Incorporation of Climate Change in Intensity-Frequency-Duration (IFD) Design Rainfall Estimates

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The current Intensity-Frequency-Duration (IFD) design rainfalls, used in the identification of floodplain risk management options and development decisions, were derived assuming that any climatic trends would have a negligible effect on IFDs. In the 25 years since the publication of the current IFD estimates, there have been significant advances in the awareness and understanding of climate change. As a consequence, decision makers now need to consider the impacts of climate change on flood producing rainfall events and the associated ramifications on management decisions. Although the revision of the IFD design rainfalls being undertaken by the Australian Bureau of Meteorology (the Bureau) will produce IFD estimates for the current climate regime, the status of climate change science means that revised IFD estimates for future climate regimes will not be available for several years. In the interim, policy makers and practitioners providing advice on flood behaviour and risk need to assess how climate change may impact on design rainfall estimates and the flow on effects to future flood risk. This paper provides an overview of the current and future advice available for incorporating climate change in design flood studies; and suggests an interim approach.

1. INTRODUCTION

The Intensity-Frequency-Duration (IFD) design rainfalls currently used in design flood studies were developed by the Bureau of Meteorology (the Bureau) over 20 years ago. They were based on a database comprising information primarily from the Bureau's network of daily read and pluviograph stations and adopted statistical techniques considered appropriate at the time. The estimation of the IFDs explicitly assumed that the data sample at each location is representative of the long-term conditions at that station (stationarity) and that climatic trends would have negligible effect on the intensities. This absence of consideration of climate change was in keeping with the general thinking of the day which did not consider climate change to be a significant issue.

However, in response to the growing awareness and understanding of climate change, decision makers now need to consider the impacts of climate change on flood producing rainfall events and the associated ramifications on management decisions. However, there do not currently exist consistent recommendations on how to assess the impact of climate change on IFD design rainfalls. In the absence of any such advice, various approaches have been adopted.

In the following sections an overview will be presented of the current advice available in each of the states for the incorporation of climate change in design flood studies. In addition, details will be provided of a strategy prioritising the research required to enable consistent and more detailed advice to be prepared in the short to medium term. Finally, an interim approach for including a consideration of the impact of climate change on design rainfalls is suggested.

2. CLIMATE CHANGE PROJECTIONS - AVERAGE

2.1. Global

In February 2007, the United Nations Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report (AR4) (IPCC, 2007). The IPCC represents the consensus view of about 2500 climate scientists from around the world, including more than 100 Australia experts. The AR4 presents projections of future climate based on 23 General Circulation Models (GCM) that have been developed by various countries including Australia. On a global basis, the AR4 predictions for the 21st century include:

- Mean annual precipitation increases *very likely* (greater than 90% certainty) in high latitudes.
- Mean annual precipitation decreases *likely* (greater than 66% certainty) in most subtropical land regions such as southern Australia, southern Africa and the Mediterranean.
- *Very likely* (greater than 90% certainty) that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent.
- *Likely* (greater than 66% certainty) that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation.

2.2. Australia

In producing projections for Australia, the CSIRO and Bureau of Meteorology used the results from the 23 GCMs adopted by the IPCC but weighted the results of each model based on its ability to reproduce recorded patterns of temperature, rainfall and mean sea level pressure in the Australian region (CSIRO and Bureau of Meteorology, 2007). Regional projections for Australia were developed for the years 2030, 2050 and 2070 and for the greenhouse gas and sulphate aerosol emission scenarios of low, medium and high. Regional projections, shown in Table 1, are expressed as ranges of percentage change in annual precipitation for various emission scenarios.

Table 1: Projected change in annual precipitation in Australia

Year	Emission Scenario	Region	Change in Precipitation (%)
2030	Medium	Far north	0
		Elsewhere	-5 to -2
2050	Low	Far north	-5 to 0
		Central, east, north	-15 to +7.5
		South	-15 to 0
	High	Far north	-7.5 to 0
		Central, east, north	-20 to +10
		South	-20 to 0
2070	Low	Far north	-7.5 to 0
		Central, east, north	-20 to +10
		South	-20 to 0
	High	Far north	-10 to 0
		Central, east, north	-30 to +20
		South	-30 to +5

3. CLIMATE CHANGE PROJECTIONS – 'EXTREMES'

3.1. Global

A limitation of the climate change projections presented in both IPCC (2007) and CSIRO and Bureau of Meteorology (2007) is that the focus is on changes to average daily and annual values rather than the magnitude and frequency of events that are of most interest in design rainfalls and floods. In response to requests for more information on extreme weather and climate events in a changing climate, the IPCC agreed that a "Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)" (IPCC, 2012) be prepared. This report, which is scheduled for release in March 2012, will evaluate the role of climate change in altering the frequency and severity of extreme events with a focus on recent and possible future changes in climate extremes.

The SREX Summary for Policymakers (SPM) released in November 2011, provides a summary of projected changes in climate extremes, while recognizing that confidence in projections is dependent on factors including type of extreme, region, season, the amount and quality of observational data, the level of understanding of the underlying processes, and the reliability of their simulation in models. For precipitation this includes:

- It is *likely (66-100% probability)* that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21^{st} century over many areas of the globe.
- Projected precipitation and temperature changes imply possible changes in floods, although there is low confidence in projections of changes in fluvial floods.
- There is *medium confidence* (based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments.

However, the SPM emphasizes that, given the rarity of events of this nature, there are few data with which to make assessments regarding changes in the frequency or intensity of these events. It should also be noted that the events that the report consider to be 'extreme' refer to rainfall events which are beyond the 95^{th} percentile in the distribution of daily rainfalls (this is the heaviest 5% of events). These events are more frequent than the rainfall events used in deriving IFD design rainfalls. In the context of design rainfalls, extreme events are considered to be those events with an Annual Exceedance Probability (AEP) of less than (or rarer than) 1 in 2000 (Institution of Engineers, 1999).

3.2. Australia

In Australia the CSIRO and other organizations have undertaken studies to assess the impact of climate change on extreme rainfalls. (It should be noted, that in these studies, extreme rainfall is assumed to be the 1 in 40 AEP rainfall which, as discussed above, differs from the definition of extreme rainfall adopted in Australian Rainfall and Runoff (AR&R) (Institution of Engineers Australia, 1999). These studies have generally used dynamic downscaling of the GCMs to obtain results at the requisite spatial and temporal scales with the Conformal Cubic Atmospheric Model and the Regional Atmospheric Modeling Systems generally being adopted. Table 2 summarises the average and range of changes in rainfall extremes found from the CSIRO studies for 2030 and 2070.

4. MANAGING UNDER CLIMATE CHANGE

4.1. Current Advice

There is limited information available on changes to precipitation in the range of AEPs of interest for design rainfalls. In addition, the uncertainties associated with the projected changes in percentage precipitation presented in Table 2 makes the incorporation of climate change into decision making processes difficult. In the absence of definitive information, organisations and government authorities have prepared advice on what practitioners should consider in projects that use design rainfalls and have life spans of long enough duration such that climate change may affect the project. The following section summarises these sources of guidance.

Table 2: Projected regional changes in rainfall 'extremes'

Region	Ref	Emission Scenario	ARI	Duration	2030 Range of Changes	2070 Range of Changes
Greater Sydney	Abbs et al 2006a	unknown	Change in top 10 events in 40 yrs	24 hours	-40% to 40%	-40% to 70%
North East NSW	Hennessy et al 2004	A2 and IS92a	40 year	24 hours 72 hours	5% 0%	5% 5%
North Central NSW	Hennessy et al 2004	A2 and IS92a	40 year	24 hours 72 hours	5% -3%	10% 3%
North West NSW	Hennessy et al 2004	A2 and IS92a	40 year	24 hours 72 hours	-10% -3%	-7% 3%
South East NSW	Hennessy et al 2004	A2 and IS92a	40 year	24 hours 72 hours	7% 10%	5% 3%
South Central NSW	Hennessy et al 2004	A2 and IS92a	40 year	24 hours 72 hours	0% 12%	13% 4%
South West NSW	Hennessy et al 2004	A2 and IS92a	40 year	24 hours 72 hours	0% 0%	15% 10%
South East QLD	Abbs et al 2007	A2	Change in top 10 events in 40 yrs	2 hours 24 hours 72 hours	-40% to 70% -40% to 50% -40% to 50%	-40% to 70% -40% to 50% -40% to 50%
South East QLD	Abbs et al 2006b	A2	Change in top 10 events in 40 yrs	24 & 72 hrs	-30% to 40%	-20% to 70%
Central Coast NSW	Abbs et al 2006b	A2	Change in top 10 events in 40 yrs	24 & 72 hrs	-40% to 50%	-40% to 70%
Victoria & lower MDB	Abbs et al 2006b	A2	Change in top 10 events in 40 yrs	24 & 72 hrs	-20% to 40%	-40% to 70%
South Australia	McInnes et al 2003	A2, IS92a, 1% CO_2 incr. p.a.	10 year 20 year 40 year	24 hours?	-7% to 17% -9% to 16% -3% to 10%	-20% to 70% -10% to 50% -10% to 50%
Western Port	Abbs & Rafter 2008	A2	Change in top 10 events in 40 yrs	2 hours 24 hours 72 hours	-20% to 50% -10% to 30% -20% to 20%	

4.1.1. New South Wales

The NSW Department of Environment and Climate Change guidelines were published in 2007 to assist Local Government Authorities to consider climate change impacts as part of the Floodplain Management process (Department of Environment and Climate Change, 2007). Key recommendations related to sea level rises and changes to rainfall intensities. A modeling sensitivity analysis is recommended for Flood Studies and Floodplain Risk Management Studies. Recommended values for the sensitivity analysis for rainfalls included increases of:

- 10%, 20% and 30% in peak rainfall and storm volume

It is recommended that sensitivity analyses are carried out in addition to other sensitivity analyses involved in flood studies and floodplain risk management studies, as traditionally carried out based on the recommendations in the *Floodplain Development Manual* (Department of Infrastructure, 2005).

4.1.2. Queensland

The Queensland Urban Drainage Manual (QUDM) Queensland (Department of Natural Resources and Water, 2007) incorporates generic advice for climate change in the design of stormwater outlets and points practitioners to general references for climate change projections in Australia and the Fourth Assessment Report of the IPCC. CSIRO risk guidance scenarios for south-eastern and north-eastern Queensland are discussed in QUDM for low and high global warming scenarios but no specific advice on allowances or sensitivity studies is provided.

The *Queensland Inland Flooding Study* (Office of Climate Change – Department of Environment and Resource Management, 2010) recommends that rainfall intensity should be increased by 5% per degree of global warming and recommends planning horizons of 2050, 2070 and 2100. The A1FI emissions scenario has been adopted for assessing the global mean temperature projections. The temperature increases to be used to scale the rainfall intensity factor are 2°C by 2050, 3°C by 2070 and 4°C by 2100; this leads to increases of 10 to 20% in rainfall intensity. The method is limited to assessing flood risk for planning purposes and thus only applies to the 1%, 0.5% and 0.2% AEP events. No guidance is provided for more frequent or more extreme events.

4.1.3. Western Australia

The Western Australian Local Government Association (WALGA) has developed a climate change policy background paper (Bainbridge, 2009). Despite projections of decreasing annual average rainfall for most of Western Australia (Bureau of Meteorology and CSIRO, 2007), there may still be increases in extreme rainfall intensities for parts of the state. WALGA notes that this is likely to lead to increased flooding risks and financial pressure on Local Government to upgrade drainage infrastructure.

Recent flood studies have adopted different methods to examine the sensitivity of the results to potential changes due to climate change. The *Serpentine River Floodplain Management Study* (Sinclair Knight Merz, 2010) used two scenarios of high and low losses to examine the sensitivity of the results to uncertainties in the hydrologic and hydraulic modeling, including uncertainty in the IFD information due to the impact of climate change. On the other hand, the *Murray Drainage and Water Management Plan and Associated Studies* (GHD, 2010) used the 1 in 50 AEP and 1 in 500 AEP events to quantify possible upper and lower bounds for the 1 in 100 AEP event due to climate change.

4.1.4. Victoria

The *Victoria Flood Management Strategy* (State Flood Policy Committee, 1998) is currently being revised (Office of Water, 2010); the current strategy does not contain specific advice on the consideration of climate in flood studies. In the absence of specific advice, different studies have adopted different approaches.

Melbourne Water and CSIRO (2005) considered the impact of increases of 5, 10 and 20% increases in rainfall event totals per degree of warming, which given ranges of warming between 0.5 °C by 2020 and 1.4 °C by 2050, would increase rainfall event totals by up to 10% by 2020 and 28% by 2050. The *City of Port Philip case study* (NATCLIM, 2007) considered increases in the rainfall intensity of 5% by 2020, 35% by 2050 and 70% by 2100 for the 20 year ARI event. These increases in intense rainfall were considered as part of a risk assessment with impacts of increasing flooding of buildings and roads, increased pressure on storm water infrastructure, increases to beach pollution and increased road accidents for 2020. Impacts were expected to be more severe for 2050 and 2100.

4.1.5. Tasmania

As part of the Climate Futures for Tasmania project a decision support tool, ClimateAsyst, is being developed by pitt&sherry, a Tasmanian consultancy in partnership with the Antarctic Climate and Ecosystems Cooperative Research Centre (Rand et al, 2010). ClimateAsyst aims to assist policy makers and infrastructure owners to assess the potential impacts of climate change on their assets for a range of climatic variables. For precipitation, the tool currently provides projected changes in the 24 hour rainfall volumes for a range of recurrence intervals across Tasmania which can be used to scale current IFD data.

4.1.6. South Australia and Northern Territory

At this stage there appears to be no advice available in either of these jurisdictions on the effects of climate change on design rainfalls. The South Australian Local Government Association is currently undertaking a research project through the National Centre for Climate Change Adaptation Research Facility to develop a system for local government to quantify the impacts of climate change on their assets (NCCARF, 2011).

4.2. Future Advice

The current status of climate change research is not sufficiently developed to provide the advice necessary to develop IFD estimates, or other components of design floods, for possible future climates. Although relevant research has been undertaken by CSIRO and other organisations, the work is for a limited number of locations and lacks a co-ordinated, national focus. In response, the AR&R Revision Steering Committee requested that a Climate Change Research Strategy be developed to enhance understanding of how projected climate change may alter the behaviour of factors that influence the estimation of the design floods that are used in policy decisions involving infrastructure, town planning, floodplain management and flood warning and emergency management.

The AR&R Revision Climate Change Research Strategy (the Strategy) identifies priorities for research direction to be undertaken over both the short term (Stage 1 - one year) and the longer term (Stage 2 - four years). The Strategy identifies five research themes:

1. Rainfall intensity-frequency-duration relationships
2. Rainfall temporal patterns
3. Continuous rainfall sequences
4. Antecedent conditions (including baseflow)
5. Simultaneous extremes

At the time of writing, funding was being sought to enable implementation of the Strategy.

5. SUGGESTED APPROACH

The AR&R Revision Climate Change Research Strategy will provide more definitive advice on the impacts of climate change on design floods including the revised IFDs. However, in the interim practitioners, engineers and planners need to assess the possible impacts of climate change on design rainfalls that are being used to design infrastructure and make planning decisions. A suggested approach is presented below however integral to any approach is recognition of the following:

- Climate change science is an evolving science with ongoing research being undertaken both in Australia and internationally. The IPCC Fifth Assessment Report, which will provide an update of knowledge on the scientific, technical and socio-economic aspects of climate change, is scheduled to be published in 2013/14.
- The signal for changes in precipitation due to anthropogenic climate change is less straight forward than for temperature because, as a complex non-linear phenomenon, use of linear trends can be misleading.
- This is particularly the case in Australia due to the 'noise' from Australia's high natural rainfall variability on the inter-annual and inter-decadal time scale.
- This is exacerbated with events of the magnitude of those used in design flood estimation as the rarity of these events means there are few data available with which to make assessments regarding changes in the frequency or intensity of these events.
- Confidence in projections of large rainfalls is dependent on factors including the amount and quality of observational data, the level of understanding of the underlying processes, and the reliability of their simulation in models.
- Climate change projections are not forecasts.

It is suggested that sensitivity analyses be undertaken for increases in the current IFDs of:

- 10%, 20% and 30%

However, the results from the sensitivity analyses should then be assessed through the undertaking of a qualitative risk analysis. The purpose of undertaking a qualitative risk analysis is to put the results of the sensitivity analysis in context. This in turn will enable practitioners and planners to gain a qualitative understanding of the possible increased level of risk that increases in design rainfalls might have on floods levels and the severity of adverse effects to life, health, property or the environment. This will assist decision makers to decide whether the increased levels of risk are tolerable and present measures to control them are adequate or whether alternative risk control or planning measures are required. In general terms, the qualitative risk analysis would involve:

- Estimation of the risks.
- Evaluation of the risks to decide what risk level would be tolerable.
- Comparison of the risks with existing risk and planning policies.
- Decision regarding whether new policies are required.

The above approach provides practitioners and decision makers with a means of assessing the potential impacts of climate change on large rainfall events using the information and advice that is currently available while recognizing that definitive advice on how climate change will alter these events is still some years away.

6. CONCLUSIONS

Practitioners and decision makers need to consider the impacts of climate change on flood producing rainfall events and the associated ramifications on management decisions. However, the current status of climate change science means that revised IFD estimates for future climate regimes will not be available for several years. In the interim, policy makers and practitioners providing advice on flood behaviour and risk need to assess how climate change may impact on design rainfall estimates and the flow on effects to future flood risk. Although different organizations have provided advice on the consideration of climate change in flood studies and studies have been undertaken for specific areas of Australia, there does not exist a consistent approach on the consideration of climate change in flood studies. An approach for the inclusion of climate change in flood studies has been suggested which:

- Acknowledges the limitations of current climate change advice for precipitation in general and large rainfall events in particular.
- Appreciates the needs of decision makers to include an assessment of possible climate change impacts in the decision making process.
- Recognizes work that is being undertaken both in Australia and internationally to enhance understanding of how projected climate change may alter the estimation of the design floods.

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