Increasing Queensland's resilience to inland flooding in a changing climate:

Final Scientific Advisory Group (SAG) report—Derivation of a rainfall intensity figure to inform an effective interim policy approach to managing inland flooding risks in a changing climate

A joint project of:

Department of Environment and Resource Management

Department of Infrastructure and Planning

Local Government Association of Queensland

Tomorrow's Queensland: strong, green, smart, healthy and fair

Toward Q2 Tomorrow's Queensland

Queensland Government

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Derivation of a rainfall intensity figure to inform an effective interim policy approach to managing inland flooding risks in a changing climate

Note:

That the Scientific Advisory Group (SAG) agrees that:

- **a.** an increase in rainfall intensity is likely
- **b.** the available scientific literature indicates this increased rainfall intensity to be in the range of 3–10% per degree of global warming
- **c.** the SAG understands the preference for a single figure to support further policy development. More detailed analysis is required to firmly establish such a figure and this work will be undertaken as part of the review of *Australian Rainfall and Runoff*. This document will become the authoritative source of information on this issue when released in 2014. However, the SAG would consider a figure of a 5% increase in rainfall intensity per degree of global warming reasonable for informing policy development in the interim.

Recommended methodology

This paper outlines the rationale for adopting an interim methodology for assessing flooding risk in Queensland. The proposed methodology is to increase rainfall intensity at Annual Exceedance Probabilities (AEP) of 1%, 0.5% and 0.2% per degree of global temperature increase for all rainfall durations. Global temperatures are used because there is considerable more certainty in these projections compared with rainfall projections, particularly for the more intense rainfall events at a regional scale. The methodology is limited to flooding risk management for planning purposes as described by the State Planning Policy 1/03 (SPP 1/03) and does not extend to more frequent events (i.e. > 2% AEP) or more extreme events (i.e. probable maximum flood).

1. Inland flooding risk and the planning framework

Flooding risk assessment is typically based on an analysis of historical events. Society accepts a level of flooding risk and balances the impact of these rarer floods by using mitigation measures and providing emergency response services.

Generally, the level of risk accepted is a 1% Annual Exceedence Probability (AEP) (i.e. there is a 1% chance that a flood of this size will occur every year). Climate change science over recent decades has pointed to an increased risk that the size of this 1% AEP flood will be larger than that currently experienced. The 1% AEP design flood is derived from a flood frequency analysis, if sufficient records are available, or a flood modelling study.

Australia-wide, the Engineers Australia publication, *Australian Rainfall and Runoff* (AR&R) (Pilgrim, 1998), provides the accepted methodologies for undertaking flood studies. It is 23 years since this publication was last updated, and therefore it does not consider the impacts of climate change. This publication is currently under review and the updated publication will be available in 2014.

The updated AR&R publication will be the primary reference for the assessment and management of flooding risk for policy makers, planners and decision-makers when it becomes available. However, planning decisions are being made every day in Queensland and interim advice is required to inform these decisions over the next four years. This document outlines the rationale for the derivation of a rainfall intensity figure to inform an effective interim policy approach to managing inland flooding risks in a changing climate.

2. Projecting future emissions, warming and associated increased flooding risks

Future greenhouse gas emissions and resulting climate change will be a product of complex dynamic systems, determined by driving forces such as demographic development, socio-economic development and technological change. The Queensland Government, like governments around the world, utilises the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report as the pre-eminent source of information on climate change. The IPCC developed a set of future world development scenarios for emissions modelling to produce climate change projections (Special Report on Emissions Scenarios (SRES), Nakicenovic et al. 2000). These projections assist policy makers to consider climate change in their decision making.

Global mean temperature projections using the A1FI (high impact) emissions scenario are shown in Table 1. The A1FI scenario is used to guide Queensland Government policy development as global greenhouse gas emissions are tracking above this emissions scenario, and the world is not yet taking effective mitigation measures (Draft Queensland Coastal Plan, after Canadell et al 2007). In addition, global temperatures for the past decade have been the warmest on record (Arndt et al 2010), which are at the upper limits of the models projections (Rahmstorf et al 2007).

The A1FI scenario approximates continuation of the fossil fuel intensive status quo for global development. It describes a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Using the A1FI emissions scenario, the best estimate of projected change in annual mean temperatures in Queensland is an increase of up to 2.4 °C by 2050, and 3.6 °C by 2070 (DERM 2009).

These estimates for Queensland are similar to projections for the global mean temperature shown in Table 1, which is predicted to increase by between 2.4 and 6.4 °C (relative to 1980-1999) by the year 2100, with a best estimate of 4.0 °C (IPCC 2007).

Table 1: Global warming best estimate (and representative ranges) relative to 1990 for selected years for the A1FI scenario

The data are all from CSIRO's Climate Change in Australia report (CSIRO and Bureau of Meteorology, 2007: www.climatechangeinaustralia.gov.au), which is based on the IPCC 2007 report.

	2030		**2050**		**2070**		**2100**	
	Best estimate	Representative range	Best estimate	Representative range	Best estimate	Representative range	Best estimate	Representative range
A1FI	0.87 °C	0.52–1.39°C	1.8 °C	1.08–2.88°C	2.9 °C	1.74–4.64°C	4.0°C	2.4–6.4°C

3. Projected increases in rainfall intensity

Climate change science is providing evidence that a warming atmosphere will lead to enhanced water vapour content in the lower part of the atmosphere. Walsh and Pittock (1998) indicate that in the absence of substantial changes in atmospheric dynamics, the increased water-holding capacity of the atmosphere as a result of increased temperature should lead to higher precipitation intensity. Specifically, the Clausius-Clapeyron theory suggests for each 1°C increase in temperature, the amount of water vapour a parcel of air can hold increases by approximately 7% (e.g. Allen and Ingram, 2002).

Recent analyses by Hardwick Jones et al. (2010) investigated whether extreme precipitation scales with precipitable water content in the atmosphere for sites across Australia. These results indicated that rainfall bursts of up to 60-minutes scale with mean daily surface temperature according to the Clausius-Clapeyron theory or greater for most sites across Queensland. However, the relationship appeared to break down when daily rainfall was analysed. The conclusion of the authors was that sea surface temperatures should be further investigated to determine how increased precipitable water may translate to increased heavy rainfall events.

The analyses required to understand how increases in precipitable water may translate to increased rainfall intensities is likely to take several years before a robust conclusion is attained. In the absence of these analyses, an interim methodology is being proposed based on the evidence available in the scientific literature.

A recently-released report from the National Academy of Sciences (NAS, 2010) concludes that "Extreme precipitation is likely to increase as the atmospheric moisture content increases in a warming climate. Typical magnitudes are 3–10% per degree C warming, with potentially larger values in the tropics, and in the most extreme events globally."

The IPCC has also recognised the relationship between water vapour and temperature. Specifically, the IPCC states that:

- "In the boundary layer[1], the increase in water vapour with temperature in proportion with the Clausius-Clapeyron relation is uncontroversial" (IPCC 2001, ch 7.2).
- "Observations are consistent with the physical understanding regarding the expected linkage between water vapour and temperature, and with intensification of precipitation events in a warmer world… consistent with rising amounts of water vapour in the atmosphere, there are widespread increases in the numbers of heavy precipitation events and increased likelihood of flooding events in many land regions, even those where there has been a reduction in total precipitation" (TS3.4 in IPCC 2007).

In simulations of climate change scenarios, global mean precipitable water and column water vapour increase with global mean surface temperature at a rate of ~7.5% K^{-1} (O'Gorman and Muller 2010; Schneider et al. 2010 and references therein), while global mean precipitation and evaporation increase more slowly (2-3% K^{-1}) with temperature (Schneider et al. 2010). Whilst there is a strong dependence on latitude and whether rates of change are expressed with respect to regional or global-mean surface temperatures, values for column water vapour (red solid line) for latitudes that bound Queensland (vertical black dashed lines) are similar to that of the global mean (~7.5% K-1), with values of ~6-7.5% with respect to global temperature, and ~7-8% with respect to zonal-mean temperature (Figure 1).

[1]The boundary layer is the turbulent, well-mixed shallow layer near the ground, which can be regarded as being directly moistened by evaporation from the surface.

Figure 1

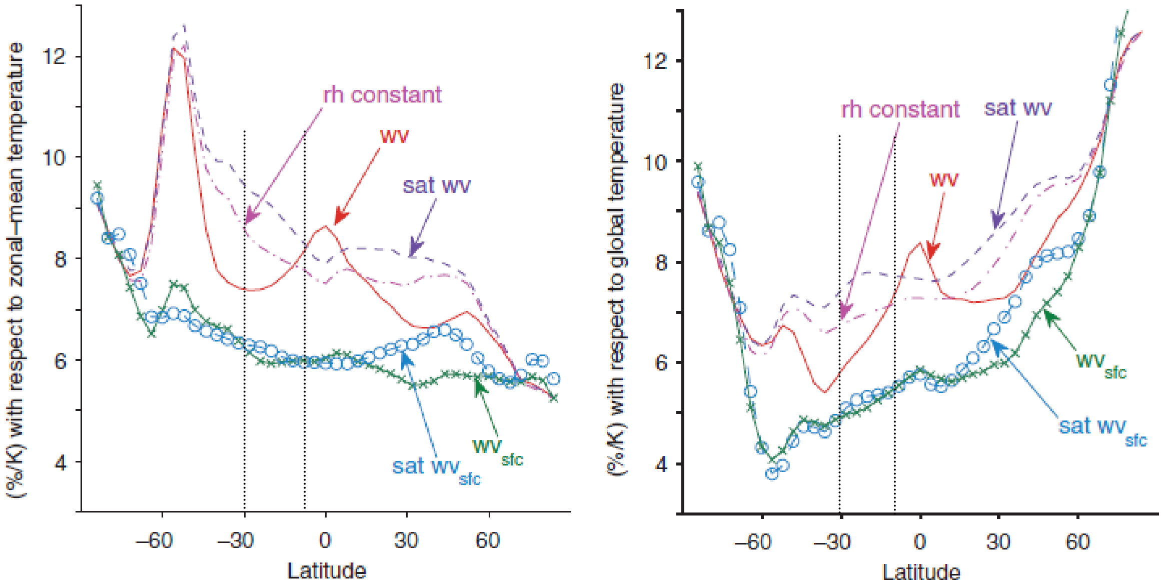

Figure 1: Rates of change (% K−1) of column water vapor (wv) (red solid), column water vapor with an invariant distribution of relative humidity (rh constant) (pink dashed–dotted), saturation column water vapour (sat wv) (purple dashed), surface specific humidity (WVsfc) (green line and crosses), and surface saturation specific humidity (sat WVsfc) (blue line and circles). Rates of change are with respect to zonal-mean surface air temperature (left panel) and global-mean surface air temperature (right panel). The values shown are multi-model means of estimates of the differential rates of change and differences between 1980–1999 and 2080–2099. (Source: O'Gorman and Muller, 2010). Dashed black vertical lines denote the latitudes that bound Queensland.

Recent work of Rafter and Abbs (2010), who used extreme value analyses to calculate the percentage increases of intense rainfall from a suite of Global Climate Models (GCMs), shows considerable variation across projections. Some models indicate a decrease, though the majority do indicate an increase in intense events (Figure 2; Table A1, Appendix 1). Some of the results show very large percentage changes and this is explained by a poor fit of the rainfall data to the statistical model in the late 21st century for these models. However, the models were selected as they provided a reasonable representation of the hydrological cycle over the Australian region. Therefore, they are included in the summary of the model outputs.

Figure 2

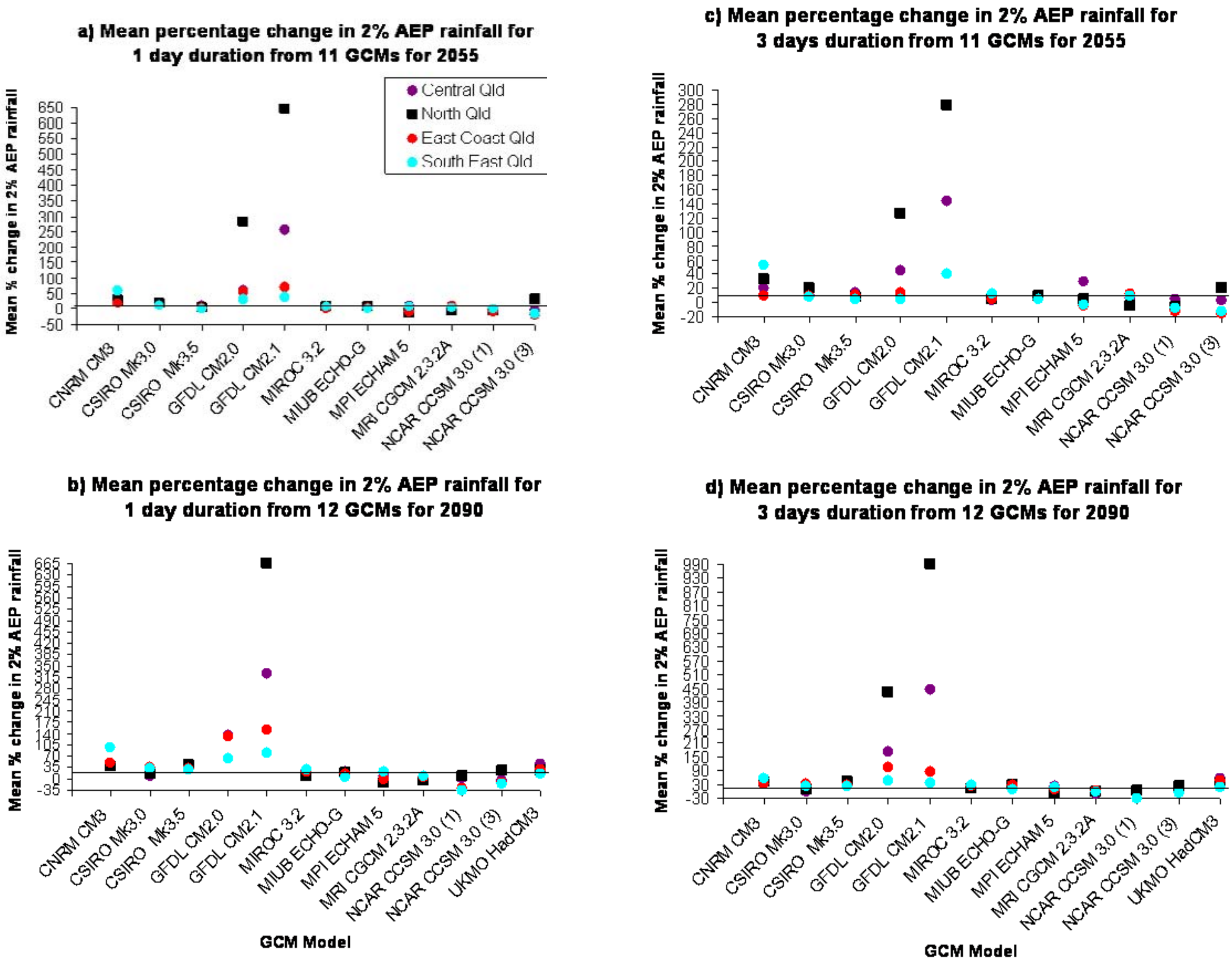

Figure 2: Projected mean percentage change in 2% AEP rainfall for 1 and 3 days duration from 11 GCM models for 2055 (Figures 2a and 2c), and from 12 GCM models for 2090 (Figures 2b and 2d). Source: Rafter and Abbs (2010; unpublished). Black horizontal line is the proposed percentage increase using the interim methodology recommended by the Inland Flooding Study (i.e., 10% increase for 2055 and 20% increase for 2100).

Though uncertain, there is a risk that this increased water vapour content will translate to more intense rainfall events. These conclusions are reinforced by the NAS report (NAS 2010, page 104), which states that considering the combined literature on the physical basis for changes in extreme precipitation in a warming climate, together with model results and observational studies, there is a strong basis for concluding that precipitation extremes should increase with temperature in most parts of the globe.

The proposed recommended methodology is based on global mean temperature because there is greater certainty on a global scale of the response of precipitation extremes to increases in temperature than on local scales. As well as the amount of water vapour in the atmosphere, precipitation intensity at specific locations is determined by other factors such as the atmospheric dynamics that transport the water vapour (e.g. Schneider et al. 2010). Therefore, the best estimate of the risk of an increase in rainfall intensity is determined by global relationships.

Therefore, as the lower atmosphere warms, the atmospheric water vapour also increases, which increases the risk of more intense rainfall events. Therefore, the recommended interim methodology for the Inland Flooding Study is to increase rainfall intensity for the design frequency of interest (1%, 0.5% or 0.2% AEP) by 5% per degree increase in global mean temperature.

4. Factors affecting AEP neutrality

Flood studies for planning purposes rely on a defined flood event that is obtained from the assumption that a defined rainfall event of a particular AEP translates to a flood event of the same AEP. The translation of a rainfall event to a flood event of the same AEP requires the assumption of neutrality be maintained. There are many factors that impact neutrality, with the antecedent condition being an important consideration.

There have been considerable discussions about how antecedent conditions may impact the AEP neutrality assumption, and the requirements to adjust the initial losses of the hydrological models to account for the enhanced drying periods that are also projected by the GCMs. An analysis of Queensland rainfall clearly shows a decadal response related to the ENSO (El Niño Southern Oscillation) phenomena and the Interdecadal Pacific Oscillation (IPO). Rainfall and streamflow in Queensland have previously been shown to be significantly enhanced during the La Niña phase of ENSO. During the negative phase of the IPO ‘wetter’ conditions are experienced across Queensland. During these negative IPO decades, enhanced La Niña rainfall and streamflow has been demonstrated to occur (Verdon et al. 2004). In the absence of projections of changes in these conditions the evidence suggests that maintaining the current antecedent characteristics is warranted for the interim methodology being proposed.

The AR&R review will be undertaking analyses to further investigate this and the interim methodology will be updated to reflect these more detailed analyses when they become available.

5. Results of applying methodology in case study area

The steps involved in undertaking the methodology are described in Figure 3. This methodology has been applied to assess the potential implications of the proposed methodology in assessing future flooding risk in the case study catchment of the Burnett River.

Figure 3

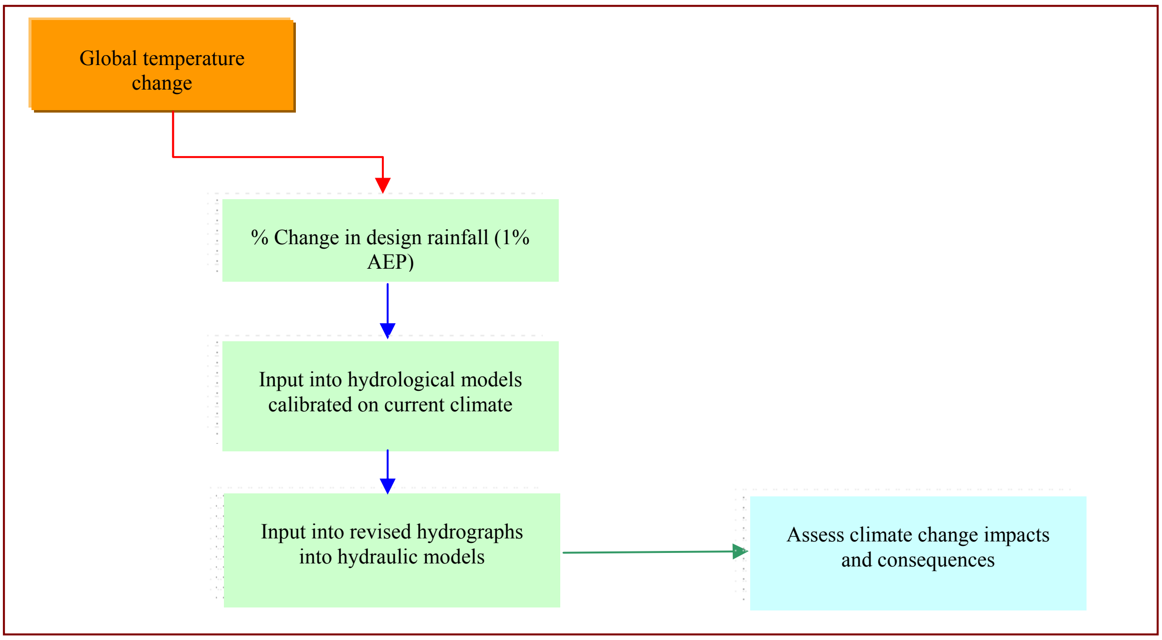

Figure 3. Flow chart of climate change flooding risk assessment based on temperature changes.

Hydrological and hydraulic models were previously developed and calibrated for the study area as part of a flood study undertaken by the local government authority under the Natural Disaster Mitigation Program (jointly funded by the Australian and Queensland Governments). These models were used to simulate a range of potential future climate scenarios.

To assess the sensitivity of the method, two relationships between increases in rainfall and temperature were modelled (5% and 7% per 1ºC corresponding to the proposed percentage change and the Clausius-Clapeyron theoretical relationship respectively). These two relationships were applied to a range of temperature increases (1ºC to 4ºC which in turn correspond to different predicted timeframes depending on the GCM scenario).

The scenarios were simulated by increasing the design rainfall totals by the respective percentage increase corresponding to the selected relationship and temperature increase (design rainfalls were based on the CRC Forge methodology in the original Flood Study (Jörissen, 2008)). Initial and continuing losses, and spatial and temporal rainfall patterns were not adjusted. These scenarios were applied to the existing 100, 200 and 500 year Average Recurrence Interval (ARI)[2] design rainfall events.

Figure 4 below provides an indication of the potential impact these future climate scenarios may have on the current 100 year ARI design flood level based on preliminary flood modelling in the case study area. The figure shows a series of flood ‘totems’ marking peak design flood level at a nominated location. The first totem shows the existing 100, 200 and 500 year ARI levels based on the original flood study. The second and third totem show the potential future 100 year ARI level for a 5% and 7% increase in rainfall per 1ºC respectively. Each totem shows how the level is predicted to change for a 1ºC to 4ºC increase in temperature. For the scenario based on a 7% increase in potential rainfall per 1ºC associated with a planning horizon of 100 years and assuming a 4ºC increase in temperature, the future 100 year ARI level is predicted to be approximately equivalent to the current 500 year ARI.

Figure 4

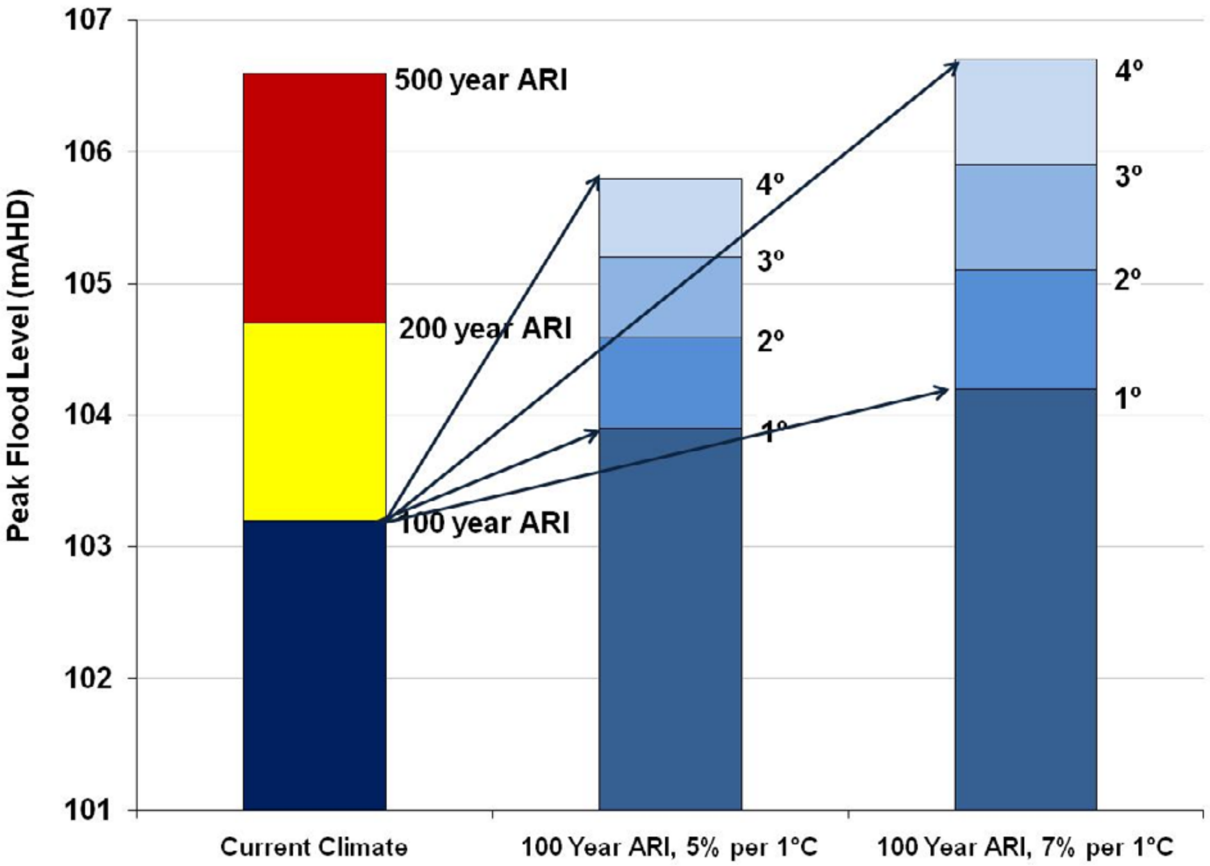

Figure 4. Flood totems for case study for current and selected future climate change scenarios.

[2] The 100 year ARI is equivalent to the 1% AEP rainfall event, the 200 year ARI equivalent to the 0.5% AEP rainfall event, and the 500 year ARI equivalent to the 0.2% AEP rainfall event.

6. Conclusions and options for flooding risk management policy

The physical relationship between water vapour content and temperature of the atmosphere provides a basis for translating this increased risk of extreme rainfall to the policy domain. Given the uncertainty associated with the rainfall projections from the GCMs, particularly at the 99^{th} percentile, and the greater certainty with respect to temperature projections, the use of the Clausius-Clapeyron theory provides the most robust interim measure on which to base the increases in rainfall intensity.

The NAS (2010) report recognises that there is uncertainty of the impacts of precipitations changes on flooding because of poorly understood interactions between precipitation characteristics and river basin hydrology.

In parallel to the proposed scientific methodology outlined in this paper, as part of this study a planning advisory group have reviewed current Queensland land use-related flooding risk management approaches. A review has also been conducted of national and international approaches to assessing future flooding risk associated with climate change, and the most pertinent approaches have been summarised in Appendix 2.

Adoption of the recommendation outlined at the start of this paper provides an interim response to a very challenging problem. This methodology will apply only to flooding risk assessment for planning as prescribed in SPP 1/03.

If this recommendation turns out to underestimate the changes (and the evidence produced to date would suggest it will), then further increases will be recommended through the revision of AR&R. Taking this first step now will make these increases more acceptable in the future.

APPENDIX 1

Table A1

Mean percentage change in 2% AEP rainfall projected for 1 and 3 days duration from 11 GCM models for 2055 and 12 models for 2090 (from Rafter and Abbs 2010).

Year	**Duration (days)**	**GCM**	**Queensland region**				**Proposed % increase using Qld interim method (5% per 2ºC and 4°C warming at 2055 & 2100)**
			Central	North	East Coast	South East	
2055	1	CNRM CM3	31.3	27.4	16.7	58.7	10
		CSIRO Mk3.0	18.7	17.1	12.7	10.6	
		CSIRO Mk3.5	13.0	6.3	3.8	2.8	
		GFDL CM2.0	58.4	279.9	56.4	32.4	
		GFDL CM2.1	255.2	641.7	70.6	37.2	
		MIROC 3.2	3.9	9.3	0.7	8.5	
		MIUB ECHO-G	7.1	7.7	3.3	2.0	
		MPI ECHAM 5	10.7	-12.4	-8.9	8.2	
		MRI CGCM 2.3.2A	0.2	-6.8	10.1	3.8	
		NCAR CCSM 3.0 (1)	2.3	-7.0	-7.5	0.3	
		NCAR CCSM 3.0 (3)	-4.7	32.5	-20.1	-16.3	
2055	3	CNRM CM3	20.7	32.4	9.9	53.5	10
		CSIRO Mk3.0	11.1	20	9.8	7.7	
		CSIRO Mk3.5	14.3	7.4	11.5	4.1	
		GFDL CM2.0	45.5	126.4	14.5	4.7	
		GFDL CM2.1	143.6	278.8	40.7	40.0	
		MIROC 3.2 (medres)	2.6	4.5	5.4	12.5	
		MIUB ECHO-G	6.0	9.4	5.6	4.4	
		MPI ECHAM 5	30.4	5.5	-4.4	-2.3	
		MRI CGCM 2.3.2A	6.6	-4.6	11.9	10.1	
		NCAR CCSM 3.0 (1)	4.4	-5.7	-11.9	-6.9	
		NCAR CCSM 3.0 (3)	3.5	20.8	-14.8	-12.0	

Year	Duration (days)	GCM	Queensland region				Proposed % increase using Qld interim method (5% per 2ºC and 4°C warming at 2055 & 2100)
			Central	North	East Coast	South East	
2090	1	CNRM CM3	46.3	41.1	49.2	97.4	20
		CSIRO Mk3.0	10.4	14.6	34.7	31.5	
		CSIRO Mk3.5	39.2	43.8	33.2	30.3	
		GFDL CM2.0	133.5	15969.6	130.5	62.3	
		GFDL CM2.1	323.6	669.8	151.3	80.5	
		MIROC 3.2 (medres)	25.1	7.7	23.5	29.2	
		MIUB ECHO-G	23.9	20.4	15.6	4.6	
		MPI ECHAM 5	10.7	-10.1	-0.6	23.6	
		MRI CGCM 2.3.2A	-4.9	-3.9	6.2	7.8	
		NCAR CCSM 3.0 (1)	2.4	10.1	-26.6	-34.4	
		NCAR CCSM 3.0 (3)	-4.9	26.7	-10.8	-13.4	
		UKMO HadCM3	47.0	25.3	30.6	16.8	
2090	3	CNRM CM3	40.1	40.4	35.1	57.1	20
		CSIRO Mk3.0	0.9	9.3	33.5	24.8	
		CSIRO Mk3.5	39.9	43.0	28.0	21.0	
		GFDL CM2.0	172.4	435.6	105.0	46.6	
		GFDL CM2.1	444.8	990.4	86.3	38.5	
		MIROC 3.2 (medres)	23.5	14.7	24.2	30.2	
		MIUB ECHO-G	16.5	26.7	26.5	9.2	
		MPI ECHAM 5	21.0	-3.8	7.5	16.2	
		MRI CGCM 2.3.2A	-9.0	-3.1	3.8	1.4	
		NCAR CCSM 3.0 (1)	-0.2	3.1	-28.4	-32.1	
		NCAR CCSM 3.0 (3)	2.1	22.5	-7.8	-7.9	
		UKMO HadCM3	57.3	33.8	46.6	16.7	

APPENDIX 2—Planning approaches for considering climate change impacts on flooding risk by other jurisdictions

The review of other jurisdictions provides justification for increasing the 99th and higher percentile rainfall events:

- New South Wales has adopted a sensitivity approach recommending a 10%, 20% and 30% increase in rainfall intensity at this percentile. This sensitivity approach was based on the bounds of the projected 40-year daily rainfall changes by 2030 and 2070 that resulted from modelling undertaken by CSIRO (Hardwick Jones et al. 2010).
- The Victorian Flood Management Strategy was launched in 1998 and is currently undergoing revision. A draft of the revision was scheduled for release in December 2008 but has been delayed. It is expected that the issue of climate change will be included, but that no specific guidelines for assessing future flooding risk under climate change will be provided (personal communication from Mike Edwards, Floodplain Manager, Department of Sustainability and Environment).
- The Western Australian Local Government Association (WALGA) has released a policy paper outlining their commitment to help both mitigate and adapt to future climate change (Bainbridge 2009). They further acknowledge the higher risk of more intense rainfall and increased subsequent flooding events projected over large areas of the state. In relation to policy frameworks such as local planning schemes, land use zonings, local planning policies and environmental protection policies, local council decision making will 'need to be cognisant of climate change implications in a very demonstrable way in order to meet the 'reasonable' test in their defence'.
- New Zealand has increased the rainfall intensity across all return periods up to the 1-in-100 year events for all durations for amounts ranging from 3.5% to 8% per degree of global warming. The 8% per degree of global warming applies to the higher percentile events.
- The United Kingdom has adopted a mixture of percentage increases in rainfall and streamflow for its flood studies as outlined in Table A2.

Table A2

Recommended national precautionary sensitivity ranges for peak rainfall intensities, peak river flows, offshore wind speeds and wave heights from the UK's 'Planning Policy Statement 25: Development and Flood Risk' .

Parameter	1990–2025	2025–55	2055–85	2085-2115
Peak rainfall intensity—use for small catchments and local/urban drainage sites	+5%	+10%	+20%	+30%
Peak river flow volume—use for larger catchments(>5 km2)	+10%	+20%		

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