s)	Historic Period	Distbn	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 4 "Dams" based on NRM estimates								

SKM

	Continuous Record	Historic Data (m^3/s)	Historic Period	Distbn	Prior Info (regional)	Q100 Estimate at Savages Crossing (m^3/s)	Main Objective	Comments
4A	1909-2000	No	1890-2000	GP	No	3590	Assess the impact of dams on Q100 at Savages Crossing based on NRM's assessment of flows if dams had been in place for the historic period of record.	According to this series, the Q100 is reduced to about 30% of that expected without Wivenhoe and Somerset dams. Note: method used to obtain adjusted data series not assessed by SKM. Refer to parallel SKM report on the impact of dams from a hydrological routing perspective.
4B	1909-2000	No	1890-2000	LPIII	No	4920	Assess impact of LPIII as an alternative distribution for this series.	Q100 estimate is sensitive to choice of distribution (Q100 is approx. 30% higher than GP estimate in 4A)

SKM

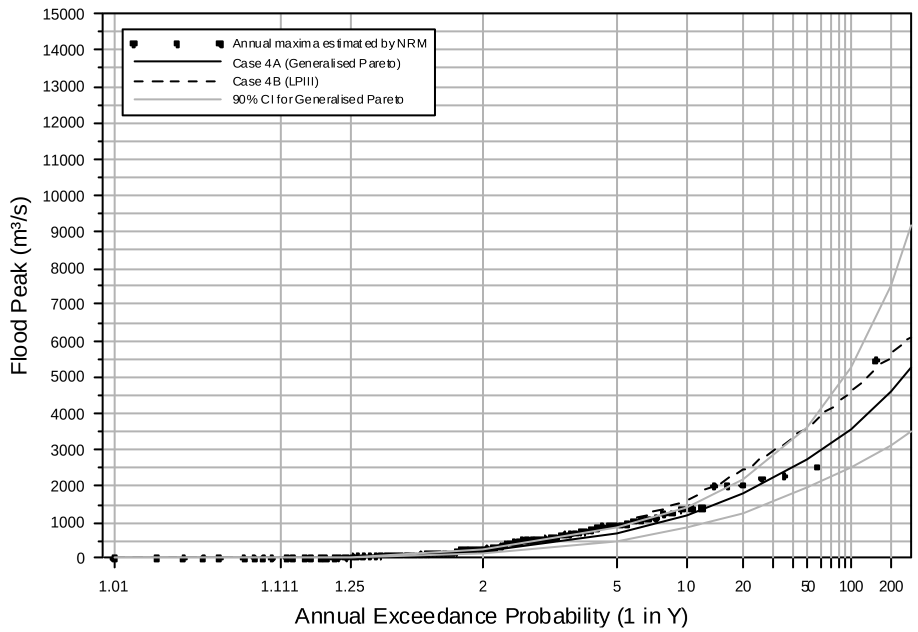

Figure 3.7 Assessment of the "post-dams" annual maxima series provided by NRM using both GP and LPIII distributions.

3.6 Summary of analysis results

The analyses in the preceding subsections indicate that there is considerable variation in the Q100 (1 in 100 AEP peak flow rate) at Savages Crossing. The analyses are summarised in Table 3.7.

A regional frequency analysis was conducted to assist in the estimation of flood frequency at Savages Creek (GS143001). The main benefit of adopting a regional approach to flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (e.g. at Savages Crossing 45% of the peak flows lie beyond the maximum rating) then the regional information provides useful information on the appropriateness of the at-site estimates.

Flood peaks were available at eight relevant sites in the Brisbane catchment, including the site at Savages Crossing (GS143001). The Generalised Pareto probability distribution was selected for the flood frequency analysis on the basis of the L-Moment ratios at eight sites.

Regional information was incorporated in the Bayesian analysis of flood peaks that is performed by FLIKE. The regional information was incorporated into the Bayesian analysis as prior frequency distributions of the parameters of the Generalised Pareto distribution. The Bayesian analysis requires for each parameter:

- its prior mean (or expected) value;
- its prior standard deviation; and,
- its correlation with other parameters.

The prior mean and standard deviation of the scale (?) and shape (?) parameters were obtained from the regional average L-moments of the seven sites that excluded Savages Crossing. The prior parameter values that were adopted for the Bayesian analysis are shown in Table 1.

Table 3.6 Prior parameters for Bayesian analysis of flood peaks at Savages Crossing (GS143001).

Value	Scale parameter, ?	Shape parameter, ?
Mean	939	-0.274
Standard Deviation	458	0.297

The cross-correlation between the scale and shape parameters was simply assumed to be the same as found from the parameter inference statistics computed by FLIKE (r = 0.6). This information was used rather than the sample statistics from the regional parameter set as it was considered that correlation between parameters from the one river system was likely to over-estimate the actual degree of correlation.

Table 3.7 Summary of flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)

	Continuous Record	Historic Data (m³/s)	Historic Period	Distribution	Prior Information	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 1 **Pre -Wivenhoe and Somerset**								
1A	1909-1951	No	1909-1951	GP	No	6 690	Assess the continuous record of Savages Crossing Data that is unaffected by large dams	Ignores all information in the fifty years of data post Somerset (and post-Wivenhoe) dam and the historic 1893 event. Also excludes prior information from regional analysis
1B	1909-1951	1893 (Qp=13000)	1847-1951	GP	No	14 070	As for 1A except includes the best estimate of the 1893 historic peak	By excluding the data post Somerset dam the frequency of the 1893 event is overestimated, consequently the Q100 estimate is judged to be conservative..
1C	1909-1951	1893 (Qp=13000)	1847-1951	GP	Yes	11 970	As for 1B except includes regional information	The regional information has a significant influence on the Q100 estimate and partially compensates for the impact of the frequency of the 1893 event in 1B. Note similarity of Q100 estimate to that for 2B where the unadjusted post- Somerset but pre-Wivenhoe data was included.
1D	1909-1951	1825(Qp=13200) 1893 (Qp=13200	1825-1951	GP	No	15 690	As for 1B with the addition of the historical event of circa 1825 (diary notes from early explorers with heights in the order of the 1893 event)	The plotting position of this event is outside the 90% confidence interval. Hence the magnitude is highly questionable and should be excluded from consideration.
1E	1909-1951	1893	1847-1951	LPIII	No	13 720	Test the difference re LPIII distribution instead of GP	Relatively minor difference to 1B (the equivalent data fitted with the Generalised Pareto distribution)
1F	1909-1951	1893 (Qp=14500)	1847-1951	GP	Yes	12 660	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable higher estimate)	Magnitude taken from P Baddiley "not unreasonable" estimate of 1893 peak. Q100 at Savages Crossing is influenced but not overly sensitive.
1G	1909-1951	1893 (Qp=12000)	1847-1951	GP	Yes	11 560	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable lower estimate)	Magnitude taken from P Baddiley URBS modelling calibrated to 1974, daily temporal pattern and cont loss of 2.5mm/hr. Q100 at Savages Crossing is influenced but reasonably insensitive.
1H	1909-1951	1893 (Qp=13000)	1847-1951	LPIII (ARR87 incl historic data)	No	7667	Determine Q100 using ARR87 method for including historical data.	This method gives a significantly lower Q100 for Savages Crossing. Note: the ARR87 method gives a Q100 of 6179m³/s if the historical data is excluded.
Case 2 **Pre Wivenhoe, no adjustments made for Somerset**								
2A	1909-1982	No	1909-1982	GP	Yes	7 870	Test inclusion of additional 31 years of record.	Q100 increases (note record includes 1974 event) but excludes the historic data including the flood of record (1893) so Q100 is underestimated.
2B	1909-1982	1893	1847-1982	GP	Yes	11 500	As for 2A plus historic data. Indicate sensitivity to effect of Somerset on Q100 estimate	Inclusion of historic data is very important (cf 2A). Q100 estimate is not overly sensitive to the influence of Somerset in the record (at least prior to Wivenhoe dam) Q100 estimate at Savages Crossing is likely to be greater than Q100 estimate here as data has *not* been adjusted for effect of Somerset dam. Refer to 3a for analysis of data adjusted for dams. Consistent with 1C and 3A Q100 estimates.

Case 3 **"No Dams" based on NRM adjusted estimates**								
3A	1890-2000	No	1890-2000	GP	No	11 900	Assess Q100 from "no dams" adjusted data series produced by NRM.	Q100 estimate is consistent with 1C and 2B. Note: method used to obtain adjusted data series not assessed by SKM.
3B	1890-2000	No	1890-2000	LPIII	No	13 150	Assess impact of LPIII as an alternative distribution for this series.	Q100 is more sensitive to choice of distribution for this data set than observed between 1B and 1E above.
Case 4 **"Dams" based on NRM estimates**								
4A	1909-2000	No	1890-2000	GP	No	3590	Assess the impact of dams on Q100 at Savages Crossing based on NRM's assessment of flows if dams had been in place for the historic period of record.	According to this series, the Q100 is reduced to about 30% of that expected without Wivenhoe and Somerset dams. Note: method used to obtain adjusted data series not assessed by SKM. Refer to parallel SKM report on the impact of dams from a hydrological routing perspective.
4B	1909-2000	No	1890-2000	LPIII	No	4920	Assess impact of LPIII as an alternative distribution for this series.	Q100 estimate is sensitive to choice of distribution (Q100 is approx. 30% higher than GP estimate in 4A)

SKM

3.6.1 Best Estimates from flood frequency assessment

SKM has assessed the information and provided a "best" estimate and a plausible range for the "no dams" scenario, ie assuming that Somerset and Wivenhoe dams were not present. It should be noted that the upper and lower range of estimates are speculative, and do not take into consideration information that may be available from other independent sources (such as rainfall-based flood event modelling).

An additional assessment of the "current" scenario, ie with Somerset and Wivenhoe dams present and operated using current operating procedures is also provided. This is based on the data series that has values adjusted for the effect of the dams as assessed and provided by NRM. Note that no assessment of the plausible range for this estimate is possible as the method for adjusting the data series is not currently available.

The results are presented in Table 3.8.

Table 3.8 Most plausible estimates of the Q100 peak flow at Savages Crossing.

Scenario	"Best" estimate	Likely lower estimate	Likely Upper estimate
"No dams"	12 000	10 000	14 000

The best estimate for the "no dams" scenario was adopted after consideration of all the analyses, with particular attention paid to the convergence of the Q100 estimates based on the three most relevant data series, namely:

- the inclusion of all unadjusted Savages Crossing records (1909-1951) , the best estimate of the 1893 flood of record, the inclusion of prior information from the regional analysis and the adoption of the Generalised Pareto distribution (refer 1C, Q100=11 970)
- pre-Wivenhoe Savages Crossing records consisting of unadjusted peaks (1909-1982), NRM estimated peaks (1890-1908) which included the 1893 flood of record (refer 2B, Q100= 11 500m^3/s); as no allowance made for Somerset dam, the Q100 could be expected to be higher than 11 500m^3/s.
- the "No dams" series from NRM which included estimates of peak flows for Savages Crossing from 1890-2000 (refer 3A).

The boundaries of the plausible range of flow estimates are reasonably broad. This reflects the following significant sources of uncertainty:

- the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum estimated 1974 peak flow; this causes considerable uncertainty on the flow estimates for the large flows that influence the flood frequency assessment in the range of the Q100.
- scarcity of information regarding the 1893 event in terms of its flow magnitude (there is considerable uncertainty in rainfall –runoff modelling results as there is scarce data on key event characteristics such as temporal pattern, losses etc). This event has a significant influence on the Q100 estimate (although inclusion of regional information lessens the impact of the uncertainty)
- choice of distribution and the appropriate parameters; and,
- adjustment of data for the effect of the dams.

As an example of some of the above uncertainties, there is reasonable evidence for 1974 “no dams” peak flow rate to be somewhere between 7 500m³/s and 11 000m³/s.

3.7 Comparison ofQ100 estimates from flood frequency analysis and hydrological modelling

Modelling of the Q100 event using:

- Calibrated RAFTS model
- CRC FORGE 1 in 100 AEP rainfall estimates (with areal reduction factors and spatial distribution)
- 30 hr (critical duration for Savages Crossing) ARR87 temporal pattern
- zero initial and continuing losses
- no dams in the model

gave a Q100 at Savages Crossing of 11400m³/s. It would be reasonable to expect some losses with a 1in 100 AEP event and hence the hydrological modelling results could be expected to be lower, say in the order of 10, 500m³/s.

The difference between the results requires more detailed assessment than is available in the scope and timing of the current assessments. Potential factors influencing the difference in Q100 estimates include:

- potential for partial area storms
- variation in temporal patterns
- variation in spatial patterns
- variation in losses
- adjustment of data for influence of dams

- estimation of the 1893 flood peak
- estimation of the 1974 flood peak
- uncertainty in the rating curve at Savages Crossing and hence estimation of the flood peaks above the maximum gauged flood.

4. Future proposed work

5. Conclusions

6. References

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Kuczera, G. Comprehensive at-site flood frequency analysis using Monte Carlo Bayesian inference, Water Resources Research, 35(5), 1551-1558, 1999.

Peel, M.C., Q.J. Wang, R.M. Vogel and T.A. McMahon (1999): "Are L-Moment ratio diagrams useful for distribution selection for frequency analysis?". *Water '99 Joint Congress*, Institution of Engineers Australia, Brisbane, 6-8 July 1999, p 1099-1104.

Appendix A Original Scope of Work

The original scope of work proposed for assisting in the review of the Brisbane River flood studies was as follows:

Scope of Work

1) Collect and Collate Data. This task involves the collection of stream gauge information and discussions with hydrographers from various Stream Gauge Authorities to determine the reliability of readings at individual Gauging Stations. The amount of time available will dictate the degree to which the quality of the annual maxima can be assessed, and any caveats on the remaining uncertainty will be noted in the report.
2) Undertake a regional and at-site flood frequency analyses (FFA) for the Brisbane River Catchment under 'No Dams' conditions for selected sites.
3) Document findings of the Flood Frequency Analysis stating assumptions and outcomes of the investigation.
4) Meet with the Expert Panel to discuss the Flood Frequency Analysis Outcomes. An allowance of one face-to-face meeting has been allowed for in the fee estimate.
5) Remove Wivenhoe and Somerset Dams from the RAFTS model. Input the CRC Forge Rainfall Estimates into the RAFTS model and apply Areal Reduction Factors. Adjust loss rates to the RAFTS model for the 100 year ARI event until flows match those predicted by the FFA. The loss rates will then be assessed to determine whether they are within acceptable limits for the catchment. Note that this is a milestone for the investigation. Should the loss rates not be within acceptable limits, other factors will have to be investigated extending time and costs associated with the investigation, or else appropriate caveats noted in the report.
6) Assuming the previous milestone has been satisfied, Wivenhoe and Somerset Dams will be reintroduced into the RAFTS model along with the adopted loss rates. Hydrograph information from the RAFTS model would then be used as input into the NRM Dam Operation's model to determine an outflow hydrograph from Wivenhoe Dam. This outflow hydrograph would reflect Dam Operation release procedures. The Outflow hydrograph will then be input into the RAFTS model and the RAFTS model will be re-run to determine 100 year ARI flows at Moggill.
7) Assess importance of Starting Water Level (SWL) of Wivenhoe and Somerset Dams. To this end, long term synthetic data on water levels (corresponding to current operating conditions) will be obtained from SEQB (?) and used to assess the range of starting levels likely to be associated with floods of differing severity. Depending on the outcome of this analysis, either a fixed starting level will be adopted or else a joint probability approach will be used. The time

available and nature of the starting level information will dictate the level of sophistication appropriate to the joint probability approach (if required), and discussions will be held with BCC prior to tackling this aspect of the problem.

8) Prepare a report documenting the findings of the FFA and the RAFTS modelling.

Appendix B Flow Gauging Stations Omitted from Consideration

STATION	RIVER	STATNAME	CATCH AREA (km²)	LENGTH_ OF RECORD	WHY N
143222A	Atkinson_Dam	Atkinson_Creek_Outlet		20	Small c
143234A	Atkinson_Dam_Hea			6	Small c
143228A	Bill_Gunn_Dam	Lake_Dyer	3	18	Catchn
143027A	Blunder_Ck	King_Avenue_Bridge	31	8	Urban
2121	Blunder_Ck	King_Ave-_Durack		14	Urban
1594	Breakfast_Ck	Opposite_Newstead_House		5	Urban
1579	Breakfast_Ck	Sedgley_Park_Retention_Basin-_New_Market		6	Urban
1525	Breakfast_Ck	Opposite_Mann_Park-_Bowen_Hills		9	Urban
143104B	Bremer	Rosevale	67	21	Catchn
143104A	Bremer	Rosevale	77	34	Catchn
143110A	Bremer	Adams_Bridge	125	35	Catchn
143940	Bremer	Stokes_Crossing	180	21	ALERT
143909	Bremer	Rosewood	543	-99	ALERT
143833	Bremer	Rosewood_Alert	543	9	ALERT
143908	Bremer	Rosewood_TM	543	25	ALERT
143934	Bremer	Walloon_Bvrt	585	-99	ALERT
143805	Bremer	Walloon_Alert-P	585	9	ALERT
143911	Bremer	Ipswich	1850	-99	ALERT

143956	Bremer	Three_Mile_Bridge_Alert	1870	-99	ALERT
143954	Bremer	Ipswich_Alert		-99	ALERT
143953	Bremer	One_Mile_Bridge_Alert		-99	ALERT
143852	Bremer	Brassall(Hancocks_Br)_Al		5	ALERT
143115A	Bremer	Berry's_Lagoon		9	Recorc
143831	Brisbane	Devon_Hills_Alert	2160	9	ALERT
143922	Brisbane	Devon_Hills_Bvrt	2190	-99	ALERT
143002A	Brisbane	Plainlands	3950	12	Recorc
143005A	Brisbane	Watts_Bridge	4602	20	Recorc
143008A	Brisbane	Middle_Creek	6704	20	Recorc
143026A	Brisbane	Wivenhoe	7023	3	Recorc
143036A	Brisbane	Wivenhoe_Headwater	7023	17	Recorc
143035A	Brisbane	Wivenhoe_Tailwater	7023	17	Recorc
143907	Brisbane	Lowood	10062	-99	ALERT
143941	Brisbane	Lowood_Bvrt	10062	-99	ALERT
143827	Brisbane	Lowood_Alert-P	10062	9	ALERT
143916	Brisbane	Mt_Crosby	10600	-99	ALERT
143839	Brisbane	Mt_Crosby_Alert	10600	9	ALERT
143925	Brisbane	Mt_Crosby_TM	10600	28	ALERT
143951	Brisbane	Moggill_Alert	12600	-99	ALERT
143915	Brisbane	Moggill_Bvrt	12600	-99	ALERT
143924	Brisbane	Moggill_TM	12600	-99	ALERT

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143900	Brisbane	Caboonbah		-99	ALERT
143914	Brisbane	Gregor_Creek		-99	ALERT
143920	Brisbane	Gregor_Creek_Bvrt		-99	ALERT
143902	Brisbane	Murrumba		-99	ALERT
143005	Brisbane	Watts_Bridge		-99	ALERT
143903	Brisbane	Wivenhoe		-99	ALERT
143868	Brisbane	Colleges_Crossing_Alert		4	ALERT
143918	Brisbane_Estuary	Bishop_Island		-99	ALERT
143217A	Buaraba_Ck	Vineyard	63	10	Catchm
143211A	Buaraba_Ck	15.8km	251	12	Catchm
143224A	Buaraba_Ck	Diversion_Channel		19	Catchm
143094A	Bulimba_Ceek	Mansfield	57	26	Urban
143004A	Bulimba_Ck	Belmont	51	22	Urban
1591	Bulimba_Ck	End_of_Aquarium_Ave._Hemmant		5	Urban
1528	Bulimba_Ck	Doughboy_Pde-_Hemmant		9	Urban
1804	Bulimba_Ck	Greenwood_St-_Wishart		9	Urban
1831	Bulimba_Ck	Merion_Pl-_Carindale		9	Urban
1707	Bulimba_Ck	Old_Cleveland_Rd-_Carindale		9	Urban
143926	Bundamba_Ck	Ripley_Alert	35	-99	Urban
143959	Bundamba_Ck	Harding_Street_Alert	96	-99	Urban
143958	Bundamba_Ck	Blackstone_Bridge_Alert	97	10	Urban
143955	Bundamba_Ck	Bundamba_School_Alert	102	-99	Urban

143854	Bundamba_Ck	Bundamba_(Hanlon_St)_Al	109	7	Urban
143114A	Bundamba_Ck	Mary_Street	110	11	Urban
143307A	Byron_Ck	Causeway	79	28	Catchr
143012A	Cooyar_Ck	51.5km.	443	4	Record
143015B	Cooyar_Ck	Damsite	963	13	Record
143015A	Cooyar_Ck	Damsite	963	22	Record
143013A	Cressbrook_Ck	The_Damsite	321	16	Record
143952	Cressbrook_Ck	Rosentreters_Bridge	440	-99	ALERT
143921A	Cressbrook_Ck	Rosentretters_Bridge	447	17	Record
143921	Cressbrook_Ck	Rosentreters_Bridge_TM	477	-99	ALERT
143806	Cressbrook_Ck	Rosentreters_Bridge_Al	477	9	ALERT
143857	Deebing_Ck	Churchill_Alert		-99	ALERT
143021A	Ekibin_Ck	Dudley_Street.	13	1	Urban
143011A	Emu_Ck	Raeburn	439	24	Catchr
143932A	Ennogera_Ck	Bancroft_Park	70	10	Urban
143932	Enoggera_Ck	Bancroft_Park_TM	67	-99	Urban
1531	Enoggera_Ck	100_M_U/S_From_Original_E_e529		6	Urban
1532	Enoggera_Ck	Enoggera_Dam-_The_Gap		9	Urban
1529	Enoggera_Ck	Kelvin_Grove_Rd-_Kelvin_Grove		9	Urban
143208A	Fifteen_Mile_Ck	Dam_Site	87	33	Catchr
143214A	Flagstone_Ck	Windolfs	142	14	Catchr
143233A	Flagstone_Ck	Brown-Zirbels_Road		10	Catchr

1717	Gold_Ck	Reservoir-_Brookfield_(Brisbane_Water)		-99	Urban
143028A	Ithaca_Ck	Jason_Street	10	31	Urban
1535	Ithaca_Ck	Jason_St-_Ithaca		9	Urban
143304A	Kilcoy_Ck	Mount_Kilcoy	127	36	Catchr
143304B	Kilcoy_Ck	Mount_Kilcoy_Weir	131	15	Catchr
143235A	L_Clarendon_Head			6	Offstre
143215A	Laidley_Ck	Mulgowie_Weir	154	14	Catchr
143209A	Laidley_Ck	Mulgowie1	167	5	Catchr
143209B	Laidley_Ck	Mulgowie2	167	36	Catchr
143225A	Laidley_Ck	Showgrounds_Weir_Head_Wat e	233	19	Catchr
143226A	Laidley_Ck	Showgrounds_Weir_Tail_Wate	233	19	Catchr
143943	Laidley_Ck	Laidley	285	-99	Catchr
143923	Laidley_Ck	Thornton		-99	Catchr
143229A	Laidley_Ck	Warrego_Highway		13	Catchr
143202A	Lockyer_Ck	Russell_Siding	271	7	Catchn
143203C	Lockyer_Ck	Helidon_Number_3	357	16	Catchn
143203A	Lockyer_Ck	Helidon	357	45	Catchn
143203B	Lockyer_Ck	Helidon_No.2	382	24	Catchn
143904	Lockyer_Ck	Gatton	1550	-99	ALERT
143204A	Lockyer_Ck	Wilsons_Weir	1655	29	Catchn
143905	Lockyer_Ck	Glenore_Grove	2230	-99	ALERT
143906	Lockyer_Ck	Glenore_Grove_Bvrt	2230	-99	ALERT

143807	Lockyer_Ck	Glenore_Grove_Alert	2230	9	ALERT
143206A	Lockyer_Ck	Brightview_Weir	2393	20	Catchn
143917	Lockyer_Ck	Lyons_Bridge	2530	-99	ALERT
143913	Lockyer_Ck	Lyons_Bridge_Bvrt	2530	-99	ALERT
143819	Lockyer_Ck	Lyons_Bridge_Alert-P	2530	9	ALERT
2142	Lota_Ck	Rickertt_Rd_Ransome		4	Urban
143213B	Ma_Ma_Ck	Ma_Ma_Weir	226	9	Catchn
143213A	Ma_Ma_Ck	Harms	227	4	Catchn
143213C	Ma_Ma_Ck	Harm's		8	Catchn
143032A	Moggill_Ck	Upper_Brookfield	23	27	Urban
143020A	Moggill_Ck	Misty_Morn	61	9	Urban
143020	Moggill_Ck	Misty_Morn_TM		-99	Urban
1722	Moggill_Ck	Fortrose_St-_Kenmore		8	Urban
2143	Moolabin_Ck	Brisbane_Golf_Club-_Tennyson		14	Urban
143219A	Murphys_Ck	Spring_Bluff	18	24	Urban
1549	Norman_Ck	Joachim_St-_Holland_Park_West		9	Urban
1552	Norman_Ck	South_East_Freeway-_Greenslopes		9	Urban
1555	Norman_Ck	Caswell_St-_East_Brisbane		10	Urban
143033A	Oxley_Ck	New_Beith	60	27	Urban
143019A	Oxley_Ck	Upstream_Beatty_Road	152	3	Urban
143019B	Oxley_Ck	Downstream_Beatty_Road	152	6	Urban
143019	Oxley_Ck	Beatty_Road_TM		-99	Urban

1588	Oxley_Ck	Mouth_of_Oxley_Creek		5	Urban
1727	Oxley_Ck	New_Beith_(DNR)+F31		8	Urban
2023	Oxley_Ck	Corinda_High_School-_Corinda		12	Urban
2125	Oxley_Ck	Beatty_Rd-_Acacia_Ridge		14	Urban
2111	Oxley_Ck	Johnson_Rd-_Forestdale		14	Urban
143024A	Pullen_Pullen_Ck	Moggill_Road	27	4	Urban
1745	Pullen_Pullen_Ck	Pinjarra_Rd-_Pinjarra_Hills		6	Urban
143983	Purga_Ck	Loamside_Alert	215	8	ALERT
143869	Purga_Ck	Peak_Crossing_Alert		4	ALERT
143218A	Redbank_Ck	Holcomb	55	8	Urban
143216A	Redbank_Ck	Water_Treatment_Works	60	11	Urban
143231A	Redbank_Ck	Clarendon_Number_2		10	Urban
143230A	Redbank_Ck	Clarendon_Pump_Station		10	Urban
143306A	Reedy_Ck	Upstream_Byron_Creek_Junct	56	28	Catchr
143111A	Reynolds_Ck	Moogerah_Dam_Headwater	226	36	Head g
143112A	Reynolds_Ck	Moogerah_Tailwater	227	23	Tail ga
143220A	Sandy_Ck	Forest_Hill	102	7	Urban
143232A	Sandy_Ck	Forest_Hill		8	Urban
143030A	Sandy_Ck	Indooroopilly		22	Urban
143223A	Seven_Mile_Lagoo	Diversion_Channel		20	Diversi
143023A	Small_Catchment	Algester	1	4	Urban
143022A	Stable_Swamp_Ck	Interstate_Railway	19	11	Urban

2129	Stable_Swamp_Ck	Musgrave_Rd-_Coopers_Plains		14 Urban
143303A	Stanley	Peachester	104	76 Catchr
143938	Stanley	Woodford_TM	220	-99 ALERT
143829	Stanley	Woodford_Alert-P	220	9 ALERT
143901	Stanley	Woodford	250	-99 ALERT
143301B	Stanley	Donnelly_Dell	1227	4 Record
143301A	Stanley	Hazeldean	1242	3 Record
143305	Stanley	Somerset_Dam	1330	-99 ALERT
143818	Stanley	Somerset_Dam_Hw_Alert-B	1330	9 ALERT
143817	Stanley	Somerset_Dam_Hw_Alert-P	1330	9 ALERT
143305A	Stanley	Somerset_Dam	1336	24 Head g
143960	Stanley	Peachester		-99 ALERT
143106A	Warrill_Ck	Aratula_Weir	122	7 Catchn
143102A	Warrill_Ck	Kalbar_No.1	465	46 Catchn
143102B	Warrill_Ck	Kalbar_No.2	468	13 Catchn
143937	Warrill_Ck	Kalbar	470	-99 ALERT
143910	Warrill_Ck	Harrisville	725	-99 ALERT
143912	Warrill_Ck	Harrisville_TM	725	-99 ALERT
143825	Warrill_Ck	Amberley_Alert-P	850	9 ALERT
143933	Warrill_Ck	Amberley_Bvrt	862	-99 ALERT
143117A	Warrill_Ck	Junction_Weir_H/W		5 Record
143118A	Warrill_Ck	Junction_Weir_Tailwater		6 Record

143116A	Warrill_Ck	Toohill's_Crossing		6	Record
143105A	Warrill_Ck_East	Churchbank_Weir	149	50	Catchn
143031A	Water_St._Drain	Exhibition_Ground		5	Urban
143939	Western_Ck	Kuss_Road	200	21	Urban
143861	Western_Ck	Grandchester_Alert		4	Urban
1583	Wolston_Ck	700m_U/S_Wacol_Station_Rd-_Wacol		6	Urban
143962	Woogaroo_Ck	Brisbane_Road_Alert		-99	Urban
143927	Woogaroo_Ck	Opossum_Alert		-99	Urban
143961	Woogaroo_Ck	Alice_Street_Alert		7	Urban

Appendix C Location of select stream gauges

Insert figure 3.1 from skm BR Fs report here.

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Appendix D Regional Flood Frequency Information

D.1 Introduction

The main benefit of adopting a regional approach to flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (e.g. at Savages Crossing 45% of the peak flows lie beyond the maximum rating) then the regional information provides useful information on the appropriateness of the at-site estimates.

Regional analysis also provides a means to transpose flood peaks from one location to another. For example, examination of the manner in which flood peak varies with catchment area allows peak flows estimated at Savages Crossing to be transposed down to the Port Office.

This Appendix describes the regional information used to help inform the analysis undertaken at Savages Crossing.

D.2 Selection of Data

Given the time constraints of this review, the only data that could be incorporated was that which was readily available and for which there was a reasonable level of confidence in its consistency and quality.

As noted in Section 2.1 only NRM gauge flow data was both immediately available and of sufficient quality for the regional analysis. Annual maxima instantaneous flow rates were extracted for 8 stations in the Brisbane River catchment in Southern Queensland. The stations that were assessed in the analysis are listed in Table D.1.

The location of the gauges can be seen in the catchment map in Appendix C.

The composite record for Brisbane River at Lowood / Vernor / Savages Creek has the longest period of record prior to the construction of Wivenhoe Dam. It is reasonably close to the start of the hydraulic model set up to determine flood elevations and to route design floods along the most downstream reaches of the Brisbane River. It is the natural point to determine the key flood quantiles for use in estimating the appropriate design losses and performance of the rainfall runoff model.

The eight sites in Table D.1 were adopted initially to assist in the selection of the distribution to fit to the flood data as discussed in Section D.3.

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Table D.1 Flow gauging stations used in the regional analysis of pre-Wivenhoe Dam floods.

River	Station Name	Station Number	Years of Record	C'ment Area (km²)	Max gauged flow as % of max estimated flow
Brisbane River	Brisbane River @ Savages Crossing	143001	72	10172	45%
Bremer River	Bremer River @ Walloon	143107	40	622	42%
Cressbrook Creek	Cressbrook Creek @ Rosentreters Bridge	143921	15	447	35%
Lockyer Creek	Lockyer Creek @ Lyons Bridge	143210	22	2486	25%
Lockyer Creek	Lockyer Creek	143207	53	2965	10%
Brisbane River	Brisbane River @ Gregors Creek	143009	39	3866	67%
Warrill Creek	Warrill Creek @ Amberley	143108	40	914	26%
Purga Creek	Purga Creek @ Loamside	143113	28	215	12%

D.3 Selection of Frequency Distribution and Parameters

The first four L-Moments of the maxima samples were computed at each of the eight sites in Table D.1. An L-moment diagram was constructed to assist in the choice of distribution appropriate to the flow data. Figure 3.1 shows that there is some scatter among the eight sites in the plot of L-Kurtosis v L-Skew (4^{th} v 3^{rd} L-Moment). This scatter is typical of such analyses and it is often difficult on the basis of such plots to make a definitive choice of distribution (eg Peel et al., 1999). Either the Pearson III or Generalised Pareto distributions could be chosen.

Also shown on Figure D.1 is the regional average L-moments obtained from all eight sites (and weighted by their length of record). It is evident that BremerR @Walloon (143107A) and BrisbaneR @ Gregor's Ck (143009A) are two sites most dissimilar to the regional average, an inspection of the at-site records (Appendix E) indicate considerable differences between the distribution of the annual maxima and the regional Generalised Pareto quantiles. Accordingly, these two stations were excluded from subsequent analysis.

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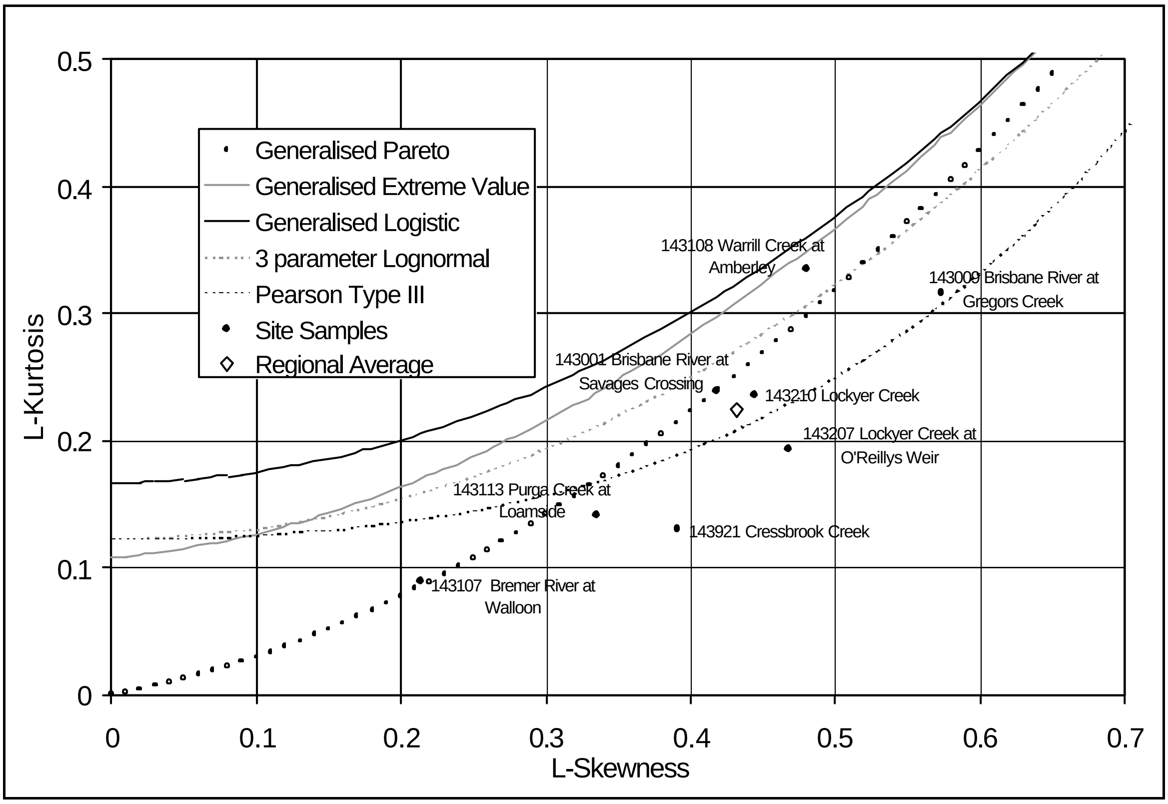

Figure D.1 L-Moment Ratio diagram for six flow gauging stations in the Brisbane River catchment

For assessment of peak flows at the lower reaches of the major Brisbane River system (approximately 13,500km^2), the response of small tributaries is less relevant than that of the larger tributaries and sub-catchments. Consequently the remaining stations with small catchment areas were excluded. They were Purga Creek @ Loamside (143113) and Cressbrook Creek @ Rosentreters Bridge (143921).

The average regional L-moments were recalculated for the remaining data. The position of the catchment average L-moments on the L-moment ratio diagram (Figure D.2) supports the adoption of the Generalised Pareto distribution.

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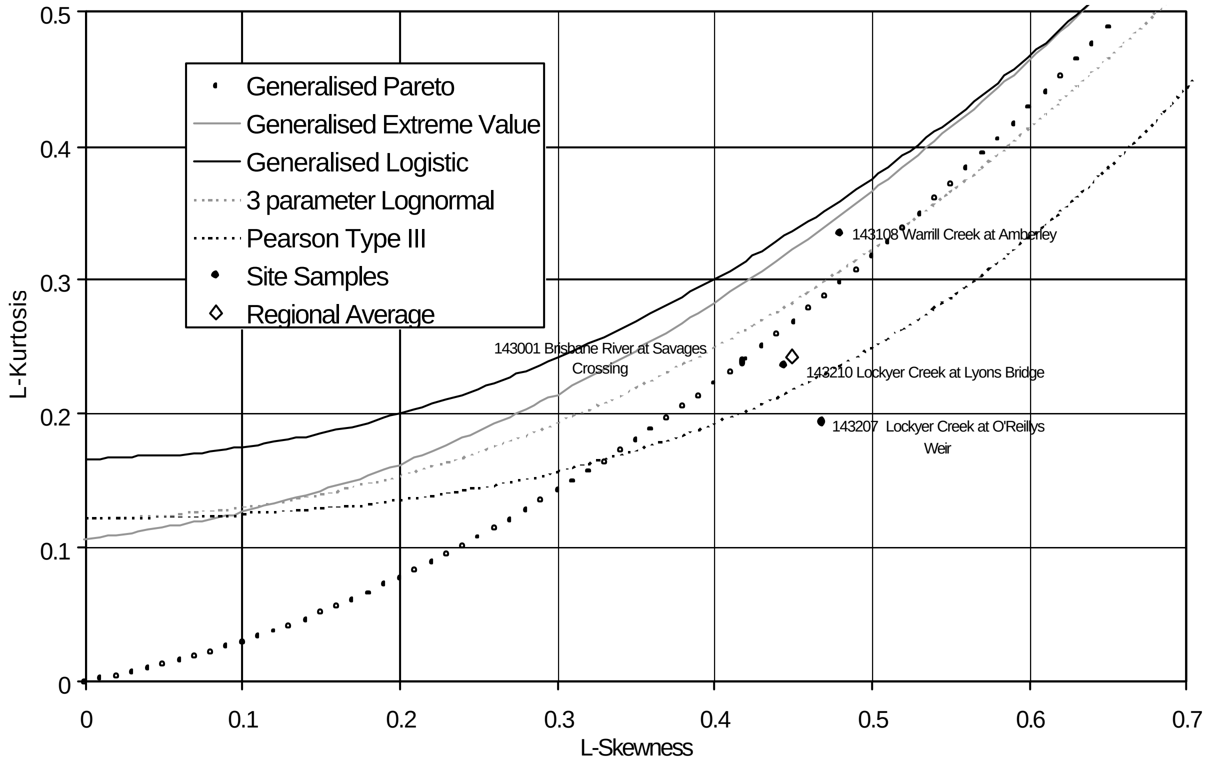

Figure D.2 L-Moment Ratio diagram for the most relevant and reliable flow gauging stations in the Brisbane River catchment (pre- Wivenhoe Dam)

The Generalised Pareto distribution was adopted for the regional analysis on the basis that the regional average L-Moment values lie closest to this distribution, and the L-Moments of the individual sites are scattered around the theoretical curve.

The Generalised Pareto distribution was adopted with parameters given in Table D.2.

- **Table D.2 Regional parameter values of the adopted Generalised Pareto distribution**

Parameter	Values obtained including information at Savages Crossing	Values obtained excluding information at Savages Crossing
Location parameter, ?	-0.062	-0.096
Scale parameter, ?	0.811	0.795
Shape parameter, ?	-0.230	-0.275

D.4 Parameters of Prior Distribution for Bayesian Analysis of Flood Peaks

Regional information can be incorporated in the Bayesian analysis of flood peaks that is performed by FLIKE. The regional information is incorporated into the Bayesian analysis as prior frequency distributions of the parameters of the flood frequency distribution that has been selected. The Bayesian analysis requires for each parameter:

- its prior mean (or expected) value,
- its prior standard deviation,
- its cross-correlation with the other parameter(s) of the distribution.

The prior mean values of the scale (?) and shape (?) parameters were obtained from the regional average L-moments of the seven sites that exclude Savages Crossing. These values are listed in the right column of Table D.2. The scale parameter (?) from the regional analysis shown in Table D.2 is computed from the L^{CV} ($=L^2/L^1$). The prior estimate of the scale parameter for gauging station 143001 is therefore computed from:

$$\hat{?}_{143001} ? L^{1}_{143001} ? ^{CV}_{Regional} ? 1181 ? 0.795 ? 939$$

The prior standard deviations of the scale and shape parameters were obtained by computing the parameter values from the L-moments at each of the seven sites, excluding Savages Crossing. The prior estimate of the standard deviation for each parameter was computed as the standard deviation of the parameter value from the seven sites. This computation is shown in Table D.3. The standard deviation for the scale parameter is computed from the L^{CV}. The standard deviation of the prior estimate of the scale parameter for gauging station 143001 is therefore computed from:

$$?_{?,143001} ? L^{1}_{143001} ? ^{CV}_{?,Regional} ? 1181 ? 0.388 ? 458$$

The cross-correlation between the scale and shape parameters was simply assumed to be the same as found from the parameter inference statistics computed by FLIKE (*r* = 0.6). This information

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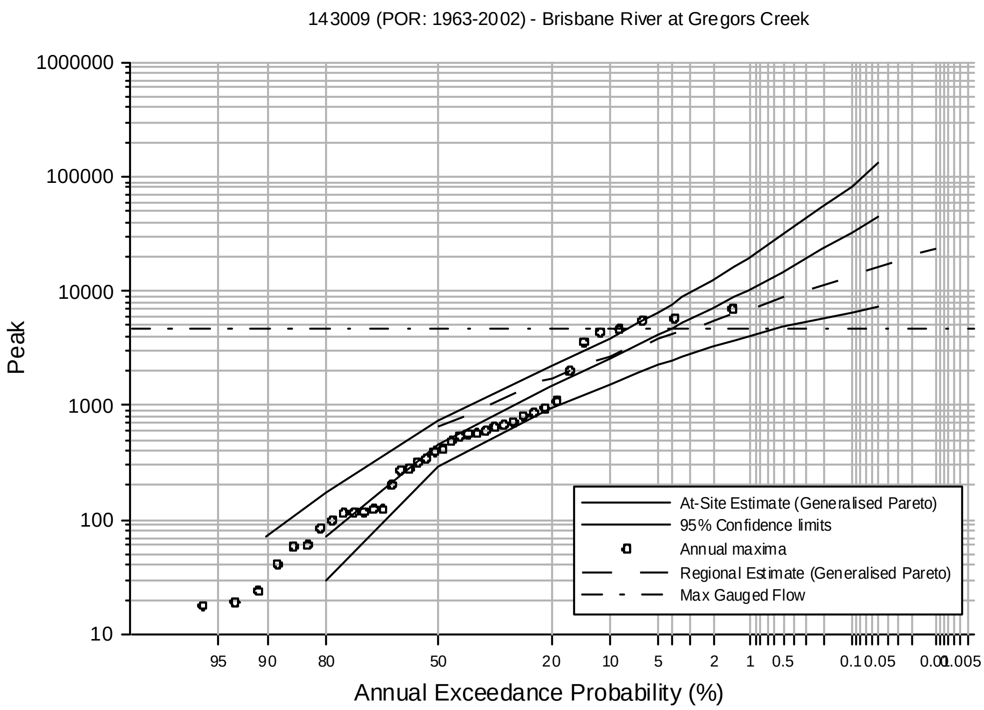
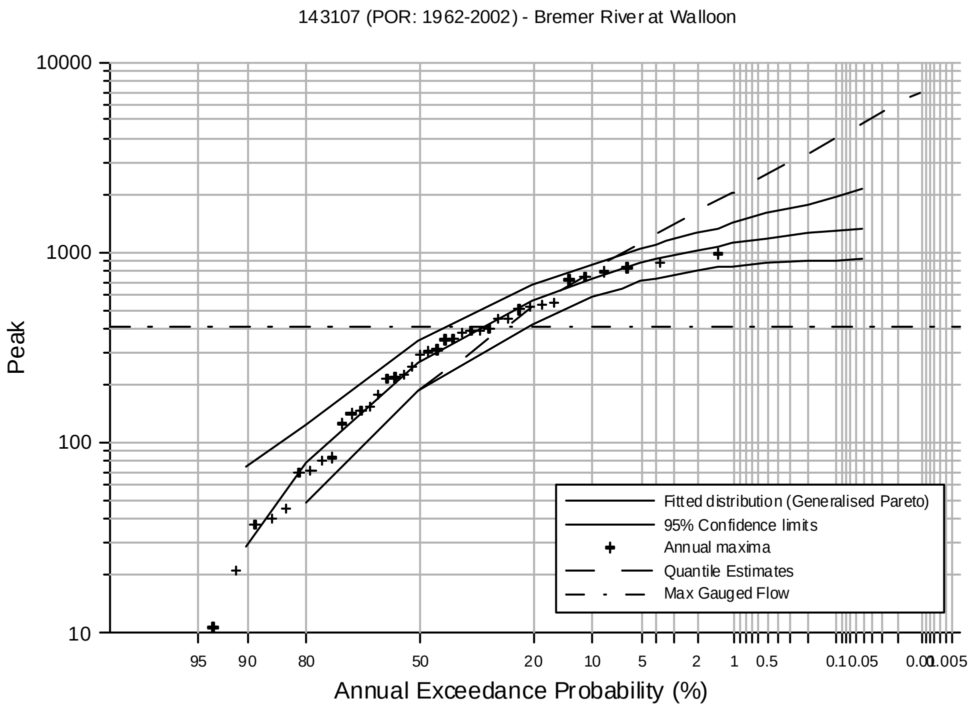
was used rather than the sample statistics from the regional parameter set as it was considered that correlation between parameters from the one river system was likely to over-estimate the actual degree of correlation.

Table D.3 Estimates of prior standard deviation and cross-correlation in parameter values of the adopted Generalised Pareto distribution

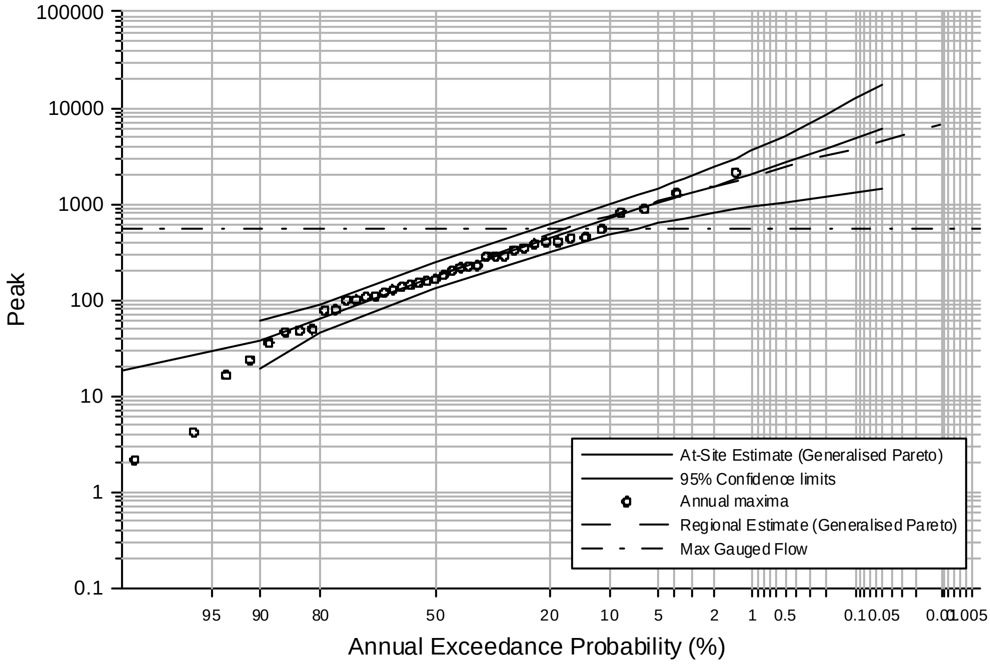
Site Number	Gauging Station Name	Scale parameter, ?	Shape parameter, ?
143009	Brisbane River @ Gregors Creek	0.573	-0.467
143107	Bremer River @ Walloon	1.502	0.300
143108	Warrill Creek @ Amberley	0.724	-0.268
143113	Purga Creek @ Loamside	1.573	0.279
143207	Lockyer Creek	0.833	-0.279
143210	Lockyer Creek @ Lyons Bridge	0.815	-0.275
143921	Cressbrook Creek @ Rosentreters Bridge	0.948	-0.185
Standard Deviation of Parameter		**0.388**	**0.297**

At-Site/Regional Analysis of Selected Gauges

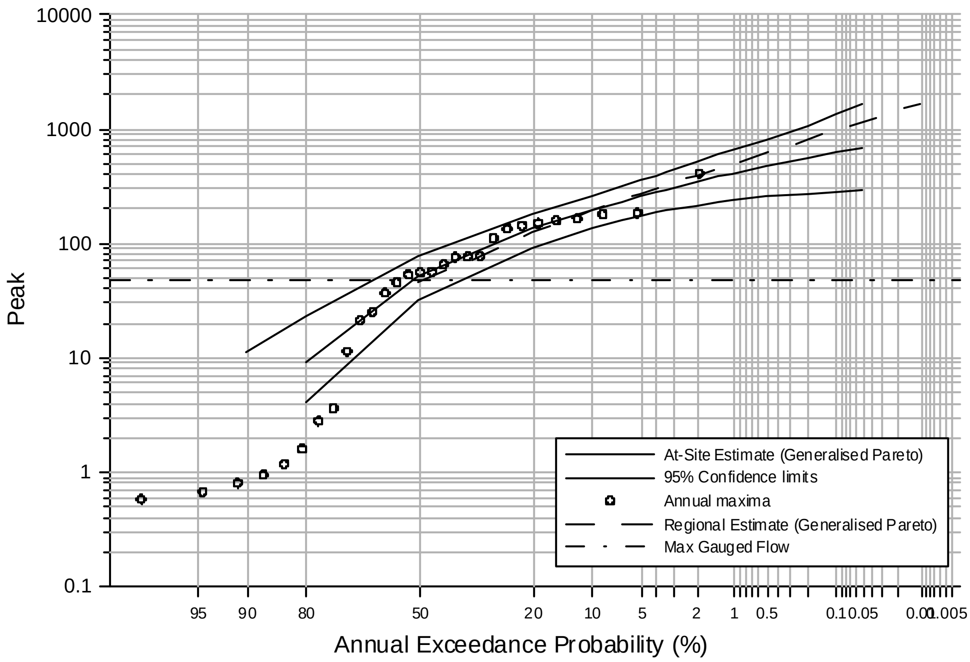


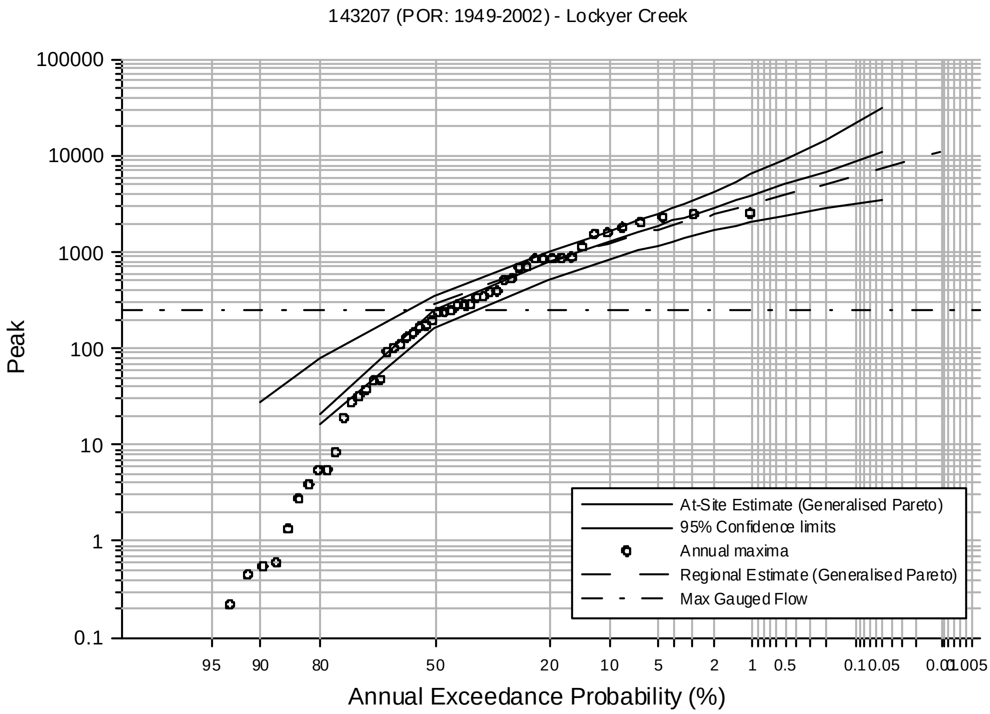


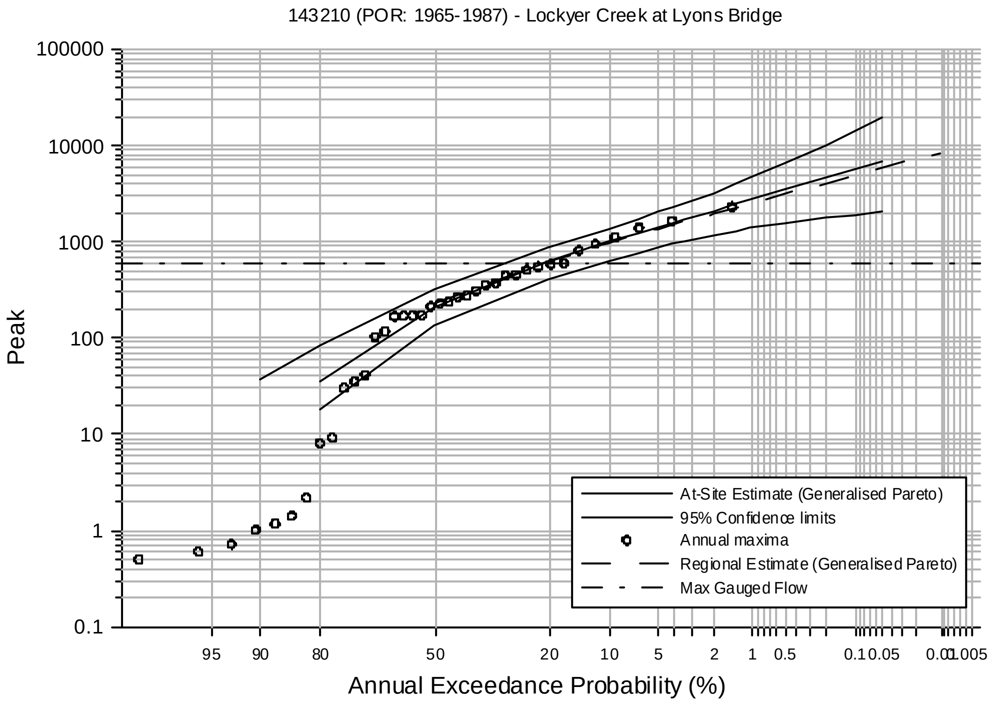
143108 (POR: 1962-2002) - Warrill Creek at Amberley



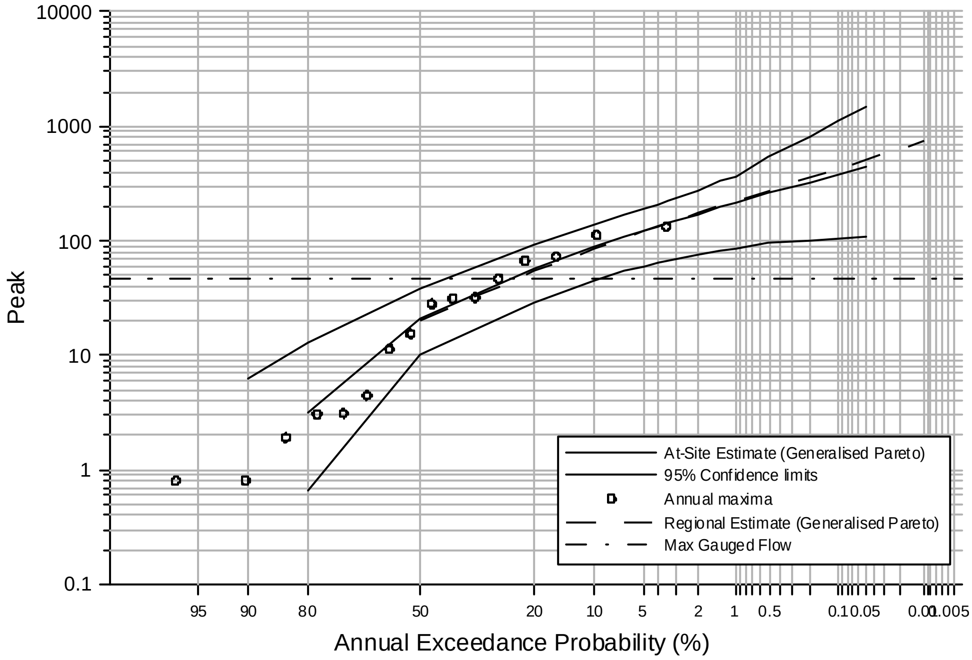
143113 (POR: 1974-2002) - Purga Creek at Loamside




143207 (POR: 1949-2002) - Lockyer Creek
Peak
Annual Exceedance Probability (%)
At-Site Estimate (Generalised Pareto)
95% Confidence limits
Annual maxima
Regional Estimate (Generalised Pareto)
Max Gauged Flow


143210 (POR: 1965-1987) - Lockyer Creek at Lyons Bridge
Peak
Annual Exceedance Probability (%)
At-Site Estimate (Generalised Pareto)
95% Confidence limits
Annual maxima
Regional Estimate (Generalised Pareto)
Max Gauged Flow

143921 (POR: 1987-2002) - Cressbrook Creek at Rosentreters Bridge



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- Further Investigations
- Final Issue
- Compiled 18 December 2003

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Hydrological Modelling Draft A	22/08/2003	M. Salisbury	S. Abbey	22/08/2003	
Hydrological Modelling Draft B	29/08/2003	M. Salisbury	S. Abbey	29/08/2003	
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Statistical flood frequency Draft A	PDF	PDF	Barry Ball (Brisbane City Council)
Statistical flood frequency Draft B	PDF	PDF	Barry Ball (Brisbane City Council)
Hydrological Modelling Draft A	Electronic	Electronic	Peter Barnes (Brisbane City Council)
Hydrological Modelling Draft B	Electronic	Electronic	Peter Barnes (Brisbane City Council)
Draft Final	Hard Copies	5	Peter Barnes (Brisbane City Council)
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Executive Summary

Brisbane City Council (BCC) appointed an Expert Panel to review the flood investigations undertaken for the Brisbane River. Sinclair Knight Merz was approached to assist the Expert Panel with their review. The Expert Panel requested that Sinclair Knight Merz undertake flood frequency analyse of the available data and provide a "best" estimate of the likely 1 in 100 annual exceedance probability (AEP) peak flow rate at Savages Crossing and the Brisbane Port Office Gauge. This peak flow rate is also referred to as the Q100 event.

The primary tasks for Sinclair Knight Merz were to:

- undertake statistical flood frequency analysis, and to
- update the estimates of flood frequency from rainfall-runoff modelling with the new information.

The rainfall-runoff modelling utilised models developed as part of the Brisbane River Flood Study (Sinclair Knight Merz, 1998). Additional information and statistical techniques have been included in reassessing the plausible range of the Q100 flood.

The two tasks provide independent assessments of the Q100 event; firstly a statistical assessment of the streamflow data and secondly a rainfall-runoff modelling assessment.

This technical report has been prepared for expert technical reviewers, and familiarity with the flood frequency techniques adopted, such as regional analysis and Bayesian techniques, hydrological terminology and abbreviations is generally assumed.

Statistical flood frequency analysis

The Expert Panel requested that Sinclair Knight Merz undertake statistical flood frequency analysis of the available data and come up with a best estimate of the likely Q100 at Savages Crossing. An estimate of the Q100 for the "no dams" case (i.e. the peak flow that would occur if the dams were not present) was requested with an indication of the sensitivity of the estimate to the various sources of uncertainty leading to a plausible range for the Q100 estimate.

Statistical frequency analysis was undertaken using a range of at-site and regional methods. The main benefit of adopting a regional approach to statistical flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (e.g. the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum peak flow) then the regional information provides useful information on the appropriateness of the at-site estimates. The regional information was incorporated using Bayesian theory.

Sinclair Knight Merz has assessed the flood series data and provided a "best" estimate and a plausible range for the "no dams" scenario, i.e. assuming that Somerset and Wivenhoe dams were not present. It should be noted that the upper and lower estimates of the range are notional, and do not take into consideration information that is available from other independent sources (such as rainfall-based flood event modelling).

The results are presented in **Table ES1**.

- **Table ES1 Most Plausible Estimates of the Q100 Peak Flow at Savages Crossing Based on Statistical Flood Frequency Analysis**

Scenario	"Best" estimate	Likely lower estimate	Likely Upper estimate
"No dams"	12,000	10,000	14,000

The best estimate for the "no dams" scenario was adopted after consideration of substantial sensitivity analyses, with particular attention paid to the convergence of the Q100 estimates based on the three most relevant data series.

The boundaries of the plausible range of flow estimates are reasonably broad. This reflects the following significant sources of uncertainty:

- the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum estimated 1974 peak flow; this introduces considerable uncertainty on the flow estimates for the large flows that influence the flood frequency assessment in the range of the Q100,
- scarcity of information regarding the 1893 event in terms of its flow magnitude (there is considerable uncertainty in rainfall –runoff modelling results as there are scarce data on key event characteristics such as temporal pattern, losses, etc.). This event has a significant influence on the Q100 estimate (although inclusion of regional information lessens the impact of the uncertainty),
- choice of frequency distribution and the appropriate parameters, and,
- adjustment of data for the effect of the dams.

As an example of some of the above uncertainties, there is reasonable evidence that the 1974 "no dams" peak flow rate is somewhere between 7,500 m^3/s and 11,000 m^3/s. Such uncertainty has a direct bearing on the uncertainty in the "best" estimate of the Q100 event.

Rainfall-runoff modelling

The second method with which SKM was requested to assess the Q100 flow was rainfall-runoff modelling. This method takes design rainfall information and routes it through the catchment by simulating the depth, temporal and spatial patterns of the storm, subsequent losses (e.g. the soil, interception by vegetation, etc.), movement through the streams, rivers and dams until it reaches the Brisbane Port Office.

The Brisbane River Catchment is approximately 13,500 km^2 and includes Wivenhoe and Somerset Dams. The catchment area upstream of these dams is approximately 7,000 km^2 and therefore there is potential for flood mitigation benefits for areas below the dams. The potential for flood mitigation is dependent on the following factors:

- dam operating procedures,
- dam levels at the start of a flood event, and,
- spatial and temporal patterns of the storm.

The most sophisticated way to jointly assess the above factors (along with other factors such as variability in rainfall spatial and temporal patterns, loss rates, reservoir level and gate operation failure) is by Monte Carlo analysis. Monte Carlo analysis would provide a more accurate estimate of the Q100 and reduce the overall uncertainty in the flood estimates. To account for the above factors, sensitivity analysis was undertaken separately for spatial patterns, temporal patterns and starting water levels in the dams. Sensitivity to dam operation procedures was not undertaken as part of this study.

Revised rainfall estimates and dam operating procedures have been included in this investigation to determine new flow estimates.

Revised Rainfall Depths

The Department of Natural Resources and Mines (DNRM) provided 1 in 100 AEP CRC-FORGE rainfall estimates. These estimates included Areal Reduction Factors (ARF) which account for the reduction in rainfall depth with increasing catchment area. The rainfall estimates as supplied also contained the design spatial distribution of rainfall over the catchment.

Rainfall depths from CRC-FORGE were input into the RAFTS rainfall-runoff model (Sinclair Knight Merz, 2000) for pre-dams conditions, and a series of spatial patterns were modelled. A range of peak flows was determined at Savages Crossing and these are presented in **Table ES2**.

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- **Table ES2 Pre dams 1 in 100 AEP Flow Estimates at Savages Crossing from Rainfall-Runoff Modelling**

Scenario	Median (m^3/s)	Lower Estimate (m^3/s)	Upper Estimate (m^3/s)
No Dams	10,000	8,000	11,500

The median peak flow produced by the RAFTS model for the range of spatial patterns using a standard temporal pattern was approximately 10,000 m^3/s using an Initial Loss of 10 mm and a Continuing Loss of 1.0 mm/h. This compares to the statistical frequency estimate (i.e. analysis of recorded flow data) of 12,000 m^3/s.

Sensitivity to Spatial Pattern of Rainfall

The CRC-FORGE estimates for various spatial patterns with a standard AR&R 1987 temporal pattern were run through the DNRM Dam Operations model (Department of Natural Resources and Mines, 2003). This model predicts an outflow hydrograph from Wivenhoe Dam. The Wivenhoe Dam outflow hydrograph was then input into the RAFTS model and peak flow estimates were calculated at Savages Crossing. Peak flows ranged approximately from 3,000 m^3/s to 8,000 m^3/s. The median value of peak flow for post-dam conditions with variation in spatial pattern was estimated to be 6,200 m^3/s.

Sensitivity to Temporal Pattern of Rainfall

Using a catchment average 48-hour CRC-FORGE rainfall depth (ARF applied), the RAFTS model was then re-run using various temporal patterns for pre-dams conditions. When zero losses were applied, the range of flows was between 12,000 m^3/s and 13,800 m^3/s. This indicates that by incorporating the natural variation in spatial and temporal patterns it might be possible to reconcile the results obtained using statistical methods and rainfall-runoff modelling analysis. While zero loss rates are not realistic, the objective of this sensitivity analysis was to show that temporal patterns can have an impact on the magnitude of flows. A sensitivity analysis to variation in rainfall temporal pattern was not undertaken for post-dam conditions.

Sensitivity to Wivenhoe Reservoir Level

A sensitivity analysis was undertaken to variations in the starting water level in Wivenhoe Dam. The analysis used the 1 in 100 AEP 72-hour storm with standard temporal patterns and an Initial Loss of 10 mm and Continuing Loss of 1.0 mm/h. If Wivenhoe Dam is assumed full at the start of the event, the peak flow at Savages Crossing and Brisbane Port Office was estimated to be 5,400 m^3/s and 5,000 m^3/s respectively. If the dam was assumed to be at 75% full, the peak flow at Savages Crossing and Brisbane Port Office was reduced to 3,500 m^3/s and 4,400 m^3/s respectively.

Q100 estimate at the Brisbane Port Office

The main objective of the report was to determine 1 in 100 AEP peak flows and flood levels at the Brisbane Port Office. To do this, the MIKE11 hydraulic model (Sinclair Knight Merz, 2000) was used to account for routing effects from Savages Crossing to the Brisbane Port Office. The flows predicted by MIKE11 compared well to the flows predicted by RAFTS at the Brisbane Port Office. A rating curve from the hydraulic model was used to predict flood levels at the Brisbane Port Office.

Based on the current level of investigation, it is clear there is uncertainty in any estimate of the 1 in 100 AEP flood event at the Brisbane Port Office. **Table ES3** provides a range of estimates with a 'best estimate', upper estimate and lower estimate.

- **Table ES3 Range of Estimates at the Brisbane Port Office for the 1 in 100 AEP Flood with Dams**

Condition	Peak Flow (m^3/s)	Peak Flood Level (m AHD)
Lower Estimate	5000	2.76
Best Estimate	6500	3.51
Upper Estimate	8000	4.41

The information for the two historical flood events (1893 and 1974) was run through the RAFTS model for the pre and post-dam conditions. For post-dam conditions, the estimated peak flow at the Brisbane Port Office for the 1893 and 1974 flood events were 9,500 m^3/s and 6800 m^3/s respectively. It should be noted that the uncertainty in some of the historical data, 1893 in particular, is considerable.

The best estimate of 6,500 m^3/s was adopted after consideration of the RAFTS modelling for current design spatial pattern, various historical patterns and the performance of the model in reproducing flows at Savages Crossing for pre-dam flows. The estimate of the lower end of the plausible range of the Q100 estimate is 5,000 m^3/s. It was adopted with particular consideration to the range of results from the sensitivity to the spatial patterns. The estimate of the upper end of the plausible range was taken to be 8,000 m^3/s. This upper bound was adopted after particular consideration of the variation in the spatial patterns, the sensitivity to temporal patterns, and the 1974 peak flow results for the 'Somerset only' then 'Somerset and Wivenhoe' dams scenarios.

The peak flows presented in this report are less than those predicted in the Brisbane River Flood Study (Sinclair Knight Merz, 1998). The factors that influence the changes in peak flows are:

- inclusion of the lower CRC-FORGE rainfall depths with Areal Reduction Factors;
- consideration of variation in temporal and spatial characteristics of rainfall;

- better representation of dam operating procedures, and
- inclusion of regional streamflow information in the statistical flood frequency analysis.

The following actions could be undertaken to further improve this analysis:

- Undertake rainfall-runoff modelling in a Monte Carlo framework to explicitly consider the natural variations in spatial and temporal patterns of rainfall and variations in initial dam storage levels (other variables such as variable rainfall losses and gate failure likelihood can also be incorporated). This will provide the most robust estimates of Q100 that accurately reflect the combined influences of these stochastic factors.

  It is noted that while undertaking rainfall-runoff modelling in a Monte Carlo framework is an accepted method, it is not a standard method for flood studies.
- Re-calibrate the Ipswich City Council's MIKE 11 hydraulic model within the Brisbane City Council Boundary.

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1. Introduction

1.1 Background

Sinclair Knight Merz prepared a flood study for the Brisbane River in 1998. Since this time, there have been changes to the information used in assessing the flood levels along the lower reaches of the Brisbane River. These include:

- CRC-FORGE rainfall estimates that have been prepared for the Brisbane River catchment (Department of Natural Resources and Mines, 2003a),
- modifications to procedures for flood operations at Wivenhoe and Somerset Dams since the initial Brisbane River Flood Study Report (Sinclair Knight Merz, 1998) was completed, and
- additional and/or revised flood flow data.

An Expert Panel was appointed by Brisbane City Council to review the flood studies undertaken for the Brisbane River in the light of this new information, with particular emphasis on the flood flows and associated levels in the lower reaches including Brisbane City.

Sinclair Knight Merz was approached to assist the Expert Panel with their review. The primary tasks for Sinclair Knight Merz were to:

- undertake statistical flood frequency analysis, and to
- Update the flood frequency estimates from rainfall-runoff modelling with the new information.

The details of the tasks that were originally agreed are presented in **Appendix A**.

1.2 Scope of Report

This report addresses the tasks presented in **Appendix A**, namely to:

1) Collect and Collate Data. This task involves the collection of stream gauge information and discussions with hydrographers from various Stream Gauge Authorities to determine the reliability of readings at individual Gauging Stations.
2) Undertake a regional and at-site flood frequency analyses (FFA) for the Brisbane River Catchment under 'No Dams' conditions for selected sites.
3) Document the findings of the flood frequency analysis, stating assumptions and outcomes.
4) Review previous reports, CRC-FORGE rainfall estimates and historical streamflow data.
5) Undertake a Regional Flood Frequency Analysis (pre-dams).
6) Undertake hydrologic modelling (pre-dams).

7) Undertake hydrologic modelling (dams in place).
8) Analyse catchment sensitivity using various temporal patterns and historical spatial patterns.
9) Undertake a sensitivity analysis of starting reservoir levels.
10) Perform hydraulic modelling to produce flood frequency estimates at Moggill and the Brisbane Port Office.
11) Report on the findings of the statistical flood frequency analyses and the rainfall-runoff and hydraulic modelling.

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2. Sources of Data for Statistical Flood Frequency Analysis

Gauging station data were obtained from the Department of Natural Resources and Mining (DNRM) and the Commonwealth Bureau of Meteorology (BoM). Different types of data were collected, including:

- recorded water elevation above the gauge datum,
- flow data estimated from a rating relationship, and
- rating tables.

In some instances the data were processed in some additional manner, as discussed below.

A number of reports on large flood events and the analysis thereof were made available.

2.1 Department of Natural Resources and Mining Data

There are two sources of data from DNRM:

- Recorded water elevation data and associated flow estimates,
- Estimates of "no dams" flood peaks at Savages Crossing that had been adjusted to *exclude* the influence of the dam(s) where appropriate.
- Estimates of "with dams" flood peaks at Savages Crossing that had been adjusted to *include* the influence of one or more of the dam(s) where appropriate.

All data sets have been analysed without assessment as to the method of obtaining the peak flow rates. That is the data sets were taken "as provided."

A significant amount of recorded data was not selected for the reasons discussed in relation to the BoM data below.

2.2 Bureau of Meteorology Data

Stations from the BoM have generally been omitted at this stage for a number of reasons. The reason for each site being omitted is stated in **Appendix B** (along with other sources of gauged data). The primary reasons for omission were:

- short record length,
- small catchment area, and/or
- uncertainty in the rating curve.

The last reason included either very low gauged flow or the rating curve was changed by BoM to a "calibration curve" for use in real time flood forecasting.

Elevation data for a number of sites of direct interest to this study, such as Moggill, and the Brisbane Port Office were also obtained.

Appendix C shows the location of the stream gauges that were used in the statistical flood frequency analysis.

3. Statistical Flood Frequency Analyses

3.1 Introduction

The Expert Panel requested that Sinclair Knight Merz undertake statistical flood frequency analyse of the available data and come up with a best estimate of the likely 1 in 100 annual exceedance probability (AEP) peak flow rate at Savages Crossing. This peak flow rate is also referred to as the Q100 event. An estimate of the Q100 for the "no dams" case (i.e. peak flow that would occur if the dams were not present) was requested with an indication of the sensitivity of the estimate to the various sources of uncertainty leading to a plausible range for the Q100 estimate.

The sources of data have been documented in **Section 2**.

The sources of uncertainty that could affect the Q100 estimate at Savages Crossing include:

- adjustment of data for the influence of the dams,
- uncertainty in the rating curves that relate recorded river level to flow rate,
- the magnitude of historic data (especially 1893 and 1825),
- the period of record associated with the historic data,
- choice of frequency distribution,
- selection of parameters for the distribution, and
- method of including historical data.

DNRM provided three series of data. The series are provided in **Appendix D**. The first was the "gauged flows at Savages Crossing" (1909-2000). This was a composite series from Savages Crossing/Lowood/Vernor stations. The second series was for "both dams working" in which they made some adjustments that they considered appropriate for the effect on the flow rates if the dams had been in place for the entire period. The precise method for adjusting the data has not been detailed; the method as provided is included with the data series in **Appendix D**. The third series of data (1890 - 2000) was adjusted so as to represent the peak flow rates expected if Somerset and Wivenhoe dams had not existed over the entire period. Frequency analysis of this data was undertaken along with various unadjusted data.

The statistical frequency analysis was undertaken using a range of at-site and regional methods. The main benefit of adopting a regional approach to statistical flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (e.g. the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum peak flow) then the regional information provides useful information on the appropriateness of the at-site estimates.

Regional information was incorporated in the Bayesian analysis of flood peaks that was performed using the FLIKE program (v4.5 as supplied by Assoc Prof George Kuczera in June 2003). The regional information was incorporated into the Bayesian analysis as prior frequency distributions of the parameters of the Generalised Pareto (GP) distribution. Some preliminary relevant information is contained in the next section and greater detail of the regional method is reported in **Appendix E** and **Appendix F**.

The Expert Panel was interested in understanding how the statistical flood frequency analysis results were affected by the addition of dams, the inclusion of various gauged/historical data and use of various statistical techniques. Four cases as listed below were developed to meet the Expert Panel's requirements.

Case 1. Analysis of pre-Somerset and pre-Wivenhoe data ie. data that was unaffected by Somerset and Wivenhoe dams were assessed. Data prior to 1951 were analysed.

Case 2. Analysis of pre-Wivenhoe data with no correction for Somerset dam; consideration given to all data as recorded or estimated with no attempt made to assess the effect of Somerset dam on the flow magnitudes.

Case 3. Analysis of "no dams" data as estimated by DNRM; the data set that contained the flows that DNRM estimate would have occurred in the absence of Somerset and Wivenhoe dams was assessed.

Case 4. Analysis of post-dam data estimated by DNRM; assessment of the data set that contained the flows that DNRM estimate would have occurred if Somerset and Wivenhoe dams were present for the entire period of record.

The analyses undertaken to determine the "best" estimate from statistical flood frequency analysis and a plausible range are summarised in **Table 3-1**.

The individual analyses including the data, techniques, the objective and comments on the results of each analysis are included in **Table 3-3** to **Table 3-6** and summarised in **Table 3-7**. The effects on the flood frequency curves of each of the analyses are shown in **Figures 3-1** to **3-7**.

As noted previously, this report has been prepared for expert reviewers with a high level of understanding. The explanations, comments and discussion are as concise as possible to enable the broad range of analyses to be succinctly presented for ease of comparison.

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- **Table 3-1 Summary of statistical flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)**

	Continuous Record	Historic Data (m^3/s)	Historic Period	Distribution	Model for fitting distrib'n	Prior Inform'n (regional)	Main Objective
Case 1 Pre -Wivenhoe and Somerset							
1A	1909-1951	Excluded	1909-1951	GP	FLIKE	Excluded	Assess the continuous record of Savages Crossing Data that is unaffected by large dams
1B	1909-1951	1893 (Qp=13000)	1847-1951	GP	FLIKE	Excluded	As for 1A except includes the best estimate of the 1893 historic peak
1C	1909-1951	1893 (Qp=13000)	1847-1951	GP	FLIKE	Included	As for 1B except includes regional information
1D	1909-1951	1825 (Qp=13200) 1893 (Qp=13200	1825-1951	GP	FLIKE	Excluded	As for 1B with the addition of the historical event of circa 1825 (diary notes from early explorers with heights in the order of the 1893 event)
1E	1909-1951	1893	1847-1951	LPIII	FLIKE	Excluded	Test the difference re LPIII distribution instead of GP
1F	1909-1951	1893 (Qp=14500)	1847-1951	GP	FLIKE	Included	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable higher estimate)
1G	1909-1951	1893 (Qp=12000)	1847-1951	GP	FLIKE	Included	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable lower estimate)
1H	1909-1951	1893 (Qp=13000)	1847-1951	LPIII	ARR87 incl historic data	Excluded	Determine Q100 using ARR87 method for including historical data.

GP = Generalised Pareto Distribution

LPIII = Log-Pearson III Distribution

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	Continuous Record	Historic Data (m³/s)	Historic Period	Distribution	Model for fitting distribn	Prior Inform'n (regional)	Main Objective
Case 2 **Pre Wivenhoe, no adjustments made for Somerset**							
2A	1909-1982	Excluded	1909-1982	GP	FLIKE	Included	Test inclusion of additional 31 years of record.
2B	1909-1982	1893	1847-1982	GP	FLIKE	Included	As for 2A plus historic data. Indicate sensitivity to effect of Somerset on Q100 estimate
Case 3 **"No Dams" based on DNRM adjusted estimates**							
3A	1890-2000	Excluded	1890-2000	GP	GetDat	Excluded	Assess Q100 from "no dams" adjusted data series produced by DNRM.
3B	1890-2000	Excluded	1890-2000	LPIII	GetDat	Excluded	Assess impact of LPIII as an alternative distribution for this series.
Case 4 **"Dams" based on DNRM estimates**							
4A	1909-2000	Excluded	1890-2000	GP	GetDat	Excluded	Assess the impact of dams on Q100 at Savages Crossing based on DNRM's assessment of flows if dams had been in place for the historic period of record.
4B	1909-2000	Excluded	1890-2000	LPIII	GetDat	Excluded	Assess impact of LPIII as an alternative distribution for this series.

GP = Generalised Parts Distribution

LPIII = Log-Pearson III Distribution

3.2 Regional Frequency Analysis

A regional statistical frequency analysis was conducted to assist in the estimation of flood frequency at Savages Crossing (GS143001). The main benefit of adopting a regional approach to statistical flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (e.g. the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum peak flow) then the regional information provides useful information on the appropriateness of the at-site estimates.

Flood peaks were available at eight relevant sites in the Brisbane River catchment, including the site at Savages Crossing (GS143001). The Generalised Pareto probability distribution was selected for the statistical flood frequency analysis on the basis of the L-Moment ratios at eight sites.

Regional information was incorporated in the Bayesian analysis of flood peaks that is performed by FLIKE. The regional information was incorporated into the Bayesian analysis as prior frequency distributions of the parameters of the Generalised Pareto distribution. The Bayesian analysis requires for each parameter:

- its prior mean (or expected) value,
- its prior standard deviation, and
- its correlation with other parameters.

The prior mean and standard deviation of the scale (α) and shape (κ) parameters were obtained from the regional average L-moments of the seven sites that excluded Savages Crossing. The prior parameter values that were adopted for the Bayesian analysis are shown in **Table 3-2**.

- **Table 3-2 Prior parameters for Bayesian analysis of flood peaks at Savages Crossing (GS143001)**

Value	Scale parameter, α	Shape parameter, κ
Mean	939	-0.274
Standard Deviation	458	0.297

The cross-correlation between the scale and shape parameters was simply assumed to be the same as found from the parameter inference statistics computed by FLIKE ($r = 0.6$). This information was used rather than the sample statistics from the regional parameter set as it was considered that correlation between parameters from the one river system was likely to over-estimate the actual degree of correlation.

FLIKE was used to derive quantile estimates for Cases 1 and 2, but due to difficulties with the data sets a Sinclair Knight Merz program *GetDat* was used to assess Cases 3 and 4. The *GetDat* program is based on Hosking and Wallis' L-Moments routines, and includes Monte Carlo simulation for estimation of confidence limits. No prior or regional information was assessed in Cases 3 and 4.

Greater detail of the regional analyses is provided in **Appendix E** and **Appendix F**.

3.3 Case 1: Analysis of Pre-Somerset and Pre-Wivenhoe Data

The data set for these runs was the DNRM unadjusted gauge data (1909-1951) supplemented by historical data as noted in the table below.

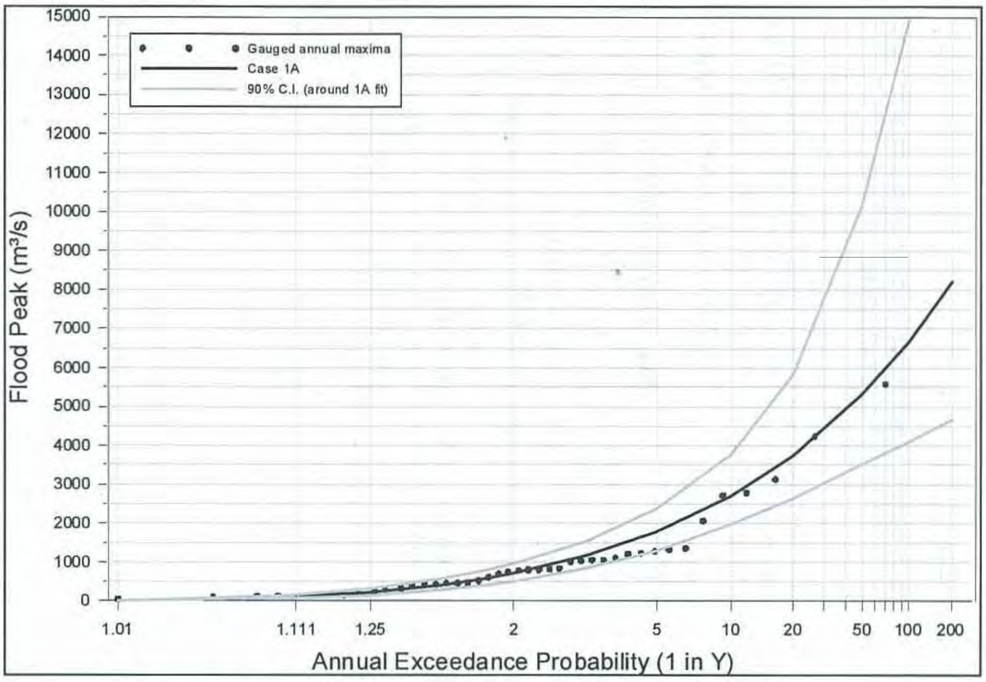
The Case 1 analyses investigate the primary sources of uncertainty in the data apart from adjustments for the influence of the dams.

The results are tabulated with comments in **Table 3-3** with specific influence on curves plotted in **Figures 3-1** to **3-3** so that the influence of specific assumptions can be compared graphically.

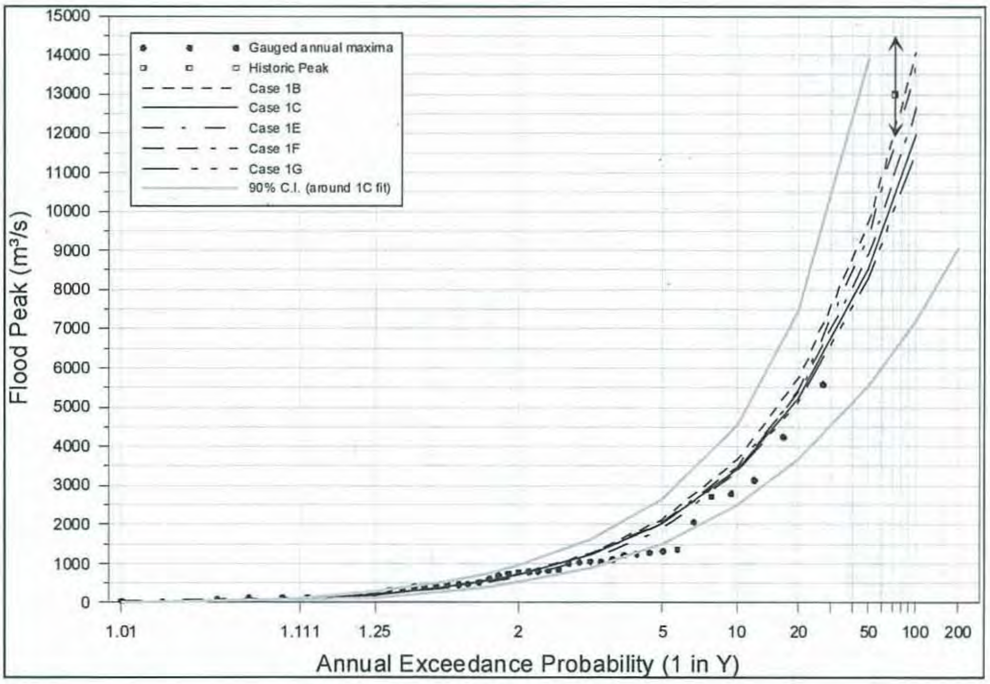
- **Table 3-3 Summary of Case 1 statistical flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)**

	Continuous Record	Historic Data (m³/s)	Historic Period	Distrib-ution	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 1 Pre -Wivenhoe and Somerset								
1A	1909-1951	No	1909-1951	GP	No	6 690	Assess the continuous record of Savages Crossing Data that is unaffected by large dams	Ignores all information in the fifty years of data post Somerset (and post-Wivenhoe) dam and the historic 1893 event. Also excludes prior information from regional analysis
1B	1909-1951	1893 (Qp=13000)	1847-1951	GP	No	14 070	As for 1A except includes the best estimate of the 1893 historic peak	By excluding the data post Somerset dam the frequency of the 1893 event is overestimated, consequently the Q100 estimate is judged to be conservative..
1C	1909-1951	1893 (Qp= 13000)	1847-1951	GP	Yes	11 970	As for 1B except includes regional information	The regional information has a significant influence on the Q100 estimate and partially compensates for the impact of the frequency of the 1893 event in 1B. Note similarity of Q100 estimate to that for 2B where the unadjusted post- Somerset but pre-Wivenhoe data was included.
1D	1909-1951	1825 (Qp= 13200) 1893 (Qp= 13 200	1825-1951	GP	No	15 690	As for 1B with the addition of the historical event of circa 1825 (diary notes from early explorers with heights in the order of the 1893 event)	The plotting position of this event is outside the 90% confidence interval. Hence the magnitude is highly questionable and should be excluded from consideration.
1E	1909-1951	1893	1847-1951	LPIII	No	13 720	Test the difference re LPIII distribution instead of GP	Relatively minor difference to 1B (the equivalent data fitted with the Generalised Pareto distribution)

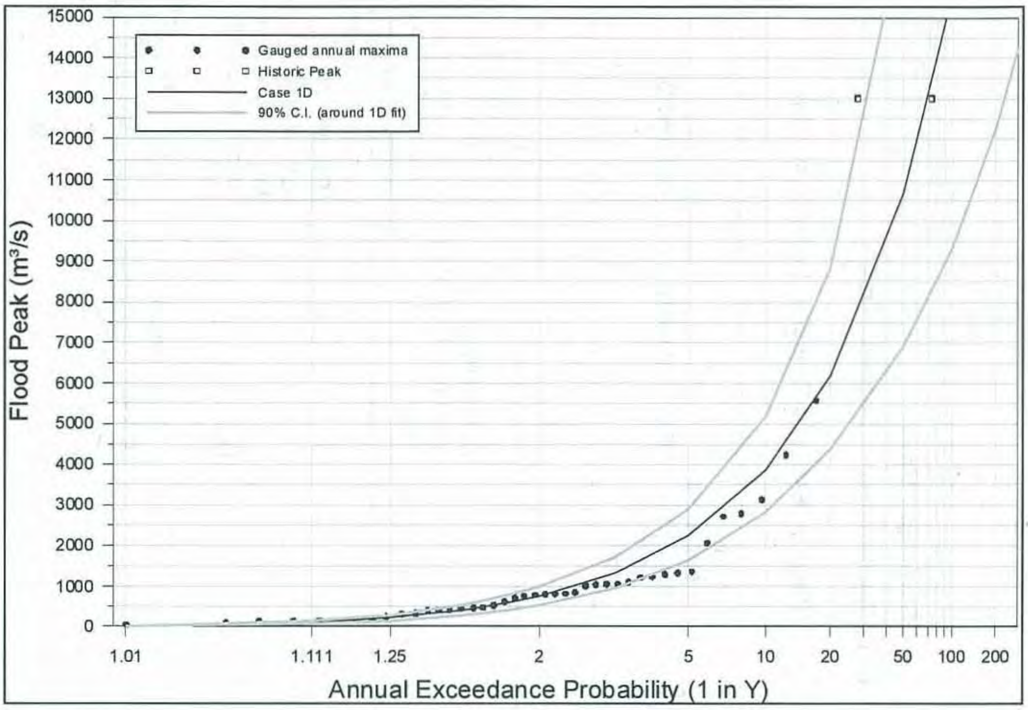
	Continuous Record	Historic Data (m³/s)	Historic Period	Distrib-ution	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
1F	1909-1951	1893 (Qp= 14500)	1847-1951	GP	Yes	12 660	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable higher estimate)	Magnitude taken from BoM "not unreasonable" estimate of 1893 peak. (BoM 2003) Q100 at Savages Crossing is influenced but not overly sensitive.
1G	1909-1951	1893 (Qp= 12 000)	1847-1951	GP	Yes	11 560	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable lower estimate)	Magnitude taken from BoM URBS modelling calibrated to 1974, daily temporal pattern and cont loss of 2.5 mm/hr. (BoM 2003) Q100 at Savages Crossing is influenced but reasonably insensitive.
1H	1909-1951	1893 (Qp= 13 000)	1847-1951	LPIII (ARR87 incl historic data)	No	7667	Determine Q100 using ARR87 method for including historical data.	This method gives a significantly lower Q100 for Savages Crossing. Note: the ARR87 method gives a Q100 of 6179m³/s if the historical data is excluded.



- **Figure 3-1 Generalised Pareto Distribution fitted to the 1909-1951 pre-dams data at Savages Crossing**



- **Figure 3-2 Comparisons of variations in statistical flood frequency for various assumptions on pre-dams data for Savages Crossing**



- **Figure 3-3 Assessment of the inclusion of a 1825 estimate of a flood possibly of the same magnitude as the 1893 event**

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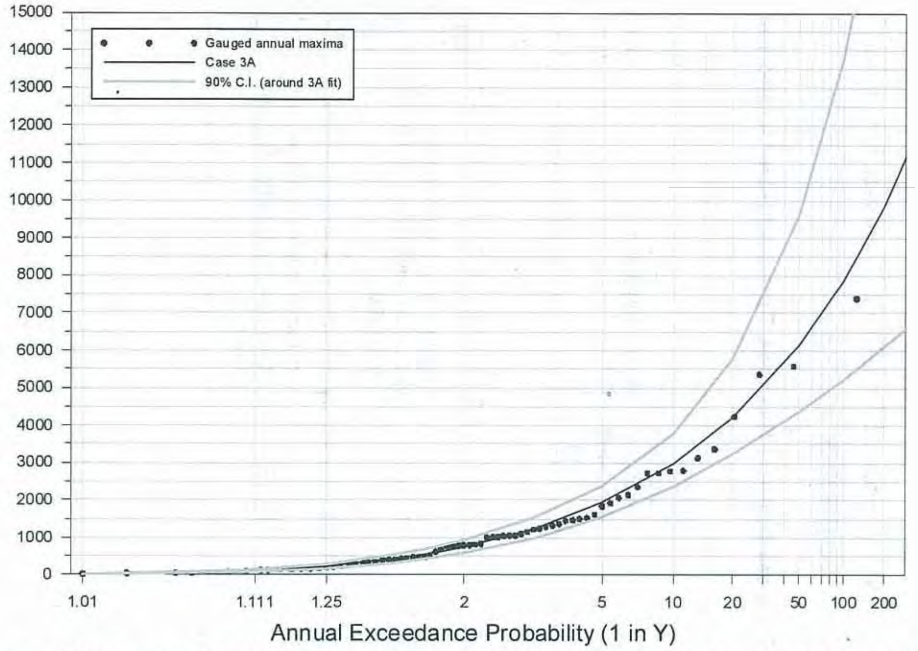
3.4 Case 2: Analysis of Pre-Wivenhoe Data With No Correction for Somerset Dam

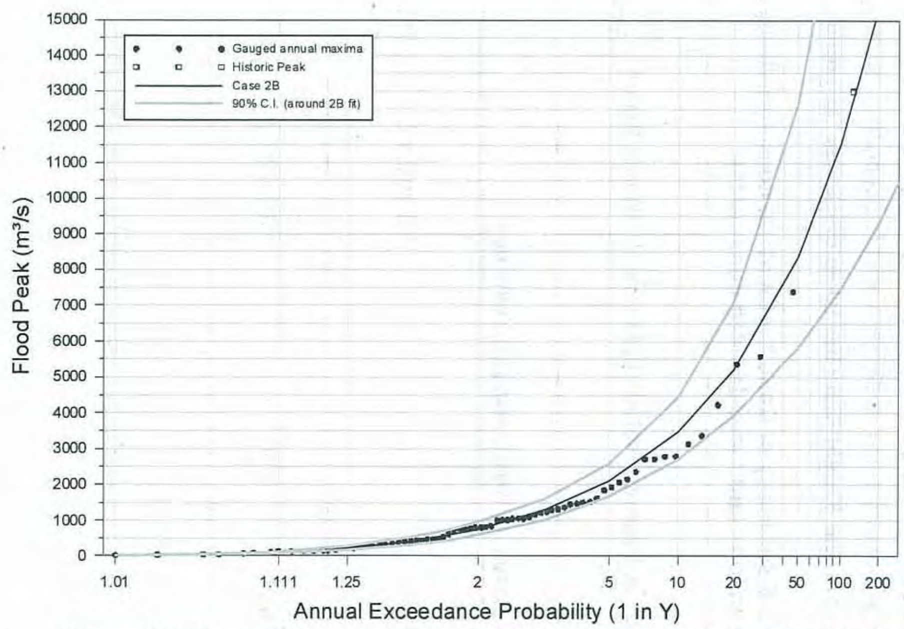
These analyses were based on gauged flows up to 1982, with no corrections made for the influence of Somerset Dam.

- **Table 3-4 Summary of Case 1: statistical flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)**

	Continuous Record	Historic Data (m³/s)	Historic Period	Distrib-ution	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 2 Pre Wivenhoe, no adjustments made for Somerset								
2A	1909-1982	No	1909-1982	GP	Yes	7 870	Test inclusion of additional 31 years of record.	Q100 estimate increases (note record includes 1974 event) but excludes the historic data including the flood of record (1893) so Q100 is underestimated.
2B	1909-1982	1893	1847-1982	GP	Yes	11 500	As for 2A plus historic data. Indicate sensitivity to effect of Somerset on Q100 estimate	Inclusion of historic data is very important (cf 2A). Q100 estimate is not overly sensitive to the influence of Somerset in the record (at least prior to Wivenhoe dam) Q100 estimate at Savages Crossing is likely to be greater than Q100 estimate here as data has *not* been adjusted for effect of Somerset dam. Refer to 3a for analysis of data adjusted for dams. Consistent with 1C and 3A Q100 estimates.



■ **Figure 3-4 Assessment of the pre-Wivenhoe gauged data without 1893 event**



■ **Figure 3-5 Assessment of the pre-Wivenhoe gauged data with 1893 event**

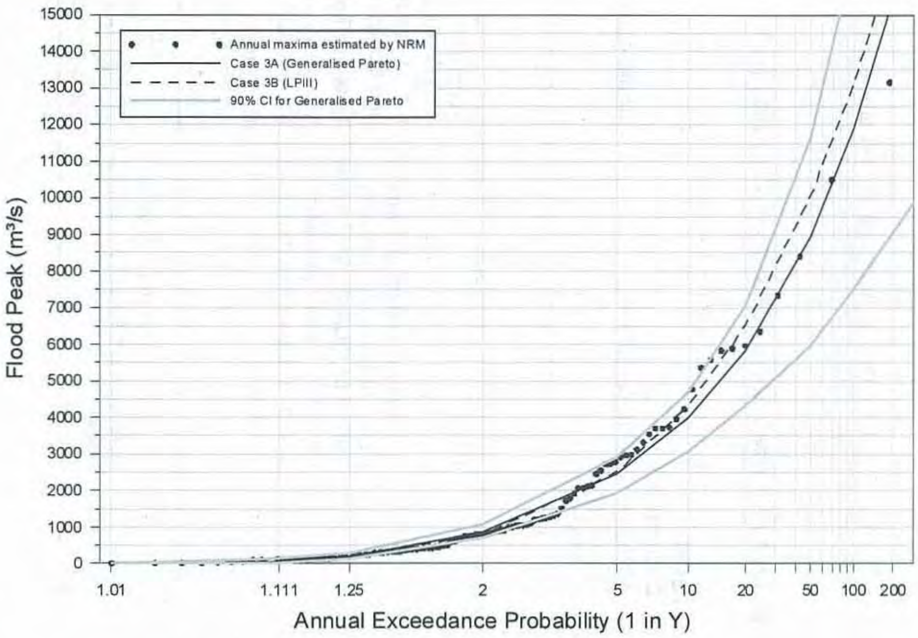
3.5 Case 3: Analysis of "No Dams" Data Estimated by DNRM

Note effect of Somerset dam is highly variable depending on its operation. DNRM has assessed the effect of Somerset dam on the flood data series. Sinclair Knight Merz has taken this series "as provided" and analysed the statistics.

- **Table 3-5 Summary of Case 3: statistical flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)**

	Continuous Record	Historic Data (m^3/s)	Historic Period	Distrib-ution	Prior Info (regional)	Q100 Estimate at Savages Crossing (m^3/s)	Main Objective	Comments
Case 3 "No Dams" based on DNRM adjusted estimates								
3A	1890-2000	No	1890-2000	GP	No	11 900	Assess Q100 from "no dams" adjusted data series produced by DNRM.	Q100 estimate is consistent with 1C and 2B. Note: method used to obtain adjusted data series not assessed by SKM.
3B	1890-2000	No	1890-2000	LPIII	No	13 150	Assess impact of LPIII as an alternative distribution for this series.	Q100 is more sensitive to choice of distribution for this data set than observed between 1B and 1E above.

SKM



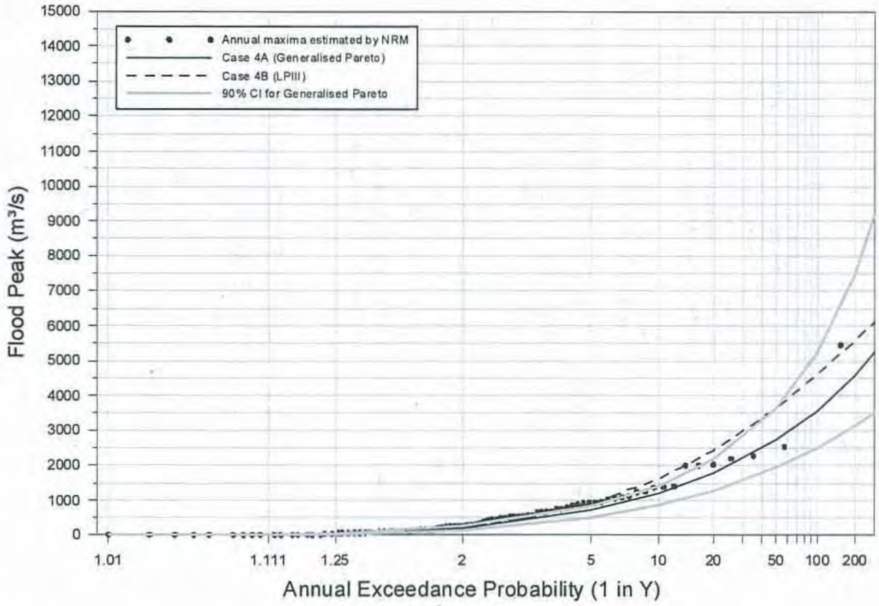
- **Figure 3-6 Assessment of the "no –dams" annual maxima series provided by DNRM using both GP and LPIII distributions**

3.6 Case 4: Analysis of Post-Dam Data Estimated by DNRM

These analyses were based on the "post-dam" data set provided by DNRM. As noted in Section 3.4 the data has been taken and analysed on an "as provided" basis.

- **Table 3-6 Summary of Case 4: Post-dam Data - statistical flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)**

	Continuous Record	Historic Data (m³/s)	Historic Period	Distrib-ution	Prior Info (regional)	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 4 "Dams" based on DNRM estimates								
4A	1909-2000	No	1890-2000	GP	No	3590	Assess the impact of dams on Q100 at Savages Crossing based on DNRM's assessment of flows if dams had been in place for the historic period of record.	According to this series, the Q100 is reduced to about 30% of that expected without Wivenhoe and Somerset dams. Note: method used to obtain adjusted data series not assessed by SKM. Refer to later sections for the impact of dams from a hydrological routing perspective.
4B	1909-2000	No	1890-2000	LPIII	No	4920	Assess impact of LPIII as an alternative distribution for this series.	Q100 estimate is sensitive to choice of distribution (Q100 is approx. 30% higher than GP estimate in 4A)



- **Figure 3-7 Assessment of the "post-dams" annual maxima series provided by DNRM using both GP and LPIII distributions.**

3.7 Summary of Analysis Results

The analyses in the preceding subsections indicate that there is considerable variation in the Q100 (1 in 100 AEP peak flow rate) estimate at Savages Crossing. The analyses are summarised in **Table 3-7**. As noted above, the summary is intended to succinctly present the broad range of sensitivity analyses for expert reviewers who are familiar with the concepts, common discipline abbreviations and analysis methods.

Table 3-7 Summary of statistical flood frequency analyses for peak flows at Savages Crossing (refer to text for abbreviations and more detailed comments)

	Continuous Record	Historic Data (m^3/s)	Historic Period	Distribution	Prior Information	Q100 Estimate at Savages Crossing (m^3/s)	Main Objective	Comments
Case 1 Pre -Wivenhoe and Somerset								
1A	1909-1951	No	1909-1951	GP	No	6 690	Assess the continuous record of Savages Crossing Data that is unaffected by large dams	Ignores all information in the fifty years of data post Somerset (and post-Wivenhoe) dam and the historic 1893 event. Also excludes prior information from regional analysis
1B	1909-1951	1893 (Qp=13000)	1847-1951	GP	No	14 070	As for 1A except includes the best estimate of the 1893 historic peak	By excluding the data post Somerset dam the frequency of the 1893 event is overestimated, consequently the Q100 estimate is judged to be conservative.
1C	1909-1951	1893 (Qp=13000)	1847-1951	GP	Yes	11 970	As for 1B except includes regional information	The regional information has a significant influence on the Q100 estimate and partially compensates for the impact of the frequency of the 1893 event in 1B. Note similarity of Q100 estimate to that for 2B where the unadjusted post- Somerset but pre-Wivenhoe data was included.
1D	1909-1951	1825(Qp=13200) 1893 (Qp=13200	1825-1951	GP	No	15 690	As for 1B with the addition of the historical event of circa 1825 (diary notes from early explorers with heights in the order of the 1893 event)	The plotting position of this event is outside the 90% confidence interval. Hence the magnitude is highly questionable and should be excluded from consideration.
1E	1909-1951	1893	1847-1951	LPIII	No	13 720	Test the difference re LPIII distribution instead of GP	Relatively minor difference to 1B (the equivalent data fitted with the Generalised Pareto distribution)
1F	1909-1951	1893 (Qp=14500)	1847-1951	GP	Yes	12 660	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable higher estimate)	Magnitude taken from BoM "not unreasonable" estimate of 1893 peak. Q100 at Savages Crossing is influenced but not overly sensitive.(BoM 2003)
1G	1909-1951	1893 (Qp=12000)	1847-1951	GP	Yes	11 560	Test the impact of uncertainty in the magnitude of historic 1893 peak (reasonable lower estimate)	Magnitude taken from BoM URBS modelling calibrated to 1974, daily temporal pattern and cont loss of 2.5mm/hr. (BoM 2003) Q100 at Savages Crossing is influenced but reasonably insensitive.
1H	1909-1951	1893 (Qp=13000)	1847-1951	LPIII (ARR87 incl historic data)	No	7667	Determine Q100 using ARR87 method for including historical data.	This method gives a significantly lower Q100 for Savages Crossing. Note: the ARR87 method gives a Q100 of 6179m³/s if the historical data is excluded.
Case 2 Pre Wivenhoe, no adjustments made for Somerset								
2A	1909-1982	No	1909-1982	GP	Yes	7 870	Test inclusion of additional 31 years of record.	Q100 estimate increases (note record includes 1974 event) but excludes the historic data including the flood of record (1893) so Q100 is underestimated.
2B	1909-1982	1893	1847-1982	GP	Yes	11 500	As for 2A plus historic data. Indicate sensitivity to effect of Somerset on Q100 estimate	Inclusion of historic data is very important (cf 2A). Q100 estimate is not overly sensitive to the influence of Somerset in the record (at least prior to Wivenhoe dam) Q100 estimate at Savages Crossing is likely to be greater than Q100 estimate here as data has *not* been adjusted for effect of Somerset dam. Refer to 3a for analysis of data adjusted for dams. Consistent with 1C and 3A Q100 estimates.
Case 3 "No Dams" based on DNRM adjusted estimates								
3A	1890-2000	No	1890-2000	GP	No	11 900	Assess Q100 from "no dams" adjusted data series produced by DNRM.	Q100 estimate is consistent with 1C and 2B. Note: method used to obtain adjusted data series not assessed by SKM.
3B	1890-2000	No	1890-2000	LPIII	No	13 150	Assess impact of LPIII as an alternative distribution for this series.	Q100 is more sensitive to choice of distribution for this data set than observed between 1B and 1E above.

	Continuous Record	Historic Data (m³/s)	Historic Period	Distribution	Prior Information	Q100 Estimate at Savages Crossing (m³/s)	Main Objective	Comments
Case 4 **"Dams" based on DNRM estimates**								
4A	1909-2000	No	1890-2000	GP	No	3590	Assess the impact of dams on Q100 at Savages Crossing based on DNRM's assessment of flows if dams had been in place for the historic period of record.	According to this series, the Q100 is reduced to about 30% of that expected without Wivenhoe and Somerset dams. Note: method used to obtain adjusted data series not assessed by SKM. Refer to later sections for the impact of dams from a hydrological routing perspective.
4B	1909-2000	No	1890-2000	LPIII	No	4920	Assess impact of LPIII as an alternative distribution for this series.	Q100 estimate is sensitive to choice of distribution (Q100 is approx. 30% higher than GP estimate in 4A)

3.8 Best Estimates from statistical flood frequency assessment

Sinclair Knight Merz has assessed the information and provided a "best" estimate and a plausible range for the "no dams" scenario, i.e. assuming that Somerset and Wivenhoe dams were not present. It should be noted that the upper and lower range of estimates are notional, and do not take into consideration information that is available from other independent sources (such as rainfall-based flood event modelling reported in the subsequent chapters). The results are presented in **Table 3-8**.

The best estimate for the "no dams" scenario was adopted after consideration of all the analyses, with particular attention paid to the convergence of the Q100 estimates based on the three most relevant data series, namely:

- the inclusion of all unadjusted Savages Crossing records (1909-1951) , the best estimate of the 1893 flood of record, the inclusion of prior information from the regional analysis and the adoption of the Generalised Pareto distribution (refer 1C, Q100=11 970 m^3/s)
- pre-Wivenhoe Savages Crossing records consisting of unadjusted peaks (1909-1982), DNRM estimated peaks (1890-1908) which included the 1893 flood of record (refer 2B, Q100= 11 500m^3/s); as no allowance made for Somerset dam, the pre dams Q100 could be expected to be higher than 11 500m^3/s.
- the "No dams" series from DNRM which included estimates of peak flows for Savages Crossing from 1890-2000 (refer 3AQ100 = 11,500 m^3/s).

Table 3-8 Most plausible estimates of the Pre dams Q100 peak flow at Savages Crossing

Scenario	"Best" estimate	Likely lower estimate	Likely Upper estimate
"No dams"	12 000	10 000	14 000

The boundaries of the plausible range of flow estimates are reasonably broad. This reflects the following significant sources of uncertainty:

- the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum estimated 1974 peak flow; this causes considerable uncertainty on the flow estimates for the large flows that influence the statistical flood frequency assessment in the range of the Q100,
- scarcity of information regarding the 1893 event in terms of its flow magnitude (there is considerable uncertainty in rainfall –runoff modelling results as there is scarce data on key event characteristics such as temporal pattern, losses, etc.). This event has a significant influence on the Q100 estimate (although inclusion of regional information lessens the impact of the uncertainty),

- choice of distribution and the appropriate parameters, and
- adjustment of data for the effect of the dams.

As an example of some of the above uncertainties, it is plausible that the 1974 "no dams" peak flow rate was somewhere between 9 000 m^3s-1 and 11 000 m^3s-1.

The lower bound of this range is based on assuming the reported flow from the actual event of 7393 m^3s-1 as a minimum estimate. Adoption of this as a lower bound estimate would assume that there was a gauge/rating error in the order of the attenuation attributable to Somerset Dam. Discussions with BoM staff indicated that their modelling of the event suggested that 2350 m^3/s of additional peak flow could have occurred from Somerset if the dam had not been present. Given some attenuation of this peak between Somerset Dam and Savages Crossing and some allowance for uncertainty in the rating curve, a value in the order of 9 000 m^3/s is considered to be a reasonable lower estimate of the plausible range of the peak flow of the 1974 event assuming "no dams."

The higher bound is based on two sources: (i) report from BoM (August 2003) in which 10 800m^3/s was estimated based on rainfall runoff routing and (ii) the DNRM assessment of 10 500 m^3s-1 for the "no dams" peak.

An additional assessment of the "current" scenario, i.e. with Somerset and Wivenhoe dams in place and operated using current operating procedures is also provided (Case 4 – refer **Section 3.6**). This is based on the data series that has values adjusted for the effect of the dams as assessed and provided by DNRM. Note that an assessment of the plausible range for this estimate is not possible, as DNRM has not provided documentation for the method for adjusting the data series.

4. Rainfall-Runoff Modelling

Rainfall-runoff modelling was undertaken to determine flows within the lower reach of the Brisbane River with Wivenhoe Dam and Somerset Dam in place. The RAFTS rainfall-runoff model developed for the Ipswich Rivers Flood Studies (Sinclair Knight Merz, 2000) was used for this investigation. The Ipswich Rivers Flood Studies RAFTS model is based on the original Brisbane River Flood Study RAFTS model prepared for Brisbane City Council.

4.1 Assumptions

- The Ipswich Rivers Flood Studies (Sinclair Knight Merz, 2000) RAFTS model was used for the investigation.
- The Department of Natural Resources and Mines (DNRM, 2003) Wivenhoe and Somerset Dam Operations Model was used to determine dam outflows.

Unless otherwise stated, the parameter set used for the RAFTS modelling was as follows:

- Initial Loss Rate = 10 mm
- Continuing Loss Rate = 1.0 mm/h
- All model runs were undertaken for the 1 in 100 (1%) AEP flood event only.

4.2 Methodology

The following Methodology describes the process that was used to determine 1 in 100 AEP peak flows at Moggill and the Brisbane Port Office.

- Remove Wivenhoe Dam and Somerset Dam from the RAFTS model.
- Input CRC-FORGE Rainfalls in the RAFTS model using various historical rainfall distributions.
- Run the RAFTS hydrologic model (pre-dams) for the 1 in 100 AEP flood event for a series of duration's spatial and temporal patterns to determine the critical duration storm.
- Inflow hydrographs were then extracted from the RAFTS model and input into the DNRM Dam Operations Model.
- The DNRM Dam operations model was then run and an outflow hydrograph from Wivenhoe Dam was generated.
- Upstream of Wivenhoe Dam was removed from the RAFTS model and the outflow hydrograph generated by the DNRM dam operations model was used at this location.
- The RAFTS model was then re-run to determine 1 in 100 AEP flows at Savages Crossing, Moggill and the Brisbane Port Office Gauge.

- A sensitivity analysis was then performed using Wivenhoe and Somerset Dam operating procedures assuming different starting water levels in Wivenhoe and Somerset Dams at the start of the flood event.

4.3 Pre-dams RAFTS Modelling

The object of the pre-dams modelling was to compare statistical flood frequency estimates and the flow estimates produced by RAFTS. Good agreement between the flow estimates resulting from the statistical flood frequency analysis and RAFTS provides a robust flood flow estimate. CRC-FORGE rainfall estimates were input into the RAFTS model using various spatial distributions. A sensitivity analysis was also undertaken to determine the effects that temporal patterns have on variation of peak flows.

4.3.1 CRC Rainfall Estimates – Standard CRC-FORGE Distribution

CRC-FORGE rainfall estimates for varying durations were input into the model with Areal Reduction Factors (ARF) applied (Department of Natural Resources and Mines, 2003a). **Table 4-1** presents the rainfalls depths and adjusted rainfall depths (ARF's applied) used in the RAFTS model.

- **Table 4-1 CRC-FORGE Rainfall Depths for Brisbane River Catchment with Applied Areal Reduction Factors – 1%AEP**

	24 Hour (mm)	30 Hour (mm)	36 Hour (mm)	48 Hour (mm)	72 Hour (mm)	96 Hour (mm)	120 Hour (mm)
CRC-FORGE Rainfall	247	268	285	317	358	385	402
CRC-FORGE Rainfall with ARF applied	188	209	229	263	308	338	358

The CRC-FORGE rainfall estimates were spatially distributed across the catchment. Maps of the 24 hour spatial pattern are presented in **Appendix G**. Standard temporal patterns (ARR 1987) were then applied and the RAFTS model was run for a range of durations. An Initial Loss of 10 mm and a Continuing Loss of 1.0 mm/h was adopted.

The peak flows for Savages Crossing using the CRC-FORGE rainfall estimates with ARF's applied are presented in **Table 4-2**.

- **Table 4-2 Peak Flows for CRC-FORGE Spatially Distributed with Areal Reduction Factors for 1 in 100 AEP Flood – Pre-dams**

Location	24 Hour (m^3/s)	30 Hour (m^3/s)	36 Hour (m^3/s)	48 Hour (m^3/s)	72 Hour (m^3/s)	96 Hour (m^3/s)	120 Hour (m^3/s)
Savages Crossing	8387	**9607**	8379	8626	9192	8128	8384
Moggill	7607	9015	7588	8004	**10101**	9180	9446
Brisbane Port Office	7608	9015	7589	8005	**10106**	9190	9463

Note: - Bold values indicate the critical duration at each location

- Flows at Moggill and Brisbane Port Office should be considered indicative only.

4.3.2 Sensitivity to Spatial Pattern of Rainfall

To determine the impact spatial patterns have on peak flows, seven historical spatial patterns were used. These spatial patterns were selected as they were significant flood events and data were readily available. The 24 hour rainfall spatial pattern for each historical event were determined and a ratio was applied to rainfall depth until the catchment average rainfall depth matched the CRC-FORGE Rainfall Depths (ARF applied) for each duration.

The seven historical spatial patterns assessed are:

- January 1893 – most of the rainfall occurred on the north-west portion of the catchment upstream of Wivenhoe and Somerset Dams.
- February 1893 – the majority of the rainfall fell on the eastern half of the catchment.
- January 1931 – high rainfalls occurred along the eastern catchment boundary
- March 1955 – high rainfalls were experienced upstream of Wivenhoe dams on the Brisbane River and Stanley Rivers.
- January 1974 – this event produced high rainfalls along the eastern boundary and Lower Brisbane River Catchment.
- April 1996 - high rainfalls in the Lockyer and Lower Brisbane River Catchments.
- February 1999 – high rainfalls fell upstream of Wivenhoe Dam.

Maps of each of the above historical spatial patterns are presented in **Appendix G**.

Each of the historical spatial patterns were applied with standard temporal patterns (AR&R 1987). RAFTS was then run (pre-dams) with an Initial Loss of 10 mm and a Continuing Loss of 1.0 mm/h was applied.

Peak flows are presented in **Table 4-3**. Note that for all spatial distributions the 30 hour rainfall duration is the critical duration storm at Savages Crossing and the 72 hour flood is the critical duration at Moggill and Brisbane Port Office. Flows presented at Moggill and the Brisbane Port Office in **Table 4-3** should be considered indicative only. More reliable estimates of design floods at the lower gauges are produced by the hydraulic model, as discussed in **Chapter 5**.

- **Table 4-3 Pre- dams Peak Flows for 1 in 100 AEP Rainfall and Historical Spatial Distributions**

Spatial Distribution	Savages Crossing (m^3/s)	Moggill (m^3/s)	Brisbane Port Office (m^3/s)
January 1893	11507	10196	10198
February 1893	10062	**9501**	**9504**
January 1931	8543	8026	8030
March 1955	**10046**	9619	9623
January 1974	8005	9112	9117
April 1996	8621	8917	8922
February 1999	11205	10197	10200

Note: - Bold values indicate the median flow at each location
- Flows at Moggill and Brisbane Port Office should be considered indicative only.

A full listing of peak flow rates at Savages Crossing, Moggill and Brisbane Port Office are present in **Appendix H**.

4.3.3 Sensitivity to Temporal Pattern of Rainfall

To assess the sensitivity of the catchment with respect to temporal patterns, a series of patterns were applied for the catchment average CRC-FORGE Rainfall 48 hour storm duration. An Initial Loss of 0 mm and a Continuing Loss of 0 mm/h was applied.

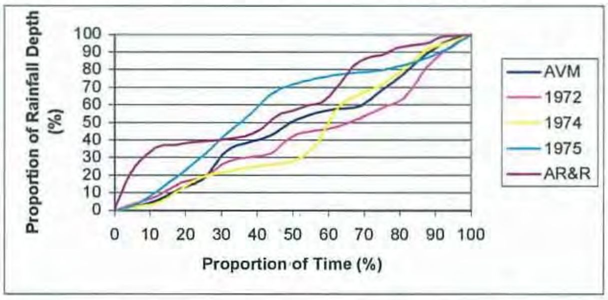
The temporal patterns that were used in the sensitivity analysis were:

- AVM – Average Variability Method,
- 1972 – This is a back loaded temporal pattern extracted from the January 1972 flood event,
- 1974 – A mid loaded temporal pattern extracted from the January 1974 flood event,
- 1975 – This is a front loaded temporal pattern extracted from the December 1975 flood event, and
- AR&R 1987 – Standard temporal pattern as provided in the 1987 edition of Australian Rainfall and Runoff.

These temporal patterns are shown in **Figure 4-1**. Note that the AVM pattern was developed from temporal patterns used in the BoM development of the recently revised Generalised Tropical Storm Method (GTSM-R). In summary, the method involves:

- ranking the rainfall depths in descending order for each period,
- the percentage of the total storm rainfall occurring in the period of each rank is found,
- the average rank for each period and the average percentage of the rainfall depth in the period of each rank are then calculated, then
- to obtain the temporal pattern, the period with the lowest average rank is assigned the average percentage of rain for the rank 1 periods, the second lowest average rank is assigned the average percentage of rain for the rank 2 periods, and so on for all selected periods.

The AVM method is described in greater detail in Pilgrim et al. (1969).



- **Figure 4-1 Temporal Patterns for the 1% AEP 48 Hour Storm Event**

The resulting peak flow estimates using the temporal patterns described above are presented in **Table 4-4**.

- **Table 4-4 Sensitivity to Peak Flow to Temporal Pattern of Rainfall**

	48 hour Temporal Pattern				
Location	AR&R (m^3/s)	AVM (m^3/s)	1972 (m^3/s)	1974 (m^3/s)	1975 (m^3/s)
Savages Crossing	11967	12635	12858	13864	13032
Moggill	12817	13464	13287	14115	13634
Brisbane Port Office	12817	13464	13287	14115	13634

4.3.4 Discussion

Table 4-3 and **Table 4-4** show that spatial and temporal patterns have a significant effect on peak flows. The works undertaken show that by varying spatial and temporal patterns, the peak flow estimates at Savages Crossing can vary considerably. A Monte Carlo analysis could be undertaken to improve the accuracy of the Q100 flow estimate and help to reduce the uncertainties arising from the work undertaken so far. The historical spatial distributions produce pre-dams peak flows at Savages Crossing that range from 11,500 m^3/s to 8,000 m^3/s with the median peak flow of 10,050 m^3/s. The estimated peak flow at Savages Crossing using the CRC-FORGE spatial pattern was estimated to be 9600 m^3/s.

If an Initial Loss of 0 mm and Continuing Loss of 0 mm/h are applied to the CRC-FORGE 30 hour storm (critical at Savages Crossing), the peak flow from the RAFTS model was predicted to be 11,278 m^3/s. It should be noted that the 'best estimate' of peak flow at Savages Crossing from the statistical flood frequency analysis was estimated to be 12,000 m^3/s. This means that in order to reconcile peak flow estimates between RAFTS rainfall runoff modelling and the statistical flood frequency analysis, further work would need to be undertaken. This work would involve investigation of specific combinations of spatial and temporal patterns and application of acceptable loss rates to the RAFTS model. It is anticipated that this investigation would result in the reconciliation of flow estimates at Savages Crossing.

4.4 Comparison of Q100 estimates from statistical flood frequency analysis and hydrological modelling

Modelling of the Q100 event using:

- Calibrated Brisbane River Catchment RAFTS model
- CRC-FORGE 1 in 100 AEP rainfall estimates (with areal reduction factors and spatial distribution)
- 30 hr (critical duration for Savages Crossing) ARR87 temporal pattern
- zero initial and continuing losses
- no dams in the model

produced a Q100 at Savages Crossing of 11278 m^3/s. It would be reasonable to expect some losses with such an event and hence the hydrological modelling results, using typical design parameters, could be expected to be lower, say in the order of 10, 500m^3/s.

The difference between the results and those from the statistical frequency analysis of flood records (**Chapter 3**) indicates that there are underlying factors that have not been adequately addressed to date. This would require more detailed assessment than is available in the scope and timing of the current assessment. Potential factors influencing the difference in Q100 estimates include:

- potential for partial area storms
- variation in temporal patterns
- variation in spatial patterns
- variation in losses
- adjustment of data for influence of dams
- estimation of the 1893 flood peak
- estimation of the 1974 flood peak
- uncertainty in the rating curve at Savages Crossing and hence estimation of the flood peaks above the maximum gauged flood.

The development of a Monte Carlo framework for analysing the factors affecting flood magnitude would enable the natural variation in the first four factors to be explicitly modelled. This would provide the insights necessary to resolve the differences between the two independent Q100 estimates.

4.5 Post-dams RAFTS Modelling

Inflows to Somerset Dam and Wivenhoe Dam and outflows at Lockyer Creek and Bremer River were extracted from the pre-dams RAFTS model results and run through the DNRM Dam Operations Model (Department of Natural Resources and Mines, 2003b). These inflows were based on the outputs presented in **Appendix H** and included an Initial Loss of 10 mm and Continuing Loss of 1.0 mm/h.

The outflow volume from Wivenhoe Dam produced by the DNRM Dam Operations model was compared to the total inflow volume into Wivenhoe and Somerset Dams. The comparison found good consistency between the hydrograph volumes.

Outflow hydrographs at Wivenhoe Dam were determined using the DNRM Dam Operations model and then used in RAFTS for the CRC-FORGE and historical spatial patterns to determine flows at Savages Crossing, Moggill and Brisbane Port Office.

4.5.1 CRC Rainfall Estimates – Standard CRC-FORGE Distribution

The parameters described in **Section 4.3.1** were used for the Post-dams RAFTS modelling.

The CRC-FORGE rainfall estimates with ARF's applied are presented in **Table 4-5**.

- **Table 4-5 Peak Flows for CRC-FORGE Spatially Distributed with Areal Reduction Factors for the 1 in 100 AEP Rainfall – Post-dams**

Location	24 Hour (m^3/s)	30 Hour (m^3/s)	36 Hour (m^3/s)	48 Hour (m^3/s)	72 Hour (m^3/s)	96 Hour (m^3/s)	120 Hour (m^3/s)
Savages Crossing	2069	3356	2186	2399	**5368**	2335	2502
Moggill	3017	3690	2999	3302	**5043**	3811	3990
Brisbane Port Office	3020	3691	3001	3305	**5044**	4073	4177

Note: - Bold values indicate the critical duration at each location

- Flows at Moggill and Brisbane Port Office should be considered indicative only.

4.5.2 Sensitivity to Spatial Pattern of Rainfall

The parameters described in **Section 4.3.2** were used for the Post-dams RAFTS modelling. Peak flows are presented in **Table 4-6**. Note that the critical duration storm at Savages Crossing, Moggill and Brisbane Port Office range from 72 to 120 hours for Post-dam Conditions. Flows presented at Moggill and the Brisbane Port Office in **Table 4-6** should be considered as indicative only. More accurate flows have been determined from the hydraulic modelling (**Chapter 5**).

- **Table 4-6 Post-dams Peak Flows for the 1 in 100 AEP Rainfall and Historical Spatial Distributions**

Spatial Distribution	Savages Crossing (m^3/s)	Moggill (m^3/s)	Brisbane Port Office (m^3/s)
January 1893	7847 (120hr)	7120 (120hr)	7121 (120hr)
February 1893	6568 (120hr)	5850 (120hr)	**5851** (120hr)
January 1931	3279 (120hr)	3218 (120hr)	3411(120hr)
March 1955	**6241** (72hr)	5709 (72 hr)	5710 (72hr)
January 1974	4771 (96hr)	**5841** (96hr)	5852 (96hr)
April 1996	4162 (72hr)	5019 (72hr)	5035 (96hr)
February 1999	7431 (120hr)	6819 (120hr)	6819 (120)

Note: - (120hr) denotes the critical storm duration

- Bold values indicate the median flow at each location
- Flows at Moggill and Brisbane Port Office should be considered indicative only.

4.5.3 Sensitivity to Starting Water Level in Wivenhoe Dam

Wivenhoe Dam has 1,165 gigalitres (GL) of storage capacity for water supply purposes up to its full supply level of EL 67.0 m AHD (Australian Height Datum). A further 1,450 GL ref of storage capacity is available above the Full Supply Level, up to a level of EL 75.0 m AHD for the temporary storage of flood waters, i.e. the total capacity of Wivenhoe Dam is 2,615 GL. The flood storage is held empty, except when required, to store flood waters (SEQWB 1998 –1999).

The catchment area above Wivenhoe Dam is approximately 7,080 km^2. Assuming no losses, the total runoff volume for the 1 in 100 AEP flood (average CRC-FORGE rainfalls with ARF applied) for durations ranging from 24 hours to 120 hours are presented in **Table 4-7**.

- **Table 4-7 Flood Runoff Volumes from the 1 in 100 AEP Rainfall Events above Wivenhoe Dam**

Storm Duration (hours)	CRC Rainfall Depth with ARF Applied (mm)	Runoff Volume (Gigalitres)
24	188	1331
30	209	1480
36	229	1621
48	263	1862
72	308	2180
96	338	2393
120	358	2534

Table 4-7 shows that if Wivenhoe Dam is at FSL, the 1 in 100 AEP 30 hour (flood runoff volume can almost be fully stored between FSL and EL 75.0 m without release. For 1 in 100 AEP events with longer durations, Wivenhoe Dam would have to be lower than FSL to store the entire flood runoff volume before the EL 75.0 m is exceeded (no releases).

Given the current operational procedures, it is unlikely that releases would not occur during a flood event, particularly if Wivenhoe Dam were at FSL at the start of the flood event. To determine the impacts starting water level have on flood flows downstream, a number of sensitivity runs were done for the 1 in 100 AEP 72-hour storm. Dam Starting Water Levels (SWL) have been assumed at 75% full and 50% full with current Operating Procedures.

Peak flows assuming different Wivenhoe Dam starting water levels are presented in **Table 4-8**.

- **Table 4-8 Flows for Dam Starting Water Levels Sensitivity Analysis for the 1 in 100 AEP 72 Hour Storm**

Location	FSL - RL 67 m AHD (m^3/s)	SWL 75% - RL 64 m AHD (m^3/s)	SWL 50% - RL 60 m AHD (m^3/s)
Savages Crossing	5368	3486	3334
Moggill	5043	4376	4376
Brisbane Port Office	5044	4402	4402

Note: - Flows at Moggill and Brisbane Port Office should be considered indicative only.

Table 4-8 shows that the reduction in flow is approximately 13% at the Brisbane Port Office Gauge between the dam being at FSL and 75% full. It is interesting to note that flows do not change significantly between the 75% and 50% starting water levels.

4.5.4 1893 and 1974 Historical Flood Events

The information from the two historical flood events (1893 and 1974) were run through the RAFTS model and flows at Savages Crossing were reconciled with measured estimates. Wivenhoe and Somerset Dams were then input into the model and operating procedures were applied.

The resulting Post-dam flows are presented in **Table 4-9**.

- **Table 4-9 Predicted Post-dam Flows for the 1893 and 1974 Historical Flood Events**

	1893 (IL = 0 and CL = 0.5mm/h)		1974 (IL =0mm and CL = 2.5mm/h)	
Location	No Dams (m^3/s)	Somerset and Wivenhoe in Place (m^3/s)	Somerset in Place (m^3/s)	Somerset and Wivenhoe in Place (m^3/s)
Savages Crossing	13258	9563	7554	3882
Moggill	13856	9517	9850	6639
Brisbane Port Office	13869	9519	9874	6801

Table 4-9 indicates that the peak flows for the historical events at the Brisbane Port Office are above the 1 in 100 AEP CRC-FORGE estimate (5044 m^3/s), and the median spatial pattern estimate of 5851 m^3/s.

There are many uncertainties associated with the 1974 peak flow estimate and even more with the 1893 event. However, it is clear from **Table 4-9** that the effect of the dams on events of such magnitude is significant. While flows predicted by the RAFTS model at the Brisbane Port Office are only indicative, they provide a reasonable estimate as calibration of this model has been undertaken. The most accurate way to assess flows at the Brisbane Port Office Gauge would be to use a hydraulic model.

It should be noted that the predicted flow for the 1974 event, assuming that Wivenhoe dam had been in place, is 6,800 m^3/s at the Brisbane Port Office Gauge. This is larger than the 'best estimate' of the 1 in 100 AEP event at the Brisbane Port Office of 6,500 m^3/s. This is thought to be due to the 1974 spatial pattern (see **Appendix G**) where the majority of rainfall fell within the Lower Brisbane and Bremer River Catchment. For rainfall events where the majority of rainfall falls below the dams, the resultant flood will have a lower associated probability (i.e. will be expected to happen less often) after post Wivenhoe compared to prior to the construction of Wivenhoe. This study did not further investigate partial catchment storms on the over the Lower

Brisbane, Bremer and Lockyer catchments apart from the overall sensitivity of spatial patterns (**Section 4.5.2)** The magnitude of the modelled 1974 event 'with dams' was a strong influence on the selection of the values proposed as the 'best estimate' and the notional 'upper limit' of the Q100 at the Port Office (**Section 4.5.5**).

4.5.5 Discussion

The variability of flows predicted for the post-dams catchment is further affected by the introduction of Wivenhoe and Somerset Dams. Monte-Carlo analysis would be an appropriate way to investigate the complex interactions between dams and variations in losses, spatial and temporal patterns to obtain the best possible estimate of the 1 in 100 AEP flood event.

The CRC-FORGE spatially distributed peak flow at Savages Crossing was estimated to be 5,368 m^3/s for the post-dams case. The historical spatial distributions produce peak flows at Savages Crossing that range from 7847 m^3/s to 3279 m^3/s with the median peak flow of 6,241 m^3/s.

Based on the preceding investigations, it is clear there is uncertainty in any estimate of the 1 in 100 AEP flood event at the Brisbane Port Office. **Table 4-10** provides a range of estimates with a 'best estimate,' upper estimate and lower estimate. Given the current information, the 'best estimate' of peak flow at the Brisbane Port Office would be 6500 m^3/s with an upper and lower limit of 8,000 m^3/s and 5,000 m^3/s respectively. While the estimates predicted by RAFTS at Moggill and the Brisbane Port Office should be considered indicative, previous modelling shows that flows predicted by RAFTS are consistent with flows predicted by the MIKE11 hydraulic model.

- **Table 4-10 Range of Estimates at the Brisbane Port Office for the 1 in 100 AEP Flood with Dams**

Condition	Peak Flow (m^3/s)	Peak Flood Level (m AHD)
Lower Estimate	5000	2.76
Best Estimate	6500	3.51
Upper Estimate	8000	4.41

The best estimate of 6,500 m^3/s was adopted after consideration of the RAFTS modelling for current design spatial pattern, various historical patterns, the performance of the model in reproducing flows at Savages Crossing for pre-dam flows and the modelling of the 1974 event with Wivenhoe dam in place (**Section 4.5.4**). The estimate of the lower end of the plausible range of the Q100 estimate is 5,000 m^3/s. It was adopted with particular consideration to the range of results from the sensitivity to the spatial patterns. The estimate of the upper bound of the plausible range was taken to be 8,000 m^3/s. This upper bound was adopted after particular consideration of the variation in the spatial patterns, the sensitivity to temporal patterns, and the 1974 peak flow results for the 'Somerset only' then 'Somerset and Wivenhoe' dams scenarios.

A Monte-Carlo analysis would improve the accuracy of the 1 in 100 AEP flood estimate and reduce the uncertainty in plausible range of the flood estimates.

The peak flows presented in this report are less than those predicted in the Brisbane River Flood Study (Sinclair Knight Merz, 1998). The factors that influence the changes in peak flow estimates are:

- inclusion of the lower CRC-FORGE rainfall depths with areal reduction factors,
- consideration of variation in temporal and spatial characteristics of rainfall,
- better representation of dam operating procedures (the previous study Sinclair Knight Merz 1998), assumed emergency operating procedures which minimised the mitigation affects that Wivenhoe and Somerset Dams have on the lower Brisbane River),
- In the 1998 study, the emphasis was to match statistical flood frequency estimates at Moggill and the Brisbane Port Office. The reliability of the streamflow at Moggill and Brisbane Port Office is questionable as these gauges are river level gauges and tidal effects are difficult to account for at these locations. After discussions with DNRM, who have just developed a new composite flood series at Savages Crossing, it was concluded that the most appropriate location to reconcile flows between rainfall based methods and statistical flood frequency estimates was at Savages Crossing. For this investigation the focus was placed on Savages Crossing, as discussed in **Chapter 3**, and
- inclusion of regional streamflow information in the statistical flood frequency analysis.

Rainfall-runoff modelling using a Monte Carlo framework could be undertaken to explicitly consider the natural variations in spatial and temporal patterns of rainfall and variations in initial dam storage levels (other variables such as variable rainfall losses and gate failure likelihood can also be incorporated). This would correctly reflect the combined influences of these stochastic factors and improve the accuracy of the estimated Q100 flood magnitude. It would also reduce the uncertainty of the Q100 flood estimates.

5. Hydraulic Modelling

The MIKE11 hydraulic model developed for the Ipswich Rivers Flood Studies was used to determine peak flood levels at the Brisbane Port Office Gauge. It should be noted that this model is an extension of the Brisbane River Flood Study MIKE11 hydraulic model and that the model was re-calibrated as part of the Ipswich Rivers Flood Studies work.

While the calibration at the Moggill and Brisbane Port Office is good, other sections of the reach within Brisbane City have not been calibrated, as the main focus was to calibrate the model within the Ipswich City Boundary. For the purposes of this investigation this model will provide good flood level estimates at Moggill and Brisbane Port Office, however care should be taken when flood level estimates are derived in other areas of Brisbane City.

5.1 Assumptions

Hydraulic modelling was undertaken assuming MHWS tide at the Brisbane River Bar.

5.2 MIKE11 Modelling

The Ipswich Rivers Flood Studies MIKE11 hydraulic model was used for the assessment. This model routes flows from approximately 10 km downstream of Savages Crossing to the Brisbane River Bar. The model also includes Bremer River and other smaller tributaries, which accounts for most of the major tributaries in the downstream reaches of the Brisbane River. The hydraulic modelling was undertaken for the 1 in 100 AEP spatially distributed over the catchment. Rainfall durations ranging from 24 to 120 hours were assessed.

5.3 Results

The peak flow rates and flood levels at Moggill and Brisbane Port Office are presented in **Table 5-1**.

- **Table 5-1 Peak Flood Levels and Flows for the 1 in 100 AEP CRC-FORGE Spatial Distributed Rainfall**

	Moggill		Brisbane Port Office	
Duration (hours)	Q (m^3/s)	WL (m AHD)	Q (m^3/s)	WL (m AHD)
24	3269	9.41	3337	1.79
30	4117	11.27	4047	2.15
36	3317	9.61	3331	1.79
48	3647	10.36	3717	2.00
72	**5195**	**13.24**	**5059**	**2.68**
96	4103	11.54	4472	2.42
120	4231	11.77	4853	2.48

Note: - Bold values indicate the critical duration at each location

5.4 Discussion

Comparison of Table 4-5 and **Table 5-1** indicates that there is good consistency between the peak flows estimated by RAFTS and the peak flows estimated by MIKE 11 at the Brisbane Port Office. Some confidence can therefore be taken in using RAFTS flow outputs and rating curves produced by MIKE11 at the Brisbane Port Office.

Using the 'best estimate and upper and lower limits of peak flows at the Brisbane Port Office presented in **Section 4.5.5**, a rating curve was used to predict flood levels at the Brisbane Port Office for the 1 in 100 AEP flood event. Peak flood levels and corresponding flows are presented in **Table 5-2**.

- **Table 5-2 Peak Flood Level and Peak Flow Estimates for the 1 in 100 AEP Flood Event at Brisbane Port Office**

Condition	Peak Flow (m^3/s)	Peak Flood Level (m AHD)
Lower Estimate	5000	2.76
Best Estimate	6500	3.51
Upper Estimate	8000	4.41

Note that these estimates should be considered indicative because the tide level variation during flood events may vary. The levels presented in the above table are based on a Mean High Water Spring Tide (0.918 m AHD) at the Brisbane River Bar.

6. Conclusions

Detailed investigations have been undertaken to assist the Expert Review Panel to assess the likelihood of floods in the lower reaches of the Brisbane River. The assistance has been centred on the two tasks of:

- undertaking statistical flood frequency analysis, and
- updating the estimates of flood frequency from rainfall-runoff modelling with new information.

The rainfall-runoff modelling utilised models developed as part of the Brisbane River Flood Study (Sinclair Knight Merz, 1998). Additional information and statistical techniques have been included in reassessing the plausible range of the 1 in 100 annual exceedance probability (AEP) flood, which is also referred to as the Q100 flood.

The two tasks provide independent assessments of the Q100 event, firstly a statistical assessment of the streamflow data and secondly a rainfall-runoff modelling assessment.

Statistical flood frequency analysis

The Expert Panel requested that Sinclair Knight Merz undertake statistical flood frequency analysis of the available data and come up with a best estimate of the likely Q100 at Savages Crossing. An estimate of the Q100 for the "no dams" case (i.e. the peak flow that would occur if the dams were not present) was requested with an indication of the sensitivity of the estimate to the various sources of uncertainty leading to a plausible range for the Q100 estimate.

Frequency analysis was undertaken using a range of at-site and regional methods. The main benefit of adopting a regional approach to statistical flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (e.g. the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum peak flow) then the regional information provides useful information on the appropriateness of the at-site estimates. The regional information was incorporated using Bayesian theory.

Sinclair Knight Merz has assessed the flood series data and provided a "best" estimate and a plausible range for the "no dams" scenario, i.e. assuming that Somerset and Wivenhoe dams were not present. It should be noted that the upper and lower estimates of the range are notional, and do not take into consideration information that is available from other independent sources (such as rainfall-based flood event modelling).

The results are presented in **Table 6-1**.

- **Table 6-1 Most plausible estimates of the Q100 peak flow and its plausible range at Savages Crossing based on statistical flood frequency analysis**

Scenario	"Best" estimate	Likely lower estimate	Likely uUpper estimate
"No dams"	12,000	10,000	14,000

The best estimate for the "no dams" scenario was adopted after consideration of substantial sensitivity analyses, with particular attention paid to the convergence of the Q100 estimates based on the three most relevant data series.

The boundaries of the plausible range of flow estimates are reasonably broad. This reflects the significant sources of uncertainty in the recorded data, length of record, choice of distribution and adjustment of the data for the effect of the dams. As an example of some of the above uncertainties, there is reasonable evidence for 1974 "no dams" peak flow rate to be somewhere between 7,500 m^3/s and 11,000 m^3/s (**Section 3.8**). Such uncertainty has a direct bearing on the uncertainty in the "best" estimate of the Q100 event.

Rainfall-runoff modelling

The second method by which SKM was requested to assess the Q100 flow was rainfall-runoff modelling. This method takes design rainfall information and routes it through the catchment by utilising design depth, temporal and spatial patterns of the storm, losses (e.g. the soil, interception by vegetation, etc), movement through the streams, rivers and dams until it reaches the Brisbane Port Office.

The most appropriate way to jointly assess the above factors (along with other factors such as variability in rainfall spatial and temporal patterns, loss rates, reservoir level and gate operation failure) is by Monte-Carlo analysis. Given the restrictions on time for this current investigation, this analysis could not be undertaken. To account for the above factors, sensitivity analysis was undertaken separately for spatial patterns, temporal patterns and starting water levels behind the dams. Sensitivity to dam operation procedures was not undertaken as part of this study.

Revised Rainfall Depths

The Department of Natural Resources and Mines (DNRM) provided 1 in 100 AEP CRC-FORGE rainfall estimates. These estimates included Areal Reduction Factors (ARF) which account for the reduction in rainfall depth with increasing catchment area. The rainfall estimates as supplied also contained the design spatial distribution of rainfall over the catchment.

Rainfall depths from CRC-FORGE were input into the RAFTS rainfall-runoff model (Sinclair Knight Merz, 2000) for pre-dams conditions, and a series of spatial patterns were modelled. A range of peak flows were determined at Savages Crossing and these varied between 8,000 m^3/s and 11,500 m^3/s.

The median peak flow produced by the RAFTS model for the range of spatial patterns using a standard temporal pattern was approximately 10,000 m^3/s using an Initial Loss of 10 mm and a Continuing Loss of 1.0 mm/h. This compares to the statistical frequency estimate (i.e. analysis of recorded flow data) of 12,000 m^3/s.

Sensitivity to Spatial Pattern of Rainfall

The CRC-FORGE estimates for various spatial patterns with a standard AR&R 1987 temporal pattern were run through the DNRM Dam Operations model (Department of Natural Resources and Mines, 2003). This model predicts an outflow hydrograph from Wivenhoe Dam. The Wivenhoe Dam outflow hydrograph was then input into the RAFTS model and peak flow estimates were calculated at Savages Crossing. Peak flows ranged approximately from 3,000 m^3/s to 8,000 m^3/s. The median value of peak flow for post-dam conditions with variation in spatial pattern was estimated to be 6,200 m^3/s.

Sensitivity to Temporal Pattern of Rainfall

Using a catchment average 48-hour CRC-FORGE rainfall depth (ARF applied), the RAFTS model was then re-run using various temporal patterns for pre-dams conditions. When zero losses were applied, the range of flows was between 12,000 m^3/s and 13,800 m^3/s. This indicates that by incorporating the natural variation in spatial and temporal patterns it should be possible to reconcile the results obtained using statistical methods and rainfall-runoff modelling analysis.

A sensitivity analysis to variation in rainfall temporal pattern was not undertaken for post-dam conditions.

Sensitivity to Wivenhoe Reservoir Level

A sensitivity analysis was undertaken for variations in the starting water level in Wivenhoe Dam. The analysis used the 1 in 100 AEP 72-hour storm with standard temporal patterns and an Initial Loss of 10 mm and Continuing Loss of 1.0 mm/hr. If Wivenhoe Dam is assumed full at the start of the event, the peak flow at Savages Crossing and the Brisbane Port Office was estimated to be 5,400 m^3/s and 5,000 m^3/s respectively. If the dam was assumed to be at 75% full, the peak flow at Savages Crossing and the Brisbane Port Office was reduced to 3,500 m^3/s and 4,400 m^3/s respectively.

Q100 Estimate at the Brisbane Port Office

The main objective of the report was to determine 1 in 100 AEP peak flows and flood levels at the Brisbane Port Office. To do this, the MIKE11 hydraulic model (Sinclair Knight Merz, 2000) was used to account for routing effects from Savages Crossing to the Brisbane Port Office. The flows predicted by MIKE11 compared well to the flows predicted by RAFTS at the Brisbane Port Office. A rating curve from the hydraulic model was used to predict flood levels at the Brisbane Port Office.

Based on the current level of investigation, it is clear there is uncertainty in any estimate of the 1 in 100 AEP flood event at the Brisbane Port Office. **Table 6-2** provides a 'best estimate and the associated plausible range within which the Q100 estimate lies.

Table 6-2 Range of Estimates at the Brisbane Port Office for the 1 in 100 AEP Flood

Condition	Peak Flow (m^3/s)	Peak Flood Level (m AHD)
Lower Estimate	5000	2.76
Best Estimate	6500	3.51
Upper Estimate	8000	4.41

The peak flows presented in this report are less than those predicted in the Brisbane River Flood Study (Sinclair Knight Merz, 1998). The factors that influence the changes in peak flows are:

- inclusion of the lower CRC-FORGE rainfall depths with Areal Reduction Factors,
- consideration of variation in temporal and spatial characteristics of rainfall,
- better representation of dam operating procedures, and
- inclusion of regional streamflow information in the statistical flood frequency analysis.

To reduce the uncertainty in the above estimates, the following actions would serve to increase the accuracy of the 1 in 100 AEP flow estimates.

- Undertake rainfall-runoff modelling in a Monte Carlo framework to explicitly consider the natural variations in spatial and temporal patterns of rainfall and variations in initial dam storage levels (other variables such as variable rainfall losses and gate failure likelihood can also be incorporated). This will provide the most robust estimate of Q100 that correctly reflects the combined influences of these stochastic factors.
- Re-calibrate the Ipswich Rivers MIKE 11 hydraulic model within the Brisbane City Council Boundary.

7. References

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Appendix A Original Scope of Work

The original scope of work proposed for assisting in the review of the Brisbane River flood studies was as follows:

Scope of Work

1) Collect and Collate Data. This task involves the collection of stream gauge information and discussions with hydrographers from various Stream Gauge Authorities to determine the reliability of readings at individual Gauging Stations. The amount of time available will dictate the degree to which the quality of the annual maxima can be assessed, and any caveats on the remaining uncertainty will be noted in the report.
2) Undertake a regional and at-site flood frequency analyses (FFA) for the Brisbane River Catchment under 'No Dams' conditions for selected sites.
3) Document findings of the flood frequency Analysis stating assumptions and outcomes of the investigation.
4) Meet with the Expert Panel to discuss the flood frequency Analysis Outcomes.
5) Remove Wivenhoe and Somerset Dams from the RAFTS model. Input the CRC-FORGE Rainfall Estimates into the RAFTS model and apply Areal Reduction Factors. Adjust loss rates to the RAFTS model for the 1 in 100 AEP event until flows match those predicted by the FFA. The loss rates will then be assessed to determine whether they are within acceptable limits for the catchment. Note that this is a milestone for the investigation. Should the loss rates not be within acceptable limits, other factors will have to be investigated extending time and costs associated with the investigation, or else appropriate caveats noted in the report.
6) Assuming the previous milestone has been satisfied, Wivenhoe and Somerset Dams will be reintroduced into the RAFTS model along with the adopted loss rates. Hydrograph information from the RAFTS model would then be used as input into the DNRM Dam Operation's model to determine an outflow hydrograph from Wivenhoe Dam. This outflow hydrograph would reflect Dam Operation release procedures. The Outflow hydrograph will then be input into the RAFTS model and the RAFTS model will be re-run to determine the 1 in 100 AEP flows at Moggill.
7) Assess importance of Starting Water Level (SWL) of Wivenhoe and Somerset Dams. To this end, long-term synthetic data on water levels (corresponding to current operating conditions) will be obtained from SEQWB and used to assess the range of starting levels likely to be associated with floods of differing severity. Depending on the outcome of this analysis, either a fixed starting level will be adopted or else a joint probability approach will be used. The time available and nature of the starting level information will dictate the level of

sophistication appropriate to the joint probability approach (if required), and discussions will be held with BCC prior to tackling this aspect of the problem.

8) Prepare a report documenting the findings of the FFA and the RAFTS modelling.

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Appendix B Flow Gauging Stations Omitted from Consideration

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Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143222A	Atkinson Dam	Atkinson Creek Outlet		20	Small catchment area, offstream storage	DNRM
143234A	Atkinson Dam Hea			6	Small catchment area, offstream storage	DNRM
143228A	Bill Gunn Dam	Lake Dyer	3	18	Catchment area too small	DNRM
143027A	Blunder Creek	King Avenue Bridge	31	8	Urban creek in Brisbane area, Small catchment	DNRM
2121	Blunder Creek	King Ave- Durack		14	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1594	Breakfast Creek	Opposite Newstead House		5	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1579	Breakfast Creek	Sedgley Park Retention Basin-New Market		6	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1525	Breakfast Creek	Opposite Mann Park- Bowen Hills		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143104B	Bremer River	Rosevale	67	21	Catchment area too small	DNRM
143104A	Bremer River	Rosevale	77	34	Catchment area too small	DNRM
143110A	Bremer River	Adams Bridge	125	35	Catchment area too small	DNRM
143940	Bremer River	Stokes Crossing	180	21	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143909	Bremer River	Rosewood	543		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143833	Bremer River	Rosewood Alert	543	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143908	Bremer River	Rosewood TM	543	25	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143934	Bremer River	Walloon Bvrt	585		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143805	Bremer River	Walloon Alert-P	585	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143911	Bremer River	Ipswich	1850		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143956	Bremer River	Three Mile Bridge Alert	1870		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143954	Bremer River	Ipswich Alert			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143953	Bremer River	One Mile Bridge Alert			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143852	Bremer River	Brassall(Hancocks Br) Al		5	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143115A	Bremer River	Berry's Lagoon		9	Record length too short	DNRM
143944	Brisbane River	Linville	2005	47	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office

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Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143007A	Brisbane River	Linville	2009	39	Gauge ignored as catchment area below initial threshold. Possibly useful for future studies.	DNRM
143831	Brisbane River	Devon Hills Alert	2160	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143922	Brisbane River	Devon Hills Bvrt	2190		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143002A	Brisbane River	Plainlands	3950	12	Gauge ignored as record length below initial threshold. Possibly useful for future studies.	DNRM
143002B	Brisbane River	Fulham Vale	3950	34	Gauge ignored as record length below initial threshold. Possibly useful for future studies.	DNRM
143005A	Brisbane River	Watts Bridge	4602	20	Record length too short	DNRM
143008A	Brisbane River	Middle Creek	6704	20	Record length too short	DNRM
143026A	Brisbane River	Wivenhoe	7023	3	Record length too short	DNRM
143036A	Brisbane River	Wivenhoe Headwater	7023	17	Record length too short	DNRM
143035A	Brisbane River	Wivenhoe Tailwater	7023	17	Record length too short	DNRM
143907	Brisbane River	Lowood	10062		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143941	Brisbane River	Lowood Bvrt	10062		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143827	Brisbane River	Lowood Alert-P	10062	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143916	Brisbane River	Mt Crosby	10600		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143839	Brisbane River	Mt Crosby Alert	10600	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143925	Brisbane River	Mt Crosby TM	10600	28	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143951	Brisbane River	Moggill Alert	12600		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143915	Brisbane River	Moggill Bvrt	12600		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143924	Brisbane River	Moggill TM	12600		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143900	Brisbane River	Caboonbah			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143914	Brisbane River	Gregor Creek			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143920	Brisbane River	Gregor Creek Bvrt			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143902	Brisbane River	Murrumba			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office

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Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143005	Brisbane River	Watts Bridge			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143903	Brisbane River	Wivenhoe			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143018A	Brisbane River	Avoca Vale	1498	20	Record length too short (post Wivenhoe)	DNRM
143868	Brisbane River	Colleges Crossing Alert		4	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143918	Brisbane River Estuary	Bishop Island			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143217A	Buaraba Creek	Vineyard	63	10	Catchment area too small	DNRM
143211A	Buaraba Creek	15.8 km	251	12	Catchment area too small	DNRM
143224A	Buaraba Creek	Diversion Channel		19	Catchment area too small	DNRM
143094A	Bulimba Creek	Mansfield	57	26	Urban creek in Brisbane area, Small catchment	DNRM
143004A	Bulimba Creek	Belmont	51	22	Urban creek in Brisbane area, Small catchment	DNRM
1591	Bulimba Creek	End of Aquarium Ave. Hemmant		5	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1528	Bulimba Creek	Doughboy Pde- Hemmant		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1804	Bulimba Creek	Greenwood St- Wishart		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1831	Bulimba Creek	Merion Pl- Carindale		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1707	Bulimba Creek	Old Cleveland Rd- Carindale		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143926	Bundamba Creek	Ripley Alert	35		Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office
143959	Bundamba Creek	Harding Street Alert	96		Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office
143958	Bundamba Creek	Blackstone Bridge Alert	97	10	Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office
143955	Bundamba Creek	Bundamba School Alert	102		Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office
143854	Bundamba Creek	Bundamba (Hanlon St) Al	109	7	Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office
143114A	Bundamba Creek	Mary Street	110	11	Urban creek in Ipswich area, Small catchment	DNRM
143307A	Byron Creek	Causeway	79	28	Catchment area too small	DNRM
143012A	Cooyar Creek	51.5km.	443	4	Record length too short	DNRM
143015B	Cooyar Creek	Damsite	963	13	Record length too short	DNRM

Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143015A	Cooyar Creek	Damsite	963	22	Record length too short	DNRM
143013A	Cressbrook Creek	The Damsite	321	16	Record length too short	DNRM
143952	Cressbrook Creek	Rosentreters Bridge	440		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143921A	Cressbrook Creek	Rosentreters Bridge	447	17	Record length too short	DNRM
143921	Cressbrook Creek	Rosentreters Bridge TM	477		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143806	Cressbrook Creek	Rosentreters Bridge Al	477	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143857	Deebing Creek	Churchill Alert			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143021A	Ekibin Creek	Dudley Street.	13	1	Urban creek in Brisbane area, Small catchment	DNRM
143011A	Emu Creek	Raeburn	439	24	Catchment area too small	DNRM
143010A	Emu Creek	Boat Mountain	915	11	Catchment area too small	DNRM
143010B	Emu Creek	Boat Mountain	915	27	Catchment area too small	DNRM
143932A	Enoggera Creek	Bancroft Park	70	10	Urban creek in Brisbane area, Small catchment	DNRM
143932	Enoggera Creek	Bancroft Park TM	67		Urban creek in Brisbane area, Small catchment	BoM, Queensland Regional Office
1531	Enoggera Creek	100 M U/S From Original E e529		6	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1532	Enoggera Creek	Enoggera Dam- The Gap		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1529	Enoggera Creek	Kelvin Grove Rd- Kelvin Grove		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143208A	Fifteen Mile Creek	Dam Site	87	33	Catchment area too small	DNRM
143214A	Flagstone Creek	Windolfs	142	14	Catchment area too small	DNRM
143233A	Flagstone Creek	Brown-Zirbels Road		10	Catchment area too small	DNRM
1717	Gold Creek	Reservoir- Brookfield (Brisbane Water)			Urban creek in Brisbane area, Small catchment	South East Queensland Water
143028A	Ithaca Creek	Jason Street	10	31	Urban creek in Brisbane area, Small catchment	DNRM
1535	Ithaca Creek	Jason St- Ithaca		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143304A	Kilcoy Creek	Mount Kilcoy	127	36	Catchment area too small	DNRM
143304B	Kilcoy Creek	Mount Kilcoy Weir	131	15	Catchment area too small	DNRM

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Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143235A	Lake Clarendon Head			6	Offstream storage	DNRM
143215A	Laidley Creek	Mulgowie Weir	154	14	Catchment area too small	DNRM
143209A	Laidley Creek	Mulgowie1	167	5	Catchment area too small	DNRM
143209B	Laidley Creek	Mulgowie2	167	36	Catchment area too small	DNRM
143225A	Laidley Creek	Showgrounds Weir Head Water	233	19	Catchment area too small	DNRM
143226A	Laidley Creek	Showgrounds Weir Tail Water	233	19	Catchment area too small	DNRM
143943	Laidley Creek	Laidley	285		Catchment area too small	BoM, Queensland Regional Office
143923	Laidley Creek	Thornton			Catchment area too small	BoM, Queensland Regional Office
143229A	Laidley Creek	Warrego Highway		13	Catchment area too small	DNRM
143202A	Lockyer Creek	Russell Siding	271	7	Catchment covered by other gauges DS	DNRM
143203C	Lockyer Creek	Helidon Number 3	357	16	Catchment covered by other gauges DS	DNRM
143203A	Lockyer Creek	Helidon	357	45	Catchment covered by other gauges DS	DNRM
143203B	Lockyer Creek	Helidon No.2	382	24	Catchment covered by other gauges DS	DNRM
143904	Lockyer Creek	Gatton	1550		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143204A	Lockyer Creek	Wilsons Weir	1655	29	Catchment covered by other gauges DS	DNRM
143905	Lockyer Creek	Glenore Grove	2230		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143906	Lockyer Creek	Glenore Grove Bvrt	2230		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143807	Lockyer Creek	Glenore Grove Alert	2230	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143206A	Lockyer Creek	Brightview Weir	2393	20	Catchment covered by other gauges DS	DNRM
143201A	Lockyer Creek	Tarampa	2405	17	Gauge ignored as catchment area below initial threshold. Possibly useful for future studies.	DNRM
143201B	Lockyer Creek	Tarampa Number 2	2405	22	Gauge ignored as catchment area below initial threshold. Possibly useful for future studies.	DNRM
143917	Lockyer Creek	Lyons Bridge	2530		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143913	Lockyer Creek	Lyons Bridge Bvrt	2530		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office

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Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143819	Lockyer Creek	Lyons Bridge Alert-P	2530	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143227A	Lockyer Creek	O'Reilly's Weir Tailwater	2965	5	Record length too short	DNRM
2142	Lota Creek	Rickertt Rd Ransome		4	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143213B	Ma Ma Creek	Ma Ma Weir	226	9	Catchment area too small	DNRM
143213A	Ma Ma Creek	Harms	227	4	Catchment area too small	DNRM
143213C	Ma Ma Creek	Harm's		8	Catchment area too small	DNRM
143032A	Moggill Creek	Upper Brookfield	23	27	Urban creek in Brisbane area, Small catchment	DNRM
143020A	Moggill Creek	Misty Morn	61	9	Urban creek in Brisbane area, Small catchment	DNRM
143020	Moggill Creek	Misty Morn TM			Urban creek in Brisbane area, Small catchment	BoM, Queensland Regional Office
1722	Moggill Creek	Fortrose St- Kenmore		8	Urban creek in Brisbane area, Small catchment	Brisbane City Council
2143	Moolabin Creek	Brisbane River Golf Club-Tennyson		14	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143219A	Murphys Creek	Spring Bluff	18	24	Urban creek in Brisbane area, Small catchment	DNRM
1549	Norman Creek	Joachim St- Holland Park West		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1552	Norman Creek	South East Freeway-Greenslopes		9	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1555	Norman Creek	Caswell St- East Brisbane River		10	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143033A	Oxley Creek	New Beith	60	27	Urban creek in Brisbane area, Small catchment	DNRM
143019A	Oxley Creek	Upstream Beatty Road	152	3	Urban creek in Brisbane area, Small catchment	DNRM
143019B	Oxley Creek	Downstream Beatty Road	152	6	Urban creek in Brisbane area, Small catchment	DNRM
143019	Oxley Creek	Beatty Road TM			Urban creek in Brisbane area, Small catchment	BoM, Queensland Regional Office
1588	Oxley Creek	Mouth of Oxley Creek		5	Urban creek in Brisbane area, Small catchment	Brisbane City Council
1727	Oxley Creek	New Beith (DNR)+F31		8	Urban creek in Brisbane area, Small catchment	Brisbane City Council
2023	Oxley Creek	Corinda High School- Corinda		12	Urban creek in Brisbane area, Small catchment	Brisbane City Council
2125	Oxley Creek	Beatty Rd- Acacia Ridge		14	Urban creek in Brisbane area, Small catchment	Brisbane City Council

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Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
2111	Oxley Creek	Johnson Rd- Forestdale		14	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143024A	Pullen Pullen Creek	Moggill Road	27	4	Urban creek in Brisbane area, Small catchment	DNRM
1745	Pullen Pullen Creek	Pinjarra Rd- Pinjarra Hills		6	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143983	Purga Creek	Loamside Alert	215	8	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143113A	Purga Creek	Loamside	215	30	Catchment area too small	DNRM
143869	Purga Creek	Peak Crossing Alert		4	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143218A	Redbank Creek	Holcomb	55	8	Urban creek in Ipswich area, Small catchment	DNRM
143216A	Redbank Creek	Water Treatment Works	60	11	Urban creek in Ipswich area, Small catchment	DNRM
143231A	Redbank Creek	Clarendon Number 2		10	Urban creek in Ipswich area, Small catchment	DNRM
143230A	Redbank Creek	Clarendon Pump Station		10	Urban creek in Ipswich area, Small catchment	DNRM
143306A	Reedy Creek	Upstream Byron Creek Junct	56	28	Catchment area too small	DNRM
143103A	Reynolds Creek	Moogerah	190	37	Catchment area too small	DNRM
143103B	Reynolds Creek	Moogerah	190	6	Catchment area too small	DNRM
143111A	Reynolds Creek	Moogerah Dam Headwater	226	36	Head gauge affected by dam site	DNRM
143112A	Reynolds Creek	Moogerah Tailwater	227	23	Tail gauge affected by dam site	DNRM
143220A	Sandy Creek	Forest Hill	102	7	Urban creek in Brisbane area, Small catchment	DNRM
143232A	Sandy Creek	Forest Hill		8	Urban creek in Brisbane area, Small catchment	DNRM
143030A	Sandy Creek	Indooroopilly		22	Urban creek in Brisbane area, Small catchment	DNRM
143223A	Seven Mile Lagoon	Diversion Channel		20	Diversion channel	DNRM
143023A	Small Catchment	Algester	1	4	Urban creek in Brisbane area, Small catchment	DNRM
143022A	Stable Swamp Creek	Interstate Railway	19	11	Urban creek in Brisbane area, Small catchment	DNRM
2129	Stable Swamp Creek	Musgrave Rd- Coopers Plains		14	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143303A	Stanley River	Peachester	104	76	Catchment area too small	DNRM
143938	Stanley River	Woodford TM	220		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office

Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143829	Stanley River	Woodford Alert-P	220	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143901	Stanley River	Woodford	250		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143301B	Stanley River	Donnelly Dell	1227	4	Record length too short	DNRM
143301A	Stanley River	Hazeldean	1242	3	Record length too short	DNRM
143305	Stanley River	Somerset Dam	1330		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143818	Stanley River	Somerset Dam Hw Alert-B	1330	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143817	Stanley River	Somerset Dam Hw Alert-P	1330	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143305A	Stanley River	Somerset Dam	1336	24	Head gauge affected by dam site	DNRM
143302A	Stanley River	Silverton	1339	49	Data obtained, but uncertainty as to appropriate rating	DNRM
143960	Stanley River	Peachester			ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143212A	Tenthill Creek	Tenthill	447	35	Catchment area too small	DNRM
143106A	Warrill Creek	Aratula Weir	122	7	Catchment covered by other gauges DS	DNRM
143102A	Warrill Creek	Kalbar No.1	465	46	Catchment covered by other gauges DS	DNRM
143102B	Warrill Creek	Kalbar No.2	468	13	Catchment covered by other gauges DS	DNRM
143937	Warrill Creek	Kalbar	470		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143910	Warrill Creek	Harrisville	725		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143912	Warrill Creek	Harrisville TM	725		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143101A	Warrill Creek	Mutdapily	771	43	Catchment covered by other gauges DS	DNRM
143825	Warrill Creek	Amberley Alert-P	850	9	ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143933	Warrill Creek	Amberley Bvrt	862		ALERT Gauge - likely to be poor data	BoM, Queensland Regional Office
143117A	Warrill Creek	Junction Weir H/W		5	Record length too short	DNRM
143118A	Warrill Creek	Junction Weir Tailwater		6	Record length too short	DNRM
143116A	Warrill Creek	Toohill's Crossing		6	Record length too short	DNRM
143105A	Warrill Creek East	Churchbank Weir	149	50	Catchment covered by other gauges DS	DNRM
143031A	Water St. Drain	Exhibition Ground		5	Urban creek in Brisbane area, Small catchment	DNRM

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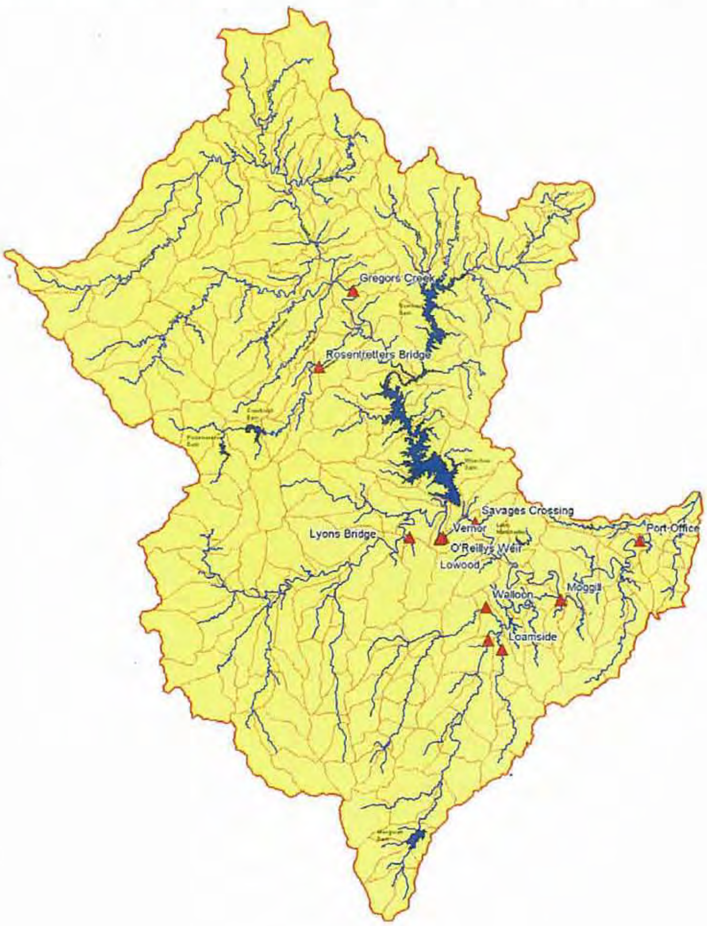
Station Number	Stream Name	Site Name	Catchment Area (km²)	Years of Record	Reason data was not used in statistical flood frequency analysis	Data Provider
143939	Western Creek	Kuss Road	200	21	Urban creek in Brisbane area, Small catchment	BoM, Queensland Regional Office
143861	Western Creek	Grandchester Alert		4	Urban creek in Brisbane area, Small catchment	BoM, Queensland Regional Office
1583	Wolston Creek	700m U/S Wacol Station Rd-Wacol		6	Urban creek in Brisbane area, Small catchment	Brisbane City Council
143962	Woogaroo Creek	Brisbane River Road Alert			Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office
143927	Woogaroo Creek	Opossum Alert			Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office
143961	Woogaroo Creek	Alice Street Alert		7	Urban creek in Ipswich area, Small catchment	BoM, Queensland Regional Office

Appendix C Location of select stream gauges

- **Location of stream gauge sites that were used in flood frequency analysis**



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Appendix D Flood Data Series for Savages Crossing from DNRM

Date	Gauged flow at Savages Crossing/Lowood Recorded Values	No Dams	Both Dams Working	Date*
11/03/1890		7343		
09/06/1891		1790		
04/04/1892		3953		
03/02/1893		13156		
21/04/1894		1060		
26/01/1895		1194		
12/02/1896		3699		
02/03/1897		432		
11/01/1898		5889		
30/01/1899		211		
23/05/1900		313		
21/03/1901		885		
15/10/1901		142		
1/06/1903		1717		
18/04/1904		351		
19/01/1905		816		
14/03/1906		745		
1/06/1907		302		
15/03/1908		6356		
17/07/1909		325		
28/12/1909	814	814	501	16/01/1910
13/01/1911	1317	1317	535	
4/03/1912	461	461	251	25/06/1912
23/06/1913	416	416	133	
27/02/1914	234	234	8	
11/02/1915	1035	1035	51	
12/04/1916	159	159	60	
29/01/1917	475	475	83	
13/12/1917	522	522	386	
8/05/1919	91	91	8	
22/01/1920	402	402	8	
11/06/1921	1237	1237	260	
30/12/1921	1280	1280	745	
16/10/1922	46	46	8	
12/02/1924	173	173	125	
21/06/1925	778	778	111	
6/01/1926	126	126	73	
27/01/1927	2715	2715	1028	
20/04/1928	4225	4225	927	
21/01/1929	2064	2064	682	4/04/1929
30/06/1930	749	749	332	1/06/1930
6/02/1931	5575	5575	1114	
10/12/1931	328	328	257	
20/01/1933	312	312	300	
23/02/1934	614	614	241	6/01/1934
26/02/1935	120	120	38	18/01/1935
24/03/1936	139	139	8	
17/03/1937	1103	1103	527	
28/05/1938	1052	1052	218	
17/03/1939	460	460	251	
3/03/1940	697	697	106	
25/01/1941	425	425	291	
10/02/1942	1360	1360	557	
31/12/1942	833	833	529	
31/12/1943	1208	1208	461	
13/06/1945	140	140	140	
26/03/1946	1052	1052	484	23/01/1946
2/03/1947	803	803	270	
11/12/1947	796	796	796	
4/03/1949	1013	1013	542	
1/03/1950	2788	2788	2530	
1/02/1951	3125	3125	2270	
18/06/1952	18	18	8	
24/03/1953	1002	1002	76	
14/07/1954	1922	1922	1091	13/02/1954
30/03/1955	5363	5363	667	
12/03/1956	2141	2141	890	
23/12/1956	214	214	61	
11/06/1958	1520	1520	922	
19/02/1959	1494	2560	1234	
14/11/1959	1451	2730	656	

* Peak occurred at a different time according to operational rules in with dams case

Yellow	Generated using IQQM model of catchment with calibrated 6 six hourly disaggregation.
Blue	Gauged Flow at Savages Crossing/Lowood/Vernor
Orange	Gauged Flows affected by Somerset
Green	Gauged flows affect by Somerset and Wivenhoe
Blue	Flows adjusted to remove the impact of Somerset removed.
Light green	Flows adjusted to remove the effect of Somerset and Wivenhoe
Purple	Flows routed through WIVOPS program using inflows into Somerset and Wivenhoe.

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Appendix E Regional statistical flood frequency Information

E.1 Introduction

The main benefit of adopting a regional approach to statistical flood frequency analysis is that it incorporates additional information that is not available at the one gauge. Where there are doubts about the reliability of the extrapolated flood estimates at the gauge (eg. the maximum gauged flow at Savages Crossing is in the order of 30-45% of the maximum peak flow) then the regional information provides useful information on the appropriateness of the at-site estimates.

Regional analysis also provides a means to transpose flood peaks from one location to another. For example, examination of the manner in which flood peak varies with catchment area allows peak flows estimated at Savages Crossing to be transposed down to the Brisbane Port Office.

This Appendix describes the regional information used to help inform the analysis undertaken at Savages Crossing.

E.2 Selection of Data

Given the time constraints of this review, the only data that could be incorporated was that which was readily available and for which there was a reasonable level of confidence in its consistency and quality.

As noted in **Section 2.2** only DNRM gauge flow data were both immediately available and of sufficient quality for the regional analysis. Annual maxima instantaneous flow rates were extracted for 8 stations in the Brisbane River catchment in Southern Queensland. The stations that were assessed in the analysis are listed in **Table E-1**.

The location of the gauges can be seen in the catchment map in **Appendix C**.

The composite record for Brisbane River at Lowood / Vernor / Savages Creek has the longest period of record prior to the construction of Wivenhoe Dam. It is reasonably close to the start of the hydraulic model set up to determine flood elevations and to route design floods along the most downstream reaches of the Brisbane River. It is the natural point to determine the key flood quantiles for use in estimating the appropriate design losses and performance of the rainfall runoff model.

The eight sites in **Table E-1** were adopted initially to assist in the selection of the distribution to fit to the flood data as discussed in **Section E.3**.

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- **Table E-1 Flow gauging stations used in the regional analysis of pre-Wivenhoe Dam floods**

River	Station Name	Station Number	Years of Record	C'ment Area (km²)	Max gauged flow as % of max estimated flow
Brisbane River	Brisbane River @ Savages Crossing	143001	72	10172	45%
Bremer River	Bremer River @ Walloon	143107	40	622	42%
Cressbrook Creek	Cressbrook Creek @ Rosentreters Bridge	143921	15	447	35%
Lockyer Creek	Lockyer Creek @ Lyons Bridge	143210	22	2486	25%
Lockyer Creek	Lockyer Creek	143207	53	2965	10%
Brisbane River	Brisbane River @ Gregors Creek	143009	39	3866	67%
Warrill Creek	Warrill Creek @ Amberley	143108	40	914	26%
Purga Creek	Purga Creek @ Loamside	143113	28	215	12%

E.3 Selection of Frequency Distribution and Parameters

The first four L-Moments of the maxima samples were computed at each of the eight sites in **Table E-1**. An L-moment diagram was constructed to assist in the choice of distribution appropriate to the flow data. **Figure E-1** shows that there is some scatter among the eight sites in the plot of L-Kurtosis v L-Skew (4^{th} v 3^{rd} L-Moment). This scatter is typical of such analyses and it is often difficult on the basis of such plots to make a definitive choice of distribution (e.g. Peel et. al., 1999). Either the Pearson III or Generalised Pareto distributions could be chosen.

Also shown on **Figure E-1** is the regional average L-moments obtained from all eight sites (and weighted by their length of record). It is evident that Bremer River @Walloon (143107A) and Brisbane @ Gregor's Creek (143009A) are two sites most dissimilar to the regional average, an inspection of the at-site records (**Appendix F**) indicate considerable differences between the distribution of the annual maxima and the regional Generalised Pareto quantiles. Accordingly, these two stations were excluded from subsequent analysis.

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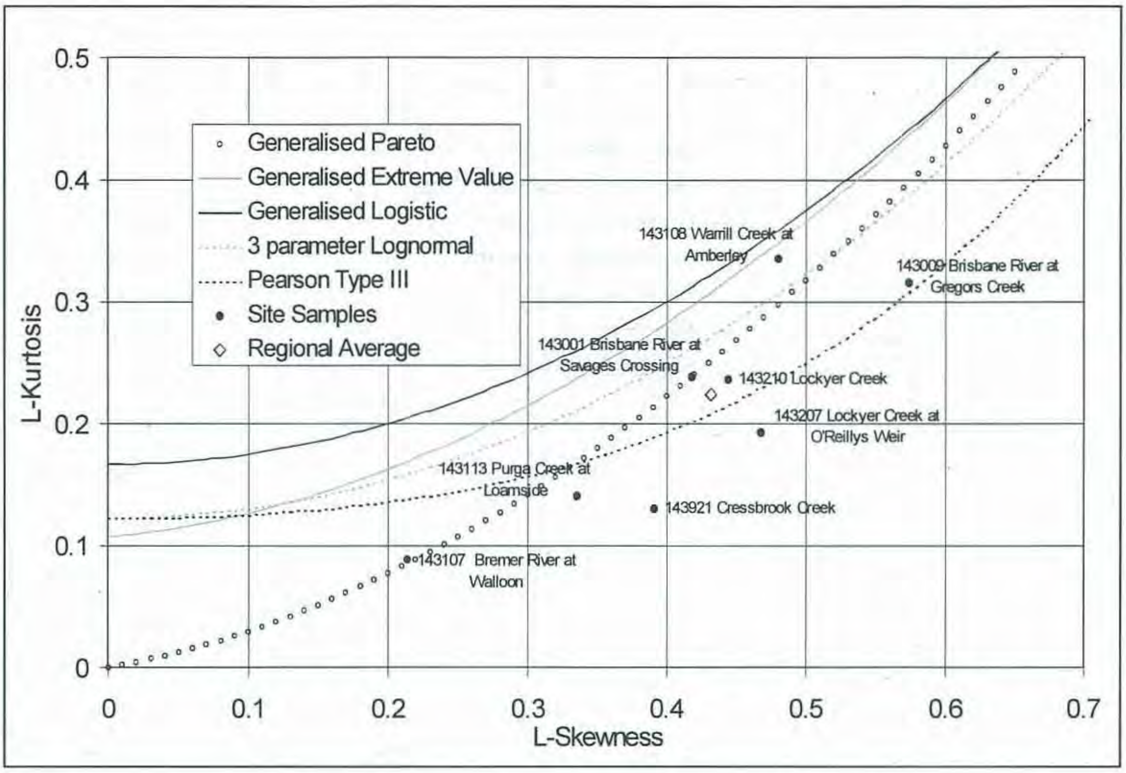

- **Figure E-1 L-Moment Ratio diagram for six flow gauging stations in the Brisbane River catchment**

For assessment of peak flows at the lower reaches of the major Brisbane River system (approximately 13,500 km²), the response of small tributaries is less relevant than that of the larger tributaries and sub-catchments. Consequently the remaining stations with small catchment areas were excluded. They were Purga Creek @ Loamside (143113) and Cressbrook Creek @ Rosentreters Bridge (143921).

The average regional L-moments were recalculated for the remaining data. The position of the catchment average L-moments on the L-moment ratio diagram (**Figure E-2**) supports the adoption of the Generalised Pareto distribution.

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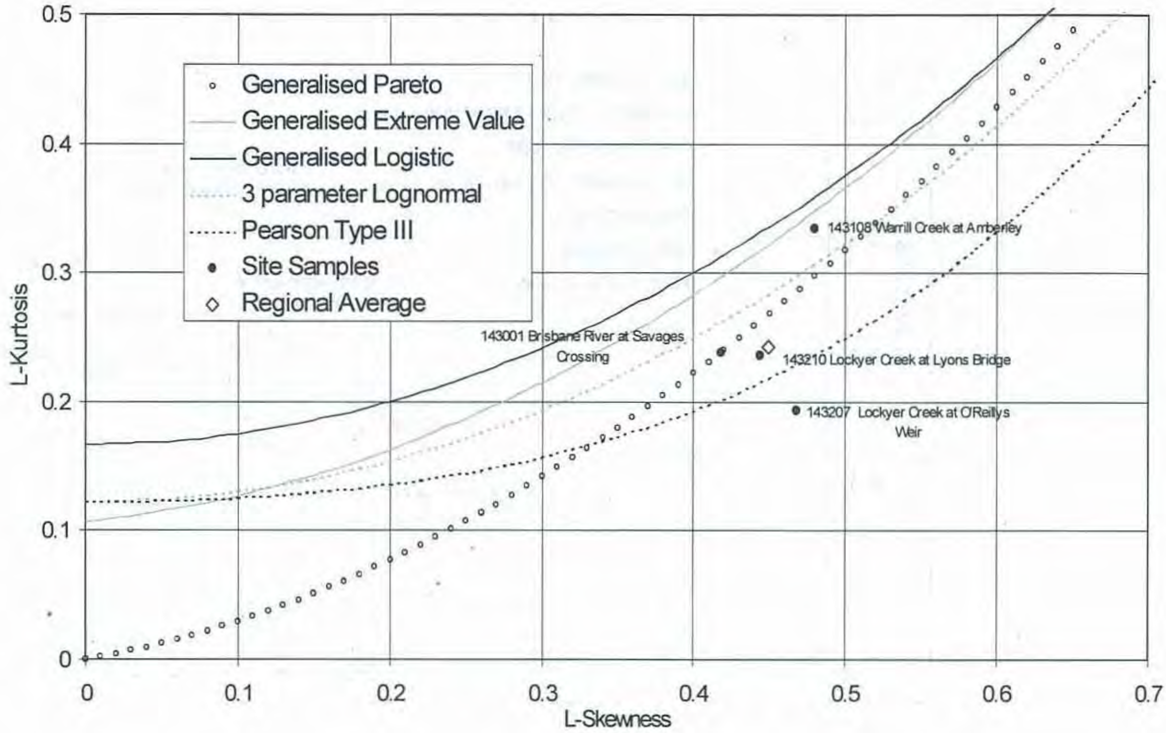

- **Figure E-2 L-Moment Ratio diagram for the most relevant and reliable flow gauging stations in the Brisbane River catchment (pre- Wivenhoe Dam)**

The Generalised Pareto distribution was adopted for the regional analysis on the basis that the regional average L-Moment values lie closest to this distribution, and the L-Moments of the individual sites are scattered around the theoretical curve.

The Generalised Pareto distribution was adopted with parameters given in **Table E-2**.

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- **Table E-2 Regional parameter values of the adopted Generalised Pareto distribution**

Parameter	Values obtained including information at Savages Crossing	Values obtained excluding information at Savages Crossing
Location parameter, ξ	-0.062	-0.096
Scale parameter, α	0.811	0.795
Shape parameter, κ	-0.230	-0.275

E.4 Parameters of Prior Distribution for Bayesian Analysis of Flood Peaks

Regional information can be incorporated in the Bayesian analysis of flood peaks that is performed by FLIKE. The regional information is incorporated into the Bayesian analysis as prior frequency distributions of the parameters of the flood frequency distribution that has been selected. The Bayesian analysis requires for each parameter:

- its prior mean (or expected) value,
- its prior standard deviation, and
- its cross-correlation with the other parameter(s) of the distribution.

The prior mean values of the scale (α) and shape (κ) parameters were obtained from the regional average L-moments of the seven sites that exclude Savages Crossing. These values are listed in the right column of **Table E-2**. The scale parameter (α) from the regional analysis shown in **Table E-2** is computed from the L^{CV} ($=L^2/L^1$). The prior estimate of the scale parameter for gauging station 143001 is therefore computed from:

$$\hat{\alpha}_{143001} = L^1_{143001}\alpha^{CV}_{\text{Regional}} = 1181 \times 0.795 = 939$$

The prior standard deviations of the scale and shape parameters were obtained by computing the parameter values from the L-moments at each of the seven sites, excluding Savages Crossing. The prior estimate of the standard deviation for each parameter was computed as the standard deviation of the parameter value from the seven sites. This computation is shown in **Table E-3**. The standard deviation for the scale parameter is computed from the L^{CV}. The standard deviation of the prior estimate of the scale parameter for gauging station 143001 is therefore computed from:

$$\sigma_{\alpha,143001} = L^1_{143001}\sigma^{CV}_{\alpha,\text{Regional}} = 1181 \times 0.388 = 458$$

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The cross-correlation between the scale and shape parameters was simply assumed to be the same as found from the parameter inference statistics computed by FLIKE ($r = 0.6$). This information was used rather than the sample statistics from the regional parameter set as it was considered that correlation between parameters from the one river system was likely to over-estimate the actual degree of correlation.

- **Table E-3 Estimates of prior standard deviation and cross-correlation in parameter values of the adopted Generalised Pareto distribution**

Site Number	Gauging Station Name	Scale parameter, α	Shape parameter, κ
143009	Brisbane River @ Gregors Creek	0.573	-0.467
143107	Bremer River @ Walloon	1.502	0.300
143108	Warrill Creek @ Amberley	0.724	-0.268
143113	Purga Creek @ Loamside	1.573	0.279
143207	Lockyer Creek	0.833	-0.279
143210	Lockyer Creek @ Lyons Bridge	0.815	-0.275
143921	Cressbrook Creek @ Rosentreters Bridge	0.948	-0.185
Standard Deviation of Parameter		**0.388**	**0.297**

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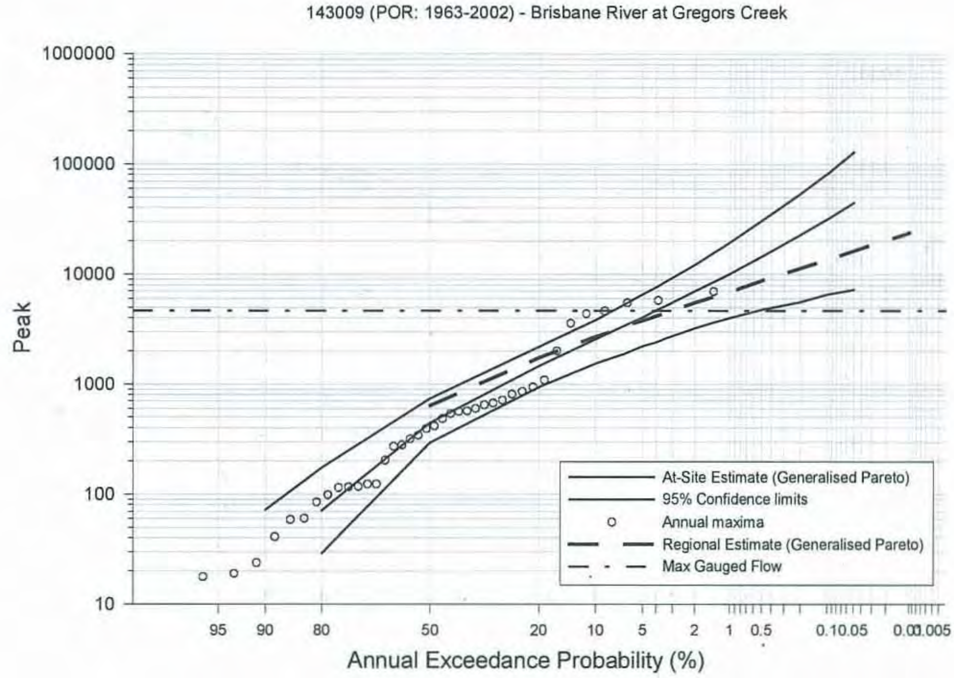
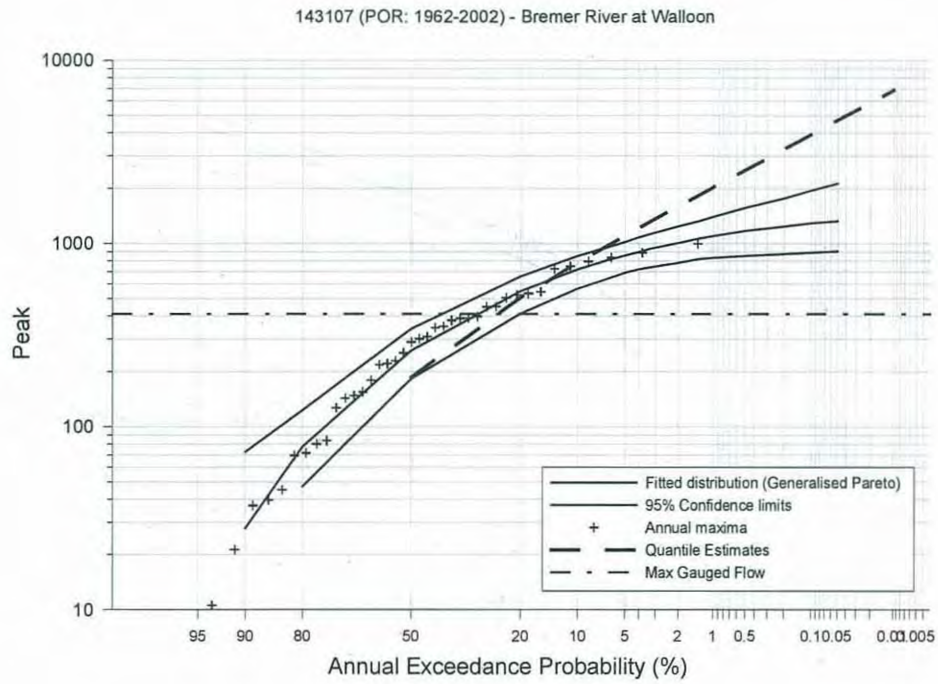
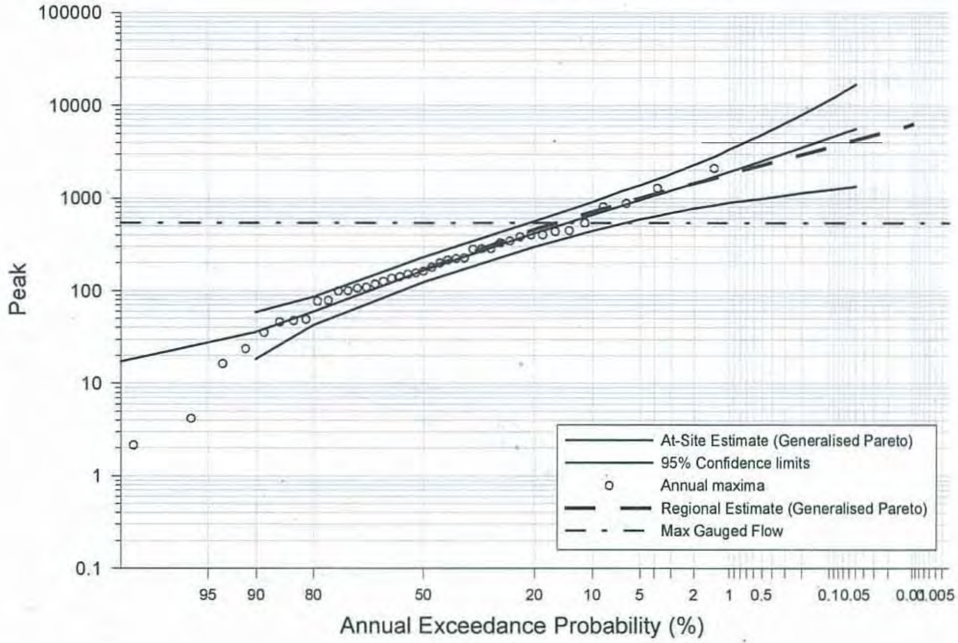
Appendix F At-Site/Regional Analysis of Selected Gauges

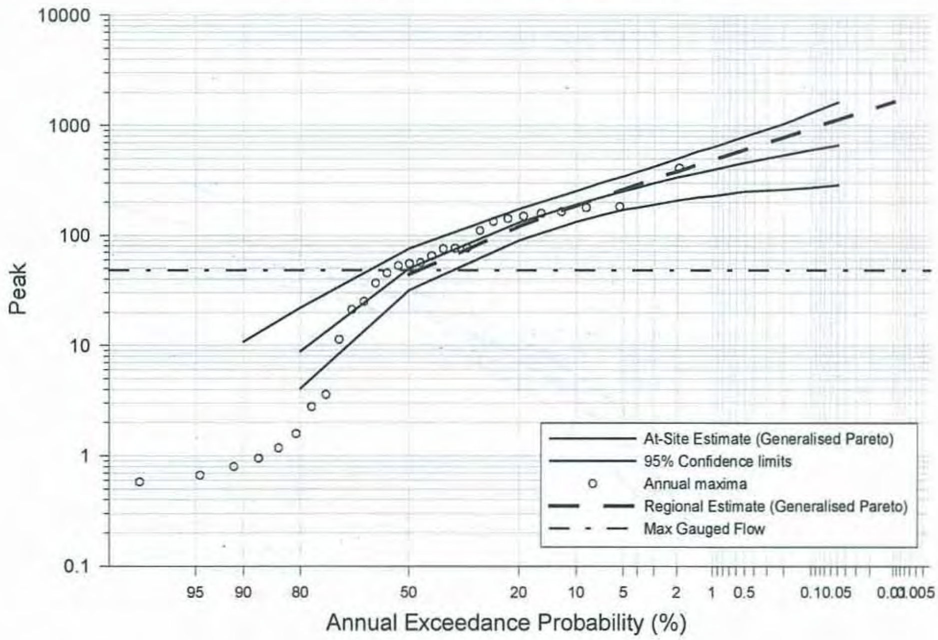




143108 (POR: 1962-2002) - Warrill Creek at Amberley



143113 (POR: 1974-2002) - Purga Creek at Loamside



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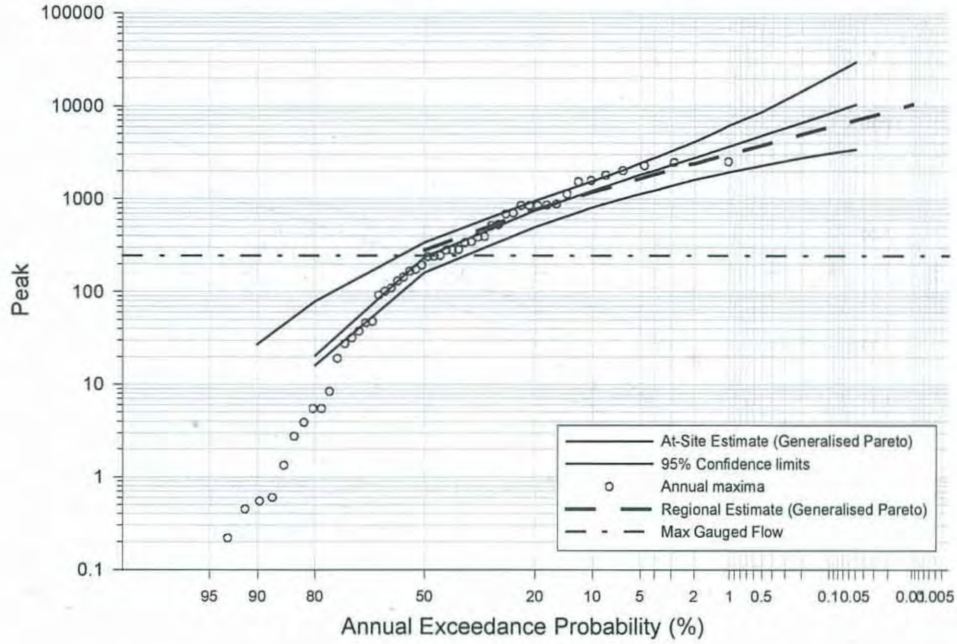
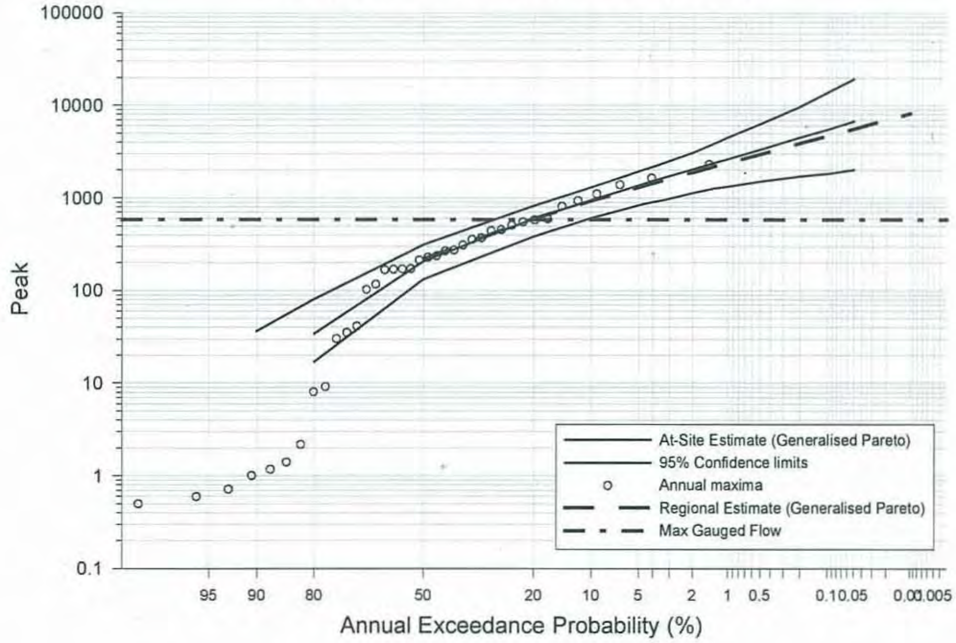
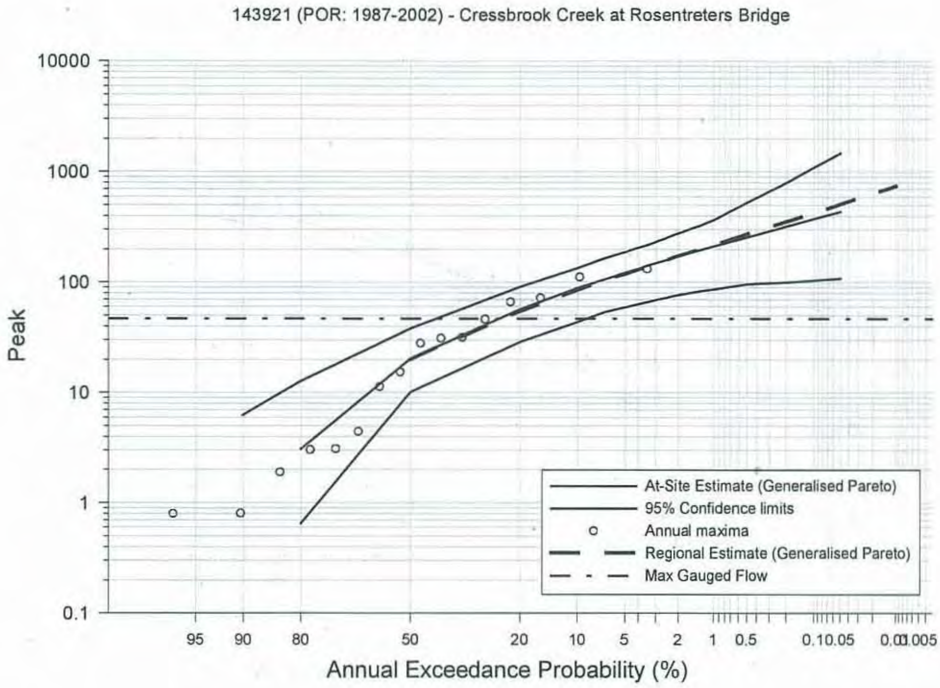
143207 (POR: 1949-2002) - Lockyer Creek



143210 (POR: 1965-1987) - Lockyer Creek at Lyons Bridge




143921 (POR: 1987-2002) - Cressbrook Creek at Rosentreters Bridge
10000
1000
100
10
1
0.1
Peak
95
90
80
50
20
10
5
2
1
0.5
0.10.05
0.010.005
Annual Exceedance Probability (%)
At-Site Estimate (Generalised Pareto)
95% Confidence limits
Annual maxima
Regional Estimate (Generalised Pareto)
Max Gauged Flow

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Appendix G Historical Spatial Distributions

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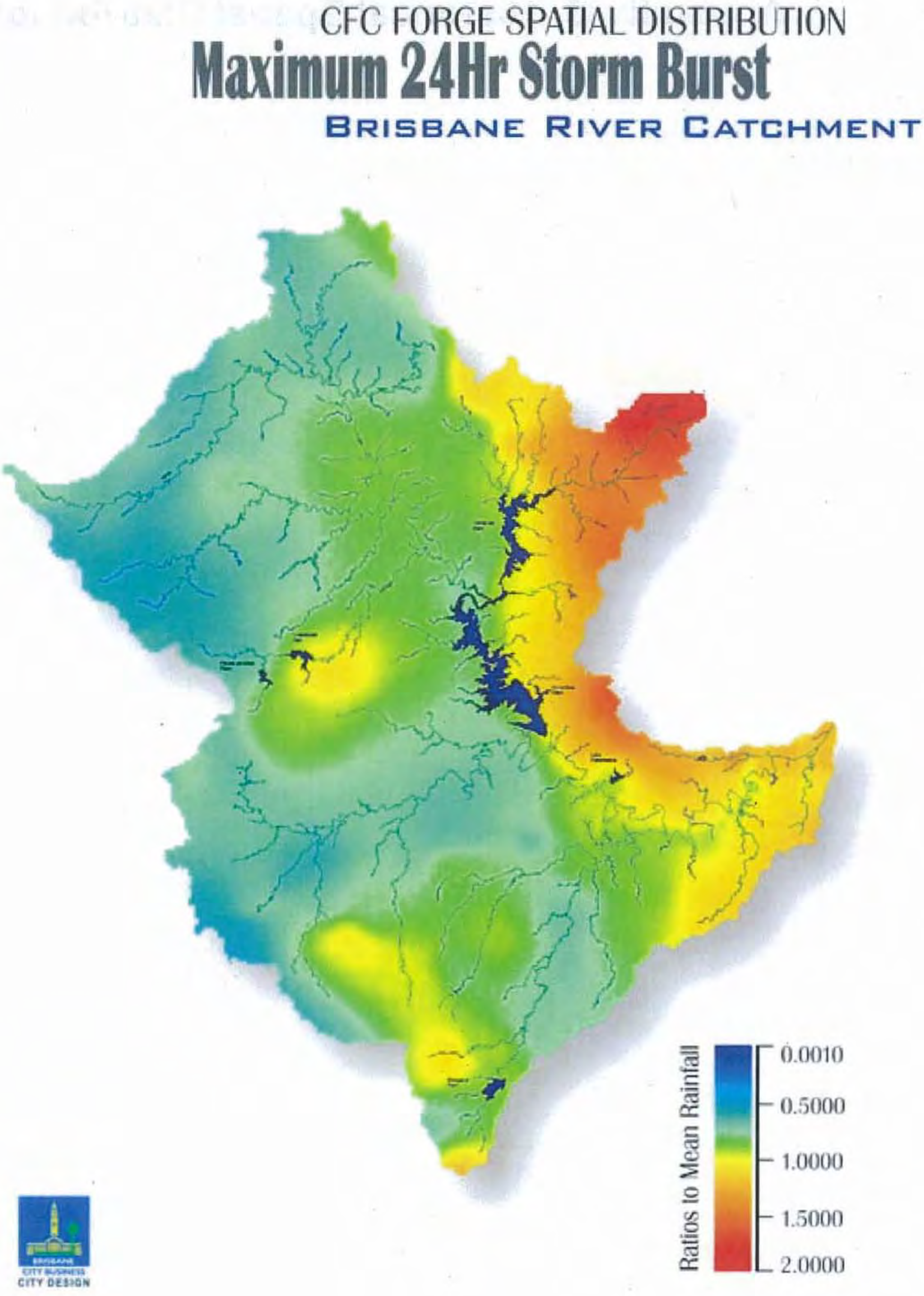
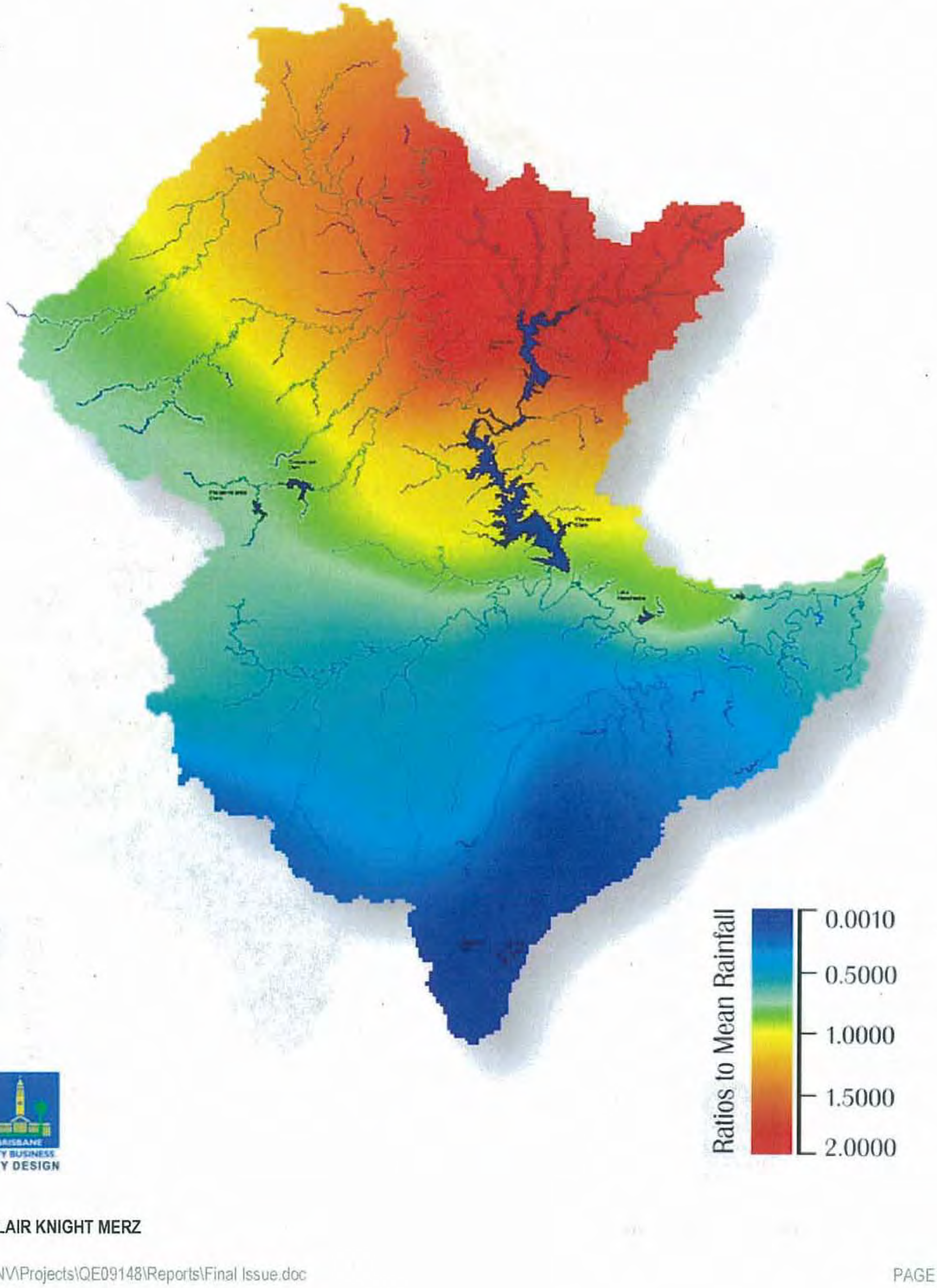

CFC FORGE SPATIAL DISTRIBUTION
Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
0.0010
0.5000
1.0000
1.5000
2.0000
BRISBANE
CITY BUSINESS
CITY DESIGN

SKM

JANUARY 1893 SPATIAL DISTRIBUTION
Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT

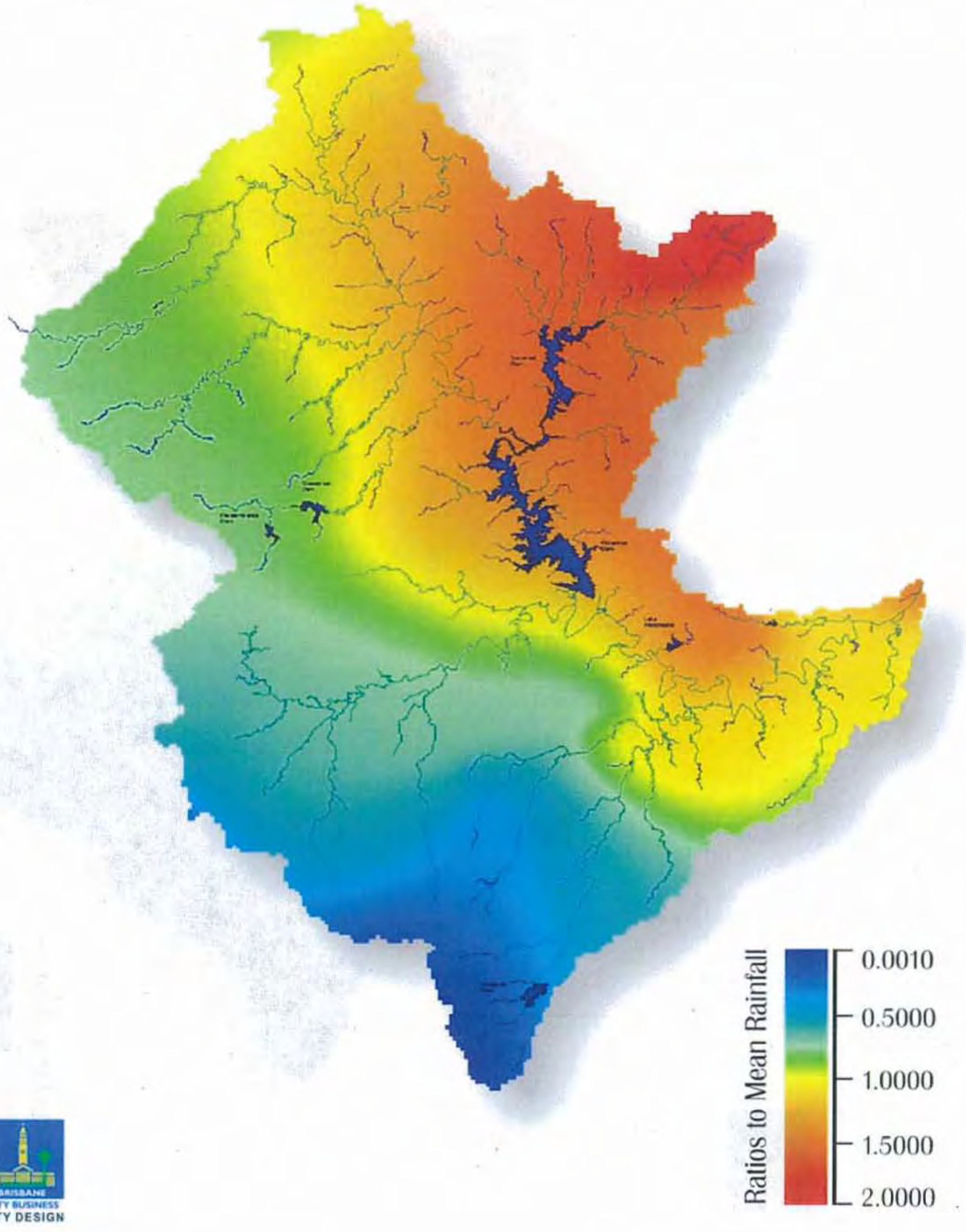


BRISBANE CITY BUSINESS CITY DESIGN

BCC.009.6890

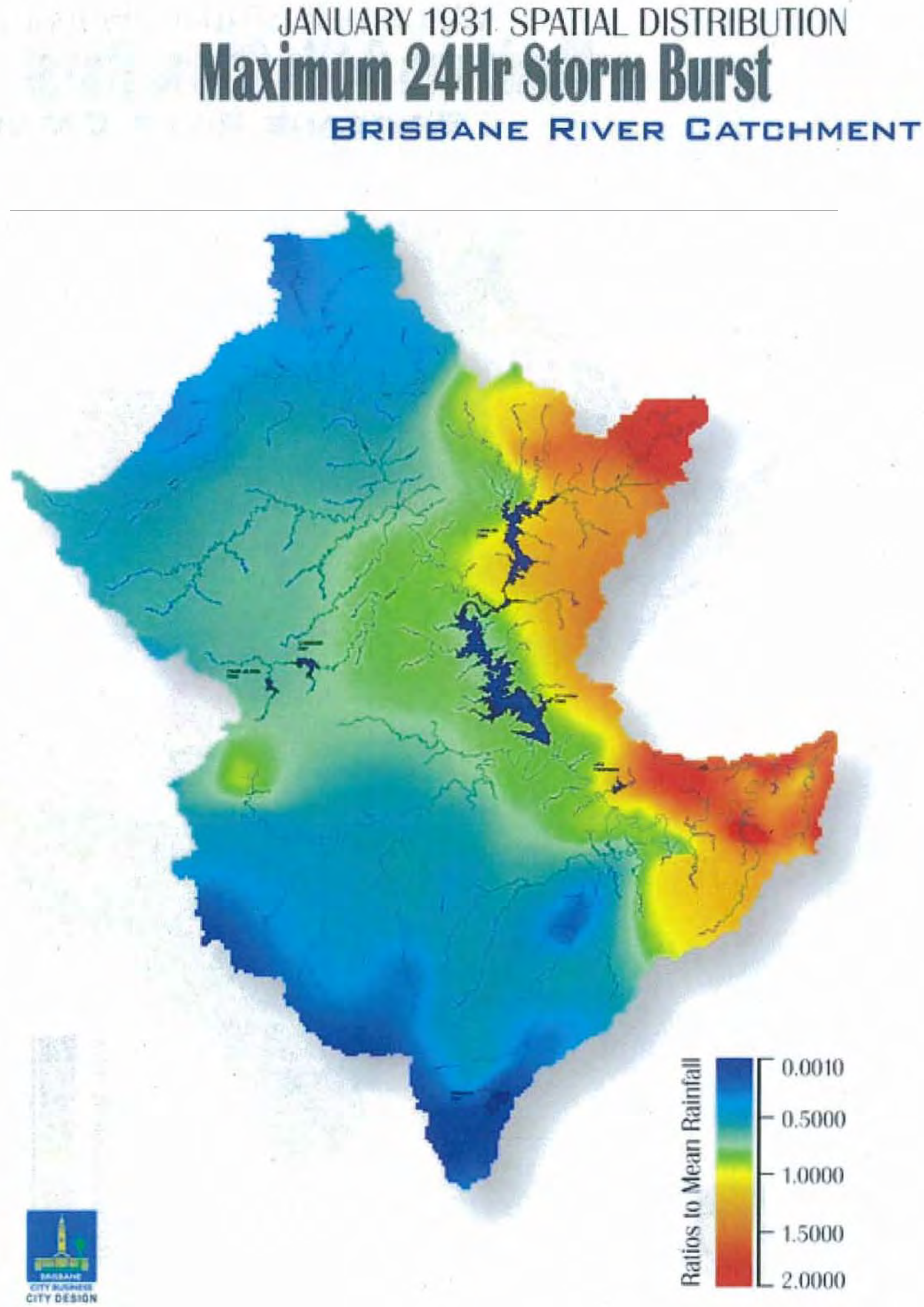
SKM

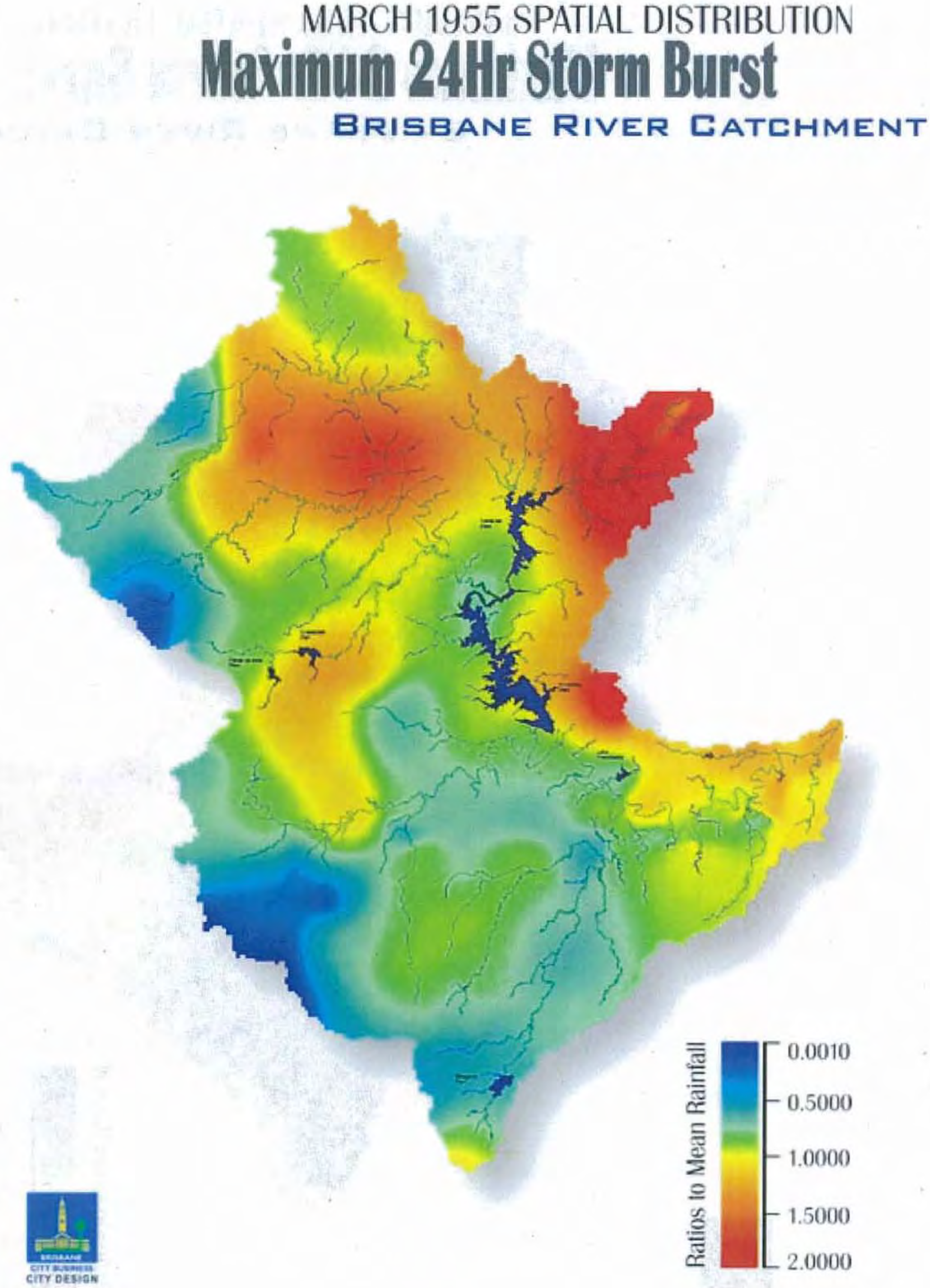
FEBRUARY 1893 SPATIAL DISTRIBUTION
Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT



BRISBANE CITY BUSINESS
CITY DESIGN

SKM


JANUARY 1931 SPATIAL DISTRIBUTION
Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
0.0010
0.5000
1.0000
1.5000
2.0000
BRISBANE CITY BUSINESS
CITY DESIGN


MARCH 1955 SPATIAL DISTRIBUTION
Maximum 24Hr Storm Burst
BRISBANE RIVER CATCHMENT
Ratios to Mean Rainfall
0.0010
0.5000
1.0000
1.5000
2.0000

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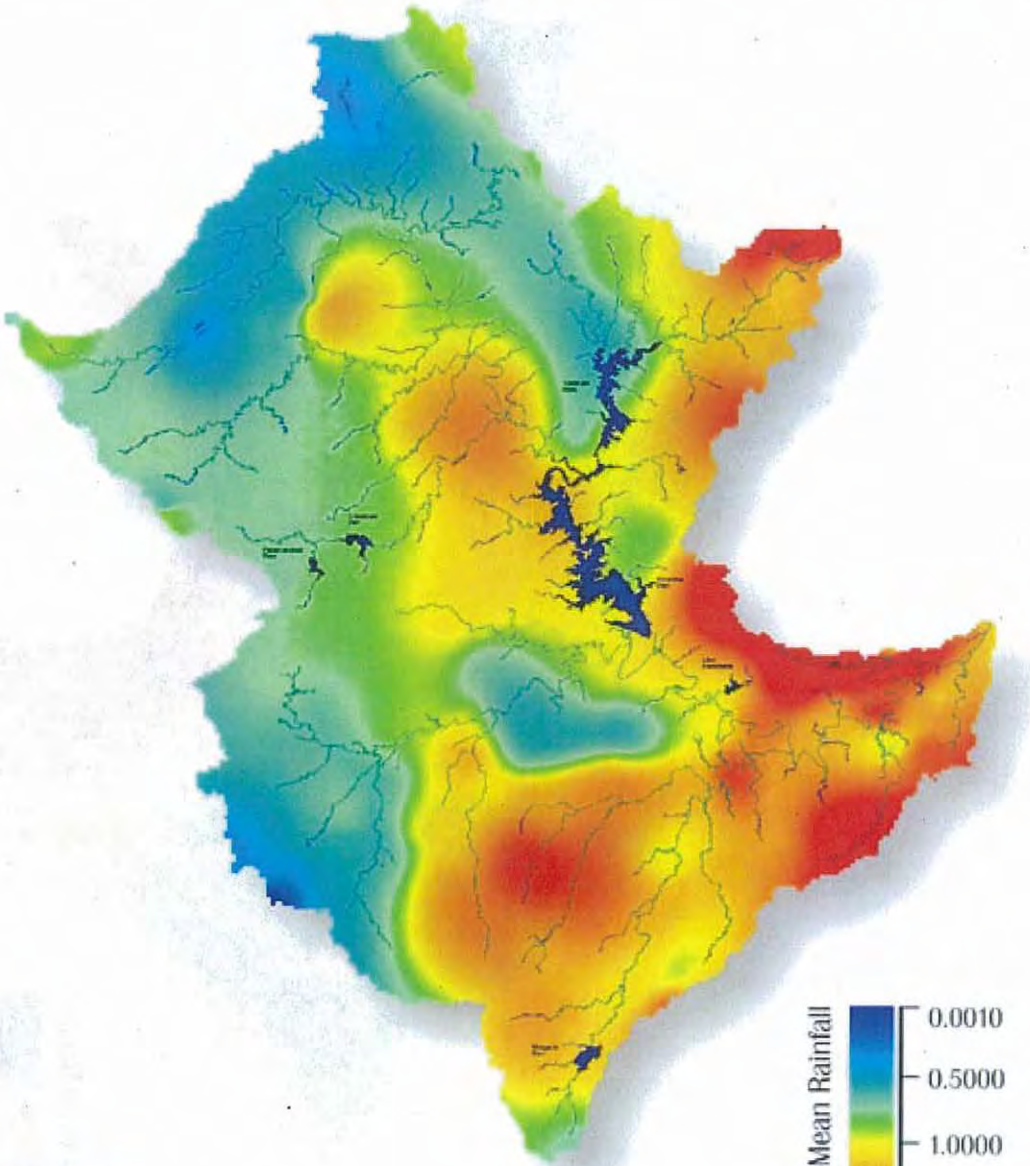
JANUARY 1974 SPATIAL DISTRIBUTION

Maximum 24Hr Storm Burst

BRISBANE RIVER CATCHMENT



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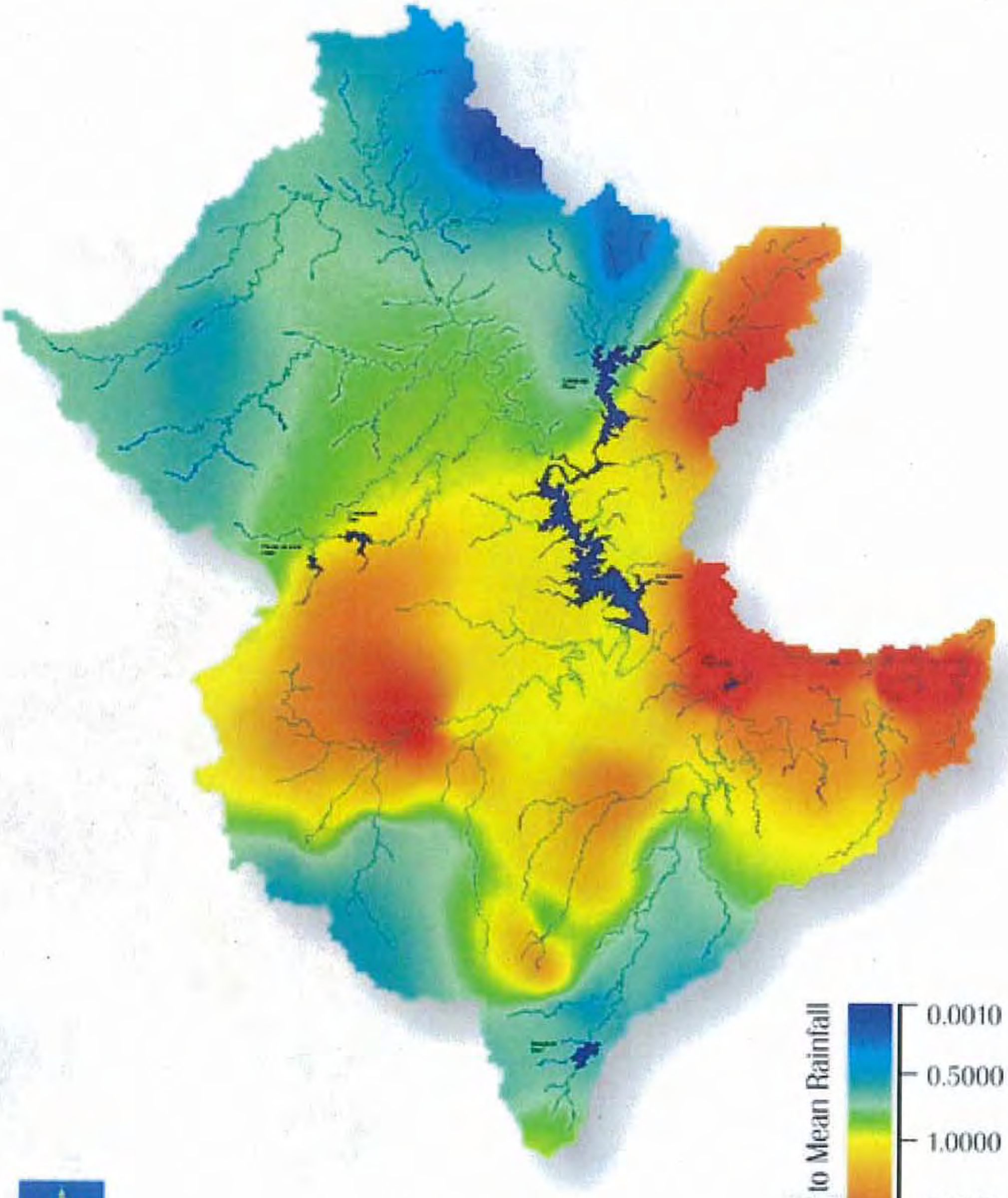
APRIL 1996 SPATIAL DISTRIBUTION

Maximum 24Hr Storm Burst

BRISBANE RIVER CATCHMENT



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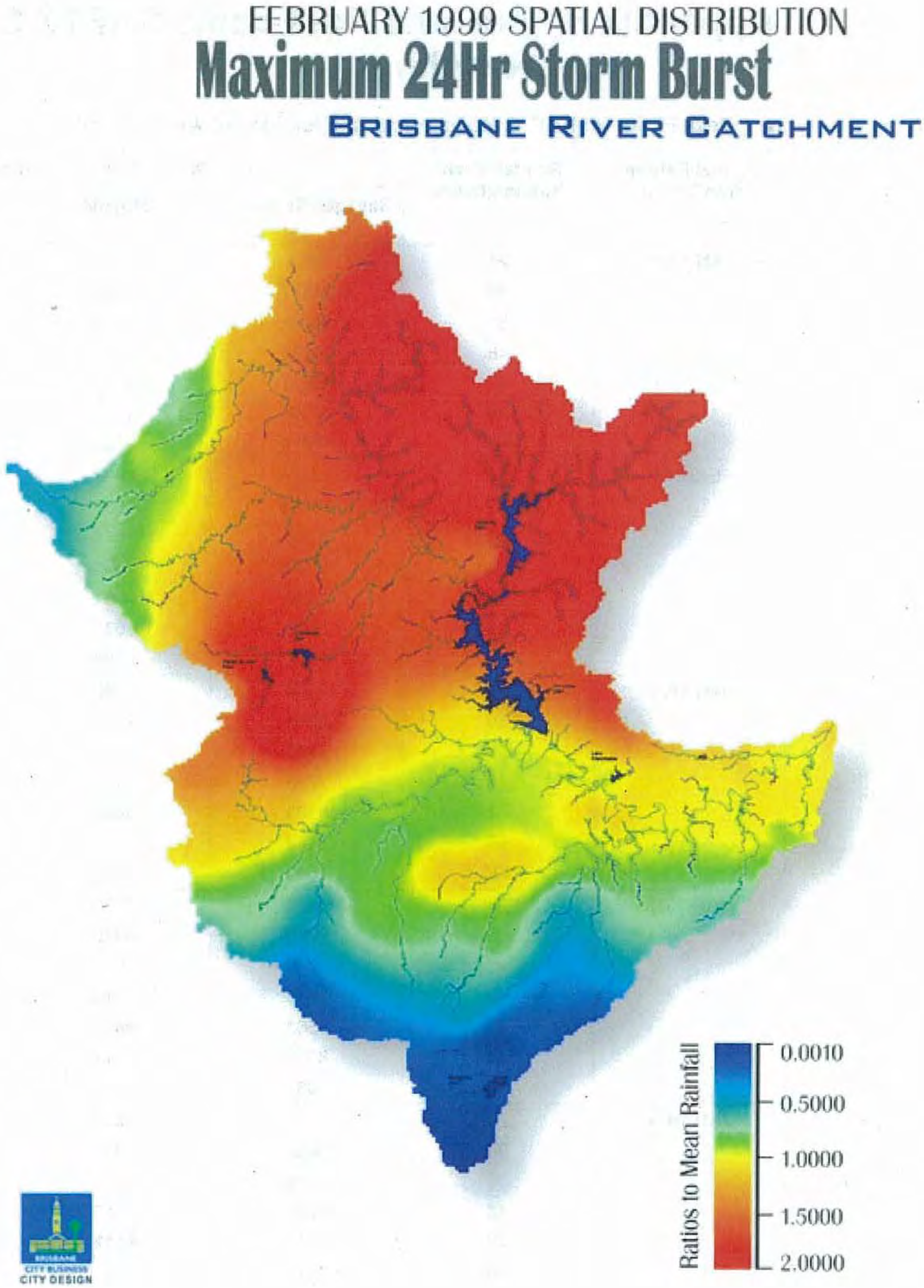

BCC.009.6896

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Appendix H Pre- and Post-dams RAFTS Model Results

- **Peak Flows for RAFTS Model, Pre-Dams for 1 in 100 AEP Rainfall**

Spatial Pattern from Event	Rainfall Event Duration(hours)	1 in 100 AEP Peak Flow in m³/s		
		Savages Crossing	Moggill	Brisbane Port Office
JAN 1893	24	9861	7927	7927
	30	**11507**	9792	9793
	36	9810	7932	7932
	48	10238	8534	8535
	72	10911	**10196**	**10198**
	96	9774	9392	9394
	120	10074	9639	9641
FEB 1893	24	8698	7502	7502
	30	**10062**	8788	8789
	36	8682	7512	7512
	48	9012	7865	7866
	72	9634	**9501**	**9504**
	96	8568	8632	8636
	120	8804	8898	8904
JAN 1931	24	7505	6745	6745
	30	**8543**	7648	7648
	36	7476	6775	6776
	48	7712	7190	7191
	72	8183	**8026**	**8030**
	96	7140	7514	7610
	120	7360	7630	7713
MAR 1955	24	8671	7536	7537
	30	**10046**	8925	8925
	36	8689	7553	7554
	48	8955	7915	7916
	72	9563	**9619**	**9623**
	96	8376	8745	8750
	120	8635	8997	9002
JAN 1974	24	7058	7202	7203
	30	**8005**	8046	8049
	36	7049	7072	7073
	48	7227	7527	7528
	72	7714	**9112**	**9117**
	96	6729	8154	8161

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Spatial Pattern from Event	Rainfall Event Duration(hours)	1 in 100 AEP Peak Flow in m³/s		
		Savages Crossing	Moggill	Brisbane Port Office
	120	6879	8432	8454
APR 1996	24	7531	7067	7068
	30	**8621**	7966	7966
	36	7549	7078	7079
	48	7748	7425	7427
	72	8287	**8917**	**8922**
	96	7184	8034	8043
	120	7399	8170	8182
FEB 1999	24	9631	7884	7884
	30	**11205**	9708	9708
	36	9578	7893	7894
	48	9981	8443	8444
	72	10642	**10197**	**10200**
	96	9512	9384	9387
	120	9809	9626	9629

Note: Critical flows at each location are shown in **bold**.

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- **Peak Flows for RAFTS Model, Post-Dams for 1 in 100 AEP Rainfall**

Spatial Pattern from Event	Rainfall Event Duration(hours)	1 in 100 AEP Peak Flow in m^3/s		
		Savages Crossing	Moggill	Brisbane Port Office
JAN 1893	24	3026	2909	2909
	30	6008	4705	4705
	36	3474	3284	3284
	48	5366	3880	3880
	72	7323	6699	6699
	96	7596	6892	6892
	120	**7847**	**7120**	**7121**
FEB 1893	24	1877	2061	2070
	30	3818	3449	3449
	36	1935	2203	2211
	48	3471	3148	3148
	72	6197	5615	5615
	96	6310	5595	5596
	120	**6568**	**5850**	**5851**
JAN 1931	24	1872	2051	2319
	30	1926	2708	3314
	36	1884	2452	2836
	48	1758	2382	2580
	72	3079	3146	3968
	96	3170	2940	3383
	120	**3279**	**3218**	**3411**
MAR 1955	24	1925	2345	2350
	30	3524	3433	3433
	36	2063	2541	2544
	48	3272	3013	3013
	72	**6241**	**5709**	**5710**
	96	5926	5339	5340
	120	6151	5584	5585
JAN 1974	24	1753	3324	3326
	30	2467	3987	3989
	36	1871	3279	3350
	48	1943	3627	3633
	72	3307	4418	4965
	96	**4771**	**5841**	**5852**
	120	2911	3656	3662
APR 1996	24	3554	3399	3400
	30	4067	4137	4138

Spatial Pattern from Event	Rainfall Event Duration(hours)	1 in 100 AEP Peak Flow in m^3/s		
		Savages Crossing	Moggill	Brisbane Port Office
	36	3535	3260	3260
	48	3605	3690	3691
	72	**4162**	**5019**	**5035**
	96	3492	4378	4417
	120	3509	4571	4663
FEB 1999	24	3424	2886	2887
	30	5789	4442	4442
	36	3575	3150	3147
	48	4604	3494	3495
	72	6879	6447	6448
	96	7217	6623	6624
	120	**7431**	**6819**	**6819**

Note: Critical flows at each location are shown in **bold**.