Queensland
Government

GHD

FEBRUARY 2013

Department of State Development,
Infrastructure and Planning

Brisbane River Catchment Floodplain Studies

Technical Scoping Framework

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Executive Summary

This report forms a part of the Queensland Government response to the recommendations of the *Queensland Floods Commission of Inquiry* (QFCI) following the damaging Brisbane River floods in January 2011. Specifically it addresses *Recommendation 2.2*, which calls for a new and comprehensive “flood study” of the Brisbane River Catchment. In response, this report provides a best practice methodology framework that addresses the substance and intent of the QFCI recommendations and should, with appropriate resourcing, lead to the successful implementation of the requisite studies to the very high standard required to significantly advance understanding and management of flood risks associated with the Brisbane River catchment.

The purpose of this Technical Scoping Framework is therefore to set out a process of technical enquiry, identification of knowledge, data, and evaluation of options and actions that will lead to the timely and successful implementation of a variety of flood risk related outcomes. In combination, these are designed to better understand, plan for and avoid the ongoing and future risk to people and property of the damaging effects of floods within the Brisbane River, its tributaries and extensive urban floodplain, for generations to come. The process advocated is fully risk-based, comprehensive in scope and necessarily innovative to meet the identified and peer-agreed complexity of the Brisbane River system.

The resulting key guidance and recommendations are then embodied into a series of draft technical Scopes of Work that form Appendices to this report.

The Framework addresses, *inter alia*:

- A description of the context of flooding problems associated with the Brisbane River catchment and associated rivers and tributaries;
- A brief history of regional flood events and their impacts, as well as potential future impacts;
- A review of national and international best practice approaches and guidelines;
- Identification of the many jurisdictional overlaps, stakeholder organisations and intellectual resources available to address the problems;
- Recognition of the principal climate drivers that dictate flood frequency and intensity on a range of space and time scales and the potential for longer term climate change;
- The need to collate many data sources, to assess their quality, consistency and relevance in order to address future study needs, and the identification of data gaps;
- A review of the technical approaches and resources available to address the study objectives and the identification of methodology gaps requiring targeted research offering both immediate and future long-term value to the various stakeholders;
- A high-level work plan, schedule and draft Scopes of Work for the detailed technical and non-technical studies (e.g. flood hazards, hydrology, hydraulics, risk assessment, floodplain management, communication and stakeholder consultation) that will collectively and consistently build to form the basis of a comprehensive flood modelling and risk assessment system;

The resulting system model capable of informing decision makers as to (1) the present levels of risk in all its complexity, (2) the options that are now available to reduce risk and (3) to be the enabling tool for ongoing future risk-reduction planning (strategic and emergency).

The process followed in constructing the Framework has been one of:

- Engagement and consultation with stakeholders leading to the discovery of relevant resources (data, models, techniques);
- Consultation with a range of technical specialists (government, consultant, research) having the knowledge and experience needed to deliver the targeted outcomes;
- Peer review and transparency in development of the recommended investigation programme options.

This report recommends a series of inter-linked high quality technical studies to achieve the aims and intended outcomes. These are necessarily detailed and of sufficient scope and duration to match the already identified and agreed complexity of the river system and the climatic drivers that lead to damaging floods.

While there are many component parts to the recommended series of individual best practice studies, with data collection being a significant precursor, the process can be summarised in terms of two principal elements, as follows:

1. A series of tasks that will lead to the accurate quantification of the present and potential future flood hazard across the entire catchment - the probabilistic **Flood Study**, and
2. series of subsequent tasks that will combine the hazard information with community vulnerability to determine the risks and cost of flooding, leading to the identification of viable risk mitigation strategies (planning and/or infrastructure changes) – the comprehensive **Floodplain Management Study**.

Each of these work elements is expected to require up to 3.5 years to complete, and must be conducted mainly in sequence. Across this timeframe, extensive ongoing community and stakeholder consultation is proposed that will be informed by the progressive release of the technical study results, such as flood risk maps and the identification of viable mitigation options.

With an overall project duration of potentially up to 7 years from initial investigation through to final implementation of completed Council floodplain management plans, this process will be similar to but within the current typical 10 year cycle for revision of Local Government Planning Schemes.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.2 and the other assumptions and qualifications contained throughout the Report.

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1. Introduction

The Brisbane River and its associated tributaries represent one of the most complex fluvial systems in Australia. Rising in the Great Dividing Range and fed by some of the highest rainfall areas in Queensland outside of the tropics, it shares its floodplain with two major cities – Brisbane and Ipswich – often with devastating consequences. Although the Somerset and Wivenhoe Dams provide essential flood mitigation in addition to their water security role, the Brisbane River, the Bremer River and other smaller tributaries remain significant contributors to flood risk in this region. Coupled with the impact of several major creeks that traverse urban areas, the high runoff from the built landscape and the tidal connectivity directly influenced by Moreton Bay storm surge, this river system presents with significant complexity. Considering the great vulnerability of many of the urban areas that were settled in times past and the subsequent pressure to intensify development in marginal low-lying areas, this has formed the dangerous cocktail of social and economic disruption and tragic loss of life that, in modern times at least, was witnessed in 1974 and again in 2011.

While there have been many investigations over the past 50 years into the potential hazard of flooding within the Brisbane River catchment, none have been sufficiently resourced to provide a comprehensive and complete understanding of the full range of possible damaging flood events in terms of their magnitude, frequency and duration. Until this is done, from source to sea, the river's response will remain elusive and unpredictable in both the emergency and planning context. This uncertainty will also be exacerbated for future generations with the potential for changing climate conditions – especially the possibility of increased extreme rainfall rates and the impact of a projected slowly rising sea level.

While enhanced real-time mitigation of flooding will have an important part to play in reducing the substantial impacts of flood disasters, long term planning is of paramount importance to managing the risk of the inevitable extremes of nature. To enable informed decision making, the benefit of proposed adaptation strategies must be able to be considered relative to their cost and, most importantly, needs to consider the full range of hazard magnitudes up to the Probable Maximum Flood (PMF) – not simply the commonly adopted but somewhat arbitrary 100 year Average Return Period (Q100) (or 1% AEP – Annual Exceedance Probability). An over-reliance on necessarily simplified risk metrics in the past has unfortunately fostered community and policy complacency in this regard.

An adequately resourced, well-scoped and comprehensive investigation is therefore needed to provide a high standard technical basis to underpin the identification of a comprehensive range of options to best minimise the human, economic, social and environmental cost of flood impacts in the future. A whole of community commitment will then enable responsible cost-effective and environmentally sustainable development of the Cities of Brisbane and Ipswich and their adjacent regional and rural floodplain areas.

1.1 Purpose of this Report

This report forms a part of the *Queensland Government response to the Queensland Floods Commission of Inquiry* (QFCI 2011a, 2012; Queensland Government 2012). For reference, Appendix A provides an extract/summary of the QFCI recommendations that are specific to this task and Appendix B provides the Terms of Reference for this study. The approach and content of the proposed studies are also derived in part from the earlier project planning review (GHD 2012a). The acronym applied to the target activities arising from that review and continued here is BRCFS – the Brisbane River Catchment Floodplain Studies.

Mindful of the social and political imperative, the substance and intent of the many QFCI recommendations and the technical challenges implicit in this task, this report provides a methodology framework that should, with adequate resourcing, lead to the successful implementation of the requisite studies to the very high standard required to significantly advance understanding and management of the Brisbane River catchment flood risks.

The purpose of the Framework is therefore to set out a process of technical enquiry, identification of knowledge, data, evaluation of options and actions that will lead to the timely and successful implementation of a variety of study outcomes. In combination, these are designed to better understand, plan for and avoid the ongoing and future risk of damaging effects of floods on people and property within the Brisbane River catchment and its extensive urban floodplain, for generations to come. The process advocated is fully risk-based, comprehensive in scope and necessarily innovative to meet the identified and peer-agreed complexity of the Brisbane River system (e.g. QFCI 2011b,c and Joint Flood Taskforce 2011). The resulting key guidance and recommendations have then been embodied into a series of draft technical Scopes of Work that are provided separate from this report.

The Framework addresses, inter alia:

- A description of the context of flooding problems associated with the Brisbane River catchment and associated rivers and tributaries;
- A brief history of regional flood events and their impacts, as well as potential future impacts;
- A review of national and international best practice approaches and guidelines;
- Identification of the many jurisdictional overlaps, stakeholder organisations and intellectual resources available to address the problems;
- Recognition of the principal climate drivers that dictate flood frequency and intensity on a range of space and time scales; namely annual, inter-annual, decadal, inter-decadal and also the potential implications of climate change in the longer term context;
- The need to collate many data sources, assess their quality, consistency and relevance to addressing future study needs, and the identification of gaps in data;
- A review of the technical approaches and resources available to address the study objectives and the identification of methodology gaps requiring targeted research offering both immediate and future long-term value to the various stakeholders;
- A high-level work plan, schedule and draft Scopes of Work for the detailed technical and non-technical studies (e.g. flood hazards, hydrology, hydraulics, risk assessment, floodplain management, communication and stakeholder consultation) that should collectively and consistently build to form the basis of a comprehensive flood modelling and risk assessment system;
- A resulting system model capable of informing decision makers as to (1) the present levels of risk in all its complexity, (2) the options that are now available to reduce risk and (3) to be the enabling tool for ongoing future risk-reduction planning (strategic and emergency).

The process followed in constructing the Framework has been one of:

- Engagement and consultation with stakeholders leading to the discovery of relevant resources (data, models, techniques);
- Consultation with a range of technical specialists (government, consultant, research) having the knowledge and experience needed to deliver the targeted outcomes;

- Peer review and transparency in development of the recommended investigation programme options.

1.2 Assumptions and Limitations

The scope of this document was limited by:

- The amount of time provided to undertake the study; and
- The documentation provided or able to be sourced within the time available;

It is also noted that:

- GHD was not engaged to undertake a review of the existing governance structure of the Brisbane River Catchment Flood Study or to recommend governance arrangements other than those intrinsic to the successful conduct of a specific study. Any description herein of high level governance is GHD's interpretation of the existing or proposed governance arrangements;
- GHD was not engaged to undertake a review of the proposed budgets to undertake the Brisbane River Catchment Flood Study and was not advised that a budget constraint applied in regard to the need for recommending "best practice" approaches. However, pragmatic and achievable approaches have been proposed;
- GHD was not provided with any specific details of the related Seqwater hydrologic studies that were still underway (e.g. consultant work plans, peer review reports or interim results) and was reliant on personal communications from Seqwater officers as to the likely content of the final study outcomes.

2. Assessing Flooding Risks

2.1 The Flood Risk Assessment Process

Floods result from extremes of rainfall (rate, concentration and/or duration) across the natural landscape that produce an excess of runoff into watercourses significantly that is above the average conditions experienced on, say, an annual basis. These extremes of rainfall result from the occurrence of specifically severe weather systems interacting with the natural topography in such a way as to typically concentrate their effects through a variety of spatial and temporal characteristics. The causative severe weather systems are naturally associated with low pressures and high winds that will also generate a storm surge response over and above the expected tidal variation at a coastline. For coastal rivers, this oceanic response will propagate upstream into a river system and act to potentially increase the severity of flooding, especially in the lower reaches. The relative timing of the rainfall and the storm tide (tide plus surge) effects, the topology of the river system and the integrated response of the catchment to each impulse, then determines the actual impact of these rainfall and ocean interactions. In addition to this natural extreme climatic variability, projected long term climate change effects should also be considered.

In order to understand the risk of flooding one must seek to understand the many complex physical processes that lead to the flood response and the statistical nature of those interactions. Where a river system has structural mitigation by way of a dam, the design and operation of the dam is an additional parameter needing to be considered. Following adequate understanding, one can then reliably assess the risks of flooding by way of considering the vulnerability to communities, infrastructure and the environment. This permits the development of appropriate plans for tactical (emergency) responses in conjunction with strategic (planning) responses. Figure 2-1 summarises this conceptual process, which forms the basis of the development of the methodologies recommended in this study.

2.2 Floodplain Fundamentals

A floodplain can be broadly defined as an area of land adjacent to a river, stream, lake or watercourse, or a coastal flat that is subject to inundation from time to time. Floodplains are the “high flow condition” portions of a river or creek, whereas what is typically referred to as “the river” - the more obvious bed and banks - is the “low flow condition” portion.

While floodplains are often desirable places to live, it must be recognised that these areas also form part of the ecological health of a marine/riverine/lacustrine system. Their natural function is to store and convey floodwaters and sediment rich in nutrients that is a food store for the natural ecology of a riverine system. Flooding is inevitable on floodplains and cannot be entirely prevented. Use of floodplains can, however, be managed to limit the impact on the environment and the community. Floodplains should only be developed and used in an environmentally, economically and socially sustainable manner, and land use must have regard not only for their inherent environmental functions and integrity of their wetlands, but also for their hydraulic functions in conveying and storing floodwaters.

Flood-prone (or flood-liable) land is identified nationally as land inundated by the *Probable Maximum Flood* (PMF), defined as the largest flood that could conceivably occur at a particular location (ARMCANZ 2000, GHD 2011). While by definition the PMF cannot be exceeded, for practical purposes it is typically estimated to represent a probability of exceedance somewhere between 1 in 10,000 and 1 in 10,000,000 years on average – i.e. very rare yet possible events. Generally, it is not physically or economically possible to provide general protection against the full range of floods to the PMF event. Traditionally in Queensland, floodplain management has adopted the extent and levels of flooding corresponding to the 100-year *Average Recurrence Interval* (ARI)[1] or the 1% *Annual Exceedance Probability* (AEP) flood, as the nominal *Designated Flood Event* (DFE)[2] for planning purposes, although lower flood levels (i.e. greater than 1% AEP) are believed to have been adopted in the past for some areas. In Queensland flood planning policy, the DFE is the magnitude of flood event adopted in a specific part of the floodplain as the design standard for flood protection. The difference between the PMF and the DFE flood event is then deemed the compromise between the level of protection the community is willing to pay and the assumed risk the community might be prepared to accept when floods greater in magnitude than the DFE event occur. This is conceptually illustrated in Figure 2-2 below.

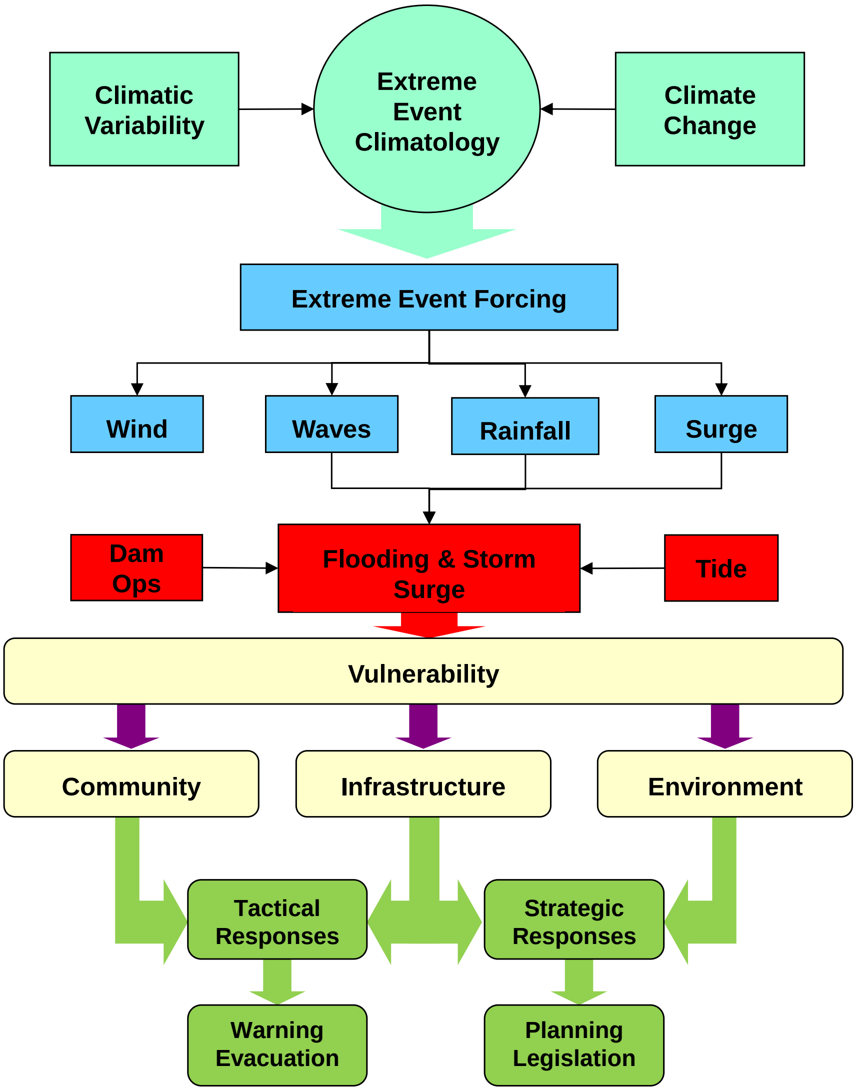

Figure 2-1 The flood risk assessment process for coastal rivers (after Harper 2001)

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[1] Also interchangeable with the *Average Return Period* or "Return Period" (refer Section 2.4)
[2] Also often termed the *Defined* Flood Event

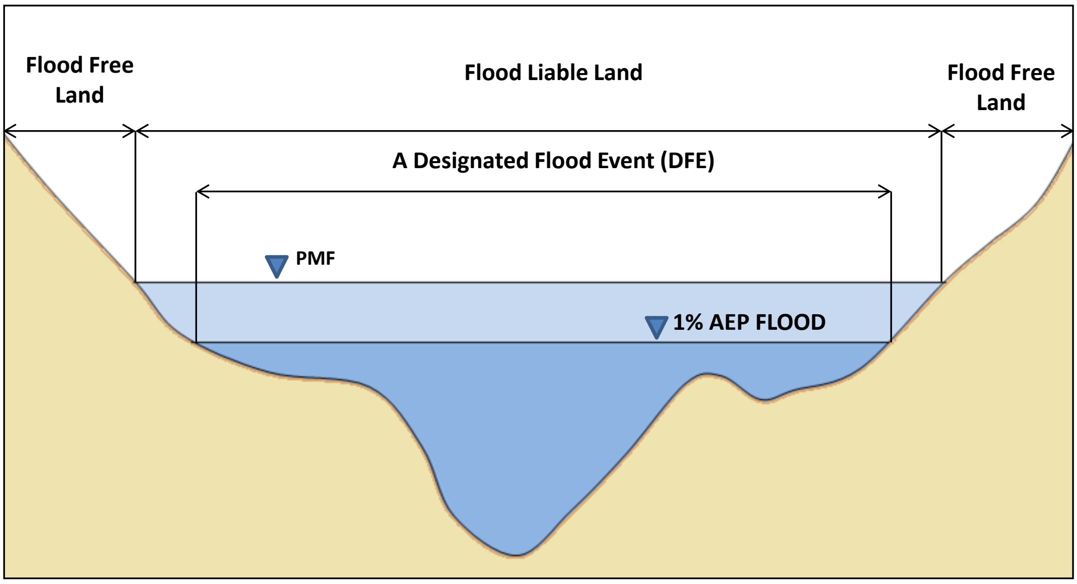

Figure 2-2 Conceptual classification of flood-liable and flood-free land

In seeking to reduce private and public losses resulting from floods, the social and economic benefits of floodplain occupation and the particular environmental attributes of flood-prone land must be recognised and balanced against the costs of the occupation of that land. Philosophically this is a rational approach to risk management but one that can only be successful where the full scale of potential losses and risk is known by a community, and where the tolerance level of the affected community is determined and hopefully agreed. The experience in Brisbane from the application of the nominal 1% AEP as the DFE, without including consideration of the full flood risk profile, would indicate that this is neither an affordable nor an accepted level of protection. A *Floodplain Management Study* (FMS) should therefore be used to determine the most appropriate level of risk for a specific situation.

River systems are of course the result of evolution of the natural landscape over millions of years (refer Section 3.3) and their topology reflects the complexity of the processes that form and continually re-shape them, even on human time scales. One of the more fundamental concepts of floodplain risk is the typical inter-relationship between flood level and floodplain extent, illustrated below in Figure 2-3. The upper reaches of a river system (region 3 below) are generally comprised of steeper and narrower streams, such that not only does the terrain increase in height but the slope of the flood risk line (flood level vs. probability of exceedance) is steepest. In the lowest reaches (region 1 below) it is generally the flattest, conceptually becoming horizontal when entering the sea (if ignoring the ocean water level variation). Conversely the extent of flooding, or area, is typically greatest in the lower reaches where the slope of the flood level probability curve is least. This is the area typically possessing the greatest vulnerability because of the historical settling and human development of rivers and their floodplains along the coastal margins, and inland areas where floodplains have afforded arable land.

This natural interplay adds to the difficulty of explaining flood risks to different segments of a community located along the length of a single river system. Often the quoting of flood heights at one single location has little relevance for other locations and, due to the variability in rainfall and runoff distribution and the hydraulic characteristics of the river, the highest experienced flood levels at different sites are not always caused by the same flood events.

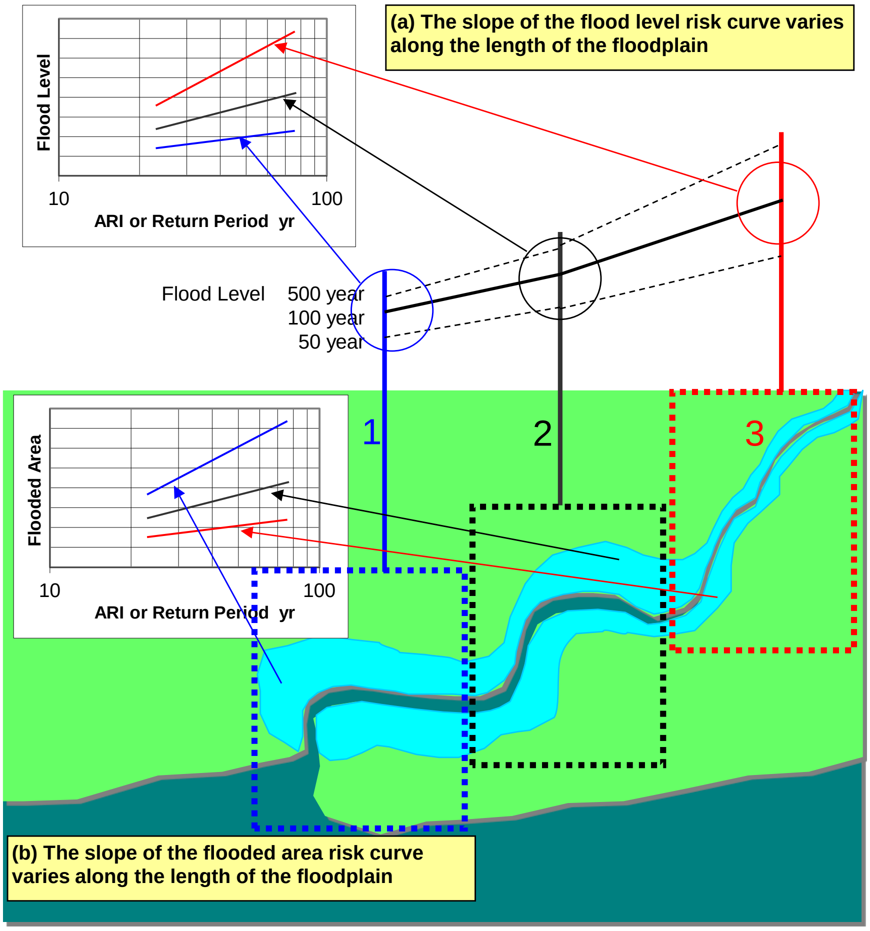

Figure 2-3 Flood level versus floodplain extent

2.3 Risk Analysis and Management

The management of a hazardous natural phenomenon such as flooding involves balancing the relative costs and benefits of using the floodplain. By applying risk management techniques together with an appropriately detailed understanding of the full range of flood behaviour, robust long term management decisions regarding the floodplain can be made with some confidence.

The correct application of risk management principles is critical to the success of the floodplain management process. This looks at how often floods (the hazard) will occur, the consequences of floods of a range of magnitudes, the vulnerability of the community and its resilience to recover from flood events. It then seeks answers through management measures such as reducing the likelihood or reducing the consequences of flooding.

Risk is the measure of something happening that will have an impact and it is measured in terms of *likelihood exposure* and *consequences*, whereby:

- Risk *likelihood* is the probability of an event occurring; and
- Risk *exposure* arises from the possibility of economic, financial or social loss or gain, physical damage or injury or delay.
- Risk *consequences* are the impacts from the event occurring;

Risk analysis is the systematic process of identifying the critical hazards, and analysis of risks associated with particular hazards, by estimating their likelihood and evaluating potential consequences. Risk management is the set of activities concerned with dealing with the potential risks by devising and implementing responses that address the likelihood and or consequence of identified risks. In the context of floodplain management this involves management of risks associated with natural and built assets and activities on the floodplain so as to ensure optimal use of the floodplain (considering economic, social, environmental and cultural impacts) whilst controlling flood losses to an *acceptable* level. It is also important to understand and manage the risks associated with the impact floodplain development may have on floodplain function and on the physical characteristics of flood. That is, development and flood protection in one location can exacerbate flood risks in another.

A risk management process involves four interrelated activities:

- Establishing the context of how risk management will be applied to flooding;
- Identification of the risk to be managed (flood) and the area requiring investigation;
- Analysis of the risk resulting from the hazard and the vulnerability, and
- Risk management (or treatment) seeks ways to mitigate the risk.

The floodplain management process, described in this Framework (Section 8.4), is a particular example of risk management approaches and is developed in accordance with the guidelines set out in ISO (2009), as illustrated below.

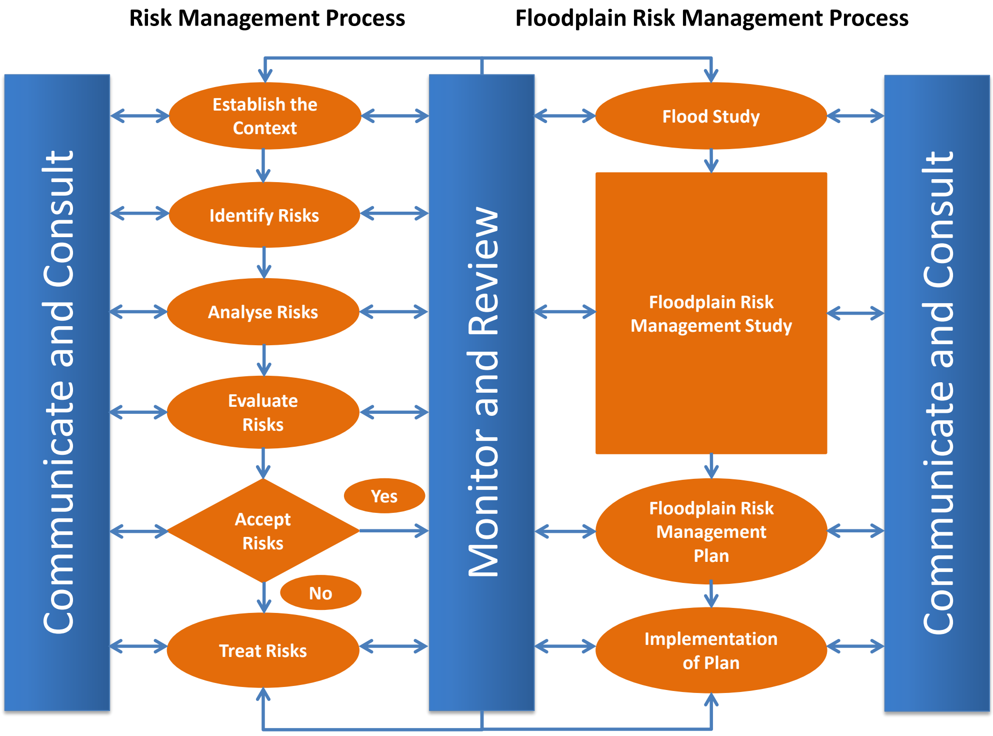

Figure 2-4 The risk management process applied to floodplain management (anonymous)

2.4 Event Exceedance Probability

This study variously discusses hazards and levels of risk in terms of the so-called Return Period (or Average Recurrence Interval ARI) having units of years, or the (average) Annual Exceedance Probability (AEP) which is the chance of at least one event in any given year. The AEP is approximately the reciprocal of the ARI, expressed as a percentage.

The Average Return Period (or ARI) is the *average* number of years between successive events of the same or greater magnitude. For example, if the estimated 100-year ARI flood level is 3.0 m AHD then, over a very long period of time, a 3.0 m AHD[3] level flood or greater will be expected to occur on average once each 100 year period. In actuality, such a flood level will

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[3] AHD is Australian Height Datum

occur sometimes more frequently or sometimes less frequently than 100 years. It follows that it is highly unlikely that a flood of *exactly* 3 m will ever occur.

It is also important to note that in any “N”-year period, the “N”-year ARI event has a 64% chance of being equalled or exceeded. This means that the example 3.0 m flood level has a better-than-even chance of being exceeded by the end of any 100-year period. Also, if the 100-year event (i.e. an exceedance of the 100-year ARI flood level) were to occur, then there is still a finite possibility that it could occur again soon, even in the same year, or that the 1000-year event could occur, for example, next year. Clearly if such multiple events continue unchecked then the basis for the estimate of, say, the 100-year event might then need to be questioned, but statistically this type of behaviour can be expected.

A more consistent way of considering the above (Harper 2012) is to include the concepts of “exposure period” and “encounter probability” which, when linked with the return period, provide better insight into the problem and can better assist management risk decision making. These various elements are linked by the following formula (Borgman 1963):

$$T = - N / \ln [1 - p]$$

where p = encounter probability within the exposure period 0 to 1

N = the design life or planning horizon (years)

T = the average return period or ARI (years)

This equation describes the complete continuum of probability when considering the prospect of at least one event of interest occurring. More complex equations describe other possibilities such as the risk of only two events in a given period or only one event occurring.

Figure 2-5 illustrates the above equation graphically. It presents the variation in probability of at least one event occurring (the encounter probability) versus the period of time considered (the exposure period, planning horizon or design life). The intersection of any of these chosen variables leads to a particular ARI and a selection of common ARI values is indicated. For example, this shows that the 100-year ARI event has a 40% chance of being equalled or exceeded in any 50 year period. This seems more likely than the concept of “once each 100 years” as conveyed by, say, the “Q100” concept. Indeed it indicates that if you occupied a property at this particular flood elevation for your adult lifetime, then it is almost “50-50” that you will experience that flood and its impacts.

The level of risk acceptable in any situation is necessarily a conscious management decision. For example, accepting a 5% chance of occurrence in a design life of 50 years means that the 1000-year ARI event should be considered. A similar level of risk is represented by a 1% chance in 10 years. By comparison, the 100-year ARI is equivalent to about a 10% chance in 10 years. AS1170.2 (Standards Australia 2012), for example, dictates a 10% chance in 50 years criteria or the 500-year ARI as the minimum risk level for wind speed loadings on engineered structures.

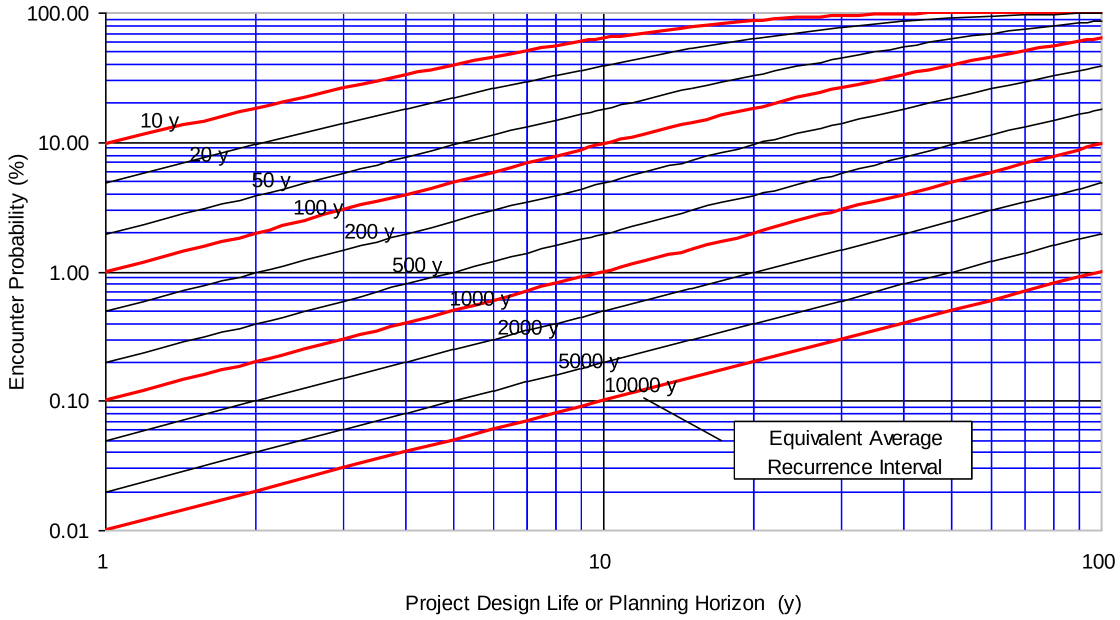

Figure 2-5 Relationship between encounter probability, planning horizon and average recurrence interval (after Harper 2012)

2.5 Types of Uncertainty

Flooding events (or flood *hazards*) result from typically natural processes within a range of variability that can be estimated by a variety of techniques, each of which contain uncertainty in their estimates. It is important to recognise that uncertainty in such analyses results from:

- The variability due to the random temporal and spatial fluctuations of natural (stochastic) processes – the *natural uncertainty*, and
- The uncertainty with regard to data and measurements – the *data uncertainty*, and
- The imperfect representation of natural processes by assumptions, analyses and models – the *model uncertainty*.

It is important that all types of uncertainty are addressed and tracked in order to understand the overall reliability of the study outcomes (e.g. Melching et al. 1990, Vreugdenhil 2005, Merz and Thieken 2009, Lerat et al. 2012).

2.6 Best Practice Approaches

To the extent possible, a survey and discovery of relevant “best practice” approaches for estimating and managing flood risks has been undertaken and the essential elements of those approaches have been considered in formulating later recommendations. This extends to a non-exhaustive examination of international approaches to gauge relevance for Australian needs. It is important to note that there are many dimensions to this complex multi-disciplinary field of investigation, ranging from data collection, statistical analysis, hydrologic and hydraulic estimating methods, numerical model design and construction, mapping, stakeholder consultation, economics, disaster response and policy. In this brief overview we present a summary of some of the more significant and generally accepted approaches that have developed over many decades, as well as those developing methodologies designed to advance progress in this field.

2.6.1 Australian Practice

The national guideline document for the estimation of design flood characteristics in Australia is *Australian Rainfall and Runoff* (AR&R), published by the professional engineering body Engineers Australia[4] and derived mainly from volunteer effort by membership of its National Committee on Water Engineering. The original publication dates from 1958, with significant updates in 1977 and 1987 and a minor update in 1999. The principle reference is Pilgrim (1987) but there is an active revision process currently underway that has had the benefit of COAG[5]-endorsed funding from the Department of Climate Change and Energy Efficiency under the National Adaptation Framework for Climate Change. The current revision process includes 24 research projects[6], which have been designed to fill the many knowledge gaps that have arisen since the 1987 edition. The research projects commenced in 2009 and presently extend to 2015. Some of the outcomes of those already completed are referenced in subsequent sections. Project 19, for example, addressing climate change issues, is not due for completion until 2015. Accordingly the present Brisbane River studies cannot necessarily rely on the availability of many of the planned AR&R updates.

AR&R has focused principally on the analysis and estimation of flood events from the perspective of hydrological science and engineering hydraulics. Separately, exemplified by work done by Smith and Greenaway (1988), was the identified need to assess potential flood damages as a basis for mitigation action. It was the first edition of the NSW Floodplain Management Manual in 1986 where the growing issue of risk assessment and floodplain management and planning policy was similarly addressed. Much later but more generally, this was targeted by a coordinated Federal and State government initiative often referred to as the “SCARM” report (ARMCANZ 1998)[7], this being the acronym for the *Standing Committee on Agriculture and Resource Management*. The catalyst for this initiative, as is often the case, was the occurrence of several significant floods and failure of some levee systems. This landmark document consolidated a number of other State initiatives and research activities and drew on overseas experiences at the time. Importantly, it sought general consistency with whole of risk cycle management as set out in the then Australian and New Zealand risk management standard, ASNZ4360, and introduced concepts of floodplain assets and costs, emergency planning and safety, integrated planning needs, defined flood event concepts and residual risk, damage assessment, mapping, liability, and funding. It also addressed the linkages between coastal river systems and adjacent ocean systems. Many State government policies and guidelines rely on the SCARM report as the broader basis for their recommendations, as does this present study, because of its essential advocacy of a comprehensive risk-based approach. It does not however specifically consider ecological and/or resource management issues except as they relate to the human occupation of the floodplain.

Around this time (1992 – 2005) there was also increased attention to the environmental value of catchments and the Cooperative Research Centre for Catchment Hydrology[8] undertook a wide range of studies, with the CRC-FORGE methodology (i.e. DNRM 2003) for extreme rainfall estimation being a significant contribution to the practice of flood studies.

In the wake of the SCARM report, the State of Victoria undertook a process of floodplain management policy reform which established policy and procedures for State wide consistency in floodplain risk assessment and management processes. That reform initiated development of a methodology for floodplain damage assessment and management options comparison (DNRE

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[4] http://www.ncwe.org.au/arr/index.html and http://www.engineersaustralia.org.au/about-us/role-and-activities and http://www.engineersaustralia.org.au/water-engineering

[5] Council of Australian Governments; http://www.coag.gov.au/

[6] http://www.ncwe.org.au/arr/Website_links/ARR_General_Flyer.pdf

[7] http://www.publish.csiro.au/Books/download.cfm?ID=2260

[8] http://www.catchment.crc.org.au/ (now as http://www.ewater.com.au/)

2000)[9] which became known simply as the “Rapid Assessment Method” (RAM). The Victorian RAM has become a widely-used analytical approach in Australia. More recently Victoria has also released specific guidelines for coastal catchment management (DSE 2012)[10]. In New South Wales, the Floodplain Management Manual was updated in 2001 and re-released as the Floodplain Development Manual (NSWFDM) in 2005 (DIPNR 2005)[11]. This document is now widely regarded as the reference standard for floodplain risk management guidance in Australia. However, while it provides a robust investigation and policy framework, it does not prescribe specific approaches and SCARM, AR&R, RAM and other methodologies are essential adjuncts to any practical implementation.

In Queensland, the 1992 initiative to develop the Urban Drainage Manual provided a detailed manual for urban hydraulic design that, when later updated (DNRW 2007)[12] acknowledged the concept of integrated catchment modelling and ecologically sustainable development, but did not represent a floodplain management standard. Following the RAM approach, Queensland also developed flood damage estimation guidelines (DNRE 2002)[13]. In the policy context, State Planning Policy 1/03 provides high level guidance (Queensland Government 2003).

The National Flood Risk Advisory Group (NFRAG)[14] additionally provides a national focus for addressing flood management issues, especially in regard to emergency management needs. Since 2005 it has prepared a number of high-level guidelines and, with its wide membership, provides a forum and advocacy for flood-related issues.

Emergency Management Australia is also a source of relevant material regarding flooding, with the UN-sponsored *International Decade for Natural Disaster Reduction* (1990-2000) being a specific catalyst for preparation of a range of emergency response guidelines.

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[9] http://www.water.vic.gov.au/__data/assets/pdf_file/0019/15265/RAM-Report.pdf
[10] http://www.vcc.vic.gov.au/assets/media/files/Guidelines_for_Coastal_CMAs.pdf
[11] http://www.environment.nsw.gov.au/floodplains/manual.htm
[12] http://www.derm.qld.gov.au/water/regulation/drainagemanual.html
[13] http://www.derm.qld.gov.au/water/regulation/pdf/guidelines/flood_risk_management/tangible_flood_damages.pdf
[14] http://www.ga.gov.au/hazards/governance/national-committees-hazards/national-flood-risk-advisory-group.html

2.6.2 International Approaches and Initiatives

United Kingdom (UK)

A series of damaging flood events during the 1990s in the UK, in concert with growing concerns over projected climate change, instigated a large number of flood-related projects. Only some of the more recent studies and guidance are briefly discussed.

Among the earlier studies was MAFF (2000), which offers valuable generic risk assessment advice and analysis techniques within a flooding and coastal defence context. Subsequently, then as DEFRA, a national appraisal of assets at risk from flooding and coastal erosion was undertaken in 2000 and then updated to include climate change effects (DEFRA 2001). This addressed a variety of adaptation options. Following further devastating flooding in England in 2007, this work was summarised for policy makers by the Environment Agency (EA 2009) and built on the developing UK Foresight initiative (described below). Finally the current Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) Project[15] seeks to meet the EA requirements for flood risk reporting. It adopts a systems approach to develop a series of practical tools and analysis techniques to enable risk managers to deal effectively with complex flood defence systems. It includes the National Flood Risk Assessment (NAFRA) initiative, the Modelling and Decision Support Framework (MDSF) developed to support Catchment Flood Management Plans and accesses a National Flood and Coastal Defence Database (NFCDD).

A parallel development from 2002 onwards was the flood and coastal defence component of the UK Foresight Project[16], which instigated the Flood Risk Management Research Consortium (FRMRC) – a 10 year program costing £15.5M, targeted at addressing future flood risk for projected climates in 2030 and 2100. Stage 2 of the FRMC concluded in 2008 and application of the techniques developed are being disseminated internationally[17].

European Union (EU)

A major collaborative project in the EU space is FLOODsite[18], which addresses the EU Flood Directive of 2007 (6th framework) that member states will have undertaken a preliminary flood risk assessment of their river basins and associated coastal zones by 2011, and where real risks of flood damage exist, they must develop flood hazard maps and flood risk maps by 2013. Finally, by 2015 flood risk management plans must be drawn up for these zones. These plans are to include measures to reduce the probability of flooding and its potential consequences. The budget available to the FLOODsite initiative has been €14M through contributions of 37 member organisations.

The *Collaborative Research on Flood Resilience in Urban areas* (CORFU)[19] project involves 17 European and Asian institutions, funded by a grant from the European Commission (7th framework), with a total budget of €5.3M over 4 years, having commenced in 2010. The stated aim of CORFU is to enable European and Asian partners to learn from each other through joint investigation, development, implementation and dissemination of short to medium term strategies for more scientifically sound management of the consequences of urban flooding in the future. The cost-effectiveness of resilience measures and integrative and adaptable flood management plans for various scenarios will be quantified and the project will look at advanced and novel strategies for improved flood management in cities. Outcomes to date from the project are unclear, but an international conference is planned in September 2013 to disseminate its findings.

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[15] http://www.rasp-project.net/RASP_project.htm

[16] http://www.bis.gov.uk/foresight/our-work/projects/published-projects/flood-and-coastal-defence

[17] Presentations were also made at the International Flood Risk Management Symposium: Brisbane, Sept 2012.

[18] http://www.floodsite.net

[19] http://www.corfu7.eu/

The Netherlands

Separate from but related to the EU initiatives is work specifically addressing the chronic vulnerability of this low lying nation located between major European rivers (Rhine, Scheldt and the Muese) and the North Sea. Prompted by significant flood events in 1993 and 1995 (e.g. Hallie and Jorissen 1997) the Dutch Government revised its flood risk management policy in 2011, the first major change from the cost-benefit approaches developed in the 1950s and 1960s towards a more integrated risk-based approach (Jonkman et al. 2010), and one that specifically considers loss of life. This approach lends itself to regionally specific risk criteria on the basis of the vulnerability of the community, resulting in risk zones logically having different return period criteria (Figure 2-6; numbers shown are “dike ring” codes)

The revised DELTA Program plans to spend €1-1.8 billion per year up to 2100 to protect the country against high water flooding episodes as well as maintain standards of freshwater supply, and is a concerted effort by the national government, provincial authorities, municipal authorities and water boards, with input from civil society organisations and the business community. The Room for the Rivers project is another major intervention (€2B)to allow increases water discharge without increasing flood levels for some 250 km of river system.

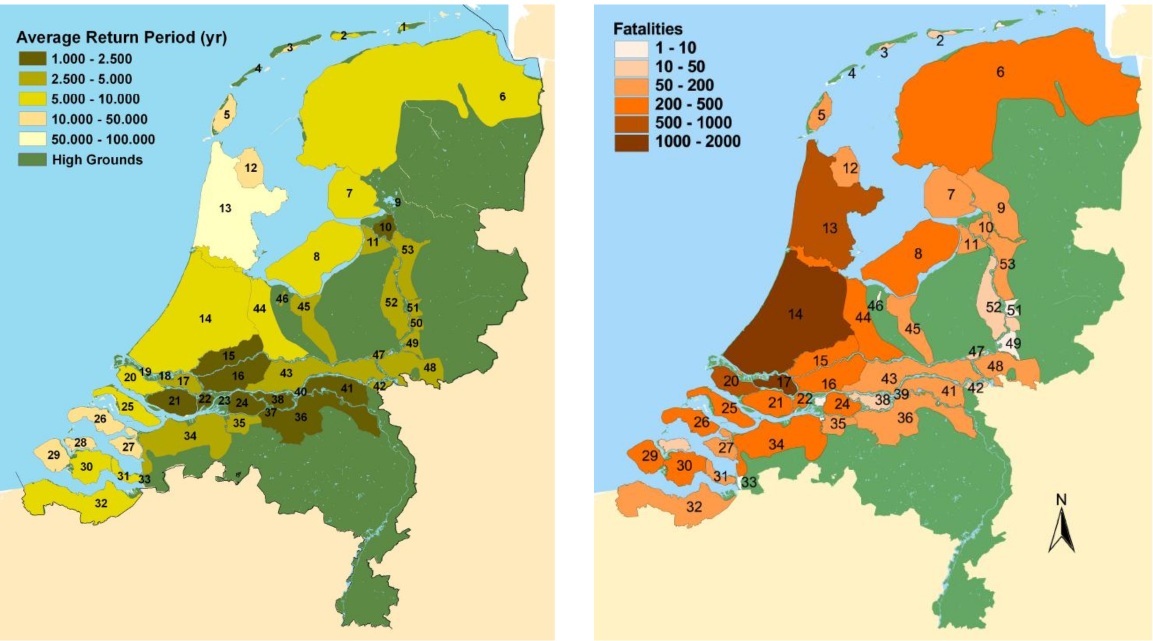

Figure 2-6 Example of flood risk assessment in The Netherlands showing risk zoning (left) relative to the estimated fatalities prevented (right) (from Jonkerman et al. §Figures 3 and 4).

United States of America (USA)

In the USA, responsibility for flood risk is spread across a wide range of organisations (refer USACE 2011) and has had a nationally legislated and under-written flood insurance program linked to mitigation actions with national risk mapping in place since 1968 (e.g. FEMA 2002, 2011). The Federal Emergency Management Authority (FEMA) developed the HAZUS all – hazards risk assessment software during the 1990s and the US Geological Survey (USGS) continues to augment its capabilities to assist risk managers. Also, the US Army Corps of Engineers plays a major role in flood planning, flood defences and dams and the Bureau of Reclamation also has a role in dam safety. Notwithstanding these efforts the USA continues to experience very significant flooding impacts from its major river systems (Mississippi and

Missouri), and especially in association with hurricane storm surge (e.g. Hurricane Katrina 2005 and Hurricane Sandy 2012).

Other

The World Meteorological Organization (WMO) Associated Programme on Flood Management and Global Water Partnership initiatives maintains a website[20] resource that provides a wide range of generic flood risk and management advice, methodologies and tools, especially relating to potential climate change issues (e.g. WMO 2009).

China has a major exposure to flood risk, as recently assessed by the Asian Development Bank (ADB 2011), particularly in association with typhoons and associated coastal risks. Likewise Japan can suffer extreme flash flooding in its maritime setting from typhoons and the National Institute for Land and Infrastructure Management (NILIM) has been conducting studies in particular on changes in flood peaks as a possible result of future climate change (USACE 2011).

Many other countries have active flood risk management programmes (e.g. Canada[21]) with a common theme being interaction with the coastal zone and the consideration of climate change (e.g. BCME 2011).

2.6.3 Comments and Conclusions

Australia clearly lacks the type and level of national investment shown by many international approaches, in spite of our own considerable flooding risks and costly ramifications. This likely reflects to a large extent our lack of a national engineering-based agency, which tend to be the main driver internationally. Without a national framework the conduct of individual studies is therefore without specific guidance on methodologies, acceptable levels of risk or community expectations.

It is clear that international efforts addressing flood risks have been much more proactive than in Australia at least since the 1990s, and that prospects of climate change triggered by a sequence of damaging events have fuelled their very significant investment, especially in Europe. Another principal difference between approaches has been the recognition internationally of the need to address coastal flooding and sea level rise in conjunction with river flooding.

As a large continent with a small population, Australia has specific challenges, but our exposure to damaging floods still easily justifies a significant investment in long-term flood risk management. Without the prolonged El Niño that persisted for a generation (refer Section 4.1.2) it is possible that the need to invest further in, for example urgent and overdue AR&R research, would have come much earlier than the present COAG initiatives allowed.

Leaving aside the high level of investment evident in international initiatives, there is no specific evidence that the detailed collective methodologies exemplified by, for example, AR&R, SCARM, RAM and the NSWFDM are any less suitable or effective in principle, given suitable resourcing. However, the growing realisation of the complexity of managing flood risks for coastal rivers with the prospect of climate change, especially rainfall climatology in the context of floods, and associated significant sea level rise well exceeds the capability of application of routine methods of analysis that have become entrenched as a result of a regime of low investment. The scope and number of AR&R research projects attempting to “raise the bar” above the routine is evidence enough of the challenges that must be met in the immediate future, especially for complex coastal river systems in urban environments. This Framework therefore seeks to apply the highest level of analysis rigour.

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[20] http://www.apfm.info/helpdesk.htm

[21] http://www.mnr.gov.on.ca/en/Business/LUEPS/2ColumnSubPage/271829.html

2.7 The Adopted Floodplain Risk Management Investigation Process

The process adopted here follows the conceptual approaches of ARMCANZ (2000) and DIPNR (2005) (*aka* SCARM and NSWFDM respectively) and in detail derives from GHD (2011). A four step process is identified as summarised in Figure 2-7:

- The top row of this figure relates to the standard risk analysis stage;
- The second row identifies the main study tasks, some of which have been scoped here in accordance with the present study Scope of Work[22]. The very significant interaction required between these tasks has been highlighted. Other tasks, such as *Implementation of a Plan* and *Monitoring and Review* involve external involvement;
- The third row provides an index into various sections of this Framework study report;
- The fourth row provides a plain language description of the activities;
- The fifth row identifies the typical skills and/or responsibilities associated with each step;
- The final row notes the typical *Stakeholder Engagement* activities.
- This figure also acknowledges that Local Government is responsible for implementation of floodplain management in Queensland (refer Section 6.3).

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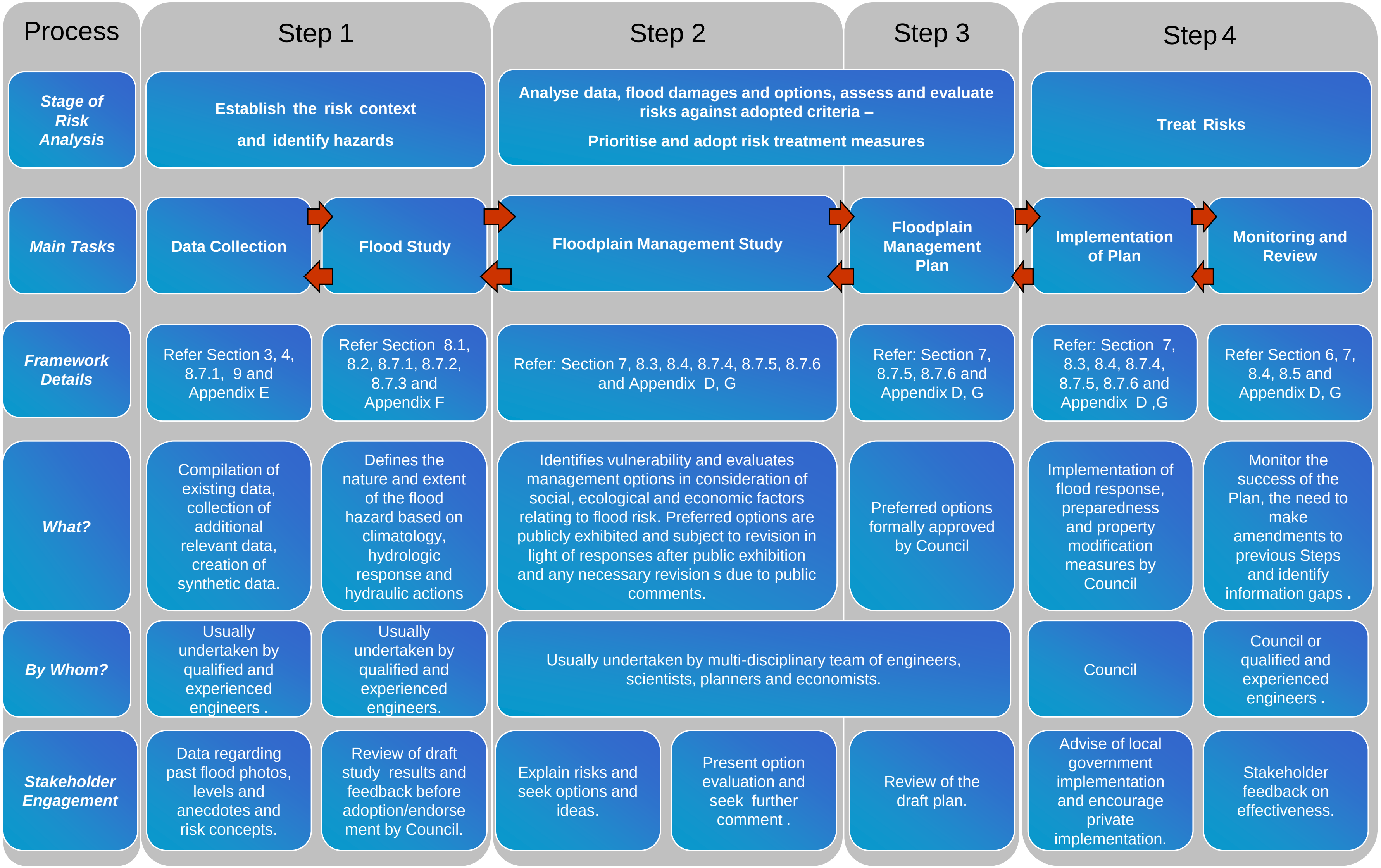
[22] A *Data Collection* activity has already been separately commissioned by DNRM (2012).



Process	Step 1		Step 2		Step 3	Step 4	
Stage of Risk Analysis	**Establish the risk context and identify hazards**		**Analyse data, flood damages and options, assess and evaluate risks against adopted criteria – Prioritise and adopt risk treatment measures**			**Treat Risks**	
Main Tasks	**Data Collection**	**Flood Study**	**Floodplain Management Study**		**Floodplain Management Plan**	**Implementation of Plan**	**Monitoring and Review**
Framework Details	Refer Section 3, 4, 8.7.1, 9 and Appendix E	Refer Section 8.1, 8.2, 8.7.1, 8.7.2, 8.7.3 and Appendix F	Refer: Section 7, 8.3, 8.4, 8.7.4, 8.7.5, 8.7.6 and Appendix D, G		Refer: Section 7, 8.7.5, 8.7.6 and Appendix D, G	Refer: Section 7, 8.3, 8.4, 8.7.4, 8.7.5, 8.7.6 and Appendix D ,G	Refer Section 6, 7, 8.4, 8.5 and Appendix D, G
What?	Compilation of existing data, collection of additional relevant data, creation of synthetic data.	Defines the nature and extent of the flood hazard based on climatology, hydrologic response and hydraulic actions	Identifies vulnerability and evaluates management options in consideration of social, ecological and economic factors relating to flood risk. Preferred options are publicly exhibited and subject to revision in light of responses after public exhibition and any necessary revision s due to public comments.		Preferred options formally approved by Council	Implementation of flood response, preparedness and property modification measures by Council	Monitor the success of the Plan, the need to make amendments to previous Steps and identify information gaps .
By Whom?	Usually undertaken by qualified and experienced engineers .	Usually undertaken by qualified and experienced engineers.	Usually undertaken by multi-disciplinary team of engineers, scientists, planners and economists.			Council	Council or qualified and experienced engineers .
Stakeholder Engagement	Data regarding past flood photos, levels and anecdotes and risk concepts.	Review of draft study results and feedback before adoption/endorsement by Council.	Explain risks and seek options and ideas.	Present option evaluation and seek further comment .	Review of the draft plan.	Advise of local government implementation and encourage private implementation.	Stakeholder feedback on effectiveness.

Figure 2-7 The adopted floodplain risk investigation process

3. The Brisbane River Catchment

3.1 Present Context

The Brisbane River basin includes a total area of approximately 13,600 km^2. Approximately one half of this total catchment area is downstream of the Wivenhoe Dam. A significant degree of residential, commercial and industrial development has occurred on the floodplain in the urban centres of Brisbane and Ipswich since European settlement.

The following overview of the basin and its principal catchments is largely from AGSO (2001, §Chapter 9) after Harper:

Detailed in Figure 3-1 the catchment is bounded to the west by the Great Dividing Range and by a number of smaller coastal ranges to the east and north. Most of the catchment comprises of forest and grazing land, with the exception of the Brisbane – Ipswich metropolitan regions and numerous small rural townships. The headwaters are at the northerly extent of the catchment bounded by the Brisbane Range. The overall length of the main stream is approximately 300 km.

The major tributaries of the Brisbane River are best summarised in terms of its principal sub-catchments, which include:

Upper Brisbane

This comprises the mainstream of the upper Brisbane River and tributary watercourses including Cooyar and Emu Creeks, which have their headwaters in the Great Dividing Range to the north-west. This area has lower average annual rainfall than the remainder of the catchment.

Stanley

This sub-catchment is formed by the Stanley River, which rises in the foothills of the Conondale and D’Aguilar Ranges to the north-east. Somerset Dam, a major water supply and flood mitigation dam, is located just upstream of the junction of the Stanley and Brisbane Rivers.

Wivenhoe

This consists of Cressbrook Creek bounded by the Great Dividing Range to the west. This catchment is dominated by Wivenhoe Dam, the largest dam in the south east, which when filled extends upstream to Somerset Dam.

Lockyer

The Lockyer Creek is bounded by the Great Dividing Range to the south and west and represents the largest of the sub-catchments of the Brisbane River. Other major tributaries include Laidley and Tenthill Creeks. The lower floodplains of the Lockyer Valley support intensive agriculture, including vegetables and small crops.

Bremer

The Bremer sub-catchment occupies 1,500 km^2 of the southernmost corner of the Brisbane River catchment and is bounded by the McPherson Ranges to the south. The Bremer River flows through the City of Ipswich and joins the Brisbane River near Moggill. Warrill Creek, the major tributary, accounts for almost two-thirds of the catchment area and joins the Bremer approximately ten kilometres upstream of Ipswich. Heavy rainfall in the Bremer-Warrill headwaters can cause major flooding of Ipswich as well as agricultural and rural areas throughout the catchment. Localised flooding in the Ipswich area can also be caused by local creek systems, including the Bundamba and Woogaroo Creeks. During heavy rainfall, these small creeks rise very quickly and can cause significant flooding in urban areas. Flooding in the Ipswich area can also occur due to backwater flooding from the Brisbane River when it is in major flood. Tidal effects from Moreton Bay are still felt at Ipswich, some 80 km from the mouth of the Brisbane River.

Lower Brisbane

This covers the catchment from the confluence with the Bremer, through to the river's mouth into Moreton Bay, refer Figure 3-2 . Much of this catchment is located within the metropolitan regions of the City of Brisbane. Flooding in the Brisbane City area can also be caused by local tributaries including Oxley and Bulimba Creeks on the south side, and Moggill and Enoggera Creeks in the western and northern suburbs. During intense rainfalls, the suburban creeks rise very quickly and can cause significant flooding of streets and houses.

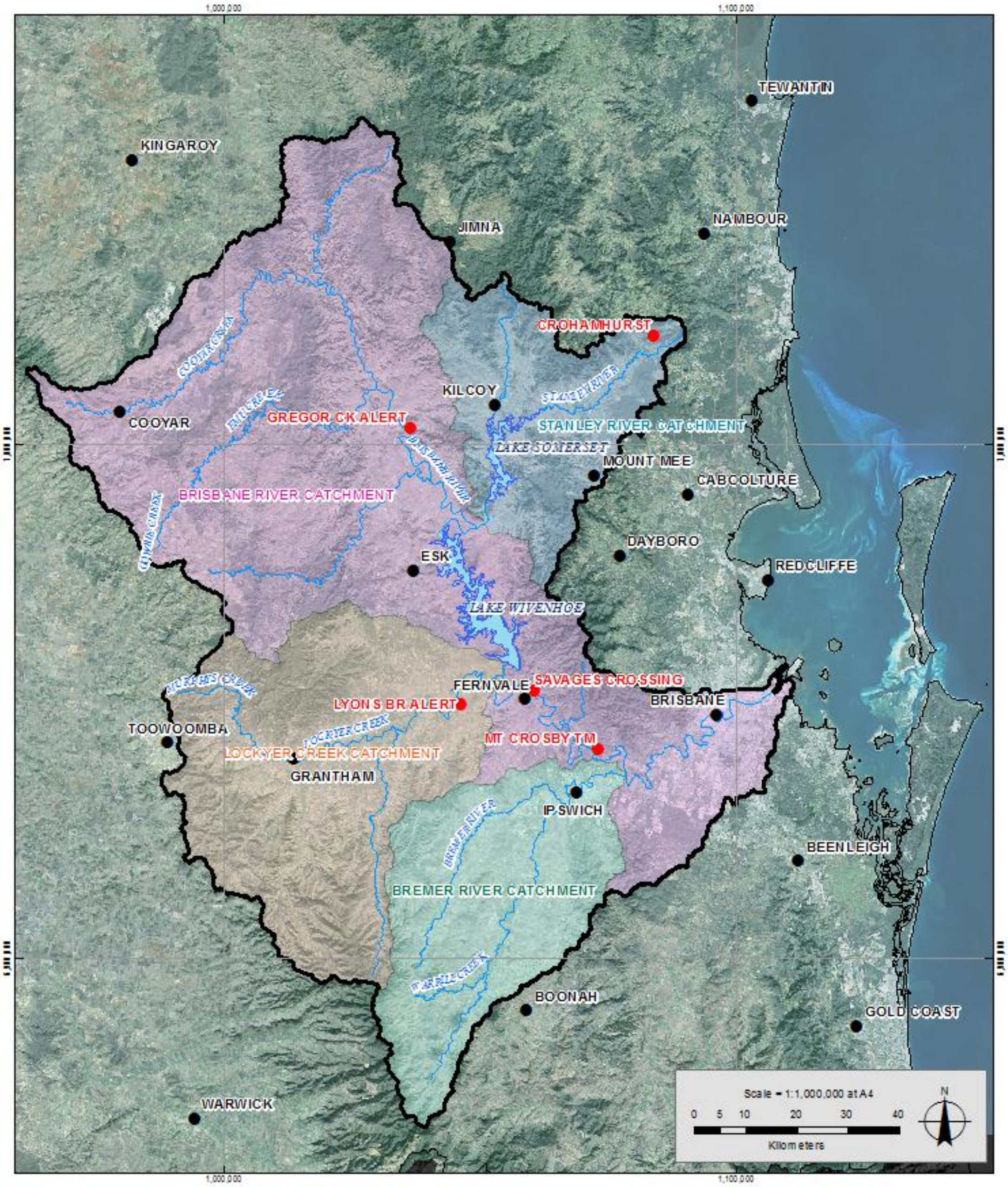


Figure 3-1 The Brisbane River basin and associated catchments

Major Brisbane Creeks

Brisbane City is traversed by many creeks, some of which cause local flash flooding problems. The following creeks flow into the Brisbane River and are usually subject to backwater effects when the Brisbane River is in flood (refer Figure 3-2).

Enoggera Creek

The headwaters of Enoggera Creek sit in the D'Aguilar Ranges near Mt Nebo. The creek flows through Brisbane Forest Park into the Enoggera Reservoir, then via The Gap, Bardon and Ashgrove. It is joined by Ithaca Creek at Kelvin Grove, which rises near Mt Cootha and passes through Bardon and Ashgrove. In the lower reaches Enoggera Creek becomes Breakfast Creek and continues on through Herston to enter the Brisbane River at Newstead.

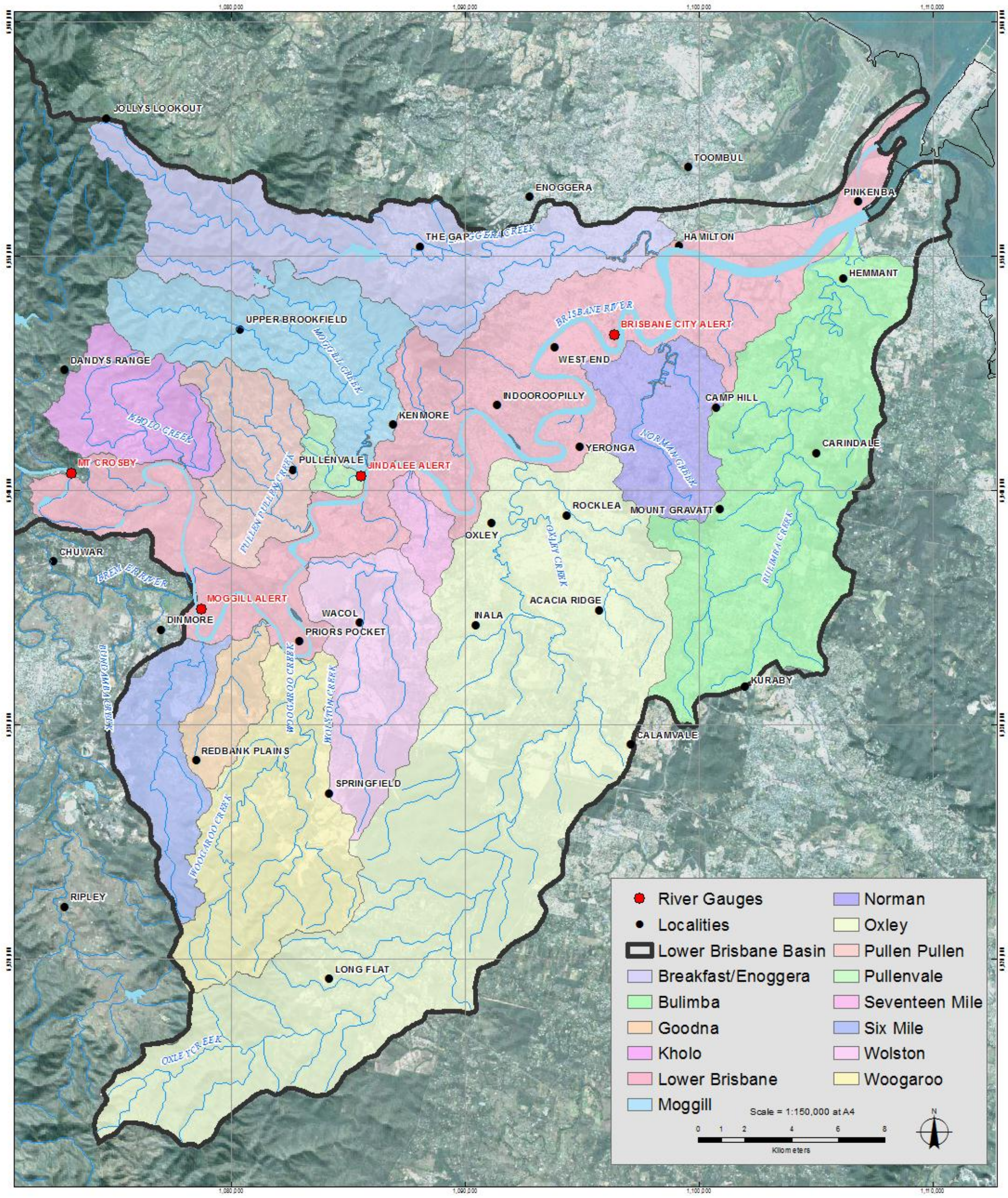


Figure 3-2 The Lower Brisbane River catchments

Moggill Creek

The headwaters of Moggill Creek are on the southern side of Mt Cootha. The creek flows through Brookfield and Kenmore and enters the Brisbane River just upstream of Jindalee Bridge.

Bulimba Creek

The headwaters of Bulimba Creek are in the Eight Mile Plains area. It flows through the suburbs of Wishart and Carindale before entering the Brisbane River near Hemmant.

Oxley Creek

Oxley Creek is the largest of the metropolitan creeks and has a relatively long flood concentration time. It rises in the area south of Greenbank Military Training Area and flows through the suburbs of Forestdale, Acacia Ridge and Rocklea. The main flooding problems are in the lower reaches around Rocklea and Corinda.

3.1.1 The Needs of a Modern City

Flooding is a world-wide and progressively more urban problem. Like many large cities, for reasons of trade, transport and amenity, Brisbane has been developed in an area historically susceptible to flooding, and as the population grows there is an increasing need to protect people, property, infrastructure and business from potential flood impacts that were unforeseen in earlier planning and policy decisions.

In addition to the potential for immediate economic damage caused by flooding, a lack of adequate protection against flooding may be harmful to future economic opportunity as the urban business area is perceived as a high-risk area for investment.

Set against this is a growing demand for access to the river’s many amenities and attractions such that there is a desire to live close to the river, which also represents the centre of commerce and entertainment.

3.1.2 Water Security

Somerset Dam and especially Wivenhoe Dam have design flood attenuation capacity, but these are secondary to their principal role of providing water security for the rapidly growing population of south-east Queensland. Any uninformed move towards increasing their flood attenuation role at the expense of lowering the full supply level and enlarging the flood compartment, will have direct negative consequences on the long term water availability for the region, especially in consideration of projected future climate change impacts, such as increased temperatures and potentially reduced total rainfall. In any case, the 2011 event confirmed that the potential flood volume from extreme flooding events may well exceed the entire capacity of the existing dams. The optimum operational balance between water supply and flood attenuation is a complex mathematical problem that can only be reliably informed by a much better understanding of the long term regional rainfall climatology, predicted demographic demands and the statistical nature of extreme flooding events.

3.1.3 Safety

Flooding is the principal cause of fatalities associated with natural hazards in Australia. Typically loss of life occurs due to conscious attempts to cross flooded roadways in rising and rapidly flowing conditions and specifically contrary to emergency agency advice. While this is directly related to poor risk choices, a reduction in the frequency of flooding through mitigation or its impacts through infrastructure improvement can act to reduce this incidence. More concerning is the loss of life associated with flash floods, as evidenced by the impact of the 2011 event in the Lockyer Creek and the associated event in Toowoomba. These are difficult to anticipate and warn with current levels of monitoring technology and forecast capability. Their fatal impacts can however also be reduced through investigation, warning-response systems, infrastructure improvements and appropriate land use. Notwithstanding this, the greatest contributor to increased safety against flood risks in south-east Queensland will come from more complete understanding of the flood hazard itself and the application of appropriate long-term planning responses that will reduce, to the extent practicable, the residual risks to acceptable community standards

3.1.4 Resilience to Hazards

A conventional emergency management view of resilience consists of four components:

- Prevention;
- Preparation (or Planning);
- Response; and
- Recovery.

This system, referred to as the PPRR system of emergency management, highlights important components of a resilience strategy but these are not necessarily sequential stages of an emergency operation.

Importantly:

- Flood prevention (or mitigation) activities can only be comprehensively, objectively and effectively defined via a floodplain management planning process.
- Flood prevention activities are aimed at reducing existing flood risk and controlling future flood risk.
- Flood preparation, response and recovery activities are targeted at managing residual risk.

Thus, while the flood emergency planning system, which forms part of the overall resilience strategy for an area, embraces the four PPRR components, prevention/planning can only be effectively undertaken via a floodplain management planning process, which is described in detail in this Framework.

3.2 Historical Flooding Overview

As a point of reference here, it is noted that the Bureau of Meteorology uses the following definitions[23] in flood warnings to reflect both the possible range of flood levels at a specific location and the vulnerability of a specific community within a river system:

- Minor flooding
  - Causes inconvenience. Low-lying areas next to watercourses are inundated which may require the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged.
- Moderate flooding
  - In addition to the above, the evacuation of some houses may be required. Main traffic routes may be covered. The area of inundation is substantial in rural areas requiring the removal of stock.
- Major flooding

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[23] http://www.bom.gov.au/water/awid/

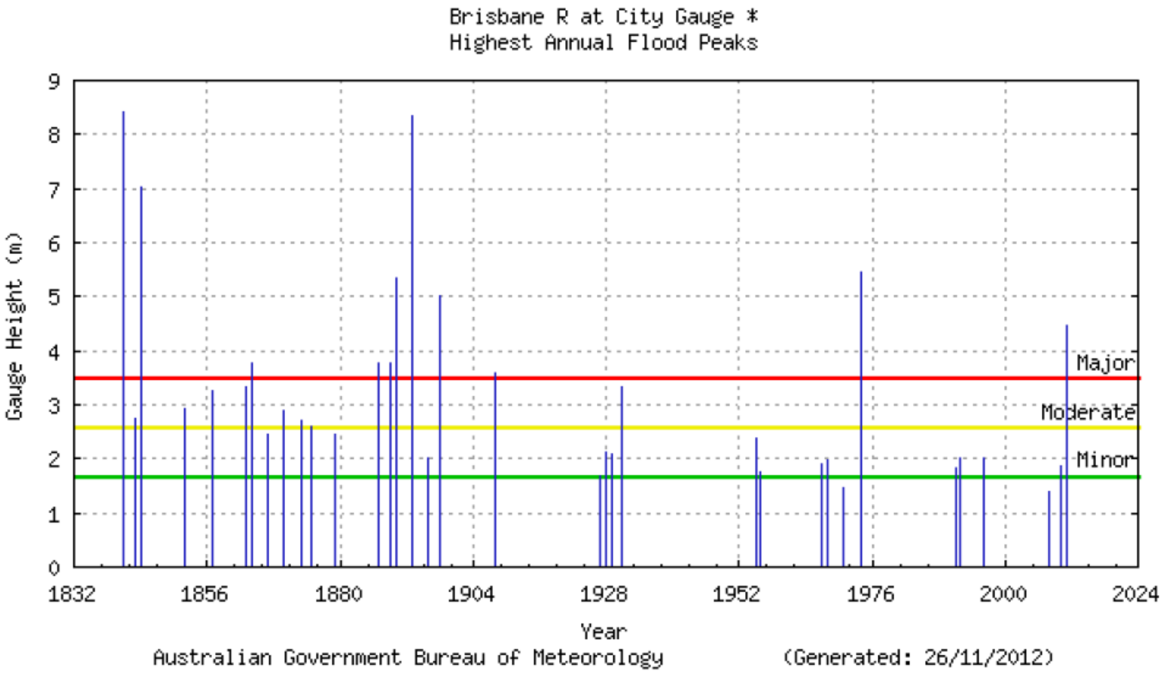
- In addition to the above, extensive rural areas and/or urban areas are inundated. Properties and towns are likely to be isolated and major traffic routes likely to be closed. Evacuation of people from flood affected areas may be required.

It should be noted that these flood classifications are qualitative assessments of the severity of flooding expected at pre-defined levels on a reference flood gauge at which a particular community becomes impacted and the levels will likely vary considerably from one community to another along the one river system. The classifications are based on flood consequences, not flood frequency. Importantly, it does not follow that a *major* flood has a low probability of occurrence – merely that there is a high vulnerability of that community for flood levels at or higher than the defined major flood level.

Data on significant flood levels for Brisbane extend back to the 1840s and at Ipswich back to 1893. The details of these historical flood events on a highest-annual basis are summarised in Figure 3-3 together with the qualitative minor, moderate and major thresholds for reference. Importantly, this is not a homogenous statistical record because of the extensive lower river changes made in the mid-1800s to mid-1900s (WMAwater 2011) that have likely affected the outflow flood characteristics. Other significant changes include the completion of Somerset Dam in 1959, and Wivenhoe Dam in 1985 (each with mitigating roles) and also development of the floodplain over time.

Nevertheless, at Brisbane, there have been 11 major floods since 1841, the highest of 8.43 m AHD at the City Gauge, but with February 1893 actually experiencing two major floods and one minor flood within about a fortnight. The two major floods were 8.35 m and 8.09 m at the City Gauge located at the lower end of Edward Street. The next highest recorded level is the 1844 flood of 7.03 m. Even allowing for the likely attenuating impacts of Somerset and Wivenhoe Dam, a possible recurrence of these events prompts sobering thoughts compared with the extensive damage in modern times caused by the lesser 1974 and 2011 events. Meanwhile, Ipswich has experienced 18 major floods in the same period, making it nominally twice as flood-prone as Brisbane. A key issue in particular for Ipswich and the western parts of Brisbane City, is the high depths of flooding that occur in larger floods, together with high velocities in some areas, and relatively short warning times in which responding agencies and residents are able to take appropriate damage-reduction activities.

The three particularly significant historical flood events that have affected the cities of Brisbane and Ipswich – in February 1893, January 1974, and January 2011 – are briefly discussed below, while Table 1 summarises the widely spatially-varying rainfall totals for these major events.



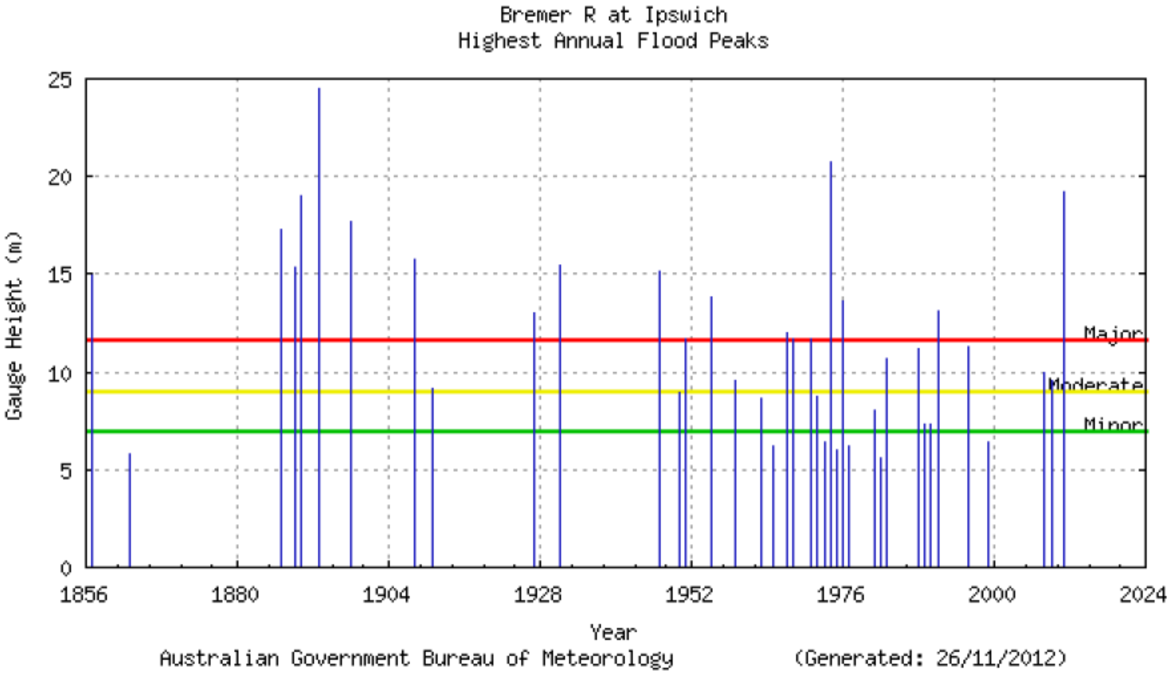


Figure 3-3 Summary of historical peak AHD flood levels in the Brisbane River at the City Gauge (top) and the Bremer River at Ipswich Gauge (bottom)

Table 1 A comparison of major flood rainfall event totals (mm) (Baddiley 2012)

Sub-catchment	Station	1893a (6 days)	1974 (6 days)	2011 (4 days)
Stanley	Crohamhurst/Peachester	2067	709	788
	Woodford	991	592	642
Upper Brisbane	Monsildale/Linville	477	208	306
	Esk	445	448	325
Lockyer	Toowoomba	251	301	239
	Helidon	284	275	262
	Laidley	270	503	215
Bremer	Franklyn Vale	225	565	346
	Ipswich	255	605	175
Lower	Enoggera	534	906	278
	Brisbane	477	650	178

*Rainfall totals in millimetres. For comparative purposes only, location may vary.

3.2.1 1893 Floods

The first of the two major flood events on 5th February 1893 damaged large parts of urban Ipswich and Brisbane, and is one of the largest events on record in terms of both total catchment rainfall, and total area inundated with flood waters. It was during this event that both the Indooroopilly Railway Bridge and the Victoria Bridge were destroyed. The flood peak at Ipswich of 23.6 m was more than 4 m higher than in the 2011 event, and close to 4 m higher also at the Brisbane City gauge. In the Jindalee area, the 1893 peak was over 5.5 m higher than experienced in 2011. The 1893 flood, of course, occurred prior to construction of the Somerset and Wivenhoe Dams in the upper Brisbane River and other channel modifications in the lower Brisbane. The cause of the flood (Callaghan 2012) can now be interpreted to have been a Tropical Cyclone that made landfall north of Yeppoon on February 1st that then facilitated the development of an East Coast Low offshore of the Sunshine Coast. This subsequently came onshore and concentrated rainfall mainly in the Stanley River catchment, although the metropolitan creeks and lower Brisbane River also received considerable falls and widespread falls continued for several weeks and subsequently produced the second major flood on the 19th. As discussed in Section 4.2, these were ideal conditions for producing extreme rainfall.

3.2.2 1974 Flood

The 1974 floods caused around $200M (1974 dollars) in damage and resulted in 14 deaths. This event was subsequent to the construction of Somerset Dam in 1956, and the associated flood attenuation mitigated the impact of flooding in Brisbane and Ipswich urban areas. Like the 2011 event, it triggered a considerable amount of research and investigation into flood hazard in the following years (refer Section 8.5) and underpinned the need for a flood mitigation capability for the subsequent Wivenhoe Dam. In stark contrast to the 1893 events, the primary characteristic of the 1974 flood was heavy rainfall and outflows in the Bremer River and Lower

Brisbane River areas, including the metropolitan creeks, rather than the Brisbane and Stanley River catchments. The meteorological background to this event is discussed in Section 4.2.

3.2.3 2011 Flood

Flooding from the January 2011 event resulted in 35 deaths in South East Queensland - in part a reflection of increased urbanisation of flood plains. Substantial damage was inflicted on services and utilities in the Brisbane metropolitan and Ipswich areas. Very heavy rainfalls were recorded in the catchment areas upstream of the Wivenhoe and Somerset dams, and in areas in the vicinity of and below Wivenhoe Dam, including in Lockyer Creek and the Bremer River system above Ipswich on an already saturated catchment. Effective operation of the Somerset and Wivenhoe dams attenuated the peak flow discharges into the lower Brisbane River, reducing flood levels and consequently damage to urban areas and infrastructure. Despite this, flood peaks recorded along the Bremer River in Ipswich City and in the Brisbane River were the highest since the 1974 flood. Ipswich recorded a flood peak of 19.25 m at the David Trumpy Bridge, and the Brisbane City gauge reached 4.46 m. Very intense rainfalls were recorded in the catchment areas upstream of the Wivenhoe and Somerset dams, set against an already saturated catchment. The lethal flash flood in the Lockyer Creek, much of which resulted from rainfall in ungauged areas, combined with higher Lockyer Creek inflows on the following day, by-passed Wivenhoe Dam (Lockyer Creek enters the Brisbane River downstream of the dam) and added significantly to the flows in the lower Brisbane, which also impacted Ipswich on the Bremer River due to the backwater effect. It is important to note, however, that the intense rainband in Lockyer Creek also extended into the Bremer River catchment, resulting in high Bremer River flows, fast river rises and flooding at Ipswich City. The meteorological background to this event is discussed in Section 4.2.

3.2.4 Summary

Figure 3-4 provides a comparison of flood level hydrographs at Brisbane, Ipswich and Gregor Creek (on the Brisbane River upstream of Wivenhoe Dam) for the 1974 and 2011 events for reference. These have been time-aligned to the peak below Wivenhoe Dam and illustrate differences in the temporal scale of the two floods, the effect of tide in the lower reaches and insight into the mitigating impact of the Wivenhoe Dam (completed in 1985) on the initial inflow peak at Gregor Creek in 2011. The 2011 flood peak in the Bremer River at Ipswich was about 1.5 m lower than in the 1974 event. At the Brisbane City gauge, the 2011 peak flood level was close to 1 m lower than in 1974, and almost 2 m lower upstream in the Moggill and Jindalee areas.

The 1893 and 2011 floods are characterised by more significant rainfall in the Upper Brisbane River and Stanley River catchments, while the 1974 flood experienced more significant rainfall in the Bremer River catchment and Brisbane metropolitan areas. Analysis of the total flood volume at the location of Wivenhoe Dam indicates that the volume in the 2011 event was almost twice that of the January 1974 event, and was likely to be similar to the 1893 flood (Seqwater 2011).

This sample of the major flood events illustrates that the hydrological and hydraulic characteristics of the contributing catchments within the Brisbane River system are very complex and known to have varied significantly between these damaging historic flood events.

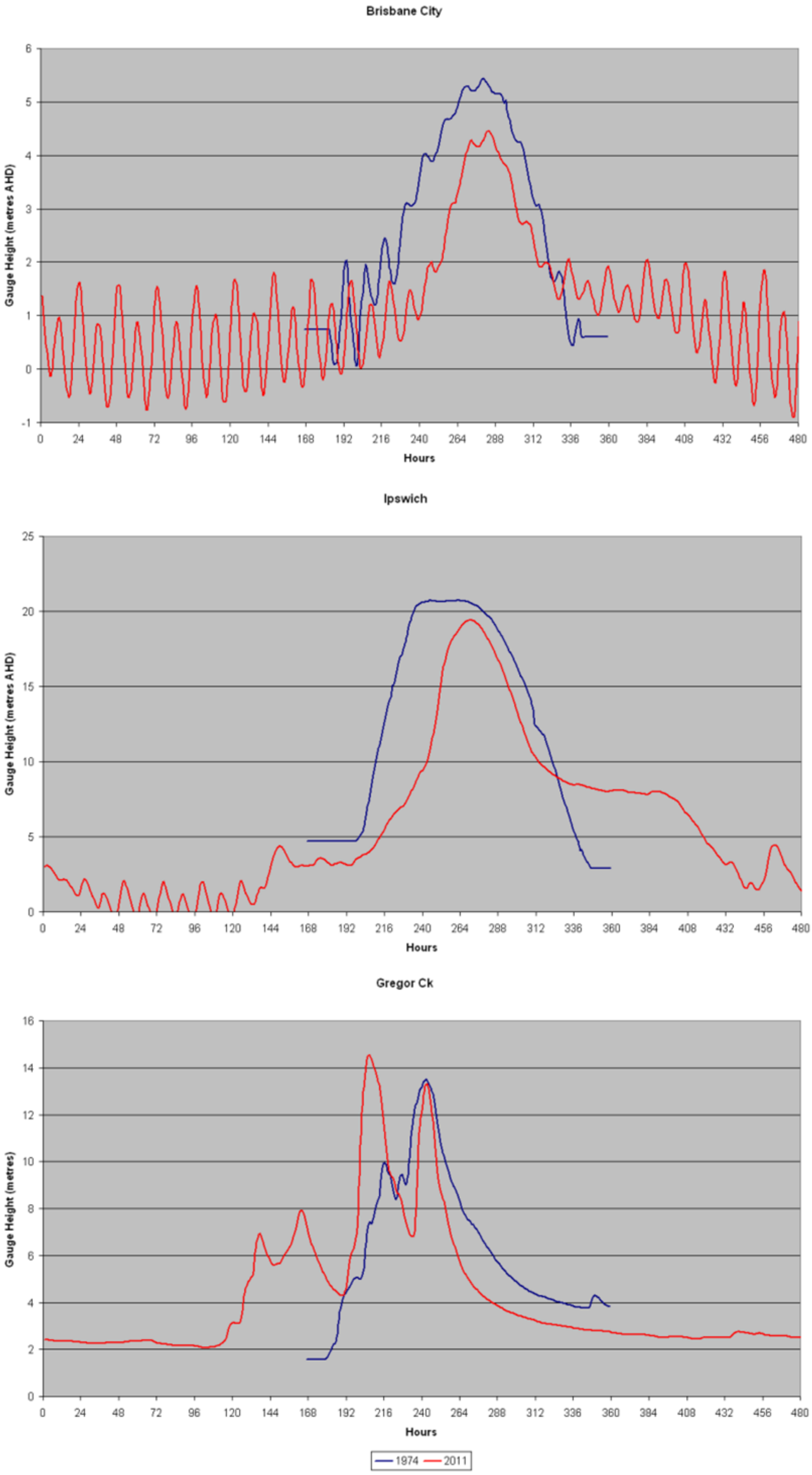


Figure 3-4 A comparison of (peak aligned) flood level hydrographs at Brisbane, Ipswich and Gregor Creek (Upper Brisbane River) for the 1974 and 2011 events (Baddiley 2012)

3.3 Geomorphological Overview

The geomorphology of the Brisbane River basin, of relevance to flooding, can be sub-divided into three main areas as follows:

- The Upper Brisbane River encompassing the catchment upstream of Wivenhoe Dam.
- The catchments of Lockyer Creek and the Bremer River, which enter the Brisbane River immediately downstream of Wivenhoe Dam.
- The Middle/Lower Brisbane River extending from Wivenhoe Dam downstream to the mouth of the river at Moreton Bay.

The following sections provide a brief summary of existing information on each of these areas, focussing on the general characteristics of each area and river responses to flood events, in particular the 2011 flood event.

3.3.1 Upper Brisbane River

The geomorphology of the Upper Brisbane River catchment is well documented in Shellburg and Brooks (2007). Major tributaries that contribute to the Upper Brisbane River include Emu Creek and Ivory Creek (including Maronghi and Anduramba Creeks), while minor tributaries include Gregors Creek, Neara Creek and Spring Creek. The Stanley River catchment joins the Brisbane River within the backwater reaches of Wivenhoe Dam.

The upper Brisbane River is structurally aligned with the Esk Trough, composed of Triassic sedimentary and volcanic rock (Caitcheon et al. 2005a,b). The trough is capped with Quaternary alluvium along river valley floodplains, older Quaternary (Pleistocene or older) alluvium on terraces, and pediment colluvium on shallow hill slopes (Brizga and Finlayson 1996; Brennan and Gardiner 2004).

Waye (1997) defined and delineated four different geomorphological units along the upper Brisbane River:

- Active channel and floodplain deposits within the “high banks”,
- Intermediate terraces generally less than 300 m wide,
- High terraces and alluvial plain some of which may date to the Pliocene, and
- Esk Basin conglomerate, sandstone and shale with andesitic and trachytic volcanics.

Shellburg and Brooks (2007) consider that the surfaces that Waye (1997) defines as ‘intermediate terraces’ might actually be contemporary floodplains according to hydrological data. This implies that the river is subject to relatively frequent large flood events capable of inundating the high level floodplains.

One of the key defining attributes of the Upper Brisbane River itself is the size of the ‘macro-channel’ which at Gregors Creek gauge has bank-full dimensions in the order of the 50 yr ARI discharge. This macro-channel exhibits a meso or low-flow channel set within benches, ledges and smaller floodplains inset within the macro-channel. Bedload is dominated by cobble, gravel and sand sediments.

Brizga and Finlayson (1996) indicated that the upper Brisbane River has been relatively stable in its planform geometry in recent times, with only localised changes in channel position (bank erosion or avulsion) over the photo record assessed (1951-1993). However, Brizga and Finlayson (1996) noted the susceptibility of the inset floodplains and benches to stripping (i.e. erosion of floodplain sediment) during large magnitude floods.

Impacts on the upper catchment arising from European settlement include forest clearing and logging, cattle grazing, agriculture, sand and gravel mining, and road building resulting in destabilising hill slopes, channel networks, stream banks and stream beds. This has resulted in a more connected and efficient channel network, which increases flow transfer and the supply of coarse and fine sediment to downstream reaches and into Wivenhoe Dam.

Based on statements of evidence supplied to the QFCI, the upper Brisbane River in the vicinity of Harlin experienced significant bank erosion and enlargement of the macro-channel in 2011 by (anecdotally) up to 100 m. Statements attributed this to the operation of Wivenhoe Dam during the event, implying that releases from the dam resulted in rapid drawdown of flood waters upstream around Harlin, causing higher flow velocities and extensive bank erosion. However, Abernethy (2011) discounts that the dam operations would have influenced flow behaviour and erosion in the Harlin section of the river with evidence that the hydrograph of the event from the Gregors Creek gauge (downstream of Harlin) rose and fell independently of the steady rise in water level experienced in Wivenhoe Reservoir during the event.

Nevertheless, other statements of evidence supplied to the QFCI indicate that the erosion experienced at Harlin during the 2011 event was unprecedented in living history despite the river being subject to similar event magnitudes in the last 50 years or so. It may be that other factors that influence immediate pre-flood channel conditions such as drought, land management and sand/gravel extraction practices in the locality have contributed to the significant erosion experienced at Harlin. Disregarding the actual causes of the erosion, the statements further suggest that the upper Brisbane River experiences flood events of similar magnitude or higher to that of the 2011 event relatively frequently.

3.3.2 Lockyer Creek/Bremer River

The catchments of Lockyer Creek and Bremer River discharge into the Brisbane River downstream of Wivenhoe Dam. These catchments drain the south-eastern portion of the Brisbane River catchment and are characterised by steep confined headwater valleys transitioning to the main creek channels which meander through a downstream expanding alluvial valley.

Thompson et. al. (2012) describe that the upper tributaries of Lockyer Creek in confined valleys were subject to extensive erosion during the 2011 flood event, with the channel expanding by up to 3 times the pre-flood width. Channel adjustments within the alluvial sections were less pronounced, which was attributed to lower stream powers in response to the downstream reduction in stream gradient and the increase in valley width allowing flows to dissipate across floodplains.

In a preliminary study of the palaeoflood record for the Lockyer valley, carbon-14 dating indicates that the Lockyer valley has experienced floods of similar magnitude to the 2011 event (Sandercock, 2012). The results indicate a flood of comparable magnitude was found to have occurred approximately 1,000 year before present. However, Sandercock (2012) stresses that a more extensive study[24] would likely yield evidence for flood events in the past 1,000 years. In addition, dating from the confined reaches subject to severe erosion during the 2011 event indicates that these systems have been catastrophically eroded in the past, with carbon 14 dates of 1,881 +/- 25 and 10,693 +/- 31 years before present obtained from boulder/debris flow deposits.

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[24] It is understood that research is currently underway into aspects of the river geomorphology by Griffith University funded by Government contributions, but no specific information was able to be sourced within the timeframe for this study.

3.3.3 Middle/Lower Brisbane

Below Wivenhoe Dam, the Brisbane River flows through a valley of variable width exhibiting partly confined and confined valley settings downstream to the tidal limit, some 90 km upstream of the mouth at Moreton Bay. Navigational dredging is purported to have increased the tidal limit from its original 16 km upstream of the mouth. This tidal limit marks the boundary between the middle Brisbane River and the estuarine, largely urbanised lower Brisbane River.

Abernethy (2011) describes that bank erosion as a result of the 2011 flood event along the middle Brisbane River varied greatly in type, largely reflecting the localised conditions at each erosion site inspected. By comparing the 2011 flood hydrograph as gauged at Mt Crosby weir with a modelled natural (i.e. no Wivenhoe Dam) hydrograph of the event, Abernethy (2011) demonstrated that the flood drawdown rates for the actual event were much slower than the rate had Wivenhoe Dam not been constructed. This would have limited slumping induced bank failures and, given the varied and localised nature of erosion, Abernethy (2011) concluded that the operation of Wivenhoe Dam during the event and the subsequent reservoir drawdown period was likely to have not exacerbated bank erosion along the middle Brisbane River.

There is limited available information on sediment transport, scour and aggradation along the middle to lower Brisbane River and how this affects flood levels. Anecdotal evidence indicates that many pools are significantly deeper than they were prior to the 2011 flood event. This indicates that the river experienced considerable bed scour during the height of the flood, with only modest redeposition of muds and sands during the waning of the flood event such that the scoured sections did not attain their pre-flood levels. Infilling of scoured sections is likely to occur through the cumulative deposition of sediments from subsequent smaller magnitude flood events and tidal sediment transport processes.

3.3.4 Flood Behaviour Implications

The Upper Brisbane River macro-channel has a high discharge conveyance capacity. This, coupled with a low co-efficient of roughness largely due to limited riparian vegetation coverage, means the main channel is an efficient conduit for flood flows, allowing flows to be transmitted to Wivenhoe Dam in greater volumes and at faster rates than potentially would have occurred in pre-European disturbance times. This is further compounded by catchment clearance and soil degradation resulting in increased hill-slope run-off rates to tributaries feeding the Brisbane River that have also evolved into more efficient flow transmission systems since European settlement.

As discussed above, tributaries of Lockyer Creek in confined upper catchment positions were subject to catastrophic erosion during the 2011 flood event, resulting in stripping of most vegetation within the valley floor and significant channel enlargement. Hence, the flow transmission capacity of these upper reaches would have increased, potentially prior to the peak of the event, resulting in higher peak discharges being transferred to the open valley floors of the middle to lower reaches. It is likely that it will take several decades for these upper catchment tributaries to return to a semblance of their pre-flood condition. As a result, in their scoured state, they will continue to be highly efficient at transmitting flows to downstream reaches.

Further, preliminary evidence suggests that the upper reaches of these tributaries have been subject to similar catastrophic erosion in the relatively very recent geologic past. Hence, there is a propensity for tributaries in confined upper catchment positions within the Brisbane River catchment to undergo catastrophic erosion during extreme events. The resultant heightened flow transmission under such conditions is likely to impact on downstream flood peaks and is worthy of consideration in hydrological modelling of extreme events.

The morphology of the middle/lower Brisbane River underwent more modest, localised adjustments during the 2011 flood event, with slumping type failures being relatively common along the middle Brisbane River. Such bank failures are generally associated as occurring during the falling limb of flood events, and therefore these adjustments would have negligible impact on peak flood levels along the middle to lower Brisbane River.

In respect to sediment transport and channel bed changes through aggradation and scour, the middle to lower Brisbane River during large flood events is likely to scour significantly. While the increased channel capacity as a result of scour could reduce flood levels locally, the increase in channel capacity is likely to be relatively insignificant in comparison with the sheer magnitude of discharges during flood events. As a result, channel bed changes during flood events are unlikely to have a significant influence on flood levels. Nevertheless, other statements of evidence supplied to the QFCI indicate that the erosion experienced at Harlin during the 2011 event was unprecedented in living history despite the river being subject to similar event magnitudes in the last 50 years or so. It may be that other factors that influence immediate pre-flood channel conditions such as drought, land management and sand/gravel extraction practices in the locality have contributed to the significant erosion experienced at Harlin. Disregarding the actual causes of the erosion, the statements further suggest that the upper Brisbane River experiences flood events of similar magnitude or higher to that of the 2011 event relatively frequently.

Additional information on sediment transport potential in the Brisbane River generally is contained in Marston (2000), Brown and Root (2001) and, with respect to the lower reaches, in Odd (1980).

4. Climatological Inputs

This section considers the essential role of climatology (on large time and space scales), meteorology and oceanography (on smaller scales) on the risk of damaging flood events in the Brisbane River catchment. These are aspects that have not been fully investigated in previous flood studies for the south-east Queensland region but must be addressed in order to fully understand the flooding behaviour.

Importantly, heavy rainfall capable of causing riverine flooding (flash and non-flash) in South East Queensland can arise from a number of different meteorological mechanisms, as described below (based on AGSO (2001) after Harper):

Severe Thunderstorms

- Isolated storms typically may cause flash flooding in relatively small catchments;
- Organised systems may extend to affect more than one catchment.

Tropical Cyclones

- Capable of causing widespread flooding across the south-east region;
- Typically heaviest rainfall is associated with coast-crossing and decaying phase;
- May interact with and draw the monsoon trough southwards creating an extensive rainfall event over the whole state (e.g. BoM 1974);
- Will be accompanied by storm surge components.

East Coast Lows

- Capable of causing widespread flooding across the south-east region (e.g. BoM 1996);
- More common in autumn and early winter;
- Establish large scale moist onshore flow conditions;
- Heavy rainfall is triggered by upper level coupling creating large scale lifting of the onshore flow;
- Will be accompanied by storm surge components.

Other

- Fronts and troughs;
- Low pressure systems;
- Coastal convergence;
- High pressure intensification in the Tasman Sea, combined with upper trough interaction.

All of these potential flood producing events are also influenced by the south east Queensland regional topography, which provides significant orographic lift to assist the creation of favourable conditions for heavy rainfall. Understanding of the detailed characteristics of these major flood producing mechanisms, including the role of scales of interaction in time and space, is essential for an understanding of the range of variability, intensity, frequency and duration of damaging flood events in the Brisbane river catchment. Aspects of this are discussed in the following sections.

4.1 Planetary Scale Interactions

4.1.1 Seasonal

The principal variability in heavy rainfall producing events is the annual seasonal cycle. This is usefully summarised simply by considering the half-yearly 90 percentile non-exceedance statistic of rainfall as shown in Figure 4-1. This highlights the very widespread nature of summer rainfall events but also the persistence of winter rainfall along the coastal fringe of south-east Queensland, which is facilitated by the topography. Thus it is still possible to experience significant flood events in the region of the Brisbane River catchment during the winter half-year.

Tropical Cyclones are typically associated with the summer monsoon trough and typically contained within the period November to April with a late-season bias, although exceptions do occur. East Coast Lows are mainly a winter half-year phenomena, but again exceptions are not uncommon. Severe Thunderstorms tend to follow the cyclone season, but with an early-season bias such that October to December are typically the most active.

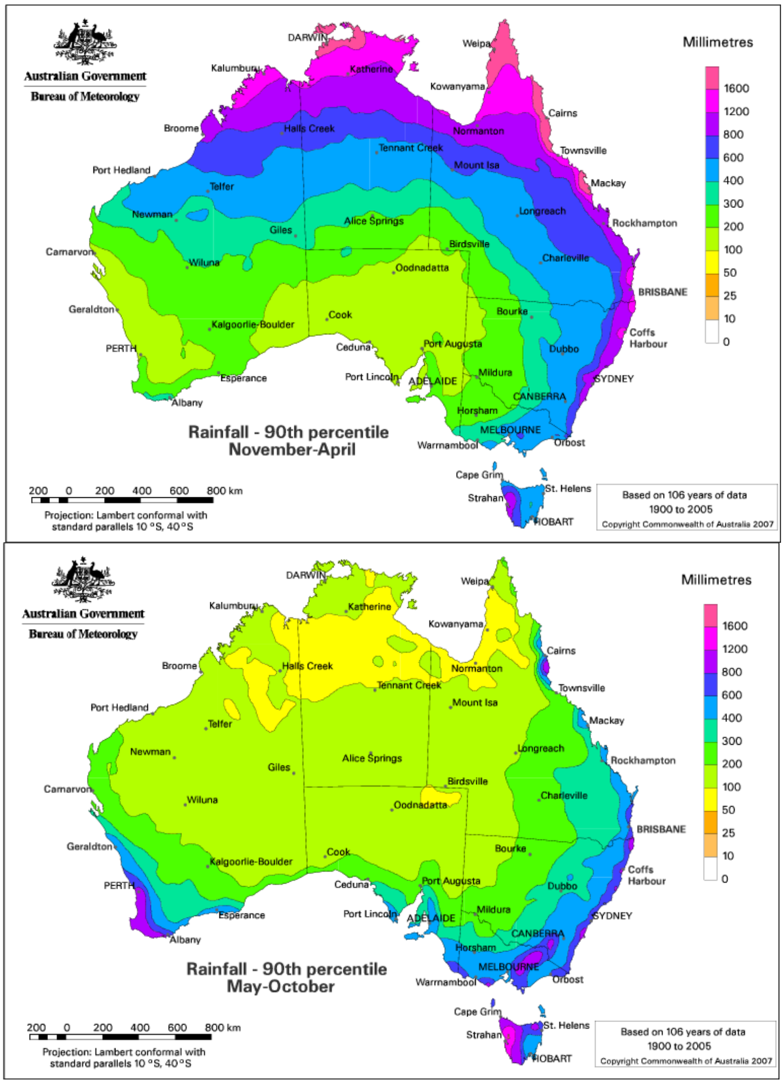

Figure 4-1 Extreme rainfall statistics for summer (top) and winter (bottom) half-years.

4.1.2 Inter-Decadal (ENSO)

The variability in Queensland east-coast rainfall totals over a 3 to 5 year span is now known to be strongly associated with the *El Niño - Southern Oscillation* (ENSO) phenomenon (e.g. Nicholls 1992, Basher and Zheng 2000). ENSO refers to a quasi-biennial oscillation of the sea surface temperatures (SST) in the eastern tropical Pacific Ocean. During a so-called El Niño period, the SST is warmer than normal in the east and rainfall and tropical cyclone activity in northern Australia tends to decrease. In the reverse situation, called La Niña, the SST in the eastern Pacific is cooler than normal and rainfall and tropical cyclone activity increases along the east coast of Australia.

The *Southern Oscillation Index* (SOI) is a measure of the strength of the ENSO episodes, derived from surface pressure data at Darwin and Tahiti. To illustrate this apparent dependency, the SOI is plotted on Figure 4-2, together with the annual frequency of occurrence of tropical cyclones within 500 km of Brisbane since 1959. Considering the 5-yr averages, it can be seen that a generally persistently negative SOI (El Niño) has been associated with a decrease in tropical cyclone occurrences over the past 20 years in this region. Since 1959 the number of El Niño - La Niña cycles is approximately equal, although the strengths have varied. This suggests that the long-term average frequency of occurrence of 0.9 tropical cyclones per season for the statistical region is reasonably reliable. However, it should be noted that ENSO fluctuations specifically alter the true likelihood of tropical cyclone risks (rainfall and storm surge) in any particular year of exposure. History shows that this variability can be of the order of a factor of 4, thus emphasising the high natural variability that can occur.

Importantly, some researchers (e.g. Power et al. 1999) suggested that the trends of the 1980s and 90s may have started reversing and that the western Pacific could enter a period of prolonged La Niña activity in the new millennia, although the following years had only mild La Niña or near neutral conditions persisting. Even 2008/09, with a persistently high SOI, was not classed as a strong La Niña due to mixed SST signals across the Pacific. However 2010/11 established itself as one of the strongest La Niña events on record, ranking amongst the top 5 since 1900, and arguably facilitating extensive and persistent flooding across much of Queensland, including the January 2011 event that severely impacted Ipswich and Brisbane, and included the occurrence of Cyclone *Yasi* in Far North Queensland.

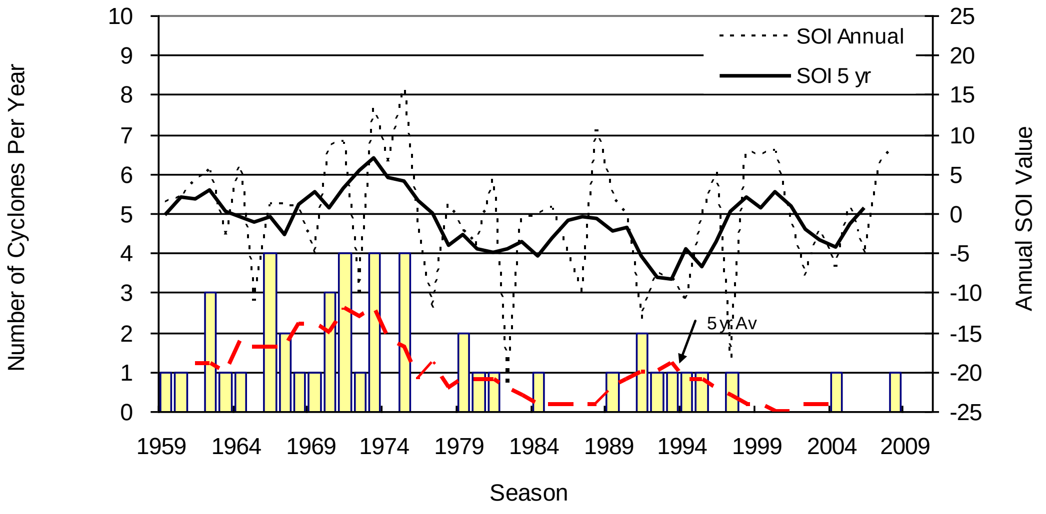

Figure 4-2 Variability in tropical cyclone occurrence and the SOI within a 500 km radius of Brisbane

While East Coast Low events have not been historically categorised as completely as tropical cyclones, evidence suggests (AGSO 2001) that the frequency of such storms affecting south-east Queensland is higher during periods of negative SOI (El Niño periods) and lower during positive SOI periods (La Niña periods). This is opposite to the observed tropical cyclone behaviour. However, the intensity appears to be higher during La Niña periods, possibly because of the enhanced trade winds and the higher SST anomaly, which both affect the rate of intensification. Likewise, Severe Thunderstorm event data suggests a pattern similar to that of East Coast Lows, although the quality of the dataset for these small scale events is impacted significantly by the demographic and observational changes over recent decades.

4.1.3 Multi-Decadal (IPO)

Power et al. (1999) was among the first to highlight the potential importance for Australian climate of an apparent 10 to 30 year longer-term cycle of ocean temperatures in the Pacific Ocean. This oscillation is also measured in terms of relative SST heating or cooling but relates more to the whole of the tropical Pacific Ocean region rather than just differences between the eastern and western limits. Termed the *Inter-decadal Pacific Oscillation* (IPO), this long-term variation in mean SST appears to further modulate the effect of ENSO on rainfall in Australia. When the IPO is “positive”, the tropical ocean is slightly warmer than average while to the north and south the temperatures are slightly less than average. During this period the effect of ENSO on rainfall appears to be less significant. When the IPO is “negative”, the tropical ocean is slightly cooler and ENSO seems to be much more strongly correlated with Australian rainfall. Figure 4-3 summarises the joint variability of the SOI and the IPO climate indices from 1876 to present.

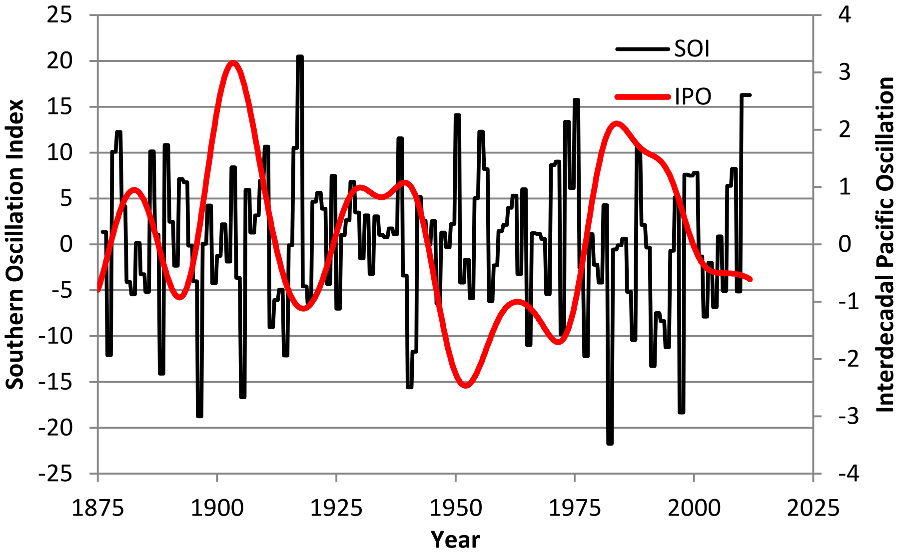

Figure 4-3 The joint variability of SOI and IPO climate indices.

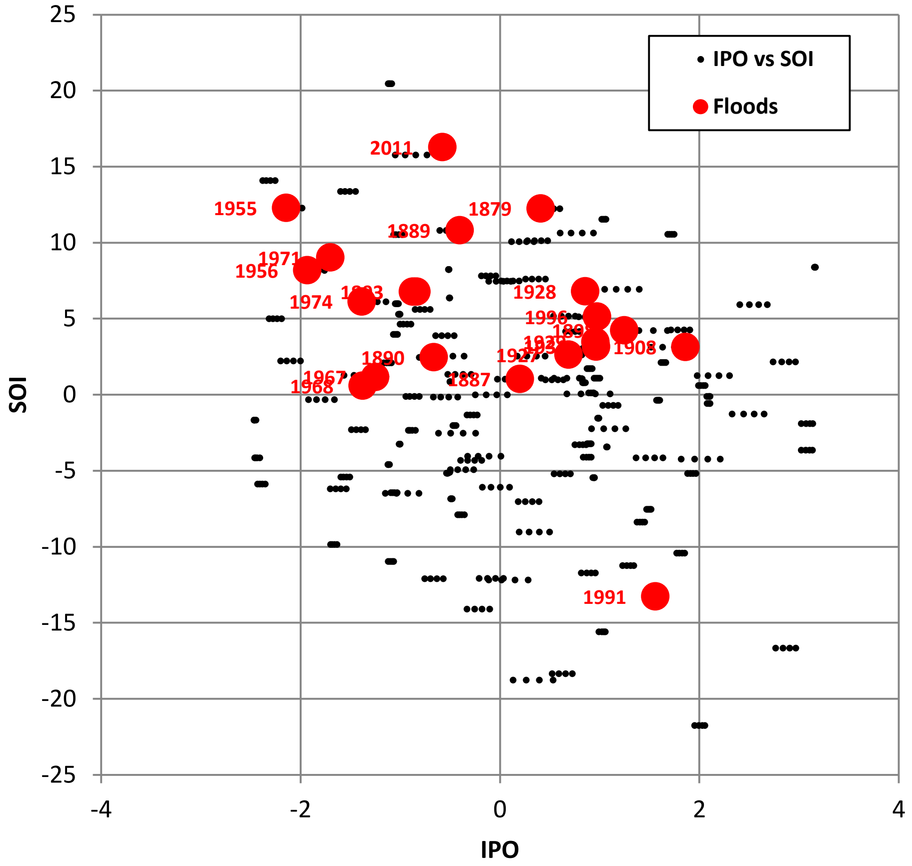

Figure 4-4 The joint SOI-IPO and significant floods in the Brisbane River

Figure 4-4 emphasises the strong relationship between these broadscale (time and space) climate indices and the occurrence of significant flooding in the Brisbane River. The 2011 event is conspicuous as being associated with the highest SOI value and the skew towards positive SOI (La Niña) and negative IPO (cool) is clear. Notwithstanding this, significant floods can still occur under apparently less favourable broadscale conditions for other reasons, as indicated by the 1991 event.

Callaghan and Power (2010) describe a possible modulating effect of the IPO on Australian tropical cyclone activity which suggests that damaging impacts in Queensland are more likely during negative (cooler) phases of the IPO, which is associated with warmer ocean temperatures near Queensland. Since the mid-1970s, there has been a prolonged positive phase of the IPO that is only now (2000-2010) showing some signs of reversal. If this is correct, it may suggest that tropical cyclone incidences along the Queensland coast could increase, especially in the south-east region. At this time there is no specific guidance available on the possible inter-decadal trends in East Coast Lows or Severe Thunderstorm events that may impact variability in significant flooding events in south-east Queensland over the coming decades.

4.1.4 Climatic Variability versus Climate Change

Over the past two decades there has been a growing awareness of the potential impacts that human-induced global climate change may have (e.g. IPCC 2007) on a variety of climate parameters. The traditional statistical analysis of historical rainfall and storm tide events for use in flood-related studies are based on an assumption that the natural environment, although highly variable, remains “statistically stationary” and that probability distributions for events such as tropical cyclones and sea level can be considered as unchanging with the passage of time.

However, the proven rise in atmospheric carbon dioxide levels and an increasing trend in mean air and sea temperatures and rising sea levels points to the likelihood of the Earth being subject to an enhanced "greenhouse" effect, which means that these statistically-stationary assumptions will be in error to some extent. Consequently, some consideration of the possible impacts of projected future climate change on modifying the extreme rainfall and storm tide experience is certainly justified. Later sections address these considerations. However, with the exception of sea level rise projections and tropical cyclones, the currently available advice at the regional level for changes in rainfall intensity or frequency is typically highly variable, reflecting the highly localised nature of these effects. Sensitivity analysis therefore remains a principal analysis tool, although as discussed later, DERM (2010a,b) and DERM (2012) already provide guidelines and recommendations for considering increased rainfall rates and sea level rise respectively.

Notwithstanding the possible long-term anthropogenic effects on climate, it is important to appreciate the broad spectrum of climate variability as a continuum and directly deal with that variability, whether gradual, cyclical or secular. For example, the IPO effect has also been considered as being related to the large-scale oceanic thermohaline circulation that exists between the oceanic depths of the Atlantic and the Pacific Ocean. This has a periodicity estimated to be of the order of 1,000 years and has been identified as a potential indicator of hurricane incidence in the Atlantic basin (Landsea et al., 1994). Various paleoclimate analyses (e.g. Nott et al. 2007) also indicate significant long term periodicity in climate parameters based on proxy geologic or geomorphic evidence.

4.2 Regional Meteorology – The Rainfall Component

Heavy rainfall-producing events in south-east Queensland that are capable of initiating a significant riverine flooding response result from specifically identifiable sets of atmospheric conditions. In addition to the high correlations with the SOI and IPO climate indices discussed earlier that provide the conducive broadscale environment, an examination of the meteorology of all known major floods in the region (Callaghan 2012) reveals the synoptic-scale interactions that are also necessary to produce the heavy rainfall episodes.

4.2.1 Large-Scale Environment (Synoptic)

The majority of heavy rainfall events were associated with winds where the direction turns anticlockwise with height above the surface up to the middle levels. This occurs when strong to gale-force onshore winds are drawn into an overland trough system extending up to at least the 500 hPa level. The typical cloud structures observed with most of these events are nimbostratus with isolated areas of cumulonimbus. This differs from the cloud associated with heavy rainfall from summer thunderstorms, which are associated with low static stability, dominated by cumulonimbus cloud and associated with all winds above 1.5 km elevation having a westerly component. The summer thunderstorm extreme rainfall events tend to be short lived, localised and produced flash flooding, whereas the heavy rainfall events associated with the turning of the wind with height typically produce more widespread rainfall resulting in river flooding.

An example of this large-scale situation is given in Figure 4-5 showing the mean sea level NCEP/NCAR[25] analysis of pressures and winds following the coast-crossing of so-called[26] Tropical Cyclone *Wanda* on 24/01/1974. When *Wanda* moved inland it became absorbed into a large overland monsoon depression, with a strong high pressure cell in the Tasman Sea forming a blocking pattern. It can be shown that the developing upper-level structure of winds during this time had the characteristics capable of producing very heavy rainfall from the large supply of heavily moisture-laden warm marine air.

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[25] http://nomad3.ncep.noaa.gov/ncep_data/index.html

[26] *Wanda* would not have been classified as a tropical cyclone under present Bureau of Meteorology criteria.

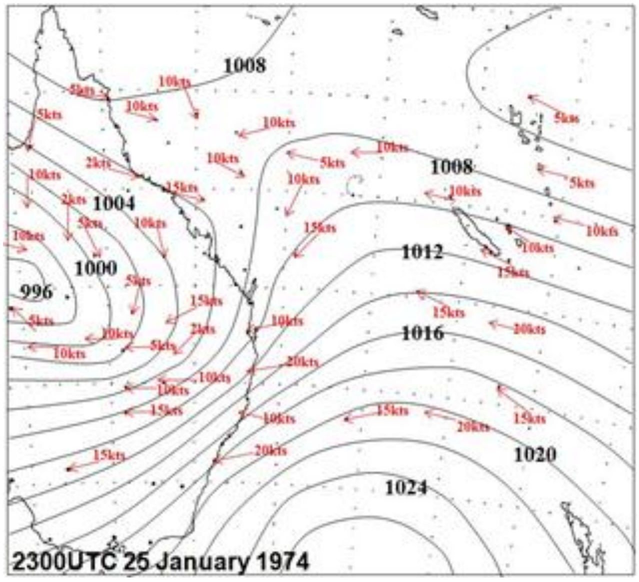

Figure 4-5 The mean sea level synoptic setting for the 1974 flood event (Callaghan 2012)

For the five day period from 9 am Thursday 24 January 1974 to 9 am Tuesday 29 January 1974 rainfall in the Brisbane metropolitan area ranged from 500 mm to 900 mm and exceeded 300 mm in all but the extreme western parts of the Brisbane River catchment area. Among the highest 5 day totals were 1318 mm at Mount Glorious, in the catchment of the middle reaches of the Brisbane River (prior to Wivenhoe Dam construction), and 819 mm near the head of Oxley Creek. Brisbane city recorded 650 mm during this period.

In the catchments of the Brisbane Metropolitan creeks heavy rain first occurred over a 12 hour period ranging from 197 mm at the City to 236 mm at Enoggera Reservoir and 280 mm at Mount Nebo. The rain then eased but returned the following day with 151 mm in the City, and 202 mm at Enoggera Reservoir. A third period of intense rainfall was then experienced over an 8 hour period when 132 mm was recorded in the City.

4.2.2 Small-Scale Environment (Mesoscale)

While the synoptic scale considers 100 to 1000 km and from 1 to 10 days, the mesoscale covers the range 10 to 100 km and the order of 6 to 24 hr. Within these scales of motion are significant coastal convergence and topographic interactions capable of producing the type of intense rainfall variability described above in terms of a series of “waves” of heavy rainfall during the 1974 flood event.

With the benefit of modern radar and numerical model analyses, the mesoscale complexity of the most recent 2011 event becomes evident, as illustrated in Figure 4-6. These images are 3 hours apart yet show significant reorganisation of the principal rainfall structures and the very intense line (or band) of thunderstorms overlaying the upper reaches of the Brisbane and Stanley Rivers that later abated but then again reformed resulting in doubly-peaked hydrographs of inflow into the dams over a 2 day period. The vast majority of rainfall from the thunderstorm band occurred over the period between 5 am and 3 pm 11 Jan 2011, giving rates of over 300 mm in 10 hours

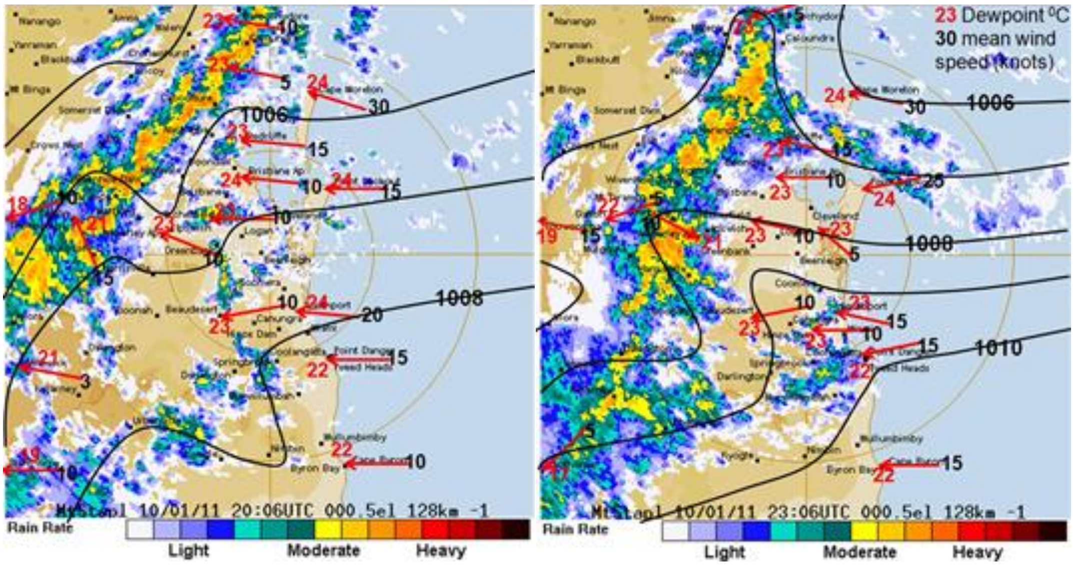

Figure 4-6 Bureau of Meteorology radar images and mean sea level analyses for 11 Jan 2011 (Callaghan 2012)

4.2.3 Micro-Scale Environment (Convective)

The so-called micro-scale is then the size and time applicable to the lifetime of individual convective storm cells of the type that may be organised collectively at the mesoscale, as discussed above. However, individual storm cells (often “supercell” type storms) are capable of initiating flash floods, as exemplified by the Toowoomba/Lockyer Creek events that were imbedded within the wider 2011 flood event. Figure 4-7 shows detailed radar images only 1 hour apart that chronicle the passage of a severe storm cell interacting with the escarpment west of Esk. It was responsible for both the Lockyer Creek and the Toowoomba flash flood events and the associated considerable loss of life, but was of such a small spatial scale that the heaviest rainfall was not recorded by any official rain gauge[27].

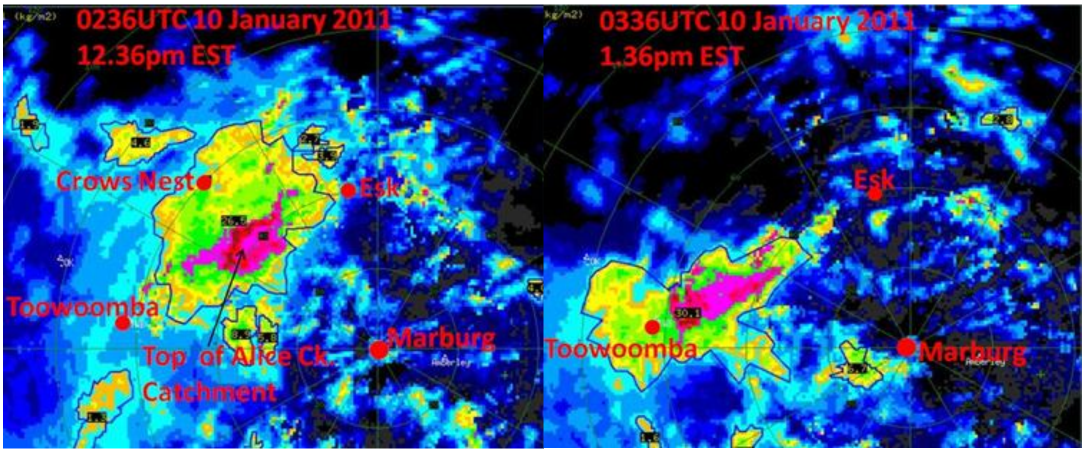

Figure 4-7 Bureau of Meteorology high resolution radar images for 10 Jan 2011 (Callaghan 2012)

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[27] One unofficial total reported was 210 mm in just over 30 minutes from a farmhouse in the headwaters of the Lockyer Creek.

4.2.4 Summary: The Importance of Scale

From the above examples it is clear that rare flood events in the Brisbane River catchment arise from complex combinations of rain-producing features having a variety of time and space scales. In isolation, each feature might not be capable of producing a major flood, but in combination they can link temporally and spatially to potentially deliver rates of rainfall that might normally be associated only with regions in the deep tropics. Table 2 below summarises the essential elements of these time and space scales typical of the Brisbane River catchment.

Table 2 Rainfall time and space scales relevant to the Brisbane River catchment (Baddiley 2012)

Scale	Duration	Length/Area	Flood response	Example	Meteorological scale
Regional: Basin-wide and larger	~1-10 days	100 - 1000 km 10,000 to greater than 1,000,000 km^2	Basin-wide rainfall producing high catchment wetness & runoff from all parts	1974 & 2011: Widespread rain over southern Qld; days to week or so of rains persisting over entire Brisbane River catchment.	Synoptic Upper/surface low pressure systems; tropical cyclones
Sub-catchments ("partial area storms")	~6 hrs – 1 day (or longer)	10 – 100 km 100 - < 10,000 km^2	High runoff from subcatchments. Often determines main peak	Tuesday 11 Jan 2011: Convective band of intense rain over Wivenhoe, Lockyer, Bremer persisting for approx 12 hours before easing quickly in-situ	Mesocale e.g. Convergence zones, mesoscale lows, convective complexes. Near stationary & non-stationary.
Headwater catchments, creeks & local areas, including in "flat areas"	0 – 6 hours	1 - >10km 10 to several hundred km^2	Flash flood	Monday 10 Jan 2011: Topographically enhanced Lockyer flash floods. Rainfall >100 mm per hour. 1974: Flash floods in Brisbane & Ipswich creeks. "Flat areas"	Mesocale Near stationary & non-stationary. Convective, possibly thunderstorm cells.

This complexity typically overwhelms considerations of characterising and analysing flood events and has traditionally necessitated a purely statistical assessment of recorded rainfall data as the basis for flood studies (refer Section 8.1). However the consideration of suitably representative spatial and temporal structures remains an essential component in advancing the accuracy of flood analyses for extreme events and developing appropriate operational and planning responses. Embedding detailed consideration of these complexities is further warranted in the case of the flood risk assessment on the Brisbane River catchment floodplains given its very high vulnerability.

4.3 Regional Oceanography – The Ocean Water Level Component

The ocean tidal influence in the Brisbane River currently penetrates some 90 km upstream of the mouth in Moreton Bay into the Bremer River and past the City of Ipswich[28], where the maximum tide range is actually amplified relative to the Bay by about 3% (MSQ 2012). The relative timing of high tides and flood peaks has a direct effect on the lower reaches of the river system but this influence reduces further upstream, especially in larger floods. However, Brisbane City floods reaching up to possibly 8 m AHD are considered to be affected by the tide (Baddiley 2012). The presence of tidal anomalies (aka *storm surges*) will essentially combine with the expected tidal signal and propagate similarly. Any further increases in mean sea level (refer Section 4.4.3) however will fully penetrate the river system and such changes will over time directly modify the statistics of extreme flood levels.

4.3.1 Astronomical Tides

Astronomical tides are the regular periodic variation in water levels due to the gravitational effects of the Moon and Sun, which can be predicted with generally very high accuracy at any point in time (past and present) if a sufficiently long period of measurements are available. The highest expected tide level at any location is termed the *Highest Astronomical Tide* (HAT) and occurs once each 18.6 year period, although at some sites tide levels similar to HAT may occur several times per year[29]. These more frequent so-called *king* tides are merely those that are collectively close to the very highest possible tides and in the Brisbane region these occur in December-January during daylight hours but also in May-June at night.

Astronomical tides in the Brisbane region are semi-diurnal, meaning that there are two high and two low tides each day. Also, there is a marked diurnal inequality, which is the sometimes significant difference between heights of consecutive high or low tides. The Standard Port for the region is the Brisbane Bar, which is located near the river mouth into Moreton Bay, and although data was first collected in 1878, the period of reliable and consistent data collected automatically is limited to post-1980. The following table summarises the established standard tidal planes at the Brisbane Bar referred to Australian Height Datum (AHD), which is close to the Mean Sea Level[30] (MSL).

Table 3 shows that the commonly experienced mean *spring* range of the tide (the average of the highest excursion each fortnight as a result of the Moon being *new* or *full*), is of the order of 1.9 m for much of the river. During the opposite lunar period of the *neaps*, the mean range is of the order of 1.1 m. However, with the highest tides in the year coinciding with the tropical cyclone season it is no surprise that both the 1974 and 2011 January flood events coincided with reasonably high tidal levels that exacerbated the impacts of flooding. The maximum possible tidal range in some parts of the river is of the order of 3 m.

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[28] The tidal prism has been modified over time as a result of dredging of the river bar and various navigational improvement works from 1864 through to 1965 (as summarised by WMAwater 2011)

[29] HAT levels are often exceeded annually due to the presence of non-astronomic storm surge.

[30] Maritime Safety Queensland presently makes small adjustments each year (0.0003 m) to reflect the influence of long-term sea level rise.

Table 3 Tidal planes at the Brisbane Bar (MSQ 2012)

Tidal Plane	Abbreviation	m AHD
Highest Astronomical Tide	HAT	1.49
Mean High Water Springs	MWHS	0.93
Mean Sea Level	MSL	0.03
Mean Low Water Springs	MLWS	-0.87
Lowest Astronomical Tide	LAT	-1.24

The tidal propagation upstream is actually amplified by the geometry of the river as it generally narrows, such that the maximum tidal range can be up to 10% higher than that at the entrance to Moreton Bay, as shown in Figure 4-8. There is also a phase lag in the time of the tide peak by about 2.5 h between the Bay and Ipswich, implying a speed of propagation of about 34 km/hr.

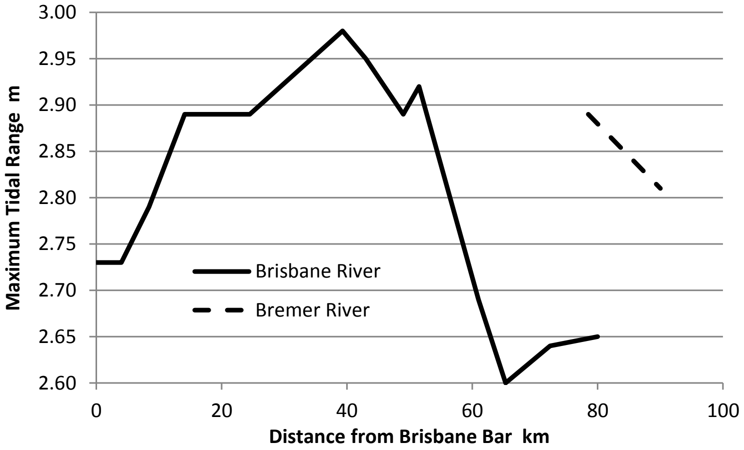

Figure 4-8 Tidal range variation along the length of the river derived from published data (MSQ 2012)

4.3.2 Storm Surge

The storm surge or *meteorological tide* is essentially the difference between the expected astronomical tide level and the actual ocean level at any time, neglecting any localised surface wave activity (so-called *sea* or *swell*). When analysing ocean water levels to extract the predictable astronomical tide signal, this water level component is also referred to as the *residual* or the tidal *anomaly*. There are many potential sources for this storm surge component, ranging from the relatively benign passage of frequent low-amplitude coastally-trapped long-waves that are not associated with the local meteorological condition. Large scale adjustments to the broadscale atmospheric pressure field such as the passage of strong high pressure systems can also cause ocean level fluctuations. The East Australian Current, formed of large warm-cored ocean gyres propagating southwards from the tropics, also contributes to oscillation in the mean levels. However the most likely significant source of storm surge will be regional severe weather events, which will almost certainly be associated with heavy rainfall.

A storm surge occurs as the combined result of the severe atmospheric pressure gradients and wind shear stress of the storm acting on the underlying ocean (Harper 2001). It manifests as a long-period “wave” capable of sustaining above-normal water levels over a number of hours or even several days. The wave travels with and ahead of the storm and may be amplified as it progresses into shallow waters or is confined by coastal features (such as Moreton Bay). Typically the length of coastline that is severely affected by a *Tropical Cyclone* storm surge is of order 100 km either side of the track although some lesser influences may extend many hundreds of kilometres. The magnitude of the surge is affected by several factors such as storm intensity, size, speed and angle of approach to the coast and the coastal bathymetry. Extra-tropical storm systems such as *East Coast Lows* may have an extended (time and space) influence but normally at a magnitude lower than that from a severe tropical cyclone. Small scale weather systems such as severe thunderstorms are incapable of generating a storm surge response, except in very localised shallow water situations.

4.3.3 Storm Tide

Because Australia generally experiences what is called a *macro-tidal* environment, where tide ranges can be very significant, it is essential that the storm surge threat always be considered in combination with the astronomical tide. The term *storm tide* (Harper 1999,2001; DERM 2012) is therefore used in Queensland to refer to the combined water level made of tide, surge and potentially wave setup, and is expressed as an absolute vertical level, preferably in AHD.

Figure 4-9 summarises the various water level components of a storm tide, which at an exposed natural beach should also consider the possible localised contribution from breaking wave setup. Wave runup is a further potential (intermittent) threat but because of its highly localised effects is not normally included in the storm tide level. In respect of ocean tailwater levels affecting the Brisbane River, only the Tide+Surge component is relevant. However, because of the shallow semi-confined waters of Moreton Bay, regional open ocean storm surge is naturally amplified during extreme events and could potentially reach magnitudes of the order of 2 m.

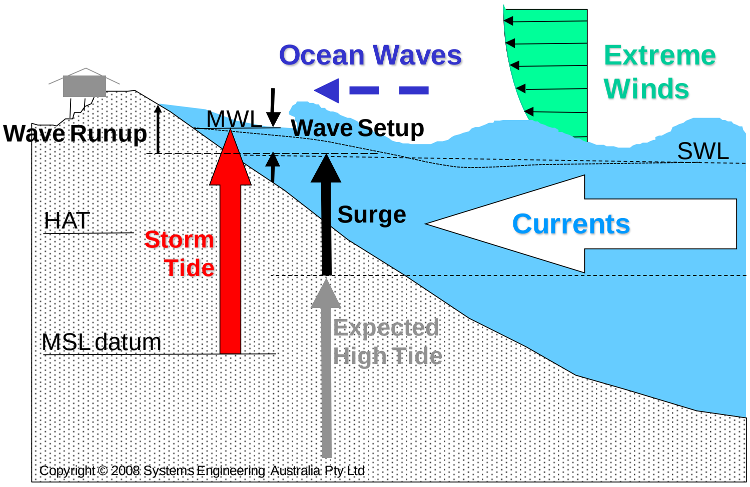

Figure 4-9 Water level components of an extreme storm tide (after Harper 2001)

As indicated by the historical data summarised in Table 4 there is a real storm tide threat in the region, even though much of the earlier data is uncertain. Notably this record also reflects the inter-decadal IPO/SOI trends discussed earlier.

4.4 Climate Linkages

4.4.1 Rainfall, Storm Tide and Flooding

In the south-east Queensland coastal region, many large scale and persistent flood-producing weather events will also likely be accompanied by an oceanic storm surge component. The relative timing of runoff, concentration, propagation of the flood wave and the dynamic downstream ocean storm tide tailwater level will then determine the degree and outcome of interaction. For example, the travel time of peak floods in the Brisbane River can vary significantly: around 30 h from Wivenhoe Dam to the City, although Ipswich is affected by flooding in the Bremer River within 6 to 12 h of the rainfall occurring (Baddiley 2012).

A reminder of this storm surge, tide and rainfall interaction occurred as a result of the effects of ex-TC *Oswald* over the Australia Day weekend during the period of preparation of this report. Persistent gale force winds created a 0.9 m storm surge anomaly that combined with the high tide and river outflows on the 28th Jan to cause moderate levels of flooding across the region.

NCWE (2012) recently proposed a methodology for assessing the extent of these linkages by directly comparing contemporaneous rainfall records and tidal anomalies at three locations - Brisbane, Mackay and Sydney. This identified the expected linkage between long duration rainfall and storm surge and also the spatial and temporal dimensions to the relationship, as summarised in Figure 4-10 for the two types of joint-probability modelling approaches used (from their §Figure 5.3 and 5.7). In these examples a “dependence parameter” of 1 indicates a direct correlation. Brisbane was noted to have the strongest dependency amongst the three sites. This study notes the importance of these types of links for coastal rivers and makes several recommendations for further research and investigation, noting that potential climate change is an associated factor.

Table 4 Selected historical storm tide events in south-east Queensland (following Harper 1999)

Date	Place	Event	Reference Central Pressure (hPa)	Storm Surge (m)	Storm Tide Level (m AHD)	Inundation Above HAT (m)
08-Jun-1891	Brisbane		?	?	1.8	0.3
19-Feb-1894	Brisbane		"cyc"	0.6	1.6	0.2
11-Feb-1915	Brisbane			0.6		
16-Jun-1928	Brisbane		?	?	1.7	0.2
05-Feb-1931	Brisbane		982	1.1	2.0	
01-Feb-1934	Brisbane		?	1.2	?	
20-Jan-1938	Brisbane		992	0.5	1.4	
25-Mar-1946	Brisbane		?	0.7		
23-Jan-1947	Brisbane		?	0.6	?	
28-Jan-1948	Brisbane		?	0.5	1.8	0.3
18-Jan-1950	Brisbane		?	0.6	1.8	0.3
25-Jan-1951	Brisbane		?	?		
21-Feb-1954	Coolangatta		973	>1?	2?	?
17-Feb-1957	Brisbane	Clara?	943?	>0.5	?	
31-Dec-1962	Brisbane		978	0.8	?	
01-Jan-1963	Brisbane	Annie	987	0.8		
29-Jan-1967	Moreton Bay	Dinah	945	2?	2.8?	1.5?
07-Feb-1974	Brisbane	Pam	965	0.7	1.9	0.4
12-Mar-1974	Caloundra	Zoe	968	1		
14-Feb-1981	Gold Coast	Cliff	985	0.7		
26-Apr-1989	Beachmere	Charlie	972	0.6	1.5	0.2
17-Mar-1993	Gold Coast	Roger	985	0.7	1.3	
28-Jan-2013	Brisbane	Oswald	995	0.9	1.8	0.2

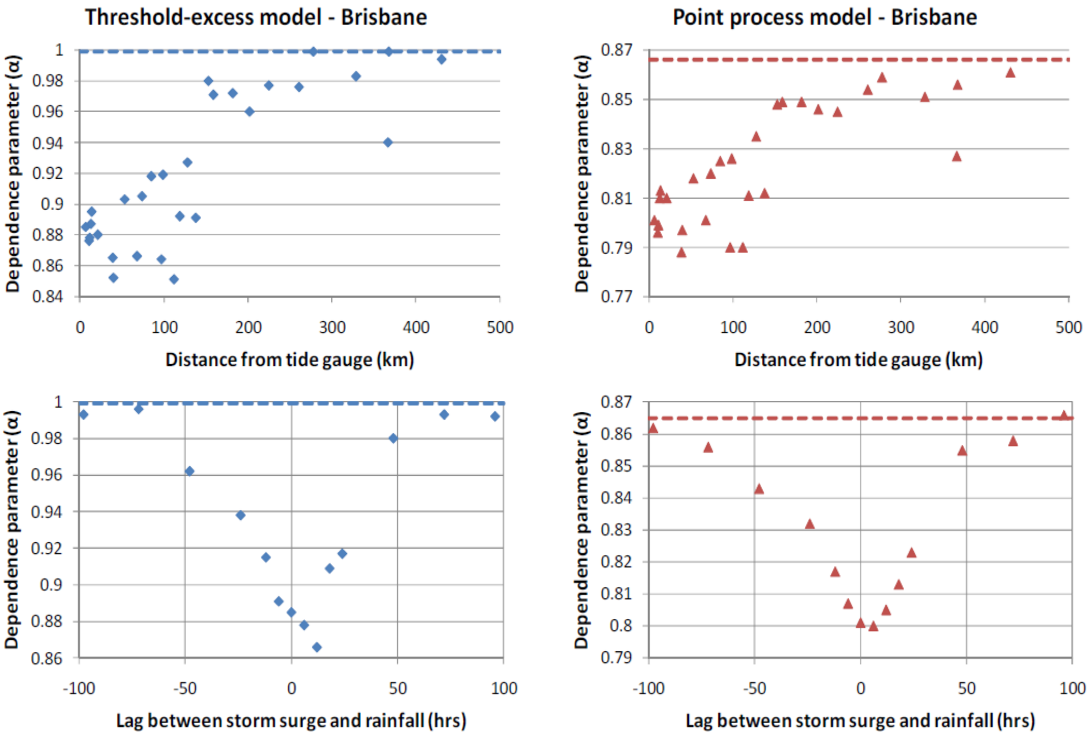

Figure 4-10 Dependence between tide gauge and rain gauge for Brisbane (NCWE 2012)

4.4.2 Potential for Increased Storm Activity or Intensity

Tropical Cyclones

(a) Potential changes in intensity

Given specifically favourable conditions, tropical cyclones can continue to intensify until they are efficiently utilising all of the available energy from the immediate atmospheric and oceanic sources. This *Maximum Potential Intensity* (MPI) is typically assumed to be a function of the climatology of regional sea surface temperature (SST) and atmospheric temperature and humidity profiles.

Although IPCC (2007) does address aspects of future tropical cyclone climatology, this area of research is advancing rapidly and the preferred reference is Knutson et al. (2010), which summarises the status of current research in this area and concludes that there is an agreed likely increase in the MPI of tropical cyclones as the mean global temperature rises of between +3% to +21% by the year 2100 (between +2% and +11% if expressed as maximum wind speed rather than central pressure deficit). The regional reference MPI pressure deficit for Brisbane under present climate conditions is estimated as of the order of 70 hPa (Holland 1997a, 1997b).

(b) Potential changes in frequency and track

Likewise, Knutson et al. (2010) report that the consensus from many advanced modelling studies is that the global frequency of tropical cyclones will actually either decrease or remain essentially unchanged. There is an expressed low confidence in some modelling studies that project changes ranging from -6 to -34% globally, and up to ±50% or more in individual basins by 2100. Regarding tracks, there is low confidence in estimates of changed areas of genesis or tracks.

(c) Potential changes in rainfall rates

As noted by Knutson et al. (2010) the theoretical expectation is that there is roughly a 7% increase in total precipitable water vapour per degree Celsius warming. They imply this to result in about a 10-14% potential increase in rainfall rate by 2100 based on current mean temperature projections for the tropics of 1.5 to 2° C.

However, Knutson et al. (2010) advise that a consensus of modelling studies indicates that tropical-cyclone-related rainfall rates are likely to increase with mean atmospheric warming of the order of 20% within 100 km of a storm centre, with a range of projections from +3% to +37%. Notwithstanding this, rainfall estimates from climate models in general and tropical cyclones in particular (model or data) tend to be very highly variable.

It should be noted that while rainfall can scale with storm intensity due to moisture convergence, it is often the size and speed of a storm that dictates the total precipitation (rainfall depth) over a specific catchment. Hence the changed potential for flooding can only be assessed with regard to these and other associated parameters such as topography. Considering the likelihood of reduced frequency of occurrence, it remains possible that the total rainfall from tropical cyclones in future climates may actually decrease and this could act to reduce the likelihood of extreme flooding.

East Coast Lows

(a) Potential changes in intensity

There is no specific advice available with respect to potential changes in the intensity of ECLs, although modelling studies have provided conflicting evidence. McInnes et al. (2007) is the most comprehensive climate change assessment available for the NSW coast and utilises outputs from a number of CSIRO climate models, focusing on two locations as indicative coastal environments. Although the study attempted to provide indications of future trends for 2030 and 2070, the results are highly variable across a range of parameters. Taking the higher estimates of change in each case, the study suggested that as a result of intensity and frequency changes the 100-year ARI average storm surge might vary within a range of ± 4% by 2070. These analyses are considered to be too variable to be regarded as reliable indicators for the south-east Queensland region. A more practical alternative could be to utilise sensitivity analyses of the principal storm climate assumption.

(b) Potential changes in rainfall

This could arguably be assumed to be typical of that expected for tropical cyclones however DERM (2010a,b) presents a recommendation derived from an assessment of various global climate models for a 5% increase in rainfall rate per degree Celsius of warming applicable to “inland flooding” considerations. Taken in conjunction with the upper-limit A1FI emissions scenario (IPCC 2007), this recommends assuming a 2° C rise by 2050, 3° C by 2070 and 4° C by 2100, yielding a rainfall rate increase of 20% by 2100. Although based on different temperature assumptions, it can be noted that this has the same magnitude as the Knutson et al. (2010) recommendation for tropical cyclones.

Severe Thunderstorms

There is no specifically practical advice available on the possible changes in intensity or frequency of these small scale systems under projected future climate conditions. However in regard to rainfall rates it is reasonable to assume changes similar to that for the broad scale systems.

4.4.3 Sea Level Rise

Global sea levels are expected to rise as a consequence of enhanced greenhouse warming of the earth (IPCC 2007). The observed rate of global average sea level rise measured by TOPEX/Poseidon satellite altimetry during the decade 1993 to 2003 was 3.1 ± 0.7 mm p.a., although there are large regional differences. This is close to the currently estimated total of 2.8 ± 0.7 mm p.a. for the following climate-related contributions, in order of decreasing contribution:

- An accelerating thermal expansion throughout the 21st century;
- The melting of glaciers;
- Retreat of the Greenland ice shelf; and
- Antarctic ice losses.

The official projections of global average sea level rise by 2100 are in the range 0.18 to 0.59 m (IPCC 2007, CSIRO 2007; 5% to 95% confidence levels for six greenhouse gas emission scenarios). These represent increases in the lower limit of about 0.1 m over the previous IPCC assessment reductions at the higher limit due to a separate consideration of ice flow uncertainties. However, making allowance for the ice flow uncertainties increases the upper limit by 2100 to levels only slightly lower than those previously adopted (e.g. NCCOE 2004 and 2012). Accordingly the sea level trends displayed in Figure 4-11 based on IPCC assessments are consistent with the recommendations of DERM (2012) of +0.5 m by 2050 and +0.8 m by 2100 for application to Queensland coastal regions (relative to 1990 levels).

The IPCC 5th Assessment Report is due for release in 2013 and the expectation is that a further small increase in the upper limit of sea level rise expectations by 2100 will be recommended (Harper, *personal communication*). Notwithstanding this there remains significant uncertainty in the projections given that some data analyses (e.g. Watson 2011) show measured trends for Australian tide gauges do not necessarily support the previously modelled projections.

Finally, although the year 2100 is normally quoted as the upper limit for consideration, it is important to note that if greenhouse gas concentrations were stabilised (even at present levels), sea level is nonetheless predicted to continue to rise for hundreds of years under the assumptions embodied in current global climate models. Although the range of uncertainty is still high, the potential impact of this on future planning in coastal regions cannot be ignored.

4.5 Conclusions

This Section has considered aspects of the climatology, meteorology and oceanography of the south-east Queensland region that are the driving the mechanisms for generating damaging floods in the Brisbane River catchment. These elements need to be considered when attempting to accurately estimate the risk of flooding across the region and to develop appropriate options for flood mitigation and planning for future sustainable development needs.

Firstly, understanding is required of the role of slowly varying climatic conditions, such as the ENSO/SOI and IPO indices that reflect the broadscale environment. Here we note that between the 1974 flood event and the 2011 event, the regional climate of south-east Queensland had been dominated by dry El Niño conditions that led to a major drought and ironically focused Government attention on water security needs. Indications are, for example, that the next 30 years may well be much wetter.

Next, the scales (time and space) of the various severe weather components (synoptic, meso and micro) must be considered, together with their range of variability in terms of frequency and intensity and how they can combine to produce extreme rainfall and associated high ocean water levels that create the flood event.

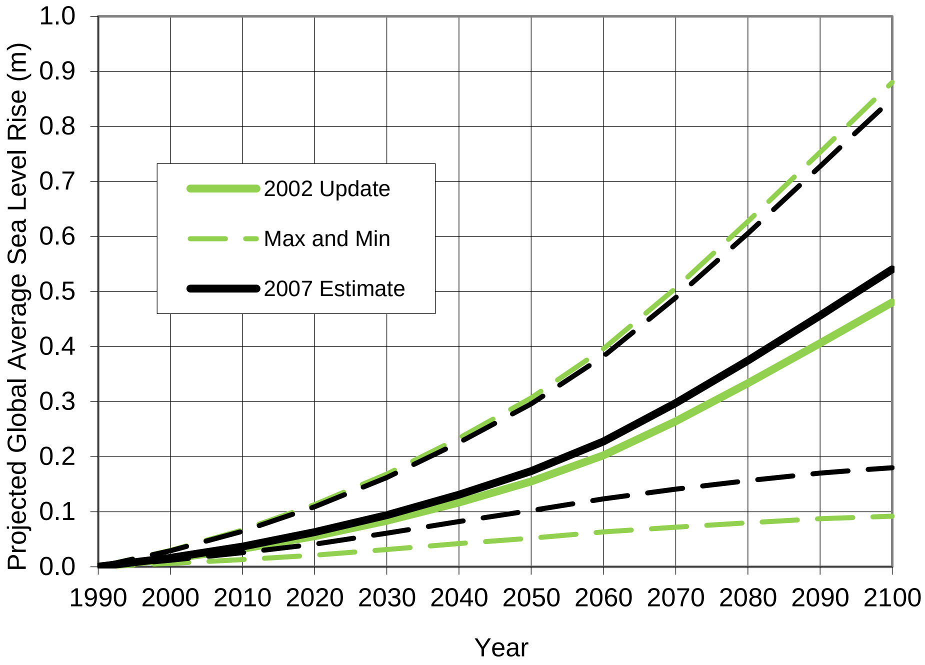

Figure 4-11 Comparison of changing sea level rise projections (after NCCOE 2004 and 2012)

Finally, the prospect of potential climate change should be considered with respect to the influence on rainfall rates, sea level rise and storm surge. For example, considering tropical cyclones:

- The possible upper limit of projected tropical cyclone intensity should be represented by a 10% increase in MPI by 2050 and a 20% increase by 2100;
- No changes in storm frequency are recommended for the year 2050, but a nominal precautionary allowance for a +10% change should be assumed by the year 2100;
- Increases of 20% in rainfall rates within 100 km of tropical cyclones by 2100 should be considered;
- Storm surge estimates will scale with intensity change.

Considering East Coast Low event types:

- Increases of 20% in rainfall rates by 2100 should also be considered;
- Nominal increases in storm surge magnitude of 10% by the year 2100, with a 5% increase applied for 2050, should be considered.

Considering potential future sea level rise:

- A rise of 0.3 m by 2050 and 0.8 m by 2100 should be considered (DERM 2011).

In conclusion, the long term effects of potential sea level rise will act directly on increasing the flood risk within coastal rivers on time scales that will likely require a significant planning response. Importantly, although the year 2100 is normally quoted as a reference time, if greenhouse gas concentrations were stabilised even at present levels, sea level is nonetheless predicted to continue to rise for hundreds of years. Although the range of uncertainty of these projections is still high, the potential impact of this on future planning in coastal flood prone regions cannot be ignored (e.g. GHD 2012b).

5. Catchment Response Issues

5.1 Rainfall Runoff Components (Hydrologic)

Hydrology is the scientific study of the waters of the Earth with relation to the effects of precipitation and evaporation upon the occurrence and character of water in streams, lakes, and on or below the land surface. The conversion of rainfall to runoff is complex and the quantity of rainfall that becomes runoff is influenced by many processes. The two broad aspects that influence runoff are:

- Climate and in particular precipitation; and
- Physical characteristics of the catchment.

The impact of the climate on runoff depends on a number of factors: rainfall intensity, duration of rainfall, distribution of rainfall, direction of the rainfall event and antecedent conditions to name a few. The physical characteristics of the catchment include land use, soil type, drainage area, shape of the catchment, elevation, slope, orientation of the catchment, the drainage network and other artificial structures and drains. Some of these issues are discussed further below.

5.1.1 Intensity and Duration

When rainfall intensity exceeds the catchment infiltration capacity and surface runoff is produced, stream flow tends to increase with increase in intensity of rainfall. In general the increase in stream flow is not at the same rate as the rainfall excess because of the lag effect resulting from storage. Regardless of the intensity, long durations of rainfall will increase surface runoff, as infiltration capacity tends to decrease during a rainfall event. Therefore, even if the intensity is relatively minor, rainfall of long duration may produce considerable surface runoff.

Intensity-frequency-duration (IFD) estimation procedures have been under revision for several years (e.g. BOM 2005, which considered the area covered by southeast Queensland area) and are the subject of ongoing AR&R research.

5.1.2 Temporal Patterns

The variation of intensity of rainfall over a period of time is referred to as the temporal pattern. The temporal pattern is most commonly and reliably measured at a point with a pluviograph[31] at ground level, although modern radar has the ability to (crudely) estimate rainfall both temporally and spatially over discrete regions.

Temporal patterns can have a significant effect on the estimation of flow rates, particularly on catchments regulated by dams. Design temporal patterns are derived by the *Average Variable Method* which seeks to average out the range of patterns but there is known to be considerable variability. This is evident from a perusal of the Generalised Tropical Storm Method Revised patterns (BOM 2003b). The majority of rainfall may occur towards the start of the event (front-loaded storms) while other events may experience rainfall towards the end of that event (back-loaded storms). The back-loaded storms may cause problems for dam operators once the storage is full.

5.1.3 Spatial Patterns

During a rainfall event it is unlikely that the rainfall will be uniformly distributed over a catchment. The distribution of rainfall across the catchment is generally referred to as the spatial

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[31] An instrument that continuously measures rainfall volume that falls into a receiving vessel, as opposed to a rain gauge that may simply collect rainfall over a period and then be manually emptied.

distribution. The larger the catchment the less likely rainfall will be uniformly distributed. For small catchments high flows are generally caused by intense thunderstorm events, while for larger catchment areas higher flows are generally produced by storms of lesser intensity but covering a larger area. In short, there is a scale-interaction between the catchment and the weather system producing the rainfall.

In the case of areas influenced by tropical rainfall such as the Brisbane River catchment (as discussed in Section 4), major flooding is often associated with tropical or extra-tropical systems that deliver rain across very large areas (catchment-wide scale). BoM (2003b) provides some guidance on the spatial distribution of rainfall, which is represented by the TAF (topographical adjustment factor) which reflects the prevailing topography. In the present method this is a static parameter and may not adequately reflect the true climatic drivers for rainfall distribution of past events nor future events.

5.1.4 Direction of Rainfall Events

The direction in which a storm travels across a catchment can significantly influence the resulting runoff rate. If for example, the storm was to start at the top of the catchment and travel in the general direction of river flow, the runoff from the upper portion of the catchment could reach the downstream outlet around the same time as the runoff from the lower portion of the catchment, thereby increasing the peak flow rate. If the storm were to start at the lower portion of the catchment moving towards the upper portion, then the runoff from the lower portion would typically have exited out of the catchment before flow from the upper portion arrives, thereby reducing the peak flow rate. However, the total volume of runoff could be the same for both scenarios. The random nature of such events means that it is difficult to make allowance for these effects without a statistical simulation approach.

5.1.5 Antecedent Conditions

The amount of rainfall that has fallen prior to a significant event can influence the amount of runoff that occurs. When the soil moisture content is high, the infiltration capacity is low and therefore the catchment may be susceptible to floods. This is also sometimes referred to as the degree of saturation of the catchment.

The amount of soil moisture is a function of several factors including baseflow, available soil moisture capacity (sometimes referred to as field capacity), rainfall, and evaporation. Evaporation is a function of temperature, solar radiation, windspeed, and humidity. Different soils have varying soil moisture capacities; for example sand can absorb more moisture compared with a clay soil. Very dry catchments have the potential to soak up significant amounts of rainfall. In Queensland, up to 140 mm of rainfall (AR, 1999) may be absorbed by the pervious parts of a catchment before generating any runoff. Soil moisture accounting should be incorporated into hydrologic modelling of the Brisbane River catchment.

5.1.6 Land Use and Soil Type

Land use can have a large impact on the amount of runoff. For example in urban areas rain falling on hard surfaces will tend to run off quickly and be concentrated in the stormwater network before discharging into the receiving waterway. If the same rain was to fall on a forest area with dense vegetation and thick layer of ground cover, less or no (depending on the rainfall event) runoff might occur. In any catchment the soil type can also influence runoff characteristics because different soil types have different infiltration capacities. There usually needs to be a balance between model complexity and data simplification. It may not be feasible to include all dominant soil type and land uses within the Brisbane River catchment, and some form of classification will likely be needed.

5.1.7 Slope and Orientation

In general the ground slope affects the rate of runoff. With a steep slope the velocity of overland flow is increased, thus shortening the period of infiltration and producing a greater concentration of surface water in the receiving waterway.

The orientation of the catchment can also affect the transpiration and evaporation losses due largely to the amount of sun received and the heat absorbed into the soil.

5.1.8 Drainage Network

The number of watercourses, layout or arrangement of the drainage network can also influence the rate of runoff. The more efficient a drainage network is, then the quicker the stream flow and vice versa. The drainage network characteristics can also inform other catchment parameters such as soil properties and cohesion. Highly developed floodplains often have significantly modified drainage networks involving straightening and removal of natural vegetation.

5.1.9 Artificial Structures and Drains

Artificial structures such as storages and drains can significantly influence flood flows but cannot necessarily prevent damaging flooding. The influence of a storage will depend on the volume of runoff and the level of the storage at the start of the event and hence the volume available. For illustration, Figure 5-1 below is a conceptual diagram illustrating the possible and plausible range of flood peak attenuation offered by Somerset and Wivenhoe Dams, together with some of the major flood experience.

Dams with gated structures add a layer of complexity because any operating rules need to achieve a mitigating outcome that is effective across a wide range of historical or potential large to extreme events. That is, the gate operating rules should not worsen flooding for another event even though it appears favourable for other scenarios when compared to a base operating strategy. As previously mentioned, temporal patterns can have a significant influence on the operation of a gated dam.

Open drains can speed up removal of surface runoff and therefore increase the flood flow from the area drained. Drains can also be used to divert flows around and across catchments. Embankments on drains can also influence flow across the catchment.

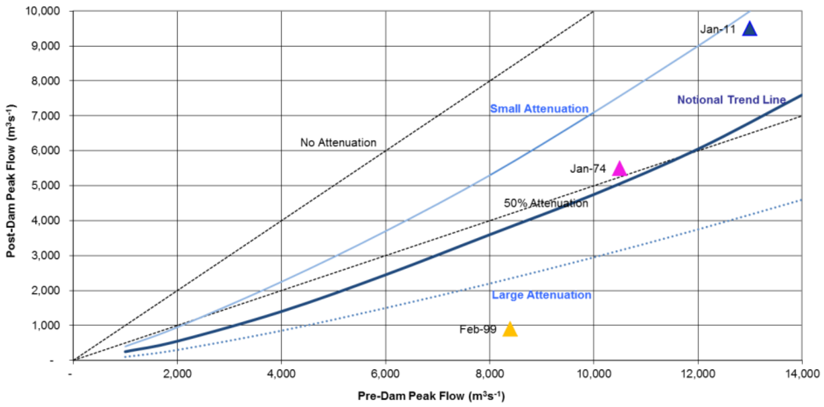

Figure 5-1 Possible and plausible ranges of flood peak attenuation by Somerset and Wivenhoe Dams (from Weinman 2011)

5.1.10 Rating Curves

A rating curve is traditionally a graph that represents the relationship between discharge and water level for a given location on a river – usually at a designated river gauging station.

The development of a rating curve typically involves field measurements of the stage (river level) and corresponding discharge in the river at several discrete times across a range of flood events. The recording of river discharge is more difficult than recording flood level and generally has a higher level of uncertainty compared with recorded flood levels.

Often the largest rated flood by field measurements is much smaller than the largest known flood. Some rating sites are established with a view to reliably estimating catchment runoff volume for water supply reliability (i.e. yield) purposes. Here, only the lower end of the rating curve is established by field measurements and the rating curve is extrapolated for higher gauges. Rating curves for flood warning stations tend to have a broad range of field observations such that the degree of extrapolation is reduced. However, there is usually still a significant amount of extrapolation that introduces uncertainty. This is especially so for those sites where the river breaks its banks and flood waters start to spread out into the floodplain. The choice of control for a gauging station may also be significant. The rating may also need to be adjusted from event to event for those sites were erosion occurs during the course of a flood.

Several different types of rating curves can exist depending on the geometry and flow regime.

- For steady geometry and steady flow conditions – a single value stage-discharge relationship is generally found;
- For unsteady flow conditions – looped rating curves (showing hysteresis effects) are generally found and can only be practically determined by hydraulic modelling.

Rating curves are typically used to convert the discharge hydrographs predicted by hydrologic models to flood level hydrographs and recorded flood level time series to discharge time series. Consequently, rating curves play an important role in the calibration of hydrologic models and it is imperative that adequate consideration be given to the accuracy of rating curves during the calibration process.

For the present project, it is recommended that a detailed review of existing rating curves be undertaken and detailed 2D and/or 3D hydraulic modelling be undertaken in the vicinity of significant gauging stations.

5.2 Flood Propagation Component (Hydraulic)

The propagation of flood flow is influenced by many factors including:

- Channel and terrain geometry;
- Surface roughness of flow paths;
- Hydraulic controls; and
- Hydraulic energy gradients.

5.2.1 Bathymetry and Topography

Floodplain topography and channel geometry have a significant impact on the propagation of flood flows. Details such as floodplain land use, channel bed slope, channel width, obstruction, expansion and constriction within a flow path can either impede or accelerate flood flows.

5.2.2 Surface Roughness

The surface resistance of a flow path/channel can have considerable effects on the estimation of flood flow. The following factors are known to increase flow resistance and reduce the speed of flood flows:

- Vegetation on channel bed, overbank flow areas and floodplains;
- Irregularities in the bed and banks of channels (e.g. dunes or ripples);
- Presence of buildings on the flood plain; and
- Abrupt variations in the channel cross sections in terms of shape, bends or obstructions.

Reliable hydraulic modelling to estimate physical flood characteristics requires the establishment of data sets that reflect the actual surface roughness of the floodplain and active flow areas. Roughness should also be considered in the calibration of flood hydraulic models in order that they as best as possible replicate behaviour of actual historic floods.

Many of the factors that influence surface roughness change with time as land-use varies, development that is in place, and even seasonally as crops and other floodplain and waterway vegetation vary.

Contemporary regional flood hydraulics estimation should include a process of custodianship and ongoing maintenance of “layers” of critical input data with planned periodic updates of existing conditions. This will also assist in cost effective re-estimates of flood hydraulic characteristics to be easily made. Additionally, the ability to re-estimate flood hydraulics for the purposes of testing likely impacts of proposed land-use changes is an important function for integrating floodplain management into strategic land-use planning processes.

Maintaining a whole-of-region hydraulic roughness data layer is a critical adjunct for coordinated and consistent results generation and across multi-jurisdictional floodplain management responsibility and where multiple agencies will potentially be separately using a single model and model platform.

5.2.3 Hydraulic Controls

Hydraulic controls can impede the propagation of flood flows in a channel or flow path significantly by means of an obstruction in the flow cross sectional area or by imposing boundary conditions.

Some examples of hydraulic controls are:

- Expansions and contractions within the channel geometry or flow paths;
- Downstream boundary conditions such as tail water levels or storm tide levels;
- Waterway crossings such as culvert and bridges;
- Hydraulic structures such as flow intakes, diversions, weirs and gates;
- Linear infrastructure such as roads and railway alignments; and
- Flood mitigation infrastructure such as levees and embankments.

5.2.4 Energy Gradients

The energy gradient, which is the sum of the hydraulic gradient and the velocity head at any particular point along a flow field, drives the propagation of flood flows. The slope of the hydraulic gradient for a given channel length is the main factor contributing to the flow of water from upstream to downstream reaches, affecting the speed at which it flows. A greater hydraulic gradient slope increases the speed of flood flow within the channel.

The following factors influence the energy gradient of a channel:

- Cross sectional area of flow;
- Overall head (energy) available to drive flows through the location; and
- Frictional losses over the section of interest.

Section 8.2 contains an overview of broad-scale hydraulic energy and related issues as they relate to the Brisbane River catchment.

6. Floodplain Vulnerability Issues

Effective and responsible floodplain management requires a sound understanding of the geographic distribution of flood risks faced by the community. Hence an analysis of the flood hazard (magnitude and frequency) as it varies across the floodplain is a principal requirement.

Typically two primary flood hazard categories should be considered:

- Hydraulic and Environmental Function Hazards: the impact of human floodplain use and environmental floodplain function on flood behaviour, and
- Anthropogenic Hazards: the impact of flooding on people and development.

6.1 Hazard Categories

6.1.1 Hydraulic Hazards

Flood hazard relates to the level of danger present at a site on a floodplain, which depends on the behaviour of the flood at that location and, importantly, changes with the probability of the event. Generally, the rarer the flood the greater is the hazard. Accepted practice (ARMCANZ 2000, DIPNR 2005) has been to develop hydraulic hazard category tables or graphs, and although there are variants on where the thresholds are drawn, these consider how combinations of flood depth and flood velocity can have damaging consequences depending on what is exposed to that flood hazard.

Table 5 Example hydraulic hazard categories

Low Risk to Life and Property		High Risk to Life and Property		
H1	H2	H3	H4	H5
No significant life risk Property risk limited to direct contact with floodwaters such as building contents	Low life risk. Able bodied adults can walk safely. Cars may float with risks to life and property	Medium life risk. Able bodied adults cannot safely walk Only large vehicles (trucks) can safely travel.	Major life risk Light frame buildings (e.g. houses) will fail structurally. Engineered buildings may suffer damage.	Extreme life risk Majority of buildings not engineered to resist flood waters could fail.

6.1.1 Environmental Function Hazards

The catchments, floodplains and waterways of the Brisbane River catchment contain and provide internationally and locally important environmental functions upon which economic, human health, and downstream environmental benefits are derived.

Flood hydrology and hydraulic characteristics are the drivers for these important environmental functions and services. Of particular importance are flow depth, extent, duration, and velocity. In this case the hazards to be considered would be the potential loss of important hydrologic and hydraulically driven environmental floodplain and waterway functions due to changes in flood hydraulics. Understanding of types and locations of critical environmental floodplain function/services that need to be maintained, followed by analysis of the risks to floodplain environmental functions that may result from maintaining and/or changing flood hydraulics is fundamental to sustainable interaction of human and environmental floodplain use benefits.

6.1.2 Anthropogenic Hazards

A more comprehensive analysis than the hydraulic hazard categorisation alone is needed to establish the wide range of risks that need to be managed and this can only be made from within the strategic framework of a floodplain management plan. The determination of the risks requires the detailed results from a flood study and the hydraulic hazard categorisation, along with an assessment of all the related hazard factors, such as, for example:

- Topography and its effect on emergency response options in rising floodwaters;
- Effective flood evacuation access;
- Duration of flooding affecting accommodation needs or reconstruction/maintenance;
- Evacuation metrics (numbers, types, mobility);
- Effective warning time / rate of rise of floodwaters;
- Flood preparedness in reducing impacts;
- Obstruction and blockages (e.g. effects of floating debris);
- Type of development (residential, industrial/hazardous);
- Vulnerability (persons and building material and contents);
- Critical and cumulative consequences (e.g. damage to emergency infrastructure);
- Water entering buildings (safety of egress, electrical safety, stability);
- Coincident storm tide hazards (which necessitate hazard categories involving wave activity and possibly high winds).

6.2 Integrated Assessment of Flood Risk

Many factors contribute to flood hazards and thus flood risk. In particular, the hazards and resulting risks of flood on people and activities on the floodplain are wide and varied. In addition to physical impacts to infrastructure - the social, economic and environmental hazards and risks are required to be considered during analysis of the existing floodplain conditions, and in the reduction of risks (i.e. the benefit due to implementation of risk reduction measures).

A floodplain risk management study will need to consider the cost and benefits of flood risk management measures along with the costs and risks associated with social, economic, and environmental issues wider than simply the flood risks alone. An example would be the risks and costs associated with water supply security due to potential alterations to Wivenhoe and Summerset Dams and the associated costs that may accrue from alternative water supply methods. This is particularly important for the Brisbane River catchment as the primary purpose of both Wivenhoe and Somerset dams is regional water supply for communities and economic activities for the region well beyond the floodplain. The need to balance risk of local flood mitigation verses the risk to reduction of water supply, and thus the need for alternative supplies to maintain regional water security, must be considered[32].

Other related risk balances that must be considered are the safety of the dams, achieved largely by safe operations, as compared with potential for localised downstream flood risk reduction that might be afforded by alternative dam operations and arrangements.

In order to assess and compare risk reduction measures, tangible and intangible risks due to a wide range of flood hazards, some physical, some social, and some economic is required that should consider:

- Existing flood risks;
- Potential future flood risks based upon current land-use planning schemes;

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[32] In the parlance of the associated Wivenhoe Dam and Somerset Dam Optimisation Study (WSDOS) administered by the Department of Energy and Water Supply WSDOS studies, this is the so-called “integrated assessment” step.

- Change in flood risk due to implementation of potential mitigation measures (i.e. the benefit resulting from implementation); and
- Residual flood risks (those that are not mitigated against).

Leading practice for floodplain management normally has flood risks determined quantitatively for tangible consequences on an Annual Average Damages (AAD) monetary basis, with the timing of interventions, especially with an increasing hazard such as projected climate change, assessed using Net Present Value (NPV) analyses. Relationships between flood magnitude and consequential economic losses are used to inform the economic analyses (refer Section 8.3) and may be obtained from past flood experiences or theoretical analyses, aggregated on the basis of determined exposure data.

Intangible flood risks should be assessed using adaptation of the common qualitative risk assessment approach of classification by way of a “risk table”, such as that illustrated in Table 6, often in association with Multi-Criteria Analysis.

A key element to the risk management decision making process is the inclusion of the concept of *risk acceptability*. For each hazard to be assessed, thresholds of risk acceptability must be discussed and agreed by, or on behalf of, the community. These thresholds will guide decisions around the need, or otherwise, for treatment to reduce a particular risk or acceptance of resulting risks without effort and costs to treat.

A dual approach of using qualitative and quantitative risk assessment is desirable in order to include adequate consideration of the social perceptions and levels of acceptance of risk, while also providing measurability and repeatability in the process. Importantly, the qualitative aspect provides for involvement, ownership, and thus likely greater acceptance of the outcomes by the impacted communities and stakeholders.

Table 6 An example qualitative risk assessment table

Event range yr (ARI)	Maximum hazard category of surrounding floodwater						
	H1	H2		H3-H5			
		<24 hr	>24 hr	<24 hr		>24 hr	
				Non vulnerable population	Vulnerable population	<1,000people	> 1,000people
1,000 - PMF	🟩	Acceptable	🟩	🟩	🟨	Tolerable	🟨
100-1,000	🟩	🟩	🟩	Acceptable	Tolerable	Tolerable	🟨
50 to <100	🟩	🟩	🟨	Tolerable	🟨	Tolerable	Unacceptable
>10 to <50	🟩	Acceptable	🟨	🟨	Unacceptable	Unacceptable	Unacceptable
10	🟩	🟩	🟨	🟨	🟥	🟥	🟥

6.3 The Role of Planning Legislation

Two significant pieces of legislation support the need for the floodplain management processes within Queensland. These Acts of State Parliament are:

- The *Sustainable Planning Act (2009)*; and
- The *Disaster Management Act 2003*.

Other Acts that support floodplain management include:

- The *Coastal Protection and Management Act 1995* (as amended to 1 February 2013) contains supporting requirements that apply to specific coastally-connected areas only.
- The *Water Act 2000* provides for water supply catchment protection, water allocation including environmental flows, as well as control measures for efficient water use in water related developments that are self-assessable and code-assessable under the *Sustainable Planning Act 2009.*
- The *Water Supply (Safety and Reliability) Act 2008* provides for the protection of water environmental values other than public health including referrable dams and flood mitigation.

Sustainable Planning Act 2009

The *Sustainable Planning Act (2009)* (or SPA) guides the coordination and integration of planning in Queensland at the local, regional and state level.

The Purpose of the Act is "*to seek to achieve ecological sustainability by—*

(a) Managing the process by which development takes place, including ensuring the process is accountable, effective and efficient and delivers sustainable outcomes; and

(b) Managing the effects of development on the environment, including managing the use of premises; and

(c) Continuing the coordination and integration of planning at the local, regional and State levels."

Under the SPA, *Ecological Sustainability* is defined as "a balance that integrates—

(a) Protection of ecological processes and natural systems at local, regional, State and wider levels; and

(b) Economic development; and

(c) Maintenance of the cultural, economic, physical and social wellbeing of people and communities. (§Chapter 2, Part 1, Section 3)

To achieve the requirements of SPA, local government is required to prepare Planning Documents that identify areas of natural hazard, which includes flooding from all sources, so that its development decision making process:

- Is accountable, coordinated, effective and efficient;
- Takes account of short and long-term environmental effects of development at local, regional, State and wider levels, including, for example, the effects of development on climate change;
- Applies the precautionary principle;
- Seeks to provide for equity between present and future generations;
- Ensures the sustainable use of renewable natural resources and the prudent use of non-renewable natural resources by, for example, considering alternatives to the use of non-renewable natural resources;

- Avoids, if practicable, or otherwise lessening, adverse environmental effects of development, including, for example, climate change and urban congestion, and adverse effects on human health (§Chapter 1, Part 2, Section 5).

State Planning Policies (SPP) are made to protect and regulate matters of ‘state interest’ as legislated under §Chapter 2, Part 4, Division 2 of the *Sustainable Planning Act 2009*. They are statutory instruments the *Statutory Instruments Act 1992*. Local governments must ensure that state planning policies are reflected in the local government planning schemes. In circumstances of non-compliance, the state planning policy overrides the planning scheme. SPPs that support floodplain management are described in subsequent sections.

Disaster Management Act 2003

The *Disaster Management Act 2003* (DMA) forms the legislative basis for disaster management arrangements for Queensland including:

- Establishing disaster management groups for the State, Disaster Districts and Local Government areas;
- Detailing planning requirements at each level;
- Maintaining the role and operations of the State Emergency Service (SES) and establishment of Emergency Service Units (ESUs); and
- Providing for the conferring of powers on selected individuals and groups.

The main objectives of the DMA are:

- To help communities:
  - Mitigate the potential adverse effects of an event;
  - Prepare for managing the effects of an event; and
  - To effectively respond to and recover from a disaster or an emergency situation.
- To provide for effective disaster management for the state; and
- To establish a framework for the management of the SES to ensure the effective performance of their functions. (§Part 1, Division 2).

The objectives of the current DMA have been amended to include reference to the following principles of disaster management (inter alia):

- Effective disaster management requires planning across all four phases of disaster management: prevention, preparation, response and recovery;
- That all hazards, whether natural or caused by humans, should be managed using a disaster management framework; and
- That it is primarily local governments that are responsible for managing disasters in their local government area and that district and state groups should provide local governments with appropriate resources and support to be able to manage disaster operations.

The functions of a local government under the DMA are to:

- Ensure it has a disaster response capability;
- Approve its local disaster management plan prepared under §Part 3 of the DMA;
- Ensure information about an event or a disaster in its area is promptly given to the District Disaster Coordinator (DDC) for the Disaster District in which its area is situated;

- Perform other functions given to the local government under this Act. (§Part 5, Section 80).

Local government is best situated to provide first-hand knowledge and understanding of social, economic, infrastructure and environmental issues within their respective communities and are ideally placed to support their community from a disaster management perspective. This is achieved through the Local Disaster Management Group (LDMG) where Local Governments coordinate their response to a disaster.

§Section 57 (1) requires local governments to develop a local disaster management plan (LDMP) as a part of their response capability for disaster management in their area. §Section 57 (2)(f) further requires that the LDMP must address matters stated in the disaster management guidelines and §Section 58 states that the LDMP must be consistent with the disaster management guidelines.

§Section 63 (1) gives authority to the Chief Executive of the Department to prepare guidelines to inform State, District and Local Groups about the preparation of plans and matters to be included in plans.

State Planning Policies

Proposed Single State Planning Policy

A key initiative of the current State government is the preparation of a single State Planning Policy (SPP). This proposed new SPP would replace the existing suite of 13 separate policies and aims to “simplify and clarify the State’s interest” (Queensland Government, 3 December 2012).

Proposed State Interests, Part 1 of the State Planning Policy (Queensland Government, November 2012), was released for consultation in November 2012[33]. It presents a proposed framework of state interests in the planning and development assessment system. The full draft State Planning Policy is expected to be released by June 2013.

Floodplain management is incorporated in the proposed State Interest: Natural Hazard (Queensland Government, November 2012):

- “Flooding, bushfires, landslides, storm tide inundation and coastal erosion are uncontrollable forces of nature. It is the responsibility of all levels of government, industry and the community to minimise the impact these priority natural hazards may have on people, social wellbeing, property, the economy, the environment and infrastructure.”

§Part 1 also proposes a standard planning approach to address natural hazards based on the following principles (Queensland Government, November 2012):

- “Creating certainty and avoiding unnecessary delays in approving appropriate development
- Maintaining safety from natural hazards in new and existing communities
- Understanding that land use planning is a core risk management response which may occur in conjunction with structural works, community awareness and emergency management
- The use of mapping, risk assessment and planning responses are fit-for-purpose
- Ensuring communities understand natural hazards and the extent to which they are acceptable, tolerable and intolerable

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[33] Proposed State Interests, Part 1 of the State Planning Policy – Draft for Consultation (November 2012). http://www.dlg.qld.gov.au/statewide-planning/state-planning-policies.html, accessed 22 Jan 2013.

- Utilising the best information and technology to identify, analyse, evaluate and communicate current and future natural hazards and risks
- Avoiding, mitigating, adapting and building resilience to natural hazards in broad hectare, infill and existing development areas"

The existing state planning policies relevant to floodplain management area outlined below.

State Planning Policy 1/03: Mitigating the Adverse Impacts of Flood, Bushfire and Landslide 1.0

State Planning Policy 1/03: Mitigating the Adverse Impact of Flood, Bushfire and Landslide came into effect on 1 September 2003 and is the keynote policy for the management of natural hazards in Queensland.

§Section 5.2 of the supporting Guideline (Queensland Government 2003) states: "…the intention of the SPP is that, wherever practicable, natural hazard management areas should be identified through a comprehensive and detailed natural hazard assessment study. Outcome 4 of the SPP requires natural hazard management areas to be identified when planning schemes are made or amended, and these should be integrated with the planning strategies and detailed planning measures required under Outcomes 5 and 6 of the SPP."

§Section 7.5 of the SPP notes that measures that minimise risks to people, property, economic activity and the environmental also include "strategies that prevent material increases in the extent of the severity of natural hazards." As a result, the planning scheme should not only consider the risk of natural hazard management areas in the location of uses, but "should aim to maintain the flood carrying capacity of rivers, streams and floodways, and the flood storage function of floodplains and waterways."

§Section 5.7 of the Guideline states that "a default mechanism for flood hazard management was not adopted for the SPP as reliable flood data was not available. Therefore, the development assessment components of the SPP apply in relation to flood only where a local government has adopted a Designated Flood Event (DFE) for managing development, and that DFE has been translated into a natural hazard management area (flood) identified in the planning scheme. A local government wishing to address flood issues urgently could identify a natural hazard management area (flood) and appropriate development assessment criteria in a temporary local planning instrument prior to making or amending the planning scheme."

§Section 5.8 of the Guideline states that "in relation to flood hazard management, the SPP sets out the State's position that generally, the appropriate flood event for determining a natural hazard management area (flood) is the 1% Annual Exceedance Probability (AEP) flood. However, the SPP recognises that the adoption of a different DFE may be appropriate depending on the circumstances of individual localities and the proposed land use for the area, e.g. a 0.2% AEP may be the desirable DFE for an emergency services building or hospital. The adoption of a lower DFE would require the local government to demonstrate by thorough analysis that the proposed level of flood protection is appropriate to the circumstances of the locality."

§Appendix 2 of the Guidelines – "Undertaking Natural Hazard Assessment - Flood" – indicates that (§Section A2.8) "Outcome 4 of the SPP requires natural hazard management areas for flood to be identified in planning schemes". §Section A2.11 indicates that "natural hazard management areas (flood) ideally should be determined from a comprehensive floodplain management study".

SPP 1/03 is currently being reviewed to inform the proposed Single State Planning Policy (see previous section). The review will consider such matters:

- "The extent to which planning schemes comply with SPP 1/03

- How flood studies should be conducted
- Whether natural hazard management areas for flood should be based on a 'zones of risk' approach – low, medium, and high for instance – or continue to be determined by reference to a defined flood event
- How to take into account the Queensland Reconstruction Authority's work, and in particular part 2 of the guideline to TSPP 2/11 (see following section)
- The recommendations made in the report Increasing Queensland's resilience to inland flooding in a changing climate: Final report on the Inland Flooding Study, which include the following:
  - The review (of State Planning Policy 1/03) should consider whether there should be a standard method for undertaking a flood study and determining a defined flood event
  - The review should consider developing criteria that make clear the circumstances in which it is appropriate to use a defined flood event greater than, or less than, a 1% AEP flood, as a planning control for residential development
  - The review should consider how to improve the integration of land use planning and disaster management
- Whether there should be a department or departments responsible for monitoring whether planning schemes appropriately reflect the (next) state planning policy that deals with flood and include a flood map derived from an adequate flood study
- The recommendations of the Queensland Floods Commission of Inquiry (QFCI 2012).

Temporary State Planning Policy 2/11: Planning for Stronger, More Resilient Floodplains (expired)

Temporary State Planning Policy 2/11: Planning for Stronger, More Resilient Floodplains (Queensland Government 2011) commenced on 20 September 2011 and expired on 20 September 2012. TSPP 2/11 was prepared in response to widespread floods of 2010/2011. The interim measure sought to facilitate the incorporation of an 'Interim Floodplain Assessment Overlay' and associated minor amendments to local government planning schemes giving effect to matters suspended in paragraphs §A3.1 and §A3.2 of Annex 3 of SPP 1/03.

Although, the TSPP is now repealed, the two-part Guidelines (QRA 2011, 2012) is available through the Queensland Reconstruction Authority website. The guideline aims to help introduce consistent and specific planning controls into the land use planning framework:

- "*Part 1 – Interim measures to support floodplain management in existing planning schemes* delivers a toolkit that includes interim planning scheme measures and supporting mapping to those Councils who currently do not have any floodplain mapping. The mapping has been produced with the support of DERM and the mapping product provided represents an Interim Floodplain Assessment Overlay (Floodplain Maps). The Guideline also identifies a clear implementation path for those Councils that choose to adopt the interim code provisions and mapping."
- "*Part 2 – Measures to support floodplain management in future planning schemes* provides more detailed floodplain assessment guidance to Councils who are looking to prepare their new Planning Schemes under the Sustainable Planning Act 2009 (SPA)."

6.4 Recommendations

Although a Floodplain Management Study is not a formal requirement of either the Sustainable Planning Act (2009) or the Disaster Management Act (2003), associated guidance does identify that natural hazard management areas (flood) ideally should be determined [for management] from a comprehensive floodplain management study. This does encourage local government to implement investigation and planning activities and planning processes that will inform the formal planning and disaster management processes.

There is a growing expectation within the community that State and Local governments will be capable of managing natural disasters in an efficient and effective manner that minimizes loss of life and property. It is within the Legislative requirements above and the community expectations that Local Governments should develop Floodplain Management frameworks and studies.

The relationship of State Legislation and the Floodplain Management Process is shown in Figure 6-1 below. This relationship is based on current legislation and State Planning Policies and may be revised subsequent to the outcome of current legislative reviews, in particular the development of the proposed Single State Planning Policy described in Section 6.3.

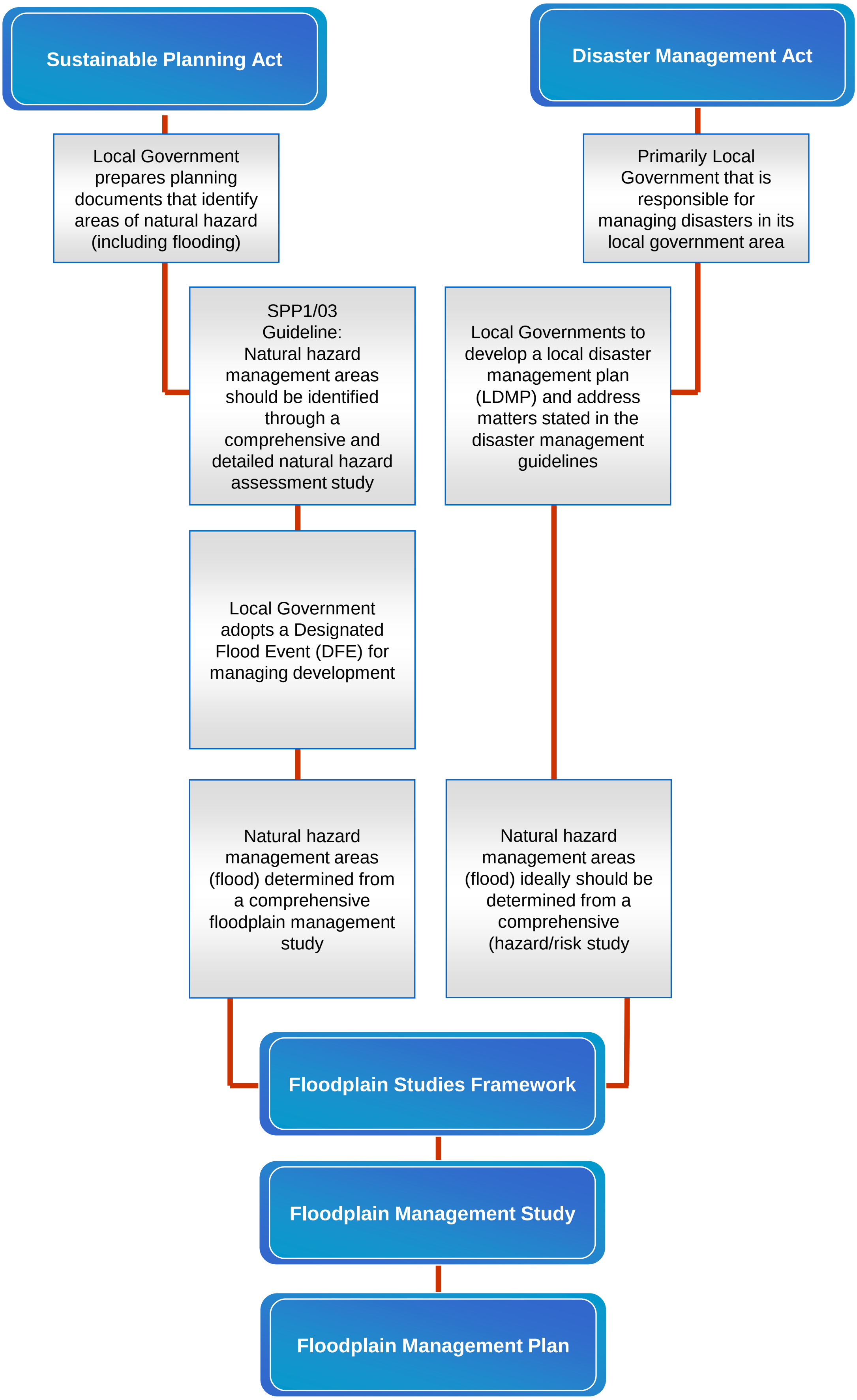

Figure 6-1 Current legislation and the floodplain management process (after GHD 2011)

7. Communication and Stakeholder Consultation Issues

7.1 Roles and Responsibilities

The primary responsibility for the application of floodplain management policy in Queensland rests with local government. However, all levels of Government have some degree of responsibility for floodplain management, which requires the effective and active participation of governments at all levels, developers of the floodplain and the community at large (GHD 2011).

7.1.1 Commonwealth Government

The Commonwealth Government has a general responsibility for the economic and social well-being of the nation. To this end, the Commonwealth Government currently:

- Encourages the development of effective long-term strategies for the sustainable management of the nation's floodplains;
- Provides meteorological, flood and ocean forecasting services by the Bureau of Meteorology;
- Supports the development of emergency management capabilities through the activities of Emergency Management Australia; and
- Provides financial assistance under various funding initiatives including:
  - The Natural Disaster Relief and Recovery Arrangement (NDRRA), administered by the Department of Finance in conjunction with State and Territory Treasury Departments when flood damage and disruption is greater than a preset amount; and
  - The National Partnership Agreement on Natural Disaster Resilience (NDR), which allows for partial funding of disaster mitigation works and initiatives via the States and Territories based upon its natural disaster risk priorities.

7.1.2 State Government

The roles of each relevant State Government Agency are summarised below. The principal floodplain management role of State and Territory Governments has been stated as follows (DPIE, 1992):

"....to develop appropriate standards and strategic approaches for floodplain management and to ensure that they are applied in a coordinated and integrated fashion across the State. This role encompasses the provision of expert technical support via a principal water resources authority(s), of planning advice through a state planning agency and of effective counter disaster and welfare services".

Agencies

- Department of Natural Resources and Mines:
  - data custodianship
  - technical knowledge and support
- Department of State Development and Infrastructure and Planning:
  - strategic planning
- Department of Energy and Water Supply:
  - strategic planning

- Department of Public Works and Housing:
  - strategic planning
- Department of Science, Information Technology, Innovation and the Arts:
  - technical knowledge and support
- Queensland Treasury:
  - financial assistance
- Department of Community Safety / Emergency Management Queensland:
  - emergency planning and management
- Queensland Police:
  - emergency management, coordination and assistance to communities in times of flooding.
- Department of Local Government:
  - administration and support
- Department of Transport and Main Roads:
  - provides a safe and efficient road network that deals with flood impacts by minimising the flood risk to the travelling public, and restoring relevant flood affected infrastructure; and
  - makes predictions of road closures/re-openings and possible failure modes, if any.
- Department of Communities, Child Safety and Disability Services:
  - lead agency for human recovery services (coordination, emergency accommodation, food and clothing, financial support).
- Department of Environment and Heritage Protection:
  - environmental approvals
- Energex Ltd:
  - provides electricity supply infrastructure in flood prone areas;
  - maintains integrity of electricity supply;
  - ensures safe operation of electricity infrastructure in flood conditions; and
  - reinstates electricity infrastructure to provide immediate serviceability.

Obligations of Government Agencies

It is a fundamental principle of floodplain management that government agencies, be they Local, State or Commonwealth, are bound by the best practice principles of the Framework.

Government agencies undertaking works or developments on flood-prone land must comply with the provisions of floodplain management plans. When planning such works or developments, it is essential that the agency takes into account the nature and extent of the flood problem, the impact of the development on flood behaviour, and the impact of flooding on likely hazard levels at the development site.

If the proposed development is or could form part of infrastructure required for flood emergency management, e.g. a police station, hospital, telephone exchange or school, consideration should be given to relocating the development at a flood-free site (i.e. above or more importantly beyond the influence of the PMF if possible), or ensuring that the proposed development can meet its intended emergency use when a flood eventuates.

Government agencies should seek the advice of local government with respect to flood behaviour, EMQ with respect to flood emergency procedures, DSDIP, as well as Council, in relation to planning considerations and the natural resource and environmental protection agencies in relation to environmental matters.

7.1.3 Local Government

Local government in Queensland has a number of roles and responsibilities in the effective management of the floodplain, as detailed below.

Preparation of Floodplain Management Plans

Flood-prone land needs to be managed in accordance with its flood risk. This is achieved through the preparation and implementation of a floodplain management plan, which also considers the social, environmental and economic costs and benefits of the use and management of flood prone land. As part of this process, a Council requires sound information concerning flood behaviour, flood impacts and the other planning factors that affect the use of flood prone land.

The preparation of a floodplain management plan is most effectively undertaken within the process described in this Framework, involving the compilation of a flood study and a floodplain management study prior to defining a floodplain management plan.

Development and involvement of stakeholder consultation

Local Council will provide advice and information regarding the most appropriate timing of stakeholder consultation to inform the study and plan. Council would be involved by:

- Providing key inputs via technical working groups and other stakeholder involvement (outside of agencies represented on the technical working groups) to inform the study and options development (and subsequent plan)
- Assisting to develop key messages to ensure local communities understand the project, constraints and opportunities, to help build awareness and acceptance of Brisbane's flooding history and context flood risks, impacts and benefits.

Planning Schemes

It is expected Councils will seek to incorporate the planning provisions of floodplain management plans into their statutory planning instruments (i.e the formal Planning Scheme).

Local Disaster Management Plan (Flood Provisions)

The preparation of a Local Disaster Management Plan and appropriate flood risk assessment and management provisions therein, is the responsibility of local government. In addition via the LDMP provisions, local government has shared responsibility for the planning and provision of people, equipment and facilities to assist in flood mitigation and flood response activities.

For the local disaster plan to be effective, local government needs to work in concert with EMQ to promote flood awareness in the community by supplying flood data and advice to property owners, residents, visitors, potential purchasers and investors. In recognition of the turnover in residents, and often low retention of emergency advice, such information should be regularly communicated and in various formats readily accessible to the relevant audiences.

Implementation and Review of Management Strategies

Once a floodplain management plan has been adopted, local government is responsible for the administration, communication and public awareness of the provisions of the plan, including:

- The investigation, design, construction and maintenance of structural flood mitigation works;
- The establishment of a formal asset management program for floodplain management measures;
- The administration of land use controls;
- The administration of building controls (e.g. minimum floor levels);
- The provision and maintenance of plant, equipment and manpower, as specified in the local flood emergency plan for the area; and
- Fostering, in conjunction with EMQ, improved flood awareness through public education programs.

Floodplain management measures, be they structural or otherwise, constitute a valuable community asset; public funds have been spent on analysis, design, construction and implementation of these management measures. As such, the measures need to be effectively managed and maintained to ensure that they will perform as required, on those infrequent occasions when they are needed.

It is also essential that the floodplain management plan and preferably also the Local Disaster Management Plan, be reviewed in detail on a regular basis, every 5 to 10 years without flooding but immediately after a flood event that tests the management measures.

7.1.4 Developers

Conforming Developments

Once a floodplain management plan has been prepared, most if not all of the provisions and conditions relating to suitable or 'conforming' developments on the floodplain will be specified in the plan. This will assist developers in their preparation of applications for such developments.

Before preparing and submitting applications, developers should be advised to liaise with local government regarding the provisions and conditions of conforming developments.

Non-Conforming Developments

Subject to the specific Planning Scheme requirements, a floodplain management plan, , need not necessarily exclude non-conforming developments. However, it will serve to alert both local government and the developer to the fact that, in general terms, non-conforming developments are not appropriate to the flood risk and flood hazard at the proposed site.

Should a developer wish to propose a non-conforming development, a number of detailed technical studies would normally need to be undertaken at the developer's expense to justify the proposal. These studies would include:

- A flood study that addresses the following for a range of flood events up to the PMF:
  - Impact of floods on the proposed development;
  - Impact of the development on existing flood behaviour and flood hazard at other locations;
  - Hazard levels at the proposed development site; and
  - Any additional demands on emergency services associated with the development.
- An economic study to demonstrate that the proposed development is equitable and is economically and socially justified on a local community and regional basis;
- An environmental study to identify and address any adverse environmental impacts; and

- A floodplain management study to demonstrate that the development does not exacerbate and ideally enhances current floodplain management arrangements and will not place people at undue risk.

Developers should liaise with local government regarding the scope and detail of issues to be addressed in the supporting studies. If there are significant adverse impacts, the proposal should specify compensatory measures that reduce the impacts to likely acceptable levels. Compensatory measures would then be subject to separate approval by consent authorities.

Where required by Councils, developers could also be expected to contribute to the costs of floodplain management measures arising from the effects of their development.

7.1.5 The Flood Prone Community

The community has a basic responsibility in regard to the management of residual flood risk - to both inform themselves and keep up-to-date with appropriate action to take in the event of a flood.

Residual flood risk can best be addressed through personal household or business flood emergency plans. If these plans are to be successful, it is essential that the community knows what to do and how to do it effectively when flood warnings are issued. Council and EMQ have an important role to play in raising flood awareness through public education, flood risk notification campaigns and information provision.

In areas where structural flood mitigation works have been built, individuals should be aware that in general the works do not eliminate flood hazard, and that problems and danger can arise when floods greater than the design flood event occur. For example, when levees are overtopped, water levels within the protected area can rise quickly and evacuation routes may be cut, creating hazardous conditions. Communities should be aware of the levels of risk, likelihood of floods, including those that may exceed design standards of protection works. Communities should also be aware how to interpret regional or local flood warning information as it relates and is likely to manifest in flood risk at their areas of interest on the floodplain. All of these issues should be addressed in the floodplain management plan for the area. As part of these plans, flood prone individuals should be made aware of the flood risk to which they are exposed, the functioning of the flood warning and evacuation systems, and appropriate actions to be taken when warnings are issued. This information should be freely available from the local agency. The general community - both flood prone and flood-free individuals - should be encouraged to inform themselves of flooding matters.

7.2 Recommendations

The governance established to deliver the FMS and FMP must ensure collaboration and decision making across both State and Local governments, specifically those identified in the QFCI recommendation 2.4 – Somerset Regional Council, Ipswich City Council and Brisbane City Council, at all levels of the Study; including technical, project control and executive steering levels.

At a minimum it is recommended the organisations represented as part of the WSDOS[34] Floodplain Management Technical Working Group form part of the established governance for decision making for the FMS and FMP.

These may form the basis of a technical reference group (TRG) to assist the Planning Implementation Group if considered necessary. Figure 1 describes the suggested governance structure for the implementation of communication and stakeholder consultation throughout the development of the FMS and FMP.

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[34] The Wivenhoe Dam and Somerset Dam Optimisation Study

Communication and Stakeholder Consultation Plan

A comprehensive Plan should be developed to ensure communication and stakeholder engagement activities are coordinated and integrated with the overall FMS and FMP project programs. At a minimum, this Plan would:

- Confirm the overall communication and engagement goal
- Outline measureable objectives and associated key performance indicators
- Include a detailed stakeholder analysis and stakeholder management database
- Include Key Messages and supporting facts to ensure clear, accurate and consistent communication to stakeholders
- Confirm the communication tools proposed to ensure maximum community reach and accessibility of information (including social and traditional media tools, gov2.0 principles)
- Include a detailed Communication Action Plan, outlining the major strategies and approaches to be adopted throughout the project
- Include a 6-monthly review of the Plan against the key performance indicators, and be adjusted as required (live document).

Community engagement sub-committee

The study-wide technical reference group should be supported and informed by a dedicated community engagement sub-committee established early in the process. This committee would include senior and experienced communication and engagement professionals to represent the relevant departments, agencies and organisations to oversee the development of stakeholder and community engagement activities.

Aside from reporting to the TRG, the role of the community engagement sub-committee would be to participate in the reviewing, coordination and monitoring of a stakeholder and community engagement plan, thus providing a link between flood prone communities and the responsible authorities.

Sub-committee tasks would include:

- Providing the regional and political context, reputational risks and strategic insights to guide the overall approach to engaging in their area
- Identification of the level of engagement required to help define tasks
- Input, feedback and authorisation of a stakeholder and community engagement plan
- Facilitate the sign-off of communication documents and activities.

Queensland Government Communication Manager

The sub-committee should be supported by a Communication Manager from the appropriate Queensland Government department.

The Communication Manager would provide the key coordination role on behalf of the community engagement sub-committee, liaising with the relevant stakeholders, organising meetings, and overseeing the work of consultants developing the plans and materials required to communicate and engage with the communities affected by the FMP. The Project Officer would work closely with the successful community engagement consultant/s to help plan and implement the substantial volume of communication and stakeholder consultation requirements.

Communication and stakeholder consultation consultant

Experienced communication and stakeholder consultation consultant/s with prior knowledge and experience in delivering sensitive consultation programs, would be required to work on behalf of the community engagement sub-committee to provide dedicated support to the Queensland Government Communication Manager for design and delivery of engagement activities throughout the program.

The consultant would assist with keeping the program on-strategy, on-message, and within budget and on time. They should have the depth of experience to lead and facilitate to resolve program-wide reputational risks and issues (such as extensive negative media attention, local community push-back, etc) with relevant Ministerial Media Advisors and Local Council communication and media officers.

Along with the Queensland Government Communication Manager, the consultant/s should assist each of the sub-committee members to deliver their engagement activities across each of the regions.

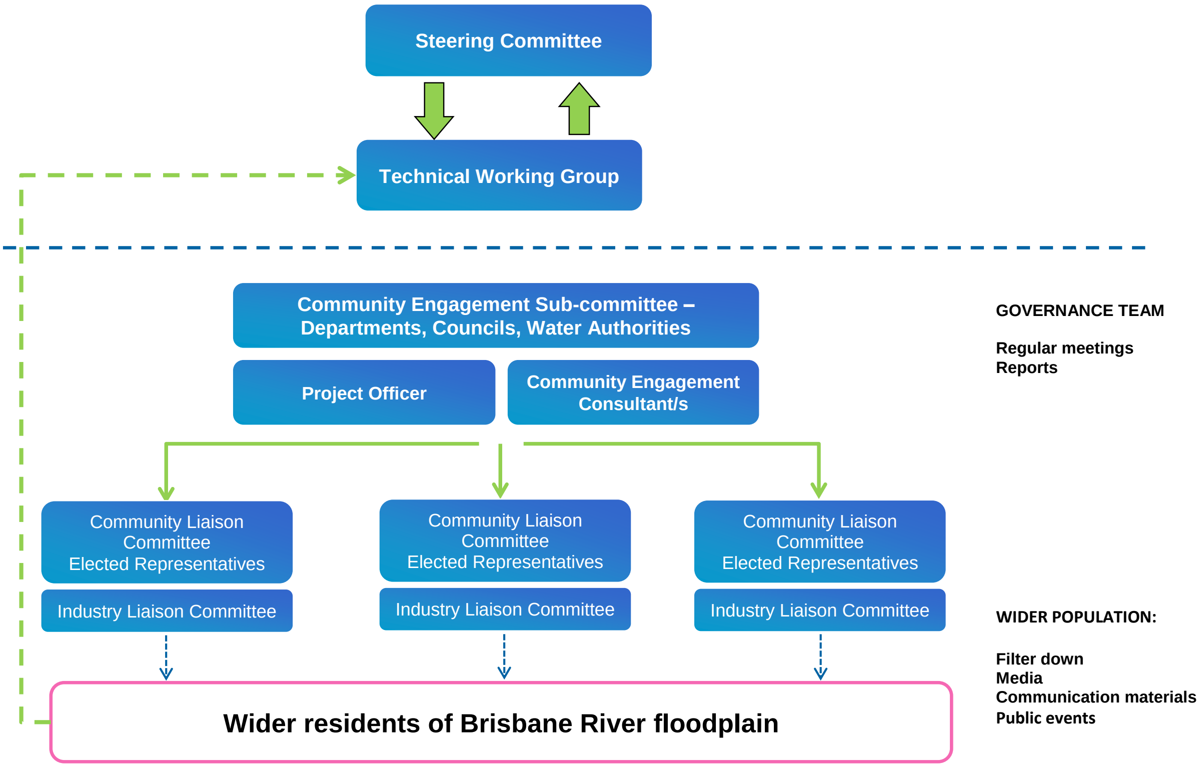

Figure 7-1 Project governance to manage community engagement activities

8. Methodologies and Tools

8.1 Hydrologic Modelling Approaches

8.1.1 Current Practice

As discussed in Section 2.6.1, flood estimation in Australia is almost entirely undertaken using procedures documented in Australian Rainfall and Runoff (Pilgrim 1987 aka AR&R). The choice of flood flow estimate method for a specific case is primarily a matter of finding the appropriate balance between the required accuracy for the application, the level of effort that can be invested into the flood analysis and the consequences of the outcomes of the investigation. Figure 8-1 below illustrates how these factors and the availability of data and expertise affect the selection of an appropriate method from the range of commonly applied techniques.

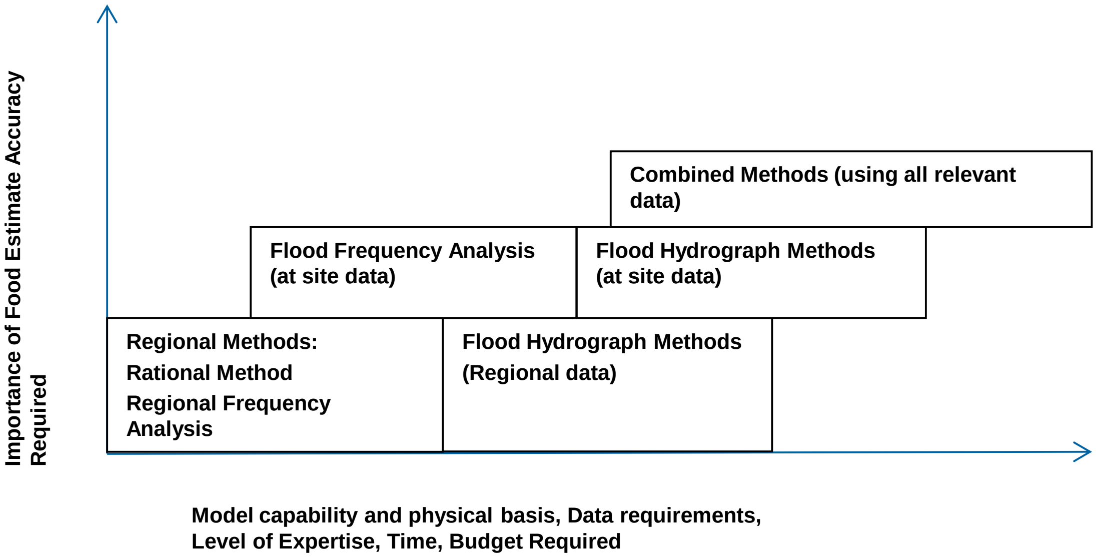

Figure 8-1 Selection of flood flow estimation method (after Weinmann and Mein 2000)

As noted by Rahman et al. (2001) “Rainfall based flood estimation techniques are commonly adopted in hydrologic practice. The currently used methods are based on the *Design Event Approa*ch; they use a probabilistic rainfall depth, in combination with representative values of other inputs, and then assume that the resulting flood has the same frequency as that of the rainfall depth input.” Whilst this approach represents common practice in Australia (and overseas) it suffers several significant limitations as discussed below.

AR&R states that “*in many applications of design flood estimation, the intention is to derive a flood of selected probability of exceedance from a design rainfall of the same probability. However, each section of the design model introduces some joint probability*[35]*, resulting in the fundamental problem that the true probability of the derived flood may be obscure, and its magnitude may be biased with respect to the true flood magnitude with the same probability as the design rainfall, especially at the low probabilities of interest in design*”.

Several approaches have been used in practice to try and deal with this issue:

- Use of median values of variables other than rainfall depth;
- Derivation of design relations or data from comparison of values of the same probability obtained from frequency analyses of observed floods and rainfalls; and

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[35] The probability that two or more specific outcomes will occur in an event.

- Consideration of the joint probabilities of variables contributing to the flood discharge.

On the use of median values AR&R states that "*while rigorous proof is not possible, use of median values is likely to lead to a flood estimate of similar probability to that of the design rainfall. In some regions, seasonality of values may need to be considered. This approach has been used as a basis for much of the design data in this document. There is a need for research to test this approach.*"

On the derivation of design relations compared to frequency analyses of observed floods and rainfall, AR&R states that "the effects of other variables are automatically taken care of by this approach, as the flood of selected probability is directly linked with the rainfall of the same probability."

On the consideration of the joint probabilities of the variables AR&R states that "*the stochastic*[36] *nature of the variables can be incorporated into the flood estimate by means of transition probability matrices, or a large number of simulations using values drawn randomly from assumed probability distributions of the variables. While this approach is theoretically superior to the two described previously, uncertainty at the low probabilities of interest in design is increased by lack of definition of the tails of the several probability distributions involved.*"

As noted in Section 2.6.1, a major revision of AR&R is underway but much of the work will not be available within the present project timeline. One of the aspects under review is: should the revision continue to primarily rely on the design storm approach or should alternative approaches be considered.

8.1.2 Joint Probability Developments

For example, consideration is being given to number of alternative approaches to the design event approach. In general, two are being considered:

- Total Joint Probability Approach; and
- Event Joint Probability Approach.

The total joint probability approach seeks to evaluate all joint probability interactions over a long period of time, commonly referred to as *continuous simulation*. The key to this approach is that the simulation is long enough to account for all significant joint probability interactions.

The event joint probability approach evaluates joint probability interactions during storm *events* only. The effect of preceding conditions, commonly referred to as antecedent conditions, on variables that affect storm response is incorporated by assuming probability distributions describing these variables at the start of the storm. These distributions have to be derived separate from the event analysis.

8.1.3 Event Joint Probability

More recently, a design flood estimate technique based on the joint probability approach termed Monte Carlo[37] simulation has been developed in Australia (Rahman et al., 2002 and Weinmann et al. 2002). The technique "treats four inputs (rainfall duration, intensity, temporal pattern and initial losses) as probability-distributed variables. A large number of runoff events (in the order of thousands) are simulated using these probability-distributed and other fixed input variable/model parameters and then routed through a calibrated runoff routing model. The resulting flood peaks are then subjected to a non-parametric frequency analysis to determine a derived flood frequency curve" (Rahman et al, 2003).

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[36] Involving or containing a random variable or variables.

[37] A problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs

In the case of the specialised discipline of storm surge driven coastal flooding risk assessment, it is now established leading practice in Australia to utilise event joint probability and many thousands of event simulations. The previous computational barriers are largely now overcome, and the methods and techniques are directly applicable to “climate to coast” flood risk assessment (e.g. Harper 2001).

8.1.4 Total Joint Probability

Whilst total joint probability or continuous simulation is regarded as the more rigorous approach to the joint probability problem of flood estimation, there are two main disadvantages. One disadvantage is the computational requirements; the other disadvantage is the limited temporal and spatial availability of pluviograph information that is needed to support the simulation. However the disadvantage of the computational requirements are becoming less of an issue as the computer technology develops enabling large numbers of calculations to be undertaken in less time.

To overcome the limited temporal and spatial data, stochastic rainfall models that can produce very long synthetic records are being created. Stochastic rainfall models need to be able to be applied over a wide area, in excess of those with pluviograph records. The challenge remains on the application to larger catchments were spatial distribution of rainfall is important.

Under stochastic rainfall modelling, events are understood to be governed by systems that, in the whole or as a summation of independent parts, are governed by probability distributions. Several approaches may be taken in this stochastic framework. One approach that represents a recognised “best practice” falls under point processes (Cox and Isham 1980).

Point processes are temporal representations of rainfall, wherein occurrence, intensity, and duration are all formed from independent processes. In rainfall modelling, the main groupings of these point processes fall under the Neyman-Scott and the Bartlett-Lewis approaches. (Entekhabi et al. 1989, Cowpertwait 1991).

In the Neyman-Scott framework, storm occurrence is modelled as Poisson processes. Rain cells stagger from the storm origins, usually of either a Poisson or geometric random variable in structure. These are rooted on the occurrence of the storm. Depending on the variant of the Neyman-Scott model, arrival times, durations, and intensities may be designated as independent random processes (typically exponentially distributed).

Bartlett-Lewis processes follow a similar structure as the Neyman-Scott processes, except that these usually have one rain cell arriving simultaneously with the storm origin. The temporal frameworks of both the Neyman-Scott as well as the Bartlett-Lewis methods have also been extended to spatio-temporal applications.

Established software packages are available based on these approaches (e.g. Burton et al. 2008).

8.1.5 Hydrologic Tools

There are numerous hydrological tools available for the estimation of the magnitude of runoff resulting from rainfall. In very general terms methods are available which estimate either peak flows or hydrographs (flow versus time). Methods used to calculate peaks flows include the Rational Method and flood frequency analysis. There are numerous models available to estimate a flood hydrograph by runoff routing, which involves the routing of rainfall excess through a model representing the catchment storage. A brief discussion on each method is given below.

Rational Method

The Rational Method is amongst the simplest and oldest techniques and is based on a very idealised model of the hydrological process. It assumes that a rainfall event is areally uniform over the catchment and temporally constant for the duration of the storm event, with a constant loss. It is completely unsuitable for any complex river system.

Flood Frequency Analysis

Flood frequency analysis (FFA) is a method than can be used to determine the expected frequency of floods of different magnitudes based on an analysis of an observed homogeneous series of flood events.

Typically, a series of annual maximum flood events is extracted from a record of streamflow data from a stream gauging station with a sufficient length of record[38] with the following properties:

- The flood events are random and independent of each other;
- The events in the flood series are homogenous, stationary (no significant time trend) and consistent (not affected by changes in the method of measurement); and
- The flood data being analysed is representative of the flood conditions of interest.

The data series is then analysed and a theoretical probability distribution is fitted that should represent the flood frequency distribution of the observed floods. The fitted distribution is then used to estimate flood magnitudes across the required range of Annual Exceedance Probabilities.

There are a number of flood frequency analysis methods and theoretical probability distributions that can be used to assess streamflow data. These include the Log-Pearson 3 distribution, the L-moment and L-H moment methods and other approaches such as Bayesian based techniques.

The type of FFA method and the probability distribution used to fit stream flow data can have a significant impact on resultant design flow estimates. As such, FFA for large complex catchments should be undertaken by suitably experienced practitioners with careful consideration given to the results of such analysis.

Runoff-Routing Models

There are numerous models available to estimate a flood hydrograph by runoff routing. Runoff routing involves the routing of rainfall excess through a model representing the catchment storage.

Runoff routing involves the following requirements:

- Selection of an appropriate conceptual model of catchment storage;
- Evaluation of the model parameters for the particular catchment concerned;
- Determination of the rainfall excess in a form suitable for input to the storage model; and
- A flood routing procedure for routing the rainfall excess through the catchment storage model to produce the surface runoff hydrograph.

Most runoff routing models contain conceptual storages, and storage routing procedures are used to route flows through the model. Hydrological knowledge and expertise are important in the choice of a model and its application and are generally more important than the model used.

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[38] The sufficiency of the record length is a subjective decision but one that directly impacts the likely precision of the fitted estimates. Typically extrapolation beyond 3 times the time period of the data is regarded as unreliable.

While some have more physically realistic structures than others, all models are only approximations of reality and require care and expertise in their application and interpretation. When these requirements are fulfilled, many of the models should give acceptable and useful results.

Several different network models are used in Australian practice for rural, urban and partly rural and urban catchments. Used properly, each should give similar results of good accuracy some of these are described in more details below.

In these network models, the storages are arranged to represent the drainage network of the catchment. The distributed nature of the storage is represented by separate series of concentrated storages for the main stream and for major tributaries. This provides a degree of physical realism. A major advantage of this type of model is that it is relatively easy to realistically model the effects of changes to the catchment, such as the construction of a reservoir or retarding basin or the lining of a channel. A brief description of some of the models typically used in Australia is given below.

RORB

RORB (Laurenson et. al. 2010) is an interactive runoff and streamflow routing program that calculates catchment losses and streamflow hydrographs resulting from rainfall events and/or other forms of inflow to channel networks. It is used for:

- Flood estimation;
- Spillway and retarding basin design; and
- Flood routing.

In flood estimation applications, the program may be used on rural, urban or partly rural and partly urban catchments. It is mostly used for design flood investigations but, if the user can provide independently a procedure for evaluating the loss parameters in real time, it may also be used in flood forecasting. In retarding basin and spillway design applications, the program calculates the design inflow hydrograph, provides for interactive adjustment of outlet dimensions until a design criterion is met, and can then route the outflow hydrograph further downstream. In flood routing applications, single and multiple reaches, networks of streams and lateral inflow and outflow can be modelled.

RORB has a capability to conduct Monte Carlo simulations using a stratified sampling approach. The User Manual indicates the program samples rainfalls over the range from 1-year ARI to in excess of 500-year ARI (or the range of user defined ARIs), though results are only provided for a narrower range of likelihoods that are found to be reliably derived through Monte-Carlo simulation. The rainfall distribution is divided into a number of discrete sampling intervals to reduce the number of simulations required to define the rarer events of interest

Watershed Bounded Network Model (WBNM)

The following description has been taken from AR&R (Pilgrim 1987). This model structure is generally similar to that for RORB, although it is based on more detailed consideration of geomorphological relations. The main difference is that the WBNM has two different types of storages for two different types of sub-catchments. Ordered basins are complete sub-catchments where no water flows into the area across watershed boundaries. The storage represents transformation of rainfall excess within the sub-catchment to the hydrograph of surface runoff at the downstream end of the sub-catchment. Inter-basin areas are sub-catchments with a stream draining upstream areas flowing through them. As well as the transforming of rainfall excess into runoff as for ordered basins, these sub-catchments have a transmission storage which routes the upstream runoff through the stream in the sub-catchment. As the storage characteristics and storage delay times of the two types of runoff are different, the provision of these two types of storage is physically realistic. Also, the shapes of ordered basins and inter-basin areas are different.

RAFTS

The following description has been taken from AR&R (Pilgrim 1987). The Runoff Analysis and Flow Training System Model (RAFTS) includes:

- Separate routing of impervious and pervious areas;
- More sophisticated loss models;
- Enhanced capabilities for urban runoff modelling and detention basin design; and
- Provision for very large river basin analysis.

The RAFTS model incorporates more sophisticated loss routines than the other models. In addition to an initial loss-continuing loss rate option, the model allows the use of the infiltration, wetting and redistribution algorithms of the Australian Representative Basins Model (Body and Goodspeed, 1979; Black and Aitken, 1977). A further option that can be provided in RAFTS is a stochastic/deterministic loss model that links the probabilities of rainfall and soil moisture to estimate rainfall excess and runoff frequency curves (Goyen, 1983).

URBS

The URBS model (Carroll 2004) has been under development over the past 15 years. Its technical basis is in the work carried out by Laurenson & Mein and later as WT42 developed by the Queensland Department of Natural Resources and Mines. The primary focus of its development has been flood forecasting and design flood hydrology. An important feature of the model is its capability to link directly with flood monitoring systems to perform real-time flood forecasts (Carroll, 2009, URBS User Manual Version 4.40). URBS also has the ability to perform Monte Carlo simulations (e.g. Rahman et al. , Charalambous et al. 2005).

URBS is a runoff-routing networked model of sub-catchments based on centroidal inflows. Two runoff routing models are available to describe catchment and channel storage routing behaviour. These are the URBS Basic and Split routing models. The Basic model is a simple RORB-like model (Laurenson and Mein 1990) where stream length (or derivative) is assumed to be representative of both catchment and channel storage. The Split Model separates the channel and catchment storage components of each sub-catchment for routing purposes. Irrespective of the model used, each storage component is conceptually represented as a non-linear reservoir.

The derived or assumed model parameters are set at the sub-catchment level and can be compared directly with similar catchments without requiring a re-scaling of calibrated parameters. (D. G. Carrol, personal communication)

HEC-HMS

HEC-HMS (USACE 2000) is a runoff-routing model capable of simulating precipitation-runoff processes in dendritic watershed systems. It is designed to be applicable in a wide selection of both physiographic features and storm configurations for any catchment modelling problem. It hosts several infiltration loss approaches, including the Soil Conservation Service (SCS, US Department of Agriculture) curve number, Green and Amp, initial and constant, Smith Parlange, and Soil Moisture Accounting methods.

Seven methods are incorporated in HEC-HMS to evaluate excess precipitation into surface runoff. Unit hydrograph methods include Clark, Snyder, and SCS approaches. An option for specifying unit hydrographs is also provided in the system. Other techniques include modified versions of the Clark hydrograph.

Baseflow options included in HEC-HMS include recession, constant monthly, linear reservoir, and nonlinear Boussinesq methods. The use of these methods depends on the general features of the observed baseflow. Nonlinear Bousinessq methods in general provide baseflow estimates similar to recession methods, in which parameters can be estimated from measureable parameters of the watershed.

Several routing methods are available in HEC-HMS to simulate the lag and attenuation of peak flow from within open channels. The more common applications usually work well with the Muskingum method or the modified Puls method. Muskingum (McCarthy, 1938) methods simulate routing based on estimates of a travel time through a reach and a factor that represents the influence of both inflow and outflow in a particular river reach. Modified Puls methods are used to model a reach as a series of cascading level pools with user-specified storage-discharge relationships.

HEC-HMS can also simulate flows through lakes or a reservoir. Storage-discharge relationships are often used to characterise lakes in the modelling. Reservoirs are simulated by describing the physically spillway and/or other outlet structures. Pumps may also be supplied as a reservoir feature, which are often linked to water depth in collection ponds or stage in the main channel.

8.2 Hydraulic Modelling Approaches

Hydraulic modelling is a form of numeric modelling typically undertaken to assess the behaviour of fluid flow by solving a system of equations based on the principles of conservation of mass, momentum and energy. Hydraulic modelling in relation to flood studies, is typically undertaken to estimate for a given flood discharge or flood hydrograph, the corresponding flood level, depth and velocity at a given location.

There are a range of hydraulic modelling tools available including one dimensional spatial (1D), two dimensional (2D) and three-dimensional (3D) models capable of modelling steady and unsteady flow regimes. However, due to the complexity of fluid flow - all hydraulic models are required to make a set of approximations when solving for the conservation of mass, momentum and energy and are therefore all limited in some way. With appropriate application though some of these limitations will reduce by increasing the model complexity to better represent the natural system.

Given the limitations in each of the modelling approaches, it is important to determine which modelling tool is best suited for a study, based on the purpose and requirements of the study. For example, a 1D hydraulic modelling approach may not be suitable for assessing complex two-dimensional flow patterns on a large flat coastal floodplain. In determining which model may be best suited for a study, an assessment of the model limitations should be undertaken and a site inspection conducted to understand the terrain, existing flow behaviour, land use and vegetation of the study area.

8.2.1 One-Dimensional (1D) Models

1D hydraulic models are typically used in situations where the flow is in one longitudinal direction, flow patterns are well known and there is no significant change in flow distribution or channel shape. In 1D models, the channel geometry is generally represented as cross sections at specific locations along the waterway and the flow velocity is averaged over the flow cross section.

Definition

The 1D hydraulic model is defined by a model requiring only one spatial dimension to express the flow field at any given point along the river or creek - i.e. it requires that variables such as velocity and water depth change mostly in one defined direction along the channel. Although flow is generally described in three physical dimensions, in some instances there are negligible changes in the direction of one or two physical dimensions. For these cases, a 1D model is usually sufficient to model discharges through a simple river or channel system and provide an estimate of hydraulic parameters such as water level, water depth, and flow velocity.

1D models can be further divided into steady state and unsteady state models. Steady state models are typically 'backwater' type models based on the energy equation whilst unsteady models are generally based on variants of the St Venant momentum equation. Steady state models use a single flow rate (not varying with time) throughout the whole simulation of a model whereas unsteady state models consider the variation of flow with regards to time. Steady state models are more conservative (tend to overestimate water levels) as they assume a constant flow of water throughout the model simulation whereas flow volumes in unsteady models are usually limited to the volume of water associated with the storm event hydrograph(s)[39]. The selection between a steady or unsteady model depends largely on the purpose and requirement of the hydraulic assessment.

Examples of commercially available 1D hydraulic models include MIKE 11 (by DHI) and HEC-RAS (by the US Army Corps of Engineers).

Overview

Short run-time and low data requirements are the two main advantages of a 1D hydraulic model. Depending on the geometry being modelled, the set up and simulation of a 1D model is also relatively easy compared with a 2D or 3D model. 1D models are best suited for modelling steady or unsteady state flows through simple river systems, in-channel flows and minor floodplain flows. They are also often used to check and confirm head losses estimates at hydraulic structures in 2D models.

Input into 1D models includes reasonably detailed cross sectional data capturing the overall channel geometry and physical changes (such as bends, drops, constrictions and expansions) in the floodplain or channel; hydrological input (steady state inflows or hydrographs) and details of waterway crossings (such as culverts or bridges). 1D models can contain loops and multiple branches to represent more complex situations.

Typical outputs for a 1D model include long section and cross sectional flood profiles as well as tabulations of water surface elevation, cross-section averaged velocity, and discharge at each cross-section among others. Most 1D models do not have the capacity to map the results of hydraulic assessments on a 2D domain. However, GIS based software can be used to construct a time varying water surface elevation through temporal and spatial extrapolation of 1D hydraulic model results.

Limitations

1D models are not suitable for wide and generally flat floodplains or floodplains involving complex river systems and large amounts of 2D floodplain flow. Unsteady 1D models are generally based on a variant of the Saint Venant momentum equation. The following assumptions are made in the derivation of this equation:

- Pressure distribution in the vertical direction at any cross section is hydrostatic;
- Velocity is uniform within a cross section;

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[39] The hydrograph is the representation of the time-varying flow.

- Channel is prismatic with a small bottom slope;
- Steady-state resistance laws are applicable under unsteady conditions; and
- There is no significant lateral inflow or outflow.

Prior to undertaking any unsteady state 1D hydraulic modelling, the modeller needs to ensure that the assumptions are not significantly compromised.

1D hydraulic models are also not recommended when visualisation of 2D flow dynamics is required. Although results from 1D models can be easily extrapolated onto a 2D domain, the spatial resolution and level of detail presented are not as detailed as results generated from a 2D or 3D model.

8.2.2 Two-Dimensional (2D) Models

Two-dimensional hydraulic models are typically used for modelling of floodplains, complex and interacting flow paths, coastal systems and marine situations where flow patterns do not follow a clearly pre-defined path. Two-dimensional models calculate water levels, depths and velocities across a grid that is representative of the bathymetry and topography of the study area.

Definition

2D hydraulic models require 2 spatial coordinate dimensions to express the flow field. 2D models compute the velocity vector magnitude and direction throughout the model domain. As opposed to 1D models - flow in the 2D models does not have to be constrained to the general direction of the river centreline as flow can propagate in lateral and longitudinal directions across a continuous terrain surface at a specified grid resolution.

2D hydraulic models can also be coupled to 1D model domains to allow for a more detailed assessment of the hydraulic behaviour of in-channel flows and structures that may not be accurately represented within the selected grid resolution of the 2D model terrain (sub-grid effects).

Examples of commercially available 2D hydraulic models include MIKEFLOOD (by DHI), TUFLOW (by BMTWBM) and SOBEK (by Delft Hydraulics).

Overview

2D models are recommended for the following situations:

- when modelling complex rivers systems where flow patterns are clearly two-dimensional and 1D model assumptions are invalid;
- to assess overland flow and sheet flow in wide floodplains where the terrain is generally flat;
- when the study demands a higher level of spatial accuracy for the model outputs (for example the prediction of flood risk and flood hazard management, mapping etc);
- where floodplain storage or diversion of flood flows using levees or other works is significant;
- to allow for varying model resolution within one model domain. Many 2D modelling suites allow for this;
- to assess flow patterns in a large floodplain and also assess flow through minor drainage conveyances in 1D. This is done through 2D / 1D coupling;
- to model study areas with spatially varying landuse/vegetation across the floodplain; and
- when realistic visualisation of two-dimensional flow fields is crucial.

2D modelling requires high resolution geo-referenced bathymetric and topographic terrain data as well as hydrological inputs either in terms of steady state inflows, or dynamic hydrographs and tailwater conditions. These are input into the model as boundary conditions or as source points at the outlet of sub-catchments. Land-use details are generally incorporated into the model as a roughness map indicating the spatial distribution of estimated hydraulic roughness across the model domain.

Typical outputs of the 2D models include water surface elevations, water depths and velocity plots as well as flood extent details. Most 2D models provide a good interface for viewing 2D model results. These results can also be easily exported into various GIS software such as ArcGIS™ and MapInfo™ for post processing and additional GIS assessments.

Limitations

2D models are based on the Saint Venant (shallow water) equations that assume that vertical accelerations (and hence velocities) are negligible such that flow velocities are averaged over the depth at a given location, vertical pressure gradients are likewise hydrostatic, and horizontal pressure gradients result from displacement of the free water surface. As such, 2D models are not recommended for use when an understanding of the vertical distribution of hydraulic parameters is required. Two dimensional models are also not well suited to the simulation of supercritical flow.

2D model results can be very sensitive to the changes made in the terrain data, depending upon the model resolution. As such, it is important that the modeller undertake manual checks to ensure that the ground elevation data, particularly at critical locations such as waterway crossings or embankments for example are represented as accurately as possible in the 2D domain. The practical size of 2D model domains and the number of active computational points is generally limited by software capability and the available computing capacity. For large floodplains that need to be modelled - a relatively large grid size (low resolution) may be required or alternately, the model may have to be divided into a number of sub-models or a nested modelling approach adopted.

8.2.3 3D Hydraulic Models

3D hydraulic models are typically required where an understanding of the vertical profile of flood flow is required and there is a need to more accurately predict shear forces in instances where the flow is complex and does not adhere to the assumptions associated with 2D modelling. Possible examples include detailed analysis of river cross-sections that are relied upon to construct rating curves. Three dimensional model may also be necessary in instances where the transport and mixing of pollutants or prediction of water quality is required.

The numerical computations undertaken by 3D models are significantly more complex than those required for 1D and 2D models and available 3D models also vary widely in terms of their complexity and capability. Three dimensional models are diverse and can be undertaken on a very small scale (for instance a model of a single hydraulic device such as a weir) or very large scale (such as a model of a lake or the coastal ocean).Given the diversity of available 3D models and applications it is recommended that a detailed review of the limitations and assumptions of available 3D models be undertaken prior to any 3D modelling being undertaken.

Table 7 Summary of comparison between 1D, 2D and 3D models

Model	1D	2D	3D
Description	Flow fields are defined in one coordinate dimension	Flow fields are defined in two coordinate dimensions	Flow fields are defined in three coordinate dimensions
Computation method	Solution of the 1D energy equation or St Venant equation	Solution of the 2D St Venant equations	Approaches ranging from layered 2D models through to fine scale Computational Fluid Dynamics Models (CFD).
Topographic Basis	Cross Sections	Digital Elevation Model	Digital Elevation Model
Terrain data required	detailed cross sectional survey	high resolution geo-referenced ground survey data	High resolution geo-referenced ground survey data and in some cases, detailed survey of structures.
Hydrological input required	Steady state flows or hydrographs to be input as source points or boundary condition	Steady state flows or hydrographs to be input as source points or boundary condition	Steady state flows or hydrographs to be input as boundary condition. Modelling of natural hydrographs is possible but not generally practical.
Typical outputs	Time series of flood levels, depths and velocities at cross section intervals	Time series and spatial GIS grids of flood levels, depths and velocities	Detailed flow characteristics in the horizontal, vertical and time, providing vertical profiles, shear, streamlines, re-circulation and water levels.
Recommended for use when modelling	1D flow	Complex 2D flow	Verification of loss parameters in 1D and 2D models or where physical model otherwise required or 3D outputs required
Not recommended for modelling	Complex 2D or 3D flow	When vertical profiles are significant	Simple flow situations
Examples of commercially available models	MIKE 11, HEC-RAS	MIKEFLOOD, SOBEK, TUFLOW	MIKE3, DELFT 3D, Open FOAM, CFX

8.2.4 Calibration of Hydraulic Models

In order for a 1D or 2D numerical hydraulic model to be considered suitable for the purposes of accurately assessing various design flood events and flooding scenarios, calibration of the model is necessary.

The calibration process involves:

- Selection of appropriate historical flood events;
- Input of historic flood event hydrographs into the hydraulic model;
- Hydraulic model simulations to determine predicted flood levels, extents and velocities;
- Comparison of predicted flood levels and extents to recorded data and anecdotal records;

- Gradual adjustment of the various model parameters such as resistance and energy loss parameters within acceptable and reasonable limits to obtain closer agreement between simulated and recorded flood levels and extents;
- Validation of the hydraulic model calibration through simulation and checking of the models ability to replicate additional historical events.
- Particularly with respect to performance around structures 1D and 2D hydraulic models can be compared with physical models and or CFD

There are a number of uncertainties that need to be considered during the calibration process including:

- Poor or insufficient availability of historic flood data;
- Poorly recorded data;
- Insufficient bathymetric and topographic survey data;
- Historic changes to bathymetric and topography; and
- Uncertainty in the accuracy of existing rating curves.

8.3 Floodplain Damage Estimation Assessment

There are a number of types of possible riverine and coastal flood damage with Table 8 showing the inter-relationship of various damage types commonly used in floodplain management studies.

8.3.1 Tangible and Intangible Damages

The most basic division of flood damages is into tangible and intangible damage categories.

Tangible damages are financial in nature and can be readily measured in monetary terms after an event but are less reliably predicted in general. They include the damage or loss caused by floodwaters wetting goods and possessions (direct damages) and the loss of wages, business interruption and extra outlays incurred during clean-up operations and in the post-flood recovery period (indirect damages).

Intangible damages do not have a ready conversion to financial values however intangible damages are real and represent a significant cost to flood affected persons, a cost that can be long-lived. These can include the increased levels of emotional stress and mental and physical illnesses related to the flood episode. Most floodplain management studies acknowledge intangible damages but do not attempt to quantify them as it is difficult, if not impossible, to quantify intangible damages in financial terms.

However, it is possible to approximate the scale of the problem by, for example, estimating how many flood-affected people may require additional medical treatment for depression or the ecological cost of the loss of a local environmental feature.

Table 8 Classes of flood damage

	Direct Actual Contact with Flood Water	Indirect Disruption Caused by the Flood
Tangible Financial	Building contents cleaning, and repair or replacement of goods; Damage to cupboards walls, doors and repair or replacement of structural item; Contents of sheds, urban infrastructure and vehicles; Damage to plant and equipment at commercial, industrial or public utilities facilities; Damage or loss of physical public assets such as schools; Damage or loss of roads, transport infrastructure and associated rolling stock, plant and equipment; Damage or loss of crops or livestock; Removal of flood debris and removal of discarded items.	Costs of evacuation; Costs for people undertaking post-flood clean-up; Loss of wages, loss of sales, loss of production, reduction in supply of agricultural products, alternative accommodation; Unavailable services; Opportunity costs; Loss of tourism revenue.
Intangible Social and Environmental	Loss of life / injury; Ill-health; Loss of memorabilia; Gain and Loss of topsoil; Loss of environmental function, services, and amenity.	Inconvenience; Worry; Ill health; Loss of future agricultural productivity; Change in groundwater recharge; Interrupted schooling.

8.3.2 Direct and Indirect Damages

The two basic categories of tangible damages are direct and indirect damages:

- Direct damages are caused by floodwaters wetting goods and possessions, thereby either damaging them irreparably or reducing their value. Some items might be capable of repair, whilst other items will be damaged beyond repair. In the first case, the direct damage is equal to the cost of repairs plus the loss in value of the repaired item. In the second case, the direct damage is equal to the pre-flood value of the item or its replacement cost.
- Indirect damages are the additional financial losses caused by the flood. These can include the extra cost of food and accommodation for evacuees (i.e. the additional cost above normal costs in a non-flood situation). It also includes any loss of wages by employees, the loss of actual and prospective production or sales by flood-affected commercial and industrial establishments, and opportunity cost to the public caused by the closure or limited operation of public facilities.

Direct Damage Categories

The direct damage to a property is commonly divided into three categories:

- Contents damage;
- Structural damage; and
- External damage.

Contents damage refers to damage to the contents of buildings, for example in the case of residential properties, damage to carpets, furniture, etc.

Structural damage refers to damage to the structural fabric of buildings, for example damage to foundations, walls, floors, doors and windows, etc. Note that structural damage also includes damage to built-in fittings (these items are regarded as part of the structure of a building).

External damage includes damage to all items external to buildings. A common and significant form of external damage is damage to parked motor vehicles. Fences, out buildings, livestock, goods stockpiles, plant and equipment are also other common external damages (loss) due to floods.

Indirect Damage Categories

Indirect damage can be conveniently divided into three categories: clean-up costs, financial costs and opportunity costs.

Clean-up costs can be treated as an indirect cost or as a category of direct costs. Much of the cost of clean-up operations arises from the time spent by people in this activity. They are either foregoing wages or other more satisfying activities when participating in clean-up operations. However, when public agencies / utilities are employed in a broad-scale clean-up, these costs can be both tangible and directly associated with the flood event.

Financial costs refer to all other actual expenses suffered by people and businesses in the flooded area, either directly or indirectly. These include loss of wages, sales, and production and alternative accommodation.

Opportunity costs refer to the absence or reduced levels of service provided by public authorities and facilities, such as school closures and limited telephone facilities. Opportunity costs are imposed on the general public, including those owning properties outside the floodplain.

Sector Costs

Tangible flood damage costs, both direct and indirect, can be usefully classified into different land use sectors, such as residential, commercial, industrial, agricultural, public institution, public utility, recreational, primary production and others. Typically, in most urban flood damage studies, only three or four sectors are recognised, these are residential, commercial, industrial (or commercial/industrial combined) and public properties. Studies encompassing rural areas will require a broader range of issues to be covered.

8.3.3 Emotional, Mental & Physical Health Costs

A flood imposes a range of intangible damages on flood victims. These include the emotional, mental and physical ill-health of the victims. Although it is impossible to fully measure these costs in financial terms, they are of significance to victims and to the post-flood recovery of the community.

8.3.4 Potential Damages

Potential damages are the maximum damages that could eventuate should such a flood occur, as opposed to the actual damages that occur. In assessing potential damages, it is assumed that no actions are taken by the flood affected population during the flood event to reduce damage, such as lifting or shifting items to flood free locations and moving motor vehicles.

Typically, damage reduction factors are used to convert potential damage estimates to actual damage estimates. Two important parameters affecting damage reduction factors are the length of the effective flood warning period and the flood preparedness of the affected population. The longer the effective warning period, the more time is available for evacuating goods and possessions. The more prepared the population, the more effective these measures will be.

8.3.5 Collection of Flood Damage Data

Each flood provides an opportunity to gather data concerning actual flood behaviour and flood damage. A critical element of a comprehensive flood response plan is the immediate initiation of flood data gathering during and immediately following onset of a flood. Surveys of actual flood damage should be undertaken as soon as practical after a flood has occurred. The data can be used to confirm the effectiveness or otherwise of management measures already in place. They also provide essential information for future flood studies and floodplain management plans.

Local Council Responsibilities

Local councils are in an excellent position to coordinate the collection of local data to assist in future flood investigations. Collection of relevant basic flood damage data need not be a lengthy or costly procedure. There are two basic steps associated with an actual flood damage survey. The first step involves identifying, where practicable, every property and/or every building which was inundated by flood waters and recording the depth of inundation or the level to which flood waters rose. The second step involves recording in detail, the extent of damage, for some or all of the buildings and properties. The two basic steps may be conducted together, within days of the flood reaching its peak, or the second step may be conducted some weeks after flood waters have receded, but while memories are still fresh. Some data on buildings in the flooded areas may be readily obtained from council records within 24 hours of a flood, and used in discussions with the owners or occupiers of flooded premises.

Urban Flood Damage Data

Basic flood damage data to be collected from urban areas (irrespective of whether the damage is caused by local overland or mainstream flooding) includes the number and type of flooded properties and depths of flooding within buildings and across grounds. No estimates of flood damage or flood loss per se are required. Each urban property that is partially or fully covered by floodwaters needs to be included in the survey, irrespective of whether or not buildings are flooded above floor level.

Note that some data need to be assessed subjectively usually on a comparative basis, such as building size. A quick inspection of house sizes can provide broad guidelines for ‘small’, ‘medium’ and ‘large’ dwellings. Similarly, house style will provide a reasonable guide to building age if that is not otherwise readily available.

Rural Flood Data

Basic flood damage data to be collected from rural areas relate to crop and stock losses on a farm-by-farm basis. These losses also should include agistment costs and fodder and feed costs. Coordination between the local council and State authorities is normally necessary to collect data on rural infrastructure damage and or extensive rural enterprise operator consultation. In the case of rural flood damage, the farmer is typically asked to estimate the value of his losses. Rural flood surveys may take longer than urban surveys because of the larger areas involved, , the wider range of enterprise types, and the regularly large variations in normal production efficiencies, and thus actual and potential losses, between different operators. There are also typically more physical aspects of a flood that need to be considered in agricultural flood damages assessment. For example, the duration of flooding is usually more important in agricultural losses assessment than in urban settings, as some crop types can survive a period of inundation, but may be lost if inundation persists. The timing of flood with the crop planting, growth, harvest cycle is also another factor to be considered, where as potential urban flood losses are likely to remain static (or very slowly varying) with time.

Coastal Storm Tide Data

Damage in the coastal margins due to the effects of storm tide (including waves) should be collected from the available historic sources (local, national and international).

8.3.6 Estimation of Flood Damage Costs

The flood damage data collected, when combined with data collected under similar situations and circumstances elsewhere, is generally used to estimate the cost of flooding for a specific urban or rural area.

The benefit and effectiveness of proposed mitigation measures can be compared by estimating:

- Flood damage that would be caused by different sized flood events that might occur now;
- The reduced flood damage that would be caused by those floods after specific mitigation measures were implemented; and
- The potential damage costs for proposed new development areas considering likely development conditions.

Potential Damage

Flood damage studies are frequently necessary for areas that have no recent records of damage in an actual flood. Potential damages should be estimated, in these cases.

In a potential damage survey, a sample of representative properties is first identified and then potential damages to these properties are determined, either by questionnaire or through personal inspection by a trained valuer. This is different from some actual damage questionnaire surveys, in which property owners estimate their own damages. Damage reduction factors are used to convert potential damage estimates to actual damage estimates.

Stage-Damage Curves

Actual and potential flood damage data can be presented as so-called stage-damage curves for different property types. Such curves relate contents (or building/structural) damage to depth of flooding above floor level. These curves are generally derived on the basis of numerous damage studies undertaken throughout Australia. Stage-damage curves can be derived for residential, industrial, commercial, rural and public properties.

DNRE (2000) aka the *Rapid Assessment Method* (RAM) has been a popular analysis method developed from a variety of sources that is amenable to GIS applications. Likewise DECCW (2007)[40] has more recently provided an alternate methodology that is spreadsheet-based. Importantly any such methods should be reviewed and assessed for suitability for local conditions before being adopted.

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[40] http://www.environment.nsw.gov.au/resources/floodplains/ResidentialDamageCurve.xls

Computer Models and Property Counts

To determine the flood damage over a specific urban area it is necessary to know the number of flooded properties, the type of flooded properties and the depth of flooding above floor level. The number of flooded properties can be determined from flood studies, flood maps, aerial photographs or from a street by street inspection.

It is generally very difficult to discriminate property types from aerial photographs. Knowledge of flood levels and floor levels throughout the flooded area will enable flood depths over the floor to be estimated for each building. Floor level data may be obtained either from council plans or by measuring floor height above ground level, with ground levels estimated from contour maps. The appropriate stage-damage curve allows the damage to be estimated for each property. A computer model or a spreadsheet is typically used to combine all these data and estimate the flood damage for different flood levels up to and including the probable maximum flood (PMF). Similar procedures are used to estimate flood damage costs for rural areas.

Accuracy and Reliability

To obtain consistent and reliable estimates of flood damage requires care and experience. Even so, such estimates are necessarily approximate. For properties of the same type, there is typically a widespread variation in damage from property to property. Stage-damage curves reflect average damages.

Thus, when using stage-damage curves to assess damage in an unsurveyed property, the estimate is necessarily approximate. However, if the sample of surveyed properties has been chosen correctly, the total damage estimate for all flooded properties can be expected to be more reliable. Further inaccuracies creep into damage estimates from uncertainties in flood, ground and floor levels. Again, if the estimation procedures are correctly chosen, there should be no gross bias in the total damage estimate. To understand and minimise these uncertainties the damage assessment should be carried out by an experienced practitioner and sensitivity testing undertaken.

8.3.7 Average Annual Damage (AAD)

Over a long period of time, a flood-liable community will be subject to a succession of floods. In many years, no floods may occur or the floods may be too small to cause significant damage. In other years, the floods will be large enough to cause significant damage and may cause catastrophic damage.

The average annual damage (AAD) is equal to the total damage caused by all floods over a long period of time divided by the number of years in that period. (It is assumed that the development situation is constant over the analysis period).

All of these cost factors have to be weighed up and evaluated in determining the relative economics of possible mitigation measures. The AAD provides a consistent means of evaluating the physical economic benefits of different mitigation measures for those aspects that can be monetarised.

Determination of AAD

We do not know the actual sequence of floods that will occur at a particular flood-liable community. However, we do know that on average, the estimated 20 year ARI event will be exceeded once every twenty years (an AEP) of 5%), the 50 year event will be exceeded on average once every 50 years (an AEP of 2%), etc. Further, by examining a range of floods, we can estimate the potential and actual damages caused by floods of different severities. The variation of flood damage with the annual likelihood of exceedance of the flood (ARI or AEP) can then be calculated on a property by property basis as illustrated in Figure 8-2.

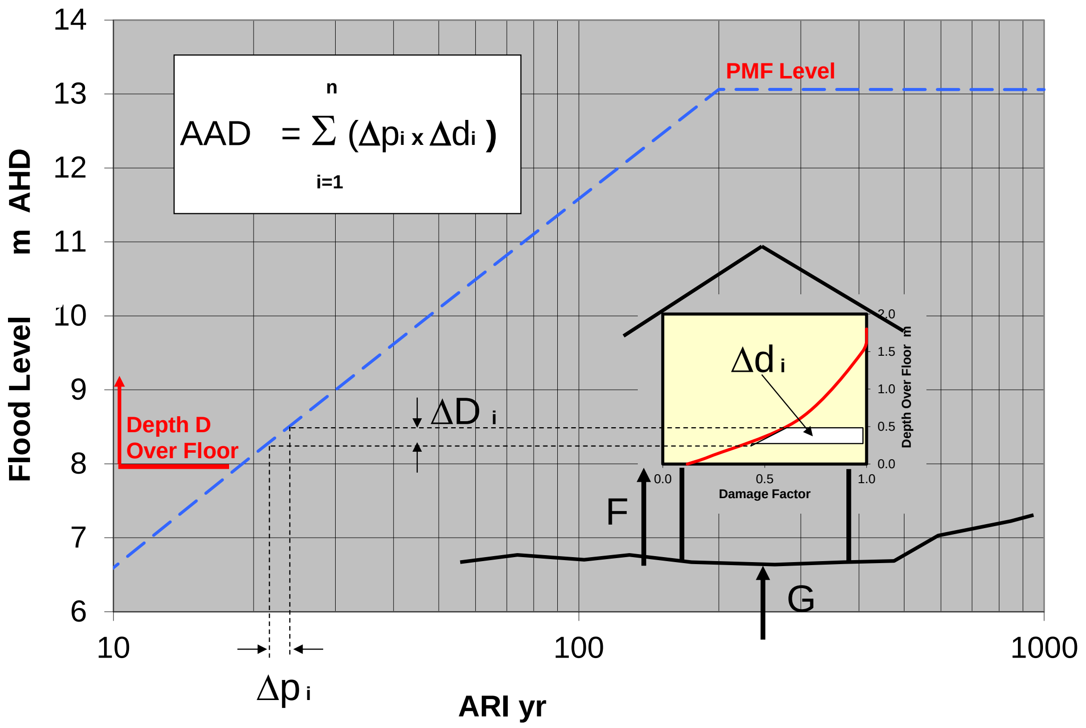

Figure 8-2 Example calculation of average annual damage for a property.

The result of such an analysis is illustrated in Figure 8-3, which indicates that in this particular example flood damage only commences above the 10% AEP flood event and the more extreme the flood, i.e. the lower the AEP, the greater the flood damage. Flood damages in this example increase slowly and linearly from the 10% (10-year ARI) up to the 5% AEP (20-year ARI) and then steepen, likely due to the increase of the flood extent in this particular example. Below the 2% AEP it steepens even more. The AAD is equal to the area under the damage – annual likelihood of occurrence curve. The choice of a specific DFE can therefore be informed by the sensitivity of AAD to AEP.

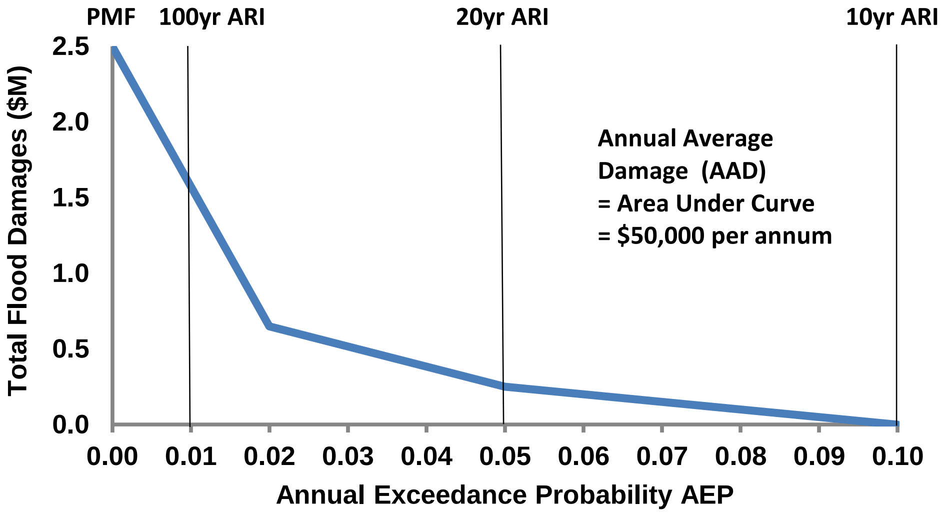

Figure 8-3 Example flood damage estimation curve

8.3.8 Future Flood Damages

It is important that the question of flood damages related to future developments on flood-prone land, urban or rural, is also considered in the formulation of a floodplain management plan.

This type of investigation should consider future land use scenarios, projected lot sizes, occupancy rates and estimated flood impacts.

Flood level information from the flood study coupled with the stage damage curves (from damage studies for existing development) can be used to assess the viability of the range of land use proposals under consideration and to provide a sound basis for the long-term, strategic management of the flood-prone land.

8.4 Floodplain Management Studies and Plans

The purpose of a Floodplain Management Study (FMS) is to identify, assess and compare various flood management options and consider opportunities for environmental enhancement as part of mitigation works. The recommendations from such studies then form the basis of a Floodplain Management Plan (FMP) to enable implementation of agreed actions and incorporation into the relevant planning scheme. Figure 8-4 provides an overview of the floodplain management process that is described in the following sections.

8.4.1 The Floodplain Management Study (FMS)

The management study draws together the results of the flood study with exposure and vulnerability data. It provides information and tools to allow strategic assessment of the impacts of management options (for existing, future and residual flood risk) on flood behaviour and hazard and the social, economic, ecological and cultural costs and benefits of options. It also provides the basis for robust decision making in the management plan (DIPNR 2005, GHD 2011).

A management plan generally involves a mix of options as it is unusual for a single management option to manage the full range of flood risks. Determining the optimum mix of measures can require complex studies, exercise of professional judgement and extensive community consultation. Typical options considered are indicated in Table 9 and should include:

- property modification measures including development controls in new areas, and voluntary purchase (retreat) and house raising in developed areas;
- response modification measures such as preparation, evacuation and associated operational logistics; and
- flood modification measures including levees and bypass channels

The impact of management works or proposed developments on flooding behaviour elsewhere should be assessed on a cumulative rather than individual or ad hoc basis within the context of the management plan. This includes both the effect of development on flood behaviour and the number of people who may require evacuation, particularly in rare flood events. Where mitigation works are considered, they should be designed to produce net positive ecological outcomes, where practical and feasible.

Selection of a Designated Flood Event (DFE) is a key tool for the management of flood risk in respect of planning structural measures to reduce current risk, and establishing development controls to avoid increase in risk due to inappropriate development on the floodplain. DFEs represent a selected flood event (ideally a certain statistical probability) and an appropriate freeboard[41]. DFEs represent a point in the continuum of possible flood magnitudes (damages, risk) that the community has adopted as the minimum acceptable/affordable standard or objective for certain flood risk management actions.

The provisions of the SPP require that appropriate DFEs be set and that these are translated into natural hazard management areas (flood) and identified in the planning scheme. Iterative processes of the Flood Study and the FMS should be undertaken to develop the required mapping and the FMS/FMP process should include appropriate actions to facilitate inclusion of these in the planning schemes by Councils at and appropriate time.

Table 9 Typical floodplain management measures

Flood Modification Measures	Property Modification Measures	Response Modification Measures
flood control dams	zoning	flood plans
bypass floodways	building and development controls	flood prediction and warning
levees	voluntary purchase	evacuation arrangements
channel improvements	house raising	recovery plans
retarding basins	flood proofing buildings	community education
flood gates	emergency egress	community preparedness

Unless the DFE is based on the PMF, a larger flood than that used to determine the DFE can always occur. It is not a matter of if such an event will occur but when it will occur. The difference in flood levels, damages, and the area of inundation and the number of dwellings to be evacuated in the PMF event relative to the event upon which the DFE is based, serves to alert government and the floodplain community to the upper limit of the costs and consequences of flooding.

Finally, in consideration of the potential changes to the climate of extreme events that cause flooding, the design life of projects must be subject to close scrutiny so as to avoid costly upgrading or redesign of adopted measures.

8.4.2 Floodplain Management Plan (FMP)

The purpose of a management plan is to provide input into the strategic and statutory planning roles of councils and to prioritise the range of management measures adopted from the FMS. It does not, by intent, purport to be the only document relevant to development of flood-prone land. The management plan provides the type of information necessary for adequate forward planning for flood prone-land. The advantages to both council and the community in general of having a properly considered management plan in place include:

- Having a proper basis for managing and using flood-prone land to provide a balance between danger to personal safety, economic losses due to flooding, and social, ecological and cultural interests. This provides the current and future community the best value from managing and using its floodplains;
- Maximising benefits of community infrastructure, such as roads, water supply and sewerage by ensuring they are not in flood-prone situations;
- Minimising personal danger to residents, visitors and emergency response personnel and community flood damage;

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[41] Freeboard is an explicit allowance for uncertainty that is often nominal (e.g. 0.3 m) but should be based on a quantitative assessment of the variance of the design event magnitude.

- Having a sound basis for the setting of appropriate budgets for flood mitigation works and programs;
- Prioritisation of available budgets and other resources to flood mitigation works at individual natural hazard areas based upon level of risk
- Land can be identified for development and the impacts of its development on flooding and the effects of flooding on the development can be effectively considered. This provides a sound basis for incorporating floodplain management outcomes in revising Council's planning instruments and development controls. It allows the community to grow in a responsible and socially cohesive fashion in consideration of flood issues. It also provides for increased certainty, from a flood perspective, for development applications in line with the relevant planning requirements; and
- Having a basis for more timely assessment of development applications for flood-prone land, especially where Council's planning instruments and development control plans and/or policies have been altered, in light of the management plan, to incorporate appropriate zonings, and flood related controls. Individual development applications are thus limited to the best way to achieve the required outcomes on individual sites.

8.4.3 Plan Implementation

Once a management plan has been adopted, it needs to be implemented. Certain components can be implemented relatively quickly, such as incorporating flood-related development controls into policy and planning instruments and flood education programs. Others require additional investigations and design, and funding.

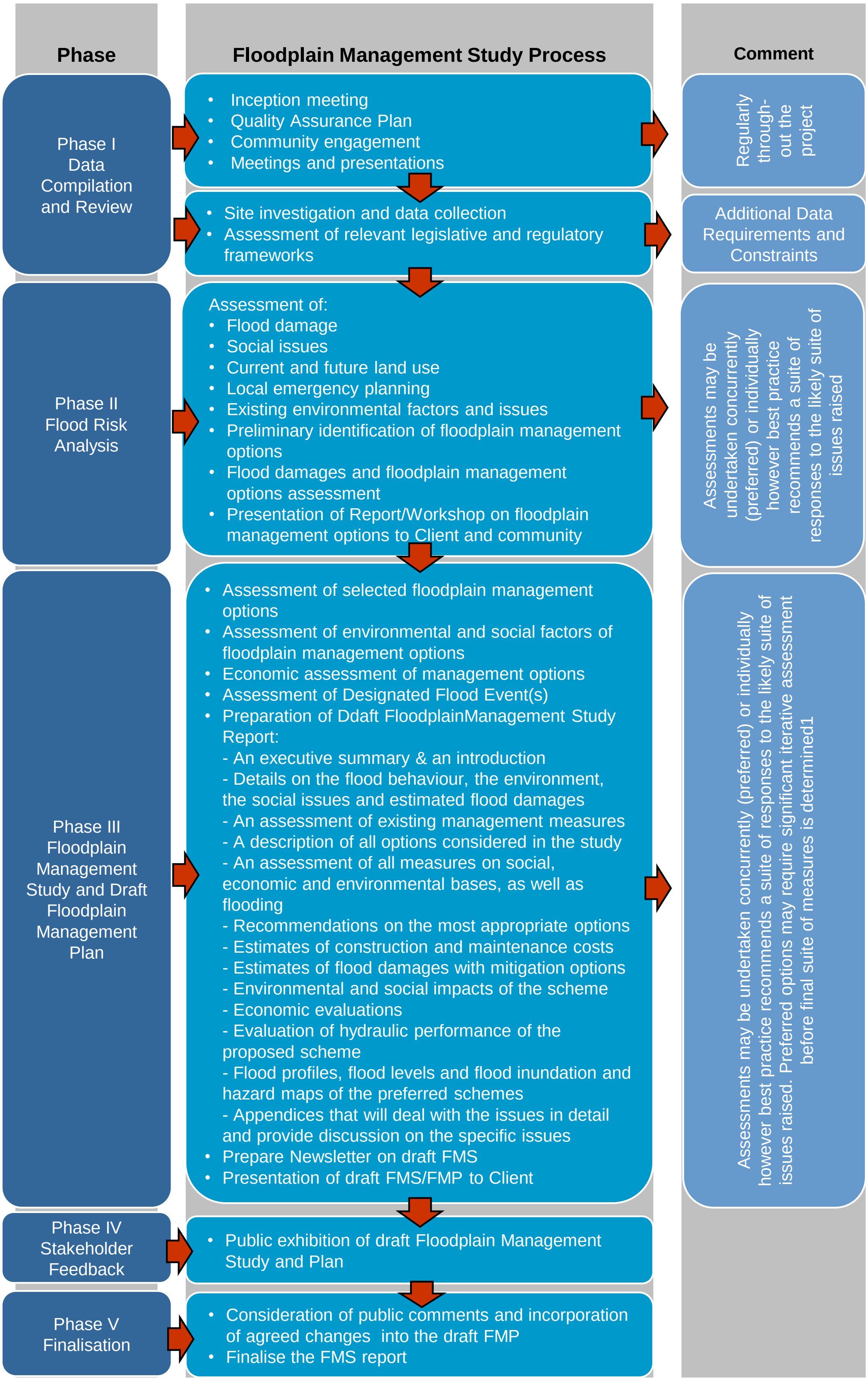
It is unlikely that any management plan could be implemented immediately in its entirety. For example, availability of funding will determine when mitigation works can commence. Consequently, an implementation strategy is required to stage components dependent on funding availability and the management plan needs to consider adoption of interim measures. The implementation strategy should be developed during the preparation of the management plan and incorporated in the plan.

8.4.4 Review of an Adopted Management Plan

Review of management plans should be triggered by the following instances:

- Elapsed time - review regularly, around every 5 to 10 years, possibly within 5 years if a damaging flood has occurred in the meantime;
- After significant flood events which provide additional data on flood behaviour;
- Where significant changes occur to the factors influencing the decisions in the plan, including changes to local flood plans;
- Where impediments to implementation exist that warrant a review; and
- Where changes in future land-use trends outside those considered in the management plan are proposed.

This review should account for changes across the full range of issues originally addressed and consider any associated emergent issues.



Phase

Floodplain Management Study Process

Comment

Phase I
Data Compilation and Review

- Inception meeting
- Quality Assurance Plan
- Community engagement
- Meetings and presentations

Regularly through-out the project

- Site investigation and data collection
- Assessment of relevant legislative and regulatory frameworks

Additional Data Requirements and Constraints

Phase II
Flood Risk Analysis

Assessment of:

- Flood damage
- Social issues
- Current and future land use
- Local emergency planning
- Existing environmental factors and issues
- Preliminary identification of floodplain management options
- Flood damages and floodplain management options assessment
- Presentation of Report/Workshop on floodplain management options to Client and community

Assessments may be undertaken concurrently (preferred) or individually however best practice recommends a suite of responses to the likely suite of issues raised

Phase III
Floodplain Management Study and Draft Floodplain Management Plan

- Assessment of selected floodplain management options
- Assessment of environmental and social factors of floodplain management options
- Economic assessment of management options
- Assessment of Designated Flood Event(s)
- Preparation of Ddaft FloodplainManagement Study Report:
  - An executive summary & an introduction
  - Details on the flood behaviour, the environment, the social issues and estimated flood damages
  - An assessment of existing management measures
  - A description of all options considered in the study
  - An assessment of all measures on social, economic and environmental bases, as well as flooding
  - Recommendations on the most appropriate options
  - Estimates of construction and maintenance costs
  - Estimates of flood damages with mitigation options
  - Environmental and social impacts of the scheme
  - Economic evaluations
  - Evaluation of hydraulic performance of the proposed scheme
  - Flood profiles, flood levels and flood inundation and hazard maps of the preferred schemes
  - Appendices that will deal with the issues in detail and provide discussion on the specific issues
- Prepare Newsletter on draft FMS
- Presentation of draft FMS/FMP to Client

Assessments may be undertaken concurrently (preferred) or individually however best practice recommends a suite of responses to the likely suite of issues raised. Preferred options may require significant iterative assessment before final suite of measures is determined1

Phase IV
Stakeholder Feedback

- Public exhibition of draft Floodplain Management Study and Plan

Phase V
Finalisation

- Consideration of public comments and incorporation of agreed changes into the draft FMP
- Finalise the FMS report

Figure 8-4 Overview of a floodplain management process

8.5 Communication and Stakeholder Consultation Activities

To ensure community acceptance of the floodplain management process, it is necessary to adopt a well-planned, comprehensive and integrated stakeholder consultation and public awareness-raising of the flood studies and floodplain management plan. This will help facilitate community and key stakeholder understanding of the flood studies and uptake of the plan and its management strategies.

Communication activities would occur in parallel with the process, and should occur throughout the life of the project program. Communication should continue following launch of the floodplain management plan to facilitate the successful implementation and to manage residual risks.

The State Government's 'Engaging Queenslanders: Community engagement in the business of government' policy (DC 2005) also identifies the importance of involving stakeholders, citizens and communities in policy development at the earliest possible stage and regularly through all stages of policy development, with the following policy outcomes:

- Gaining a greater understanding of the policy issue being considered;
- Identifying a broader range of options and possible solutions; and
- Developing more effective and sustainable policies that better meet the needs of citizens and communities.

Communication and stakeholder consultation in the floodplain management setting is not necessarily a straightforward process. The COAG report (DTRS 2004) on natural disasters in Australia identified its importance and the fact it has often been done poorly:

"Public awareness of natural hazard issues is arguably the least practised and most poorly funded mitigation measure in Australia. With very few exceptions, it is undertaken as a limited auxiliary activity to other disaster management initiatives, rather than as a sustained strategic measure to raise public consciousness and understanding of hazard risks, impacts and minimisation.

Public awareness programmes are generally limited by the following deficiencies:

- Low levels of resources;
- Lack of professional design and delivery;
- Limited audiences being targeted;
- Few programmes being subject to evaluation to assess success or otherwise, and
- Efforts being sporadic rather than sustained"

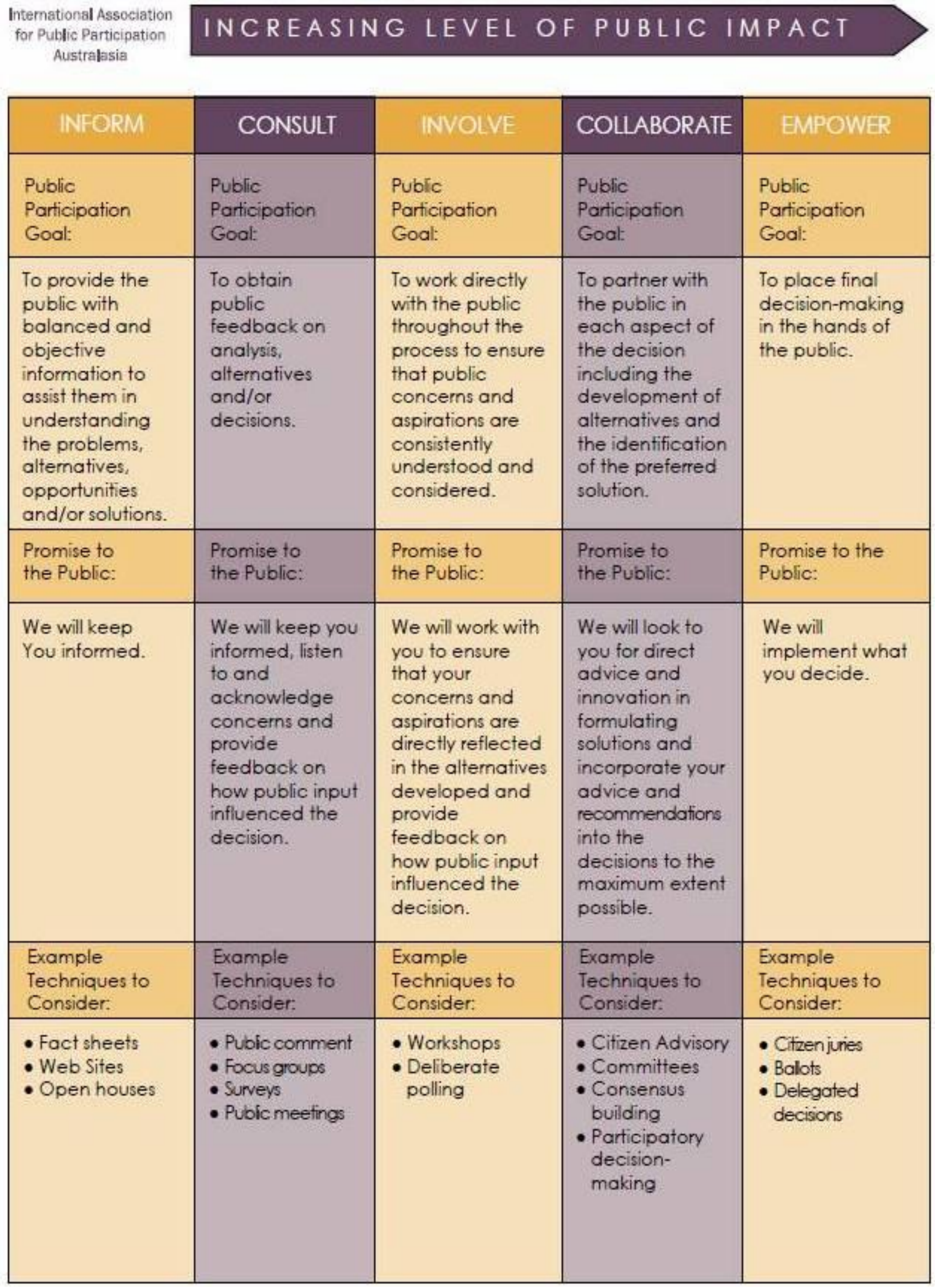
To underpin an effective Communication and Stakeholder Engagement plan, it is necessary to determine the most appropriate level of engagement for each region and according to the project sequencing.

Best-practice community engagement industry association, the International Association of Public Participation (IAP2), has developed a tool to define the level of public participation in any given issue as a spectrum relating the level of engagement to the level of public impact.

The spectrum (Table 10) includes the most basic level of engagement as simply informing the public of a course of action or policy, and this is appropriate for issues which will not significantly impact the community. Further along the spectrum of impact the greater the recommended involvement of the community.

It is acknowledged that for the BRCFS, the level of public participation as it relates to the IAP2 spectrum, would involve an INFORM and CONSULT approach however it is important to avoid building an expectation that the community would directly influence decision-making, particularly in relation to flood mitigation strategies which rely on technical inputs.

Table 10 The IAP2 public participation spectrum



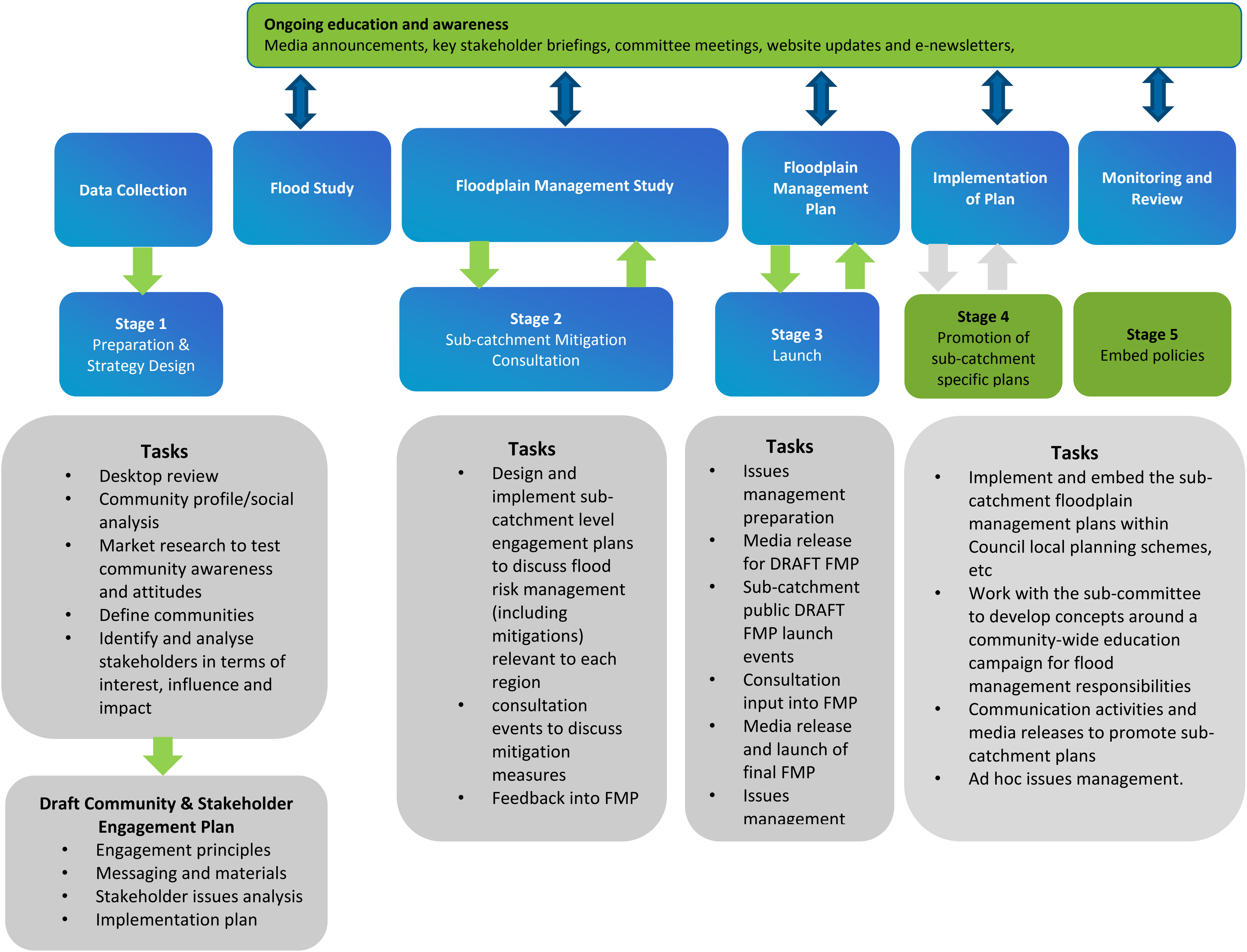
International Association for Public Participation Australasia

INCREASING LEVEL OF PUBLIC IMPACT

INFORM	CONSULT	INVOLVE	COLLABORATE	EMPOWER
Public Participation Goal:	Public Participation Goal:	Public Participation Goal:	Public Participation Goal:	Public Participation Goal:
To provide the public with balanced and objective information to assist them in understanding the problems, alternatives, opportunities and/or solutions.	To obtain public feedback on analysis, alternatives and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution.	To place final decision-making in the hands of the public.
Promise to the Public:	Promise to the Public:	Promise to the Public:	Promise to the Public:	Promise to the Public:
We will keep You informed.	We will keep you informed, listen to and acknowledge concerns and provide feedback on how public input influenced the decision.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will look to you for direct advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.
Example Techniques to Consider:	Example Techniques to Consider:	Example Techniques to Consider:	Example Techniques to Consider:	Example Techniques to Consider:
• Fact sheets • Web Sites • Open houses	• Public comment • Focus groups • Surveys • Public meetings	• Workshops • Deliberate polling	• Citizen Advisory • Committees • Consensus building • Participatory decision-making	• Citizen juries • Ballots • Delegated decisions

Based on the above approach and with regard to the various steps and activities expected for the BRCFS, Figure 8-5 provides an overview of a suitable stakeholder and community engagement process as a series of Stages.

Figure 8-5 Overview of a stakeholder and community engagement process



Ongoing education and awareness
Media announcements, key stakeholder briefings, committee meetings, website updates and e-newsletters,

Data Collection

Flood Study

Floodplain Management Study

Floodplain Management Plan

Implementation of Plan

Monitoring and Review

Stage 1
Preparation & Strategy Design

Stage 2
Sub-catchment Mitigation Consultation

Stage 3
Launch

Stage 4
Promotion of sub-catchment specific plans

Stage 5
Embed policies

Tasks

- Desktop review
- Community profile/social analysis
- Market research to test community awareness and attitudes
- Define communities
- Identify and analyse stakeholders in terms of interest, influence and impact

Draft Community & Stakeholder Engagement Plan

- Engagement principles
- Messaging and materials
- Stakeholder issues analysis
- Implementation plan

Tasks

- Design and implement sub-catchment level engagement plans to discuss flood risk management (including mitigations) relevant to each region
- consultation events to discuss mitigation measures
- Feedback into FMP

Tasks

- Issues management preparation
- Media release for DRAFT FMP
- Sub-catchment public DRAFT FMP launch events
- Consultation input into FMP
- Media release and launch of final FMP
- Issues management

Tasks

- Implement and embed the sub-catchment floodplain management plans within Council local planning schemes, etc
- Work with the sub-committee to develop concepts around a community-wide education campaign for flood management responsibilities
- Communication activities and media releases to promote sub-catchment plans
- Ad hoc issues management.

8.6 Past Regional Studies

This section outlines a chronology of flood studies for the Brisbane River catchment based on information obtained from various documents including the Queensland Floods Commission of Inquiry Final Report (QFCI 2012), WMAwater's Brisbane River 2011 Flood Event – Flood Frequency Analysis Final Report (WMAwater 2011) and SKM (2011). The studies that have been able to be identified are listed in Table 11 with the various estimates of so-called Q100[42] peak flow rates and flood levels applicable to the Brisbane City (or Port Office as it was historically) gauge illustrated in Figure 8-6. While some of these studies were only completed to a draft stage or were not specifically prepared for the purpose of estimating flooding in Brisbane City (personal communication J. Ruffini, DSITIA), this figure highlights the difficulty of such investigations and the associated high level of variability and uncertainty possible in the results. Similarly, two estimates of the level in the Bremer River at Ipswich corresponding to Q100 differed by more than 5 m (15.28 m and 20.6 m). The QFCI expert panel (QFCI 2011b,c) concluded that it was not possible to assign a Q100 flood level without a comprehensive flood study of the Brisbane River catchment and noted the complexities, including the interaction between the Brisbane and Bremer Rivers, and the significant variation of flood levels at Ipswich.

8.6.1 Chronology of Flood Studies and Outcomes

Contemporary investigations into flooding of the Brisbane River catchment date from the mid-1970s, when efforts were made to gain an understanding of the impact of the then-proposed Wivenhoe dam. The most comprehensive investigations from this period were Weeks (1984) and Hegerty and Weeks (1985) for the Queensland Water Resources Commission and Brisbane City Council, which provided the first estimates of 100-year ARI peak flow rates at Brisbane City using a calibrated runoff-routing model. The initial 1984 estimate of 5510 m^3/s was revised upwards to 6800 m^3/s in 1985 following a flood frequency analysis that included the operation of the Wivenhoe and Somerset dams. An unknown 1984 report cited by WMAwater (2011), likely associated with these studies, contained a Q100 flood level of 3.3 m AHD at the Brisbane City or Port Office Gauge. During this period, Brisbane City Council first adopted the planning level of 3.7 m AHD at the Brisbane City Gauge that remained in place until 2011 (Brisbane City Council, Submission No. 2 to the QFCI, 8 April 2011 [p2: para 2.2]; [p9: para 4.7]). This level was based on an estimate of the likely mitigating effect of an early Wivenhoe Dam design on a flood similar to the 1974 event.

The *Brisbane River and Pine River Flood Study* was commissioned by the South East Queensland Water Board as part of an overall safety review of the Board's dams and was undertaken by the former Department of Primary Industries from 1990 to 1994. Early reports prepared as part of the study through 1992 and 1993 involved the calibration of a runoff-routing model and design flood estimation. The March 1993 report, later referred to as a draft, revised the Q100 estimate up to 8580 m^3/s. A later report, completed in August 1993, determined a new Q100 estimate of 9120 m^3/s using the WT42D runoff-routing model, although several more recent sources (City Design 1999, CMC 2004) reference a different value of 9380 m^3/s that was derived from an alternative storm pattern. The *Brisbane River System Hydraulic Model Report* (DPI 1994) outlined the development and calibration of a RUBICON hydrodynamic model that extended from the Wivenhoe Dam to Moreton Bay. The operating rules for the Wivenhoe and Somerset dams in place at the time of the January 2011 flood event were originally developed as part of this body of work.

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[42] The "Q100" is a reference to the estimated 1% AEP or 100 yr ARI design flow event that is local to Queensland usage.

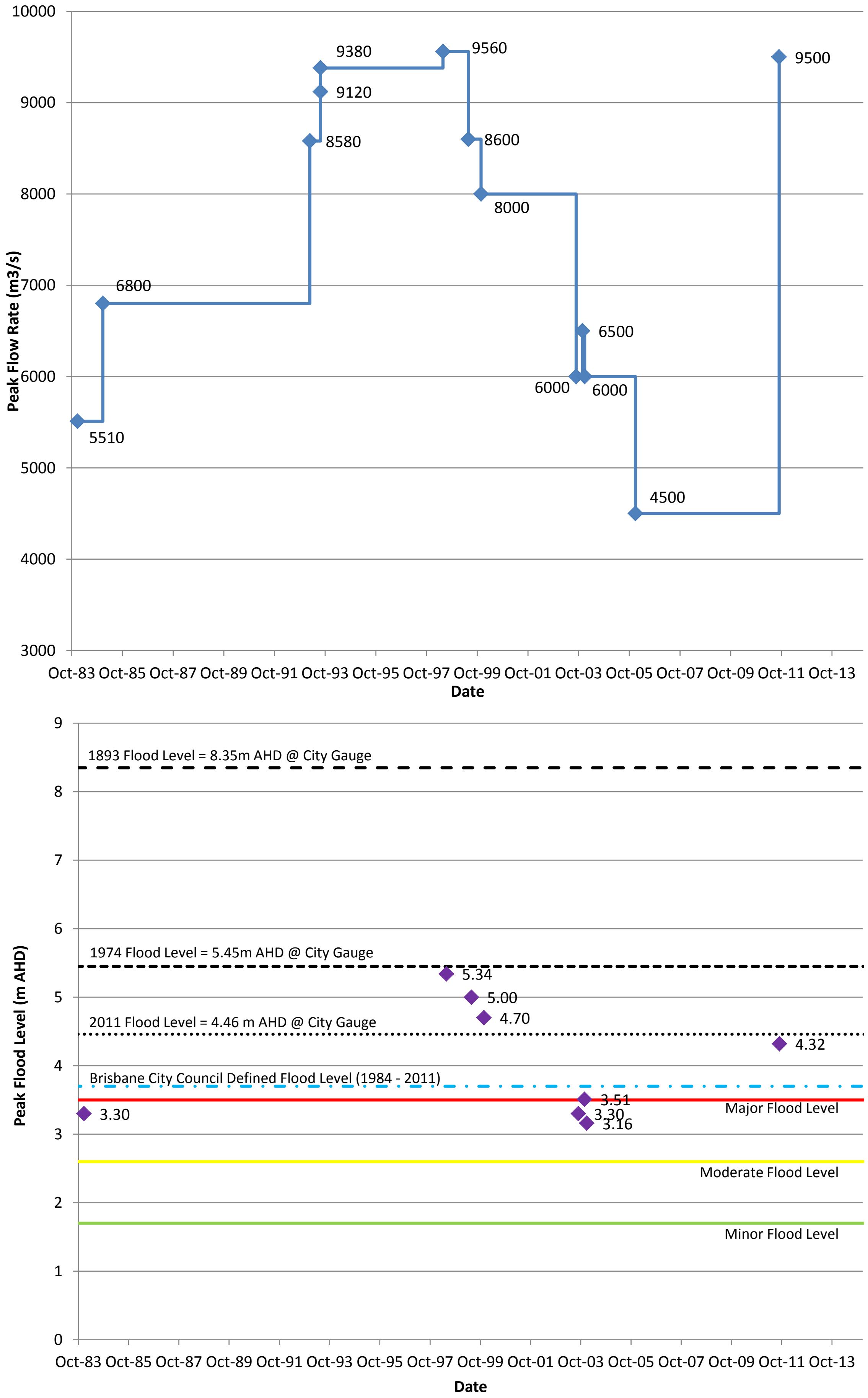

Figure 8-6 A chronology of estimated Q100 (top) and peak flood levels (bottom) for the Brisbane City Gauge (after WMAwater 2011)

The current hydrologic (RAFTS) and hydraulic (MIKE 11) models of the Brisbane River have evolved from those that were first developed for Brisbane City Council as part the *Brisbane River Flood Study* (SKM 1998). This study presented a new Q100 flow rate of 9560 m^3/s for the Port Office Gauge with a corresponding peak flood level of 5.34 m AHD. A subsequent review (Mein 1998) concluded that the "overall approach for the hydrologic component ... was appropriate", but that that "conservative assumptions in key input variables" meant the "magnitude of the Q100 produced in this study was an over-estimate". There was concern about a discrepancy between the flood frequency analysis and the rainfall runoff approach, the use of zero losses and the absence of an areal reduction factor. Mein made six recommendations relating to the study and Brisbane City Council subsequently commissioned City Design to undertake further work to address the issues. The first City Design study was completed in June 1999 and contained reduced Q100 estimates of 8600 m^3/s and 5 m AHD, although not all of Mein's recommendations had been addressed. A second City Design study (December 1999) further reduced the Q100 estimates to 8000 m^3/s and 4.7 m AHD, however issues still remained and Brisbane City Council did not revise any flood-related planning controls on the basis of this work.

Through 2000 and 2002, SKM (*Ipswich Rivers Flood Studies*) and Haliburton KBR (*Ipswich Rivers Flood Studies – Lower Bremer River Flooding Report*) further developed MIKE 11 and RAFTS models as part of the Ipswich Rivers Flood Studies for Ipswich City Council. In 2003, Brisbane City Council commissioned SKM to undertake further investigations into flood frequency using recently released CRC-FORGE rainfall data, revised flood flows and new information on dam operating procedures (*Flood Frequency Analysis of Brisbane River (Draft)* and *Further Investigations of Hydrology & Hydraulics Incorporating dam Operations and CRC Forge Rainfall Estimates (Draft)*). SKM's reports were issued to an Independent Review Panel (September 2003), which recommended a flow rate of 6000 m^3/s and a peak level of 3.3 m AHD at the Port Office Gauge for the Q100 event. The final SKM report (*Brisbane River Flood Study: Further Investigations of Flood Frequency Analysis Incorporating Dam Operations and CRC-FORGE Rainfall Estimates*), issued in December 2003, gives an estimated Q100 flow rate of 6500 m^3/s with a likely range of 5000 m^3/s to 8000 m^3/s. The corresponding peak flood level was given as 3.51 m AHD with a likely range of 2.76 m AHD to 4.41 m AHD. In two studies conducted for City Design and Brisbane City Council in 2004 (*Flood Modelling Services: Recalibration of the MIKE 11 Hydraulic Model and Determination of the 1 in 100 AEP Flood Levels* and *Flood Modelling Services: Calculation of Floods of Various Return Periods on the Brisbane River*), SKM recalibrated the 2000 MIKE 11 model and provided a new Q100 peak flood level estimate of 3.16 m AHD based on a flow rate of 6000 m^3/s that had by that time been formally adopted by Council. SKM and the Independent Review Panel made recommendations during this period for further work that would reduce the level of uncertainty in the estimates of flooding. These included a "Monte Carlo" analysis of the key hydrologic model inputs, particularly in regard to the spatial variability of rainfall which was found to have a significant effect.

A number of studies were conducted between 2005 and 2011 on flooding in the Brisbane River catchment. These included studies for the Wivenhoe Alliance (*Design Discharges and Downstream Impacts of the Wivenhoe Dam Upgrade - Q1091* 2005 and *Dam Failure Analysis of Wivenhoe Dam - Q1091* 2005) that again recalibrated the RAFTS and MIKE 11 models, and a 2009 study by City Design for Somerset Regional Council (*Flood Study of Fernvale and Lowood*) that developed a new dynamically linked 1D/2D TUFLOW model of the SRC region. In 2006, Sargent Consulting (*Ipswich Rivers Flood Study Rationalisation Project - Phase 3 - "Monte Carlo" Analysis of Design Flows - Final Report*) undertook a "Monte Carlo" analysis with a limited number of trials using the 2000 SKM RAFTS model for Ipswich City Council. The best estimate of Q100 peak flows at the Port Office Gauge was given by this study as 4500 m^3/s, with a likely range of 3000 m^3/s – 6000 m^3/s.

In 2009, City Design developed a calibrated, peer-reviewed 2D TUFLOW model of the Lockyer Valley, Ipswich Valley and Lower Brisbane River floodplains for Brisbane City Council. The primary goal of this study was to provide model outputs that could be used as flood emergency response tools. The model consisted of a 30 m grid based on 2002 LIDAR survey data. Calibration to the 1974 event was undertaken at 20 locations with +/- 1 m accuracy, with a good fit at the Brisbane City Gauge (0.01 m). The model was then used to generate flood levels and extents for 10 flood profiles derived by WRM Water and Environment as part of the *Brisbane River Extreme Flood Estimation Study* (2007). The profiles ranged from a minor event (3000 m^3/s) up to the PMF (38000 m^3/s). Spatial outputs included inundation mapping, critical infrastructure mapping, isolated areas and evacuation zone mapping.

Following the January 2011 flood event and leading up to the delivery of the *Queensland Floods Commission of Inquiry Final Report* in March 2012, a number of further hydrologic investigations and reviews were made. For Seqwater in August 2011, SKM undertook to recalibrate the 2005 MIKE 11 model and Seqwater’s URBS and WT42 models based on new data available from the recent flood. This process included deriving new rating curves based on gaugings undertaken at the Jindalee Bridge and observed levels during periods of constant release from the Wivenhoe dam, and refining the MIKE 11 model based on recent LIDAR survey. The new rating curves were found at times to differ significantly from those used in the past, having implications for the understanding of historical flood peaks and therefore design flood event estimation. A number of improvements to model schematisation and stability were made at this time, although SKM noted several outstanding issues relating to model setup and channel/floodplain representation that couldn’t be resolved due to data and time constraints.

In a separate exercise, Mark Babister (2011[a]) was asked by the Queensland Floods Commission of Inquiry to establish a best estimate of the Q100 flood at Brisbane City and to estimate the probability of the January 2011 event. Noting issues with the Port Office Gauge rating curve and difficulties in accounting for the attenuating effects of the dams, Babister estimated a new Q100 peak flow rate of 9500 m^3/s and assigned an ARI of 1 in 120 years to the January 2011 event. A number of reviews, responses, and further commentaries were received by the Commission following Babister’s report, culminating in the *Joint Expert Statement – Brisbane River Flood Frequency* (Joint Experts Panel 2011). The members of the joint experts’ panel, including Babister, concluded that a definitive statement on the reasonableness of any Q100 estimate can only be made following the completion of a comprehensive flood study.

The position of the joint experts, as reflected in the Commission’s final report, is that a comprehensive flood study is required to improve the understanding of flooding in the Brisbane River catchment. Such a study would address key causes of uncertainty encountered during past studies, and would be comprehensive in terms of the sources of data used and the range of methodologies applied. The new study would have to definitively address the full range of flood probabilities, the accuracy and reliability of historical data, tidal effects and the probabilistic interactions of a range of key model variables.

Further work following the completion of the Commission’s final report includes the *Wivenhoe Dam and Somerset Dam Optimisation Study* (WSDOS)[43] and the associated *Floodplain Management and Dam Operations* (FMDO). Details of these scopes of work are included in the *Brisbane River Catchment Floodplain Studies Planning Review* (GHD 2012). The goals of those projects include optimising the dam operation rules and addressing some of the data gaps and methodological shortcomings of the hydrologic models.

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[43] This project is administered by the Department of Energy and Water Supply.

Table 11 Past regional flood studies

Month	Year	Name	For	By
November	1975	Brisbane River Flood Investigations	Queensland Cities Commission	SMEC
	1975	Brisbane River Flood Plain Maps of Brisbane and Suburbs	Queensland Survey Office	Queensland Survey Office
	1975 - 1976	Wivenhoe Dam Tailwater Rating Derivation	The Irrigation and Water Supply Commission	The Irrigation and Water Supply Commission
June	1977	A Comprehensive Evaluation of the Proposed Wivenhoe Dam on the Brisbane River	Co-coordinator General's Department	Grigg, T.G.
September	1977	Report on the Hydrology of Wivenhoe Dam	Queensland Irrigation and Water Supply Commission	Hausler, G. and Porter, N.
	1980 - 1981	Simulation of Outflow from Wivenhoe Dam	Queensland Water Resources Commission	Queensland Water Resources Commission
	1984	Wivenhoe Dam - Report on Downstream Flooding	Queensland Water Resources Commission	Weeks, W.D.
January	1985	Hydrology Report for Manual of Operation Procedures for Flood Mitigation for Wivenhoe and Somerset Dam	Brisbane City Council and Queensland Water Resources Commission	Hegerty, K.L. and Weeks, W.D.
	1985	Report on Investigations into the Effects of Sewage Disposal to the Brisbane River	Department of Local Government	Department of Local Government
	1989	Preliminary Dambreak Analysis of Wivenhoe Dam	Queensland Water Resources Commission	Queensland Water Resources Commission
	1992	Report on Flood Data for Queensland Catchments - Including Design Flood Estimates	Queensland Water Resources Commission	Greer, M.

Month	Year	Name	For	By
	1992	Brisbane river and Pine River Flood Study - Report 7a: Brisbane River Flood Hydrology Report on Runoff-Routing Model Calibration	South East Queensland Water Board	Department of Primary Industries
March	1993	Brisbane River and Pine River Flood Study - Report 8a: Design Flood Estimation for Somerset and Wivenhoe Dam - Main Report	South East Queensland Water Board	Department of Primary Industries
August	1993	Brisbane River and Pine River Flood Study - Report 13: Brisbane River Flood Hydrology Report on Downstream Flooding	South East Queensland Water Board	Department of Primary Industries
December	1994	Brisbane River System Hydraulic Model Report	South East Queensland Water Board	Department of Primary Industries
	1994	Brisbane River and Pine River Flood Study: Report Series Volumes 1 to 24	South East Queensland Water Board	Department of Primary Industries
June	1998	Brisbane River Flood Study	Brisbane City Council	SKM
	1998	Brisbane River Flood Study Review of Hydrological Aspects	Brisbane City Council	Mein, R.
June	1999	Brisbane River Flood Study	Brisbane City Council	City Design
December	1999	Further Investigations into the Brisbane River Flood Study	Brisbane City Council	City Design
	2000	Ipswich Rivers Flood Studies	Ipswich Rivers Trust	SKM
May	2002	Ipswich Rivers Flood Studies - Lower Bremer River Flooding Report	Ipswich City Council	Haliburton BKR
August	2003	Flood Frequency Analysis of Brisbane River (Draft)	Brisbane City Council	SKM
August	2003	Further Investigations of Hydrology & Hydraulics Incorporating dam Operations and CRC Forge Rainfall Estimates (Draft)	Brisbane City Council	SKM
September	2003	Review of Brisbane River Flood Study	Independent Review Panel	Mein, R., Apelt, C., Macintosh, J., Weinmann, E.
December	2003	Brisbane River Flood Study: Further Investigations of Flood Frequency Analysis Incorporating Dam Operations and CRC-FORGE Rainfall Estimates - Brisbane River	Brisbane City Council	SKM
	2004	City Design - Flood Modelling Services: Recalibration of the MIKE 11 Hydraulic Model and Determination of the 1 in 100 AEP Flood Levels	City Design and Brisbane City Council	SKM

Month	Year	Name	For	By
	2004	City Design - Flood Modelling Services: Calculation of Floods of Various Return Periods on the Brisbane River	City Design and Brisbane City Council	SKM
	2005	Design Discharges and Downstream Impacts of the Wivenhoe Dam Upgrade - Q1091	Wivenhoe Alliance	Wivenhoe Alliance
	2005	Dam Failure Analysis of Wivenhoe Dam - Q1091	Wivenhoe Alliance	Wivenhoe Alliance
	2006	Ipswich Rivers Flood Study Rationalisation Project - Phase 3 - "Monte Carlo" Analysis of Design Flows - Final Report	Ipswich City Council	Sargent Consulting
October	2007	Brisbane River Extreme Flood Estimation Study	Brisbane City Council	WRM Water and Environment
June	2009	Brisbane River Hydraulic Model to Probable Maximum Flood	Brisbane City Council	City Design
	2009	Flood Study of Fernvale and Lowood	Somerset Regional Council	City Design
July	2011	Review of Hydraulic Modelling	Queensland Floods Commission of Inquiry	WMAwater
August	2011	Joint calibration of a Hydrologic and Hydrodynamic Model of the Lower Brisbane River	Seqwater	SKM
September	2011	Brisbane River 2011 - Flood Event - Flood Frequency Analysis	Queensland Floods Commission of Inquiry	WMAwater (Mark Babister)
September	2011	Review of Brisbane River 2011 Flood Frequency Analysis	Queensland Floods Commission of Inquiry	University of Adelaide (Dr Michael Leonard)
September	2011	Brisbane River 2011 Flood Event - Flood Frequency Analysis - Review of Report by WMAwater	Queensland Floods Commission of Inquiry	SKM (Dr Rory Nathan)
October	2011	Response to Peer Reviews of WMAwater's Brisbane River 2011 Flood Event - Flood Frequency Analysis (Sept 2011)	Queensland Floods Commission of Inquiry	WMAwater (Mark Babister & Monique Retallick)
October	2011	Review of Aspects of the report of WMAwater Report	Queensland Floods Commission of Inquiry	Bewsher Consulting (Drew Bewsher, Director)
October	2011	Provision of expert advice in relation to a report provided by WMAwater	Queensland Floods Commission of Inquiry	Uniquest (Professor Colin Apelt)

Month	Year	Name	For	By
October	2011	Expert Comments on Final Report by WMAwater	Queensland Floods Commission of Inquiry	RJ Keller & Associates (Erwin Weinmann)
October	2011	Technical Review of Flood Frequency Analysis Report	Queensland Floods Commission of Inquiry	BMTWBM (Neil Ian Collins)
October	2011	Review WMAwater Report	Queensland Floods Commission of Inquiry	WRM Water and Environment (Dr Sharmil Markar)
October	2011	Memorandum to QFCI re Comment on Selected Issues Raised by WMAwater 45	Queensland Floods Commission of Inquiry	SKM (Dr Rory Nathan)
October	2011	Joint Expert Statement - Brisbane River Flood Frequency 46	Queensland Floods Commission of Inquiry	Joint Experts Panel

8.6.1 Floodplain Management Studies

It would appear that there has not yet been a comprehensive floodplain management study undertaken of the Brisbane River catchment that would meet the best practice criteria recommended in this Framework. Notwithstanding this there are known to be a wide array of smaller studies that have variously assembled much information that is especially relevant to the integrated floodplain management task. However, few of these studies and investigations would appear to have had community or stakeholder consultation as a core part of the process.

For example, Local Governments have over time undertaken flood risk investigations on many individual catchments, and have variously looked at specific mitigation options (e.g. Brisbane City Council backwater flood prevention work), or sets of options for some individual local catchments (e.g. Ipswich River Improvement Trust studies) largely focused at understanding developable land and mitigation to allow land development. Also, the Healthy Waterways program and its outcomes have provided the type of information that would provide input to *Environmental Function* assessments of floodplains. Seqwater has also undertaken various flood risk assessments and mitigation planning over time and DNRM, for example, investigated the likely flood risks at the time in Smith (1994). Brisbane City Council (BCC 2007) has also undertaken flood damage assessments to assist in planning decisions.

Each Local Government has at various times also undertaken reviews and updates of their Local Disaster Management Plans (LDMP) usually in response to changes in the relevant legislation and policies. The most recent comprehensive series of these was in the period 2005-2009 after the State revised policy and guidelines. Each of these, if done in accord with the requirements, will have contained a disaster hazard/risk (including flood) register but are based on typically qualitative statements of the existence or otherwise of flood risks. The round of Priority Infrastructure Plan (PIP) development during the period 2006-2009 also variously looked at parts of each Local Government (the Priority Planning Areas or development areas) and identified regional flood mitigation options where appropriate.

Various programs of works and actions also took place after the 2011 flood, but for the most part were necessarily reactionary, done quickly within a context of political expediency, and not necessarily conducted in a widely coordinated fashion. Other initiatives represent longer term plans, such as the Somerset Regional Council improved flood warning/alarm infrastructure plan.

8.6.2 Storm Tide Studies

One of the earliest storm tide studies for the Moreton Bay region was undertaken for the new Brisbane Airport (McMonagle 1979). Although there have been a number of studies completed since then in the adjacent area that can be used to inform the risk of storm tide events at the Brisbane Bar (GHD/SEA 2007, CLT 2009) there has not been a comprehensive storm tide risk study undertaken specifically for the City of Brisbane,

8.6.3 Opportunities for Adaptation of Existing Tools

The extensive array of past studies in various contexts will contain useful and important knowledge that can inform new investigations and assist in methodology development. A task that would gather and collate such information into a usable form is recommended and would ideally have resulted from a more lengthy version of the present investigation. Much previously obtained knowledge has potentially not yet been fully utilised in the planning process.

The extent to which existing tools, rather than knowledge, might be usefully adapted is less clear. Although there are a number of “models” already constructed for various purposes, the variety of assumptions made and the constraints that were present during their construction will variously impact their performance. Rather than prescribe that certain models should or could form the basis of new investigations, it is recommended that the individual responders to the various work tasks be left to justify their own choices as to the suitability of existing tools and the advantages (to the project rather than responders) that might accrue from such approaches.

In any case, it would be reasonable for any State agency or Local Government modelling or analysis tools to be generally made available provided that they have (a) suitably appropriate documentation and that (b) the datasets embodied in them can be traced and verified.

8.7 Recommendations

Based on the foregoing examination of the methodologies and tools available to address the various physical and statistical elements of the necessary flood-related processes, the outcomes from previous studies and the QFCI recommendations derived from expert consensus, the following recommendations are made.

8.7.1 Climate Simulation

The essential role of climatology (on large time and space scales), meteorology and oceanography (on smaller scales) in generating damaging flood events in the Brisbane River catchment have not been fully investigated in previous flood studies for the south-east Queensland region. In the past, this has typically been precluded by the complexity of the natural systems on the one hand and a lack of relevant data, computational tools and basic understanding of the processes on the other. Accordingly, standard hydrologic approaches have relied on a combination of insitu flood frequency analyses and/or rainfall data analyses, absorbing the unknown system complexity into a more tractable simplified statistical context. However, because there is rarely sufficient data available (either in quantity, quality or homogeneity), significant assumptions are then required to attempt to reconstruct the often poorly understood temporal and spatial rainfall patterns within a specific catchment or basin. Combined with a complex river topology comprising many individually large and responsive catchments, standard hydrologic assumptions become less likely to be reliable and this is evident in the high variance of risk estimates from past flood studies of the Brisbane River. Without a significant change in approaches, this variance is likely to persist and will be reflected in ongoing uncertainty regarding the true risk of damaging floods and the most effective mitigation responses.

Additionally, the issue of lack of stationarity[44] of data sets used in statistical analyses must be addressed. This is not only essential for consideration of projected climate change trends in rainfall totals, rates and sea level rise, but is also important for understanding the non-anthropogenic multi-decadal cycles (e.g. ENSO and IPO) that have influenced the statistics of past historical events and the possible future prognosis at practical planning and development timescales.

With the significant advances over recent decades in meteorological analyses, computational tools and coupled with the historical rainfall and storm tide records, it is now considered possible to consider a more holistic approach to these problems.

A Continuous Simulation Approach

It is concluded that, in order to significantly advance understanding of the complex behaviour of flooding in the Brisbane River, that there is a need to develop and adopt a continuous simulation approach as an adjunct to standard simplified approaches. Such techniques will inevitably become the new standard for complex hydrologic analyses, as exemplified by current

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[44] Statistical stationarity is a necessary assumption for treating any data series as a random process. It implies that the data sets are not affected by any significant trend over the period of the data, such as increasing rainfall rates or increasing sea level. Such trends need to be removed from the data set and treated as non-random elements.

AR&R research programmes and worldwide academic interest in leading statistical hydrologic and coastal climate modelling techniques such as (inter alia):

- Point process modelling
- Discrete event simulation
- Continuous event simulation
- Empirical simulation techniques

It is therefore recommended to research, develop, calibrate and verify a linked extreme rainfall and storm tide *Stochastic Simulation System* applicable to the Brisbane River catchment that will enable the generation of coupled rainfall and storm tide time-series in both space and time for an extended period of synthetic climate. The period of simulation should be sufficient to adequately define the complex response of the river system to enable quantification of flood events across the range of average Return Periods of interest for the associated Flood Study (FS) and Floodplain Management Study (FMS) (this could be expected to be of the order of 10,000 years or more).

The synthetic climate data series would then replace the use of reconstructed insitu rainfall data and simple assumptions regarding coincident tailwater levels. A complete time history of storm events would then be available for hydrologic, hydraulic and flood risk modelling activities to produce fully compatible and consistent estimated time histories of river heights, flood extents, damages and the like. The simple ranking of outcomes will then directly inform the probability of exceedance of events of interest and simultaneously retain all related persistence and shape behaviour of the various elements and processes, thus informing many emergency response actions and inherently retaining the uncertainty of point estimates. This replaces the current suite of simplifying assumptions on a point probability basis and avoids the need for extrapolation to obtain extreme design levels.

Stochastic Simulation System

It is envisaged that such a system would:

- Utilise all available rainfall records for the catchment (event totals, daily totals, rates, pluviographs as available, control structure data)
- Utilise all available tidal and other water level records for the Brisbane River and its tributaries;
- Consider the meteorology of, and mechanisms leading to, extreme rainfall events in the region;
- Consider the meteorology of, and mechanisms leading to, extreme storm surge events in Moreton Bay affecting river tailwater levels;
- Incorporate knowledge of the role of inter-decadal variability in regional climate as manifested by, for example, ENSO (El Niño Southern Oscillation) and IPO (Inter-Decadal Pacific Oscillation) indices;
- Incorporate projections of changing climate parameters (rainfall distribution, rates, “storminess” and sea level rise) associated with the concept of enhanced “greenhouse” warming (e.g. IPCC 2007, 2013) to the year 2100 and beyond ;
- Be calibrated against a selection of historical flood and storm surge events above a nominated intensity threshold (Consultant to justify thresholds);
- Be verified against an independent selection of historical flood and storm surge events;
- Be validated as appropriate by comparison with other Flood Study (FS) Project outputs:

  - A Level 1 AR&R design event approach
  - A Level 2 Stochastic hydrology approach
  - Independent PMP estimates (e.g. BoM 2003a,b, DNRM 2005)
- Provide estimates of the uncertainty associated with all key parameters and the resulting estimated uncertainty of any derived quantities;
- Be strengthened through the process of independent technical peer review.

Application of the System

It is envisioned that application of such a system would:

- Be capable of generating and displaying synthetic time-series of rainfall depth over the catchment in an ordered space and time context for periods of the order of 10,000 years or more of assumed statistically stationary climate;
- Be capable of generating and displaying rainfall-coupled synthetic time-series of storm tide elevations (tide plus surge) at the Brisbane Bar for the same periods;
- Enable extraction of time series of rainfall depth at any nominated site for comparison with historical partial series data;
- Facilitate display and analysis of synthetic storm events of a nominated character or range (e.g. peak rainfall intensity, peak storm tide level, catchment and sub-catchment totals or rates etc);
- Enable statistical frequency analysis of relevant variables with associated uncertainty estimates;
- Enable determination of joint-probability relationships in space and time;
- Enable the generation of *non-statistically stationary* coupled time-series of rainfall and ocean tailwater levels consistent with future climate projections.

Development Risks

The development of a Stochastic Simulation System must be approached in the context of a targeted research activity. This is to say that the potential benefits of such a system in contributing to the study challenges is sufficiently great, even on the timelines envisaged for completion, that it is a worthwhile proposition in spite of the possibility of it failing to meet all of its objectives in its initial stages. Accordingly, the associated draft Scopes of Work proposed for the overall study do not entirely rely on this development but rather have been designed to specifically benefit from its anticipated advantages.

Advantages

The development of such a tool would represent a fundamental advancement of capabilities in flood modelling and floodplain management that will have an enduring impact on flood studies across south-east Queensland and, by extension, the rest of flood-prone Queensland for decades to come. For example, such a tool would be immediately available for the necessary follow-on studies of the many urban creeks that will need to be updated after the revision of the Brisbane River flood study and its modified tailwater conditions. This tool would enable the rapid reassessment of those many creek catchment hydrologic models to a standard fully consistent with the present study.

8.7.2 Hydrologic Assessment

A hydrologic assessment is required to develop an understanding of the full probability domain of potential rainfall runoff rates and volumes across the Brisbane River catchment. The assessment should consider:

- Meteorologic climate drivers;
- The spatial and temporal variability of rainfall patterns;
- Initial catchment conditions;
- Initial water levels in dams at the start of flood events;
- Dam operating rules and physical limitations of the dams;
- Closely occurring rainfall events; and
- Projected climate change effects by the year 2100.

Given the complexity of estimating design flow rates in a catchment as large as the Brisbane River basin and the impact of flow rate estimates on decision making, hydrologic analysis should include no-dam and with-dam conditions, as follows:

- A flood frequency analysis (FFA) of flood events extracted from streamflow records; and
- A range of hydrologic modelling approaches to derive design flood hydrographs from a range of design rainfall inputs;
- Reconciliation of flood frequency and hydrologic model results.

Flood Frequency Analysis (FFA)

As part of the WSDOS activities, it is understood that Seqwater will undertake a flood frequency analysis for a no-dam case at selected key locations. The BRCFS will require review of this analysis and the undertaking of a flood frequency analysis for the with-dam cases at key locations.

The flood frequency analysis should include:

- Analysis using a range of flood frequency methods and theoretical probability distributions;
- Defining the AEP of historical floods;
- Review of the consistency of inter-station FFA estimates, and resolution and documentation of any inconsistencies.
- Sensitivity analysis and review of the FFA for large historical floods where the observed peak flood level is inconsistent with the extrapolated range of applied rating curves.

Hydrologic Modelling Approach

In order to undertake a comprehensive hydrologic assessment, a three stage approach that includes the following levels of assessment should be considered:

- Level 1: An industry standard AR&R Design Event based approach;
- Level 2: A stochastic hydrology based approach; and
- Level 3: A full stochastic simulation based approach.

These approaches will allow comparison of the different model outputs, which would address the QFCI recommendation 2.2 that the flood study be comprehensive in terms of the methodologies applied and use different methodologies to corroborate results.

Model Basis and Setup

Again, as part of the WSDOS study, it is understood that Seqwater are developing a calibrated hydrologic model of the Brisbane River catchment that will be made available for the BRCFS. This model should be considered as the basis for the hydrologic modelling to be undertaken in the BRCFS project.

Prior to adoption of the Seqwater hydrologic model, a critical review should be undertaken to determine whether the setup of the model, which has been optimised specifically for dam operations, is suitable for meeting the objectives of the wider BRCFS study. This should include an assessment of:

- Model sub-catchment resolution;
- Spatially varying catchment characteristics (including impervious fraction, slope and porosity);
- Channel routing methods and parameters;
- The type and appropriateness of the loss model adopted;
- Existing rating curves;
- Key model parameters;
- Existing model deficiencies and/or limitations;
- The level of calibration achieved in the hydrologic model and the appropriateness and reasonableness of the parameters involved in the calibration.

It is noted that adjustments to existing rating curves may be required based on further rating curve investigations and the results of the hydraulic modelling undertaken in this study. This may require the hydrologic model to be re-calibrated or a joint calibration with the hydraulic model to account for changes in rating curves.

Given the complexity introduced to the modelling process by the presence of Somerset and Wivenhoe Dams and their operational impact during flood conditions, consideration should be given to augmentation of the existing hydrologic model set-up or the development of additional hydrologic model modules to provide dam operating rule functionality.

The hydrologic model is also required to have the capability to undertake a large number of stochastic model simulations. This may require modification of the existing Seqwater hydrologic model set-up or the development of additional hydrologic model modules to include this functionality.

Calibration and Validation

Seqwater have indicated that their hydrologic model will be calibrated to a large number of historical flood events.

A review of Seqwater’s model calibration should be undertaken and refined where necessary to meet the wider BRCFS needs. The following calibration and validation tolerances should be targeted:

- Peak flood levels: ±300 mm;
- Peak flood level at the City Gauge: ±150 mm;
- Peak flow difference of: ±10%;
- Event Volume difference of : ±15%;
- Good timing of flow and water level peaks / troughs (±1 hours); and

- Good replication of the rising and falling hydrograph limbs.

Calibration effort should be focussed on more recent and reliable flood records and readily acknowledge limitations and uncertainties. There are two primary objectives of the calibration process:

- Producing a model which is representative of real world behaviour across a wide range of events using realistic parameters. Real world behaviours that should be well replicated include hydrograph attenuation, volume, peak and timing characteristics;
- Identifying deficiencies in available calibration data so that for future events, data collection processes can be refined or extended to reduce the uncertainty in future calibrations.

Calibration of the hydrologic model is required to be undertaken for pre and post dam conditions to enable calibration to a range of events. An intermediate (partially completed dam) case may be required if the 1983 event is to be modelled.

Following completion of the hydraulic model builds, a joint calibration of the hydrologic and hydraulic models should be considered. Revisions to existing rating curves may be an outcome from other phases of the project and iterative adjustment of the hydrologic model calibration may be required.

The calibration of the hydraulic models is critical to the success of the study and sufficient time is therefore required to be given to the calibration phase of the project

Level 1 Hydrologic Modelling: ARI Design Event Approach

The creation of a suite of design storm bursts for the Brisbane River catchment is recommended. Their generation should include:

- Usage of appropriate temporal and spatial patterns;
- Appropriate consideration of areal reduction factors; and
- Appropriate non biased estimates of loss and routing parameters.

It is expected that in their derivation, the latest AR&R recommendations, the CRC-FORGE (e.g. Hargraves 2004) methodology and the latest Intensity Frequency Duration analysis available from the Bureau of Meteorology would be applied, together with the GTSMR approach (BoM 2003b) for the PMF condition.

Following calibration, hydrologic modelling should be undertaken to produce hydrographs for design flood events with Annual Exceedance Probabilities (AEP) of 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1%, 0.05%, 0.02%, 0.001%, 0.002% as well as the Probable Maximum Flood. Hydrographs are required to be produced for the full range of standard AR&R storm durations.

Level 2 Hydrologic Modelling: Stochastic Hydrology Approach

It is recommended that hydrologic modelling to determine a statistical distribution of design event flow rates at critical locations throughout the catchment be undertaken by considering the joint probability effects of:

- Spatial and temporal rainfall pattern variability;
- Saturation of the catchments;
- Initial water level in the dams at the start of a flood event;
- Dam operating rules and physical limitations of the dams;

- Closely occurring rainfall events; and
- Projected climate change effects by the year 2100.

This approach could for example, be based on (or a variant of) the Monte Carlo[45] simulation techniques developed in Australia (Rahman et al., 2002 and Weinmann et al. 2002). The technique "treats four inputs (rainfall duration, intensity, temporal pattern and initial losses) as probability-distributed variables. A large number of runoff events (in the order of thousands) are simulated using these probability-distributed and other fixed input variable/model parameters and then routed through a calibrated runoff routing model. The resulting flood peaks are then subjected to a non-parametric frequency analysis to determine a derived flood frequency curve." (Rahman et al, 2002).

The hydrographs produced by the Monte Carlo based approach are required to be statistically analysed and a selection of the hydrographs are to be used as boundary conditions for Monte Carlo based design event simulations in the hydraulic models.

Level 3 Hydrology: Full Stochastic Approach

A separate Brisbane River Stochastic Simulation Study (SSS) has been recommended to generate:

- A synthetic time-series of rainfall depth over the catchment in an ordered space (≤ 2 km) and time context (≤ hourly) for periods of not less than 10,000 years of assumed statistically stationary climate; and
- Rainfall-coupled synthetic time-series (≤ hourly) of storm tide elevations (tide plus surge) at the Brisbane Bar for periods of not less than 10,000 years of assumed statistically stationary climate.
- Following completion of the Stochastic Simulation Study, a Level 3 Hydrologic assessment should be undertaken that includes:
- Data-mining of the high density rainfall database developed as part of the Stochastic Simulation Study;
- Selection and application of a minimum of 10,000 events to the calibrated hydrologic model comprised of different combinations of rainfall depth, temporal and spatial pattern and losses derived from the Stochastic Simulation System Study;
- Statistical analysis of hydrograph outputs; and
- Development of a coupled hydrograph and tailwater database for input into the hydraulic models.

Reconciliation of Hydrologic Model Results against Flood Frequency Analysis Results

Hydrologic model results are required to be validated by comparing peak flows and flood volumes obtained through modelling with the values obtained through flood frequency analysis of historical flood records at key locations across the catchment. Any differences between the different methods at sites unaffected by backwater influence should be documented and appropriately reconciled.

8.7.3 Hydraulic Assessment

Hydraulic modelling is required to develop an understanding of the full probability domain of potential flood levels, extents, depths and velocities across the Brisbane River catchment.

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[45] A problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs

Types of Models Required

Given the complex nature of flooding across the Brisbane River floodplain as reflected in the peer-agreed recommendations of the QFCI, consideration should be given to the development of the following types of hydraulic models of the Brisbane River system:

- A fast (short run time) dynamic calibrated one-dimensional (1D) hydraulic model;
- A detailed two-dimensional (2D) or integrated 1D/2D hydraulic model; and
- Limited area three dimensional (3D) hydraulic models for specifically complex situations.

A fast dynamic calibrated 1D hydraulic model that is capable of simulating flood scenarios within a relatively short time frame and can be used by a range of agencies should be developed. It is expected that this model could form a basis for operational purposes (e.g. flood forecasting and dam operations) and would not be used directly for detailed planning purposes. The development of the model would need to include consultation with the Bureau of Meteorology and Seqwater.

A calibrated 2D hydraulic model should also be developed to provide a range of outputs that are necessary for use in flood risk assessment and floodplain planning. The required outputs include design flood levels for planning, and flood extent, depth, velocity and hazard category mapping. The 2D hydraulic model needs to be developed in a manner that will enable testing of the flood mitigation options developed during the Floodplain Management Study.

The undertaking of detailed 3D hydraulic modelling in the vicinity of existing gauging stations should be considered to more accurately determine the relationship between river discharges and flood levels at these locations, especially with regard to tidal influences.

Given that a significant amount of work has been undertaken to develop a range of existing Brisbane River catchment flood models, the development of new hydraulic models should include a review of existing hydraulic models and consideration as to whether any existing hydraulic models (or parts thereof) could be used in this study.

A range of commercially available 1D, 2D and 3D hydraulic models are available that may be suitable for the purposes of this study. The capability, assumptions and limitations of each of these models should be considered as part of the model selection process. Consideration should also be given to the ability of the model to dynamically simulate the impact of changing river bed conditions on flood levels.

Model Extent

A fast dynamic model (possibly developed using an accepted 1D hydraulic modelling platform) is required to extend from Wivenhoe Dam to Moreton Bay, include all major tributaries and be capable of simulating Brisbane River floods from a 50% AEP up to and including the currently assessed PMF design event.

A detailed hydraulic model (possibly an integrated 1D and 2D hydraulic model) is required to cover urban areas in the Brisbane and Ipswich areas and be capable of simulating Brisbane River floods from a 50% AEP up to and including the PMF design event. 3D hydraulic models may also be required in the vicinity of key gauging station locations, especially those with a significant tidal flow, complex bathymetry or sensitivity to morphologic change.

The extent of the rivers, creeks and tributaries that require hydraulic modelling is provided in Figure 8-7.

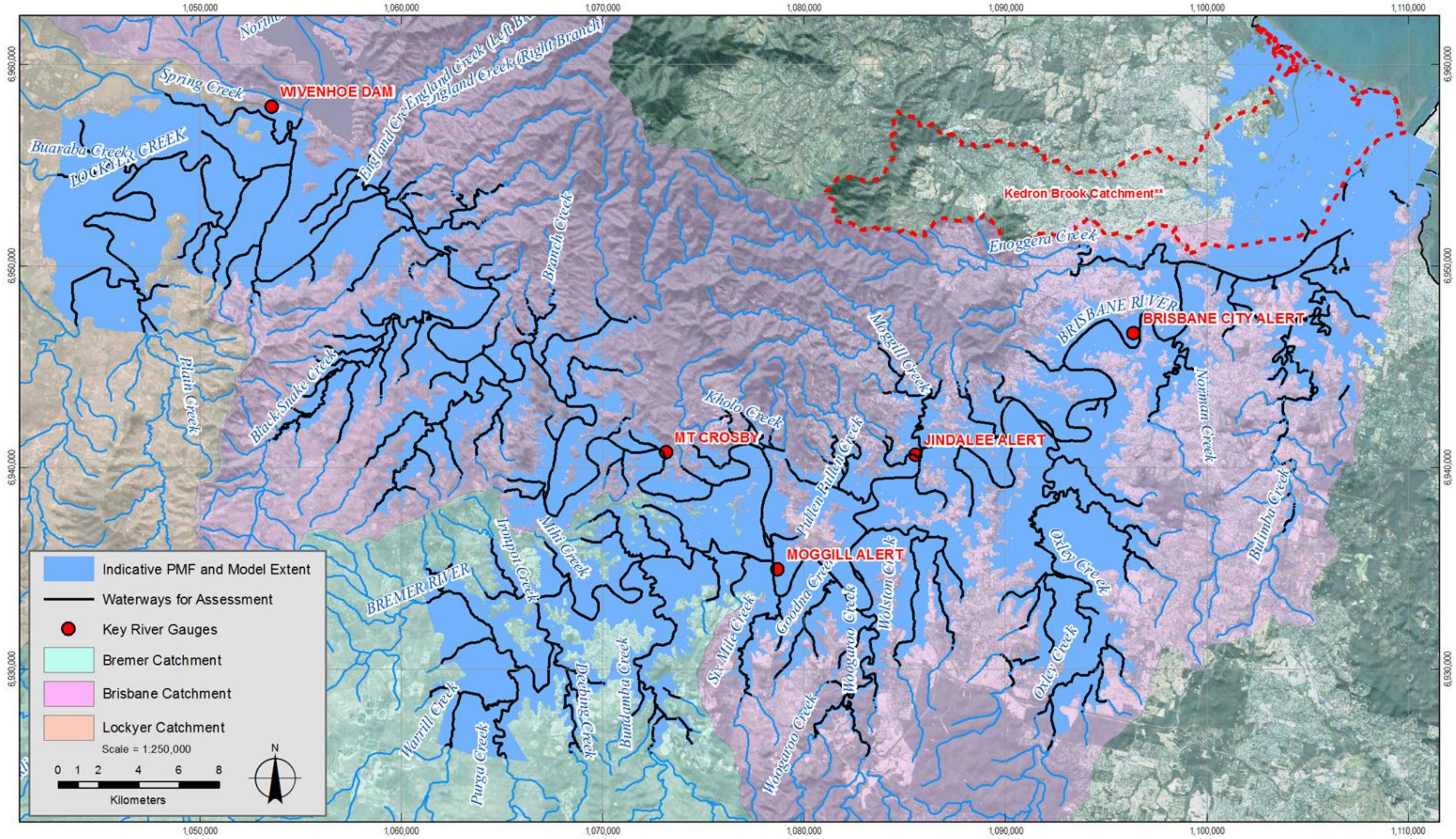

Figure 8-7 The proposed extent of hydraulic modelling

Model Resolution

In order to adequately simulate the physics of flooding within the Brisbane River catchment, careful consideration needs to be given to the location, extent and spacing of any 1D model cross sections, the cell size of 2D and 3D model grids and the depth of 3D model layers. Consideration should be given to the development of an integrated 1D/2D hydraulic model and/or the development of “nested” 2D hydraulic models that provide a greater level of resolution in key areas of importance.

Bathymetric, Topographic and Surface Roughness Representation

The topography of the Brisbane River catchment floodplain has changed significantly over time due to increasing development. The bathymetry of waterways has also changed owing to continuous erosion and accretion of the river bed. The bathymetry and topography of the system will continue to change with future land use development and other changes to the catchment.

The design of numerical hydraulic models should include consideration of bathymetric and topographic changes over time. This should include:

- Comparison of historic bathymetric and topographic survey data sets to determine the degree of change;
- Application of the most appropriate temporal change data sets to the hydraulic models; and
- Careful checking of the model set-up to ensure that all significant hydraulic features are adequately represented in the hydraulic models.

Changes to surface roughness should also be considered in a similar manner to topographic change and the most appropriate temporal change data sets applied in the hydraulic model.

Hydraulic Structures

There are a number of significant hydraulic structures[46] within the Brisbane River catchment that need to be adequately represented in the hydraulic models. Consideration needs to be given to the best method of model representation and alternative methods of checking head-loss across hydraulic structures should be considered.

Calibration and Validation

In order for the hydraulic models to be considered suitable for the purposes of accurately assessing various design flood events and flooding scenarios – calibration of the hydraulic models along the entire length of modelled reaches to an acceptable standard is essential and mandatory, as discussed below.

Calibration of the hydraulic models should be undertaken for a range of minor, moderate and major flood events and include calibration to the 1893, 1974 and 2011 events as a minimum.

The most appropriate topographic, bathymetric, hydraulic structure and land use data must be used for each calibration event.

The following calibration and validation tolerance aims should be targeted:

- Peak flood levels: ±300 mm;
- Peak flood level at the City Gauge: ±150 mm;

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[46] Bridges, levees, pipe crossings, fords, road and rail embankments, backwater prevention gates; Somerset and Wivenhoe Dam, Mt Crosby Weir, major drainage diversions; major retarding basins.

- Peak flow difference of: ±10%;
- Event Volume difference of : ±15%;
- Good timing of flow and water level peaks / troughs (±1 hours); and
- Good replication of the rising and falling hydrograph limbs.

The selection of appropriate calibration events should include consideration of the following uncertainties:

- Poor or insufficient availability of historic flood data;
- Poorly recorded data;
- Insufficient bathymetric and topographic survey data;
- Historic changes to river bathymetry and topography and the historic impact on rating curves;
- Revisions to existing rating curves.

The calibration of the hydraulic models is critical to the success of the study and sufficient time is required to be given to the calibration phase of the project.

Inflow Boundary Conditions

Inflow boundary conditions for the hydraulic models are required to be sourced from the Level 1, 2 and 3 calibrated hydrologic models. The location of inflow hydrograph boundary conditions should be carefully selected to ensure that the hydraulic simulation of surface runoff in major tributary reaches and urban areas occurs at an adequate resolution.

Tailwater Boundary Conditions

As discussed in Section 4.3, the river discharges into the shallow waters of Moreton Bay, which responds hydrodynamically to the same weather events that cause heavy rainfall in the catchment. The Brisbane River is tidal from the river mouth to approximately 90 km upstream at Colleges Crossing. The Mean High Water Spring Tide and Highest Astronomical Tide are 0.93 m AHD and 1.49 m AHD respectively at the Brisbane Bar.

Storm tide risk emanating from Moreton Bay can be significant in terms of the persistence of tidal residuals relative to flood propagation speeds. The tailwater conditions applied in the hydraulic models for historic events should be based on historic time series records whilst the tailwater conditions applied in design event scenarios should include consideration of the joint probability of rainfall and tide plus storm surge (i.e. storm tide).

Design Event Modelling

In order for the study to be comprehensive in nature, the full probability domain of potential rainfall events and associated tailwater conditions should be considered. Hydraulic models should therefore be established with a set of boundary conditions that are derived from consideration of the full probability domain of potential rainfall events (and associated tailwater conditions) from the Level 1, 2 and 3 hydrologic assessments.

Hydraulic modelling should be undertaken to encapsulate design flood events with Annual Exceedance Probabilities (AEP) of 50%, 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2%, 0.1%, 0.05%, 0.02%, 0.001%, 0.002% as well as the Probable Maximum Flood. Hydraulic modelling is required to be undertaken for a sufficient range of storm durations to enable capture of the variation in critical storm duration along all waterways. The Level 3 analysis will automatically encapsulate the full range of this variability but the Level 1 and 2 will require approximations.

Sediment Transport Modelling

An assessment of the effects of morphological (river bed and cross section) changes due to sediment erosion and deposition during flood events should be assessed for a range of flood magnitudes to determine their effects on flood levels. This should include an assessment of the effects/sensitivity of the historical dredging and bar-removal on flood levels and the rating at the Port Office.

This may be achieved through either:

- Development of a coupled dynamic 2D sediment transport model; or
- Using the 2D hydraulic model to undertake a sensitivity analysis of the river bed profile and roughness.

It is acknowledged that the development of the sediment transport component of the 2D hydraulic model is more experimental and there is a risk that this component of the study may not deliver a sufficiently accurate representation of the sediment transport processes in the Brisbane River. For example, the lack of accurate data on the river cross sections immediately before and during the 2011 flood event will affect the accuracy of this component of the study. The changing nature of bed sediments arising from dredging operations in the Lower Brisbane river will also need to be considered. Prior to dredging operations in the late 19th century, a greater proportion of coarser bed material likely allowed armouring of the riverbed to occur.

It is expected that an initial review of modelling options and available data will provide some indication on the best way to proceed with the hydraulic and sediment transport modelling. It may be more cost-effective in the short term to undertake the sediment transport study as a sensitivity analysis using the hydraulic models rather than undertaking the development of a sediment transport model.

8.7.4 Floodplain Damage Study

It is recommended that a comprehensive flood damages assessment be undertaken to support the Floodplain Management Study. This study should include the following tasks.

Data Collection

Existing contemporary Australian damage assessment methodologies (e.g. DNRE 2000, DNRM 2002; DIPNR 2005; DECCW 2007) should be reviewed to determine their local applicability. All existing data suitable for damages assessments (e.g. recent 2011 is preferred) should be located and flood damages data classified against type of structure/land-use; aggregated for land use and building types/uses.

It is anticipated that additional damages data detail will be needed and this should include:

- Development of a geospatial database of existing flood-prone building floor level and building polygons.
- A specialised survey/assessment of existing flood-prone critical infrastructure

The extent of the data collection should include the currently estimated PMF.

Critical infrastructure owners/managers should be identified and engaged in order to adequately assess exposure, vulnerability and consequence factors that will form inputs to economic damages assessments.

Stage-damage Geospatial Database

The various damage datasets should be integrated with that of the flood prone buildings and critical infrastructure to form a database capable of generating stage-damage curves for a variety of building types and uses.

Overlays should be designed that will allow for alteration to base damages estimates due to non-structural flood risk mitigation measures that may be considered at later stages of the FMS.

Flood Damage (AAD) Estimation Model

A model should be developed to enable the rapid and repeated estimation of the geospatial distribution of flood damage for a range of flood magnitudes (frequencies) and/or extents. The model should be integrated with the project geospatial databases and capable of deriving individual AAD at the property scale, and aggregating these over any nominated Flood Precinct, sub-area, suburb or local council area. The model should have the facility to estimate economic benefit (change in AAD) of alternative floodplain risk management options to be evaluated during subsequent benefit-cost analyses of the FMS process.

The model should include the ability to estimate economic damages specific to the Brisbane River catchment floodplain for, inter alia:

- Loss of human life;
- A variety of common building types in each of residential, industrial, and commercial classes;
- Loss of contents (residential);
- Damage and disruption to agriculture and fisheries;
- Damage and disruption to critical infrastructure (power supply, key hospitals & medical facilities, telecommunications, public services, emergence services, utilities, airports, port, oil refineries.); and
- Damage and disruption to transport infrastructure.

Ideally, if an appropriately robust economic metric can be obtained, the following damage estimating capability should be considered:

- Physical health effects;
- Business continuity;
- Clean-up costs;
- Social cohesion;
- Mental health effects;
- Impact on waterways, floodplain, and aquatic habitat; and
- Impact on replenishment of groundwater supplies.

8.7.5 Floodplain Management

A five phased approach is proposed for undertaking a comprehensive Floodplain Management Study (FMS) and to develop a Floodplain Management Plan(s). This process will also incorporate the necessary *risk study* components and all elements previously referred to, in the WSDOS context, as comprising an *Integrated Assessment Framework*. The conceptual view of this process is shown in Figure 8-4.

Phase I – Project Establishment, Planning and Data Collection.

The FMS will have significant data needs, much of which will be output from the associated Flood Study, but there will be additional data requirements, especially in regard to developing an accurate damage assessment methodology for tangible economic losses.

It is recommended that a Data Scoping Report be required to identify gaps at the commencement of the study and where additional data needs are identified, to specify and scope that requirement as a potentially additional work item. The wide array of past likely-relevant studies (as discussed in Section 8.6.1) should also be assembled and assessed.

Additionally, the FMS will require access to existing assets databases from State and Local authorities and should review the adequacy of these for recording the necessary flood-related information It is recommended that a single assets register should be developed to service ongoing needs across the Brisbane River catchment.

The FMS will require significant stakeholder and community consultation to help build understanding of the nature of flooding, risks and impacts, and the range of management options that may or may not be suitable. The views of stakeholders and communities are considered important to ensure the FMP will support the liveability, development, growth and prosperity of the SEQ region. The delivery of the FMS must therefore be completely integrated into the wider stakeholder and community consultation process as discussed in Section 7 and 8.5.

Phase II – Flood Risk Analysis

Flood risk analysis should be undertaken for existing floodplain conditions and for each of the floodplain management measures identified in the subsequent Phase III activities. Implicitly this requires an iterative approach.

Food hazard should be assessed through consideration of:

- Floodplain Environmental Function: the potential loss of important flood dependent environmental function or service;
- Hydraulic Hazards: the impact of development on flood behaviour; and
- Anthropogenic Hazards: the impact of flooding on development and people.

In addition to physical impacts to infrastructure, social, economic and environmental hazards and risks should be considered during the analysis of the existing conditions of the floodplain, and in the proposed measures for reduction in risks (i.e. the benefit due to implementation of risk reduction measures).

The FMS should consider the cost and benefits of flood risk management measures along with the costs and risks associated with social, economic, and environmental issues wider than simply the flood risks alone.

A common set of metrics is required to be utilised to assess and compare risk reduction measures, i.e. a method of aggregating tangible and intangible risks due to a wide range of flood hazards, some physical, some social, and some economic is required.

The FMS must provide a practical assessment of the following flood risks;

- Existing flood risks;
- Potential future flood risks based upon current land-use planning schemes;
- Change in flood risk due to implementation of potential mitigation measures (i.e. the benefit resulting from implementation); and
- Residual flood risks.

Flood risks should be determined quantitatively for both tangible consequences and intangible consequences where it is meaningful and practical to quantify these on an Annual Average Damages (AAD) monetary basis, as follows:

- Tangible (quantitative) risk assessment should be based upon assessment of AAD derived from locally-validated stage-damage curves using relationships between flood magnitude and consequential economic losses;
- Intangible flood risks should be assessed using the common qualitative risk assessment approach of classification by way of a “risk table”.

The dual quantitative/qualitative approach is required to include adequate consideration of the social and local perceptions and levels of acceptance of risk, while also providing measurability and repeatability to the process. Importantly, the dual approach, and in particular the qualitative aspect, will provide for involvement, ownership, and thus greater acceptance of the outcomes by the impacted communities and stakeholders.

The floodplain should be classified into areas of important environmental function, hydraulic hazard and anthropogenic hazard for subsequent analysis of potential flood risk in various parts of the floodplain. These categories should be used to determine appropriate types of land-use and development in flood-prone areas as a function of AEP.

In order to assist the processes of assessment and decision making, a series of geographic “Flood Precincts” should be defined, agreed and mapped across the entire floodplain: These should then be used in all flood risk and damages assessments, flood mitigation measures, recommendations, and ultimate actions. Such classifications will assist in directing and prioritising available resources to higher risk areas and risk reduction portfolios selected to treat higher risk areas. These precinct delineations should be based on, inter alia:

- Floodplain hydraulic functional zones;
- Flood hazards and risks;
- Floodplain and catchment topography;
- Community boundaries; or if necessary
- Political and administrative boundaries

Aggregate tangible risk (AAD) and intangible risks should be mapped at whole of region and flood precinct scales. Where appropriate, where data allows or where finer scale assessment is required, mapping at allotment scale should also be considered. Flood risk maps should have a consistent format and content basis across the whole of the study area and be of a standard suitable for public exhibition to convey aggregate and categorised risk acceptability bands.

Phase III – Identify and Assess Flood Risk Management Options

This phase of the study should include the preparation of emergence response mapping for the existing (including planned) floodplain development situation, comprising delineation of risks to safety evacuation routes and constraints. It would also be appropriate to undertake a review of existing development planning provisions and emergency planning provisions.

Using the flood risk maps generated in Phase II, Defined Flood Event(s) for each Flood Precinct should be prepared, as an iterative process, undertaken with stakeholder input. These will include consideration of the full range of possible flood magnitude and risks in particular geographic locations, and specific development types.

The issues to be considered in recommending DFEs should include:

- Risk to life, and influencing issues such as failure (exceed design standard) of structural flood risk mitigation works;
- Social issues;
- Economic flood damages;
- AAD associated with actual floods exceeding the DFE;

- Future development;
- Environmental issues;
- Cultural issues; and
- Freeboard considerations.

Risk reduction measures should then be considered, both structural and non-structural, with the latter likely to form a significant proportion of finally adopted FMP actions. Beside the likely significant role of planning responses or buy-back strategies, in the Brisbane River context, the operation of the current configuration of the Wivenhoe and Somerset Dams forms another non-structural risk reduction option[47]. Structural options could include changes to dam capacities, new dams, levees or diversions etc

The identified practical risk reduction measures should then be shortlisted and the benefits assessed on the basis of reduced AAD for tangible risks and qualitative assessments for intangible risks. Critically, proposed structural measures and some non-structural measures will likely require re-modelling through the Flood Study process to determine the change in the hydraulic hazard and associated anthropogenic hazard. Some of these options may incur adverse outcomes (e.g. local increases in afflux) in addition to their intended benefits. Estimates of capital and operating expenditure of the various options must also be prepared to allow benefit-cost assessments and final rankings for consideration of the preferred options.

Phase IV – Stakeholder & Public Exhibition of draft FMS

This phase should seek wide community feedback on the draft FMS and its various recommendations for risk reduction, involving public meetings and invitation for written submissions. These would then be consolidated, reviewed and considered in terms of finalising the draft study. The details of these activities should be included in the overall Communication and Stakeholder Consultation Plan.

Phase V Completion of Final Floodplain Management Study

Following the review of submissions it is likely that there will be some changes requested to the final set of recommendations. Following this, preparation of the draft Floodplain Management Plan (FMP) should commence, which will specify how and when the variously identified risk reduction measures will be implemented and their relationship with Council's various planning instruments. A further consultation process is then expected before the FMP is finalised.

This phase of the work could be regarded as a separate task or simply be included as part of the FMS scope.

8.7.6 Communication and Stakeholder Engagement

The objective of Communication and Stakeholder Engagement is to achieve positive buy-in to the processes and outcomes of the FMS and FMP.

To achieve this will require specific approaches to engagement:

Set level of engagement and be transparent

- Engage early and maintain
- Tailor the engagement activities to the target audience and purpose
- Raise awareness
- Explain why.

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[47] This should include the relationship between the full deemed supply level and the allocated flood compartment.

The following factors considered critical to the success of community engagement for the FMP include:

- Ensuring engagement occurs across appropriately across the entire catchment
- Defining the level of engagement to ensure a clear purpose for engagement throughout the life of the project (i.e. when to inform and when to consult the community for feedback)
- Identifying the appropriate communities and stakeholders with whom to engage
- Timing of engagement – both in terms of the commencement of engagement as well as the timing of specific engagement activities
- Using appropriate methods for engagement
- Managing community and stakeholders’ expectations around the process and outcomes
- Allocating suitable resources for the tasks
- Assessing success of the process and reacting to feedback.

The recommended governance and process structure for activities is as shown in Figure 7-1.

The following table highlights the suggested stages of work that are likely to occur in parallel with the study and plan phases.

Table 12 Suggested stages of communication and stakeholder consultation

Data Collection	Flood Study	Floodplain Management Study	Flood Risk Management Plan	Implementation of Plan	Monitoring and Review
Stage 1 Preparation and Strategy Design	Stage 2 Sub catchment Mitigation Consultation		Stage 3 Launch	Stage 4 Promotion of sub-catchment specific plans	Stage 5 Embed policies
Tasks Define communities Identify stakeholders Stakeholder /feedback interviews Establish community liaison committees and industry liaison committees (LGA)	Tasks Sub-catchment level targeted consultation events to discuss mitigation measures Feedback to FMP		Tasks Issues management preparation Media release for DRAFT FMP launch events Consultation input into FMP Media release and launch of final FMP Issues management	Tasks Implement within planning schemes etc.	

Stage 1 – Preparation and strategy design

This stage would involve defining the level of engagement, identifying the relevant stakeholders and communities and researching flood awareness, and establishing the committees with which to engage. Completing this stage will be a comprehensive plan.

Defining the level of engagement

To underpin an effective stakeholder and community engagement plan, the most appropriate level of engagement for each region should be determined according to the project phase. This task should be undertaken as early and precisely as possible to ensure a clear purpose for engagement throughout the life of the project. As specified earlier, the level of public participation for the BRCFS (as it relates to the IAP2 spectrum) would involve an INFORM and CONSULT approach. To avoid building an expectation that the community would directly influence decision-making, particularly in relation to flood mitigation strategies which rely on technical inputs, it is vital that the team are clear and transparent about which areas of the study can be informed and improved by community feedback to build local ownership.

Identifying stakeholders and evaluating their awareness

Working with the relevant members of a community engagement sub-committee, the appropriate local community members and other stakeholders (including industry) should be identified.

For the FMS and FMP which cover diverse geography and multiple jurisdictions, it will also be particularly important to identify the levels of understanding and awareness across the different communities of the following issues, before confirming the most appropriate approaches, key messaging and engagement activities:

- The risks of floods
- The (un)predictability of floods
- The ability and methods available to manage flood risk and floods
- Reactions to certain use of messaging which could be incorporated into the materials for the engagement program.

Research activities may include but will not be limited to:

- Focus groups with randomly selected people to represent a broad cross-section of the community (recruited using professional market research companies)
- Online surveys with known, interested stakeholders
- In-depth key stakeholder interviews.

Establish community liaison committees and industry liaison committees (for each LGA)

Community and industry liaison committees should be setup to provide a mechanism for regular engagement with key representatives of the community throughout the project.

Members would be invited to join the committee and asked to consider various potential options and approaches that are developed during the project. Feedback from these committees would test the social and economic feasibility as well as filter messages into the wider community.

Establishment of community and industry liaison can be undertaken in parallel with the process of identifying stakeholders from the community and industry.

Communication and Stakeholder Consultation Plan

The plan will need to consider both the communities and businesses potentially impacted by flooding as well as the key stakeholders representing the departments, agencies and organisations. It would include the following elements:

- Measurable objectives
- Engagement principles

- Overall program strategy
- Stakeholder database
- Stakeholder issues and mitigations
- List of communication and engagement tools
- Messaging and materials
- Implementation plan per region.

Stage 2 – Sub-catchment mitigation consultation

This should include:

- Design and implement sub-catchment level targeted consultation events to discuss mitigation measures
- Consult key stakeholders through project-established Community and Industry Liaison Committees
- Report on this consultation, synthesise into findings and provide the Planning Implementation Group with recommendations for how to incorporate feedback into the Draft Floodplain Management Plan.

Stage 3 – Launch of the Draft Floodplain Management Plan (FMP) public consultation period and distribute Final FMP

This should include:

- Working with the Community Engagement Sub-committee to prepare the media materials and launch event for the Draft FMP
- Leading on adhoc issues management activities required to reduce community resistance to the outcomes of the study and the outcomes of the plan
- Working with relevant members of the Community Engagement Sub-committee to manage the sub-catchment public consultation launch events
- Collating and coordinating public consultation feedback for each region
- Reporting on this consultation, synthesising findings and providing the Steering Committee with recommendations for how to incorporate feedback into the final Floodplain Management Plan
- Facilitating the media release and launch of the final FMP.

Stage 4 – Promotion of sub-catchment plans

This should include:

- Working with the Community Engagement Sub-committees to embed the sub-catchment floodplain management plans within Council local planning schemes, etc.

9. Data Needs

9.1 Study Requirements

A significant amount of information will be required to undertake the BRCFS project. Some of this identified information is being separately collected and collated by others under a DNRM (2012) contract, which will also consider how to make the data readily available to the necessary parties. Notwithstanding this, the information required, inter alia, for each of the modelling phases of the project is summarised below for reference.

9.1.1 Stochastic Simulation Model Requirements

- Historic and predicted tidal data;
- Meteorological data for historic flood events;
- Rainfall pluviograph and daily rainfall station time series records;
- River gauge time series records;
- Hindcast climate data
- Climatological data
- Projected climate change data

9.1.2 Hydrologic and Hydraulic Model Requirements

- Historic and recent aerial photography;
- Recent and historic topographic ground survey and river cross-sections;
- Recent and historic topographic aerial survey;
- As-constructed road and rail information;
- Recent and historic bathymetric survey of the Brisbane River, Bremer River and lower reaches of major tributaries;
- Hydraulic structure details including design levels, inverts and dimensions;
- Morphologic data including sediment transport information;
- Dam storage characteristics and operating rules;
- Historic, existing and future land use maps that correspond with model calibration events;
- Historic and predicted tidal data;
- Meteorological data for historic flood events;
- Rainfall pluviograph and daily rainfall station time series records;
- River gauge time series records;
- Existing rating curve data and associated information;
- Historic flood level survey;
- Existing hydrologic and hydraulic models and model result files;
- Information on pending development applications and proposed infrastructure/development;

Available topographic and bathymetric survey data should be acquired for each year of capture so that temporal changes to the floodplain and river bathymetry can be assessed.

9.1.3 Flood Damages Assessment

- Historical flood damages in the Brisbane region (preferably recent, e.g. 2011) but to include storm tide related damage
- Insurance claims data, where available
- Floor levels and footprints of buildings
- Classes of buildings at risk
- Sensitive infrastructure and vulnerabilities
- Coastal modification data (e.g. Rock walls, marinas etc)

9.1.4 Floodplain Management Study

- High resolution topographic data (e.g. LiDAR)
- Classes of buildings at risk
- Sensitive infrastructure and vulnerabilities
- Emergency plans

9.1.5 Communication and Stakeholder Engagement

- Relevant flood related consultation reports and stakeholder perceptions research from the study area – e.g. BCC
- Media coverage reports
- Relevant stakeholder databases to incorporate into a consolidated stakeholder database – sources could include BCC, DSDIP, other Councils
- RP Data

9.2 Recommendations

Past Relevant Studies

The wide array of past likely-relevant studies (as discussed in Section 8.6) should be assembled, collated and assessed in order to ensure the use of valuable existing knowledge is maximised. This is likely a significant task and should be commenced as soon as practicable.

Suitability of Data and Identified Gaps

Each of the proposed studies must individually assess their data needs, whether such data exists and is of suitable quality or if additional data must be captured.

Data Collection and Storage Standards

There is a wide variety of acceptable “data standards” for geophysical data and, notwithstanding these, the most critical requirement is appropriate documentation in the form of metadata (i.e. data about the data).

One of the most widely use standards are the simple standard input data formats required by various vendor applications (e.g. URBS, RAFTS, MIKE11, etc). Combined with essential metadata in some form (even ASCII) such formats are likely to be acceptable and practical. For example, it is understood that Seqwater hydrologic data will be made available in the URBS model data format.

Where possible, applicable datasets and data collection should be in accordance with DNRM Spatial Information Unit standards and/or DNRM Water Monitoring (Hydrography) Unit standards. It is understood that most State water agencies, including those in Queensland, are using the WISKI[48] database management system for storage and management of water resources related data. In addition, the Bureau of Meteorology has developed a Water Data Transfer Format (WDTF)[49] based on XML (which in itself is a standard for water data). This enables all the water agencies/industry in Australia to transfer their data to the Bureau.

Besides this, general spatial data should ideally conform to the ESRI ArcGIS™ file geo-database format for MGA94 Zone 56 and 3D feature class. Other useful GIS standards that are described on the Bureau of Meteorology GeoFabric[50] website may be helpful.

There are known to be several existing formal systems that record physical assets (e.g. register(s) of dams, Local Government ADAC systems etc). These are likely to continue to be required in their current form for their custodial needs, however there will be a need to initially interrogate these, and then allow for integrated development of a single data set as may be required for input to the Flood Study hydraulic modelling and maintenance of a regional register of flood control structures for coordinated ongoing floodplain management processes.

Intellectual Property and Data Sharing

To manage data permissions and licencing, the Bureau of Meteorology and many other agencies have adopted the Creative Commons Licence[51]. This should be negotiated with all data suppliers to ensure the ready exchange of all relevant data.

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[48] http://www.environmental-expert.com/software/wiski-water-resources-information-system-16103/view-comments and http://watermonitoring.derm.qld.gov.au/host.htm

[49] http://www.bom.gov.au/water/regulations/wdtf/index.shtml

[50] http://www.bom.gov.au/water/geofabric/documentation.shtml and http://www.bom.gov.au/water/about/publications/document/InfoSheet_5.pdf

[51] http://www.bom.gov.au/water/regulations/dataLicensing/index.shtml

10. The Recommended Project Plan

This chapter provides an overview of the project stages, interdependencies, timing and governance.

10.1 Project Flow Diagram

A schematic which provides an overview of the proposed key stages and inter-relationships of the BRCFS project is provided as Figure 10-1.

10.2 Project Schedule

A recommended high level Project Schedule summarising the timing of key stages of the project is provided in Appendix C. The Schedule has been prepared through a detailed consideration of:

- The estimated time required to complete each component of the BRCFS project;
- The timing of key study interactions required throughout the project; and
- Decision hold points for the Steering Committee review and endorsement at critical stages of the project.

It is estimated that completion of a comprehensive Brisbane River Catchment Floodplain Studies project that aims to achieve best practice (and includes both a Flood Study and a Floodplain Management Study) may require up to **7 years** to complete. Both the FS and FMS are major components of the Government's response to the Queensland Floods Commission of Inquiry Final Report (QFCI 2012) and consequently, it is strongly recommended that sufficient time be allocated to achieve technically robust best practice project outcomes.

The total timeframe of seven years is largely dictated by the individual timeframes required to complete the FS and the FMS components, and the need for completion of a comprehensive FS prior to the commencement of critical phases of the FMS. These timeframes are generally consistent with earlier draft timelines that were provided as input into the planning review (GHD 2012), where consideration was then given to the possibility of overlapping many tasks to expedite the overall studies. While overlapping of some tasks has been achieved, best practice considerations have dictated the overall timelines that are now recommended.

It is noted that the project programme will provide an interim deliverable comprised of detailed flood inundation mapping by **July 2016**.

10.3 Individual Study Durations

Recommendations regarding the duration of the individual study stages that comprise the BRCFS project are provided below.

Stochastic Simulation Study (SSS)

It is recommended that a total timeframe of **2 years** be provided for completion of the Stochastic Simulation Study. The Project Schedule indicates that the SSS should be undertaken in parallel to the initial stages of the FS and as such would not have a significant impact on the timing of FS deliverables.

The SSS will necessarily be a targeted research activity designed to accelerate the application of current knowledge to produce practical tools for the FS Level 3 hydrology and hydraulic activities and the FMS. Although the actual process can be expected to be highly iterative, it is expected to involve the following broad time allocations:

- A 3-month data collection phase.
- A minimum of 9 months of conceptual design, set-up and testing.
- An expected 6 months of calibration against historical events.
- At least 3 months of final long-term climate simulations
- Final statistical analyses and reporting in the final 3 months.

Flood Study (FS)

It is recommended that a timeframe of **3.5 years** be allowed for completion of the Flood Study. Due to the size and complexity of the study area, it is recommended that this include:

- A minimum 3 month provision for data collection (pending outcome of DNRM data collection exercise).
- A minimum 3 month provision for review and refinement of the Seqwater hydrologic model. It is noted that a sufficient period of time has been allocated for this stage to enable a detailed revision of existing rating curves through local hydraulic modelling at gauging station locations, and potential refinement of the sub-catchment resolution in Seqwater's existing model.
- A minimum 9 month provision to undertake Level 1 and 2 hydrologic modelling. It is noted that the start date for the Level 1 and 2 hydrologic modelling is critically dependent on the completion date of Seqwater's calibrated hydrologic model and the timeframe required to review and amend the model as required.
- A minimum 3 months provision to undertake Level 3 hydrologic modelling following completion of the Stochastic Simulation Study and Level 1 and 2 hydrologic modelling;
- A minimum 2 year provision for 1D hydraulic modelling. This should include provision of 1.5 years for model development, 6 months for model calibration, and 6 months for completion of Level 1, 2 and 3 design event simulations.
- A minimum 2.5 year provision for 2D hydraulic modelling. This should include provision of 2 years for model development, 6 months for model calibration and 6 months for completion of selected Level 1, 2 and 3 design event simulations. In order to minimise the FS timeframe, development of the 2D hydraulic model should be undertaken in parallel with the development of the 1D hydraulic model.
- A minimum of 3 months to complete the required level of flood inundation mapping. A period of six months has been allowed due to the size of the catchment, the extent of flood inundation during large events and the large number of LGAs that require detailed mapping outputs.
- A minimum of 6 months between issue of the Draft and Final Reports for the gathering and incorporation of stakeholder feedback into the Final Report.

Flood Damage Data Collection

In order to expedite completion of the FMS and FMP, it is recommended that a separate project to collect flood damage data, survey known and potentially affected building floor levels, and develop a revised set of flood damage curves be undertaken with commencement of this scope of work to occur at the start of the FS.

In order to allow for a comprehensive data set to be captured, it is recommended that a total timeframe of **1 year** be provided for completion of the Flood Damage Data Collection project.

Floodplain Management Study (FMS) and Floodplain Management Plan (FMP)

It is recommended that a total timeframe of **3.5 years** be allowed for completion of the Floodplain Management Study. Due to the size and complexity of the Brisbane River Catchment and the large number of flood precincts and stakeholders involved, it is recommended that this include:

- An allowance of 6 months for adequate project establishment, planning and data capture (Phase I);
- A minimum timeframe of 9 months to complete the Flood Risk Analysis (Phase II) component of the FMS;
- A minimum timeframe of 1 year to Identify and Assess Flood Risk Management Options (Phase III);
- A minimum 6 month provision for Stakeholder Feedback and Public Exhibition of the Draft FMS and FMP (Phase IV); and
- A minimum timeframe of 3 months to finalise the FMS and FMP (Phase V) following stakeholder feedback on the draft documents.

It is recommended that commencement of the FMS be staged such that the Flood Risk Analysis (Phase II) component of the FMS occurs after finalisation of the FS. In this manner, a comprehensive understanding of flood risk analysis can be developed based on the full set of FS outputs.

It is recommended that an allowance of 6 months be provided for development of the Draft FMP following completion of the FMS.

A timeframe for finalisation of the Draft FMP has not been provided as this scope of work will be controlled by the LGAs following completion of the BRCFS project.

Communication and Stakeholder and Community Engagement

Communication and stakeholder engagement is required throughout the entire BRCFS project with the greatest level of consultation and engagement needed throughout the FS and FMS.

Integral stages of communication and stakeholder engagement are highlighted in Table 12 of Section 8.5 with the detailed draft Scope of Work is provided separately.

10.4 Project Stage Descriptions

Table 13 to Table 16 provide a summary of key stages of the project. Detailed draft Scopes of Work including the required study approaches, study outputs and products are provided separately.

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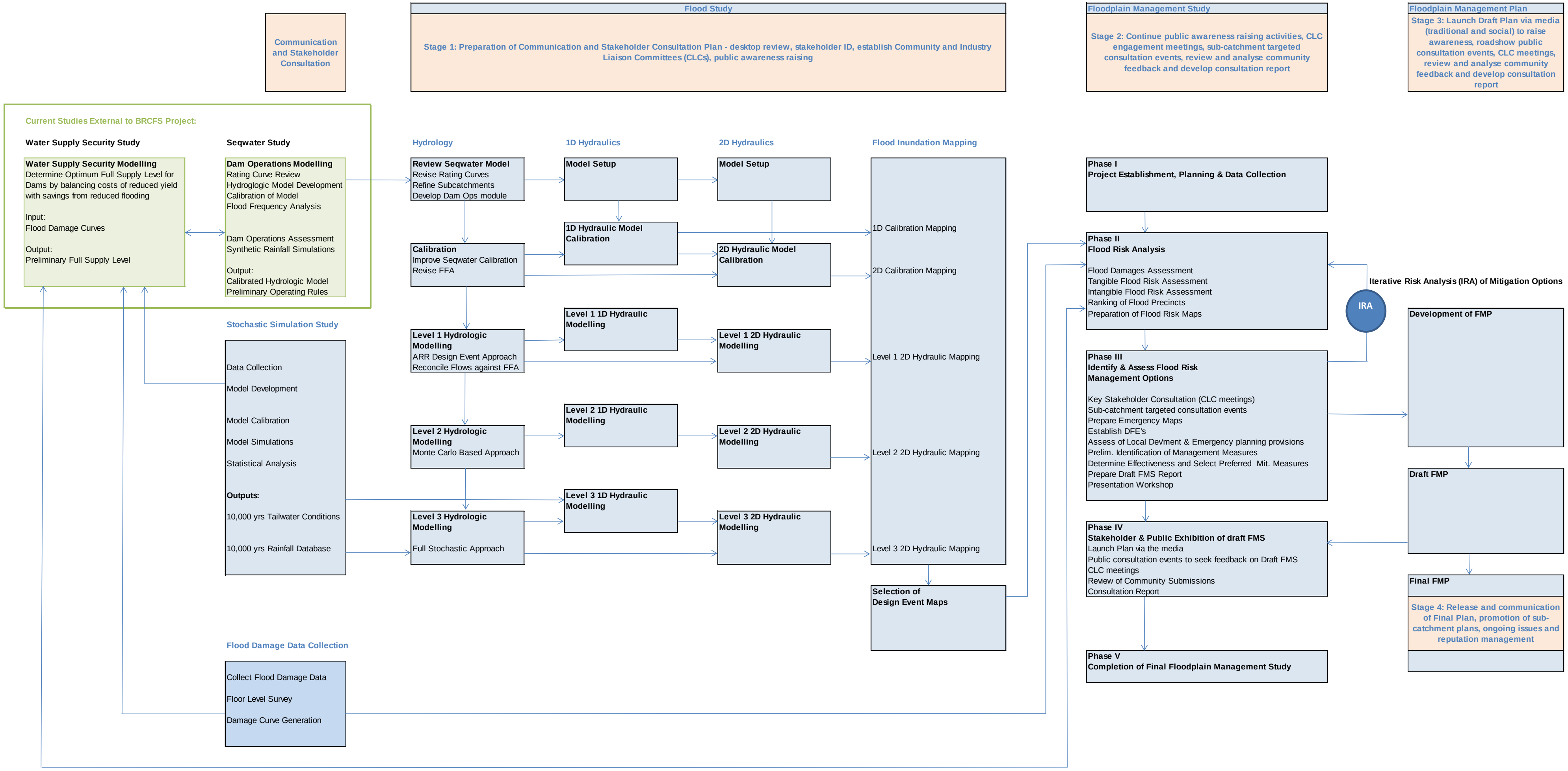

Notes:

1 IRA The iterative risk assessment involves testing flood mitigation options in the Level 2 or 3 2D hydraulic models, mapping results and undertaking a flood risk analysis as per Phase 2 of the FMS. Testing of Dam Operating rule variants will require simulations being undertaken in both the hydrologic and hydraulic models.

2 The term 1D hydraulic model has been used for the purposes of this flow diagram however, some other form of reliable fast dynamic model could be used in lieu of a 1D hydraulic model.

Figure 10-1 Project flow diagram

Table 13 Stochastic Simulation Study Stages

Stage No.	Stage Description	Key Activities	Key Products	Start Date	End Date
1	Project Start-up	Contract Establishment Project Planning	Project Plan	1/07/2013	1/08/2013
2	Data Collection	Collection of existing meteorologic and ocean climate datasets, numerical model hindcasts.	Data collection report	1/07/2013	1/10/2013
3	Model Development	Conceptual design, set-up of Stochastic Simulation Model, testing and modification, peer reviews.	Base Modelling Tool	1/10/2013	1/07/2014
4	Model Calibration	Calibration of model to historical flood events	Calibration Report	1/07/2014	1/01/2015
5	Model Simulations	Model simulations to generate: A synthetic time-series of rainfall depth over the catchment in an ordered space (≤ 2 km) and time context (≤ hourly) for periods of not less than 10,000 years of assumed statistically stationary climate; and Rainfall-coupled synthetic time-series (≤ hourly) of storm tide elevations (tide plus surge) at the Brisbane Bar for periods of not less than 10,000 years of assumed statistically stationary climate.	10,000 years of synthetic rainfall and storm tide data	1/01/2015	1/04/2015
6	Statistical Analysis	Statistical analysis of model outputs	Comparative Statistical Descriptors	1/04/2015	1/07/2015
7	Draft and Final Reporting	Draft Report Peer Review Completion of Final Report	Draft and Final reports	1/04/2015	1/07/2015
8	Project Completion / Acquittal	Handover of Study Outputs	-		1/07/2015

Table 14 Flood Study Stages

Stage No.	Stage Description	Key Activities	Key Products	Start Date	End Date
1	Project Start-up	Contract Establishment Project Planning	Project Plan	1/04/2013	1/07/2013
2	Data Collection	Data Collection Data Review Gap Analysis	Data Review Report	1/07/2013	1/01/2014
3	Hydrologic Model Calibration Review	Review Seqwater's existing model Review rating curves Develop dam operations module Calibration Reporting	Hydrologic Calibration Report	1/07/2013	1/10/2014
4	Level 1 Hydrologic Modelling	ARR Storm Burst Modelling	Standard ARR type hydrograph outputs	1/10/2013	1/04/2014
5	Level 2 Hydrologic Modelling	Monte Carlo based hydrologic analysis Generation of a statistical distribution of design event flow rates	Hydrograph database	1/01/2014	1/07/2014
6	Level 3 Hydrologic Modelling	Stochastic Hydrologic Modelling using outputs from the Stochastic Simulation Study Generation of a statistical distribution of design event flow rates	Hydrograph database and coupled tailwater conditions	1/04/2015	1/07/2015
7	1D Hydraulic Model Development	Review of existing hydraulic models Set-up of models	1D Hydraulic Model Set-up	1/07/2013	1/07/2014
8	1D Hydraulic Model Calibration	Calibration and validation of hydraulic model to 10 historical flood events Peer review	1D Hydraulic Calibration Report	1/07/2014	1/01/2015
9	1D Hydraulic Model Design Event Simulations	Level 1, 2 and 3 hydraulic model simulations	Database of 1D Flood extents, levels, depths, velocities	1/01/2015	1/07/2015
10	2D Hydraulic Model Development	Review of existing hydraulic models Set-up of models		1/07/2013	1/01/2015
11	2D Hydraulic Model Calibration	Calibration and validation of hydraulic model to 10 historical flood events Peer review	2D Hydraulic Calibration Report	1/01/2015	1/07/2015
12	2D Hydraulic Model Design Event Simulations	Level 2 and 3 hydraulic model simulations	Database of 2D Flood extents, levels, depths, velocities	1/07/2015	1/01/2016

Stage No.	Stage Description	Key Activities	Key Products	Start Date	End Date
13	Flood Inundation Mapping	Design event inundation mapping	Design Event Flood Maps	1/01/2016	1/07/2016
14	Draft and Final Reports	Draft Report Peer Review Completion of Final Report	Draft Report Final Report	1/07/2016	1/01/2017
15	Training	Development of training modules Development of training program Development of model user manuals Delivery of training program	Model training modules	1/10/2016	1/01/2017
16	Project Completion / Acquittal	Project closure	Project Completion Report		1/01/2017

Table 15 Flood Damage Data Collection Stages

Stage No.	Stage Description	Key Activities	Key Products	Start Date	End Date
1	Project Start-up	Contract Establishment Project Planning	Project Plan	1/07/2013	1/10/2013
2	Data Collection	Collection and review of existing flood damage data Collection of 2011 flood damage data Consultation with insurance sector	Flood damage database	1/07/2013	1/07/2014
3	Floor level survey	Survey of known and potentially affected building floor levels	Floor level database	1/07/2013	1/07/2014
4	Damage curve generation	Development of stage-damage curves for various building types and land uses	Flood Damage Curves	1/04/2014	1/07/2014
5	Draft and Final Flood Damage Data Report	Preparation of Draft Report Peer Review Preparation of Final Report	Draft and Final Reports	1/04/2014	1/07/2014

Table 16 Floodplain Management Study (FMS) and Floodplain Management Plan (FMP)

Stage No.	Stage Description	Key Activities	Key Products	Start Date	End Date
I	Project Establishment, Planning	Contract establishment Project planning Data Collection & review Identification of additional data needs Stakeholder & community consultation Investigate flood risk mitigation assets inventory	Project Plan	1/07/2016	1/01/2017
II	Flood Risk Analysis	Prepare community newsletter Categorise floodplain function and flood hazard Define flood planning precincts Flood damages assessment Tangible flood risk assessment Intangible flood risk assessment Ranking of flood precincts Preparation of flood risk maps	Flood risk Maps Existing conditions flood damages assessment	1/01/2017	1/01/2018
III	Identification and Assessment of Flood Risk Management Options	Preparation of Emergency Response Mapping Establish Designated Flood Events Assess local development and emergency planning provisions Identify floodplain management measures Determine Effectiveness and select preferred floodplain management measures Prepare comprehensive Draft FMS Report Planning Implementation Group / Technical Working Group presentation workshop	Emergency Mapping DFEs Draft FMS	1/01/2018	1/04/2019
IV	Stakeholder & Public Exhibition of FMS	Community consultation seminars Review of community submissions	Community Consultation Report	1/04/2019	1/10/2019
V	Finalisation of FMS and Draft FMP	Peer Review Completion of Final Report	Draft and Final Reports	1/07/2019	1/10/2019
	Project Completion / Acquittal	Handover of study outputs	-		1/10/2019

10.5 Project Governance

10.5.1 Existing Governance Arrangement

It is understood that the project will be progressed under a governance structure established by the Queensland Government to guide and oversee the implementation of the QFCI recommendations.

This includes:

- Establishment of a Steering Committee to provide overall guidance in conducting the project work; and
- Provision for peer review by an independent panel of experts experienced in flood and floodplain management studies; and
- Linkages with other interdependent projects/activities (under the auspices of other committees/working groups).

The main elements of the project governance and management arrangements are understood to be as follows:

- **Brisbane River Catchment Floodplain Studies Steering Committee (SC**) – responsible for oversight of flood studies and floodplain management studies in the Brisbane River catchment in support of the implementation of the final recommendations of the Queensland Floods Commission of Inquiry;
- **Project Director** – responsible for overall project leadership and direction;
- **Project Manager/Project Management Team** – responsible for project management and delivery;
- **Consultants** – responsible for delivering specific project tasks, investigation, assessment and reporting;
- **Brisbane River Catchment Floodplain Studies Coordinating Technical Working Group (TWG)** – responsible for data/information exchange and interaction between various interrelated and interdependent pieces of work or studies, including the project;
- **Independent Panel of Experts (IPE**) – responsible for peer review of all interrelated works, in the Brisbane River catchment (including the BRCFS project data, methodologies and outputs) and advise the Steering Committee/Project Management Team;

10.5.2 Additional Governance Recommendations

Due to the scope, scale and technical complexity of the project, the following additional governance provisions are also strongly recommended:

- **Owner's Engineer** – responsible for assisting the Project Director and Project Manager in all program and technical aspects of the project throughout its duration, as well as assisting the work of the Independent Panel of Experts;
- **Engineering Reviewer** – responsible for independent checking of key project deliverables, models, calculations, assumptions and methodologies provided by the respective task consultants, as well as assisting the work of the Independent Panel of Experts.

In order to minimise project delays, the Steering Committee (or the Independent Panel of Experts or Engineering Reviewer) will need to provide timely review, endorsement of recommended actions, and/or decisions as required within nominated timeframes.

Project governance must also ensure collaboration and decision making involving State and Local governments and a number other key organisations at all levels of the Study; including technical, project control and executive steering levels. It is recommended as a minimum the organisations represented as part of the WSDOS Floodplain Management Technical Working Group are included within the established governance. These may form the basis of a technical reference group to assist the Planning Implementation Group if considered necessary.

11. Conclusion

This Technical Scoping Framework presents a process of technical enquiry, identification of knowledge, data, and evaluation of options and actions that if adequately resourced will lead to the timely and successful implementation of a variety of study outcomes. In combination, these are designed to better understand, plan for and avoid the ongoing and future risk and significant costs of the damaging effects of floods on people and property within the Brisbane River, its tributaries and extensive urban floodplain, for generations to come.

The process advocated is fully **risk-based, comprehensive in scope and necessarily innovative** to meet the identified and peer-agreed complexity of the Brisbane River system. The resulting key guidance and recommendations have been embodied into a series of draft technical Scopes of Work that are provided separate to this report.

The Framework has addressed, inter alia:

- A description of **the context of flooding problems** associated with the Brisbane River catchment and associated rivers and tributaries;
- A brief **history of regional flood events** and their impacts, as well as **potential future impacts**;
- A review of **national and international best practice** approaches and guidelines;
- Identification of the many jurisdictional overlaps**, stakeholder organisations** and intellectual resources available to address the problems;
- Recognition of the **principal climate drivers** that dictate flood frequency and intensity on a **range of space and time scales** and the potential implications of longer term climate change;
- The need to collate many **data sources**, assess their quality, consistency and relevance to addressing future study needs, and the identification of gaps in data;
- A review of the technical approaches and resources available to address the study objectives and the identification of **methodology gaps** requiring targeted research offering both immediate and future long-term value to the various stakeholders;
- A **high-level work plan**, schedule and **Scopes of Work** for the detailed technical and non-technical studies (e.g. flood hazards, hydrology, hydraulics, risk assessment, floodplain management) that will collectively and consistently build to form the basis of a comprehensive flood modelling and risk assessment system;
- A **resulting system model** capable of informing decision makers as to (1) the present levels of risk in all its complexity, (2) the options that are now available to reduce risk and (3) to be the enabling tool for ongoing future risk-reduction planning (strategic and emergency).

The process followed in constructing the Framework has been one of:

- **Engagement and consultation** with stakeholders leading to the discovery of relevant resources (data, models, techniques);
- Consultation with a range of **technical specialists** (government, consultant, research) having the knowledge and experience needed to deliver the targeted outcomes;
- Peer review and **transparency** in development of the recommended investigation programme options.

It is concluded that in order to meet the substance and intent of the QFCI recommendations, a series of high quality inter-linked technical studies are needed to achieve the aims and intended outcomes. These are **necessarily detailed and of sufficient scope and duration** to match the already **identified and agreed complexity** of the river system and the climatic drivers that lead to damaging floods.

While there are many component parts to the recommended series of individual best practice studies, with **data collection being a significant precursor**, the process can be summarised in terms of two principal elements, as follows:

1. A series of tasks that will lead to the accurate quantification of the present and potential future flood hazard across the entire catchment - the probabilistic **Flood Study**, and
2. A series of subsequent tasks that will combine the hazard information with community vulnerability to determine the risks and cost of flooding, leading to the identification of viable risk mitigation strategies (planning and/or infrastructure changes) – the comprehensive **Floodplain Management Study**.

Each of these work elements is expected to require **up to 3.5 years to complete**, and must be conducted mainly in sequence. Across this timeframe, **extensive ongoing community and stakeholder consultation** is proposed that will be informed by the **progressive release** of the technical study results, such as flood risk maps and the identification of viable mitigation options.

With **an overall project duration of potentially up to 7 years** from initial investigation to final implementation of Council floodplain management plans, this process will be similar to but within the current typical 10 year cycle for revision of Local Government Planning Schemes.

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Appendices

Appendix A – Summary of Relevant Queensland Flood Commission of Inquiry Recommendations

The intention of the Technical Scoping Framework document is to consider the number, type and scope of investigations needed to address, inter alia, the relevant recommendations of the QFCI Final Report (QFCI 2012), in particular Recommendation 2.2, which is summarised below.

The flood study of the Brisbane River Catchment is to be carried out in accordance with process determined by Brisbane City Council, Ipswich City Council, Somerset Regional Council and the Queensland Government under Recommendations 2.5 and 2.6 of the QFCI Final Report. The study should:

- *Be comprehensive in terms of the methodologies applied and use different methodologies to corroborate results;*
- *Involve the collation, and creation where appropriate, of the following data:*
    - *rainfall data including historical and design data and radar;*
    - *stream flow data;*
    - *tide levels;*
    - *inundation levels and extents;*
    - *data on the operation of Wivenhoe and Somerset dams;*
    - *river channel and floodplain characteristics including topography, bathymetry, development and survey data;*
- *Involve determining the correlation between any of the data sets above;*
- *Produce suitable hydrologic models run in a Monte Carlo framework, taking account of variability over the following factors:*
    - *spatial and temporal rainfall patterns;*
    - *saturation of the catchment;*
    - *initial water level in dams;*
    - *effect of operating procedures;*
    - *physical limitations on the operation of the dams;*
    - *tidal conditions;*
    - *closely occurring rainfall events;*
- *Validate hydrologic models to ensure they reproduce:*
    - *observed hydrograph attenuation;*
    - *probability distributions of observed values for total flood volume and peak flow;*
    - *timing of major tributary flows;*
    - *observed flood behaviour under no dams conditions and current conditions;*
- *Produce a suitable hydraulic model or models that:*
    - *are able to determine flood heights, extents of inundation, velocities, rate of rise and duration of;*
    - *inundation for floods of different probabilities;*
    - *are able to deal with movement of sediment and changes in river beds during floods;*
    - *are able to assess historical changes to river bathymetry;*
    - *are able to be run in a short time to allow detailed calibration and assessment work;*
    - *characterise the backwater effect at the confluence of the Brisbane and Bremer rivers and other;*

  - *confluences as appropriate;*

- *Involve analysis of the joint probability of floods occurring in the Brisbane and Bremer rivers (and any other pair of rivers if considered appropriate);*
- *Be iterative, and obtain a short-term estimate of the characteristics of floods of different probabilities in all significant locations in the catchment (at least Brisbane City, Ipswich City and at Wivenhoe Dam) in order to determine the priorities for the rest of the study.*

> *Study outputs should be provided in an appropriate electronic format consistent with the requirements of relevant government (local, State and Federal) databases and information systems so that they can be easily integrated as and when required (e.g. QFCI Recommendations 2.11, 2.16 and 2.17 relating to the flood data and information derived from flood studies).*

In addition, the following QFCI recommendations, inter alia, are relevant:

2.12 Councils in floodplain areas should, resources allowing, develop comprehensive floodplain management plans that accord as closely as practicable with best practice principles.

2.13 For urban areas or areas where development is expected to occur:

a. councils with the requisite resources should develop a flood map which shows 'zones of risk' (at least three) derived from information about the likelihood and behaviour of flooding

b. councils without the requisite resources to produce a flood behaviour map should develop a flood map which shows the extent of floods of a range of likelihoods (at least three).

Appendix B – Terms of Reference for this Study

The following is an extract of the Terms of Reference for this study (DSDIP-1933-12; amended 02/10/2012):

SECTION 3 – SPECIFICATIONS Amended 2/10/2012

3.1. PURPOSE

A Consultant is required to formulate a project framework for guiding and scoping the Brisbane River Catchment Flood Study and associated Brisbane River Floodplain Management Study, a cooperative initiative of state and local government in response to the damaging flood impacts of the January 2011 event.

The Framework must be fully consistent with the recommendations of the Queensland Flood Commission of Inquiry (QFCoI) Final report and the State Government Response.

3.2. BACKGROUND

The Planning Implementation Group (chaired by DSDIP) is ultimately responsible specific areas of work, including the flood study and associated floodplain risk management studies/plans, with DNRM and DSDIP having lead responsibility for the flood study and floodplain management studies/plans respectively. DEWS is accountable for Flood Management and Dam Operations and Water Supply Security. Collectively DSDIP and DEWS are accountable for the Integrated Assessment Framework. Other inputs are provided by DTMR on bridge raising issues and Seqwater on hydrologic data and dam operations. Information flows occur among all groups.

The flood study and floodplain risk management studies/plans arises from earlier work and scoping reports implementing recommendation 2.2 of the QFCoI, including:

1. *GHD report "Brisbane River Catchment Floodplain Studies Planning Review, dated 11 September 2012'*
2. *"Draft Scope of Work to Deliver the Brisbane River Floodplain Management Plan" dated 31 July 2012*
3. *Seqwater "Brisbane River Floodplain Management and Dam Operations Scope of Work" and project brief.*
4. *WSDOS draft Workstreams project schedule prepared by SKM consultants and DEWS dated 25 July 2012*
5. *WSDOS Integrated Assessment Framework Final Report dated 12 July 2012.*

The project seeks to clearly define and integrate a scope of work for a range of related studies that can be used in preparing tender briefs for future work undertaken as part of the Brisbane River Catchment Flood Study and the associated Brisbane River Floodplain Management Study and the Integrated Assessment Framework. .

3.3. REQUIREMENTS

3.3.1 Technical Scoping Framework

The Technical Scoping Framework will build upon existing draft scoping documents already prepared by the relevant state government agencies and will produce a fully integrated project plan designed to meet the overall investigation timeframes. Consultation with the various stakeholders will be required.

Following the recommendations of the GHD report "Brisbane River Catchment Floodplain Studies Planning Review, dated 11 September 2012', it is intended that the Framework will provide the following key guidance and deliverables in accordance with the following:

1. General and Relevant Guidance:

a) Establish general data collection and storage standards relevant to the Brisbane River Catchment Flood Study and the associated Brisbane River Floodplain Management Study, including appropriate quality, formats and *metadata that will meet the requirements of the Department of Natural Resources and Mines (DNRM) Spatial Information unit.*

b) Identify the program formats and compatibility standards required and best practice technical approaches for hydrologic and hydraulic modelling that is presently available and may have application to the Brisbane River Catchment Flood Study.

c) Drawing on the GHD report recommendations, provide a detailed integrated project plan for the entire Brisbane River Catchment studies to meet the overall investigation timeframes, and schedule of interaction for each of the identified technical studies.

d) Undertake an assessment of risks and constraints to the timely delivery of the various scopes of work

e) Provide the terms of reference for an expert panel to provide overview advice to the Brisbane River Catchment Floodplain Management and WSDOS steering committees.

2. Prepare detailed scope of works and high level methodologies aligned with the integrated project plan to enable open tendering for:

a) The delivery of appropriate best practice Brisbane River Catchment Flood Study, including detailed 1D and 2D hydraulic model development and design flood modelling, including joint probability analysis and stochastic modelling using a Monte Carlo methodology

b) Investigation of identified mitigation strategies, including testing through hydraulic and hydrologic modelling, including joint probability Monte Carlo analysis

c) The delivery of appropriate best practice Floodplain Management Study for the defined study area, including detailed flood mapping (3D as required) that would enable this information to be readily accessible to stakeholders and interested parties

d) The integrated assessment framework, including:-

  1) Best practice for the assessment and evaluation of Flood damage

  2) Best practice in Risk Management

e) The delivery of appropriate best practice Floodplain Risk Management Plan for the defined study area.

f) A framework for community engagement throughout the preparation of Brisbane River Catchment Flood Study and the associated Brisbane River Floodplain Management Study

3.3.2 Deliverables

a) A report that provides a response to items 1(a) – (e)

b) A report which details the proposed scope of works for items 2(a) – (f), the scope for each item shall be sufficient to allow each element to be used in a subsequent tender brief.

c) Further recommendations about the proposed technical approaches benchmarked against best practices.

d) Further recommendations to meet the objectives of the various scopes of work

3.3.3 Delivery

The Framework study is to be completed by Friday 21 December 2012.

Endnote:

The contract was awarded on 12/11/2012 and work commenced on 19/11/2012, with delivery of draft scopes of work scheduled for 21/12/2012 and final draft scheduled for 18/01/2013. A stakeholder workshop was held on 19/12/2012.

Appendix C – Recommended Project Plan

Appendix C: Brisbane River Catchment Flood Studies - Overall Project Schedule

	Year:	2012	2013				2014				2015				2016				2017				2018				2019				2020			
Scope of Work	**Qtr:**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Technical Framework		🟦	🟦																															
DNRM Data Collection (External Project)		🟦	🟦	🟦																														
WSDOS Hydrology and Dam Optimisation Analysis		🟦	🟦	🟦	🟦																													
WSDOS Water Supply Security Assessment and WSDOS Final Options Report		🟦	🟦	🟦	🟦	🟦	🟦																											
Procurement of Consultancy Services	3 months			🟦												🟦																		
Stochastic Simulation Study	2 years				🟦	🟦	🟦	🟦🔴	🟦	🟦	🟦	🟦🔴																						
Flood Study	3 years 6 months				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																
Communication strategy	Life of project				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Flood Damage Data Collection (and Damage Curve Generation)	1 year				🟦	🟦🔴	🟦	🟦🔴																										
Floodplain Management Study	3 years 6 months															🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Floodplain Management Plan	6 months																										🟦	🟦						

Brisbane River Catchment Flood Studies - Detailed Project Schedules for the Flood Study and Floodplain Management Study/Plan:

Flood Study

	Year:	2012	2013				2014				2015				2016				2017				2018				2019				2020			
Scope of Work	**Qtr:**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Procurement	3 months			🟦																														
Project Startup	3 months				🟦																													
Data Collection	6 months				🟦	🟥																												
Preparation of Communication and Stakeholder Consultation Plan	3 months			🟦	🟦																													
Hydrologic Model Calibration Review	6 months				🟦🔴	🟥																												
Establish Community and Industry Liaison Committees (CLCs)	Ongoing				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				
Public awareness raising of the need for the Studies and subsequent Management Plan	Ongoing				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				
Level 1 Hydrologic Modelling	6 months					🟦	🟦																											
Level 2 Hydrologic Modelling	6 months						🟦	🟦🔴																										
Level 3 Hydrologic Modelling	3 months											🟦🔴																						
1D Hydraulic Model Development	1 year				🟦	🟦	🟦	🟦																										
1D Hydraulic Model Calibration	6 months								🟦	🟦🔴																								
1D Hydrauilc Model Design Event Simulations	6 months										🟦	🟦🔴																						
2D Hydraulic Model Development	1.5 years				🟦	🟦	🟦	🟦	🟦	🟦																								
2D Hydraulic Model Calibration	6 months										🟦	🟦🔴																						
2D Hydrauilc Model Design Event Simulations	6 months												🟦	🟦🔴																				
Engage with CLCs at critical points	6 months				🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦																				
Flood Inundation Mapping	6 months														🟦	🟦🔴																		
Draft and Final Reports, User Manuals, Database	6 months																🟦🟢	🟦																
Training	3 months																	🟦																
Project Completion / Acquital																		🟦																

Floodplain Management Study / Floodplain Management Plan

	Year:	2012	2013				2014				2015				2016				2017				2018				2019				2020			
Scope of Work	**Qtr:**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Procurement	1 month															🟦																		
Project Startup	1 month																🟦																	
Sub-catchment consultation events - following CLCs and prior to completion of Flood Study	6 months							🟦	🟦	🟦	🟦	🟦	🟦	🟦																				
Review and analysis of community feedback - Consultation Report	2 months														🟦	🟦																		
Public launch of DRAFT FMP	2 months																🟦	🟦																
Public awarness raising activities																	🟦	🟦																
Data Collection	2 months																🟦	🟦																
Baseline Flood Risk Analysis	1 year																		🟦	🟦	🟦	🟦🔴												
Flood Mitigation Assessment	1 year																						🟦	🟦🔴	🟦	🟦🔴								
Draft Floodplain Management Report	3 months																										🟦🔴							
Draft Floodplain Management Plan	6 months																										🟦	🟦🔴						
Roadshow public consultation of FMP	3 months																										🟦	🟦						
Community feedback analysis and reporting	6 months																											🟦	🟦					
Finalise FMS and Report	3 months																												🟦🟢					

Notes:

1	🔴	2 Week Peer Review Period
2	🟢	4 Week Peer Review Period
3	**?**	Uncertain timeframe.
4	🟥	Additional timeframe if required

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
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0	B. Harper B. Regan P. Priebbenow B. Maki	R. Fryar B. Harper		N. Davis		25/01/2013
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