# REVISION OF AUSTRALIAN RAINFALL AND RUNOFF – THE INTERIM CLIMATE CHANGE GUIDELINE

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## Abstract

This paper describes the Interim Guideline for Climate Change for Australian Rainfall and Runoff (ARR). The Interim Guideline outlines an approach to address the risks from climate change in projects and decisions that involve estimation of design flood characteristics. It draws on the most recent climate science, particularly the release of the Intergovernmental Panel on Climate Change Fifth Assessment Report in September 2013 (IPCC, 2013) as well as the new climate change projections for Australia (CSIRO & Bureau of Meteorology, 2015).

The Interim Guideline is intended to be applied to the design standard for the structure or infrastructure of interest. While its primary application is for current-climate rainfall intensities (or equivalent depths) within the range of probability of one exceedance per year or annual exceedance probabilities (AEPs) from 50% to 1%, it provides guidance for situations where the Probable Maximum Precipitation is the basis for design. At the time of writing (March 2015), the Guideline was still open for public comment and thus subject to revision.

## Introduction

Australian Rainfall and Runoff (ARR) is a national guideline document for the estimation of design flood characteristics in Australia. ARR is currently being revised to incorporate an additional 25 years of data since its last publication (1987/1999), to fill knowledge gaps with particular reference to the growth of computerised techniques, and to take into account the effects of climate change.

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. The Interim Guideline for Climate Change 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). It outlines an approach to address the risks from climate change in projects and decisions that involve design flood estimation.

This paper is organised as follows: first, a review of relevant scientific literature is presented; second, present approaches for incorporating climate change into design flood estimation in Australia, New Zealand and the United Kingdom are described; third, the rationale and structure of the Interim Guideline is described; fourth, a simple worked example is given to illustrate the calculation of rainfall intensities for projected conditions; and the last section includes some concluding remarks.

## Heavy Rainfall in a Changing Climate

### *Intergovernmental Panel on Climate Change Fifth Assessment Report*

The IPCC Fifth Assessment Report (AR5) introduced a new way of developing emissions scenarios (IPCC, 2013). These scenarios, called representative concentration pathways (RCPs), are prescribed pathways for greenhouse gas and aerosol concentrations that are used to drive global climate models (GCMs). The four RCPs (RCP8.5, RCP6, RCP4.5 or RCP2.6) are characterised by the radiative forcing produced by 2100 relative to pre-industrial values (Figure 1). Radiative forcing is the extra heat (W $m^{-2}$) that the lower atmosphere will retain as a result of additional greenhouse gases.

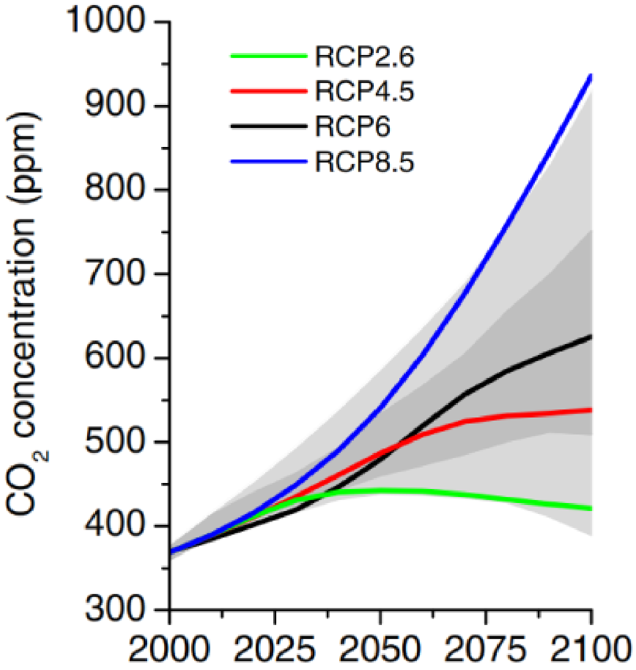


**Figure 1. Four representative concentration pathways (RCPs). Grey bands indicate the 98th and 90th percentiles (light/dark grey) of an earlier modelling study. (Source: van Vuuren et al. 2011, Figure 9.)**

A conclusion of the AR5 was that heavy precipitation events (often defined as precipitation events over some threshold such as the 95th or 99th daily rainfall percentile) over most of the mid-latitude land masses and over wet tropical regions will very likely (i.e., with at least 90 percent probability) become more intense and more frequent by the end of this century, as global mean surface temperature increases.

Further the AR5 notes that (IPCC, 2013, Section 12.4.5.5):

> “return periods of late 20th century twenty-year return values is reduced from 20 years to 14 years for a 1 degree Celsius (°C) local warming. Return periods are projected to be reduced by about 10-20% per °C over most of the mid-latitude land masses, with larger reductions over wet tropical regions”.

The AR5 followed the Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC, 2012) which summarised projected changes in climate extremes and found, in addition to likely increases in heavy precipitation events in the 21st century in many areas, that:

- Projected precipitation and temperature changes imply possible changes in floods, although there is low confidence in projections of changes in fluvial floods. 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.
- There is medium confidence (an assessment based on physical reasoning) that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments.

The AR5 identified increased frequency and intensity of flood damage to settlements and infrastructure in most parts of Australia as a key risk for the 21st Century.

### ***Regional Australian Studies into Heavy Rainfall and Climate Change***

A number of studies have examined a wide variety of statistics of heavy sub-daily and daily rainfall in Australia. Their findings include:

- 95th or 99th daily rainfall percentiles exhibit changes of sign that are consistent with those for mean rainfall changes, and indices of annual extreme frequency and intensity show decreases in the southwest and eastern coastal regions since 1950 (Gallant et al., 2007).
- Trends in extreme precipitation are correlated with trends in mean precipitation, and the rate of change of extremes show a greater rate of change than for the means (Alexander et al., 2007).
- Heavy rainfall scales with temperature at rates that are consistent with the Clausius-Clapeyron relationship for temperatures up to about 20-26 °C and durations up to 30 minutes. At greater temperatures, negative scaling is observed. Moisture availability was hypothesized to become the dominant control of how precipitation scales at higher temperatures (Hardwick-Jones et al., 2010).
- 6-minute rainfall extremes in eastern Australia exhibit a greater rate of change than those for longer duration events. There are limited changes in daily rainfall with the exception of southwest Western Australia where there is a noticeable decline (Westra and Sisson, 2011). A second study has shown that there are considerable seasonal and geographic variations in the frequency and magnitude of rainfall events, implying different dominating rainfall-producing mechanisms and/or interactions with local topography (Jakob et al., 2011).
- For 6-minute rainfall data, statistics such as the total wet period duration, storm event duration, and autocorrelation decrease with increasing temperature, while maximum wet period depth and rainfall Intensity-Frequency-Duration (IFD) curves show an increasing trend with temperature (Gyasi-Agyei, 2013).
- Changes in rainfall intensity at short durations (< 1 h) positively correlate with changes in mean maximum temperature. Changes in rainfall intensity at longer durations positively correlate with changes in the mean annual rainfall, but not with mean maximum or minimum temperatures (Chen et al., 2013).

Using extreme value theory and a fine-resolution downscaling approach, Rafter and Abbs (2009) projected increases in daily rainfall across all regions, and across most GCMs, for 20-year time slices centred in 2055 and 2090. The spatial patterns were consistent with previous studies, with smaller increases in the south and larger increases in the north.

Analysis of the latest GCM output under the Natural Resources Management (NRM) projections project has shown simulated increases in the magnitude of the wettest annual daily total and the 1 in 20 year wettest daily total in all of the NRM clusters and sub-clusters studied (CSIRO & Bureau of Meteorology, 2015). This increase was most evident in the late 21st century (2090) and RCP8.5, and was present even in regions that had the strongest simulated decrease in mean rainfall (e.g., southwest Western Australia). The projected changes for these rainfall statistics is 2 to 8% per degree °C of global average warming.

At local to regional scales, there have been a small number of analyses of the likely implications of climate change for heavy precipitation events.

Hennessy et al. (2004) found that while much of NSW shows a tendency towards drier seasonal-average conditions under enhanced greenhouse conditions, it does not necessarily follow that daily rainfall events will become less frequent or severe. By 2030 increased 1-day rainfall extremes were projected for much of the south and centre of the state, and also in the north-east, trends which strengthened by 2070. Changes in the seasonality of heavy rainfall events were also identified.

Abbs et al. (2007) investigated the impact of climate change on heavy rainfall over south-east Queensland using dynamical downscaling methods. They found that climate change is likely to result in an increase in the 2-hour, 24-hour and 72-hour rainfall extremes for a large region including the McPherson Range and the Great Dividing Range west of Brisbane and the Gold Coast. By 2030 changes in extreme rainfall intensity for 24-hour and 72-hour events are most likely to be up to an increase of 20%, and by 2070 the region along the Great Dividing Range could experience increases in intensity in these events of 20% or more. The regions of rainfall increase also increase in spatial extent over time. With regard to temporal patterns, the research findings were consistent with those of Zhao et al. (1997) and Abbs (1999) which showed that as atmospheric moisture availability is increased, the period of heavy rainfall (rainfall rates $> 25 \text{ mm h}^{-1}$) begins earlier and is more continuous.

The Climate Futures for Tasmania project found that rainfall projections to the end of the 21st century indicate higher mean annual maximum daily rainfall amounts (up to 35% in some coastal regions) and sizable increases in 6-minute rainfall rates, particularly in eastern Tasmania. Further details can be found in White et al. (2010).

Across Australia, there has been little detailed analysis of the implications of climate change for the intensity, frequency and duration characteristics of heavy rainfall events.

### ***Climate Futures***

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 and access to application-ready data sets. It provides regional information on a range of projected climate variables, including projected changes in 24-hour rainfall with a return period of 20 years. At present the tool does not include detailed projections of changes to design rainfall IFD relationships due to the paucity of available information. It utilises the RCPs and GCM simulations developed for the AR5, but recommends the use of RCP4.5 or RCP8.5 for impact assessment (Figure 1). The tool will be fully integrated into the www.climatechangeinaustralia.gov.au/en website in 2015. Owing to constraints on data availability for some variables, spatial detail will range from: NRM cluster (Figure 2) averages; to sub-cluster averages; to five km grid-averages; and to specific cities. Data from up to 48 GCMs have been analysed. The number of GCMs varies as there are fewer results available for some RCPs and climate variables.

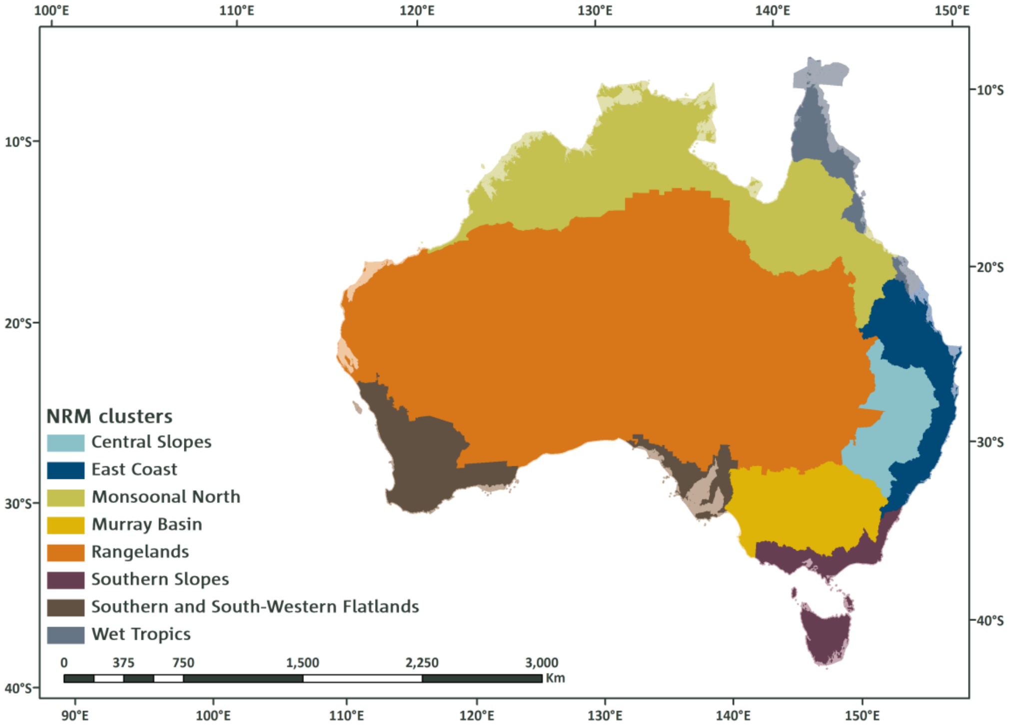


**Figure 2. Locations of NRM clusters.**

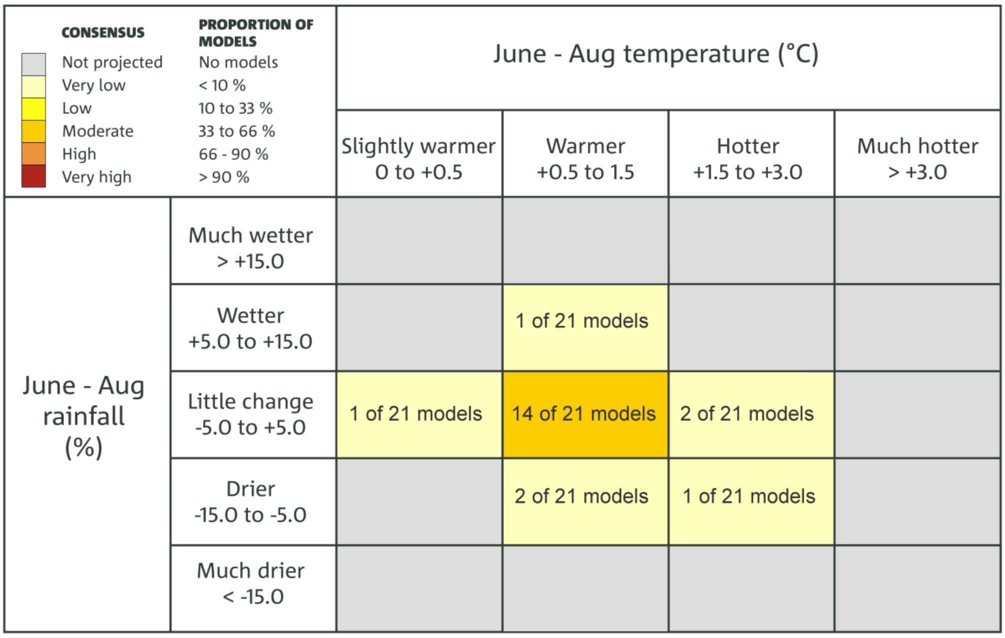
Climate Futures places the projected changes from the full suite of GCMs into classes defined by two climate variables. The changes are relative to a 20-year (1986-2005) baseline. Changes in annual mean temperature and rainfall, for example, can be tabulated for a 20-year period (e.g., centred on 2030, 2050, 2070, or 2090) and one of the four RCPs. 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.

Shown in Figure 3 is an example output from the Climate Futures web tool for the Southern Slopes NRM cluster, RCP6.0, the 20-year period centred on 2060, and the winter season. Perusal of this Figure indicates that three temperature scenarios should be considered for impact assessment: ‘slightly warmer’, ‘warmer’ and ‘hotter’. These scenarios comprise increases in winter surface temperature of 0 to 0.5, 0.5 to 1.5, and 1.5 to 3.0 °C, respectively. Note that the maximum consensus case is the ‘warmer’ temperature scenario (17 out of 21 GCMs).

## Present Approaches for Incorporating Climate Change into Design Rainfall Estimates

In the absence of robust research results or national guidance, a number of states and organisations have developed approaches for assessment of the impacts of climate change on ‘extreme’ rainfall.

The NSW Government has published guidelines to assist local government authorities to consider climate change impacts as part of floodplain management processes (DECC, 2007). A sensitivity analysis is recommended for flood and floodplain risk studies, with rainfall values for the analysis including increases of 10%, 20% and 30% in peak rainfall and storm volume. Review of these guidelines will be considered following the release of the new edition of ARR (D. McLuckie, pers. comm.).



| | CONSENSUS | PROPORTION OF MODELS |
|---|---|---|
| ⬜ | Not projected | No models |
| 🟨 | Very low | < 10 % |
| 🟨 | Low | 10 to 33 % |
| 🟨 | Moderate | 33 to 66 % |
| 🟧 | High | 66 - 90 % |
| 🟥 | Very high | > 90 % |

| | | June - Aug temperature (°C) | | | |
|---|---|---|---|---|---|
| | | Slightly warmer 0 to +0.5 | Warmer +0.5 to 1.5 | Hotter +1.5 to +3.0 | Much hotter > +3.0 |
| June - Aug rainfall (%) | Much wetter > +15.0 | | | | |
| | Wetter +5.0 to +15.0 | | 1 of 21 models | | |
| | Little change -5.0 to +5.0 | 1 of 21 models | 14 of 21 models | 2 of 21 models | |
| | Drier -15.0 to -5.0 | | 2 of 21 models | 1 of 21 models | |
| | Much drier < -15.0 | | | | |

**Figure 3. An example table from the *Climate Futures* web tool showing results for the Southern Slopes NRM Cluster (Figure 2) when assessing plausible climate futures for 2060 under RCP6.0, as defined by GCM simulated winter rainfall (% change) and temperature (°C warming).**

Practical application of the NSW approach of using 10, 20 and 30% increases for sensitivity checking, particularly around the commonly used 1% AEP design event, has resulted in the use of current design events, such as the existing 0.5% AEP and 0.2% AEP events, as proxies to test sensitivity to this range of change in rainfall intensities and storm volume. This approach reduces the number of modelling runs required and provides additional information on current flood impacts to support decision making. McLuckie et al. (2010) provides a broad scale example of the use of the 0.5% AEP event as a proxy.

The inland flooding study by the Queensland Government (2010) recommended that flood studies by Queensland State and local governments include an increase in rainfall intensity per °C of global warming. This increase can be incorporated into design flood events to inform the location and design of new development, using scaled temperature increases over time (i.e., 2 °C by 2050, 3 °C by 2070, and 4 °C by 2100).

Overseas, the New Zealand Ministry for Environment (2008) has recommended adjustments to rainfall for each 1 °C of warming. Values are given for various average recurrence intervals and for rainfall durations from less than 10 minutes up to 72 hours. Adjustments for 24-hour rainfall are based on simulation by a single regional climate model and one emissions scenario, and those for 10-minute rainfall on the theoretical increase in the amount of water held by the atmosphere for a 1 °C rise in temperature. Adjustments for other durations were obtained by logarithmic (in time) interpolation. In the United Kingdom, PPS25 (2010) lists a set of precautionary sensitivity ranges for peak rainfall intensity and peak river flow for four time slices: 1990 to 2025; 2025 to 2055; 2055 to 2085; and 2085 to 2115.

## Interim Climate Change Guideline

### *Preamble*

For consistency with the new IFD design rainfall estimates for Australia (ARR, Book II – Rainfall Estimation, 2015), the Interim Guideline is intended to be applied to the design standard for the structure or infrastructure of interest. It is applicable for current-climate rainfall intensities (or equivalent depths) within the range of probability of no more than one exceedance per year and AEPs from 50% to 1%. No adjustments to Probable Maximum Precipitation (PMP) are recommended when the design standard is the Probable Maximum Flood (PMF).

As noted above, there is a growing body of evidence that as the atmosphere warms, the atmospheric water vapour also increases, which increases the risk of more intense rainfall events. The Interim Guideline proposes that a 5% increase in design rainfall intensity (or equivalent depth) per °C of global warming should be assumed for this step until more detailed information is available. While this increase is at the lower end of that predicted by the Clausius-Clapeyron relationship for daily rainfall (about 5 to 10% per °C) it is consistent with the median results obtained from the NRM projections project.

The proposed increase in rainfall intensity has been tempered compared to the upper range of the Clausius-Clapeyron relationship because there is no guarantee that the same scaling will apply across all of the frequencies and durations typically considered in flood design. There are also a number of other factors that have the potential to affect future rainfall intensity changes over land. These factors include:

- Changes in Southern Hemispheric and regional atmospheric circulation, including changes in storm track position. These changes can lead to decreases in rainfall intensity, as is evident in southwest Western Australia.
- Changes in the frequency or character of synoptic weather systems.
- Changes in soil wetness which may increase or limit the availability of atmospheric moisture, particularly in inland regions.

Little if any information exists on potential changes in: pre-burst rainfall; storm burst volumes; rainfall spatial and/or temporal patterns; antecedent conditions and baseflow regimes; and the behaviour of simultaneous extremes. Therefore, it is recommended that only rainfall intensity (or equivalent depth) be scaled at the present time. Where there is an additional risk of coastal flooding from sea level rise the Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering published by Engineers Australia (2012) should be consulted.

### *Recommended Procedure*

The Interim Guideline proposes a six-step process for considering climate change risks in decisions involving the estimation of design flood characteristics. The process uses a decision tree approach as illustrated in Figures 5 to 7, and proceeds as follows.

#### *Step 1 – Set the Service Life or Planning Horizon*

A key consideration in the context of climate change is the service life of an asset or planning horizon of an activity. 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. Figure 4 shows the indicative service lives of assets that require design flood estimates.

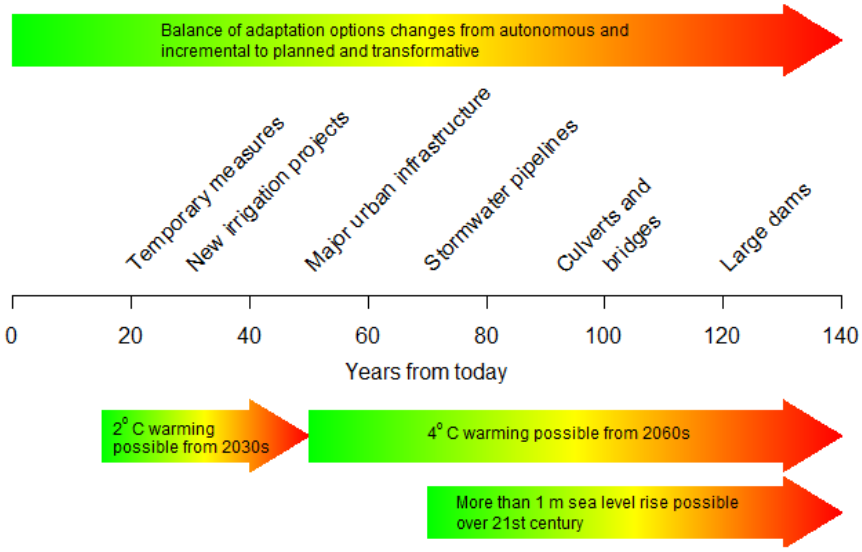


**Figure 4. Timeline illustrating lifetimes (sum of lead time and consequence time) of different types of decisions, compared with the time scales for some global environmental changes, and changing implications for adaptation. (Adapted from Stafford-Smith et al. 2011, Figure 1)**

Consider Figure 5. 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 new design rainfall IFD and temporal pattern data. Otherwise, proceed to Step 2.

*Step 2 – Set the Flood Design Standard*

Again consider Figure 5. 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 that unwarranted expenditures based on a crude scaling of the PMP will be avoided. Otherwise, proceed to Step 3.

*Step 3 – Consider the Purpose and Nature of the Asset or Activity*

Consider Figure 6. 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 cost of retrofitting assets if design rainfall IFD characteristics have changed with time.

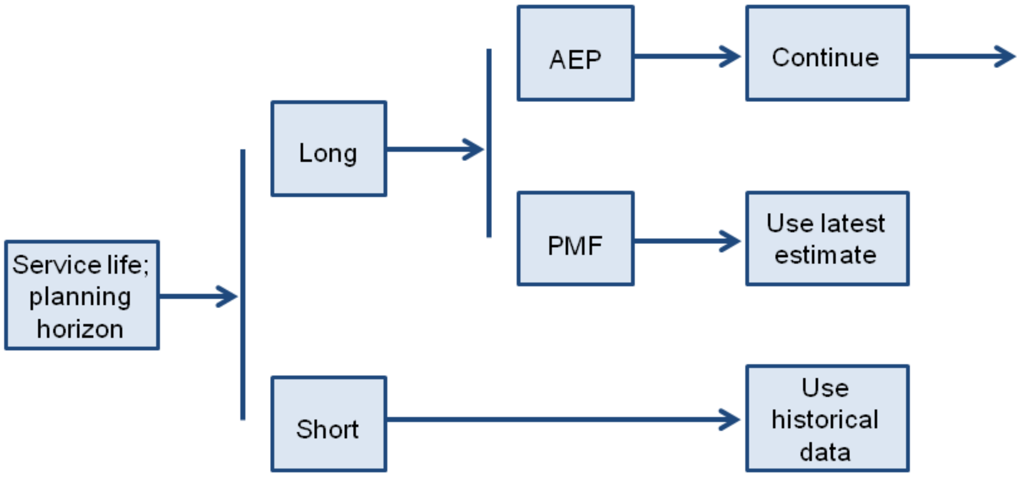


**Figure 5. Decision tree for incorporating climate change in flood design – Part 1 of 3 (AEP = annual exceedance probability; PMF = probable maximum flood; historical data = design rainfall or flood event for current-climate conditions)**

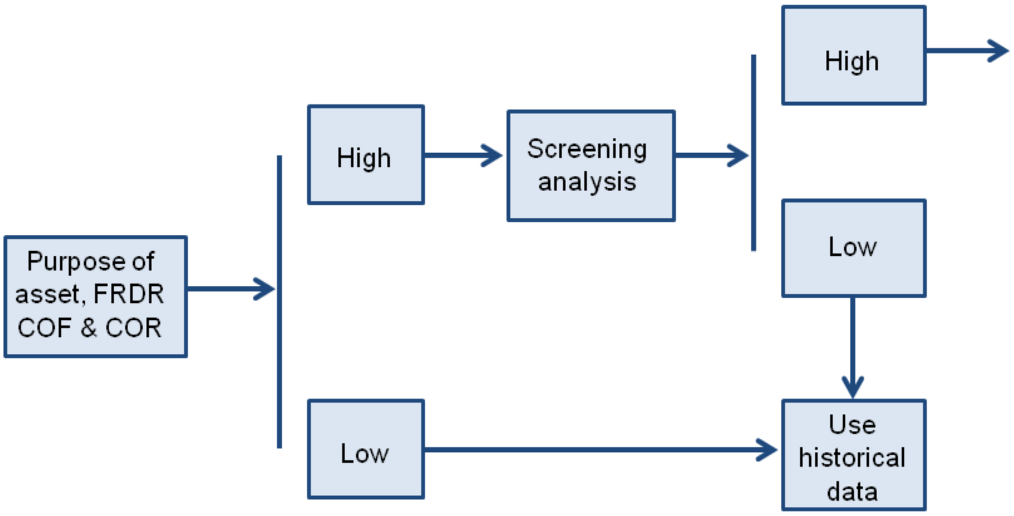


**Figure 6. Decision tree for incorporating climate change in flood design – Part 2 of 3 (FRDR = flood-related design requirements; COF = consequences of failure; COR = cost of retrofits; historical data = design rainfall or flood event for current-climate conditions)**

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.

It is proposed that the consequences of failure 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.

### *Step 4 – Carry out a Screening Analysis*

Again consider Figure 6. 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 Guideline is limited to design AEPs ≥ 1%. 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.

**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 |

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 IFD design rainfall estimates for Australia. Otherwise, proceed to Step 5.

### *Step 5 – Consider Climate Change Projections and their Consequences*

Consider Figure 7. 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 considered to be an important source of uncertainty in the use of GCM outputs (Quiggin, 2008). In reaching Step 5, the minimum basis for design should be a single mid-range RCP (RCP4.5 or RCP6.0) and the maximum GCM consensus case indicated by the Climate Futures web tool for the NRM cluster of interest. For the example illustrated in Figure 3, the maximum consensus case is the 'warmer' temperature scenario (see above). Where it can be justified on social, economic and environmental grounds the 'hotter' as well as 'warmer' temperature scenarios could be selected for subsequent analysis, along with a high-end temperature scenario for RCP8.5.

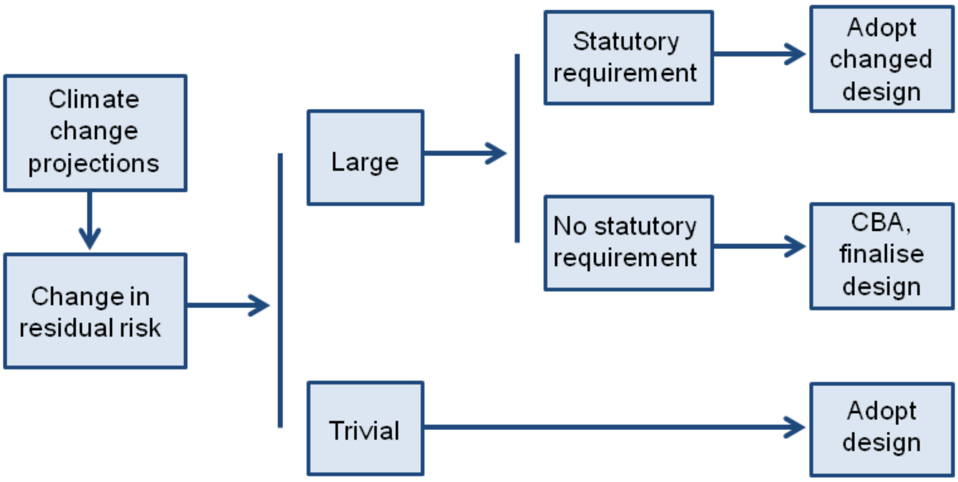


**Figure 7. Decision tree for incorporating climate change in flood design – Part 3 of 3 (CBA = cost-benefit analysis)**

Taking all of the above into account, if the cost of the modified design is low relative to the associated benefits in reduction to 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.

*Step 6 – Consider Statutory Requirements*

Again consider Figure 7. If statutory requirements relating to climate change are in place, adopt the changed design. Otherwise, carry out a detailed cost-benefit analysis of potential changes in flood-related design requirements and make an informed decision on how to proceed.

## Simple Worked Example

Physical Setting:

- Region of interest is coastal southern Victoria (Southern Slopes NRM cluster in Figure 2).
- Service life for the structure of interest is 45 years.

Assume:

- Application of Step 4 in the six-step process outlined above indicates that consideration of climate change projections is warranted.

- The analyst considers RCP6.0 and the maximum GCM consensus case as being suitable and appropriate choices for the given design setting.
- Projected changes for winter (June to August) rainfall intensities are of particular interest.
- 5% increase in rainfall intensity per °C of projected warming.

Calculation:

- Obtain Climate Futures web tool output for RCP6.0, the winter season, and the 20-year period centred on 2015 + 45 = 2060 (Figure 3).
- Maximum GCM consensus in Figure 3 (17/21) is for 'warmer' conditions, so use midpoint of the interval 0.5 to 1.5 °C. (If the maximum GCM consensus had been equally split between the 'warmer' and 'hotter' temperature scenarios, for example, the midpoint of the wider interval 0.5 to 3.0 °C could be used.)
- Projected rainfall intensity $I_p = [1.05 * (0.5 + 1.5) / 2] * I_{\text{ARR}}$ where $I_{\text{ARR}}$ is the design rainfall intensity obtained from the 2015 edition of ARR.

## Concluding Remarks

The Interim Climate Change Guideline provides guidance for engineers and decision makers who are expected to take responsibility for any application of the procedure described. At the time of writing (March 2015), a discussion paper for the Guideline was still open for public comment and thus subject to revision.

Climate change science is a dynamic field, and the most up-to-date and localised studies should be drawn on in any decisions. It is expected that the Interim Guideline will be updated over time as new research findings are released. Where exposure risks to climate change and the consequences of failure of the asset are high, more detailed 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.

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