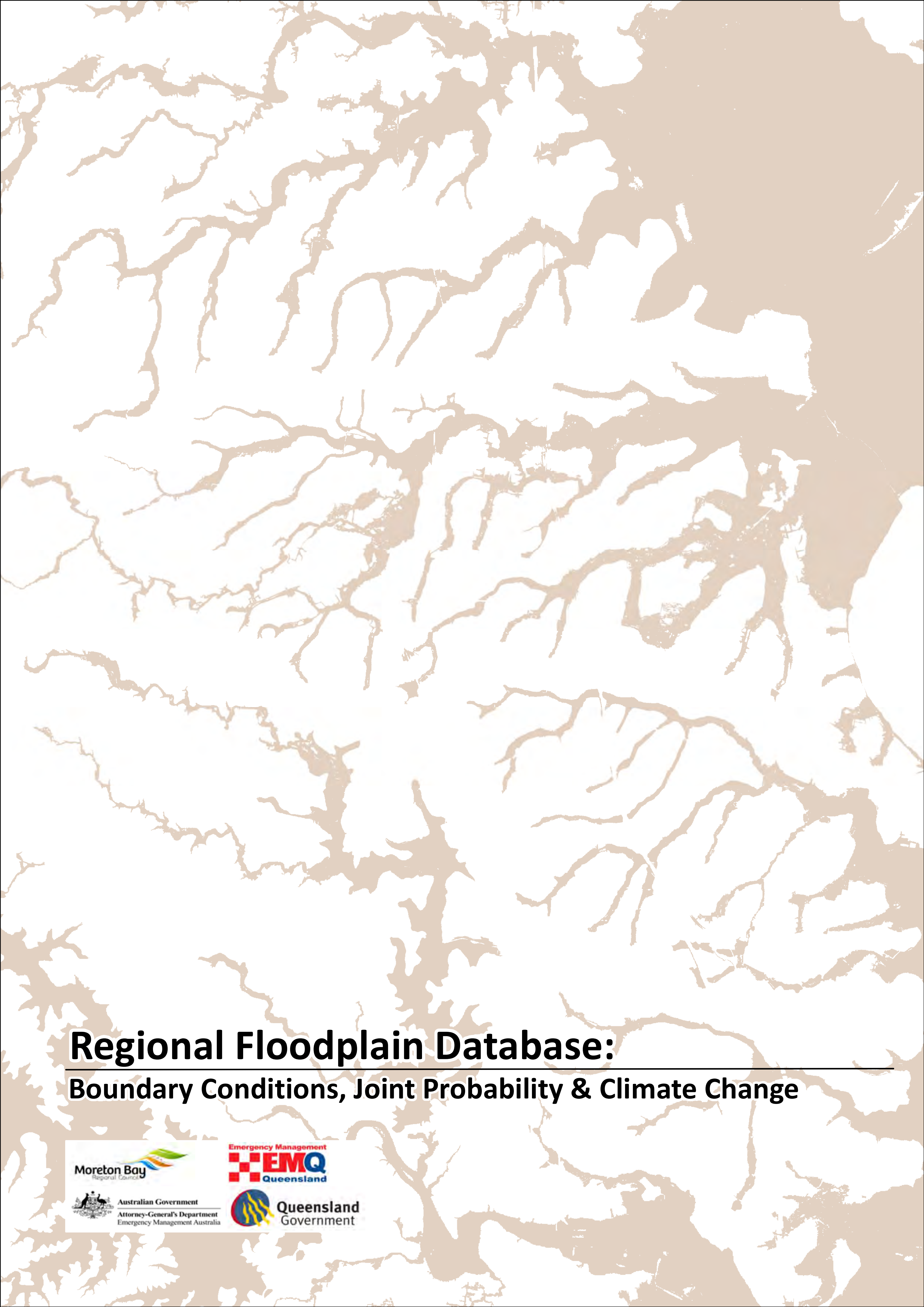

Regional Floodplain Database:

Boundary Conditions, Joint Probability & Climate Change

Moreton Bay Regional Council

Emergency Management EMQ Queensland

Australian Government
Attorney-General's Department
Emergency Management Australia

Queensland Government

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MBRC
Regional Floodplain Database

BOUNDARY CONDITIONS, JOINT PROBABILITY & CLIMATE CHANGE

- FINAL Rev 1
- 9 July 2012

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1. Introduction

Sinclair Knight Merz Pty Ltd (SKM) has been commissioned by Moreton Bay Regional Council (MBRC) to carry out an investigation into appropriate and standardised flood modelling methodologies to be adopted for use in Council’s Regional Floodplain Database Project (RFD Project).

The RFD Project involves a three year (three stage) program for the development of comprehensive flood mapping across the Moreton Bay Regional Council Local Government Area. A key focus for the project is the standardisation of methods and procedures so as to ensure consistency in the flood information produced. The Burpengary ‘Minor Basin’, incorporating Burpengary Creek, Little Burpengary Creek and Deception Bay has been selected as the Stage 1 pilot study catchment for development of these standardised methods and procedures.

This report documents the development of standard flood model boundary conditions, joint probability considerations and climate change scenarios for the Burpengary Minor Basin. Following test application Council will consider extension of the procedures documented herein for Stage 2 of the project which will include detailed flood modelling and mapping for the region.

1.1. Background

Moreton Bay Regional Council (MBRC) was formed by the amalgamation of Caboolture Shire, Redcliffe City and Pine Rivers Shire Councils (total area of 2,070 km^2). The Moreton Bay ‘Regional Floodplain Database’ Project aims to comprehensively map the floodplains of the new combined region.

The key goals of the Moreton Bay ‘Regional Floodplain Database’ are:

- a comprehensive description of flood behaviour across the region;
- strategies for management of any flooding problems identified; and
- a system/process to store and manage this information and keep it up-to-date.

The aim of the overall project is to have a consistent and standardised approach to the hydrological and hydraulic modelling used in to determine flood behaviour in across the region. The important benefits of standardisation of flood modelling are:

- regional data consistency;
- consistency of interaction between data storage and data analysis tools;

- facilitate targeted data capture that relates specifically to the models being employed;
- enhanced understanding of changes in model behaviour due to changes in their underlying parameters, allowing Council to over time develop a more robust and accurate parameter set;
- provide an opportunity for Council to develop a stronger understanding of the modelling tools being used by their consultants (difficult when a large number of different modelling packages are being used). This will enable a more thorough and critical assessment of the methodologies being employed; and
- achieve economies of scale when researching / deriving new approaches.

The scope of this sub-project was to:

- Review pilot catchment issues relating to boundary conditions, joint probability and climate risk;
- Review available spatial datasets (storm tide, preliminary floodplain mapping);
- Review current research and guidelines with respect to appropriate boundary conditions, joint probability and climate risk;
- Develop specifications, modelling processes and datasets compatible with TUFLOW for representation of boundary conditions and joint probability issues; and
- Develop of a specification for modelling climate risk scenarios.

1.2. Objectives

The objectives of this sub-project are:

- The specification of a modelling process for representation of downstream tidal boundary conditions for all design storm scenarios including location and associated time series.;
- The specification of a modelling process for representation of initial starting conditions in large water bodies for all design storm scenarios including location and associated time series.;
- The specification of climate risk scenarios to be considered by the detailed modelling sub-project (Sub-Project 2B) including sea level rise and changes in rainfall intensity based on current research; and
- Consideration of any joint probability issues associated with storm tide, initial water levels, and riverine flooding.

1.3. General Approach

The general approach for this study was to review background information and make informed recommendations for MBRC relating to boundary conditions, joint probability and climate change.

The first step was to review the range of hydrologic and hydraulic characteristics of waterways within the MBRC area, with particular focus on Burpengary Creek. From this review, the relevant factors affecting boundary conditions, joint probability and climate change within MBRC were determined.

For each factor, such as storm surge or mean sea level rise, a literature review was completed to identify:

- previous studies undertaken by or commissioned by MBRC;
- parameters and/or approaches adopted by neighbouring councils;
- relevant government policies, guidelines or studies; and
- related studies, journal papers or conference proceedings published recently.

Based on the outcomes of the literature review, a step-by-step method or procedure was recommended for the development of each model input. Where significant benefit could be derived by additional investigation of a specific parameter or local behaviour, this has been recommended.

The recommended procedures were then applied to Burpengary Creek. Parameter values are reported here and specific model input files have been developed for the pilot.

1.4. Related Sub-Projects

The RFD project involves a separate project (Sub-Project 2B) responsible for the development of hydrologic and hydraulic models for the Burpengary Creek pilot investigation. Sub-Project 2B will use Council’s nominated software modelling packages as follows:

- Hydrologic Modelling – WBNM2009
- Hydraulic Modelling – TUFLOW.

Each section of this report is devoted to one of the four key areas of boundary conditions, initial conditions in large water bodies, joint probability and climate change. Input parameters relating to each area, relevant for direct application to the Burpengary Creek catchment and Sub-Project 2B.

2. Climate Change

2.1. Introduction

Climate change has the potential to impact on flooding through a series of mechanisms, from changes in rainfall patterns to mean sea level rise. To understand future flooding risks, climate change scenarios should be included in both hydrologic and hydrodynamic modelling.

This is becoming a standard practice in local government land use planning. Byron Shire Council in northern NSW has adopted climate change flood estimates as their Defined Flood Extents (DFEs) in policy.

More locally, the former Caloundra City Council (now part of Sunshine Coast Regional Council) has adopted climate change scenarios as land use planning tools across the Mooloolah River floodplain and Caloundra South area (including Mellum Creek, Bells Creek and Duck Holes Creek). The 1 in 100 AEP flood event under climate change conditions has been used as the Defined Flood Event (DFE) for the Palmview Structure Plan Area and Caloundra South Structure Plan Areas. Furthermore, consistent climate change scenarios have been adopted as the standard for local area drainage design within these areas.

Current climate change predictions incorporate climatic changes that could influence a range of parameters used within hydrologic modelling. Potential changes include:

- Increased rainfall during large to extreme rainfall events;
- Altered spatial variation of rainfall during rainfall events;
- Altered temporal variation of rainfall during rainfall events; and
- Changes in average annual rainfall impacting on losses.

Hydrodynamic modelling will be influenced by the modification to inflows this produces. In addition, downstream tidal boundary conditions could be influenced by climate change through two main mechanisms:

- Increased Mean Sea Level (MSL); and
- Modified cyclonic activity resulting in changes to storm surge behaviour.

This section provides a discussion of each of these six mechanisms, including:

- the current government policy around adoption of climate change estimates;
- the most recent science-based estimates for climate change influence to each mechanism;
- current work being undertaken to further understand climate change inputs on each of these parameters; and
- recommendations for climate change scenarios and associated model parameters.

The information and recommendations presented here are considered the best-available at the time of publication. However, climate change science is a new and dynamic area of investigation. Our understanding of climate science is developing extremely quickly. These recommendations should be reviewed as new information becomes available. At the very least, a high level review of these recommendations relating to climate change horizons, projections and emission scenarios should be undertaken annually.

2.2. Available Data

This section provides a summary of climate change policy and how this relates to adopted climate change estimates for south-east Queensland. It also provides a summary of the available information relating to climate change horizons and emission scenarios. A full list of references including those relating to science-based climate change estimates is available in **Section 9**.

2.2.1. Climate Change Policy

In July 2008, Cabinet released a new requirement for all Cabinet/CBRC submissions to produce a Climate Change Impact Statement (CCIS). In general, flood modelling within MBRC will not be the subject of a Cabinet /CBRC submission. However, this process will be used to assess large infrastructure projects in Queensland. Thus the climate change estimates adopted for this process provide a useful benchmark.

Table 2-1 presents the climate change estimates adopted for the CCIS. It is noted that the parameters provided by Cabinet are designed to support assessments across the entire state of Queensland. These estimates therefore may not be the most appropriate for a specific project in a particular location within Queensland.

- **Table 2-1 Cabinet Requirements (2031 - 2070)**

Parameter	**Cabinet Submission Requirements**
Temperature Increase	3°C
Increased design rainfall depth	10% - 20%
Sea Level Rise	0.49 m
Storm Surge	0.50 m
Storm Surge + Sea Level Rise	0.99 m

The Queensland Government *State Planning Policy 1/03: Mitigating the Adverse Impacts of Flood, Bushfire and Landslide* (2003), sets out recommended processes for local government to following when undertaking or commissioning flood planning and modelling studies. It also provides guidance on required Defined Flood Events (DFEs) for a range of community infrastructure such as power stations and hospitals. The policy indicates that local government should consider climate change in flood studies. However, guidance on the adoption or modelling of climate change scenarios is limited to the following:

> *"The potential impacts of climate change should be addressed as part of the flood study. To date, there have been no conclusive studies that quantify the impact of climate change due to the greenhouse effect on either the frequency or intensity of major (flood) rainfall events across Queensland. It is however, important to consider the potential adverse consequences of climate change on flooding in the local context and to remember that, in addition to possible impacts on rainfall and run-off, conditions such as sea level rise and an increase in the southern excursions of tropical cyclones may have significant implications for coastal floodplains. Climate change information should be sought initially by contacting bodies such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Climate and Atmosphere, the Bureau of Meteorology, and the Queensland Centre for Climate Applications, in NR&M. However, interpretation should be undertaken by a suitably qualified professional engineer."*

DERM is currently undertaking a joint project with the Local Government Association of Queensland (LGAQ) entitled: *Climate Change and Inland Flooding*. This project is focused on a review of climate change estimation used in the *Gayndah Flood Study* (WBM, 2009).

However, the broader project goals are to:

- Review relevant science related to climate change and flooding;
- Review the current Queensland approach to flood risk management policy;
- Assess alternative policy options to incorporate climate change; and
- Provide recommendations for changes to the *State Planning Policy 1/03* for consideration in a forthcoming review of the policy.

Representatives of SKM met with a representative of DERM working on the project to discuss DERM's current approach. The project focuses on inland rather than coastal flooding and is currently at an early stage. Reviews of possible approaches to development of design rainfall under climate change were being undertaken with a proposed method expected to be adopted in March 2010. Outcomes of this project may provide further guidance on climate change scenario flood modelling in Queensland. It is recommended that MBRC keep in touch with DERM to stay up to date with developments on this project.

The Queensland Government (DERM) published its *Draft Queensland Coastal Plan – Draft Guideline Coastal Hazards* in late 2009. The coastal plan provides Recommended Storm Tide Event Levels (RSTELs) similar to the DFEs recommended for freshwater flooding SPP 1/03. The guideline document also sets out 'minimum assessment factors for determining erosion-prone areas and storm tide inundation areas'. According to the draft, the minimum parameters to be adopted are:

- A planning period of 100 years;
- A projected value for mean sea level rise of 0.8 m by 2100 relative to 1990;
- Adoption of the 1 in 100 AEP storm event or water level; and
- Adoption of a 10% increase in cyclone intensity due to climate change.

The NSW Department of Environment and Climate Change (DECC) published draft guidelines on *Practical Consideration of Climate Change in Floodplain Risk Management* in 2007. The approach advocated in this guideline is a sensitivity analysis incorporating 10%, 20% and 30% increases in peak rainfall. In addition, the guideline recommends a sensitivity analysis incorporating mean sea level rises of between 0.18m and 0.91m for NSW.

2.2.2. Climate Change Horizons

Climate change projections vary significantly dependent on the horizon for which they are predicted.

Dependent on the study, climate change projections are generally reported for the 2030, 2050 and 2070 horizons, with some reports providing only information for the 2040 horizon. Limited information is available out to 2100. There is currently reasonable certainty in climate change projections for the 2030 horizon while post-2050 estimates are much less reliable.

The end-purpose of the MBRC Regional Floodplain Database (RFD) project is to produce consistent flood estimates across the local government area for use in land-use planning.

Based on the availability and certainty of climate change projections and the end-purpose of flood modelling outputs, it is recommended that climate change scenarios be produced for the 2030-2070 planning horizon, using projections at the mid-point year of 2050 as representative of the planning horizon. This approach is adopted in Queensland Cabinet (2008).

2.2.3. Emissions Scenarios

Climate change projections are also heavily dependent on the emissions scenario used to develop them.

Emission scenarios are generally characterised as Low, Medium or High, particularly within *Climate Change in Australia* (CSIRO & BoM, 2007). Current evidence (Raupach *et al*, 2007) shows that global average temperature and atmospheric carbon-dioxide concentrations are currently tracking at or above the *High Emissions* scenarios. It is therefore recommended that where multiple emission scenarios are reported, the *High Emissions* scenario be adopted.

2.3. Methodology

The adopted methodology for development of a procedure to consistently model climate change scenarios within MBRC was to undertake a literature review of climate change policy, science-based estimates and current work for each affected mechanism.

2.3.1. Storm Surge

In addition to current climate storm tide estimates, Cardno (2009) predicted storm tide estimates for a 2050 climate change horizon based on increased intensity of cyclones. In all cases, these estimates were found to be greater than both the current climate cyclonic and non-cyclonic storm tide estimates. The “green-house affected” cyclonic estimates are considered appropriate for use in development of downstream boundary conditions for hydrodynamic modelling of a climate change scenario for 2050.

Cardno (2009) provided estimates between the 1 in 20 and 1 in 10,000 AEP. It is recommended that this level be adopted for all events rarer than 1 in 10,000 AEP.

As for the current climate storm tide estimates, a natural log-linear relationship was observed between AEP and storm tide level. Storm tide estimates under climate change can therefore be estimated using natural log-linear extrapolation for the 1 in 5 and 1 in 10 AEP events.

The "greenhouse-affected" Cardno (2009) did not include any allowance for mean sea level rise. Therefore an allowance for mean sea level rise must be added to these estimates. This is discussed in **Section 5.5.1**.

2.3.2. Mean Sea Level Rise

The National Tidal Centre of the Australian Government Bureau of Meteorology (2009) has been monitoring long term trends in mean sea level at sites around Australia since the early 1990's. The two nearest long-term monitoring sites to the Moreton Bay Regional Council area are at Port Kembla, 830 km to the south, and Rosslyn Bay, 500 km to the north. Trends in mean sea level rise have been increases of 1.9 mm/year at Port Kembla (from July 1991 to June 2009) and 1.5 mm/year at Rosslyn Bay (from June 1992 to June 2009).

If sea level rise was to continue at average rate from Port Kembla and Rosslyn Bay into the future (i.e. 1.7 mm/year), projected increases in mean sea level from 2009 levels would be 0.07 m by 2050. This is a lower bound estimate, since guidance from climate modellers are that the effects of global warming on sea level rise are expected to accelerate from current rates over the 21st Century. Historical trends in sea level rise could be explained by a combination of tectonic plate movement, natural long-term climate variability and anthropogenic global warming effects.

An estimate of mean sea level rise was determined using The Intergovernmental Panel on Climate Change (IPCC) sea level rise predictions from 2007. The worst case scenario of high fossil fuel use and upper bound sea level rise value was used.

The upper bound sea level rise prediction was 0.59m for a rise between MSL for the period 1980-1999 and projected MSL for the period 2090-2099. An estimate for accelerated ice-melt was also considered, adding an additional 0.17mm/yr to the expected rise.

In contrast to the projected climate change impacts on sea level, there is an underlying rate of rise (or fall) of sea level. At Brisbane, this has been measured and reported as

-0.22mm/yr (Mitchell et al., 2001). This results in a 0.011m decrease in sea level over a 50 year planning period.

Thus a cumulative conservative result for Mean Sea Level rise in Moreton Bay by 2050 is 0.37m. This allowance for mean sea level rise should be added to both the storm tide and MHWS levels prior to creation of the downstream boundary time series.

This allowance is currently considered a reasonable estimate. The IPCC note however, that future ice sheet contributions, which cannot be well quantified at this time, may increase the upper limit of sea level rise substantially.

2.3.3. Rainfall Depths

Abbs and McInnes (2004) report the results of limited area climate modelling of the region, based on a paper by Abbs (2004). Abbs (2004) used limited area modelling of the climate system, with a high resolution atmospheric model (7.5km horizontal resolution) embedded within boundary conditions from the CSIRO Mark 3 GCM model run for current and 2040 climate for 100 large rainfall producing events. The rainfall totals at each grid cell were extracted for the 10 largest 24-hour periods in the 100 runs, for both current and 2040 climate. The average values from each of these sets of runs were used to produce a ratio of expected change in large rainfall totals.

Figure 1 of Abbs (2004) and Figure 2 of Abbs and McInnes (2004) both show that variations in rainfall changes are very large across the study region, varying between approximately -80% and +70%. The large variability in outcomes in the figures indicates that results cannot be directly inferred from this figure, due to sampling of a limited number of model simulations with such a high-resolution atmospheric model. Abbs and McInnes (2004) state as much ("the population of events for an individual location is likely to be too small to provide a meaningful result") and therefore adopt a method of estimating changes in large rainfall depths based on pooled data from the entire South East Queensland and Northern NSW domain.

Abbs (2004) analysed the 24 hour rainfall outputs from this model domain, constructing rainfall depth versus area curves for both current and 2040 climate. Based on the curves shown in Figure 2(a) of Abbs (2004), the estimated increase in the 1 in 40 AEP rainfall depth, for a 24 hour duration event would be 30% from current to 2040 climate conditions. This level of increase is about six times larger than the projections made directly from changes in GCM precipitation.

GCM were used by Abbs and McInnes (2004) to show that there would be an increase of between 5% and 11% in the frequency of synoptic conditions that cause large rainfall events in South East Queensland by 2030. On this basis, if climate change only causes an increase in the frequency of events and not the intensity of rainfall resulting from those events then design rainfall depths would increase by between 1% and 2% under 2030 climate conditions. This should be considered as a lower bound estimate on the potential increase.

The Clausius-Clapeyron equation predicts a theoretical maximum increase of 8%, for each 1°C increase in air temperature, in the amount of moisture that can be held in the atmosphere. For very short duration events, it is commonly held that intensities should therefore also increase by 8% for each 1°C increase in average air temperature (New Zealand Government Ministry for the Environment, 2008). The New Zealand Government (2008) guidance is that this 8% per °C rule should be applied for event durations of 10 minutes and less, with a pragmatic assumption of a logarithmic reduction in intensity with event duration out to the 24 hour duration events that have been determined by atmospheric modelling.

CSIRO & BoM (2007) indicates that for 2050, the projected increases in annual temperature for the South East Queensland region ranges between 0.6°C and 3°C, depending on the GCM and emissions scenario considered. Using the 8% per °C rule, this would relate to increases in design rainfalls for very short duration events of between 4.8% and 24%. These projected changes are consistent with the changes predicted by direct analysis of rainfall from GCM and changes in frequency of synoptic events causing large rainfall totals.

A high resolution atmospheric modelling approach leads to much larger projected increases in large rainfalls than the direct predictions from GCM outputs. Abbs and McInnes (2004) predict a 30% increase in the 1 in 40 AEP, 24 hour design rainfall depth for 2040 climate, which is a percentage increase of about six times the percentage increase from the other methods. The high-resolution climate modelling approach of Abbs (2004) is probably more accurate than the other approaches that only use the global models.

Considering all of the above advice, it is appropriate to adopt a 20% increase in design rainfall depths for large rainfall events for projected 2050 climate, for events that are more common than an AEP of 1 in 40. This percentage increase is slightly larger than would be predicted from an 8% per °C increase for the upper range of global warming projections by 2030 but is less than the guidance from Abbs (2004) that uses high resolution numerical modelling. A 20% increase in design rainfall depths for large events is also consistent with the upper range provided in Cabinet guidance.

All of the discussion to date has related to "large" rainfall depths, with AEP between approximately 1 in 5 and 1 in 40. None of these publications have attempted to provide projections of "extreme" rainfall depths, as the term extreme would be defined in *Book VI* of *Australian Rainfall and Runoff* (Nathan and Weinmann, 2000), which would span the range from 1 in 100 AEP out to the PMP.

The PMP depth is estimated by maximising storm efficiency and atmospheric moisture availability. The persisting 24-hour dew point temperature is used as a surrogate for moisture availability in estimating the PMP depth. If climate change results in an increase in dew-point temperature at a particular location, storm precipitable water would increase, which would increase the PMP depth (if there is no change in maximum storm efficiency, which is conventionally assumed). Changes in PMP depth (and other design rainfalls in the extreme range) due to climate change therefore depend upon changes in dew-point temperature.

Smalley *et al.* (2006) analysed the effects of trends in dew-point temperature for Brisbane. They analysed the maximum persisting 24 hour dew-point data from each calendar month for two separate periods: 1957-1980 and 1981-2003. Smalley *et al.* (2006) found that the only month displaying a statistically significant increase in dew-point temperature was May.

Jakob *et al*. (2008, 2009) completed a study of the implications of climate change for PMP in Australia. They analysed the effects of trends in dew-point temperature and storm efficiency using historical climatic data from around Australia. They concluded that,

> *"So far we cannot confirm that PMP estimates will definitely increase under a changing climate. We are not intending to revise PMP estimates or methodology to account for effects of climate change."*

Three methods were used by Abbs and McInnes (2004) to analyse climate change in South East Queensland, which in turn were used to infer changes in design rainfall intensity.

Analyses of trends in storm dew point data for Brisbane have demonstrated that there is no reliable evidence for any change in PMP estimates under climate change scenarios. Further research is currently being undertaken by the Bureau of Meteorology, involving the analysis of much more data, to confirm the presence or absence of any trend in PMP estimates. Changes in large rainfall depths (for AEP more common than 1 in 100) can therefore not be applied to more extreme events, for which there is no statistically reliable evidence of any climate change effect.

For the purposes of analysing the sensitivity of design flood estimates to potential future climate change, the following changes to design rainfalls are recommended, for all durations between 1 and 72 hours:

- For AEP between 1 in 5 and 1 in 40, design rainfall depths should be increased by 20%. This level of increase is based upon the high resolution modelling reported in Abbs (2004);
- For PMP, no increase in design rainfall depths. This is based upon the current guidance from the Bureau of Meteorology (Jakob *et al.*, 2008);
- For AEP between 1 in 500 and the AEP of the PMP, no increase in design rainfall depths; and
- For AEP between 1 in 40 and 1 in 500, linearly interpolate the percentage increase in rainfall depth in the normal probability domain, adopting a 20% increase for the 1 in 40 event and no increase for the 1 in 500 event.

Based upon the fact that there is no specific guidance on the potential effect of climate change on areal reduction factors, it is assumed that these will remain unchanged from current guidance for Queensland (DNRM, 2005).

These recommended percentage changes can then be applied directly to the areally reduced rainfall depths in the current climate hydrologic model. Recommended increases in design rainfall depths are shown in **Section 2.5**.

These recommendations have been selected on a pragmatic basis, using information from the several studies that are available to February 2010, for the purposes of analysing the sensitivity of flood flows to potential climate change. The influence of climate change and long-term climate variability on design rainfall depths is a very active area of research. Design flood estimates should therefore be revised once credible revised estimates of design rainfall depths become available.

2.3.4. Spatial and Temporal Patterns

There has been no research or guidance to date on changes in the temporal or spatial pattern of rainfall under climate change conditions. At present climate change modelling at the sub-daily time scale has significant uncertainty surrounding its predictions. Therefore, changes to spatial or temporal patterns are not yet well understood, particularly for large and extreme rainfall events.

Hence, the impacts of climate change on flooding are best incorporated by only considering changes to design rainfall depths and adopting spatial and temporal patterns based upon historical records. Considering only increases in design rainfall depths should produce a reasonable estimate of the design flood event and this is recommended due to the lack of clear guidance and inherent uncertainty in assessing the impacts of climate change on other aspects of design flood estimation (such as spatial and temporal patterns).

2.3.5. Losses

Antecedent conditions, and design losses, will be influence by projected climate change impacts on mean annual rainfall and evaporation. However, there is currently limited research or guidance on application of these projected changes to design losses for hydrologic modelling.

Sinclair Knight Merz (2009) derived design loss estimates under climate change for the catchment of Dartmouth Dam, by analysing daily runoff volume estimates for climate change scenarios produced as part of the Murray Darling Basin Sustainable Yields Project (Chiew et al., 2008). Due to the projected decreases in mean annual rainfall in southern Australia under climate change, design initial and continuing losses for the Dartmouth Dam catchment were increased by 25% for the 2030 middle climate change scenario and 60% for the 2030 dry climate change scenario.

In brief, the method involved:

- fitting the daily rainfall runoff routing model SimHyd to historical streamflow and climate data (Chiew et al., 2008);
- applying revised projected time series of daily rainfall and evaporation data for 45 climate change scenarios to the SimHyd model (Chiew et al., 2008);
- selecting three of the series as representative of “high”, “medium” and “low” future climate change (Chiew et al., 2008);
- separation of surface runoff from baseflow from each of the daily time series of historical and climate chance scenarios (Sinclair Knight Merz, 2009);
- accumulating the daily time series of the surface runoff component into four day totals for each of the daily time series of historical and climate chance scenarios (Sinclair Knight Merz, 2009);
- extracting the annual maxima from the accumulated four day totals of surface runoff (Sinclair Knight Merz, 2009);
- performing a frequency analysis on four day volumes for the historical and each of the climate change scenarios (Sinclair Knight Merz, 2009); and
- adjusting the initial and continuing loss parameter values for an existing RORB model of the Dartmouth catchment until the 1 in 50 and 1 in 100 four day runoff volume estimates matched the respective quantile estimates for the historical and each of the climate change scenarios (Sinclair Knight Merz, 2009).

There are no streamflow gauges on Burpengary Creek with a reliable long-term continuous record (although there are two flood warning gauges). This means that a similar analysis to that performed on the Dartmouth Dam catchment could not be performed on Burpengary Creek, although such an analysis could be completed using another gauged catchment in the area (e.g. on the North Pine or Caboolture Rivers).

In the Moreton Bay Regional Council area, the median of climate change projections for 2050 are for an overall reduction in mean annual rainfall of between 2% and 10%, with no change in mean seasonal rainfalls for summer, which is the dominant flood season in south-east Queensland. Even if there were sufficient data for the above method to be applied on Burpengary Creek, given that there is virtually no predicted change in mean seasonal rainfall over the dominant flood season, design losses for the catchment are likely to remain unchanged or increase only slightly (by a few percent).

It is, therefore, reasonable (and conservative) to assume in the Moreton Bay Regional Council area that design losses determined by calibration and verification to historical floods would continue to remain the same under future climate change.

2.4. Pilot Study Parameters

Based on the methods described in **Section 2.3** and following the procedures described in **Section2.5**, the following parameter changes are recommended to produce a 2050 climate change scenario for Burpengary Creek.

2.4.1. Hydrologic Model

Percentage rainfall increases for the 2050 climate change scenario have been determined. These are presented in **Table 2-2**. These percentage increases should be applied to areally reduced rainfall depths. No further changes are recommended to hydrologic modelling parameters, including:

- No change to spatial rainfall patterns;
- No change to rainfall temporal patterns; and
- No change to design losses (initial or continuing).

- **Table 2-2 Burpengary Creek - Projected increases in design rainfall depths for 2050 under climate change (event durations between 1 and 72 hours)**

AEP (1in Y Years)	Percentage Increase in Design Rainfall Depth
5	20%
10	20%
20	20%
50	18%
100	12%
200	7%
500	0%
1,000	0%
10,000	0%
>10,000	0%

2.4.2. Hydrodynamic Model

For the 2050 climate change scenario, hydrodynamic model inflows are to be derived from the hydrologic model using the recommended rainfall increases, above.

Estuarine boundaries for climate change scenarios should be developed consistent with the methodology for estuarine boundaries discussed in **Section 5.5.1**.

2.5. Adopted Procedure Standard

It is recommended that the procedure used to produce the recommended Burpengary Creek climate change scenario, presented in **Section 2.4** be adopted for all climate change scenarios modelled in the MBRC area.

The recommended procedure for modifying the hydrologic model to represent the 2050 climate change scenario is:

1) Increase areally-reduced rainfall depths by percentages identified in **Table 2-3**.
2) Make no changes to rainfall spatial and temporal patterns or design losses.
3) Run hydrologic model.

- **Table 2-3 Projected increases in design rainfall depths for 2050 under climate change (event durations between 1 and 72 hours) – For adoption for all MBRC catchments**

AEP (1in Y Years)	Percentage Increase in Design Rainfall Depth
5	20%
10	20%
20	20%
50	18%
100	12%
200	7%
500	0%
1,000	0%
10,000	0%
>10,000	0%

The recommended procedure for modifying the hydrodynamic model to represent the 2050 climate change scenario is:

1) Replace model inflows with climate change outputs from hydrologic model.
2) If downstream boundary condition is tidal, produce climate change boundary condition by following the procedure described in **Section 5.5.1**.
3) If downstream boundary condition is riverine, adopt climate change boundary based on climate change scenario outputs/inputs from downstream model.

3. Joint Probability

Current practice for estimation of design floods is typically based on the ‘design event’ approach, in which all parameters other than rainfall are input as fixed, single values. Considerable effort is made to ensure that the single values of the adopted parameters are ‘AEP-neutral’. That is, they are selected with the objective of ensuring that the resulting flood has the same annual exceedance probability as its causative rainfall.

Joint probability assessment is relevant where another parameter, such as storm tide or initial reservoir drawdown, is also a random variable. If the parameters are independent, then it is unlikely that a 1 in 100 AEP event will occur simultaneously for both parameters. This means that the combined or joint probability of an event occurring is rarer than the probability of the single event.

There are three specific areas of joint probability relevant to the MBRC area. Each area is discussed in the relevant sections in other parts of this report:

- Riverine flooding and storm tide events (**Section 4.3.1**);
- Coincident AEP of tributary and main-river flooding (**Section 5.3.2.1**) ; and
- Reservoir drawdown prior to a design rainfall event (**Section 6.3.1**).

4. Riverine Boundary Conditions

4.1. Introduction

Within the MBRC area, riverine boundary conditions will generally only be applicable where tributary modelling is completed separately from main-river modelling.

This section provides recommendations on adoption of downstream boundary conditions in this case, focusing on coincidence of tributary and main river flooding.

4.2. Available Data

Information relating to joint probability of tributary and main-river flooding can be found in Book VI of Australian Rainfall and Runoff (Nathan and Weinmann, 2000).

4.3. Methodology

This section describes the methodology used to provide recommendations for riverine boundary conditions.

Downstream boundaries for hydrodynamic models of upstream tributaries are best developed with a sound understanding of the flood behaviour in the downstream river. For this reason, it is recommended that hydraulic modelling of downstream systems be completed prior to modelling of tributaries for which they act as a boundary.

Adoption of downstream boundary conditions for these models should be based on a sound understanding of the flood behaviour in the downstream river and the probability of coincident tributary and main-river flooding.

Where it is not possible to develop a hydrodynamic model of the downstream river, a Depth-Discharge or Stage-Discharge relationship should be developed to characterise the downstream boundary.

4.3.1. Tributary and Main River Coincidence

Peak tributary and main river flooding (downstream boundary) rarely coincides with the same AEP. It is, therefore, necessary to ascertain the appropriate probability of downstream flooding that coincides with peak flooding within the tributary to maintain AEP-neutrality.

Methods to estimate the probability of coincident flooding in a downstream system are described in Book VI of Australian Rainfall and Runoff (Nathan and Weinmann, 2000).

These methods are based on the relative area of the tributary and downstream system catchments. It is recommended that these methods be followed to determine the AEP of main river flooding to be adopted as the downstream boundary for tributary models. Where possible, a dynamic time series from the downstream model should be applied.

Where it is not possible to develop a hydrodynamic model of the downstream river, a Depth-Discharge or Stage-Discharge relationship should be adopted for the downstream boundary.

4.4. Adopted Procedure Standard

For tributary models or inland catchments, downstream boundary conditions should be based on a model of the downstream main river where possible. The adopted AEP for the downstream main-river should be based on the joint probability methods for tributary and main-river flows described in Australian Rainfall and Runoff (Nathan and Weinmann, 2000). Where a downstream model is unavailable, a stage-discharge relationship should be developed to characterise the downstream boundary.

5. Estuarine Boundary Conditions

5.1. Introduction

The majority of catchments within the MBRC area, including Burpengary Creek, are coastal rivers or creeks flowing to Moreton Bay. Downstream boundaries for hydrodynamic models of these watercourses fall into the estuarine category and will be tidally influenced.

This section discusses a range of aspects relevant to estuarine water levels and interaction with riverine flooding and provides recommendations for determining estuarine boundary conditions for hydrodynamic models of waterways.

5.2. Available Data

Historic pluviograph data was obtained from the Bureau of Meteorology. Pluviograph gauges at Deception Bay, Margate and Dayboro had a large percentage missing and did not include the 1974 flood event. The best available pluviograph datasets closest to Burpengary Creek, were for the Brisbane Airport (rainfall gauge numbers: 040223 and 040842) and Samford CSIRO (040241) gauges.

Details on astronomical tides are available from Marine Safety Queensland (MSQ) on their website and in their annual publication, *Queensland Tide Tables*.

Predicted and recorded tide data for Moreton Bay was sourced from MSQ. Historic tide gauges are located to the north and south of the MBRC coastline, at the Brisbane Bar and Caloundra Head gauges. Only limited data was available for the Caloundra site and this was excluded from the analysis on this basis.

An investigation of storm tide (storm surge + astronomical tide) levels within Moreton Bay, *Storm Tide Hazard Study – Moreton Bay Regional Council* (Cardno), was published in 2009. This study provided estimates of storm-tide levels and time of inundation for a range of annual exceedance probabilities (AEP's) at a series of locations along the MBRC coastline. This study also investigated the contribution of wave-setup and wave runup to storm tide levels in Moreton Bay.

This study represents the most current and up-to-date reference with respect to tidal conditions in the region and provided the primary input dataset for this investigation.

5.3. Discussion of Estuarine Boundary Components

In developing estuarine boundary conditions, the following aspects should be considered:

- Components of estuarine water levels.
- Coincidence of riverine flooding and storm tide events; and
- Static vs dynamic boundary;

During storm events, estuarine water levels within Moreton Bay comprise four (4) separate parts:

- the astronomical tidal cycle;
- storm surge;
- wave setup; and
- wave runup.

This section discusses these three aspects of estuarine boundary conditions and each of the four components of ocean water levels. Recommendations are developed for estuarine boundary conditions of hydrodynamic models within the MBRC area including discussion of climate change considerations.

5.4. Components of Estuarine Water Levels

5.4.1. Storm Tide Hazard Study (2009)

The *Storm Tide Hazard Study – Moreton Bay Regional Council* (Cardno, 2009) was reviewed to assess the appropriateness of the predicted tide estimates for consideration as downstream boundary conditions.

The study followed the South East Queensland Disaster Management Advisory Group (SEQDMAG) recommended method for storm tide investigations. A combination of numeric modelling and statistical methods were used to develop estimates for both cyclonic and non-cyclonic storm tides. The study focused on the annual exceedance probability (AEP) of storm tide levels, defined as the combination of:

- astronomical tide
- storm surge; and
- regional wave set-up in Moreton Bay.

Relevant parameters and estimates for near-shore wave set-up and run-up were also provided but these two components are not relevant for setting the downstream boundary of a river hydraulic model.

5.4.2. Astronomical Tide

Astronomical tide is the rise and fall of ocean levels caused by the gravitational forces of the moon, sun and rotation of the earth. Astronomical tide does not include the effects of weather on ocean levels. Tides in Moreton Bay are semidiurnal tides meaning there are usually two high tides and two low tides each day.

Lowest and Highest Astronomical Tide (LAT and HAT) are the lowest and highest tide levels which could be predicted due to astronomical forcing. These may be exceeded under extreme meteorological conditions, ie storm tide.

Mean High Water Springs (MHWS) and Mean High Water Neaps (MHWN) represent longterm mean water levels of two successive high tides; MHWS is calculated when the tidal range is at its greatest while MHWN is calculated when the tidal range is at a minimum (MSQ, 2009).

Tide levels and times vary along the coastline and are generally reported for standard and secondary ports. The closest standard port to MBRC waterways is Brisbane Bar while the closest secondary port to the mouth of Burpengary Creek is Beachmere (Caboolture River). **Table 5-1** presents key tide levels for Beachmere (MSQ, 2009).

- **Table 5-1 Tidal Planes at Beachmere (Caboolture River)**

Parameter	Level
MSL	-0.05 mAHD
HAT	1.36 mAHD
LAT	-1.26 mAHD
MHWS	0.82 mAHD
MHWN	0.45 mAHD

5.4.3. Storm Surge and Storm Tide

The term storm surge is used to indicate the component of a tide that is produced by meteorological forcing such as a low pressure system. Storm tide is the term used to cover the resultant tide level incorporating both the astronomical and surge components. Cardno (2009) investigated storm tide levels for Moreton Bay.

The estimates provided in Cardno (2009) are considered appropriate for consideration in the development of a standard downstream boundary condition for hydrodynamic modelling. The estimates provide a consistent approach to storm tide for Moreton Bay.

Cardno (2009) provided estimates for both cyclonic and non-cyclonic storm tide levels. Modelling of design flood events does not consider whether the modelled event is a cyclonic or non-cyclonic event. The maximum of the two levels is therefore the most appropriate downstream peak where a storm tide boundary is adopted for use.

Storm tide estimates were plotted against AEP for a series of locations. This was also compared to elements of the normal astronomical tidal cycle discussed in **Section 5.3.1.1**.

A natural log-linear relationship was observed for each, tying in close to HAT for events with an AEP less than one. **Figure 5-1** presents the relationship for location MBR-014, downstream of Burpengary Creek. Storm tide estimates for the 1 in 5 and 1 in 10 AEP events can be estimated using natural log-linear extrapolation.

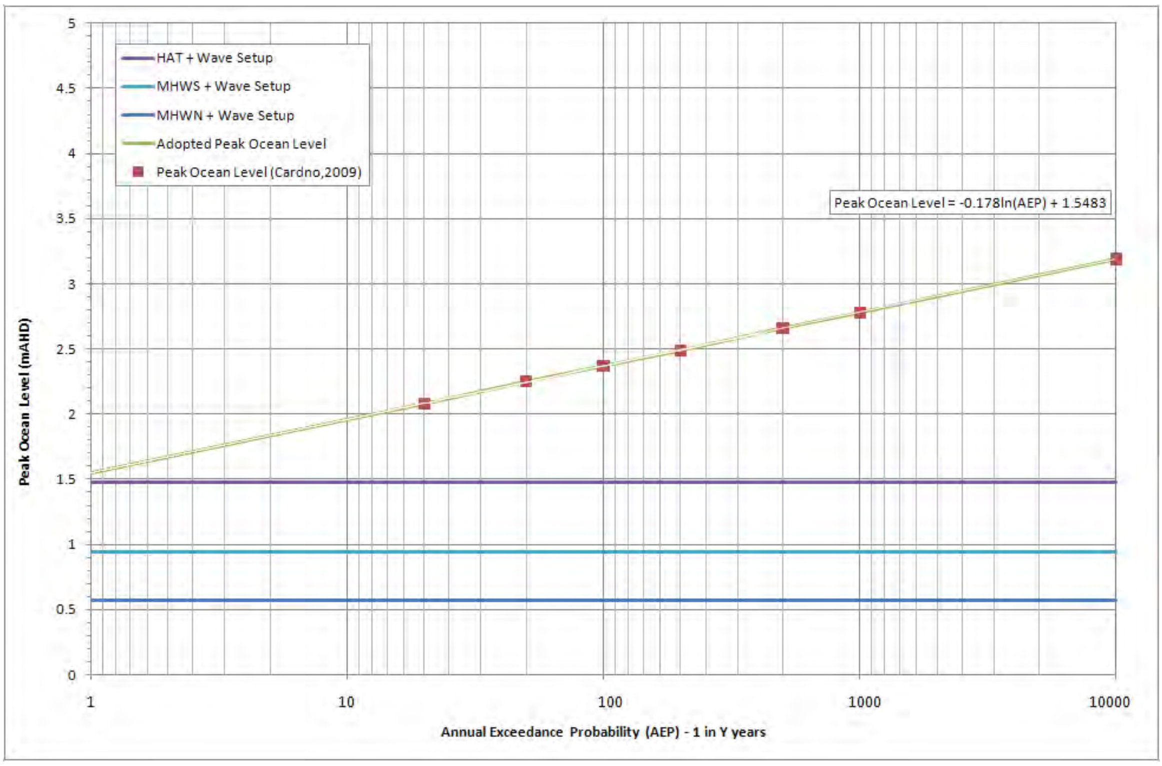


Figure 5-1 Storm Tide Levels in Moreton Bay (Burpengary Creek)

Cardno (2009) also developed a representative storm tide hydrograph at each reporting location. This hydrograph was based on a combination of:

- a Mean High Water Springs (NHWS) astronomic tidal cycle; and
- a modelled storm surge hydrograph.

5.5. Coincidence of Riverine Flooding and Storm Tide

Understanding the interaction between riverine flooding and storm tide is important in developing estuarine boundary conditions. This section discusses the joint probability of riverine flooding and storm tide as well as the timing of rainfall and storm tide events.

5.5.1. Coincidence of AEP

A review of previous studies into the joint probability of riverine flooding and storm tide in south east Queensland was undertaken.

No investigations of the joint probability of riverine flooding and storm tide were located for Moreton Bay. Brisbane City, Logan City and Redlands Council are not understood to have undertaken any assessment of storm tide flooding or joint probability of storm tide and freshwater flooding to date.

The Gold Coast City Council was contacted regarding previous work undertaken relating to the joint probability of storm surge and freshwater flooding. Staff advised that two studies had been undertaken but the results were inconclusive and the studies remain unpublished.

The former Caloundra City Council (now part of Sunshine Coast Regional Council) commissioned a study into joint probability of freshwater flooding and storm tide in 2003. The final report was published as, *Joint Probability Assessment – Storm Tide and Freshwater Flooding* (Connell Wagner, 2007). This report investigated and provided recommendations regarding coincident storm tide and freshwater flooding for the Mooloolah River floodplain and creeks flowing to Pumicestone Passage in the Caloundra South area.

These recommendations have been adopted in all hydrodynamic modelling of these catchments commissioned by the Caloundra City and Sunshine Coast Regional Councils.

This study is currently the only available discussion of joint probability of storm tide and riverine flooding for coastal catchments in south east Queensland.

The Caloundra *Joint Probability Assessment* reported different behaviour for the Caloundra South catchments in comparison with the Mooloolah floodplain. The study found that there was significant interaction between storm tide and riverine flooding in the Mooloolah River but not for the much smaller Pumicestone Passage catchments of Mellum Creek, Bells Creek, Duck Holes Creek and Lamerough Creek.

It concluded that:

- a 1 in 50 AEP storm tide event combined with a 1 in 100 AEP freshwater flooding event produced 1 in 100 AEP flood events for the Mooloolah River floodplain; and
- a 1 in 100 AEP storm tide event should be combined with a 1 in 100 AEP freshwater flooding event to produce a 1 in 100 AEP flood event for the Pumicestone Passage catchments.

The following potential reasons for the different interaction of storm tide and freshwater flooding in these two areas have been identified.

1) The magnitude difference in catchment areas. The Mooloolah River has a catchment area of approximately 202km², while catchment areas for the Pumicestone Passage Creeks range from 4km² to 74km².
2) Possible reduced storm tide exposure for creek mouths discharging within Pumicestone Passage. In comparison, the Mooloolah River floodplain is exposed directly to the ocean at the Mooloolah River mouth and at the Currimundi Lake entrance.
3) The floodplain characteristics of the different systems. The Mooloolah River has a steep upper catchment, combined with a very flat floodplain area towards the coast. The dominant flood mechanism in the Mooloolah River is floodplain storage. The Pumicestone Passage Creeks also have a steep upper catchment but are not characterised by large flood storage areas.

These characteristics were then considered to assess the potential similarities and differences between the behaviour of these catchments and catchments in the MBRC area.

The majority of coastal catchments within the MBRC area are of a similar size to the Pumicestone Passage Creeks and do not contain large areas of floodplain storage similar to the Mooloolah River, but outlet to Moreton Bay rather than Pumicestone Passage. The two large coastal catchments of the Caboolture River and Pine River are too large to be considered equivalent to the Pumicestone Passage Creeks and are not considered similar to the Mooloolah River.

The available literature does not provide specific guidance on coincidence of riverine flooding and storm tide events for waterway entrances within the MBRC area. The literature does provide recommendations for nearby catchments with the SCRC area.

However, these recommendations differ for the Caloundra South and Mooloolah River catchments.

Waterway entrances and catchment characteristics within the MBRC area are not considered sufficiently similar to either of these catchments to directly transfer the recommendations without further investigation.

For this reason, it is recommended that a joint probability assessment of Moreton Bay levels and streamflow within coastal waterways within the MBRC area be undertaken in the future. Until reliable conclusions are available on the joint probability of riverine flooding and storm tide events in the MBRC area, it is recommended that a sensitivity approach be adopted. It is recommended that a ‘storm surge’ run be incorporated into the suite of model runs that adopts a downstream boundary with a storm tide level equivalent to the AEP of the riverine flood event. This will provide an upper limit to the flood envelope.

5.5.2. Timing of Rainfall and Storm Tide

A comparison of the timing of rainfall bursts and peak storm tide levels for coincident events was undertaken.

Pluviograph rainfall data was collated for the Brisbane Airport and Samford CSIRO gauges. These gauges were chosen as the gauges with the longest records and lowest missing data within close proximity to Burpengary Creek. The two gauges were chosen to represent coastal and upper-catchment rainfall during a single event.

From the pluviograph data, the 30 largest 12 hour storm bursts were identified for each gauge. The 12 hour storm burst was adopted as representative of the Burpengary Creek critical storm duration which is expected to be in the range of 6 – 12 hours. The dates and times of the identified largest bursts were compared and 13 bursts were found to have been captured by both pluviograph gauges. It should be noted that three of these bursts occurred within the January 1974 flood event.

Tide gauge data for the Brisbane Bar gauge was available for 11 of these events and was sourced for two days either side of these events. Both predicted and observed tide records were obtained.

The rainfall bursts for the two pluviographs were compared for each of the events. This was done to ascertain if it was possible to determine the prevalent direction of storm movement, i.e. ocean to land or land to ocean. However from this comparison, it was observed that there was little or no correlation between timing of rainfall at the two gauges. Thus general storm direction could not be inferred.

The tidal anomaly (observed tide – predicted tide) was plotted for each event. The rainfall bursts for the two pluviographs were then compared to the predicted tide, observed tide and tidal anomaly readings throughout each event.

This comparison showed that, in most cases, the peak of the tidal anomaly component appears to lag the mid-point of the rainfall burst by an average of 3.5 hours. The 90th percentile confidence limits in this average lag are between 1 and 6.5 hours, making this statistically significant.

5.6. Static vs Dynamic Boundary

Tidal flushing of estuaries is a significant factor in defining flood behaviour in the downstream reaches of coastal waterways. At low tide, the flood gradient is increased allowing a higher discharge to the ocean. At high tide, the estuary is affected by the high ocean tailwaters, limiting discharge from the system.

Application of a static downstream boundary does not allow representation of this dynamic behaviour. This can result in significant over-estimation of peak flood levels within the downstream reach of the waterway and under-estimation of peak velocities within the reach.

Accurate representation of both peak water levels and velocities is most important for determining the flood hazard for a location. While the adoption of floodplain management policies and planning based on flood hazard categories may be an aim for the future, MBRC’s current policies and planning do not use flood hazard as an input, instead focusing on peak flood levels.

MBRC’s RFD program is currently concerned with producing consistent and conservative estimates of peak flood levels across the Council area. The key aims of this program are:

- to produce a standard methodology for flood modelling across the MBRC area that can be easily applied by flood modellers with a range of backgrounds and skill levels; and
- to produce a standard set of flood models across the MBRC area that can be easily and consistently updated with new information and methods in the future.

Application of a dynamic tidal boundary is more complicated than a static boundary and involves a series of assumptions around timing of rainfall, tide and storm surge. For the purposes of a consistent, simple to apply method it is recommended at this point in time that a static downstream boundary be adopted.

5.7. Recommended Procedures for Estuarine Boundary Conditions

The previous section covered background information on all aspects related to estuarine boundary conditions. From this information, there are several approaches that could be adopted for estuarine boundary conditions depending on the combination of parameters. The following describes the different options considered and the final recommended approach.

5.7.1. Options Summary

Based on the background information discussed in **Section 5.3**, **Table 5-2** describes the available options for an estuarine boundary condition. It is important to note when reviewing the advantages and disadvantages of these boundary conditions that the impact of the downstream boundary is limited to the downstream reach of the model where riverine and estuarine flooding interacts.

- **Table 5-2 Summary of Estuarine Boundary Conditions Options Considered**

Option Considered	Advantages	Disadvantages
Static Normal Tide (e.g. MHWS)	Simple to understand Simple to apply	May produce non-conservative peak levels
Static Storm Tide AEP = Riverine Flood AEP	Simple to understand Simple to apply Gives reasonable representation of peak surface	Under-prediction of velocity May produce overly-conservative peak levels Limited justification in available literature for choice of AEP
Static Storm Tide AEP < Riverine Flood AEP	Simple to understand Simple to apply Gives reasonable representation of peak surface	Under-prediction of velocity May produce overly-conservative peak levels Limited justification in available literature for choice of AEP
Dynamic Normal Tide (e.g. MHWS)	Gives reasonable representation of peak velocity Accounts for range of conditions in single event	Complex to understand Complex to apply
Dynamic Storm Tide AEP = Riverine Flood AEP	Gives reasonable representation of peak surface Accounts for range of conditions in single event	Complex to understand Complex to apply Limited justification in available literature for choice of AEP May produce overly-conservative peak levels

Option Considered	Advantages	Disadvantages
Dynamic Storm Tide AEP < Riverine Flood AEP	Gives reasonable representation of peak surface Accounts for range of conditions in single event	Complex to understand Complex to apply Limited justification in available literature for choice of AEP

5.7.2. Estuarine Boundary Condition

A static MHWS tide boundary condition is recommended for adoption for all base model runs as it is simple to justify and apply. This tide level represents a long-term average that occurs regardless of meteorological conditions.

The adoption of a MHWS boundary will produce non-conservative peak levels within the estuary, as the peak storm-tide level will be the dominant condition within the estuary. It is recommended that a sensitivity run is included in the suite of model runs where a storm tide boundary is simulated without any inflows representing riverine flooding. This will provide information on the upstream limit of storm tide flooding within the waterway.

MBRC has a separate project concerned with mapping areas affected by storm-tide and incorporating these into coastal management and planning policies. Therefore, this is considered a reasonable approach to consideration of planning levels within the estuary.

The adoption of a static MWHS boundary may also produce non-conservative peak water surface levels within the downstream reach of the model where riverine and storm tide flooding interact. It is recommended that a sensitivity run is included in the suite of model runs where a static storm tide boundary is adopted with an equivalent AEP to the riverine flooding.

Table 5-3 presents a summary of the sensitivity runs recommended to provide an appropriate flood envelope for each AEP.

- **Table 5-3 Suite of Sensitivity Runs - Estuarine Boundaries**

Run	Riverine Flooding	Estuarine Boundary
Base	1 in Y AEP	Static MHWS Tide
Upper Envelope	1 in Y AEP	Static Storm Tide AEP = Riverine Flooding AEP
Storm Tide Sensitivity	N/A	Dynamic Storm Tide 1 in Y AEP

Levels to be adopted for static MHWS boundaries can be adopted based on information available in *Semidiurnal Tide Times 2010* (MSQ, 2009). Levels to be adopted for static storm tide boundaries can be adopted from Cardno (2009). Representative dynamic storm tide hydrographs for the storm tide sensitivity runs can be adopted from Cardno (2009).

5.7.3. Spatial Location of Boundary Condition

Hydrodynamic models of coastal waterways should extend to the outlet of the waterway into the ocean with the downstream boundary applied at the mouth. This allows for:

- representation of the contraction and expansion losses at the mouth; and
- representation of the tidal volume without drowning out the hydraulic characteristics of the estuary.

5.7.4. Climate Change Scenarios

For all climate change scenarios to be run, the same estuarine boundary sensitivity runs are recommended for all AEPs to provide an appropriate flood envelope for each AEP under climate change. **Table 5-3** presents a summary of the sensitivity runs recommended to provide an appropriate flood envelope for each AEP.

- Table 5-4 Suite of Sensitivity Runs - Estuarine Boundaries – Climate Change

Run	Riverine Flooding	Estuarine Boundary
Base Climate Change	1 in Y AEP (with increased rainfall)	Static MHWS Tide + MSL rise
Upper Envelope Climate Change	1 in Y AEP (with increased rainfall)	Static Storm Tide AEP = Riverine Flooding AEP (Storm Tide + MSL rise)
Storm Tide Sensitivity Climate Change	N/A	Dynamic Storm Tide 1 in Y AEP (Storm Tide + MSL rise)

A mean sea level rise allowance of 0.37m should be added to static MHWS levels to produce a static MHWS boundary under 2050 climate change.

Peak storm tide levels under the 2050 climate change scenario can be determined based on the 'With Greenhouse' storm tide estimates in Cardno (2009). A mean sea level rise allowance of 0.37m should be added to produce the static storm tide estuarine boundary condition under 2050 climate change.

These peak storm tide levels can be used with the representative dynamic storm tide hydrographs from Cardno (2009) to produce a storm tide sensitivity boundary condition under climate change conditions.

5.8. Pilot Study Parameters

5.8.1. Base Case Scenarios

Based on the approach described in **Section 5.4** and the information provided in Cardno (2009), downstream estuarine boundaries have been determined for all recommended sensitivity runs for Burpengary Creek.

Mean High Water Springs levels to be used as the static estuarine boundary for the Base Runs can be found in **Table 5-5**.

- **Table 5-5 Static MHWS level for Base Runs for Burpengary Creek**

AEP (1in Y Years)	Peak Ocean Boundary Level (mAHD)
5	0.82
10	0.82
20	0.82
50	0.82
100	0.82
200	0.82
500	0.82
1,000	0.82
10,000	0.82
>10,000	0.82

Storm tide levels to be used as the static estuarine boundary for the Upper Envelope Runs can be found in **Table 5-6**.

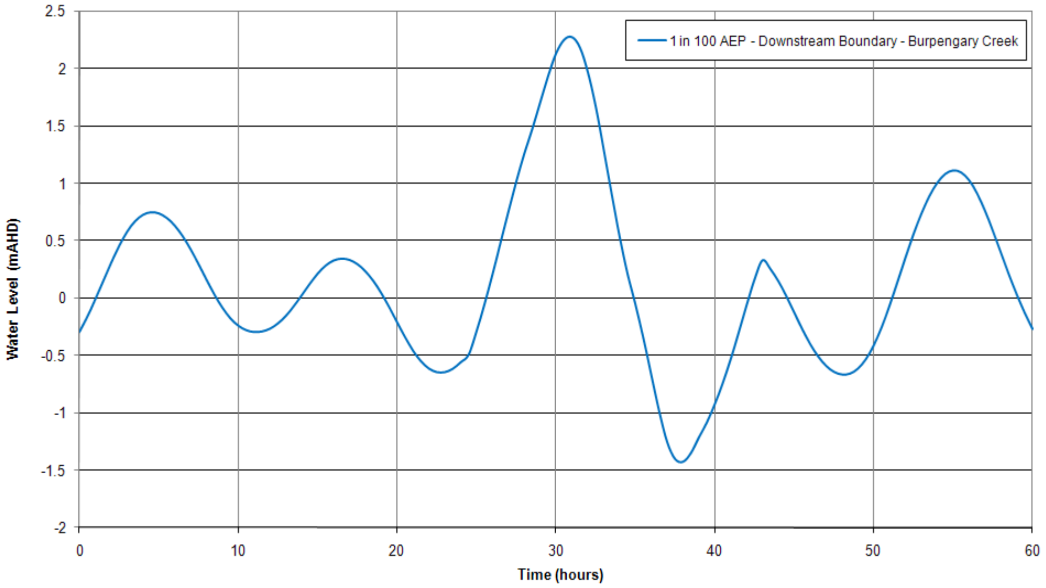
- **Table 5-6 Static Storm Tide level for Upper Envelope Runs for Burpengary Creek**

AEP (1in Y Years)	Peak Ocean Boundary Level (mAHD)
5	1.84
10	1.96
20	2.08
50	2.25
100	2.37

AEP (1in Y Years)	Peak Ocean Boundary Level (mAHD)
200	2.49
500	2.66
1,000	2.78
10,000	3.19
>10,000	3.19

Note: Includes Astronomical Tide, Storm Surge and Regional Wave Setup. Does not include local setup and runup.

The storm tide levels presented in **Table 5-6** should be used as the peak level for the dynamic storm surge hydrograph for the Storm Tide Sensitivity Runs. An example hydrograph for the 1 in 100 AEP storm tide run is presented in **Figure 5-2**.



- **Figure 5-2 Representative Time Series for 1 in 100 AEP Burpengary Creek D/S Boundary for Storm Tide Sensitivity Run**

For all sensitivity runs including a dynamic downstream boundary, it is recommended that:

- the downstream boundary tidal time series starts at MHWS;
- the initial condition at the downstream tidal boundary is MHWS; and
- the TUFLOW model be run for at least one tidal cycle as a warm-up period prior to commencement of riverine inflows.

5.8.2. Climate Change Scenarios

Based on the approach described in **Section 5.4** and the information provided in Cardno (2009), downstream estuarine boundaries have been determined for all recommended climate change sensitivity runs for Burpengary Creek.

Mean High Water Springs levels with Mean Sea Level Rise to be used as the static estuarine boundary for the Base Runs can be found in **Table 5-5**.

- **Table 5-7 Static MHWS + MSL level for Climate Change Base Runs for Burpengary Creek**

AEP (1in Y Years)	Peak Ocean Boundary Level (mAHD)
5	1.19
10	1.19
20	1.19
50	1.19
100	1.19
200	1.19
500	1.19
1,000	1.19
10,000	1.19
>10,000	1.19

Peak storm tide levels for a 2050 climate change scenario for the Burpengary Creek downstream estuarine boundary have been determined. The recommended peak water levels to be used as the static estuarine boundary for the Upper Envelope Runs can be found in **Table 5-6**. These include allowances for climate change impact on both storm surge and mean sea level rise.

- **Table 5-8 Static Storm Tide +MSL rise level for Upper Envelope Climate Change Runs for Burpengary Creek**

AEP (1in Y Years)	Peak Ocean Boundary Level (mAHD)
5	2.35
10	2.52
20	2.68
50	2.91
100	3.08
200	3.24
500	3.47
1,000	3.63
10,000	4.19
>10,000	4.19

Note: Includes Astronomical Tide, Storm Surge and Regional Wave Setup. Does not include local setup and runup. Includes climate change increase in Storm Surge and Mean Sea Level Rise.

The storm tide levels presented in **Table 5-6** should be used as the peak level for the dynamic storm surge hydrograph for the Climate Change Storm Tide Sensitivity Runs.

6. Initial Conditions (Large Water Bodies)

6.1. Introduction

Due to the large volumes involved, assumptions relating to initial conditions within large water bodies can significantly influence modelled flood characteristics.

Under-estimating initial water levels will generally decrease peak flood levels up and downstream, increase peak velocities and under-estimate the time to peak flooding. Over-estimating initial water levels may produce drowned reaches or allow storages to overtop too quickly, resulting in increased flood levels and/or decreased flood velocities.

The following section provides information relating to definition of appropriate initial conditions for

- on-stream storages; and
- the downstream tidal area.

6.2. Available Data

No specific data was used in this assessment.

6.3. Methodology

This assessment drew on SKM's previous experience in hydrologic and hydraulic modelling.

6.3.1. Initial Conditions in Water Storages

For small on-stream storages, including Lake Kurwongbah, it is generally considered a reasonable, although possibly slightly conservative, assumption that the storage is at Full Supply Level (FSL) at the start of a design rainfall event. This approach is recommended for on-stream storages within the MBRC area.

Adoption of FSL as the initial condition within Lake Samsonvale (North Pine) is also considered a reasonable assumption. However, North Pine is a sufficiently large storage that initial drawdown of the reservoir may significantly affect the outflow flood frequency curve from the storage. In this situation, using a point probability analysis to test the influence of initial reservoir drawdown on the outflow flood frequency curve from the dam is recommended. An input to the flood frequency analysis should be an investigation of the correlation between the largest historical rainfall bursts for a duration similar to the critical duration of the catchment (i.e. one day) and the initial drawdown of the reservoir.

For application in a single design event context, an initial drawdown would need to be selected for each storage that provides a match between the peak outflow and hydrograph volume to those identified from joint probability analysis runs.

An analysis of this type was undertaken by SKM as part of the Hinze Dam Alliance (2007) during the design of Hinze Dam Stage 3. This analysis used both historic and synthetic inflow and storage inflow series. The results showed that, while there was limited correlation between drawdown and inflows for frequent events, the reservoir was generally fuller at the commencement of large events for Hinze Dam, which justified the assumption of FSL prior to the event.

6.3.2. Initial Tidal Conditions

Recommendations relating to downstream tidal boundary conditions are provided in **Section 5.4.2** Initial downstream tidal conditions must be consistent with these downstream boundary conditions.

Consistent with the recommendations in **Section 5.4.2**, for sensitivity runs including a dynamic downstream boundary, it is recommended that:

- the downstream boundary tidal time series starts at MHWS;
- the initial condition at the downstream tidal boundary is MHWS; and
- the TUFLOW model be run for at least one tidal cycle as a warm-up period prior to commencement of riverine inflows where a dynamic storm tide is required (but not where a static level is used).

6.4. Pilot Study Parameters

No large water storages exist within the Burpengary Creek catchment.

Consistent with the discussion above, it is recommended that the initial conditions for the downstream boundary be set consistent with the downstream boundary condition.

6.5. Recommended Procedure

Initial conditions for downstream tidal boundaries should be set consistent with the adopted downstream boundary conditions.

The recommended procedure for setting initial conditions within on-stream storages, other than Lake Samsonvale (North Pine), is:

1) As a minimum, on-stream storage characteristics should be included in the hydrological model. Initial conditions for on-stream storages, within the hydrologic model, should be set to FSL. Resulting outflows can then be included in a downstream hydrodynamic model.
2) Where an on-stream storage will be included within the hydrodynamic model, initial conditions for the storage, should be set to FSL in the hydrodynamic model also.

Adoption of FSL as the initial condition within Lake Samsonvale (North Pine) is considered a reasonable assumption. However, due to the larger size of this storages it is considered possible that the storage may not be full at the commencement of a rainfall event. It is, therefore, recommended that an investigation of the relationship between historic inflows and initial reservoir volume be undertaken for Lake Samsonvale.

7. Pilot Study Conclusions and Recommendations

This study has made specific recommendations relating to downstream boundary conditions, initial conditions, joint probability and climate change scenarios for the Burpengary Creek pilot study. The recommended parameters include:

- A static MWHS downstream boundary;
- Complementary initial conditions for the downstream tidal boundary;
- Recommended downstream boundary sensitivity runs to produce a flood envelope:
  - Base Run (Static MHWS boundary);
  - Upper Envelope (Static Equivalent AEP Storm Tide boundary); and
  - Dynamic Storm Tide (No riverine flooding, Dynamic Storm Tide boundary)
- Percentage increases for design rainfalls under climate change; and
- Recommended downstream boundary sensitivity runs to produce a flood envelope under climate change including recommendations for:
  - Mean Sea Level Rise; and
  - Storm Tide under Climate Change.

The methodology behind, and procedures used for, the Burpengary Creek estimates have been developed such that they can be consistently applied to all catchments and waterways within the MBRC area.

Further investigation is recommended in four areas, where the available information was limited:

- Joint probability of riverine flooding and storm tide for coastal waterways within the MBRC area;
- Timing of peak storm tide levels and peak rainfalls within a single storm event is still ongoing;
- Adoption of dynamic storm tide as estuarine boundary based on resolution of the previous issues; and
- Relationship between inflows and initial reservoir volume at commencement of historic rainfall events for North Pine Dam.

8. Climate Change Parameters Adopted during Stage 2

In 2010, DERM completed a joint project with the Local Government Association of Queensland (LGAQ) entitled: *Climate Change and Inland Flooding*. This project focused on a review of climate change estimation used in the *Gayndah Flood Study* (WBM, 2009).

The broader project goals were to:

- Review relevant science related to climate change and flooding;
- Review the current Queensland approach to flood risk management policy;
- Assess alternative policy options to incorporate climate change; and
- Provide recommendations for changes to the *State Planning Policy 1/03* for consideration in a forthcoming review of the policy.

Reviews of possible approaches to development of design rainfall under climate change were undertaken and a proposed method was adopted in 2010.

The project concluded with the release of the report *Increasing Queensland's resilience to inland flooding in a changing climate: final report on the Inland Flooding study* in 2010. This report recommends 20% increase in rainfall for events up to and including 500 year for the 2100 horizon (the 2100 horizon was chosen to be the same as that recommended by the *Queensland Coastal Plan*).

The Queensland Government (DERM) published its *Queensland Coastal Plan –Guideline Coastal Hazards* in 2012. The coastal plan provides Recommended Storm Tide Event Levels (RSTELs) similar to the DFEs recommended for freshwater flooding SPP 1/03. The guideline document also sets out 'minimum assessment factors for determining erosion-prone areas and storm tide inundation areas'. The minimum parameters to be adopted are:

- A planning period of 100 years;
- A projected value for mean sea level rise of 0.8 m by 2100 relative to 1990;
- Adoption of the 1 in 100 AEP storm event or water level; and
- Adoption of a 10% increase in cyclone intensity due to climate change.

It is therefore recommended that the Stage 2 study adopt a 20% increase in rainfall for events up to and including 500 year for the 2100 horizon, as well as a mean sea level rise of 0.8m by 2100 relative to 1990.

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