Australian Rainfall and Runoff – The Interim Climate Change Guideline

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Abstract

There is now widespread acceptance that human activities are contributing to observed climate change. Human-induced climate change has the potential to alter the prevalence and severity of rainfall extremes, storm surge and floods. Recognition of the risks associated with climate change is required for better planning of new infrastructure and mitigating potential damage to existing infrastructure. Policy makers, planners and the designers of hydraulic structures will need to base their decisions on up-to-date information from reliable sources.

This paper describes the Interim Guideline for Climate Change for Australian Rainfall and Runoff (ARR) which outlines an approach to address the risks from climate change in projects and decisions that involve estimation of design flood characteristics. The Interim Guideline draws on the most recent climate science, particularly the release of the IPCC Fifth Assessment Report in September 2013 as well as the new climate change projections for Australia. For consistency with the new Intensity-Frequency-Duration design rainfall estimates for ARR, the Interim Guideline is intended to be applied to the key system design event (i.e., the design standard for the structure or infrastructure). It is applicable for current-day rainfall intensities within the range of probability of one exceedance per year and annual exceedance probabilities from 50% to 1%.

1. INTRODUCTION

Climate change is expected to have an adverse impact on heavy rainfall intensities (or equivalent depths) which could increase the risk of flooding over time at many locations in Australia. In recognition of this challenge, the Council of Australian Governments in 2007 identified the revision of Australian Rainfall and Runoff (ARR) as a priority in its National Climate Change Adaptation Framework. Revision of the ARR was recognised as an important national initiative to facilitate better planning of new infrastructure and to reduce potential damage to existing infrastructure.

The Interim Guideline for Climate Change is a component of the new edition of ARR. It provides designers and decision makers that utilise ARR with an approach to consider the implications of climate change while further research is undertaken to reduce key uncertainties. It draws on the most recent climate science, particularly the release of the IPCC Fifth Assessment Report (IPCC, 2013) as well as the new climate change projections for Australia (CSIRO & Bureau of Meteorology, 2015). The approach considers regional risks from climate change, the service life (i.e., the total period during which an asset remains in use) or the planning horizon of the decision (i.e., the length of time that a plan looks into the future), the social acceptability and other consequences of failure, and the cost of retrofits. If climate change is found to be a significant issue for the facility of interest through a screening analysis, a more detailed analysis is proposed that draws on the best available knowledge of the likely future climate and allows for changes in the intensity of heavy rainfall events over time. The Interim Guideline does not replace the need for informed judgement of likely risks, or the need for detailed local analysis (for example through the use of additional climate and hydrological modelling) where the facilities under consideration are important and the risks potentially large. It is anticipated that the Interim Guideline will be replaced gradually as new and detailed research findings are released.

This paper provides: an overview of the web-based decision support tool called Climate Futures which is used to assist in applying the Interim Guideline; a description and depiction of the Guideline steps in a decision tree format; a worked example to illustrate the calculation of rainfall intensities (or equivalent depths) for projected climate conditions; and some concluding remarks.

2. CLIMATE FUTURES WEB TOOL

CSIRO and Bureau of Meteorology (2015) have developed a Climate Futures web tool that facilitates informed selection of a sub-set of climate model results for use in impact assessments. Climate change projections are focussed on Natural Resource Management regions (or 'clusters', Figure 1) for which information, data and reports are available. Projected changes from the latest global climate models (GCMs) can be explored for 14 20-year periods centred on 2025, 2030, …, 2090; and the four representative concentration pathways (RCPs) for greenhouse gas and aerosol concentrations that were used to drive the GCMs. The RCPs are designated as RCP2.6, RCP4.5, RCP6.0 and RCP8.5, and are named according to radiative forcing values in the year 2100 relative to pre-industrial values (2.6, 4.5, 6.0 and 8.5 W m-2). Data are available from up to 40 GCMs, 6 dynamical downscaling and 22 statistical downscaling simulations. The use of RCP2.6, RCP4.5 and RCP8.5 is recommended for impact assessment (CSIRO and Bureau of Meteorology, 2015). Further information can be found at (http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/introduction-climate-futures/).

Climate Futures subdivides the projected changes in two climate variables (such as temperature and rainfall) from the full suite of GCMs into several classes, e.g. warmer-wetter, hotter-drier, much hotter-much drier. The changes are relative to a 20-year (1986-2005) baseline. The resultant classification provides a visual display of the spread and clustering of the projected changes. This provides model consensus information for each classification and assists the selection of the classifications that are of most importance for impact assessment. Generally, there is more confidence in GCM simulations of temperature than for rainfall. Projections of changes to design rainfall Intensity-Frequency-Duration (IFD) relationships are not included in the Climate Futures Tool due to the paucity of available information. Thus the Interim Guideline provides an adjustment factor for the design rainfall IFD curves in ARR (2015) informed by temperature projections alone. These temperature projections are then combined with the current best understanding of changes to extreme rainfall event intensities based on research in Australia and overseas. This research includes observation based assessments, physical arguments on the water holding capacity of a warmer atmosphere and high resolution dynamical downscaling experiments. Using these multiple lines of evidence the expected change in intense rainfalls is between 2% and 15% increase per degree of warming. Given the uncertainty in rainfall projections and their considerable regional variability, and that other factors have the potential to affect future rainfall intensities (or depths) over land such as changes in regional atmospheric circulation, synoptic systems and soil wetness, an increase of 5% has been recommended for the Guideline.

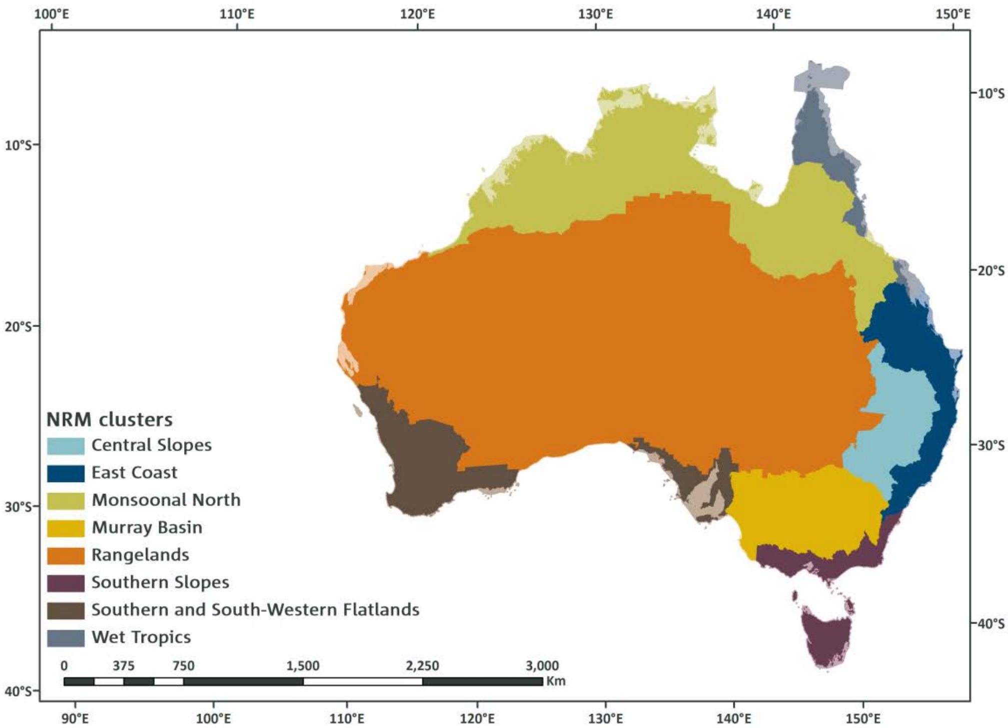

Figure 1 Locations of natural resource management clusters

3. INTERIM CLIMATE CHANGE GUIDELINE

The scope of the Interim Guideline has been limited to projected changes in rainfall intensity (or equivalent depth) because there is little available information on projected changes in rainfall temporal patterns, antecedent wetness and baseflow. For consistency with the new design rainfall IFD estimates for Australia (ARR, Book II – Rainfall Estimation, 2015), the Interim Guideline is intended to be applied to the key system design event (i.e., the design standard for the structure or infrastructure). It is applicable for rainfall intensities under the current climatic regime within the range of probability of one exceedance per year and annual exceedance probabilities (AEPs) from 50% to 1%. Other mechanisms that affect the magnitude of flooding, such as tailwater levels and oceanic processes (e.g. wind, waves and tides) are not considered.

The Interim Guideline uses a six-step process for incorporating climate change risks into decisions involving the estimation of design flood characteristics. The process uses a decision tree approach that guides the user in defining the nature of the information needed for a particular problem and reaching a recommended course of action (Figures 2 to 4).

3.1. Step 1 – Set the Service Life or Planning Horizon

The first consideration is the service life of an asset or planning horizon of an activity (Figure 2). This underpins the design philosophy and may fundamentally control the selection of material, methods and expertise. In current practice, a broad perspective on service life may be required incorporating engineering, client and community perspectives. Potential climate change considerations may influence these decisions, particularly as the risks from climate change are likely to increase over time.

If the service life or planning horizon is relatively short (less than 20 years from 2015, say) anthropogenic climate change will have negligible impact on the design rainfall IFD characteristics over that period of time. That is, the exposure risk is low, and the design process should be based on the design rainfall IFD and temporal pattern data in the new edition of ARR. Otherwise, proceed to Step 2.

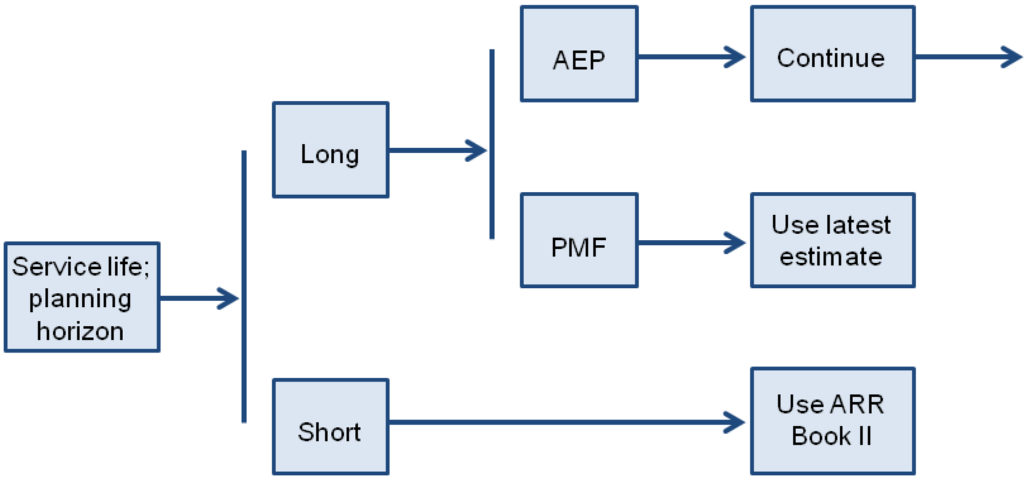

Figure 2 Decision tree for incorporating climate change in flood design – Part 1 of 3 (AEP = annual exceedance probability; PMF = probable maximum flood; ARR Book II = design rainfall intensity (or equivalent depth) for current-climate conditions)

3.2. Step 2 – Set the Flood Design Standard

Again consider Figure 2. If the design standard is the PMF, use an up-to-date estimate of PMP to determine the PMF. This approach has an appropriate degree of conservatism as PMP estimates are updated by the Bureau of Meteorology from time to time. This will ensure that any future climate change signal is captured and thus the PMP should not be further adjusted to take into account potential climate change implications. Otherwise, proceed to Step 3.

3.3. Step 3 – Consider the Purpose and Nature of the Asset or Activity and Consequences of its Failure

Consider Figure 3. Here "purpose of the asset" can refer to flow conveyance, improved safety, and reduced frequency of exposure and damage. Flood-related design requirements (e.g., minimum fill levels and minimum floor levels) need to be considered, as well as the consequences of failure (e.g., risks to life, property and the environment) and the cost of retrofitting assets if design rainfall IFD characteristics change with time.

The impact of the possible failure of the facility (e.g., asset, process or management strategy) will have direct and indirect consequences, and should be assessed in terms of primary risk outcomes as issues of cost, safety, social acceptability and environmental impact. Some categorisation of facilities may be useful when determining the consequences of failure. For example, projects or decisions involving assets involved in the delivery of essential services can have very damaging consequences if performance is significantly impaired or if failure occurs.

The consequences of failure can be rated as either low, medium or high. A suggested interpretation of this consequence risk rating is:

- Low consequence: there is risk that asset performance will be impacted but the delivery of services will be only partially or temporarily compromised, or alternative sources of services (e.g., availability of different power sources) are readily available.
- Medium consequence: significant risk that performance of important but non-critical assets and delivery of services will be impacted or fail for a short period of time.
- High consequence: significant risk that performance will be impacted or fail, leading to disruption to delivery of essential services (where alternative sources of services are not readily available). This category generally relates to high value assets, or assets of significant economic or welfare importance.

Where the consequences of impact on performance or failure and the costs of retrofitting are considered to be low, the project or decision should proceed in accordance with the original design specifications. Otherwise, proceed to Step 4.

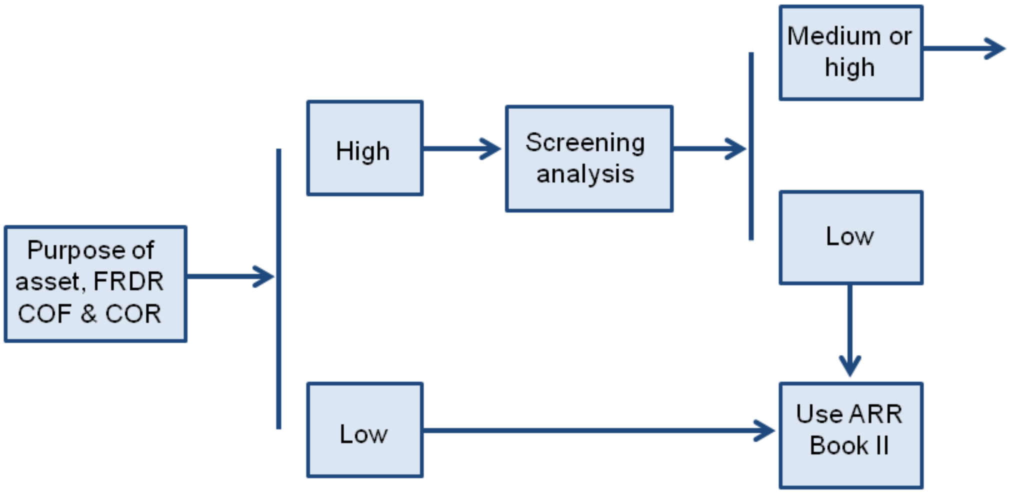

Figure 3 Decision tree for incorporating climate change in flood design – Part 2 of 3 (FRDR = flood-related design requirements; COF = consequences of failure; COR = cost of retrofits; ARR Book II = design rainfall intensity (or equivalent depth) for current-climate conditions)

3.4. Step 4 – Carry out a Climate Change Risk Screening Analysis

Again consider Figure 3. This step responds to the question: "Is climate change a significant issue for the facility of interest?" Here the risks of climate change are assessed with regard to their capacity to impair the facility's ability to perform its intended function. The description of impact or failure involves the use of heavy rainfall events with different AEPs. This task can be facilitated by use of the AEPs listed in Table 1. Recall that the scope of this Interim Guideline is limited to design AEPs more frequent than the 1% event. If the design AEP corresponds to the i^{th} row in Table 1, consider the impact of the AEP events corresponding to the $(i+1)^{th}$ and $(i+2)^{th}$ rows on the facility of interest and the associated consequences. For example, if the design AEP is 1% an analyst could consider the impact of the 0.5% and 0.2% AEP events.

The outputs from this step include a good understanding of the extent to which the risks of climate change may exceed the coping capacity of the facility to perform its intended function. If the incremental impact and consequences are low (e.g., increases in flood levels are slight) then the exposure risk to climate change is low, and the design flood should be determined using the new design rainfall IFD estimates for Australia. Otherwise, proceed to Step 5.

Table 1. Design flood annual exceedance probabilities

AEP (%)	AEP (1 in x)
5.00	20
2.00	50
1.00	100
0.50	200
0.20	500

3.5. Step 5 – Consider Climate Change Projections and their Consequences

Consider Figure 4. At this point the consequences of impact on performance and exposure risk to climate change have been judged to be medium or high. Hence consideration needs to be given to whether the original design specifications of the project or the decision need to be reviewed and adjusted. This will necessitate the use of climate change projections. The selection of projections or scenarios is an important source of uncertainty in the use of GCM outputs. In reaching Step 5, the minimum basis for design should be the low concentration pathway RCP4.5 and the maximum GCM consensus case indicated by the Climate Futures web tool for the NRM cluster of interest (Section 4). This is because RCP2.6 requires ambitious emissions reductions and the maximum consensus case is a conservative choice since it is not unduly affected by outlying GCM results. Where the additional expense can be justified on socioeconomic and environmental grounds, the maximum consensus case for the high concentration pathway RCP8.5 should also be considered.

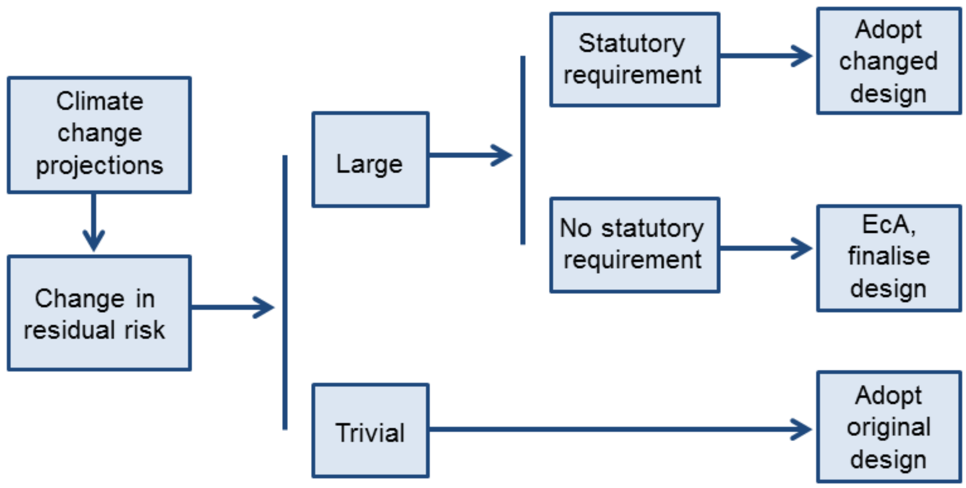

Figure 4 Decision tree for incorporating climate change in flood design – Part 3 of 3 (EcA = economic analysis)

Taking all of the above into account, if the cost of the modified design is low relative to the associated benefits in reduction of residual risk (i.e., the level of risk remaining after climate change has been have been factored into the design or planning process), adopt the changed design. Otherwise, proceed to Step 6.

3.6. Step 6 – Consider Statutory Requirements

Again consider Figure 4. If statutory requirements relating to climate change are in place, adopt the changed design. Otherwise, carry out an economic analysis (e.g., cost-benefit or cost effectiveness analysis, or multi-attribute utility theory) of potential changes in flood-related design requirements and make an informed decision on how to proceed.

4. WORKED EXAMPLE

Problem Setting:

- Catchment of interest is located in the East Coast NRM cluster (Figure 2).
- End of planning horizon centred on 2060.
- Consequence risk rating is medium.
- Application of Step 4 in the six-step process outlined above indicates that consideration of climate change projections is warranted.

Analyst's Assumptions:

- RCP4.5 and RCP8.5 and the corresponding maximum GCM consensus cases are appropriate choices for the given design setting.
- 5% increase in rainfall intensity per °C of projected warming.

Climate Futures Results:

- Table 2 illustrates output from the Climate Futures web tool
- Perusal indicates that two or possibly three temperature class intervals could be considered for impact assessment: 'warmer', 'hotter' and 'much hotter'.

Table 2. Summary of information provided by Climate Futures web tool. Maximum GCM consensus case highlighted in blue.

Climate change projections for East Coast NRM cluster at 2060 under RCP4.5 (regular font) and RCP8.5 (italic font in parentheses)		Annual Maximum Daily Temperature (°C)			
		Slightly Warmer (< 0.5)	Warmer (0.5 to 1.5)	Hotter (1.5 to 3)	Much Hotter (>3)
Annual Rainfall (%)	Much Wetter (> 15)		*1 of 40 GCMs*		
	Wetter (5 to 15)		5 of 38 GCMs *1 of 40 GCMs*	2 of 38 GCMs *3 of 40 GCMs*	
	Little Change (-5 to 5)		9 of 38 GCMs	7 of 38 GCMs *14 of 40 GCMs*	
	Drier (-15 to -5)		2 of 38 GCMs *1 of 40 GCMs*	7 of 38 GCMs *9 of 40 GCMs*	*2 of 40 GCMs*
	Much Drier (< -15)			6 of 38 GCMs *9 of 40 GCMs*	
	Totals		16 of 38 GCMs *3 of 40 GCMs*	22 of 38 GCMs *35 of 40 GCMs*	*2 of 40 GCMs*

Calculations:

- There is only one maximum GCM consensus case for RCP4.5 and RCP8.5: the 'hotter' class interval for annual maximum daily temperature (Table 2).
- The midpoint of the interval is (1.5 + 3.0) / 2 = 2.25 °C.
- The scaling factor for the rainfall is then calculated as $1.05^{2.25} = 1.12$ where 1.05 is the assumed scaling per °C of warming. (NB: the calculation of the scaling factor is based on the approximately exponential relationship between temperature and humidity.)
- If the above maximum consensus case is adopted as the basis for design, the projected rainfall intensity is given by $I_p = 1.12 * I_{ARR}$ where I_{ARR} is the design rainfall intensity obtained from the 2015 edition of ARR.

Notes:

- Had RCP4.5 and the maximum consensus case been selected as the basis for design, the model consensus for the 'warmer' class interval is not greatly smaller than that for the 'hotter' interval.
- If the model consensus for the 'warmer' class interval is deemed to be effectively tied with that for the 'hotter' class interval, consideration could be given to the use of the midpoint of the wider interval 0.5 to 3.0 °C. Following the procedure outlined above leads to a scaling factor of $1.05^{1.75} = 1.09$. The implications of changes in risk due to the use of a lower scaling factor, and the resulting costs and benefits, would need to be considered.

5. CONCLUDING REMARKS

The Interim Guideline for Climate Change provides guidance for engineers and decision makers who are expected to take responsibility for any application of the procedure described. There is no single 'correct' scenario, climate model or approach for practical decisions under climate uncertainty. Failure to acknowledge and treat uncertainty can lead to poor decisions, particularly when the consequences of failure are medium to high. When the consequences of failure are not low, a reasonable approach is to make a decision that is robust against a range of plausible futures obtained from the Climate Futures tool. Thus the Guideline has endeavoured to strike a balance between standardising practice and allowing for informed professional judgement.

As the science of climate change is continually changing, the latest published sources should always be sought for use in future assessments and decision making. It is expected that the Interim Guideline will be updated over time as new research findings are released. Where exposure to climate change and the consequences of failure of the asset of interest are high, more detailed local studies including the use of downscaling methods are recommended.

At a minimum it is recommended that the Guideline be reviewed following the release of the IPCC Sixth Assessment Report on Climate Change. Where there is an additional risk of coastal flooding from sea level rise, the Engineers Australia Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering (3rd edition, 2012) should also be consulted.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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